남태평양 도서국가 마이크로그리드 타당성조사

(최종보고서)

2019. 5.

주관기관: (주)원에너지 아일랜드

참여기관: (주)애니게이트

협력기관: 국민대학교 스마트그리드 연구실

산업통상자원부 한국에너지공단

한국에너지공단 귀중,

본 보고서를 귀 기관에서 개발도상국 온실가스저감 지원사업의 하나로 추진한 ‘남태평양 도서국가 마이크로그리드 사업 타당성조사’의 최종 보고서를 제출합니다.

2019년 5월

㈜ 원에너지아일랜드

목　　　　　차

1. 요약서

요 약 서

사 업 명	남태평양 도서국가 마이크로그리드 타당성조사		
주 관 기 관	㈜ 원에너지아일랜드	수행책임자	강 태 일
사 업 기 간	2018. 6. 1. ~ 2019. 3. 31. (10 개월)		
사 업 비 (단위 : 천원)	정부지원금 : 120,000 민간부담금 : 40,000 합 계 160,000		
참 여 기 관	(주) 애니게이트		
주 제 어 (6 ~ 10개)	팔라우, 팔릴레우, 신재생에너지, 발전원 최적화, 계통안정화, 에너지저장장치, IPP,		

1. **사업목표 :팔라우 팔릴레우에 적합한 미니그리드 기술모델 제시와 동시에 확장사업 발굴**
   - 법규 및 인허가 규정 조사: 팔라우 정부의 신재생에너지 지원정책 파악 및 신재생에너지 사업관련 인허가 및 환경영향평가 규정 파악
   - 기술적 타당성 조사 : Peleliu 신재생에너지 구축사업의 적정성 검토, 최적화된 시스템 모델 확정
   - 사업의 경제적 타당성 조사: 사업의 경제적 타당성 분석/ 사업의 재원 조달방안 수립
   - 확산사업 발굴 및 추진방안: PICTs 에 적합한 미니그리드 사업모델 제시 및 미니그리드 민자사업(IPP) 발굴
2. **사업 내용 및 범위**
   - 법규 및 인허가 과정 조사: 현지 환경영향평가 규정 조사, 팔라우 현지 에너지 법규 조사
   - 기술적타당성 조사 : 신재생발전량비율을 현재의 22%에서 50%, 75%, 100%까지 상향 조정할 경우의 LCOE 분석/계통해석
     - Homer 를 통한 시뮬레이션 결과, LCOE 가 가장 최적인 재생에너지 비율이 50%. 추가 설치 설비: PV 400kWh 및 ESS 925kWh
     - Power Factory 를 활용한 계통모형화 및 해석 후, 각 케이스별로 예상문제점 파악

- 높은 재생에너지 비율에 따른 배전망 업그레이드 방향 제시
- 마이크로 컨트롤러 알고리즘 제시

– 사업의 경제적 타당성 분석

- ODA 비용/편익 분석 방법에 근거한 계량적 비용/편익 분석
- 할인율 시나리오(8%, 10%, 12%)에 따른 민감도 분석(B/C ratio)
- Blended Finance 를 통한 사업예산 조달방안 수립

– 확장사업

- 남태평양 도서국가의 미니그리드 사업의 민자사업(IPP) 흐름 소개
- 현재 진행중인 팔라우 미니그리드 민자사업의 진행 및 Pre-F/S 분석(19 년 5 월 현재 본 입찰진행중 이며, 주관기관이 참여중)

3. **사업성과**

- 팔릴레우 미니그리드 타당성조사를 통한 미니그리드 설계에 기본적인 기술/경제적 분석 완료
- 팔라우 본섬 민자사업(IPP) 참여를 통한 미니그리드 확산사업발굴

4. **활용방안 및 기대효과**

본 사업에서 한국기업의 미니그리드 사업 수주를 위한 기본적인 기술/경제적 모형 제시하였음. 또한 확산사업 발굴을 통한 확장가능성 제시

2. 타당성조사 보고서 (한글 요약)

보고서 요약

남태평양 도서국가 마이크로그리드 사업 타당성조사

2019년 4월 26일

주관기관: ㈜ 원에너지아일랜드
참여기관: (주) 애니게이트
협력기관: 국민대학교 스마트그리드 연구실

ENERGY ISLAND anygate KMU KOOKMIN UNIVERSITY

목 차

1. 타당성조사 사업 개요

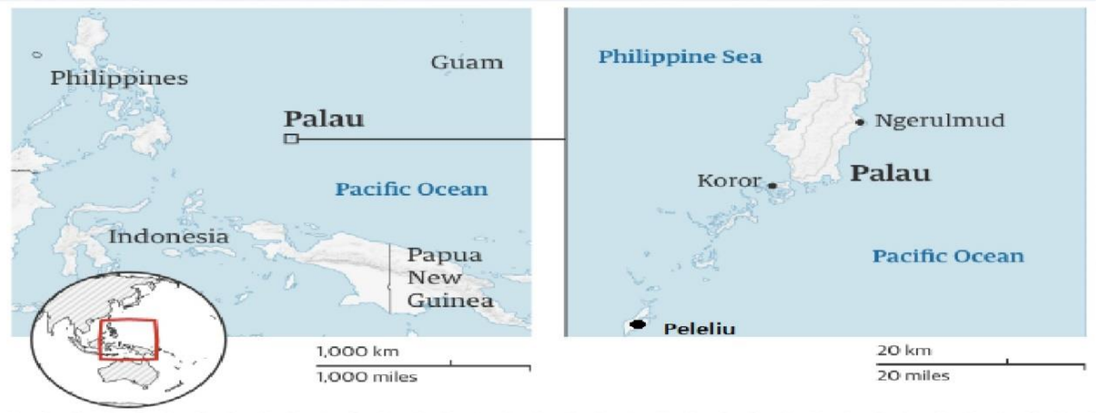
사업 개요

사업내용 • 남태평양 도서국가인 Palau의 Peleliu 섬에, 재생에너지원을 활용한 마이크로 그리드 구축 타당성조사 및 확산사업 발굴 및 추진계획 수립

사업기간 • 타당성조사: 2018. 6. 1 ~ 2019. 3. 31 (10개월)

사 업 비 • 1.6억원

사업대상지 • Palau 및 남태평양도서국가



사업 내용

기술적 타당성 조사
- Peleliu 신재생에너지 구축사업의 적정성 검토
- 최적화된 시스템 모델 확정

확산사업 발굴 및 추진방안
- PICTs에 적합한 미니그리드 사업모델 제시
- PICTs 지역 확산사업 발굴 및 사업목표, 추진방안 수립

사업의 경제적 타당성 조사
- 사업의 경제적 타당성 분석
- 사업의 재원 조달방안 수립

법규 및 인허가 규정 조사
- 팔라우 정부의 신재생에너지 지원정책 파악
- 신재생에너지 사업관련 인허가 및 환경영향 평가 규정 파악

온실가스 저감량 예측
- 시뮬레이션을 통한 신재생에너지원 발전량 및 CO_2 감소량 예측

2. 타당성조사 활동 내용

현장조사 출장 내용

구분	출장 지역	참가기관	내용
1차 출장 (18.7.21-27)	팔라우, 펠렐리우	한국 에너지 공단, 원에너지 아일랜드, 애니게이트	팔라우 정부 관계자 미팅 펠렐리우 1차 방문, 현지 일반사항 조사
2차 출장 (18.11.20-26)	피지	원에너지 아일랜드	남태평양 지역 재생에너지 & 에너지 효율센터(PECREEE) 초청 운영위원회 참석 1. 남태평양 지역 Mini-grid 확산 방안 논의 2. 남태평양 지역 Mini-grid에 적합한 사업 모델 논의
3차 출장 (18.11.24~12.1)	팔라우, 펠렐리우	원에너지 아일랜드, 애니게이트, 국민대	펠렐리우 미니그리드 기술 설계를 위한 상세 조사 현지 기술자 미팅
4차 출장 (19.1.20~26)	팔라우	한국 에너지공단, 원에너지 아일랜드, 애니게이트, 국민대	펠렐리우 미니그리드 기술 설계 공유 및 검토 펠렐리우 모델의 확산 사업 논의 MoU 체결(한국 에너지공단-Palau Energy Administration / 원에너지 아일랜드-Palau Public Utilities Corporation)
5차 출장 (19.2.17~22)	팔라우	원에너지 아일랜드	팔라우 Main IPP 사업 대상 부지 조사 팔라우 Main IPP 사업 설명회 참석 현지 건설업체 미팅 및 하도급 계약 관련 협의
6차 출장 (19.3.24~30)	팔라우	원에너지 아일랜드	팔라우 Main IPP 사업 부지 지적도 획득 및 현지 변호사와 세부 역무 합의 타당성조사 보고서 최종 공유 및 검토 현지 환경영향평가 사례 조사 현지 국제 운송업체 Eurasia Corp 미팅

현지 출장 사진


1차 출장: 펠렐리우 현장방문 조사

현지 출장 사진

2차 출장: PCREEE 주최 남태평양도서국가 미니그리드 워크샵 참석

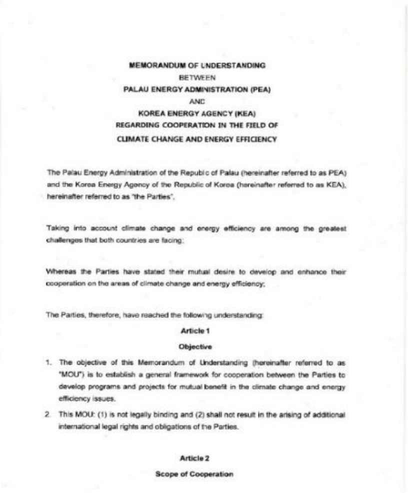
현지 출장 사진

3차 출장: 펠렐리우 기술설계 세미나

MoU

주요내용:

- 펠렐리우 미니그리드 사업화 협력 / 팔라우 에너지전환 사업 협력



MEMORANDUM OF UNDERSTANDING
BETWEEN
PALAU ENERGY ADMINISTRATION (PEA)
AND
KOREA ENERGY AGENCY (KEA)
REGARDING COOPERATION IN THE FIELD OF
CLIMATE CHANGE AND ENERGY EFFICIENCY

The Palau Energy Administration of the Republic of Palau (hereinafter referred to as PEA) and the Korea Energy Agency of the Republic of Korea (hereinafter referred to as KEA), hereinafter referred to as "the Parties".

Taking into account climate change and energy efficiency are among the greatest challenges that both countries are facing;

Whereas the Parties have stated their mutual desire to develop and enhance their cooperation on the areas of climate change and energy efficiency;

The Parties, therefore, have reached the following understanding:

Article 1

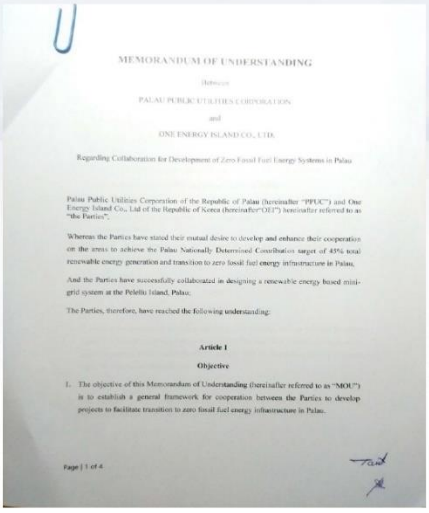
Objective

1. The objective of this Memorandum of Understanding (hereinafter referred to as "MOU") is to establish a general framework for cooperation between the Parties to develop programs and projects for mutual benefit in the climate change and energy efficiency issues.
2. This MOU: (1) is not legally binding and (2) shall not result in the arising of additional international legal rights and obligations of the Parties.

Article 2

Scope of Cooperation

에너지공단-Palau Energy Administration



MEMORANDUM OF UNDERSTANDING
Between
PALAU PUBLIC UTILITIES CORPORATION
and
ONE ENERGY ISLAND CO., LTD.

Regarding Collaboration for Development of Zero Fossil Fuel Energy Systems in Palau

Palau Public Utilities Corporation of the Republic of Palau (hereinafter "PPUC") and One Energy Island Co., Ltd of the Republic of Korea (hereinafter"OEI") hereinafter referred to as "the Parties".

Whereas the Parties have stated their mutual desire to develop and enhance their cooperation on the areas to achieve the Palau Nationally Determined Contribution target of 45% total renewable energy generation and transition to zero fossil fuel energy infrastructure in Palau,

And the Parties have successfully collaborated in designing a renewable energy based mini-grid system at the Peleliu Island, Palau;

The Parties, therefore, have reached the following understanding:

Article 1

Objective

1. The objective of this Memorandum of Understanding (hereinafter referred to as "MOU") is to establish a general framework for cooperation between the Parties to develop projects to facilitate transition to zero fossil fuel energy infrastructure in Palau.

Page | 1 of 4

원에너지 아일랜드-PPUC

3. 현지 에너지 환경 조사

팔라우 사회/경제환경 요약

구분	내용
GDP	총 GDP: $264 million (2017) 인당 GDP : USD 13,000
인구	17,661 명 (15년 Census 기준, 외국인 근로자 포함 21,000명 추정)
산업구조	농업(agriculture): 3% (201) 제조업(industry): 19% (2016) 서비스업(services): 78% (2016) * 서비스업 78%중 42.3% 는 관광업 , 나머지는 정부고용 추정
기준 통화	US dollars
신용등급	없음(소국이고, 국제거래가 많지 않음)
정치체제	대통령제(현 대통령: Tommy E Rememgesau Jr, 4선 대통령) 양원제(상원/하원 각 13명, 정당없음) *1990년 이후로는 평화적인 정권교체가 이루어지고 있음.
종교	카톨릭(45.3%), 개신교(34.9%), 이슬람(3%),국교 없음

팔라우 에너지 정책

구분	년도	내용
Net Metering Act	2009	소규모 태양광에 한해 상계(Off- Set) 형식으로 전력구매
Palau Energy Policy	2010	10년마다 갱신되는 팔라우 국가에너지 정책 2020년까지 20% 재생에너지 생산 목표
INDC Target	2015	2015년 파리기후협약에 일환으로 제출되는 INDC(Intended National Determined Contribution) 목표는 2025년까지 45% 재생에너지 생산 목표 제출
Palau Energy Act	2016	IPP(Independent Power Plant) 허가절차 수립
Palau Energy Regulatory Act	2018	재생에너지 확산을 위한 독립된 정책기구인 PEA(Palau Energy Administration) 설립

팔라우 전력 산업 구조 분석

- 팔라우 전력사업은 PPUC(Palau Public Utility Corporation)가 독점하고, 에너지 정책은 PEA(Palau Energy Administration)가 전담함. 15년에 에너지법 개정으로 IPP 참여가 가능해졌음.

- 현재 태양광은 ODA사업으로 1MW 가까이 설치되어 있지만, 상업적으로 운전하는 IPP(Independent Power Plant)는 없음.

- 팔라우 전력요금은 Energy Rate과 Fuel Rate 의 합으로 구성됨.
  - Energy Rate은 PPUC의 운영비에 대한 요금이고, 용도별로 차등 부과됨.
  - Fuel Rate은 디젤발전소의 디젤 변동비에 대한 요금이고 용도에 관계 없이 부과됨. Fuel Rate은 매 분기 디젤 가격 변동에 따라 변동됨.

2018.1.1 기준	요금 구간 (kWh)	Energy Rate	Fuel rate	전체 전기요금($/kWh)
주택용	0-150	0.02	0.177	0.197
	151-500	0.094	0.177	0.271
	501+	0.143	0.177	0.32
정부용/상업용	0-150000	0.143	0.177	0.32
	150001-250000	0.133	0.177	0.31
	250001+	0.123	0.177	0.3

4. 펠렐리우섬 마이크로그리드 기술 설계

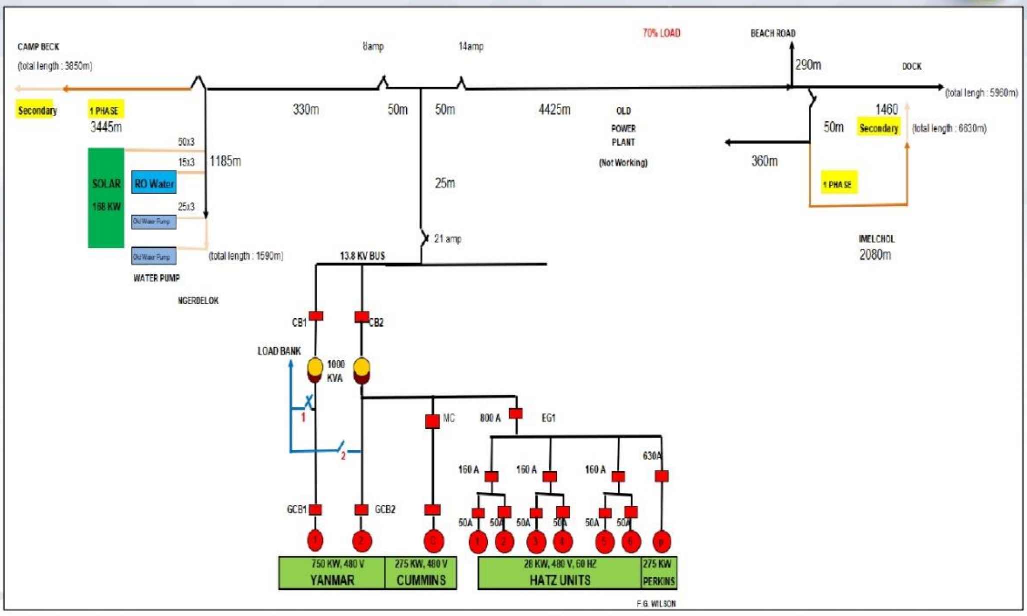
발전 설비 현황

- 펠렐리우섬은 13㎢이며 팔라우의 맨 하단에 위치하고 있고 인구는 571명이 주로 농업에 종사하고 있음.
- 디젤발전설비 용량은 2.2MW로 피크부하의 9배에 달할 정도로 크나 신형 디젤만 평상시 운전하고 구형은 백업용으로 사용 중
- UAE/일본 원조로 태양광 164kW 설치 가동중 (신재생에너지 공급율 환산 17% 수준)

발전기명	수량	대당 용량(kW)	모델	비고
Yanmar	2	750	T260ST(1999)	Hatz 정지 시 사용
Cummins	1	275	QLS9G5	운영안함(백업)
Hatz	6	28*	4L41C(2015)	주 운전
Perkins	1	300	P375-3(2017)	Peak시에만 사용

발전기명	준공년도	용량 (kW)
Peleliu PV	2013	64
Peleliu PV2	2016	100

Peleliu섬 전력계통도



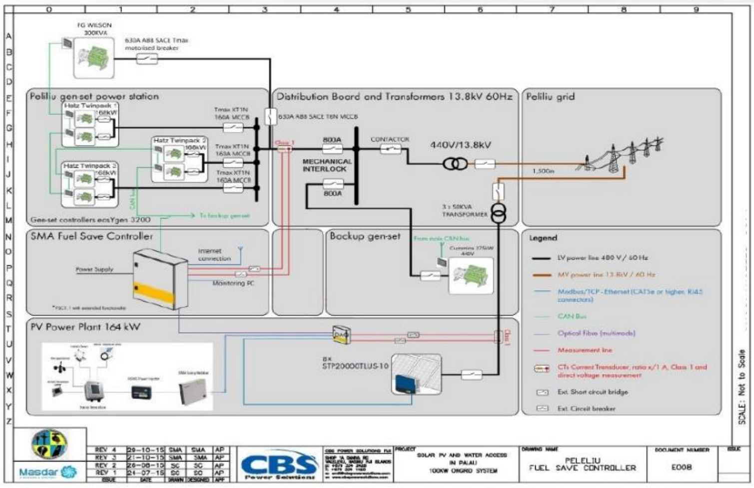
Peleliu섬의 발전량과 부하량 조사

- Peleliu 지역의 일 평균부하 및 시간별 디젤발전량, 신재생에너지 발전량 도표
- 2018년 피크부하는 약 218kW 이며 PV 설비용량은 164kW로 명목상 신재생비율은 75%임.
- 일간 부하량 대비 PV 발전량비율 17% 수준
- 디젤발전설비용량은 2.2MW이며 PV와 연동하여 전력공급중

연간 피크부하 (kW)	기존 PV (kW)	신재생발전용량/피크부하 (%)	일간신재생발전량/일간부하량 비율 (%)
218	164	75%	17%

Peleliu 발전설비 조합 운전방식

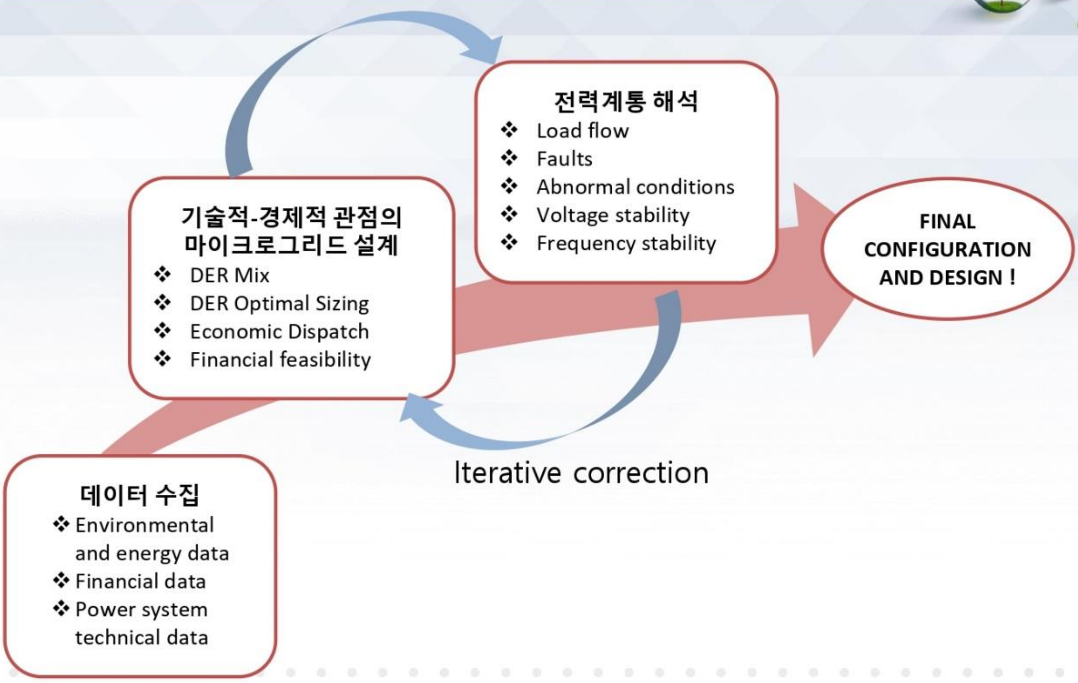
- 디젤발전기와 PV발전기는 SMA Fuel Save Controller로 연동 운전중
- 팔라우정부는 Peleliu 섬을 100% 신재생에너지원으로만 전력을 공급하는 Carbon Free Island 희망



펠렐리우 최적 마이크로그리드 구축을 위한 기술 설계 접근 방법

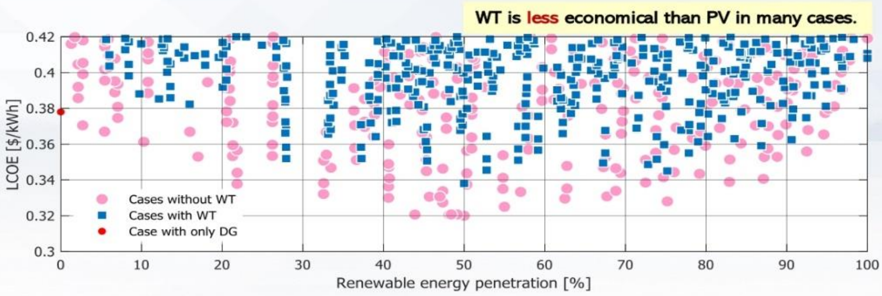
- Peleliu 섬의 향후 10년간 전력사용량 증가량 예측
- 신재생발전량비율을 현재의 22%에서 50%, 75%, 100%까지 상향 조정할 경우 전력계통이 안정적으로 운전이 가능한지 조류계산, 고장계산 수행
- 50%, 75%, 100% 증가 케이스별 DG, PV 및 ESS 적정 용량 설계 및 경제성 평가
- 50%, 75%, 100% 케이스별 신재생발전소 및 에너지저장장치 설치위치 설계
- 해석 목표
  - **Peleliu 섬의 DG발전량이 50%, 75%, 100%일 때의 발전원 비율 설계**
  - **Peleliu 섬의 DG발전량이 50%, 75%, 100%일 때의 계통 해석**
  - **DG 발전량에 적합한 Micro-controller 요구사양 분석**
  - **2020년, 2025년, 2030년의 Peleliu섬 전력계통 루트 설계**

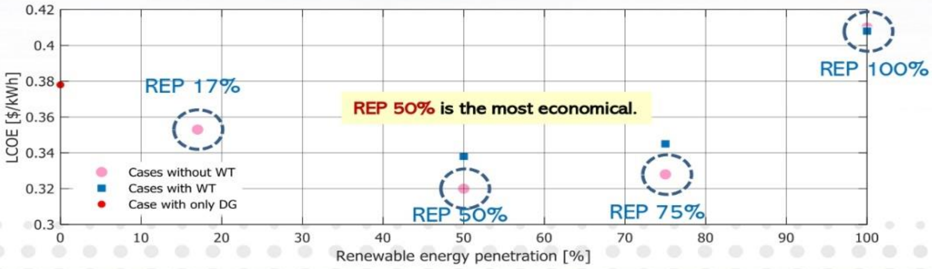
마이크로그리드 디자인 절차



신재생에너지 Mix 시뮬레이션

- **신재생에너지 발전량비율 대 경제성 분석 결과 (Homer 사용)**





펠렐리우 마이크로그리드 설계 결과

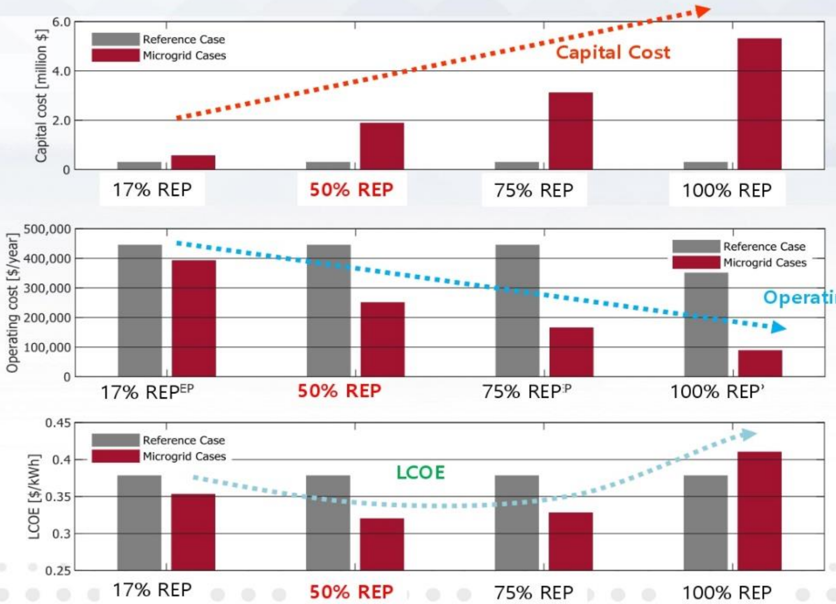
- **DG발전량비율 17%, 50%, 75%, 100% 케이스별 PV 및 ESS 용량 산정**

	Case 1 (17%)	Case 2 (50%)	Case 3 (75%)	Case 4 (100%)
PV (kW)	164	564	839	1389
WT (kW)	-	-	-	100
ESS (kWh)	-	925	2,200	3,750
ESS Converter (kW)	-	200	350	550
Diesel, FGW (kW)	300	300	300	-
Diesel, Hatz (kW)	168	168	168	-
LCOE ($/kWh)	0.353	0.320	0.328	0.408
NPC ($)	4,748,823	4,552,405	4,871,097	6,213,843
Capital cost ($)	562,000	1,884,500	3,117,000	5,318,000
Operating cost ($/year)	392,607	250,502	165,100	85,763
RE Penetration Level(%)	17	50.4	75.2	100
Fuel consumption (L/year)	320,837	182,867	93,949	0
Total emission (ton/year)	845	482	247	0

* NPC 값 계산에 각 발전원별 디젤, 신재생, ESS 투자비, 교체비, 운영관리비, 연료비의 현가 계산 반영
* NPC 값 산정 시 재생에너지 프로젝트에 범용적으로 적용되는 Homer의 기본 값인 8% 할인율 반영

펠렐리우 마이크로그리드 LCOE 추정

▪ 투자비 대 경제성(LCOE) 측면에서 DG 발전량 비율 50%가 가장 우수

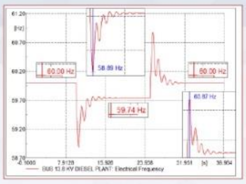


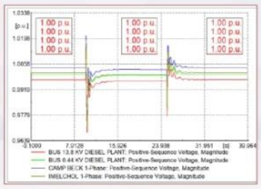
25

전력계통 해석

계통 모델링 (PowerFactory 기반)

- ➢ Single-line diagram
- ➢ Sizing of PVs, ESSs, Diesel generators
- ➢ Possible installing locations of PVs, ESSs
- ➢ Controllers for ESSs, Diesel generators
- ➢ Possible grid expansion





계통 해석 (PowerFactory 사용)

- ➢ Normal operating conditions: power, voltage, frequency
- ➢ Abnormal operating conditions: faults, severe load variations, machine-trip events, black start
- ➢ Voltage stability under different dynamic conditions
- ➢ Frequency stability under different dynamic conditions

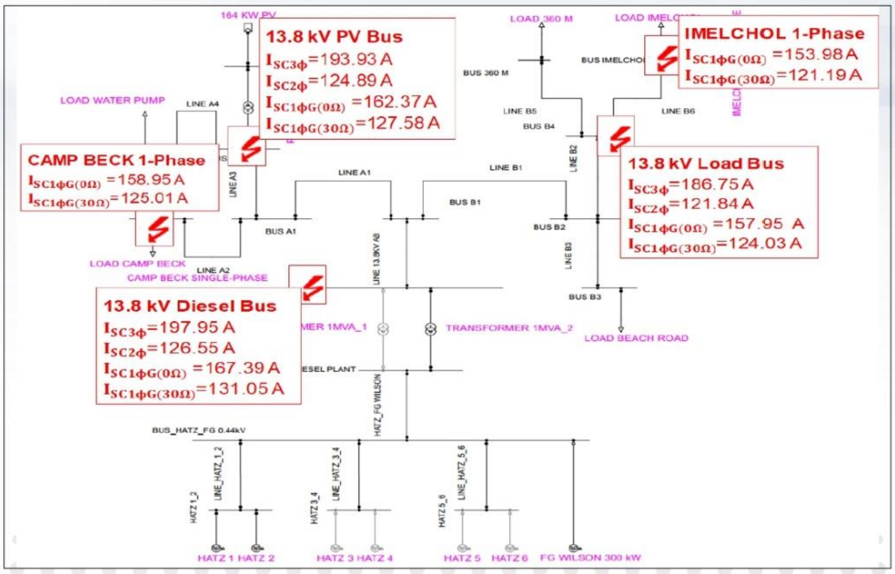
Final Configuration!

▪ **S/W Tool: PowerFactory**

전력계통 고장 해석

- 배전선로 전체 구간에서 고장이 발생하였을 때 흐르는 고장전류에 보호기기가 정상 동작하는지 분석
- 고장전류가 현재 보호기기의 설정값보다 커서 보호협조 양호

고장전류값 (17% PV)
- OCR 설정값 60A
- OCGR 설정값 6A



REP 17%, 50%, 75%, 100%에서의 고장해석 결과

- 현재 계통(17%)과 미래 Upgrade 계통(50, 75, 100%)에서의 고장 해석
- 단락 및 지락 고장전류값 종합

No.	Short Circuit Type	17% existing		50% upgraded		75% upgraded		100% upgraded	
		Min(A)	Max(A)	Min(A)	Max(A)	Min(A)	Max(A)	Min(A)	Max(A)
1	3-phase short circuit	186.75	197.95	185.16	194.74	185.16	194.74	185.16	194.74
	2-phase short circuit	121.84	126.55	119.97	123.45	119.97	123.45	119.97	123.45
	Phase-to-ground (0 ohm)	153.98	167.39	151.09	162.36	151.09	162.36	151.09	162.36
	Phase-to-ground (30 ohm)	121.19	131.05	120.20	128.76	120.20	128.76	120.20	128.76
2	3-phase short circuit	49.75	53.36	51.63	53.45	74.24	77.33	120.90	127.63
	2-phase short circuit	18.52	18.59	15.49	15.68	19.87	20.18	27.09	27.64
	Phase-to-ground (0 ohm)	38.77	42.63	35.94	38.72	40.79	43.48	48.60	51.92
	Phase-to-ground (30 ohm)	34.70	38.14	32.65	34.73	36.38	38.75	42.67	45.10
3	3-phase short circuit	231.09	248.61	235.12	248.04	256.58	271.70	300.85	321.10
	2-phase short circuit	122.37	127.89	120.17	124.08	123.23	127.32	128.54	132.92
	Phase-to-ground (0 ohm)	194.58	213.29	192.29	205.57	197.47	212.75	205.16	221.59
	Phase-to-ground (30 ohm)	141.51	154.33	141.56	150.42	143.66	154.05	146.95	157.78

펠렐리우 마이크로그리드 계통해석 결과 종합

- PEP 케이스별 조류계산, 고장해석, 안정도해석 결과 모든 케이스에서 문제없음 확인

	Load Flow			Fault Current			Stability			
	V(p.u.)						Voltage		Frequency	
	MAX	MIN	I(A)	3P short	1G (0Ω)	1G (30Ω)	Steady-State (p.u.)	Settling time(s)	Steady-state(Hz)	Settling time(s)
17 %	1.012	0.983	17.2	197.95	167.39	121.19	0.993	4.05	59.60	4.02
50 %	1.018	0.987	11.4	248.61	213.29	154.33	0.995	3.05	59.48	4.51
75 %	1.027	0.987	11.5	271.70	212.75	154.05	0.997	4.24	60.00	3.71
100 %	1.030	0.987	11.6	321.10	221.59	157.78	0.999	2.57	60.00	0.35

펠렐리우 마이크로그리드 제어 설계

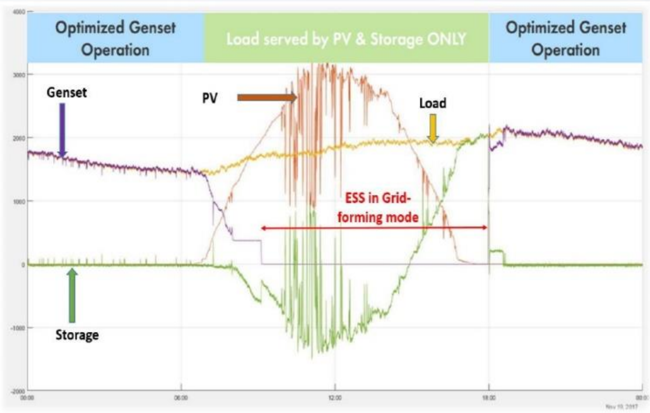
다양한 급전 전략 수행

재생에너지가 증가함에 따라, Load Following, Cycle-Charging, Diesel-on/off 등 다양한 급전전략 필요

Grid Forming vs Grid Parallel

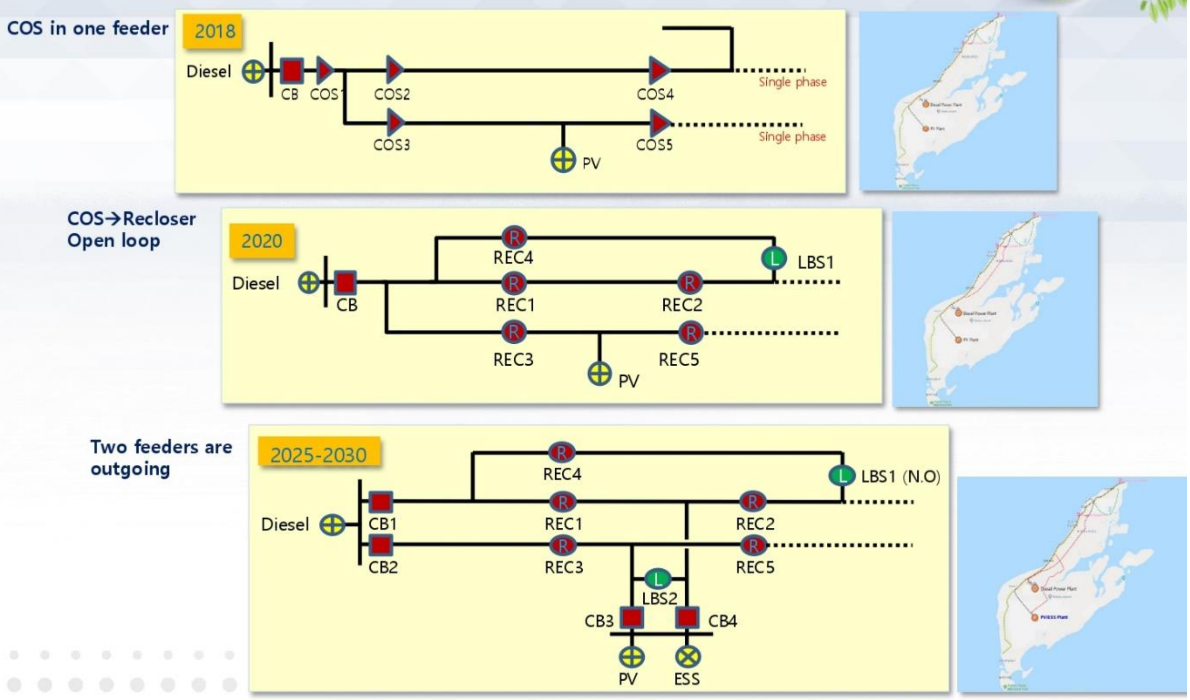
ESS가 추가됨에 따라서 주파수 조정주체의 다양화 필요. 특히 디젤발전기가 꺼질 때는 ESS가 주파수 조정 필요

-Grid Forming: ESS가 주파수 조정
-Grid Parallel: 디젤발전기가 주파수 조정



Grid Forming vs Grid Parallel 모드

펠렐리우 단계별 배전망 그리드 설계



5. 펠렐리우섬 마이크로그리드 후속사업 계획

사업내용

재생에너지 설치 용량

기술설계 결과 최적 LCOE 구성이었던 RE 50% 비율채택
- 신규 설치 용량은 PV 400kWh 및 ESS 925kWh

Micro-Controller

현재 기설치된 SMA Micro Controller는 ESS제어가 불가능하여 교체 필요. 새로운 Micro Controller는 높은 재생에너지 비율을 고려해서 아래의 사항을 포함할 필요가 있음.
- 다양한 급전전략 수행 필요
- Grid Forming vs Grid Parallel

배전망 업그레이드

ESS 신규설치를 고려해서 기술설계에서 제안된 배전망 2025-2030 배전망
- Open Loop 형태로 구성된 배전망 구성
- Cut-off Switch 를 Recloser로 교체 필요

사업예산

USD Dollar

구성	초기투자비용	교체비용 (8% 할인율 반영)	총비용
PV	800,000	0	1,427,735
ESS	462,500	86,320	
ESS Inverter	60,000	18,915	
Total	1,322,500	105,235	

- 펠렐리우 기술설계에 의한 용량 및 IRENA 2017 Cost Database를 토대로 산정
- 교체 비용은 교체 시기를 고려하여 재생에너지 프로젝트에 범용적으로 적용되는 Homer 기본 값인 8%의 할인율을 반영하여 산정

신재생에너지원 추가설치 위치 선정

- 기존 태양광발전소 옆에 PV 및 ESS 추가 설치
- PV/ESS 단지에서 배전선로 추가 인출하여 기존 선로와 연결

인허가 및 환경영향 평가 절차

팔라우의 환경영향평가는 EQPB(Environment Quality Protection Board)에서 담당

- 펠렐리우의 기존 164kW 태양광 프로젝트는 Clearance from EQPB만 받았음.
- EQPB 문의 결과, 본 프로젝트는 이전 프로젝트 처럼 EQPB Clearance만 필요할것으로 예상하나, 프로젝트 상세 정보에 따라서 EA 가능성도 배재할수 없다고 답함.

Clearance from EQPB (EQPB 허가)	Environment Assessment(EA)	Environment Impact Statement(EIS)
모든 건설프로젝트 부지 소유주의 동의 및 아래의 절차를 완료 필요 • Unexploded Ordnance(UXO) Clearance(폭발물 제거) • Erosion & Sedimentation Control Plan (ESCP, 침식 및 퇴적 방지대책)	건설프로젝트 중 특정 조건(EPPB regulation 2401-61-03)에 해당하면 별도의 환경영향평가 실시. • 6개월 이내 종료 • 전문컨설턴트 고용 필요 • 약 40-100페이지 보고서 제출	EA 대상 중 환경적으로 큰 영향을 미칠 우려가 있는 프로젝트는 별도의 EIS 실시 필요 • 1년 이상 소요 • 주민공청회 필요 • 현재 EIS 를 완료한 프로젝트는 팔라우 내에 1개 밖에 없음.

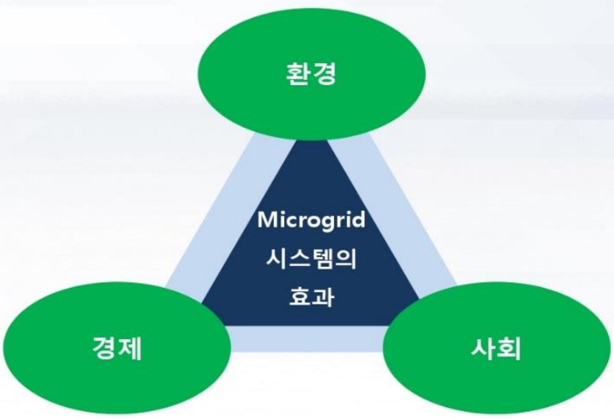
사업의 경제성 분석 (정량적 재무 효과): B/C Ratio

- Capital 투자, Replacement, O&M 및 Fuel 비용을 적용하여 B/C Ratio 분석
- 3가지의 할인율 시나리오를 통한 B/C ratio 분석
    - Homer, IDB, World Bank Case 분석을 통한 8%, 10%, 12% 시나리오 산정
- 주요 Benefit/ Cost 변수는 아래와 같음.
    - Benefit 1: 무인으로 운영되는 재생에너지 증가를 통한 운영비 감소
    - Benefit 2: 디젤 연료비 감소
    - Cost 1: 신규 재생에너지 설치로 인한 총투자비 증가
    - Cost 2: 신규 재생에너지 설비의 교체비용으로 인한 교체비용 증가
- 세부 보고서 Excel 파일은 보고서에 첨부

Scenario	Benefit	Amount	Cost	Amount	B/C Ratio
Scenario 1 (Discount Rate 12%)	Benefit 1+ Benefit 2	$1,155,488	Cost 1+Cost 2	$1,362,563	0.848024873
Scenario 2 (Discount Rate 10%)	Benefit 1+ Benefit 2	$1,337,272	Cost 1+Cost 2	$1,375,127	0.972471556
Scenario 3 (Discount Rate 8%)	Benefit 1+ Benefit 2	$1,572,658	Cost 1+Cost 2	$1,392,067	1.129728507

사업의 사회 경제적 효과 분석: 환경, 경제 및 사회적 효과

- **환경, 경제 및 사회로 구분하여 사회 경제적 효과 분석**



환경적 효과
- 기후 변화에 대한 적극적 대응 (탄소 배출 저감 효과 포함)
- 친환경 에너지 도입 및 확대
- 생물 다양성 위험 감소

경제적 효과 (정량적 재무 효과 제외)
- 에너지 접근 확대
- 빈곤 감소에 기여
- 국가 또는 지역 사회 발전 견인

사회적 효과
- 가구의 경제적 소득 증가에 기여
- 건강 증진
- 교육 기회 및 품질 향상
- 정부 및 지역 사회 참여 확대
- 적적 가격으로 에너지 사용

- **디젤 연료 사용 감소로 인하여 탄소 배출량은 기존 845 톤/연에서 482 톤/연으로 감소하여 363 톤/연의 탄소 저감 효과 창출**

후속사업 추진 계획

남태평양 중소형 도서미니그리드 확산 사업 발굴

- 펠렐리우 마이크로그리드 기술설계 모델 기반
- 우리나라 에너지기술평가원의 실증 지원 검토 중
- 남태평양 중,소형 부속도서에 "Diesel Grid Parity" 목표의 확산 사업 발굴
- SPC(Secretary of Pacific Island)/PCREEE(Pacific Center for Renewable Energy & Energy Efficiency) 협력
- GCF Funding의 민자 사업화 추진
- 2019년 6월 말 피지의 SPC/PCREEE 연차 워크샵에서 펠렐리우 마이크로그리드 사례 발표 예정

팔라우 본섬 IPP 사업 참여

- 팔라우 본섬 태양광 및 ESS IPP 사업 RfP 공고 (2019년 2월 14일)
- 남태평양 도서국가 최초의 45% 신재생에너지 목표의 민자방식 입찰사업
- 원에너지아일랜드 사업설명회 참가 (2019년 2월 18일)
- 본섬 IPP 사업 참여를 위한 사전타당성 조사 수행 (2019년 2월 ~ 3월)
- 우리나라기업의 IPP 사업 컨서시엄 구성
- IPP 사업 참여를 위한 Eligibility Requirements 서류 제출 (2019년 4월 10일)
- IPP 사업 Proposal 준비 진행

남태평양 중,소형도서 미니그리드 확산사업 발굴 계획: 그룹화 및 목표 대상 정의

- **남태평양 도서국가를 세가지 그룹으로 분류하여, Group B를 목표 대상으로 선정**

목표 대상 그룹

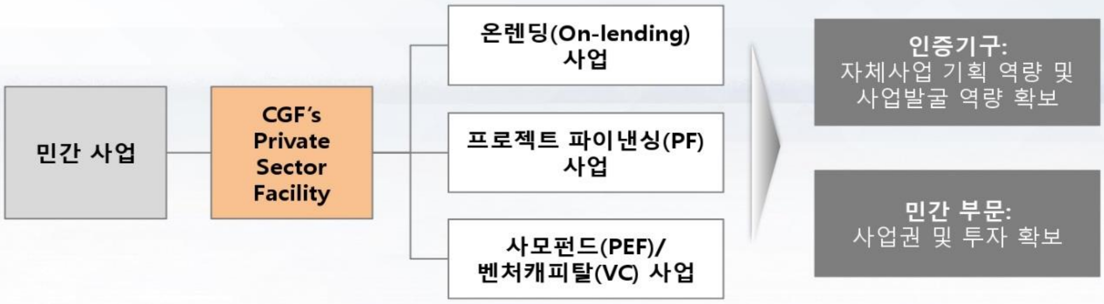
	Main Islands (Group A)	Outer Islands (Group B)	Remote Islands (Group C)
현행 전력 환경	▪ 공공 전력회사가 중앙 집중화된 전력망 운영 ▪ 대부분의 도서국은 10MW 이상이 되는 규모의 전력 시스템 ▪ 디젤을 주요 원천으로 한 전력 생산	▪ 공공 또는 민간 전력회사가 운영하는 소규모 전력망 ▪ 몇백 kW 단위에서 MW 단위까지 다양한 규모의 전력 시스템 ▪ 대부분 디젤 발전 시스템	▪ 안정적인 전력 시스템 부재 또는 디젤 기반 소규모 독립 발전 시스템 ▪ 대부분 평균 100 kW 규모의 전력량
민영 발전 사업 추진 시 제약 및 조건	▪ 현행 전력회사의 독점적 지위	▪ 재생에너지 및 ESS 기반 미니그리드에 대한 높은 수요 ▪ 수익성 있는 민영 발전 사업 추진을 위한 규모의 경제 필요	▪ 조달 및 건설을 위한 물류 환경 열악 ▪ 건설 및 운영/유지보수를 위한 역량 미흡
주요 문제점 및 해결 방안	▪ 전력망 안정화 및 재생에너지 도입 비율 확대	▪ 미니그리드 설계를 위한 높은 수준의 엔지니어링 역량 및 효과적인 통합운영관리 플랫폼 필요 ▪ 민간 부문 참여를 촉진하기 위한 혁신적인 비즈니스 모델 및 인센티브 필요	

남태평양 중,소형도서 미니그리드 확산사업 발굴 계획: 사업화 Concept 및 전략

- 복수의 중, 소형 도서를 하나의 사업단위로 Bundling
- 50% 에너지자립화 목표
- 시스템 LCOE의 Diesel Parity 달성 목표
- 통합 O&M 플랫폼 구축 및 현지인력이 역량강화를 통한 사업의 지속가능성 확보
- Blended Financing 통한 민자사업화
- SPC (Secretary of Pacific Community) 및 PCREEE (Pacific Center for Renewable Energy and Energy Efficiency)와 사업개발 및 사업설계 협력

남태평양 중,소형도서 미니그리드 확산사업 발굴 계획: Blended Financing 모델 기반 사업 추진

- 민간 부문의 투자와 공공 양허성 자금을 결합한 Blended Financing을 자금 조달 모델로 제시



* 자료원: GCF 사업 추진을 위한 효과적 혼합재원 추진방향, KPMG

- Group B에 해당하는 남태평양 중,소형 도서국의 재생에너지 기반 미니그리드 수요를 단일 프로젝트로 구성하여 SPC를 통해 GCF에 제안서 제출하여 우대조건의 Project Loan을 통한 민자사업화 추진

남태평양 중,소형도서 미니그리드 확산사업 발굴 계획: SPC와 원에너지아일랜드 간 MOU 체결

- 원에너지아일랜드는 지난 2018년12월21일 SPC와 MOU를 체결하여 Pacific Island Countries and Territories (PICT) 미니그리드 사업 촉진을 협력 관계 형성
- SPC는 2019년 2월 GCF이사회에서 남태평양의 USD 50M 이하 규모의 인프라 구출 및 역량강화 사업에 특화된 인증기구 (Accredited Entity) 로 공식 지정 됨

Pacific Community
Communauté du Pacifique

THE PACIFIC COMMUNITY
ACTION FILE
21 DEC. 2018
ACTION OFFICER

Memorandum of Understanding

between

The Pacific Community (SPC)

and

One Energy Island Co., Ltd (OEI)

Preamble

The Pacific Community ("SPC"), and One Energy Island Co., Ltd ("OEI"), collectively referred to as "the Parties";

Acknowledging the importance of opportunities and benefits of decentralized renewable energy solutions for improved livelihoods for communities through the promotion of mini-grid projects to achieve the Sustainable Development Goals (SDGs) throughout the Pacific Island Countries and Territories (PICTs).

Recognising the opportunities for SPC and OEI to collaborate in the design and implementation of a comprehensive regional mini-grid programme for PICTs which would include advanced technical designs and a right business model to promote mini-grid projects, and identifying and acquiring knowledge and financial resources required to achieve the programme goal.

Noting that there are barriers and challenges preventing mini-grid market and industry development at the government, industry, and community levels

Desiring to contribute with a feasible and practical regional programme to increase clean energy access, and improve livelihoods for communities by promoting mini-grid projects in PICTs

The Parties agree to cooperate as follows.

Article I
Purpose and Scope

1.1 The purpose of this Memorandum of Understanding (MoU) is to facilitate collaboration between SPC and OEI, particularly in the following areas of mutual interest, which provide a framework for the partnership and the basis for elaborating a commonly agreed work programme. The list does not exclude other areas deemed useful by both Parties.

Article X
Entry into Force, Modification and Termination

10.1 This MoU will enter into force on the date on which it is signed by authorized representatives of both parties.

10.2 The Parties may agree to amend this MoU through an exchange of letters between them following appropriate consultations.

10.3 This MoU may be terminated by mutual consent of the two Parties or by either Party giving the other Party six (6) months' written notice in advance. This period shall commence as from the date of receipt of the notice of termination.

For: The Pacific Community
Name: COLIN TUKUITONGA
Title: DG
Date: 21.12.18

For: One Energy Island Co., Ltd.
Name: TAEIL KANG
Title: CEO
Date: December, 15, 2018

6. 팔라우 본 섬 태양광 및 ESS IPP 사업 사전타당성 조사

경과

구분	한국측 진행 사항	팔라우 측 진행 사항
2017(하) ~ 2018	한국에너지공단(KEA)과 UNIDO 및 PCREEE (Pacific Center for Renewable Energy and Energy Efficiency)간에 남태평양 도서국가 기후변화 대응 사업협력 추진 UNIDO 남태평양 미니그리드 보급방안 조사용역 진행 원에너지아일랜드 연구조사 사업자 선정, 진행 (2018년 11월 보고서 완료, PCREEE 세미나에서발표)	팔라우정부 2025년까지 신재생에너지 자립율 45% 달성 목표 수립
2018(하) ~	(2018. 상반기) 펠렐리우섬에 디젤교체 태양광 및 ESS 미니그리드 타당성조사 확정 및 원에너지아일랜드 타당성조사 사업자 선정 (2019.1.29) 펠렐리우 섬 미니그리드 기술설계안 협의 (팔라우) (2019.1.31) 팔라우 PPUC와 원에너지아일랜드 펠렐리우 후속 실증사업 및 팔라우 본섬 IPP 사업 협력을 위한 MOU 체결 위 MOU와 별도로 KEA와 팔라우정부간 기후변화 대응사업 협력 MOU 체결 (2019년 2월) (2019.2.17~2.28) 현지 사업설명회 참가. IPP 사업 대상지 현지 조사	(2018.7) 팔라우정부(대통령) Carbon Free Island 추진 선언 ENGIE-EPS 팔라우 정부와 팔라우에 태양광 35MW ESS 45MWh 사업제안 제출 ENGIE-EPS와 PPUC간의 PPA 협의 진행 중단 PPUC가 RFP를 통한 IPP사업자 공모 입찰 방식으로 사업자 선정하기로 방침 변경 (2019.2.14) PPUC RFP 공고 (2019.2.19) 현지 사업설명회 개최

RFP 내용-1

구분	내용
PPA 조건	20년 고정가격 입찰(상호 협의 하에 5년 연장)
예상부하	- 2018년 최대부하 12.5MW 연간발전량 89.4GWh - 2020년 최대부하 14.6MW 연간발전량 96.9GWh - 2025년 최대부하 18.2MW 연간발전량 115.1GWh
용량	IPP 업자는 총 3개의 계획을 모두 제출 A. 2020년 연간발전량 대비 RE 비율 20% -기준 연간발전량: 20GWh(최소), 23GWh(최대) B. 2020년 RE 비율 20%, 2025년 RE 비율 45% - 2025년 기준 연간발전량 52GWh(최소), 55GWh(최대) C. 2020년 RE 비율 45% - 2020년 기준발전량 52GWh(최소), 55GWh(최대) * 송전손실을 감안하지 않음. * RE(Renewable Energy)는 태양광+ ESS 를 의미
부지	부지 선정 및 확보는 IPP의 책임

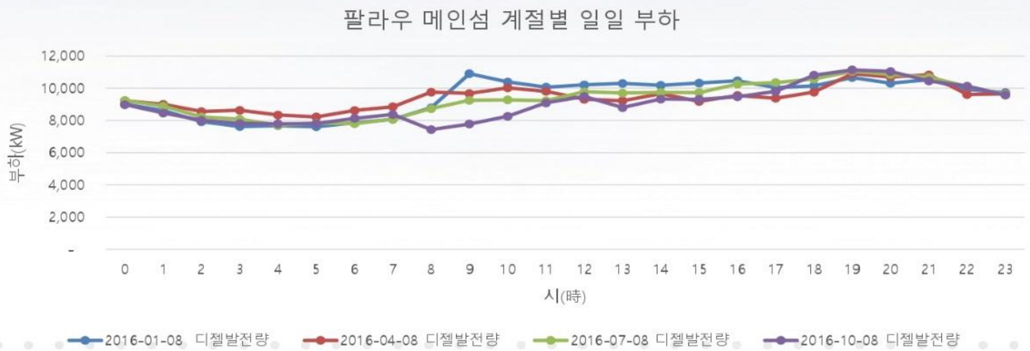
RFP 내용 -2

구분	내용
PPA 단가	고정가격으로 제출(kWh/USD) dollar * 가격 상승분 반영여부는 PPA 계약 협상시 결정
평가 항목	1. 자격심사(Eligibility requirements evaluation) 2. 기술심사(Technical evaluation) 3. 재무/금융 심사(General and financial evaluation)
주요자격요건	컨소시엄 중 Utility-scale의 PV+ESS 프로젝트를 3개 이상 수행한 기업이 있어야 함.
PPA 계약	우선 협상 대상자 선정후 별도의 타당성 보고서 제출 필요 계약 협상시 전력구매계약의 상세사항 결정

팔라우 본섬 부하

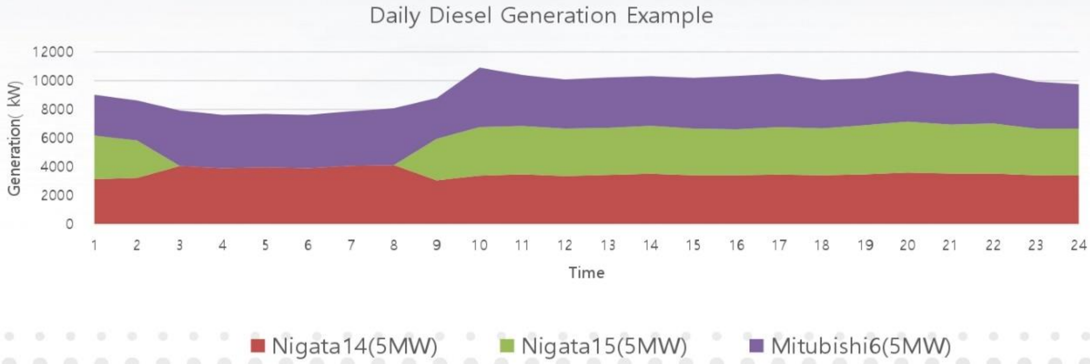
팔라우 부하는 약 7-11 MW 사이로 시간대와 관계없이 부하가 일정하고, 계절별로도 큰 차이가 없음.

2016년 기준 총발전량은 83.6GWh 로 추정(JICA 2018) RFP 에 의하면 2020년 부하 예측은 96.9GWh로 추정. 약 15.8% 의 부하 증가가 있을 것이라고 예측



팔라우 본섬 발전시스템 현황

- 팔라우에는 총 2개의 발전소가 있는데, Malakal 발전소의 Nigata 14(5MW) , Nigata 15(5 MW)가 주요 부하를 담당함.
- 이외의 Aimellik 발전소의 Mistubishi 6(5MW), Mistubishi 7(5MW) 가 5일마다 번갈아 가면서 수행(예: 1.9~14 Mistubishi6, 1.14-19 Mistubishi7)
- 주 발전기인 Nigata14, Nigata15는 유지 보수를 위해서 새벽 2-8시 사이에 번갈아가면서 휴동함.
- 이외 발전기는 거의 운영 하지 않고, 작동 여부도 불투명.



PV+ESS 용량 설계

- 용량 산출은 RFP의 조건을 시간별 부하데이터를 기반으로 산출
- Homer의 Load Following 전략을 기반으로 분석했음.
  - RFP상 2020년 발전량 기준 향후 전력수요증가분을 감안해서 결정
  - RFP상 요구조건에 맞추어서 설계
  - 마이크로 그리드 설계 프로그램인 HOMER(Hybrid Optimization of Multiple Energy Resource) 의 Load Following 전략을 기반으로 산정

RE Contribution	Diesel	PV	ESS
RE 20%	A MW	A MW	A MWh
RE 45%	B MW	B MW	B MWh

참고: 각 전원구성요소별 용량은 실제 사업제안서에 포함될 내용이어서 비공개

팔라우 본섬 사업 대상 부지 조사현황

- 대부분 경사 10~15도 의 부지임. 육안으로 보아 산림훼손 및 과도한 토목공사 불필요 판단
- 부지와 계통연계점간의 거리는 100m 이하임. 접근도로 조건 양호한 지역 (다음 슬라이드: 조사대상부지 리스트)
- 현지 변호사를 고용하여 "Title Search" (부지 소유권 및 용도규정 확인) 진행 중.

대상 부지 예시 사진(Ngardmau7)

팔라우 본섬 사업대상부지 조사현황

주	구분	면적 (m2)	설치가능 용량(kW)	주	구분	면적 (m2)	설치가능 용량(kW)
Aimelik	1	533,677	56,000	Ngardamu	4	21,600	17,000
	2	23,900	2,100		5	44,617	4,000
Ngatpang	1	457,183	50,000		6	58,844	5,000
	2	115,115	12,500	Ngaraard	1	69,374	7,000
	3	64,031	6,400		2	36,320	3,000
	4	28,517	2,500		3	75,221	7,000
	5	21,600	2,300	Ngiwal	1	231,600	23,000
	6	102,548	10,800		2	177,710	18,000
	7	130,202	13,000		3	35,829	3,000
	8	119,884	11,000	Melekeok	1	10,048	800
	9	355,360	38,000		2	246,336	26,000
Ngaremlengui	1	103,811	11,000		3	321,486	35,000
	2	127,974	13,000		4	348,442	35,000
Ngardamu	1	153,865	15,000	Nchesar	1	264,278	28,000
	2	156,462	16,000	Airai	1	107,772	10,000
	3	53,856	5,500	합계		4,597,462	486,900

사업의 경제성 분석: PPA 가격 별 IRR 추정

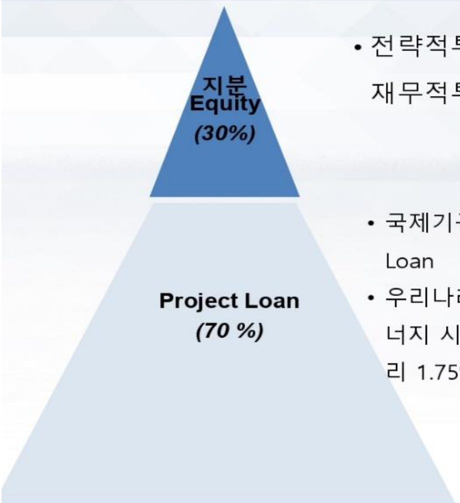
*** PPA Target price: Diesel의 Fuel Cost에 근접한 수준 목표**

PPA 단가 시나리오	RE 20%	RE 45%
A/kWh	9.87%	8.61%
B/kWh	10.86%	9.57%
C/kWh	11.83%	10.51%

변수에 대한 가정

- 사업비 (RE 20% 30 million USD , RE 45% 70 million USD)
- 사업기간 20년
- 운영 관리 $9/kW , 토지 임대비 $10/kW
- ESS 교체 비용은 초기 ESS 비용의 50% 가정

재원조달 계획



- 전략적투자자 (SI) 및 재무적투자자 (FI)의

- 국제기구를 통한 Project Loan
- 우리나라 정부의 신재생에너지 시설자금 대출 (변동금리 1.75%)

SI의 역할

- 지분투자: Equity 의 최대 50%
- EPC 및 시스템 성능보증 책임

재무적투자자(FI) 협상 전략

- 지분율 50% 또는 이상
- 재무적투자자(FI)는 사업의 경영에 참여하지 않는 대신 고수익의 우선주 배당을 목표로 참여. 또는 운영사업 희망자
- 협의 대상 FI: 국내, 외 Clean Energy 투자 Fund 또는 운영사업희망자
- FI는 recourse/limited recourse based financing에 대한 신용 혹은 CDS(Cash Deficiency Support, 현금보충약정) 제공 불가

Project Loan 조달 방안

금융조건	PPA 정부보증
재원조달방안	국가 신용 위험 보증: MIGA 측 문의 확인 1)국제금융기구 - ADB, IFC 등 동남아시아와 남태평양 국가를 cover하는 국제금융기구 PF 조달 2) 한국 정책금융기관 - KEXIM (수은), GIF (글로벌 인프라 펀드): 팔라우 신용등급이 없어서 PF 여부 불확 실 - 에너지공단 신재생 에너지 시설융자:최대 100억, 금리 1.75%(변동), 주주 담보필요
예상금융조건	선순위: 7~8%

경쟁구도 및 진행사항

Key Competitive Factor

- PPA 단가
- 계통안정화 방안: 본 IPP는 팔라우 전체 전력공급의 45%를 담당하는 것을 목표로 하고 있으므로, 기존 발전설비와 유기적인 운영방안 및 전력계통 안정화 방안 제시 필요.
- 현지 Utility 역량 강화: 현지 Utility가 재생에너지의 변동성에 대응한 경험이 없어서 태양광 ESS 및 기존 디젤발전설비의 연동운영 훈련 및 역량 강화 프로그램의 제시 필요

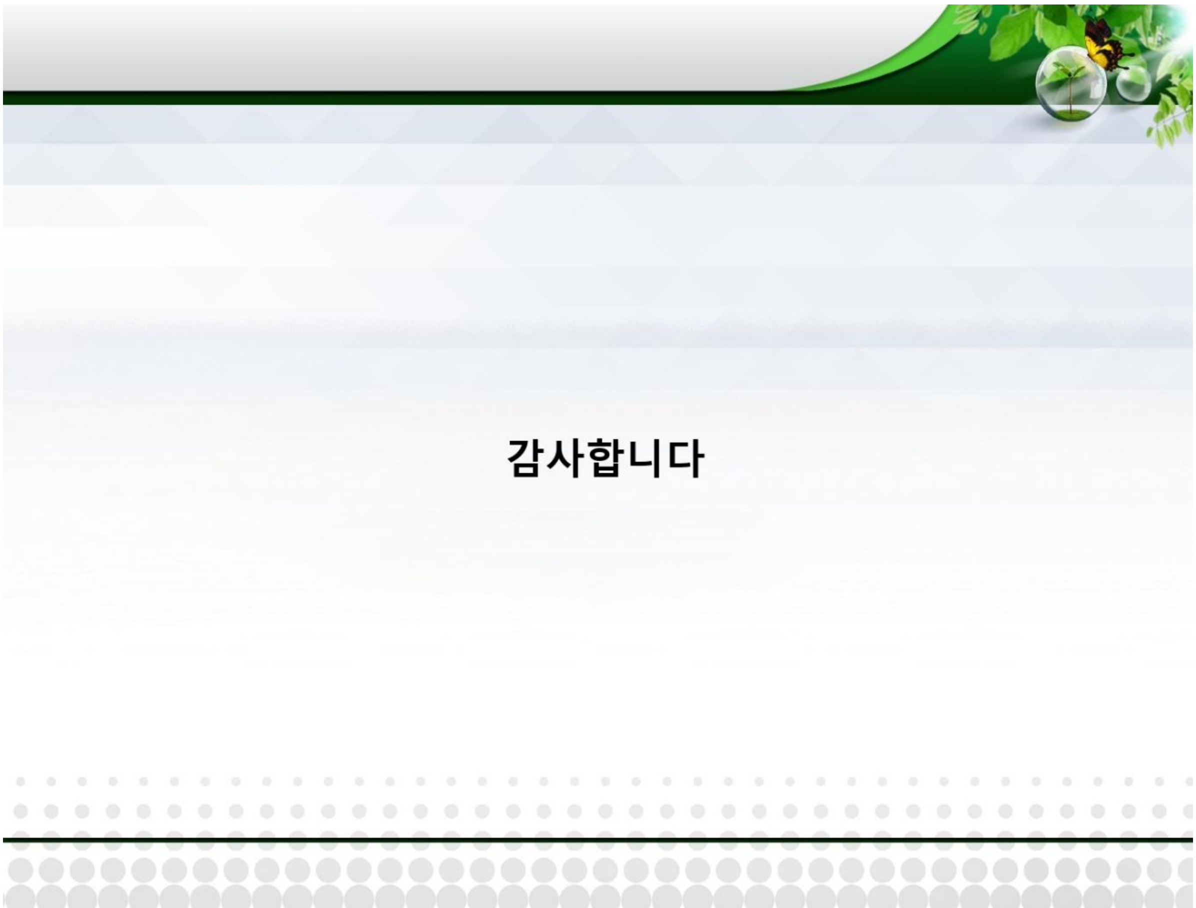
진행사항

- 4월 10일 Envelope A(Eligibility Requirements) 서류 제출
- 현재 Envelope B(Technical Part)와 Envelope C(Financial Part) 준비중(5월 30일 제출 예정)

7. 사업예산 및 집행 실적

사업예산 및 집행실적 총괄표

구분	구 분	주관기관			참여기관			합계		
번호	비 목	예산	사용	집행율	예산	사용	집행율	예산	사용	집행율
1	인건비(소계)	13,200	13,200	100%	10,800	10,800	100%	24,000	24,000	100%
	.내부인건비	13,200	13,200	100%	10,800	10,800	100%	24,000	24,000	100%
	.외부인건비	-	-	-	-	-	-	-	-	-
2	직접경비(소계)	75,800	69,720	92%	60,200	50,122	83%	136,000	119,842	88%
	.기자재 및 시설.용역비	19,100	18,869	99%	9,000	8,667	96%	28,100	27,536	98%
	.여비	26,000	21,893	84%	20,000	11,455	57%	46,000	33,348	72%
	.수용비 및 수수료	4,500	3,038	68%	-	-	-	4,500	3,038	68%
	.기술정보활동비	25,300	25,098	99%	30,500	30,000	98%	55,800	55,098	99%
	.사업활동비	900	821	91%	700	0	0%	1,600	821	51%
	.사업홍보비	-	-	-	-	-	-	-	-	-
3	간접비(소계)	-	-	-	-	-	-	-	-	-
	.간접경비	-	-	-	-	-	-	-	-	-
합계		89,000	82,920	93%	71,000	60,922	86%	160,000	143,842	90%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3. 타당성조사 보고서 (영문)

Feasibility Study of Microgrid Project at South Pacific Island Countries and Territories

2019.05

산업통상자원부

KOREA ENERGY AGENCY

Content

Abbreviation

ADB	Asian Development Bank
B/C ratio	Benefit and Cost ratio
CCPR	Composite Country Performance Rating
CIA	Central Intelligence Agency
COFA	Compact of Free Association
COS	Cot Out Switch
CPA	Country Performance Assessment.
DER	Distributed Energy Resource
EA	Environment Assessment
EIS	Environment Impact Statement
ESS	Energy Storage System
EQPB	Environment Quality Protection Board
FY	Fiscal year
GHG	Green House Gas
HOMER	Hybrid Optimization of Multiple Energy Resources
IEEE	Institute of Electrical and Electronics Engineers
INDC	Intended Nationally Determined Contributions
IRENA	International Renewable Energy Agency
IPP	Independent Power Producer
JICA	Japan International Cooperation Agency
LCOE	Levelized cost of energy
MOF	Ministry of Finance
MoU	Memorandum of Understanding
NEP	National Energy Policy
NEC	National Energy Committee
NPC	Net Present Cost
O&M	Operation & Maintenance
ODA	Official Development Assistance
PCREEE	Pacific Centre for Renewable Energy and Energy Efficiency
PEA	Palau Energy Administration
PICTs	Pacific Island Countries and Territories
PNC	Palau National Code
PPA	Pacific Purchase Agreement

PPUC	Palau Public Utilities Corporation
PV	Photovoltaic
RE	Renewable Energy
REP	Renewable Energy Penetration
RFP	Request for Proposal
RPPL	Republic of Palau Public Law
SPC	Pacific Community
WT	Wind Turbine
UNIDO	The United Nations Industrial Development Organization
UXOs	Unexploded Ordnance

1.Outline of Feasibility Study

1.1. Background of Feasibility Study

Pacific Island Countries and Territories (PICTs) include of 22 members divided into three sub regional divisions, Melanesia, Micronesia, and Polynesia. A total of about 10 million inhabitants is spread out on the islands with a total land area of about 553,409 km^2. Many people are living in rural areas on remote islands with insufficient energy access. Countries including Papua New Guinea, the Solomon Islands, Vanuatu, and Kiribati still have more than half of the population living without electricity. The remote geography of the islands remains a primary reason for making the energy supply difficult and expensive to deliver.

While the agriculture and tourism industry are important as economic sources in the PICTs, a low rate of energy access hinders their economic growth throughout the region. Moreover, most of the PICTs heavily rely on fossil fuel as main energy sources which generate Green House Gas (GHG) while making the islands more vulnerable to weather events caused by climate change. In addition, marine transportation of those energy resources also puts countries at a high risk to oil spills.

To mitigate these energy issues in the PICTs, the Pacific Center for Renewable Energy and Energy Efficiency (PCREEE) was established as a knowledge hub with a focus on information exchange regarding regional interventions, tools, and methodologies in partnership with stakeholders to promote renewable energy in the PICTs.

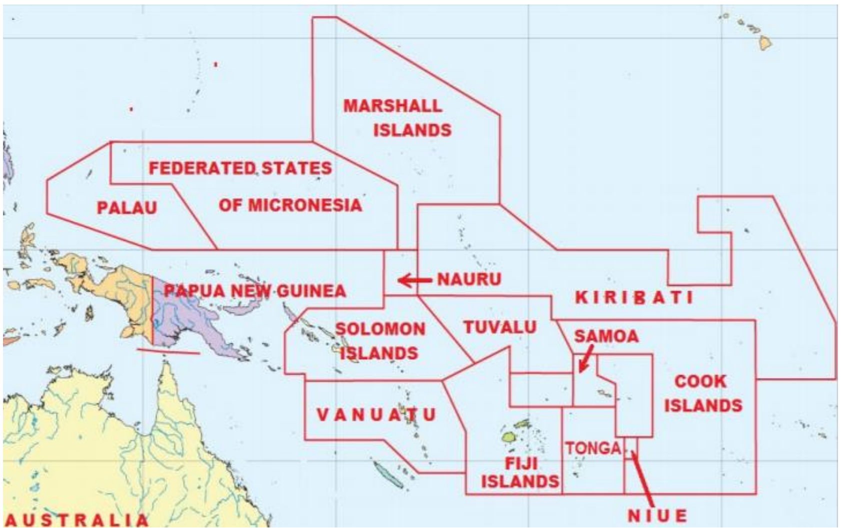


Figure 1.District in PICTs

In recent years, decentralized renewable energy systems, called mini-grids, have become an important solution to provide electricity on remote islands at an affordable cost. According to this trend, United Nations Industrial Development Organization (UNIDO) and Government of Palau request mini-grid feasibility study for Palau and Peleliu which is one of the outer islands in Palau.

1.2. Mini-grid Overview

In many islands and mountainous areas, it is expensive or physically impossible to supply electricity using transmission and distribution lines. We have installed diesel generators to supply power at island mainly in the past. However, recent trend is focusing on the construction of carbon reducing island, which has combination of renewable energy and energy storage systems to supply the power for solving the environmental pollution problems, the instability of oil prices, and falling prices of renewable energy construction.

We define microgrid as a grid of small island areas that contain renewable energy sources. Although the initial investment cost is higher than diesel generation, the microgrid has no influence on the oil price increase, the installation cost is gradually decreasing, and the advantage of the low maintenance cost is emphasized. If we make the combined design of renewable energy and energy storage system appropriately considering to the load and climate conditions of the target area, it will be possible to make the economical microgrid. However, the microgrid with renewable energy should be examined precisely in advance because it may cause complicated load flow, protection problem, system stability problem due to fluctuation of output compared to diesel generation.

The independent microgrid installed on the islands and mountainside is a small-scale power supply system consisting of renewable energy (wind power generation, solar power generation, small hydro power generation, etc.) and energy storage system. This distinguishes it from a linked microgrid that is connected to the large power grid.

It is difficult to accurately compare independent microgrid technology with other technologies objectively, but comparison is made according to the technology development trends in the following table 1. Diesel power plants have mainly been responsible for supplying power to isolated areas. Hybrid power system is classified as a combination of conventional diesel power plants with small amounts of wind power generators or solar power generators. The independent microgrid is characterized by high energy storage system dependability because the energy storage system maintains voltage and frequency for most of the time, instead of conventional diesel generators.

Issue	Internal combustion	Hybrid system	Independent microgrid
Main power source	Diesel generator	Diesel + Solar Diesel + wind power	Renewable Energy (Solar, wind power, etc.)
Frequency control	Diesel generator	Diesel or wind power + load control	Inverter + EMS
Voltage control	Diesel generator	Diesel or Synchronous exciter	Inverter
Voltage / frequency retention rate	Low	low	high
Energy storage	Oil	Oil(main) + ESS(sub)	ESS(main) + Oil (sub)
EMS	×	△	○
Initial investment cost	Low	normal	high
Operating cost	High	normal	low

Table 1.Comparison of Diesel and Microgrid

1.3. Introduction of Palau

Palau, which is located in PICTs and 800 km southeast from Philippines, is vulnerable to climate change and 100% dependent on imported energy. Due to these fact, government of Palau sets ambitious goal for renewable energy.

Total area is 458 ㎢. Even though there are 200 islands in Palau, people inhabit in only 9 islands. The capital is Melekeok and major states are Aimeliik, Airai, Angaur, Hatohobei, Kayangel, Koror, Melekeok, Ngaraard, Ngarchelong, Ngardmau, Ngatpang, Ngchesar, Negeremlengui, Ngiwal, and Peleliu. 65% of the total population live in Koror.

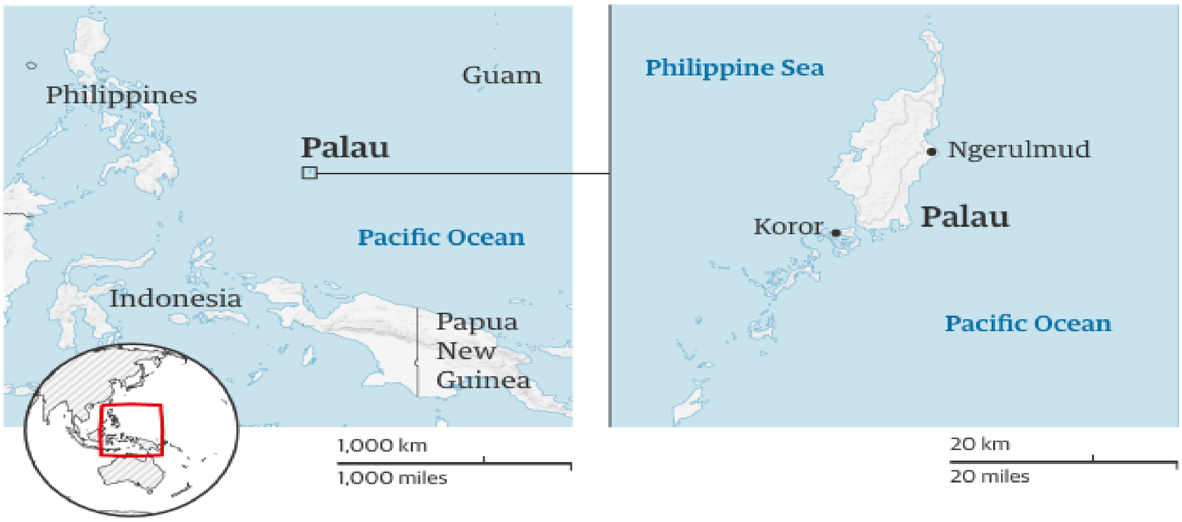


Figure 2.Map of Palau

Migrants from the Philippines settled in Palau approximately 3,000 years ago. In modern age, Japan ruled Palau from World War I until World War II. After World War II, Palau joined U.S. governed Trust Territory of Pacific Islands (TTPI).

After almost four decades of TTPI, US administration under the Palau, opted for independent status in 1978. Palau adopted its own constitution and became the Republic of Palau in 1981. It has been in a compact of free association with the US since 1993. Palau gained full sovereignty when the Compact went into effect on 1 October 1994, concluding Palau's transition from trusteeship to independence.

In 2010, Palau set National Energy Policy (NEP), to deliver clean, secure, affordable energy for all citizen and respond to the risks of climate change by adaptation and mitigation. It is renewed every 10 years (IRENA,2017): next renewal period will be 2020. NEP targeted major goals below

- 30% reduction of energy consumption
- 20% of Renewable Energy (RE) electricity generation by 2020

In 2015, Palau government submitted Intended National Determined Contribution (INDC) to United Nations Framework Convention on Climate Change (UNFCCC) at COP21(Conference of the Parties Paris Agreement). In INDC, Palau government set goals below.

- 22% energy sector emissions reductions below 2005 levels by 2025
- 45% RE target by 2025
- 35% Energy Efficiency target by 2025

1.4. Purpose of F/S study

In 2018, UNIDO and Palau government requested feasibility study for mini-grid in Peleliu to Korea Energy Agency, which is the biggest outer island in Palau. One Energy Island (OEI), which builds a consortium with Anygate and Kookmin University, conducts detailed feasibility study of Peleliu. The technical design of Pelelu minigrid is proposed.

Moreover, PICTs are trying to adopt Independent Power Plant (IPP) model. Palau also issued IPP Request for Proposal (RFP). Palau IPP RFP has similar challenges which Peleliu has faced. Therefore, this report provides preliminarily analysis and design for Palau IPP proposal based on Peleliu technical design. Considering Palau IPP proposal is early reference in IPP model in PICTs, this analysis can guide general structure and challenges where other IPP in PICTs countries might propose.

2.Socio-economic Environment

2.1.Politics

Constitution of Palau is formed in 1981. Palau is the democratic republic. The President of Palau is both head of state and head of government. The president of Palau serves 4 years-term for each. Current president is Tommy E. Rememgesau Jr. who serves the 4th term (2001-2005, 2005-2009, 2013-2017 and 2017- present). Current vice president is Raynold Oilouch.

Palau National Congress (Olbiil era Kelulau) consists of the House of Delegates and the Senate of Palau. The House of Delegates has 16 members, each serving four-year terms in single-seat constituencies. The Senate has 13 members, also serving four-year terms in multi-seat constituencies. Palau currently has no political parties. Each state also elects its own governor and legislature. Current congress is 10th congress whose term is until Jan. 2021.

Both legislative election and presidential election have been held for every 4 years since 1980 (1980, 1984, 1988, …. and 2016). There have been 10 legislative elections and 11 presidential elections: 1 presidential by-election was held in 1985.

The judicial system consists of the Supreme Court, National Court, the Court of Common Pleas, and the Land Court. The Supreme Court has trial and appellate divisions and is presided over by the Chief Justice of Palau. There are no regular military forces in Palau, and only national police is working. U.S. is responsible for defense of Palau. U.S army is granted access to islands until 2044 but it has not stationed any military force (CIA factbook).

Like other countries, politics in Palau had some turbulence in 1980s and early 1990s. However, Palau has quickly stabilized since then. There have been peaceful regime changes in Palau history.

In 2nd term of National Congress (1985-1989), Special Prosecutors Act (PNC-Chpater2-Title 5) was enacted to independently investigate major political problem. Palau is currently the only one of the Micronesian nations to employ a Special Prosecutor;

In 6th and 7th term of National Congress (2005-2009,2009-2013), Financial Institutional Act and Money Laundering and Proceeds of Crimes Act (PNC-Chapter-38-Supchapter1) were passed to supervise financial sector and prevent financial crimes. It has been a member of the Asian Pacific Group on Money Laundering (APGML) since 2002. Palau acceded to the United Nations Convention Against Corruption (UNCAC) in March 2009.

Palau ranks on the top of World Governance Indicators (WGI) index among PICTs countries, which demonstrates stability of government and capacity to effectively formulate and implement sound policies.

Countries	Estimate	Rank
Palau	1.21	89.16
Marshall Islands	1.19	88.18
Micronesia, Fed. Sts.	1.14	85.22
Tuvalu	1.08	83.74
Kribati	1.05	81.77
Samoa	0.78	72.41
Vanatu	0.69	69.95
Tonga	0.60	67.98
Solomon Islands	0.49	62.56
Fiji	0.18	52.71
Papua New Guinea	0.13	51.23

Table 2.WGI, PICTs Countries(World Bank,2017)

A. Estimate: Estimate of governance (ranges from approximately -2.5 (weak) to 2.5 (strong) governance

B. Rank: Percentile rank countries (ranges from 0 (lowest) to 100 (highest) rank)

According to "Country Reports on Human Rights Practices, Bureau of Democracy, Human Rights, and Labor" conducted in 23 February 2000, general categories for human rights of Palau shows moderate state.

Category respect of human right	Analysis
Political and Other Extrajudicial Killing	There were no reports on political or other extrajudicial killings.
Disappearance	There were no reports on politically motivated disappearances.
Torture and Other Cruel, Inhuman, or Degrading Treatment or Punishment	Prison conditions meet minimum international standards, and the Government permits visits by human rights monitors.
Arbitrary Arrest, Detention, or Exile	The Constitution prohibits arbitrary arrest, detention, or exile, and the Government observes these prohibitions.
Denial of Fair Public Trial	There were no reports on political prisoners.
Arbitrary Interference with Privacy, Family, Home, or Correspondence	The Constitution prohibits such practices, government authorities generally respect these prohibitions, and violations are subject to effective legal sanction.

Table 3. Country Reports on Human Rights Practices (U.S Department of State, 2000)

2.1.1. Foreign Relations

Palau has been having traditionally strong ties with U.S, Japan and Taiwan. Major ODAs come from 3 countries. The most important part in foreign relation of Palau is Compact of Free Association (COFA) agreement between Palau and U.S.

The COFA is an international agreement establishing and governing the relationships of free association between the United States and three pacific island nations: Federated States of Micronesia, the Marshall Islands, and Palau. These nations, together with Northern Mariana Islands, formerly composed the Trust Territory of the Pacific Islands, United Nations Trusteeship administered by the United States Navy from 1947 to 1951 and by the U.S. Department of the Interior from 1951 to 1986. Palau agreed on COFA in 1994.

The compact came into being as an extension of the U.S.–U.N. territorial trusteeship agreement, which obliged the federal government of the United States to promote the development of people of the Trust Territory toward self-government or independence as appropriate to particular circumstances of the Trust Territory and its people and the freely expressed wishes of the peoples concerned.

Category	Explanations
Economic Provision	Under the compact, the U.S. federal government provides guaranteed financial assistance over a 15-year period administered through its Office of Insular Affairs in exchange for full international defense authority and responsibilities. Economic provisions last for 15years. U.S and Palau have agreed to extend economic provision another 15 years in 2009, economic provision is extended to 2024.
Military Provision	The COFA allows the United States to operate armed forces in Compact areas, demand land for operating bases (subject to negotiation) and exclude the militaries of other countries without U.S. permission. The U.S. in turn becomes responsible for protecting its affiliate countries and responsible for administering all international defense treaties and affairs, though it may not declare war on their behalf. Citizens of the associated states may serve in America's armed forces and there is a high level of military enlistment by Compact citizens. Military provisions last for 50 years U.S. remains responsible for Palau's defense until 2044.

Table 4. Provisions of COFA by www.uscompact.org

2.1.2. Political Risk Assessment

Since Palau is small nation less than 20,000 peoples, not many quantified researches have been conducted to assess political (sovereignty) risk of Palau. Sovereignty credit rating by 3 major credit agencies (Moody's, S&P, and Fitch) do not conduct the credit assessment of Palau. Moreover, other major World Bank Country Policy and Institutional Assessments (PIA), Political Risk Services International Country Risk Guide (PRS), and Corruption Perception Index (CPI) do not provide risk assessment data for Palau.

Instead, Asian Development Bank (ADB) annually assess political risk by Country Performance Assessment (CPA). CPA is developed to judge allocation of concessional assistance resources to country performance. This system is based on the principle that aid is the most effective in accelerating economic growth and poverty reduction in countries where policy and institutional performance is strong. The assessment is conducted for Developing Member Countries (DMC) within members of ADB. There are 3 groups for assessment.

Group	Countries
PITCs	Kiribati, Marshall Islands FSM, Nauru, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Vanuatu
Group A	Afghanistan, Bhutan, Cambodia, Kyrgyz Republic. Lao PDR, Maldives, Myanmar, Nepal, Tajikistan
Group B	Bangladesh, Mongolia, Pakistan, Sri Lanka, Uzbekistan, VietNam

Table 5.Country Performance Assessment Ratings Grouping (ADB, 2016)

The overall score of CPA for Palau is above average of PICTs but below average of Group A and B. CPA uses 4 criteria. CPA uses weighted geometric function for the final the composite country performance rating (CCPR).

- **Economic Management:** Monetary and exchange rate policies, Fiscal policy, Debt policy.
- **Structural Policies:** Trade, Financial sector, Business regulatory environment
- **Policies for Social Inclusion/Equity:** Gender equality, Equity of public resource use, Building human resources, Social protection and labor, Policies and institutions for environmental sustainability
- **Public Sector Management and Institutions**

Country	Economic Management	Structural Policies	Policies for Social Inclusion/Equity	Public Sector Management and Institutions	**Policy Performance Score**	**Composite country performance rating (CCPR)**
Palau	3.2	3.3	3.5	3.3	**3.33**	**12.0**
PICTs Average	3.20	3.2	3.1	3.1	**3.15**	**10.5**
Group A average	3.80	3.7	3.9	3.7	**3.79**	**14.4**
Group B average	4.10	4	4.2	3.9	**4.04**	**16**

Table 6. Country Performance Assessment Ratings (ADB,2016)

Ranking of 27 Developing Member Countries (DMC) shows strength of Palau politics more clearly. Palau has strength in both structural policies and policy performance. However, Palau has weakness at Policies for Social Inclusion/Equity Public Sector Management and Institutions.

Economic Management Rank/Score			Structural Policies Rank/Score			Policies for Social Inclusion/Equity Rank/score			Public Sector Management and Institutions Rank/score			Policy Performance Rank/Score		
1	Uzbekistan	5.0	1	Viet Nam	4.3	1	Bhutan	4.8	1	Bhutan	5.0	1	Bhutan	21.9
2	Bangladesh	4.5	2	Cambodia	4.2	2	Viet Nam	4.7	2	Viet Nam	4.4	2	Vietnam	19.1
3	Cambodia	4.5	3	Kyrgyz Republic	4.2	3	Maldives	4.5	3	Sri Lanka	4.0	3	Uzbekistan	16.7
4	Viet Nam	4.5	4	Sri Lanka	4.2	4	Kyrgyz Republic	4.4	4	Cambodia	3.9	4	Cambodia	16.2
5	Bhutan	4.2	5	Bhutan	4.0	5	Uzbekistan	4.4	5	Mongolia	3.9	5	Bangladesh	16.2
20	Palau	3.2	6	Palau	3.3	15	Palau	3.5	16	Palau	3.3	17	Palau	16.2

Table 7. Country Performance Assessment Rating Ranking Comparison between developing member countries (DMC) in ADB (ADB,2016)

2.2. Law and Regulation

Palau has constitution which is established in 1981. The constitution prohibited ownership of Palau land. Moreover, constitution emphasizes environment protection. Under the Republic of Palau Public Law (RPPL) and Palau National Code (PNC) below, RPPL and PNC, regulations and policy which are made by each department are made.

RPPL is passed every period of national congress. RPPL numbers are labelled "Congress number with order passed". For example, Minimum Wage Act RPPL number is "RPPL 9-1" because it is the first passed bill in 9th period of National Congress.

For convenience, RPPLs are amended to PNC which shows structured view of Palau law. PNC is labeled by subject. For example, PNC chapter 30 is labor. After RPPL 9-1 is passed, it is amended according to PNC chapter 30.

RPPL Number	Name of Law	PNC reference
RPPL 9-1	Minimum Wage Amendment	Amends PNC-30-1
RPPL 9-2	Pension Plan and Retirement Fund	Amends to PNC-33-20 Also amends PNC-40-14
RPPL 9-3	Citizenship Act Amendment	Amends PNC-13-1

Table 8.Example of RPPL in 9th Period of National Congress (2013-2015)

Available sources for laws are Pacific Islands Legal Institute(http://www.paclii.org) and Paluelegal.org(http://palaulegal.org). It takes time for RPPL to amend to PNC. RPPLs passed in 10th period of National Congress does not amend to PNC yet.

2.3. Economy

2.3.1. GDP (Gross Domestic Product)

GDP of Palau is $205.3 million and GDP per Capita is $11,440 in 2016.

Fiscal Year	GDP constant prices (based on 2005) $millions	Population	GDP constant prices (based on 2005)per Capita, $
2012	178.9	17,611	10,157
2013	170.8	17,506	9,758
2014	182.7	17,501	10,437
2015	202	17,661	11,438
2016	205.3	17,943	11,440

Table 9.GDP statistics (Ministry of Finance, 2017)

While Palau MOF only provides GDP based on 2005 prices to the public, CIA factbook provides more detailed overview of GDP. GDP per capita based on 2017 price is $14,700, is ranked 115. Suriname is ranked 114 ($14,900 GDP per capita) and Columbia is ranked 116 ($14,400 GDP per capita).

GDP of Palau is mostly from services (78.8%). The major services are tourism and public service. Tourism accounts for 42.3% of GDP (Guardian 2018). Moreover, Palau has received various assistance from foreign countries and the most important assistance is COMPACT of Free Association (COFA). Government grants in 2017 is $42.2 million, which is about 15% of total GDP (Ministry of Finance, 2017). Grant is composed of US compact grants ($13.1 millions), COFA Trust Fund ($5.0 millions), US non-compact grants ($9.7 millions), other country grants ($2.6 millions), other government agencies ($7.0 millions), and other grants ($4.7 millions).

Category	**Data from CIA factbook**	**Rank**
GDP (purchasing power parity):	$264 million (2017 est.) $274.2 million (2016 est.) $274.1 million (2015 est.)	217
GDP (official exchange rate)	$292 million (2017 est.) (2017 est.)	
GDP - real growth rate:	-3.7% (2017 est.) 0% (2016 est.) 10.1% (2015 est.)	215
GDP - per capita (PPP):	$14,700 (2017 est.) $15,200 (2016 est.) $15,200 (2015 est.) note: data are in 2017 dollars	115
Gross national saving:	48.7% of GDP (2016 est.) 50.1% of GDP (2015 est.)	
GDP - composition, by end use	household consumption: 60.5% (2016 est.) government consumption: 27.2% (2016 est.) investment in fixed capital: 22.7% (2016 est.) investment in inventories: 1.9% (2016 est.) exports of goods and services: 55.2% (2016 est.) imports of goods and services: -67.6% (2016 est.)	
GDP - composition, by sector of origin:	agriculture: 3% (2016 est.) industry: 19% (2016 est.) services: 78% (2016 est.)	

Table 10.GDP details (CIA factbook)

Since Palau relies on tourism and international grant, GDP of Palau has been fluctuated according to macro-economic environment. World economic depression caused by financial crisis in 2008 caused significant decrease in Palau economy.

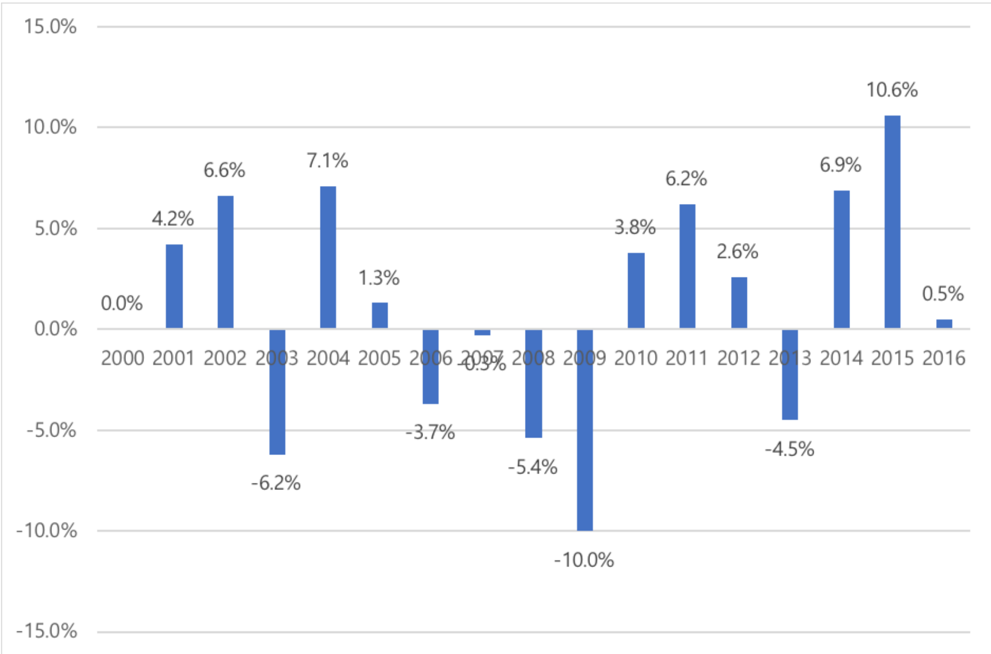


Figure 3. Real GDP Growth Rate (2005 base)(Ministry of Finance and JICA, 2018)

Palau has strong diplomatic ties with Japan and Taiwan, therefore they were top 2 countries whose people visit Palau. Japan and Taiwan granted significant amount of ODA to Republic of Palau. Palau is one of just 17 countries that has diplomatic relations with Taiwan.

Recently, Chinese tourist has increased dramatically, and China becomes the largest visiting country now, while visitors from Japan and Taiwan are decreasing. Visits of Chinese hit the peak in 2016, which is 88,476(53%) but decreased to 27% in 2016. Sudden drop of Chinese tourists led sharp drop of GDP growth rate in 2016.

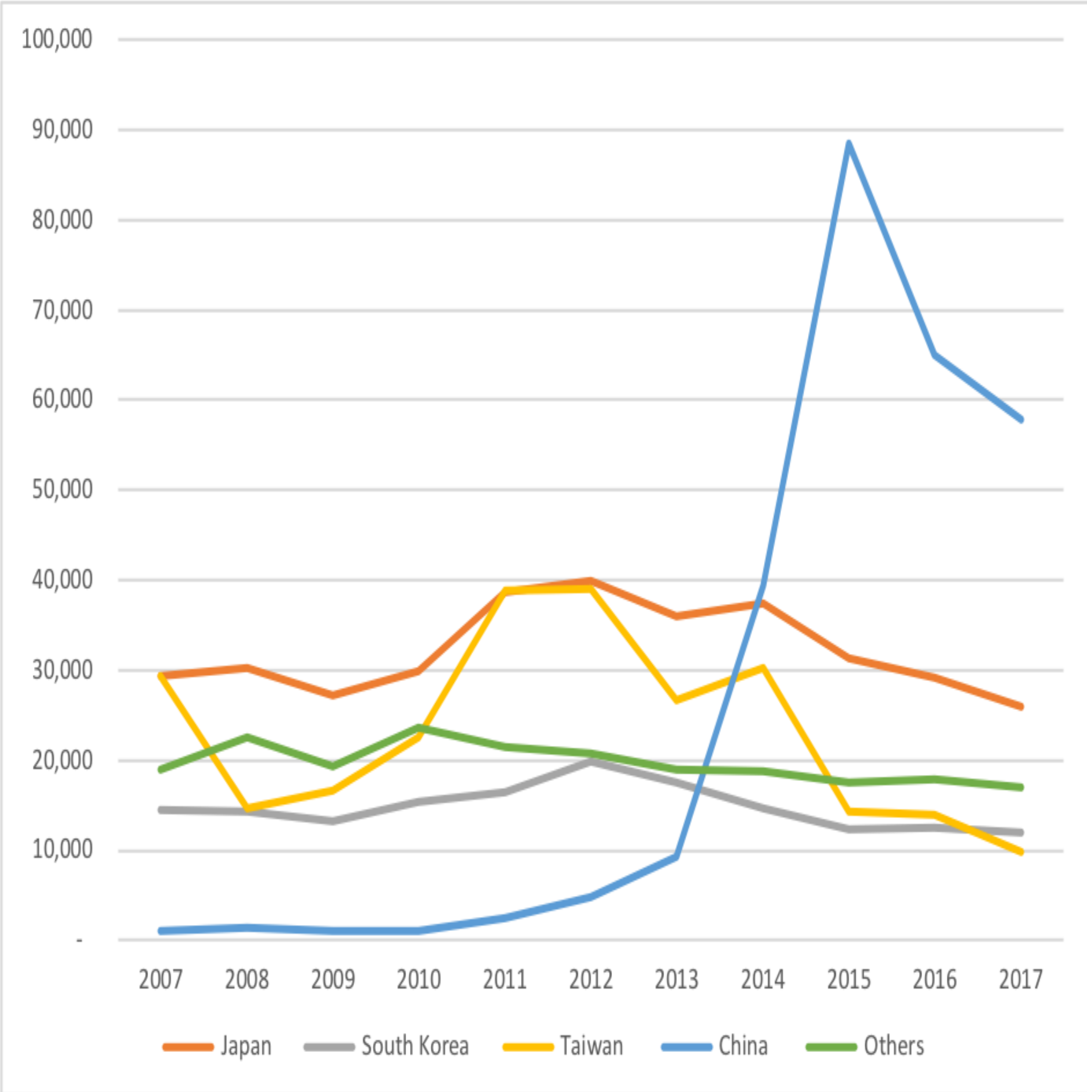


Figure 4. Tourist Visit(Ministry of Finance 2013& Ministry of Finance 2017)

The economic supports of the Compact for Palau which provided $18 million in annual subsidies and grants expired on 30 September 2009. Palau government has signed Compact Review Agreement with USA in 2010. Compact will be renewed in 2024. The outlook of GDP growth rate made by MOF is below.

Year	GDP growth rate outlook
2016	0.5
2017	-0.5
2018	3
2019	4.8

2020	5.2
2021	3
2022	0.1
2023	1.1
2024	0.9
2025	1.3
2026	1.9
2027	1.4
2028	1.5
2029	1.5
2030	1.5
2040/30	

Table 11. GDP Outlook (Ministry of Finance,2016)

2.3.2. Population

Population is 17,661 in 2015. Foreign workers with work permit in 2015 are 6,407. Philippines (3,789, 59%), Bangladesh (770, 12%), China (687,11%) are majority countries. Population has grown 1995-2015, but slightly decreased in 2005-2012. The identified cause of population decrease in 2005-2012 is world economic depression caused by financial crisis in 2008. Tourism industry of Palau faced a recession and some workers moved to other countries. Population is gradually increasing as economy of Palau recovers.

Census/ Survey Year	Population	Urban		Rural	
		Number	Percent	Number	Percent
1995	17,225	12,299	71.4%	4,926	28.6%
2000	19,129	13,303	69.5%	5,826	30.5%
2005	19,907	15,399	77.4%	4,508	22.6%
2012	17,501	14,202	81.1%	3,299	18.9%
2015	17,661	13,899	78.7%	3,762	21.3%

Table 12.Population Trends (2017, Minstry of Finance)

More than 95% of People live in Koror-Babeldaob. Koror and Babeldaob are separated islands but connected with Koror-Babeldaob Bridge. Koror and Babeldaob are the main islands of Palau. There are 5 outer islands in Palau. 5% of population live in outer islands.

Category	Population

Kayangel	54
Angaur	119
Peleliu	484
Sonsorol	40
Hatohobei	25

Table 13. Population in Outer Island (Ministry of Finance, 2015)

The population outlook published by MOF is as below. Population of Palau is estimated to grow 0.3% every year.

Year	MOF Population outlook (Person)	Population Growth rate (%)
2015	17,661	1.6
2016	17,714	0.3
2017	17,767	0.3
2018	17,820	0.3
2019	17,873	0.3
2020	17,927	0.3
2021	17,981	0.3
2022	18,034	0.3
2023	18,088	0.3
2024	18,142	0.3
2025	18,197	0.3
2026	18,251	0.3
2027	18,306	0.3
2028	18,361	0.3
2029	18,416	0.3
2030	18,471	0.3
2035	18,750	0.3
2040	19,030	0.3
2030/15	0.30%	

Table 14. Population Outlook (Ministry of Finance, 2016)

2.4. Business Environment

The Doing Business project conducted by World Bank provides objective measure of business regulation for local firms in 190 economies. Doing Business score of Palau is 55.59, which is little below than regional average.

Category	Federal States of Micronesia	Kiribati	Marshall Islands	Palau	Regional Average (East Asia & Pacific)	Samoa
Score	48.99	49.07	51.62	55.59	63.41	63.77
Rank	160	158	150	133	-	90

Table 15. Doing Business Score & Rank (World Bank 2018)

Detailed Score of Doing Business report is as below. Palau got high score for construction permit and property, but low score on insolvency procedure and minor investor protection. Low scored areas are due to the fact that there are not many cases for foreign direct investment in Palau.

Category	Score(Rank)	Explanation
Starting a business	129(81.95)	Procedures, time, cost and paid-in minimum capital to start a limited liability company
Dealing with construction permits	95(68.38)	Procedures, time and cost to complete all formalities to build a warehouse and the quality control and safety mechanisms in the construction permitting system

Table 16. Doing Business Report (World Bank, 2018)

2.4.1. Tax Policy

Summary of accountant and tax policy is as below.

Category	Content	Reference
Foreign Exchange Management	Credit or financial institutions shall keep regular reports of all transactions made in cash or bearer securities of at least US ten thousand dollars ($10.000) or its equivalent in cash or bearer securities.	PNC-Chapter-17-Crimes- §3811
Accounting Standard	Financial Institution and Government of Palau use U.S. GAAP (Generally Accepted Accounting Principle).	Palau Business Law Handbook/ Office of Public Auditors
Corporate Tax	4% for revenue.	PNC-Chapter-40-Revenue-and-Taxation- § 1201
Tax Exemption	There is no tax exemption case for energy business.	
VAT (Value Added Tax)	7% for all goods.	PNC-Chapter-40-Revenue-and-Taxation

Table 17.Accounting and Tax Policy

2.4.2. Corporation Registration

The typical process of corporation registration suggested by World Bank Doing Business in Palau 2019 is as below.

Num	Procedure	Time(day)	Charge	Agency
1	Deposit the legally required capital in a bank and obtain deposit evidence	1	$0	Office of the Attorney General,
2	Check the uniqueness of the proposed company name and reserve a name	14	$0	Corporate Registrar
3	Notarize the company deeds	1	$0	Notary
4	Pay the registration fee at the National Treasury	1	$250	National Treasury
5	Register employees for social security and obtain an employer identification number (EIN)	1	$15	Social Security Administration
6	Apply for a business license from the relevant licensing authority	5	$50	Division for Revenue and Taxation
7	Apply for a business license from the state government	4	$50	State Council

Table 18.Corporation Register Process (World Bank,2019)

The assumptions are

- Limited liability company (or its legal equivalent).
- Operation in the economy's largest business city.
- The entire office space is approximately 929 square meters (10,000 square feet).
- 100% domestically owned and has five owners, none of whom is a legal entity has a start-up capital of 10 times income per capita and has a turnover of at least 100 times income per capita.

2.4.3. Property Management and Construction Permit

Only citizens of Palau and corporations wholly owned by Palau citizens may acquire title to land or waters in Palau by constitution. For foreign investor, it is standard practice for an attorney to draft land leases.

In Doing Business 2019, World Bank highly recommends title search of land since disputes are widespread. Independent attorney should be hired to search land title. According to World Bank, attorneys are usually willing to provide due diligence after a week, but stipulate in their contract with clients which includes the search doesn't guarantee that there are no disputes or liens attached to the title.

Only less than a half of the land is surveyed with a certificate of title issued. Land title records are kept on paper and not sorted by parcel number. As a result, the officials at the Land Court have to go through thousands of pages to track transactions on a particular piece of land. It is uncommon for companies to buy or sell ownership of land and building as the records are so unreliable. In most cases, such as this one, companies would prefer to transfer a lease. The construction process suggested by World Bank is as below.

Num	Procedure	Time (day)	Charge	Agency
1	Obtain an application form for a building and zoning permit. The application form has two pages: the first one contains information about the building, while second indicates clearances to be signed by National Bureau of Land and Survey Bureau of Arts and Culture Environmental Quality Preservation Board (EQPB) Public Works	117	$4,687	State Planning Council
1.1	The clearance from National Bureau of Land and Survey	8	0	National Bureau of Land and Survey
1.2	The clearance from National Bureau of Arts and Culture	2	0	National Bureau of Bureau of Arts and Culture
1.3	The clearance from Environmental Quality Preservation Board (EQPB) - Environment Impact Statement should be done	90	$100	Bureau of Arts and Culture
1.4	The clearance from Public Works Authority	2	0	Bureau of Public Works
2	Receive foundation inspection	1	0	State Planning Council
3	Receive inspection on surroundings	1	0	State Planning Council
4	Receive inspection on structure	1	0	State Planning Council
5	Request an occupancy permit	1	0	State Planning Council
6	Receive final inspection	1	0	State Planning

				Council
7	Obtain occupancy permit	1	0	State Planning Council
8	Request and connect to water and sewage services	1	$30	National Public Works Department

Table 19. Construction Permit Process (World Bank 2019)

The assumptions are based on warehouse constructions permit. Details are

- Limited liability company (or its legal equivalent)
- Operates in the economy’s largest business city.
- 100% domestically and privately owned; has five owners, none of whom is a legal entity.
- Has a licensed architect and a licensed engineer, both registered in the local association of architects or engineers.
- not assumed to have any other employees who are technical or licensed experts, such as geological or topographical experts.
- Owns the land on which the warehouse will be built and will sell the warehouse upon its completion.
- The warehouse: which will be used for general storage activities, such as storage of books or stationery
- The warehouse is valued at 50 times income per capita.
- The warehouse will have complete architectural and technical plans prepared by a licensed architect.
- The warehouse will take 30 weeks to construct (excluding all delays due to administrative and regulatory requirements).

2.5. Labor Environment

Palau has minimum wage and temporary worker policy. The labor regulation is written in PNC Chapter 30 Labor.

Category	Content	Reference

Minimum wage	Minimum wage of Palau in set on Oct. 2013. The minimum wage in Oct. 2013 was $2.75 per hour. These was planned to increase $0.25 per hour until it reaches $3.50 per hour. Minimum wage was increased to $3.5 per hour in Oct. 2017	Palau National Code -Title 30-§125
Temporary Worker	No employer shall employ a nonresident worker Employer can hire temporary employees who are brought into the Palau within 90 days.	Palau National Code -Title 30-§122

Table 20.Labor laws

2.6.Environment Regulation

The Environmental Quality Protection Act (PNC-Title-24) governs environment protection and a composition of the Environmental Quality Protection Board (EQPB). The EQPB consists of seven directors appointed by the president under agreement of the Senate. The term of the board member is three years. Procedures and contents of environmental impact assessment in Palau are specified in the Environmental Impact Statement Regulations (Chapter 2401-61). Detail fields of the regulation are:

- Chapter 2401-01 Earthmoving Regulations
- Chapter 2401-11 Marine and Fresh Water Quality Regulations
- Chapter 2401-13 Toilet Facilities and Wastewater Disposal Systems Requirements
- Chapter 2401-31 Solid Waste Management Regulations
- Chapter 2401-33 Pesticide Regulations
- Chapter 2401-51 Public Water Supply Systems Regulations
- Chapter 2401-61 Environmental Impact Statement Regulations
- Chapter 2401-71 Air Pollution Control Regulations
- Chapter 2401-81 Ozone Layer Protection Regulations

For Environment Assessment (EA) and Environment Impact Statement (EIA), an environmental assessment can be completed in months; an environmental impact statement could take 1 year or more.

Any construction project involving earthmoving requires an approval from the (EQPB), EQPB regulations on sectors and criteria for evaluating environmental impacts include the following: If the EQPB Board decides that it is necessary to prepare and review the Environmental Impact Statement (EIS).

3.Energy Environment

3.1. Energy Policy Objective

Palau set ambitious energy policy objectives. The first goal is set in 2010 at Palau National Policy (NEP). NEP will be renewed in 2020. NEP set 5 detailed objectives. JICA 2008 report is conducted before NEP to support NEP.

The second goal is set as Intended National Determined Contribution (INDC) in 2015. The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive nationally determined contributions (NDCs) that it intends to achieve. Palau government extended due date from 2020 to 2025 and modified target.

At Palau Energy Summit at 2017 with attendees from various fields including the Pacific Community (SPC), the United States of America, New Zealand, EarthX, Earth Justice, Okeanos foundation for the sea, Grid Market, the Japan International Cooperation Agency (JICA), and the International Renewable Energy Agency (IRENA), Palau Energy Roadmap is presented. JICA (2018) is being conducted to suggest detailed RE implementation process and T/D reinforcement plan by 3 phases.

	National Energy Policy	**Intended National Determined Contribution (INDC)**	**Palau Energy Summit Action Plan**
Years	2010	2015	2017
Description	It was the first policy objective which convers various sectors in energy industry. NEP is set by government of Palau and it is still backbone of Palau Energy Policy.	It was policy objective submitted to UNFCCC for Paris Agreement	More detailed action plan to meet goal for INDC.
Target	1) Establishment of Palau Energy Administration and National Energy Committee 2) 30% reduction in overall national energy consumption by 2020. 3) 20% of electrical energy generated in Palau the end of 2020. 4) Utilization of PPUC's unused storage capacity to lower cost of maintenance and pass the savings to consumers. 5) Private sector participation in electricity supply	1) 22% energy sector emissions reductions below 2005 levels by 2025 2) 45% Renewable Energy target by 2025 3)35% Energy Efficiency target by 2025	1) Comprehensive stakeholder engagement and capacity development 2) Identification of priority technical issues. (potential sites, T/D reinforcement)

			3) Review of current legal and regulatory system (PEA, NEC) 4) Identify partnership and financing option

Table 21.major energy objectives of Palau

NEP is later stated in Palau Energy Act (RPPL-9-54). Palau Energy Administration reviews and updates the NEP on-going basis through the EMER Framework. The key matric of EMER Framework are:

- Renewable energy target
- Energy Efficiency target
- FAESP energy security indicators
- Tourism marine vessel efficiency standards
- Government green fleet efficiency standards.

3.2.Energy Regulatory

To meet goal of INDC and promote renewable energy, Palau Government established Palau Energy Administration (PEA) and National Energy Council (NEC). PEA is established under the Palau Energy Act (RPPL 9-54), which was adopted in February 2016. National Energy Council is established in August 2017 under the Executive Order 403 by President Remengesau Jr.

3.2.1.Palau Energy Administration (PEA)

There was Palau Energy Office, but it has limited authority. Palau Energy Administration is established under the Palau Energy Act in February 2016. PEA get strengthened by Palau Energy Administration Regulatory in 2018. Palau Energy Summit in 2017 concluded that role of PEA should be strengthened. PEA is regulatory body of energy sector and roles of PEA are:

- monitor all energy-related matter and responsible for reporting with climate change including PIFACC, FAESP and UNFCCC
- facilitate energy-related grants in the energy sector
- educate the public concerning energy-related matters
- coordinate maintenance contracts for solar-facilities owned by the Palau Government
- setting energy efficiency benchmarks for public utility

- assessment of annual energy report and update of NEP
- set guideline for grid-connection and review of power purchase agreement from Independent Power Plant
- review electricity tariff

3.2.2. National Energy Committee (NEC)

The action plan from Palau Energy Summit 2017 identified needs to establish oversight energy committee to manage INDC goal for Palau. NEC shall meet at least once per quarter. NEC member includes representatives from national and state government, the Council of Chiefs, the private sector, community-based organizations and outside experts as determined by Executive Committee. The duties of NEC are (execution order-403):

- Support PEA in effort to implement the Palau Energy Act and achieve Palau's renewable energy goals particularly including INDC
- Specialized sub-committees may be formed to issue policy reform, PPAs, tariff setting and planning, etc.
- Committee shall meet at least monthly, including through conference calls
- Committee shall report on a biannual basis

3.3.Energy Law

There are 3 major laws articulated to govern energy sector, which are Net Metering Act, Palau Energy Act and Palau Energy Administration Regulatory Act. Moreover, execution order of National Energy Committee also affects energy environment.

Net Metering Act was set in 2009, which was even before Palau Energy Policy. It enables many owners of residential solar and commercial solar plants to get benefit from their power plant. Palau Energy Act was set after INDC submission. After Palau Energy Summit 2017, Executive order of National Energy Committee and Palau Energy Administration Regulatory were passed since there was need to reinforce independent regulatory body.

Laws	Year	Description	Reference
Net Metering Act	2009	Allows consumers who own renewable energy in their property to use their electricity and sell back to utility and get an offset of utility bill	PNC-37-6
Palau Energy Act	2016	Establishment of PEA Allows IPP for Palau grid	RPPL-9-54
Establishing National Energy Committee	2017	Establishment of NEC to support and oversee PEA	Executive order-403
Palau Energy Administration Regulatory	2018	Clarify and strength the role of PEA as an energy regulator.	RPPL-9-54

Table 22.Energy Laws

There are 2 ways for renewable energy power plant to make profit: net metering and power purchase agreement. Net metering was set in 2009. Residential solar power plant which is mostly funded by National Development Bank of Palau (NDBP) loans offset their electricity.

Most of power plants are residential or government-owned, but there are some commercial power plants on the roof-top of large building such as WCTC Central Warehouse (263.8kw), WCTC T-Dock (225kw), Surangel (150kw). Commercial power plants are also under net-metering. There is no IPP under PAA yet as of 2018.

Category	Description	Reference
Net Metering	Renewable energy plant with net metering offset the customers own electricity requirements; Residential installation is smaller than 5 kW maximum generation, except where PPUC specially approves a larger size for connection to the net metering grid	PNC-37-6

	Commercial or industrial installation, the facility may not generate over the maximum kilowatt demand for the site unless a larger size is specially approved by the P.P.U.C. for connection. The PPUC may establish a maximum limit for the installed capacity of renewable energy systems connected to the PPUC	
IPP and PPA	Request for proposals for renewable energy projects may be made by the Energy Administration or PPUC. Unsolicited request for grid connection for renewable energy project must be made to both PPUC and the Energy Administration PPUC shall enter into Grid Connection Agreement and Power Purchase Agreement with successful applicants after submitting the proposed agreement to the Energy Administration for its review and taking into consideration the Energy Administration's comments regarding the agreement PPUC shall submit to PEA for review any contracts that finalize agreements resulting from major business negotiations. Such contracts may not be signed by PPUC unless PEA approves the contract.	RPPL-9-54 RPPL-10-23

Table 23.Comparison between Net Metering and IPP

3.4.Palau Public Utilities Corporation (PPUC)

The Public Utilities Corporation (PUC) was created on 1994.07.06. It was in charge of public electricity business in Palau. In 2013.07.06, under the RPPL No. 9-4, consolidated two independent public corporations, the Palau Water & Sewer Corporation (PWSC) and the Palau Public Utilities Corporation under one identity, the Palau Public Utilities Corporation (PPUC).

After the merger, about 112 employees from the National Government's water and waste water operation transitioned to PPUC. From an Electrical utility with 149 employees, PPUC now has a total workforce of over 200 employees serving both the electricity and water/waste water operations of the Republic of Palau. PPUC is a utility company whose 100% shares are owned by government of Palau. Business domains of Palau consists of two parts: manage and operate the electric power operation (EPO), water and wastewater operation (WWO). They are targeted to be separate business.

An organizational chart was created and adopted by the Board of Directors. The new organizational chart is modified to indicate centralization of shared services. These include the Business Office Department, Information Technology, Procurement, Accounting and Finance, Public Relations, Grants Coordination and Human Resources. Electrical operations and water and waste water operations remain as separate operations supported by the shared administrative services.

The long-term debt outstanding in 2016 is approximately 7.8 million US dollars, of which 5.9

million USD is for the electricity business. Bank loans are used for investing in new power generation facilities and renovating existing facilities.

The EPO net operating income has varied between positive and negative in the past three years.

Electric operations (EPO) continue to pursue efficiency improvement as an alternative to price increases. Electric operations have managed to hold kilowatt prices to customers at the same level since 2012. This excludes the fuel component, which recovers the cost of fuel paid by PPUC and fluctuates with world oil prices.

This achievement in price constraint is significant, given the increase of input costs and wage growth over these years. Revenue growth from power consumption by customers is anticipated to be 2% for 2018, reflecting a slight downturn after a substantial increase in 2017.

Suprima customers those who using pre-paid meters continue to increase as a share of total consumption, reflecting the initiative by Electric Operations to assist customer in managing their consumption and budget for power usage, and reduce payment arrears and outstanding debts to PPUC.

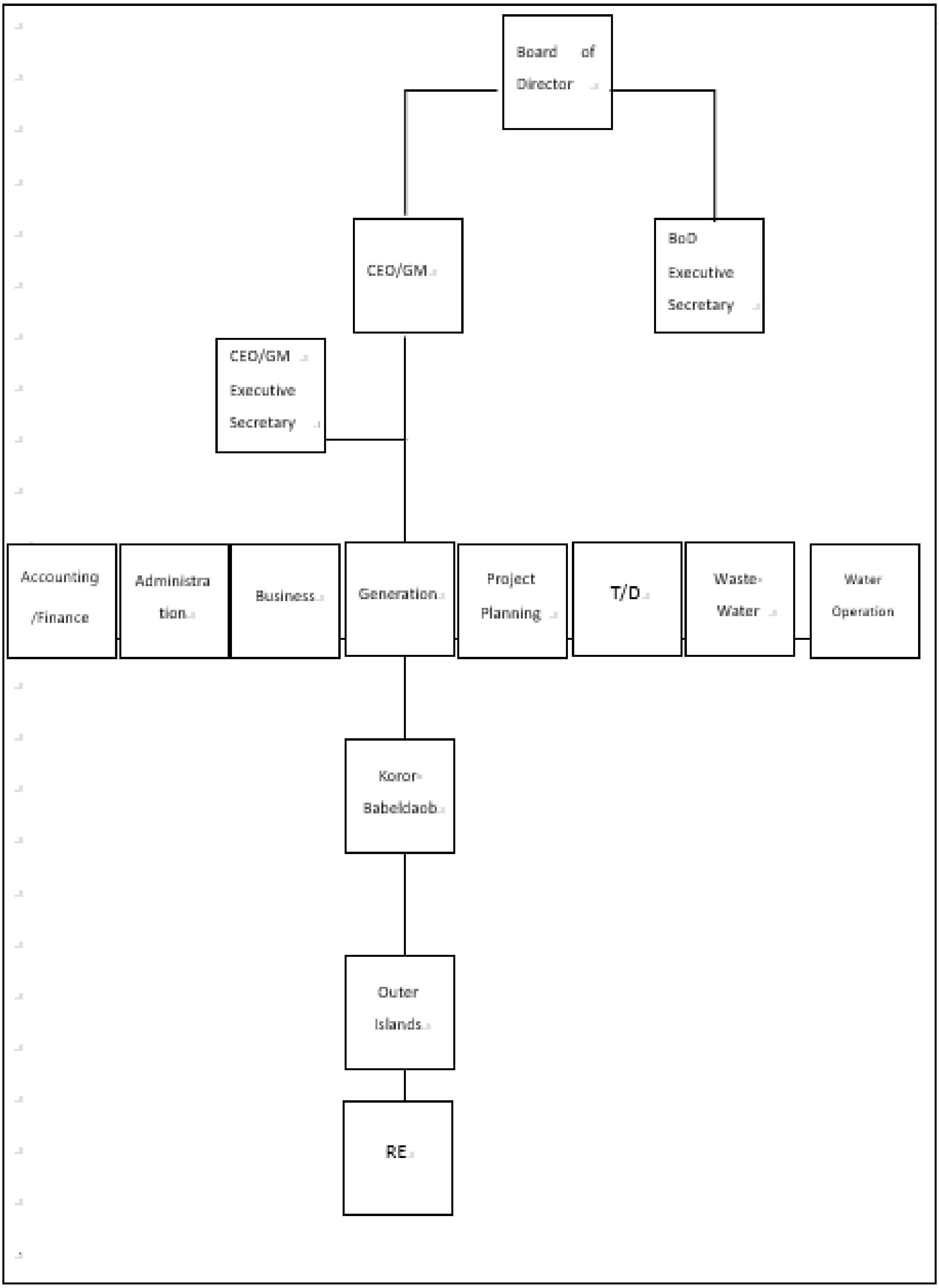


Figure 5.Organization chart of PPUC

	EPO	WWO	Elimination	Totals
Operating revenues:				
_Power	19,523,484	-	(1,942,217)	17,581,267
_Water	-	3,574,977	(79,510)	3,495,467
_Wastewater	-	1,860,942	-	1,860,942
_Other	998,586	156,859		1,555,445
Total operating revenues	**20,522,070**	**5,592,778**	**(2,021,727)**	**24,093,121**
Provision for uncollectible receivables	(124,013)	(22,053)		(146,066)
_Net operating revenues	20,398,057	5,570,725	(2,021,727)	23,947,05 5
Operating expenses:				
_Generation – fuel	11,520,541	-	-	11,520,54 1
_Depreciation	2,727,480	1,703,435	-	4,430,915
_Generation - other cost	3,807,307	-	(76,894)	3,730,413
_Administration	1,003,069	1,004,471	(41,587)	1,965,953
_Distribution and transmission	1,378,512	-	(22,608)	1,355,904
_Engineering services	536,983	-	(5,312)	531,671
_Renewable energy	243,552	-	(5,311)	238,241
_Water operations	-	3,656,800	(1,421,744)	2,235,056
_Wastewater operations				
Total operating expenses	**21,217,444**	**7,493,938**	**(2,021,727)**	**26,689,65 5**
Operating loss	(819,387	(1,923,213)		(2,742,60 0)
Nonoperating revenues (expenses):				
_Grants	42,000	-	-	42,000
_Interest income	2,179	639	-	2,818
_Interest expense	(304,219)	(71,050)	-	(375,269)
_Loss on disposal of utility plant	(157,518)	(1,316)	-	(158,834)
_Others	(32,805)	(947)		(33,753)
Total nonoperating revenues(expense)	**(450,363)**	**(72,674)**		**(523,037)**
Loss before capital contributions	(1,269,750)	(1,995,887)	-	(3,265,637)

Capital contribution:				
Grants from the Japan Government	-	10,318,720	-	10,318,720
Capital contributions from the ROP	130,800			130,800
Change in net position	**(1,138,950)**	**8,322,833**		**7,183,883**
Net position at beginning of year	39,371,864	8,675,312		48,047,176
Net position at end of year	38,232,914	16,998,145	-	55,231,059

Table 24.PPUC Combining Statement of Revenues, Expenses and Change in Net Position Year Ended Sep 30, 2017) (Office of Public Auditory,2018)

Net cash in PPUC in 2017.9.30. was $2,803,622. According to auditory report, $750,000 is secured by FIC insurance, but remaining deposits are exposed to market risk.

Category	**EPO**	**WWO**	**Elimination**	**Totals**
Cash flows from operating activities				
Cash received from customers	20,586,817	5,610,060	(2,039,638)	24,157,239
Cash payments to suppliers for goods and services	(16,115,553)	(2,469,389)	2,039,638	(16,545,304)
Cash payments to employees for services	(2,652,982)	(2,155,331)		(4,808,313)
Net cash provided by operating activities	1,818,282	985,340		2,803,622
Cash flows from investing activities:				
_Interest income	2,179	639		2,818
Cash flows from non-capital financing activities:				
_Cash received from grantor agencies	42,000			42,000
Cash flows from capital and related activities:				
_Proceeds from issuance of long-term debt	-	4,378,102	-	4,378,102
_Principal payment on long-term debt	(571,934)	-	-	(571,934)
_Interest paid on long-term debt	(306,885)	-	-	(306,885)
_Advances from the Republic of Palau	150,000	-	-	150,000
_Acquisition of utility plant	(3,297,804)	(6,234,094)		(9,531,898)
Net cash used in capital and related	(4,026,623)	(1,855,992)		(5,882,615)
financing activities				
Net change in cash and cash equivalents	**(2,164,162)**	**(870,013)**	**-**	**(3,034,175)**
Cash and cash equivalents at beginning of year				

Cash and cash equivalents at end of year	**8,342,246**	**4,047,158**	**-**	**12,389,404**
Reconciliation of operating loss to net cash				
provided by operating activities:				
Operating loss	(819,387)	(1,923,213)	-	(2,742,600)
Adjustments to reconcile operating loss				
Depreciation	2,727,480	1,703,435	-	4,430,915
Provision for uncollectible receivables	124,013	22,053	-	146,066
Pension expense	198,518	312,299	-	510,817
(Increase) decrease in assets:				
Receivables:				
_Trade	127,551	(80,363)	-	47,188
_Affiliate	(144,803)	287,643	(17,911)	124,929
_Contracts	16,138	(176,080)	-	(159,942)
_Other	(4,708)	(493)	-	(5,201)
Prepaid expenses	(9,470)	30,433	-	20,963
Inventory	(647,728)	(303,006)	-	(950,734)
Increase (decrease) in liabilities:				
Accounts payable	127,431	1,094,249	17,911	1,239,591
Accrued expenses	52,678	31,808	-	84,486
Grant advances from the Republic of Palau	(27,174)	-	-	(27,174)
Customer deposits				
Net cash provided by operating activities	**1,818,282**	**985,340**	**-**	**2,803,622**
See accompanying independent auditors' report.				

Table 25.PPUC Combining Statement of Cash Flows Year Ended Sep 30, 2017) (Office of Public Auditory,2018)

The international and local loans were acquired to purchase additional generation capacity and to finance major repairs and generation auxiliary equipment. The long- term soft loan secured by ROP from Asian Development Bank was subsequently loaned to PPUC as per the subsidiary loan agreements dated 28 March 2014. Proceeds will be used to upgrade the Koror sewerage system and construct wastewater treatment plant and sewerage network in Airai. The ADB loan amount as of 30 September 2017 reflects the total amount of the loan proceeds withdrawn and is recognized as long-term debt in the financial statements.

Loan	**Remaining Debt**		**Rate**	**Sector**	**Lender**
	2016	**2017**			
On September 4, 2006, PPUC entered into a loan with a foreign bank not to exceed $7,000,000 with interest at 3.5% per annum,	4,200,000	3,800,000	3.50 %	EPO	Taiwanese Bank

due on December 11, 2026, to finance the purchase of portable generators, a crankshaft assembly and other necessary equipment to facilitate the overhaul of aging generators. The loan is guaranteed by the Republic of Palau and is to be repaid in thirty-five consecutive semi-annual principal installments of $200,000 plus interest.					
On April 21, 2010, PPUC entered into a loan with a development bank, an affiliated organization, for $3,000,000 to finance the purchase of two generator sets. The loan is due on April 21, 2025 and is collateralized by the generator sets inclusive of auxiliary equipment.	2,233,965	2,602,034	7.50 %	EPO	National Development Bank of Palau
On March 28, 2014, PPUC entered into two loans with the ROP to finance sanitation projects in the Koror and Airai areas. The first loan is for $26,900,000 for twenty years with grace period and bears interest equal to the sum of LIBOR plus 0.60% and a maturity premium of 0.10%. The loans are guaranteed by the Republic of Palau.	1,910,229	6,159,378	LIBOR + 0.6%	EPO	ADB
On November 4, 2016, PPUC entered into a non-interest bearing loan with the Koror State Government for $300,000 to finance the acquisition of sewer pumps and parts for the State of Koror. The loan is to be repaid in monthly installments of $10,000 beginning December 15, 2016.	0	200,000	0%	WWO	Koror State Government
Total long-term debt	8,344,194	12,761,412			
Less current maturities	-572,043	-833,601			

	7,772,151	11,927,81 1			

Table 26.Statement of loan in 2017(Office of Public Auditory,2018)

PPUC adapted Automatic Fuel Price Adjustment Clause (AFPAC) methodology that calculates the fuel charge recovered from the customer on a quarterly basis and the fuel cost fluctuation depending on the world oil prices. Automatic Fuel Price Adjustment Clause (AFPAC) methodology that calculates the fuel charge recovered from the customer on a quarterly basis. Tariff table is as below.

2018.1.1	Per kWh	Energy rate	Fuel rate	Total Rate
Residential	0-150	0.02	0.177	0.197
	151-500	0.094	0.177	0.271
	501+	0.143	0.177	0.32
Commercial/ Government	0-150000	0.143	0.177	0.32
	150001-250000	0.133	0.177	0.31
	250001+	0.123	0.177	0.3

Table 27.Tariff Table in 2018.1.1(PPUC)

3.5.Previous F/S study

3.5.1.JICA (2008) report

JICA conducted the first in-depth F/S study on Palau main grid in 2008. It suggested

1) Power plant replacement including procurement of new diesel generators
2) T/D reinforcement plan
3) Adequate electricity tariff plan for PPUC
4) Energy Efficiency Plan

JICA 2008 also conducted pre-F/S study on renewable energy. However, they did not analyze in detail since cost-competitiveness of RE was relatively low in 2008 comparing to 2018. Hence, JICA suggested procuring new diesel generator in 2008.

FY	Project Title	Outline	Estimated Cost (million USD)	
			HFO	Diesel Oil
2013	Replacement of Aimeliik Power Station (Phase 1)	•Procurement of two diesel generators (5 MW class) and auxiliary machinery • Remodeling of the fuel storage and supply facilities (in the case of heavy oil firing) • Construction of the power house (including those for the two generators in Phase 2) and an	25.73	19.38

		office building		
2014	Replacement of Aimeliik Power Station (Phase 2)	•Procurement of two diesel generators (5 MW class) and auxiliary machinery	12.22	11.73
2019	Replacement of Aimeliik Power Station (Phase 3)	•Procurement of two diesel generators (5 MW class) and auxiliary machinery • Construction of additional power house (for the two new generators in Phase 3)	14.13	13.64

Table 28.Power Plant application plan suggested by JICA (JICA, 2008)

There is also transmission reinforcement.

RE roadmap	Year	Facility	Main Objective	Outline
Phase1	2020	T&D	Improvement of Maintenance Manageability	Relocation of existing 34.5kV Transmission Line Transmission line (41.8km) Airai – Aimeliik-Ngaraard 2 Distribution line (4.6km) Ngaraard 1 Countermeasure against power outage
	2020	SS	Improvement of Maintenance Manageability	Relocation of existing substations • Ngardmau • Ngaraard 1 • Ngaraard 2
	2020	SS	Improvement of power supply reliability	Construction of Koror substation 34.5/13.8kV 1 bank x 10MVA
	2020	D	Improvement of power supply reliability	Construction of 13.8kV distribution line 1 feeder (2km) x 13.8kV distribution line
	Within the period	SS	For grid protection and maintenance	Installation of circuit breaker panel Grid connected PV system (Aimeliik）
	Within the period	SS	For grid protection and maintenance	Installation of Pole mounted Switches Grid connected PV system （Ngatpang (Kokusai)） Grid connected PV system（Ngaremlengui）

Phase2	2023	T	For grid connected PV system and improvement of power supply reliability	Construction of 34.5kV transmission line Transmission line (33.5km) Malakal – Melekeok PV site Cabling (0.6km at KB bridge)
	2023	SS	Improvement of Maintenance Manageability	Expansion of Malakal substation Expansion of Malakal outgoing feeder bay
	Within the period	SS	For grid protection and maintenance	Installation of Pole mounted Switches -Grid connected PV system（Airai Airport） -Grid connected PV system（Ngchesar） -Grid connected PV system（Mlelekeok）
Phase3	2025	T&D	For grid connected PV system and improvement of power supply reliability	Construction of 34.5kV transmission line - Transmission line (13.9km) Melekeok PV site - Ngaraard 1 - Expansion of outgoing feeder at Ngaraard 1
	Within the period	SS	For grid protection and maintenance	Installation of Pole mounted Switches -Grid connected PV system（Ngiwal） -Grid connected PV system（Ngardmau（Terraces of Hill）） -Grid connected PV system（Ngardmau）

Table 29.T/D reinforcement Plan suggested by JICA (JICA, 2008)

3.5.2.Palau Energy Roadmap

Palau Energy Roadmap published in 2017.02, in collaboration with IRENA. Using Homer, the Roadmap analyzed not only Koror-Babeldaob, but also Peleliu, Angaur, Kayangel which are outer islands of Peleliu. According to the Roadmap, the future power generation mix of Palau is as Figure 2-2-3-3.1. IRENA proposed Palau power generation with Diesel 26.8 MW, PV 28.5 MW, Wind 11.3 MW and Battery 5.7 MW in 2025. While, peak demands are 13.9 MW in 2020 and 16.6 MW in 2025.

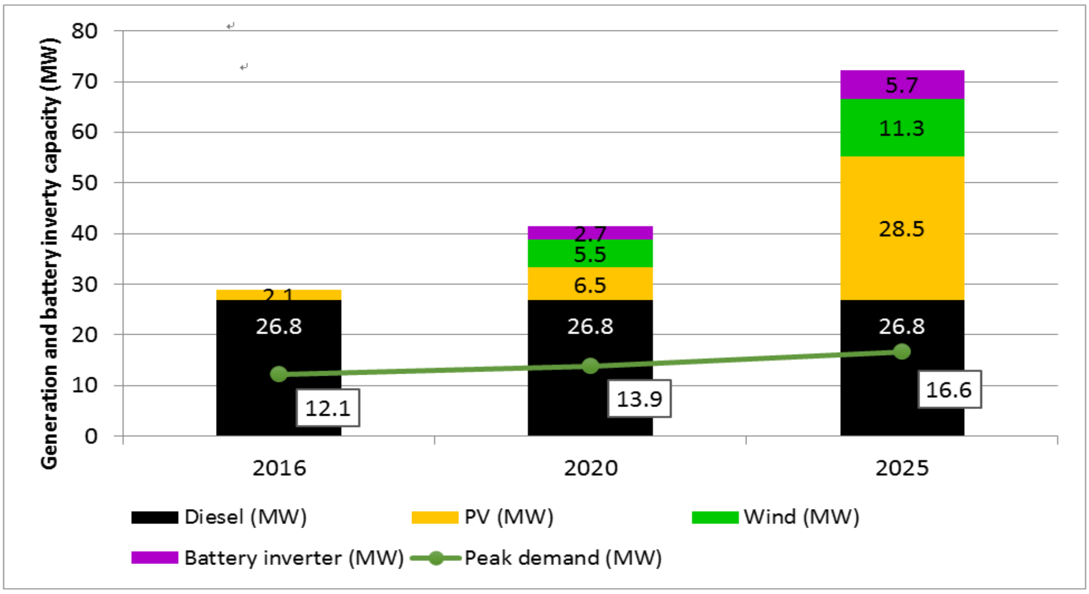


Figure 6.RE plan suggested by Energy Roadmap(IRENA,2017)

3.5.3. JICA (2018) report

JICA 2018 is new F/S study advised Palau Government for gradual implementation of PV and ESS by 3 phases. There are three types of ESS:

- **Short-term Against Fluctuation (AF):** To compensate PV output fluctuation for a few seconds to 10 minutes
- **Short-term Against Outrage (AO):** To compensate PV outage in the meantime of One-DEG stopping operation. This will be available to use for short-term fluctuation in the future.
- **Long-term Load Control (LC):** To charge surplus PV output and discharge electricity to the grid. To charge PV surplus of whole system at equal ratio.

Phase	Location	PV Capacity	ESS capacity
Phase 1 (2018-2020)	Malakal Power Station	-	AO(5MW/0.5Mwh)
	Aimeliik (Next to power plant)	5MWp(+1MWp)	AF(3MW/1.5MWh)
	Ngatpang (Kokusai)	2-3MWp(+1MWp)	AF(2MW/1Mwh)
	Ngaremlengui	5MWp(+1MWp)	AF(3MW/1.5MWh)

Phase 2 (2021-2023)	Airai Airport side by road	3MWp(+3MWp)	AF(3MW/1.5MWh)+ LC(3MW/12.6MWh)
	Ngchesar	3MWp(+1MWp)	AF(2MW/1Mwh)+ LC(2MW/8.4MWh)
	Melekeok	3MWp(+1MWp)	AF(2MW/1Mwh)+ LC(2MW/8.4MWh)
	Ngatpang (Kokusai)	-	LC(2MW/8.4MWh)
Phase 3 (2024-2025)	Malakal Power Station	-	AO(2MW/0.9Mwh)
	Aimeliik (Next to power plant)	-	LC(3MW/12.6MWh)
	Ngaremlengui	-	LC(3MW/12.6MWh)
	Ngardmau (Terraces of Hill)	3MWp(+1MWp)	AF(3MW/1.5Mwh)+ LC(2MW/8.4MWh)
	Ngardmau	5MWp(+1MWp)	AF(3MW/1.5Mwh)+ LC(3MW/12.6MWh)
	Ngiwal	3MWp(+1MWp)	AF(2MW/1Mwh)+ LC(2MW/8.4MWh)
Total		33MWp(+11MWp)	AF(21MW/10.5MWh)+ AO(7MW/1.4MWh)+ LC(22kW/92.4MWh)

Table 30.3-phases plan suggested by JICA (JICA, 2018)

4.Proposed Technical Design in Peleliu

Peleliu is a small island of about 500 people located in the south of Palau. The climate is tropical ocean climate with high temperature and humidity throughout the year. The temperature is 23 ℃ ~ 30 ℃ and annual average rainfall is 3728 mm. Electricity supply ratio is 99.8% but Renewable Energy (RE) ratio is not high. However, southern islands such as Peleliu and Angaur have more than 50% PV generation output in day time.

4.1. Peleliu Grid Operation Status

4.1.1. Distribution Line in Peleliu

The distribution voltage of Peleliu is 13,800V of 3 phases 4 wires. The distribution line voltage drops to 120/240V, 60Hz, at the delivery point to homes. The distribution line is multiple-grounded and concrete poles were installed in each pole.

Figure 7. Distribution Pole.

One distribution feeder is outgoing from diesel power plant with radial configuration and has branched at just outside of power plant to two directions. One branch is going out to north side and the other branch is going out to south side of Peleliu island. There is not any loop configuration in distribution network. In the distribution line, there is not any switch or recloser. Cot Out Switch (COS) in which fuse is built acts as a fault protector and a switch. Distribution pole numbers are not displaced in the pole.

Three-phase distribution line is constructed along the western road of island, but some branches are single-phase line. Because all wires are a bare copper conductor, AWG#2 wire of 33.6 ㎟, there are several ground faults happening sometimes such as trees-contact. COS fuse blows out when the fault occurs, and wide area have blackout situation until fuse is replaced.

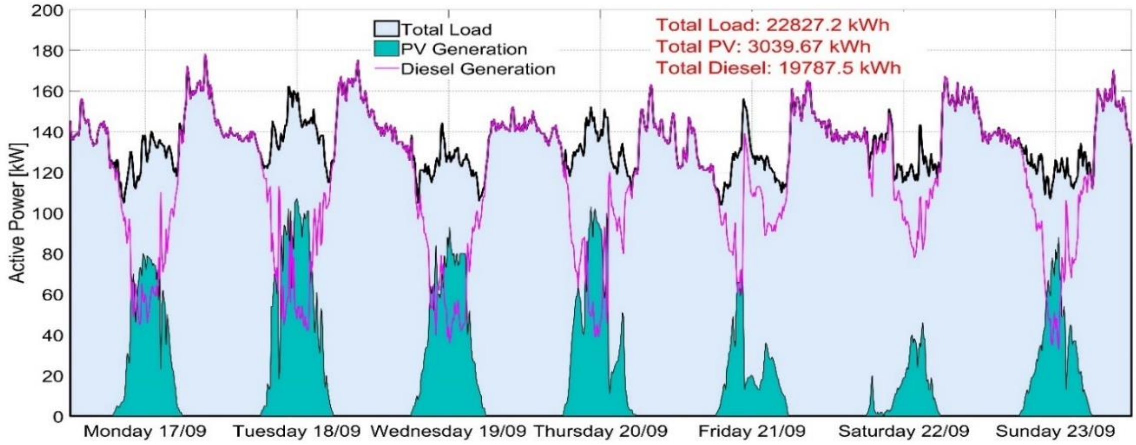
Figure 8. Feeder route of Peleliu.

4.1.2. Load Data Profile Daily Power Generation

The electricity generation and consumption profiles of Peleliu Island for 93 days mainly in September, October, and November 2018 were obtained from the central SMA Fuel Save Controller (SMA). The total load demand, diesel generation, and PV generation were recorded for two types of time-step resolutions: fast resolution of 10 seconds, and slow resolution of 10 minutes. Among 93 days, there are 70 days with almost completed data. In this section, the analysis of the downloaded daily power profiles is conducted for the 10-minute averaged data.

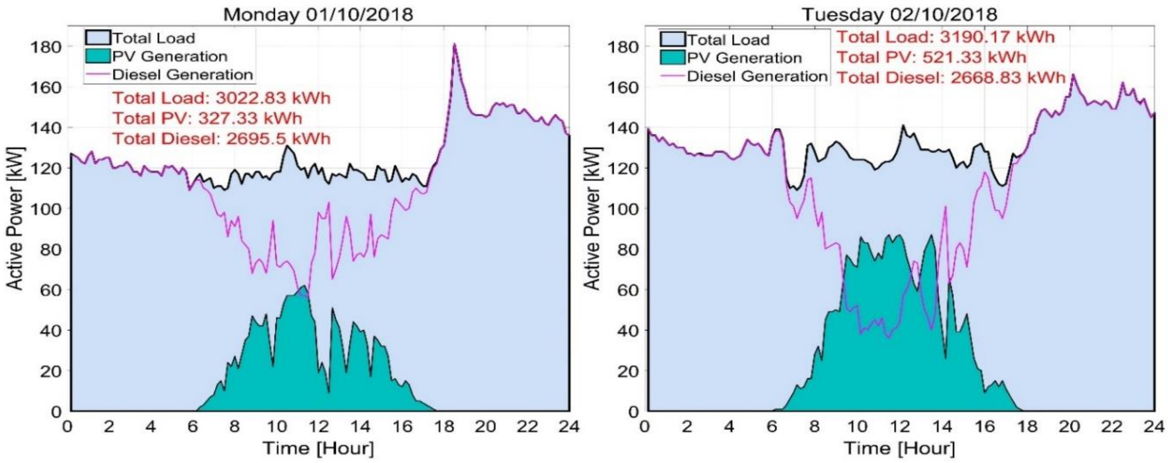
Figure 9 shows the generation and consumption profiles for a complete week. Figure 10 gives the details of energy profiles for weekdays, and weekends respectively. From these Figures we see that the total energy consumption in a weekend is higher than that in a weekday. The peak loads in both weekdays and weekends typically appear during the period between 18:00 and

22:00. The PV generation varies significantly between days because it directly depends on the weather conditions of each day.



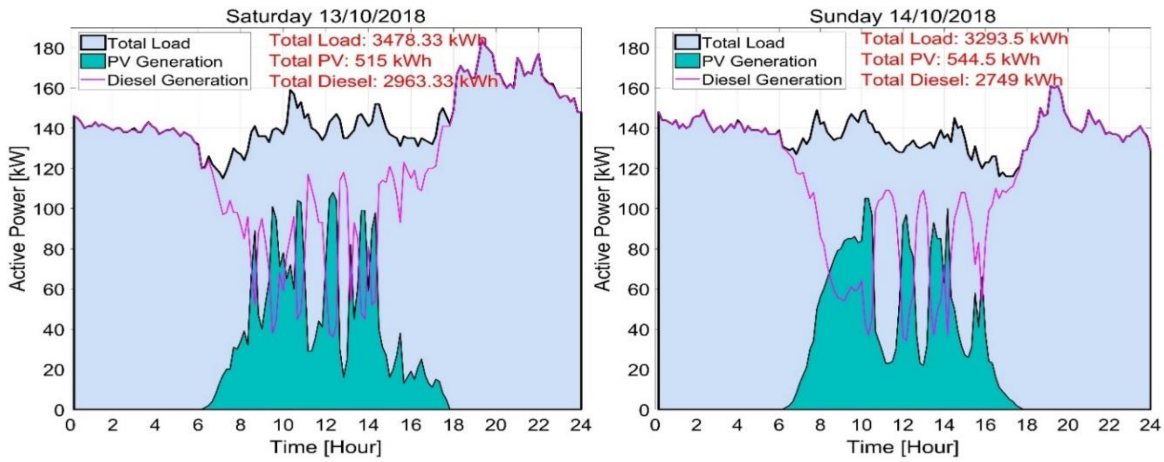
Source: SMA Fuel Save Controller at Peleliu

Figure 9. Daily generation and consumption profiles for a complete week.



Source: SMA Fuel Save Controller at Peleliu

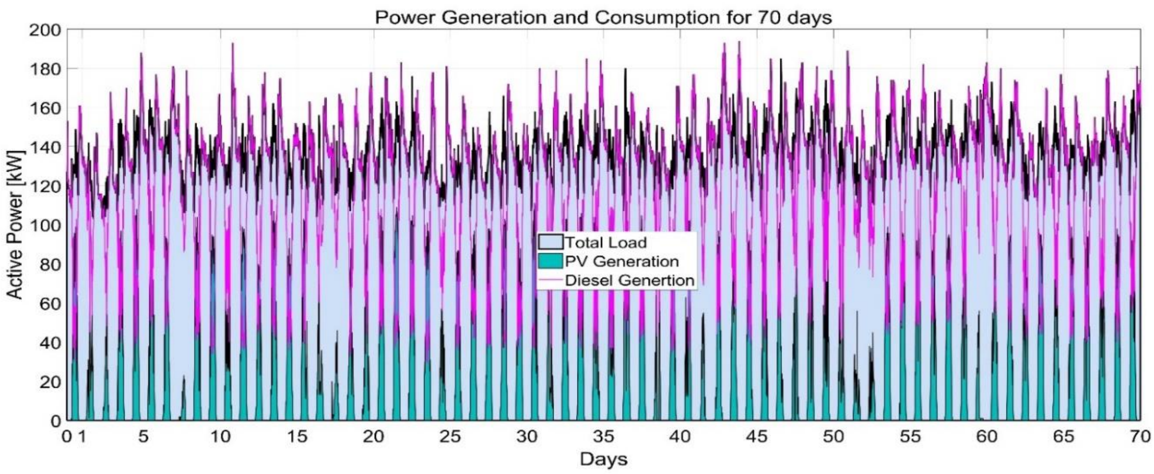
Figure 10. Daily generation and consumption profiles for two weekdays.



Source: SMA Fuel Save Controller at Peleliu

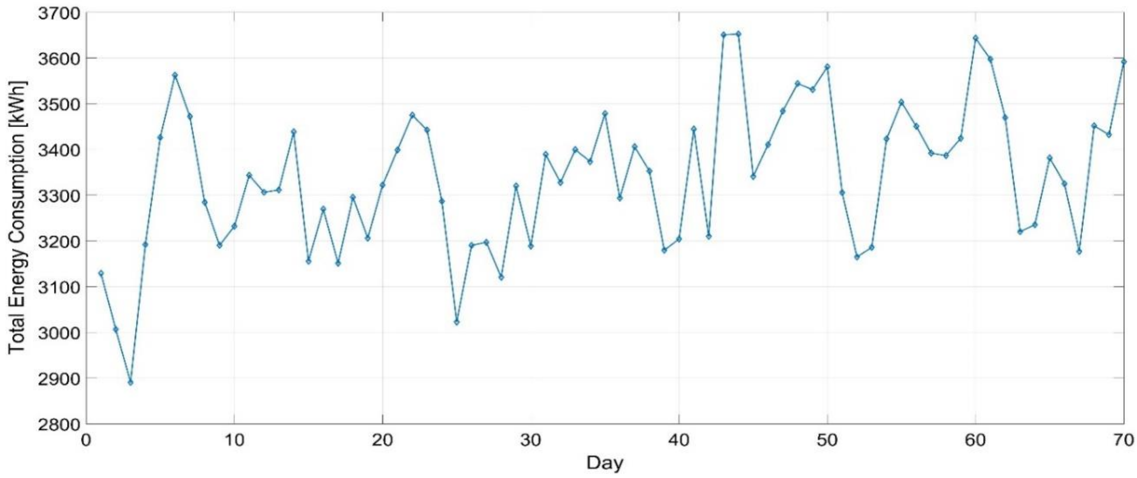
Figure 11. Daily generation and consumption profiles for two weekends.

Figure 12. shows the daily generation and consumption profiles for 70 days. *Figure 14* shows the total energy consumption of each day, and Table 31 gives some statistics about the collected data for 70 days.



Source: Data from SMA FSC at Peleliu

Figure 13. Daily generation and consumption profile of 70 days.



Source: SMA Fuel Save Controller at Peleliu

Figure 14. Total energy consumption each day.

Parameter	Unit	Value
Maximum load	kW	194
Medium load	kW	139.2
Minimum load	kW	96
Total energy consumption for 70 days	kWh	233,835.2
Total PV generation for 70 days	kWh	35,354.3
Total Diesel generation for 70 days	kWh	198,480.9
Average daily energy demand	kWh	3,340.5
Average daily PV generation	kWh	505.1
Average daily Diesel generation	kWh	2835.4

Table 31. Statistics parameters of collected data for 70 days

4.1.3. Status of diesel generators

The Peleliu island's power plant is equipped with diesel generators with a capacity as high as 2.2 MW. Total 164kW of PV are installed for the renewable energy. The peak load is 218kW for the last three years. Although PV penetration rate is high, diesel generators always supply the base-load because the solar power generation is smaller than the peak load. The diesel generator compensates for the volatility of the solar power generation which changes from time to time depending on the weather conditions. At night, diesel generators are designated to supply all of power. Because the capacity of the diesel generators is ten times as large as the peak load, only the new fuel-efficient diesel generators are operated as main generator and the old diesel generators are waited for emergency backup.

Name	Yanmar1	Yanmar2	Cummins3	Hatz1	Hatz2	Hatz3	Hatz4	Hatz5	Hatz6
Maker	Nishishiba Japan	Nishishiba Japan	Stamford England	Linz Germany	Linz Germany	Linz Germany	Linz Germany	Linz Germany	Linz Germany
Model	T260ST	T260ST	HC4E	PRO 225 D / 4	PRO 225 D / 4	PRO 225 D / 4	PRO 225 D / 4	PRO 225 D / 4	PRO 225 D / 4
Power (KW)	750	750	300	28	28	28	28	28	28
Install	1999	1999	2013	2016	2016	2016	2016	2016	2016
Volt.	440	440	480	480	480	480	480	480	480
RPM	720	720	1500	1800	1800	1800	1800	1800	1800
PF	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Freq.	60	60	60	60	60	60	60	60	60

Table 32. Peleliu Island Diesel Generator Status.

Yanmar generator is the oldest generator and consumes a lot of fuel. Yanmars are not normally activated except when Hatz generators stop for maintenance.

The Cummins generator is for backup-standby. Therefore, 6 Hatz Generators are automatically operated on load-following. One Perkins generator operates at peak demand when Hatz is insufficient.

Name	Quantity	Capacity / Unit (Kw)	Model	Remark
Yanmar	2	750	T260ST (1999)	Operation when Hatz stop
Cummins	1	300	QLS9G5	Back-up

Hatz	6	28	4L41C (2015)	Main operation
Perkins	1	275	P375-3 (2017)	For peak time

Table 33. Diesel Generator Driving Status.

The electricity generated from the diesel power plant is boosted through two 1000kVA main transformers and supplied to the 13.8kV distribution line. The primary side of the main transformer is a 440V delta connection, the secondary side is 13,800V wye connection, and the grounding method is a multiple grounding with each pole grounding. The main impedance of the main transformer is 5.75%, and there are five taps. According to the tap position, voltage is out 13,110V in E tap, 13,455V in D tap, 13,800V in C tap, 14,145V in B tap and 14,490V in A tap.

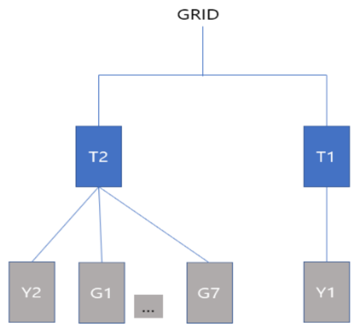


Figure 15. Main Transformer in Diesel Power Plant (1,000kW x 2)

4.1.4. PV Generation Status

Solar power is the only renewable energy source in Palau Island. Two solar power plants, 100kW and 64kW, are located adjacent to each other. The 100kW PV plant is equipped to bundle several 275W Chinese-made photovoltaic panels and then produce an integrated 100KW solar output through five SMA inverters.

(a)

(b)

Figure 16. Portion of PV Plant in Peleliu (a) 100kW (b) 64kW.

The PV output voltage is 480V, and the electricity from the 20kW SMA string inverter is boosted to 13,800V through three 50kVA single-phase transformers and supplied to distribution lines.

Figure 17. SMA Inverter in PV Plant.

Figure 18. Pole Transformer from PV to Grid.

4.1.5. Integrated Operation Algorithm for Diesel, Solar and ESS (SMA Controller)

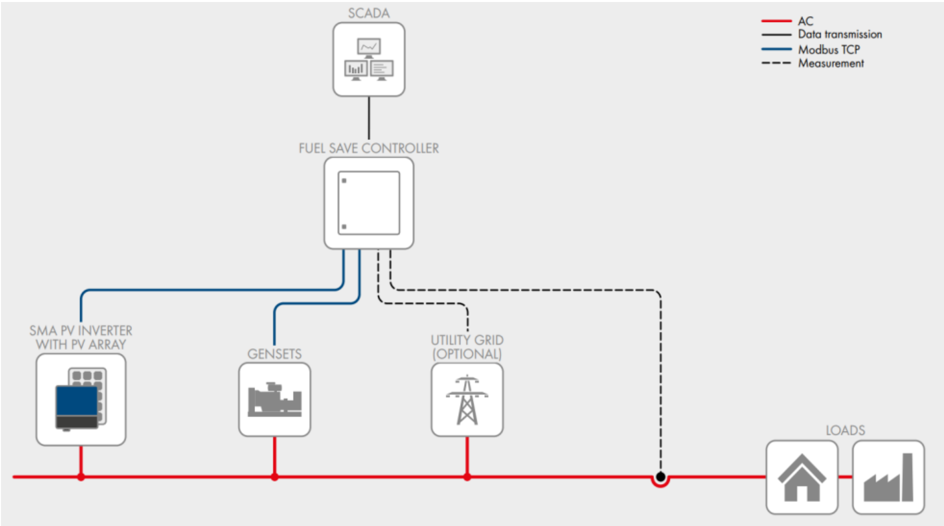
Currently the PV-diesel hybrid system in Peleliu is controlled by the SMA Fuel Save Controller (FSC). This section presents the details of Fuel Save Controller for the existing diesel-PV system. In addition, in the upgraded microgrid for Peleliu Island with higher PV penetration (50%, 75%, and 100%), energy storage system (ESS) must be integrated into the system. Therefore, this section also figures out how to integrate ESS with the Fuel Save Controller.

There are 6 HATZ diesel generators (each of 28kW), 1 FG Wilson diesel generator of 300kW, and a PV plant of 164kW. In normal conditions, PV and HATZ generators supply the load. When the PV production is low, or the load is high such that PV and HATZ generators cannot meet the load and reserve power, FG Wilson generator automatically operates to supply the load and guarantee the required reserve power. The integrated operation of diesel generators and PV system is controlled by the SMA Fuel Save Controller and the genset controller (Woodward EasyGen3000).

The Fuel Save Controller perform the following tasks:

- Monitoring the power sharing and operating states of Hatz gensets and FG Wilson generator
- Monitoring the loads and state of the local grid
- Calculating set-points for the output power of PV inverters according to configured parameter settings and the current loading conditions of gensets and loads
- Control and communication interface to PV inverters
- Recording all relevant system data for local and remote monitoring
- Emergency shutdown of PV inverters under fault conditions
- Controlling genset start-up and shutdowns. The Fuel Save Controller will send signals to EasyGen Woodward genset controller to start up or shut down generators.

The Fuel Save Controller is a solution to integrate PV into diesel genset-based utility grids. The SMA inverters are installed for PV system to convert DC power from the PV into AC power to feed in the system. The Fuel Save Controller monitors the power output of PV inverters as well as the operating state of the gensets and loads through measurement devices. Based on the measurement results, the Fuel Save Controller controls active and reactive power of the SMA inverters to guarantee the system stability. The diesel-PV system configuration with Fuel Save Controller is shown in Figure 19, and there is no utility grid in Peleliu case.



Source: SMA FSC Manual 2.0

Figure 19. Diesel-PV hybrid system with SMA Fuel Save Controller.

Based on the system specifications (such as minimum loading conditions of gensets) and the data from the load measurements, the Fuel Save Controller calculates values for active and reactive power for inverters. The power values are transmitted as setpoints to the PV inverters. The purpose of controlling reactive power output of PV inverters is to control the power factor of the gensets or the entire system. Because of the stochastic nature of PV power, the gensets must be able to provide sufficient reserve power at all times. Based on the power output of PV and measured load requirement, the SMA Fuel Save Controller calculates and sends a setpoint including the information of required reserve power directly to the genset controller, which controls startup and shutdown of diesel generators corresponding to the received setpoint. The operation of diesel-PV hybrid system with the Fuel Save Controller can be summarized by the flowchart in Figure 20 below.

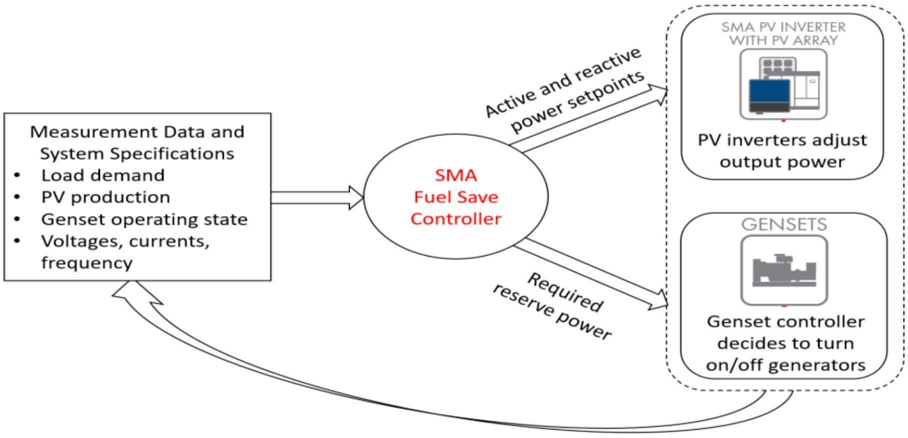


Figure 20. SMA Fuel Save Controller in a diesel-PV hybrid system.

Currently in the power system of Peleliu Island, all diesel generators are controlled by Woodward EasyGen3000 controller. All diesel generators operate in droop control, with a constraint in minimum output active power of 17%. The diesel generators share the load equally according to similar droop settings and proportional to their nominal power, as shown in Figure 21.

Source: Peleliu Diesel Power Plant

Figure 21. FG Wilson and HATZ generators share the load corresponding to their nominal power at 60.3 Hz.

In the diesel-PV hybrid system, the connection and disconnection of the gensets is performed exclusively by the genset controllers. The SMA Fuel Save Controller issues setpoints or recommendations to the genset for connection and disconnection decision. The start or stop of diesel generators is load-dependent, and it directly depends on the reserve power setpoint determined by the Fuel Save Controller. The stop of a diesel generator also depends on another parameter called "hysteresis". When the condition of disconnection hysteresis is satisfied, the genset controller decides to turn off a generator. The Woodward EasyGen3000 selects generators to be off with the objective is to balance the operating hours between all generators to minimize the operation and maintenance cost.

In the case of Peleliu power system, all gensets are in auto mode of operation during daytime. The Hatz generators are programmed to operate in parallel with the PV system until the load reaches 90% of the total nominal power of Hatz units, 151.2kW which is 90% of 168kW. If the total load supplied by the Hatz gensets reaches 151.2kW, the 300kW FG Wilson generator is controlled to start, synchronize, and share the load with Hatz generators. FG Wilson rarely operates throughout the daytime because the load powered by the Hatz is in most cases lower than 151.2kW. The possible events triggering FG Wilson to start during daytime can be:

- Very low PV production in rainy days and the load is above 151.2kW.
- Higher loads caused by special functions on the Peleliu Island which make Hatz gensets produce more than 151.2kW.
- Long periods of cloud cover which make Hatz gensets produce more than 151.2kW.

FG Wilson continues to operate until the load powered by Hatz gensets decreases to lower than 151.2kW. In this case, the Hatz units go back to normal operation, sharing the load after PV generation equally.

For the nighttime operation, to maximize the fuel consumption efficiency of diesel generators, the Hatz gensets are manually stopped after 6 p.m. or when the load powered gensets is above 168kW in the evening, when there is insufficient or no PV generation. This is because the FG Wilson can meet the power reserve requirement with its high capacity, therefore Hatz units are no longer needed at night. At 6 a.m., the system operator can turn on all Hatz gensets and operates them in Auto mode. Once all diesel generators are online, operated in Auto mode, FG Wilson shuts down, and the Hatz units together with PV supplies the load. The system goes back to the daytime operation.

4.1.6. Communication Network Configuration

In order to keep the voltage and frequency of the distribution line within the range of its rating, it is very important to cooperate with the diesel generator that compensates the fluctuation of the solar power output and the solar power output with severe output fluctuation depending on the weather condition.

The device that regulates the output of the diesel generator following and the fluctuating sunlight output fluctuation is the Fuel Save Controller, which is currently installed in the diesel power plant. In order to bring the photovoltaic generator output information to the fuel save controller in real time, an optical communication line is installed between two power plants. In the figure below, the inverter at the top is installed in the photovoltaic power plant and the HATZ controller at the bottom is installed in the diesel power plant. The real-time operation information from here is transmitted to the Fuel Save Controller which is responsible for judgment and control, and the output control command of the diesel generator is sent down.

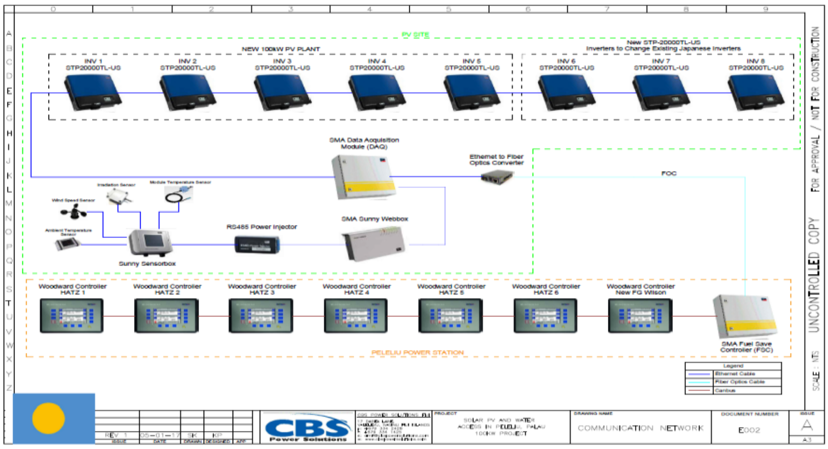


Figure 22. Fuel Save Controller (FSC) communication network.

4.2. Energy Mix Design for High RE Penetration

4.2.1. Data Preparation for Microgrid Design

In microgrid design, a number of factors need to be taken into consideration. Some of these factors are shown in figure below. Some of important factors are: the types of renewable energy resources available; the temporal evolution of the estimated amounts of energy that these sources can supply; the geographical and topographical characteristics of the remote area (related to climate, transportation of the DER, the possibility of using pumped storage, etc.); the typology of the loads and the characteristics of the demand; the associated structural and operating costs of the microgrid; and the level of quality of the energy supply demanded of it. These factors, among others, are investigated during the site visit to Peleliu.

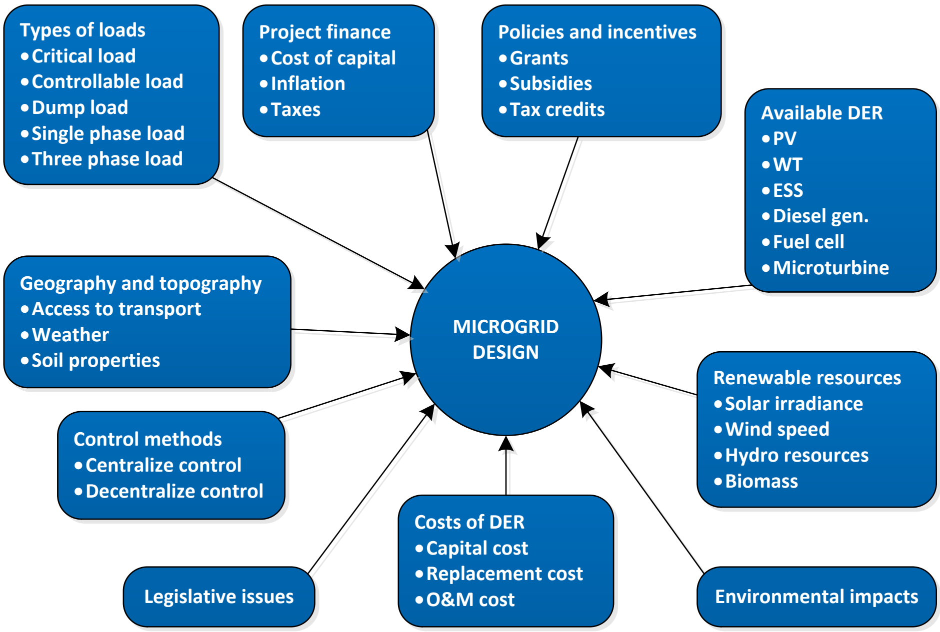


Figure 23. Factors affecting microgrid design.

The microgrid design in this study is based on the recommendations of two International Standards, namely: IEEE Draft Recommended Practice for the Planning and Design of the Microgrid (P2030.9/D2), and IEC Guidelines for Microgrid Projects Planning and Specification (IEC TS 62898-1-2017).

The design problem of microgrid generally addresses the system's configuration (which components to include), components optimal sizing, and operation strategy. The steps to be followed in designing microgrid is shown in Figure 26 and can be summarized as follows:

① Analysis and evaluation of load demand and renewable energy potential.

② Decision on the specific set of components to be considered in the design.

③ Microgrid model development.

④ Sizing and economic optimization of the system.

⑤ Simulation results and operational analysis of the resulting system.

4.2.2. Cost variables in micro-grid Design

In microgrid design, it is important to separate the costs into two parts: costs associated with each DER technology, and system cost, which are costs that are not associated with any DER. This distinction is important when sizing DER technologies, because the optimal energy mix depends on the DER costs, while the system costs do not affect the energy mix.

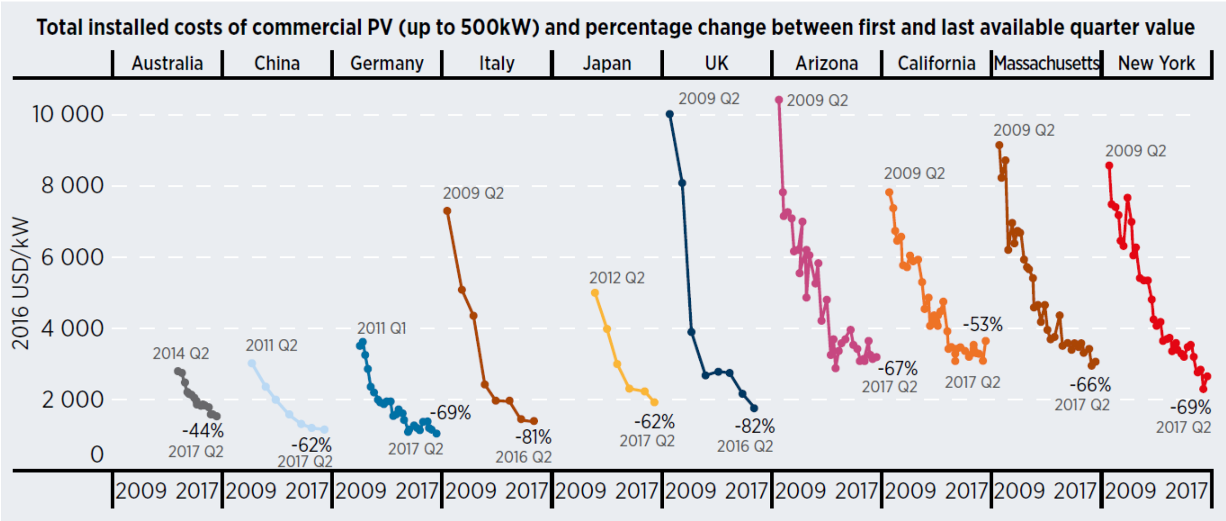
It is difficult to come up with the exact cost of any DER, as this depends on the manufacturer, technology, quantity (economy of scale), country, market segment, and many other factors. The summary of these costs for the entire DER used in this study is tabulated in Table 34. In the following sections, the detail and references for these costs of each DER are explained. Note that there are already existing PV and diesel generators in Peleliu, nevertheless, we included their installed cost in the analysis. This is necessary for a balanced comparison. The final installed cost of any design can be obtained by subtracting the installed cost of the existing components.

4.2.2.1.Costs of PV

The PV installed costs can be broadly categorized according to the market segment, i.e: utility, commercial, and residential. The market segment relevant to this study is commercial. The different market segments, locations, and the diverse point in time at which costs data are compiled can make a cost assumption challenging. However, to shed more light into the global trends of PV costs, IRENA has compiled a dataset of commercial PV costs for systems up to 500 kW. Based on this data, which is shown in Figure 24, the installed cost of PV is taken as 2,000 USD/kW. This cost can be broken down as follows (IRENA, 2017):

- Hardware: Module, inverter, cabling/wiring, grid connection, monitoring and control, racking and mounting, and safety and security.
- Installation: electrical installation, inspection, and mechanical installation.
- Soft costs: customer acquisition, financing costs, incentive application, margin, permitting, and system design.

There is no replacement cost for PV because its lifetime is 25 years, which is the same as the analysis period, resulting in no need for replacement. The operation and maintenance cost is 10 USD/kW/year, a value commonly used by many researchers.



Source: IRENA, 2017.

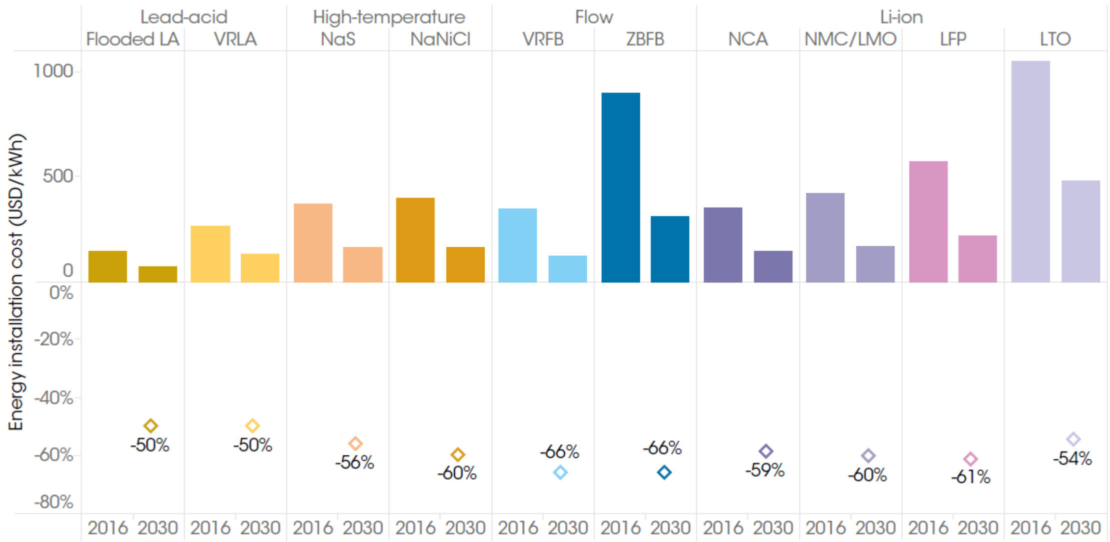
Figure 24. Commercial solar PV total installed cost by country or state, 2009-2017.

4.2.2.2. Cost of WT

For wind turbine costs, IRENA only provides costs for utility-scale projects (several MW, resulting in lower costs due to the economy of scale), and therefore these costs cannot be applied to the case of a small community like Peleliu. Therefore, we did not use IRENA data. Instead, we use the costs provided by HOMER's default inputs, which are obtained by manufacturers survey. The lifetime of WT is assumed to be 25 years, therefore, there is no replacement cost. The annual o&m cost of modern wind turbine is low and is assumed to be 1% of the installed cost.

4.2.2.3. Cost of BES

The battery energy storage considered in Peleliu is Li-ion battery. Its installed costs depend on battery chemistry, as shown in Figure 25. In this study, the cost is assumed to be 500 USD/kW. In determining the replacement cost of BES, consideration is made to the significant cost reduction potential of these technologies. The total installed cost of a Li-ion BES could fall by 54-61% by 2030 (IRENA, 2017), depending on the battery chemistry, as shown in Figure 25. Therefore, based on this analysis, and the expected lifetime of Li-ion BES of more than 10 years, the replacement cost used in this study is assumed to be 50% of the current installed cost. The nation of Palau is in a tropical climate with high temperature throughout the year, therefore, there is a need for air-conditioning for cooling the battery, since the performance of Li-ion battery deteriorates with increasing temperature. For this reason, the operation and maintenance cost is assumed to be 10 USD/kW/year (an assumption widely made in the research community).



Note: LA = lead-acid; VRLA = valve-regulated lead-acid; NaS = sodium sulphur; NaNiCl = sodium nickel chloride; VRFB = vanadium redox flow battery; ZBFB = zinc bromine flow battery; NCA = nickel cobalt aluminium; NMC/LMO = nickel manganese cobalt oxide/lithium manganese oxide; LFP = lithium iron phosphate; LTO = lithium titanate.

Source: IRENA, 2017.

Figure 25. Battery energy storage system installed energy cost reduction potential, 2016-2030.

4.2.2.4. Cost of power electronic inverter

There is no publicly available costs database for power electronics converters. Therefore, we used the default inputs provided by HOMER Pro software (Version 3.12.3). These costs are based on the manufacturer survey conducted by HOMER. The installed cost is 300 USD/kW. The replacement cost is assumed the same as the installed cost. There is no need for the O&M cost for modern power electronics converters.

4.2.2.5. Cost of diesel generator (DG)

Similar to power electronics converters, the installed cost of diesel generators is obtained from the default inputs provided by HOMER Pro software (Version 3.12.3). In addition, we consider the costs of diesel generators currently installed in Peleliu. The installed cost, replacement cost, and O&M cost are assumed to be 500 USD/kW, 500 USD/kW, and 0.03 USD/kW/hour. The cost of diesel is 1.01 USD/liter, which is obtained from the real historical cost of diesel in Peleliu Island.

2.3.5.6 Project fixed capital and operation cost

The project fixed cost is a cost that affects the microgrid as a whole. It is a cost associated with equipment that does not relate to any particular DER. These may include (but not limited to) microgrid controller, protection equipment, transformer (if required), distribution line expansion/ retrofitting (if necessary), commissioning, miscellaneous, etc.

Costs	**Value**
Photovoltaic	
Capital cost per kW[1]	$ 2,000
O&M cost per kW per year	$ 10
Replacement cost per kW	Not applicable
Wind Turbine	
Capital cost per 100 kW	$ 500,000
O&M cost per 100 kW per year	1% of capital cost
Replacement cost per 100 kW	Not applicable
Battery energy storage	
Capital cost per kWh	$500
O&M cost per kWh per year	$10
Replacement cost per kWh	$250
Converter	
Capital cost per kW	$300
O&M cost per kW per hour	Not applicable
Replacement cost per kW	$300
Diesel generator	
Capital cost per kW	$500
O&M cost per kW per hour	$0.03
Replacement cost per kW	$500
Diesel price	1.01 $/liter (3.82 $/gallon)

Table 34. Costs of DER.

In summary, the following references were reviewed to come up with the costs analyzed in this section.

① Renewable Power Generation Costs in 2017, IRENA
② Electricity Storage and Renewables: Costs and markets to 2030, IRENA
③ Annual Energy Outlook 2018 with Projections to 2050, US. Energy Information Administration
④ HOMER's Default Inputs (Based on manufacturers survey)

1 IRENA

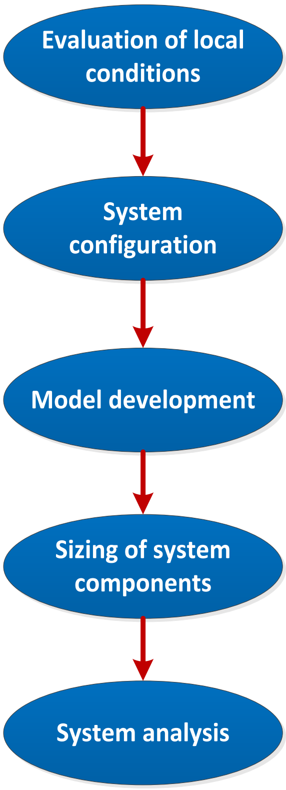


Figure 26. General microgrid design procedure.

Many different approaches have been followed in the industry in order to apply the basic steps outlined in figure above. A number of software tools are developed that integrate the design procedure, thereby significantly reduces the time and effort required in microgrid design.

4.2.3. Optimal Mix for REP levels

This section presents the results of the Peleliu Island microgrid design. The study aims to design and investigate the performance and economics of four cases of different level of renewable energy penetration. Case 1 is the existing system; with 17% REP. Cases 2 to 4 are the design with 50%, 75%, and 100% renewable energy penetration respectively. These cases are summarized in Table below.

Cases	Description
Case 1	17% renewable energy penetration. This is the current status at Peleliu.
Case 2	50 % renewable energy penetration. Case 2A is PV+ESS+Diesel, whereas Case 2B is PV+WT+ESS+Diesel
Case 3	75% renewable penetration. Case 3A is PV+ESS+Diesel, whereas Case 3B is PV+WT+ESS+Diesel
Case 4	100% renewable energy penetration. This is the ultimate goal, as the Island has a target to be Carbon Free. Case 4A is PV+ESS+Diesel, whereas Case 4B is PV+WT+ESS+Diesel

Table 35. Summary of cases under consideration.

Figure below shows simulated energy mix configuration. It is the plot of levelized cost of energy (LCOE) versus renewable energy penetration (REP). The cases denoted in cycle show the configurations with PV, ESS, and DG, whereas the cases in square show the configurations with PV, WT, ESS, and DG. The red cycle on the y-axis shows the reference case, which is the existing system before the current PV is installed, where all load demand is met by diesel generators.

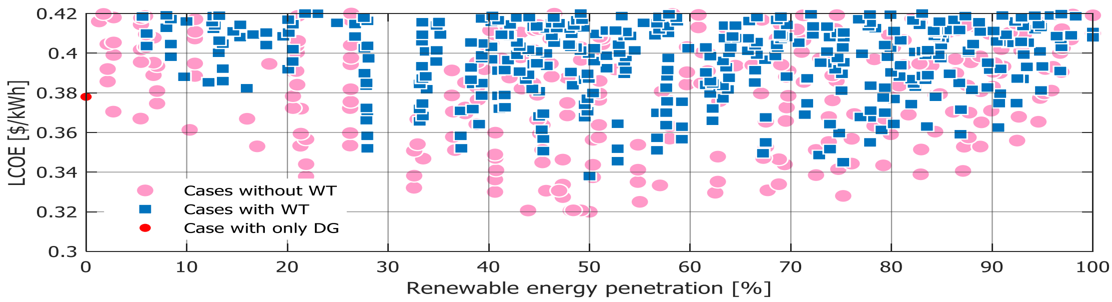


Figure 27. Simulations of scenarios according to RE Penetration

Parameter	Value	Unit
Levelized cost of energy (LCOE)	0.353	$/kWh
Net present cost (NPC)	4,748,823	$
Capital cost	562,000	$
Operating cost	392,607	$/year
Renewable penetration	17	%
Fuel consumption	320,837	liters/year
Total emission	845	ton of CO2/year

Table 36.Cost Summary of Case1

Table above shows the summary of costs for Case 1. The simulation is conducted with applying HOMER's default value of 8% nominal discount rate, which is a typical discount rate value used in renewable energy project. The levelized cost of energy is 0.353 $/kWh and the total NPC is $4,748,823. The operating cost is 392,607 $/year, which includes the annual fuel consumption of 320,837 liters/year, costing a total of 324,045$/year. Therefore, 83% of the operating cost is due to fuel cost. In Table 37, the system architecture is shown, with the current sizes of DER in Peleliu (rated power) of each component in the microgrid, which consist of 164 kW of PV, 300 kW of FG Wilson diesel generator, and a set of six HATZ generators (28 kW X 6). Table 38 shows the net present cost associated with each component in the system. The total capital cost is $562,000. Notably, this is the existing system, and hence the actual capital cost for investment is zero; but the capital value is reported here for the completeness of the analysis, and to allow for fair comparison with other cases.

Parameter	Value	Unit
Levelized cost of energy (LCOE)	0.353	$/kWh
Net present cost (NPC)	4,748,823	$
Capital cost	562,000	$
Operating cost	392,607	$/year
Renewable penetration	17	%
Fuel consumption	320,837	liters/year
Total emission	845	ton of CO_2/year

Table 36. Case 1: Cost summary.

Component	Current sizes	Units
PV	164	kW
FG Wilson generator	300	kW
HATZ generator	168	kW

Table 37. Case 1: System architecture

Component	Capital	Replacement	O&M cost	Fuel	Salvage	Total
PV	328,000	0	17,507	0	0	345,507
FG Wilson	150,000	54,742	440,110	2,049,428	-1,998	2,692,281
HATZ	84,000	22,786	198,220	1,409,686	-3,658	605,683
Total	562,000	77,528	655,837	3,459,114	-5,656	4,748,823

Table 38. Case 1: Net present cost (8% discount rate and all costs in USD)

Therefore, the optimal renewable penetration in Peleliu Island currently is 47%. In addition, the plots show that the cases without wind turbine are more economical. The only exception is at 100% REP, where the case with a wind turbine is more economical than the case without wind turbine. In the separate technical report, the results of the cases shown in figure will be presented in detail. They are the cases of interest to this study, which are summarized in table below. LCOE of various cases (above) and the cases analyzed in this study (below). Each circles and squares in the Figure represent feasible cases.

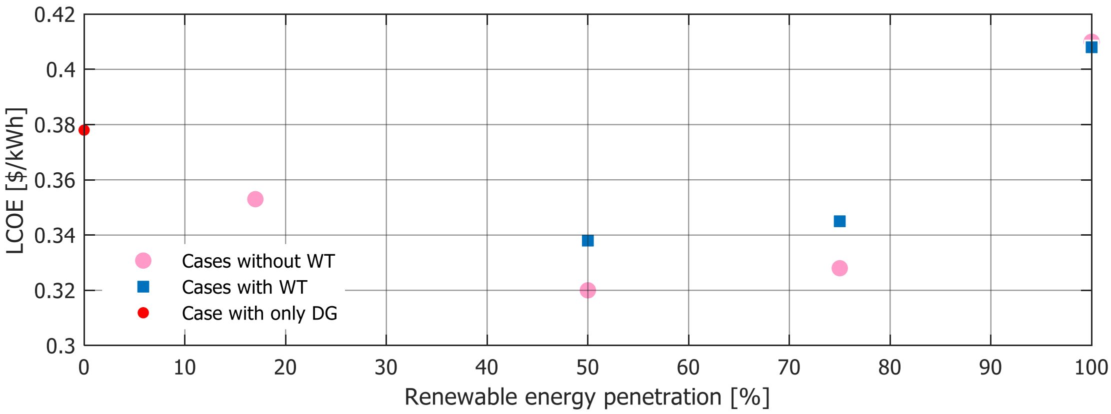


Figure 28 Simulations of scenarios according to RE Penetration

In Figure above, the circles represent cases with PV, BES, and DG, whereas the squares represent cases with PV, WT, BES, and DG. The red circle represents a reference case, where all load demand is met by DG. We can find the followings from the results.

- REP 50% and 75% have less LCOE than current Peleliu state (17%). Specifically, REP 50% is the most economical among all the cases because the LCOE is the lowest.
- To increase REP level, ESS should be installed to efficiently use the generation power of renewable energy resource. ESS can store the surplus generation power from PV (and WT) and discharge the stored energy in the evening when PV panels cannot generate electric power and also the power demand is high.
- The installation cost of more PVs and ESS is large but it can be compensated by low operating cost. The higher REP can significantly reduce the greenhouse gas emission.
- WT is not competitive compared to PV in Peleliu Island because of the high cost of energy. Therefore, WT can only be economical for 100% REP case. The structure of WT generators is complicated and especially composed of many rotating equipment devices so that they are more likely to be out-of-order than PV generators and require more engineers for maintenance. Therefore, WT is not strongly recommended in Peleliu Island.

Design and Economic Parameters		Case 1 (17%)	Case 2 (50%)	Case 3 (75%)	Case 4 (100%)
Optimal size	PV (kW)	164	564	839	1389
	WT (kW)	-	-	-	100
	ESS (kWh)	-	925	2,200	3,750
	ESS Converter (kW)	-	200	350	550
	Diesel, FGW (kW)	300	300	300	-
	Diesel, Hatz (kW)	168	168	168	-
Economic analysis	LCOE ($/kWh)	0.353	0.320	0.328	0.408
	NPC ($)	4,748,823	4,552,405	4,871,097	6,213,843
	Capital cost ($)	562,000	1,884,500	3,117,000	5,318,000
	Operating cost ($/year)	392,607	250,502	165,100	85,763
	Renewable Energy Penetration (%)	17	50.4	75.2	100
	Fuel consumption (L/year)	320,837	182,867	93,949	0
	Total emission (ton/year)	845	482	247	0

Table 39. Comparison of the results of all four cases

4.2.4. 50% of PV-ESS-Diesel Case

This report will only explain 50% of case which is optimal size. The levelized cost of energy is 0.320 $/kWh and the total NPC is $4,552,405. The operating cost is 250,502 $/year. The annual fuel consumption is 182,867 liters/year, which cost a total of 184,696$/year. In Table 41, the optimal sizes of the DERs (rated power) are shown, which consist of 564 kW of PV, 300 kW of FG Wilson diesel generator, and a set of six HATZ generators (28 kW X 6).

Table below shows the net present cost associated with each component in the system. The total capital cost is 1,884,500 $. This case is found to be the most optimal as can be shown from figure below.

Parameter	Value	Unit
Levelized cost of energy (LCOE)	0.320	$/kWh
Net present cost (NPC)	4,552,405	$
Capital cost	1,884,500	$
Operating cost	250,502	$/year
Renewable penetration	50.4	%
Fuel consumption	182,867	liters/year
Total emission	482	ton of CO_2/year

Table 40.Case 2: Cost summary.

Component	Optimal size	Units
PV	564	kW
ESS	925	kWh
ESS Inverter	200	kW
FG Wilson generator	300	kW
HATZ generator	168	kW

Table 41. Case 2: System architecture

Component	Capital	Replacement	O&M cost	Fuel	Salvage	Total
PV	1,128,000	0	60,206	0	0	1,188,206
ESS	462,500	86,320	98,742	0	-1,605	645,956
ESS Inverter	60,000	18,915	0	0	-2,920	75,994
FG Wilson	150,000	41,860	347,592	1,596,620	-10,787	2,125,285
HATZ	84,000	0	64,167	374,968	-6,170	516,964
Total	1,884,500	147,095	570,706	1,971,588	-21,483	4,552,405

Table 42.Case 2: Net Present Cost (8% discount rate and all costs in USD)

The capital cost, the net present cost of replacement cost, O&M cost, fuel cost, and salvage value are shown in Table 43.. Fuel dominates the cost in this system. The fraction of DER monthly and annual energy production that meets the load are shown in and Figure 31, respectively. FG Wilson produces more energy, followed by HATZ generators and PV. Annually, FG Wilson covers 42 % of the load, followed by HATZ generators, which covers 7%. PV and ESS cover 34% and 16%, respectively. The ESS is always charged with renewable energy, therefore the renewable energy penetration is the fraction of PV and ESS.

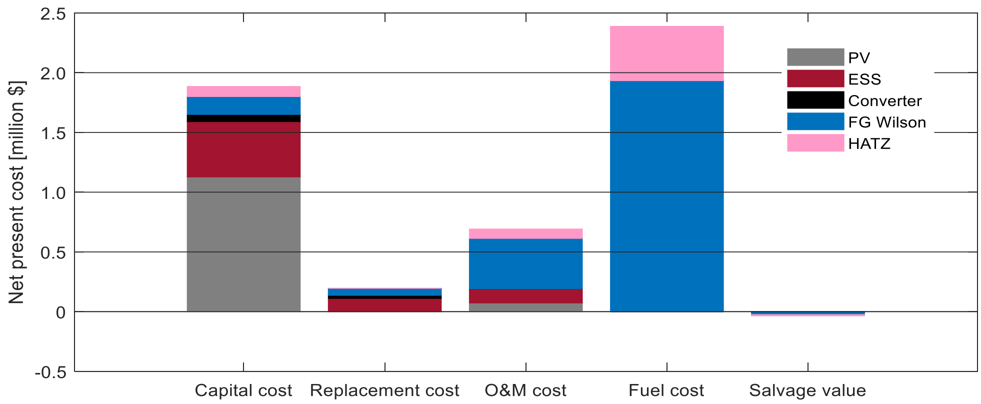


Figure 29. NPC breakdown.

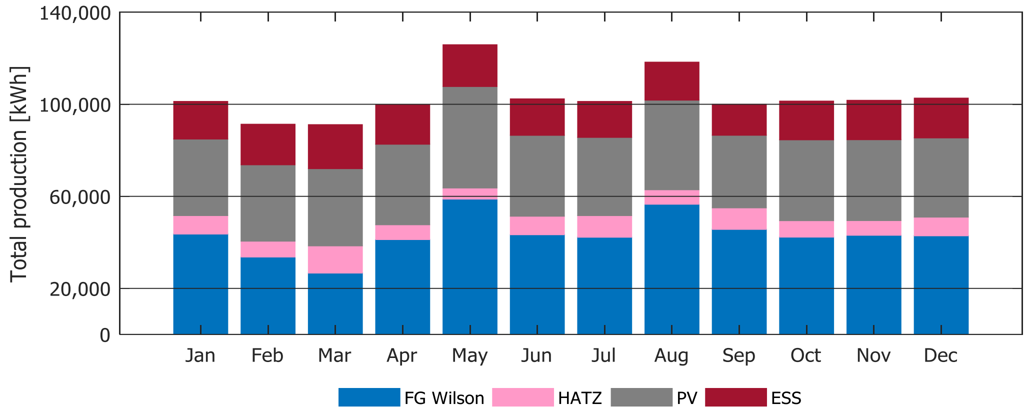


Figure 30. Monthly energy production.

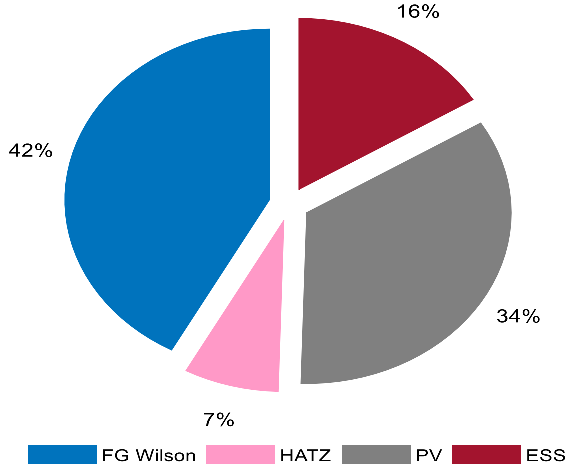


Figure 31. Total annual energy production.

The dispatch profiles of June 3 and June 22 are shown in Figure 32 and Figure 33, respectively. On June 28, FG Wilson operates during the night. During the daytime, HATZ diesel generators, PV, and ESS are combined and operated together to meet the load demand. On June 22, a large amount of PV has to be curtailed because the ESS SOC is at its maximum (100%) and all load is covered by PV.

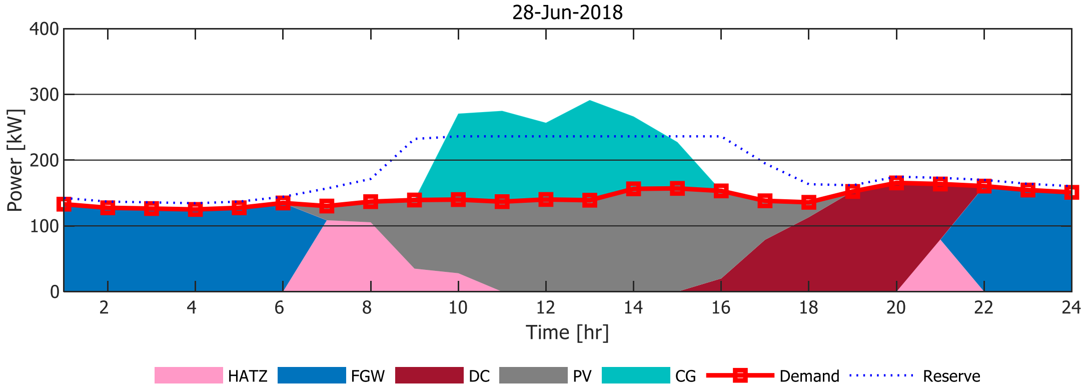


Figure 32. Case 2A: Dispatch profile of a sunny day on June 28.

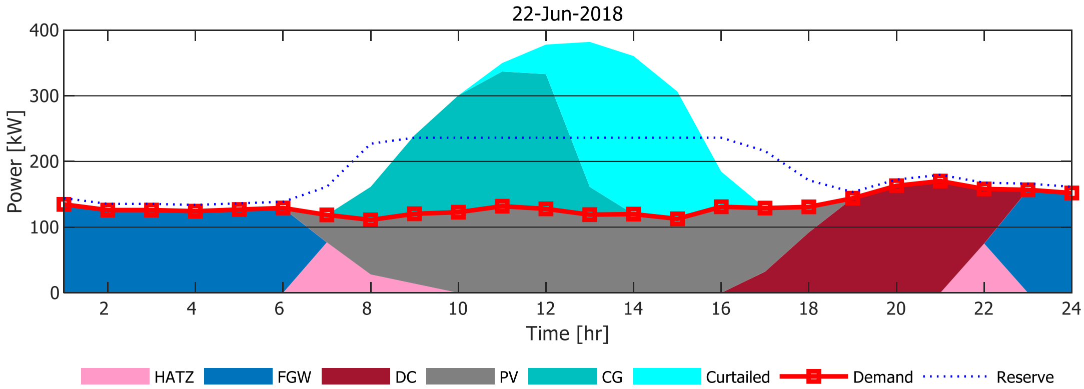


Figure 33. Dispatch profile of a sunny day June 22.

4.3. Micro-controller design for higher RE penetration

Microgrids can include multiple distributed energy resources (DERs) such as generators, energy storage devices, and renewable energy resources as well as controllable/critical loads. Microgrids generally must also include a control strategy to maintain, on an instantaneous basis, real and reactive power balance when the system is islanded and, over a longer time, to determine how to dispatch the resources. Therefore, microgrids require coordinated and coherent operation of the microgrid assets including DERs, energy storage systems, and responsive load.

The most challenge for micro-controller face for higher RE penetration is that micro-controller has to control ESS. This chapter will analysis current micro-controller which only controls PV and diesel generator. And this chapter will suggest features required for micro-controller which control PV, diesel generator and ESS.

4.3.1. Micro Controller for PV and Diesel Generator (current system)

In the current system, there are only PV and diesel generators, therefore, the operation algorithm runs diesel all the time from its minimum power up to the peak load. The PV power has the priority, therefore the diesel generators meet the net load (load minus PV power) and the required operating reserve. The current system has a central controller that manages and control the PV and diesel generators in the Island.

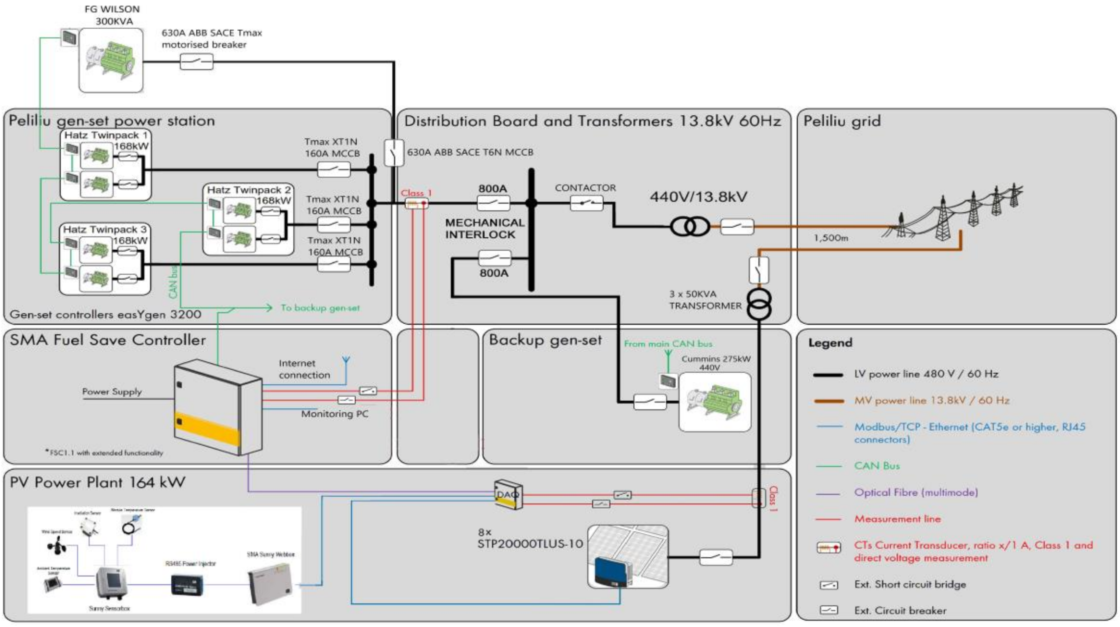


Figure 34. Microgrid control system using SMA FSC and SMA PV converters

The current operation algorithm at Peleliu Island is as follows:

- **Daytime operation (6 AM to 6 PM)**
  - During the daytime, all diesel generators are in auto mode. Depending on the load and the available PV, the Woodward easygen controllers schedule the generators.
  - The Hatz units are programmed to operate with the PV until the load reaches 90% of the total nominal power of Hatz units i.e, 90% of (6 x 28kW) = 151.2kW
  - As soon as the total load on the Hatz units reaches 151.2kW, the 300kW FG Wilson is signaled to start, synchronize and share the load with the Hatz units.
  - In this scenario, the FG Wilson will take on 35% of its nominal rated capacity i.e., 35% of 300kW = 106kW.
  - Once the FG Wilson has synchronized and taken on 35% of its rated capacity, all Hatz units will continue to operate at minimum 10% loading of its nominal rated capacity, which is 2.8kW for each Hatz unit.
  - In this scenario, the total load taken up by diesel would be (35% of 300kW) + ((10% of 28kW) x 6 units) = 121.8kW and the remaining supplied by fluctuating PV.
  - FG Wilson is unlikely to run throughout the daytime as load would not always be above 151.2kW
  - The FG Wilson will continue to operate until the load goes below 90% of the rated power of Hatz units, which is 151.2kW. At this point, the FG Wilson would shed the load by opening the contact. The Hatz units will go back to the normal operation taking over island load with fluctuating PV.
- **Night time operation (6 PM to 6 AM on the next day)**
  - To ensure maximum diesel savings, the Hatz units are manually stopped after 6pm or when the load is above 168kW in the evening where there is insignificant or no PV penetration into the grid.
  - The 168kW threshold was chosen to STOP the Hatz units because during that time the FG Wilson will also be operating and would be able to take the load from the Hatz generators gradually.
  - The 300kW FG Wilson continues to operate in Auto mode and supplies the whole island load.
  - Due to the higher capacity of the FG Wilson, Hatz units are no longer required in the night and are stopped manually. The Island load fluctuates between 98kW to 220kW in a 24Hr period.
  - At 6AM in the morning, the operator can switch ON all Hatz units and put it on Auto mode. Once all generators are online and in Auto mode, the FG Wilson will shut down and let the

Hatz units take the load with the incoming PV in the morning if the island load is below 151.2kW.

- If it is above 151.2kW, then all engines continue to operate.

The likely events triggering FG Wilson to start during daytime are mentioned below:

- 1. Rainy days and load with above 151.2kW or extended periods of cloud cover where Hatz units exceed 151.2kW (see Figure 35 for this type of day which occurs on 6 April 2018).
- 2. Higher loads caused by major functions on the island where Hatz units exceed 151.2kW (see Figure 36 for this type of day, which occurs on 6 May 2018).
- 3. Sunny day and the high production of power by PV, and therefore the required operating reserve with higher than HATZ capacity (see Figure 37 for this type of day, which occurs on 4 May 2018).

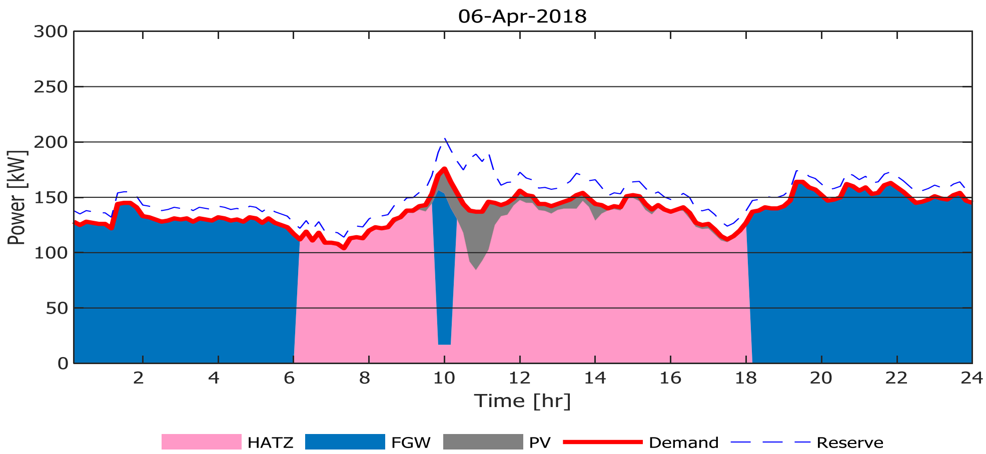


Figure 35. Rainy day and the load with above 151.2kW or extended periods of cloud cover where HATZ units exceed 151.2kW.

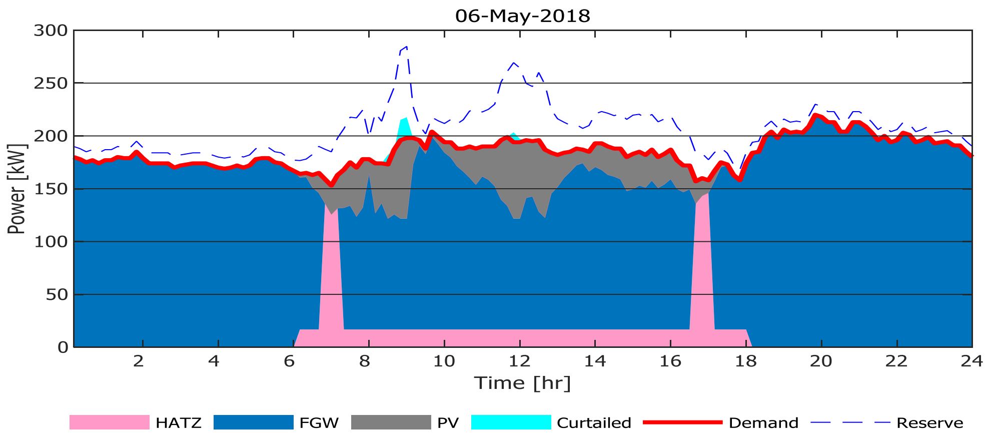


Figure 36. Higher loads, which makes the load on the HATZ units exceed 151.2 kW.

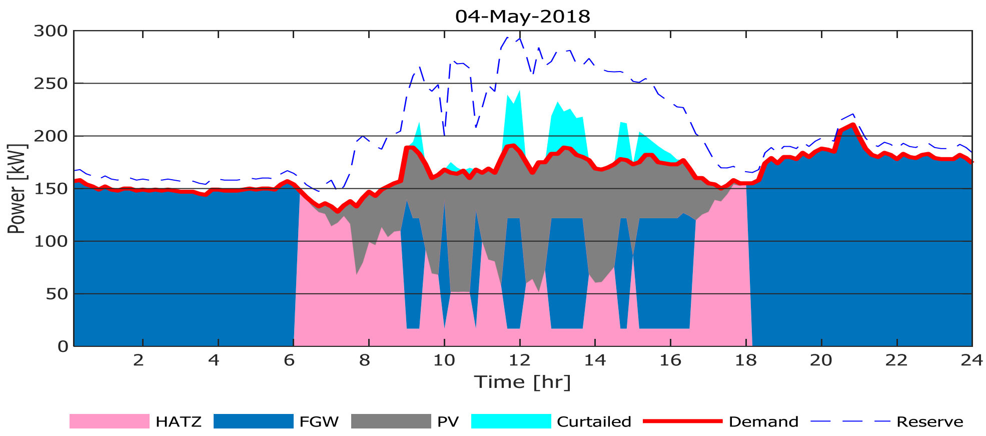


Figure 37. Sunny day and high production of power by PV, leading to higher required operating reserve.

4.3.2. Microgrid controller for Diesel-ESS-PV system

SMA Fuel Save Controller, the current micro-controller, can only control the existing Diesel and PV. According to FSC manual, the maximum peak PV generation level is about 60%. Therefore, micro-controller requires measure for a higher peak PV generation rate.

Since, current micro-grid controller is operated by SMA controller, SMA provides detailed manual and specification for SMA hybrid controller which controls PV, diesel and ESS. SMA hybrid controller also controls high PV penetration rate.

In the chapter, detailed analysis of SMA Hybrid Controller is presented to introduce clear understanding of diesel-ESS-PV hybrid controller. Comparing to PV-diesel controller, PV-diesel-ESS controller needs 2 essential features.

- **Voltage and Frequency Control**: Both diesel generator and ESS can be main controller for voltage and frequency control. ESS converter should provide both grid-parallel mode and grid-forming mode.
- **Dispatch Algorithm:** More sophisticated dispatch algorithm should be applied. SMA Hybrid Controller can be operated even in diesel-off since there is no need to use diesel generator in daytime.

4.3.2.1. Voltage and Frequency Control

The difference of this diesel-ESS-PV hybrid system is that the ESS converter has two operating modes which are grid-parallel mode and grid-forming mode. In this system, if there is any surplus power from diesel generators and PV system due to high PV generation or sudden load disconnections, this surplus power is used to charge ESS.

In grid-parallel mode, the system frequency is formed by the gensets. The PV and ESS can also support the voltage and enhance the system power factor by reactive power release. In this mode of operation, the Fuel Save Controller must calculate the power setpoints of the ESS in order to charge and discharge the battery based on the PV generation at each instant. To exactly calculate the power setpoints of ESS, the Fuel Save Controller requires the measurement data of PV power output in a very high temporal resolution. Figure 38 shows the system operation when the ESS is in grid-parallel mode.

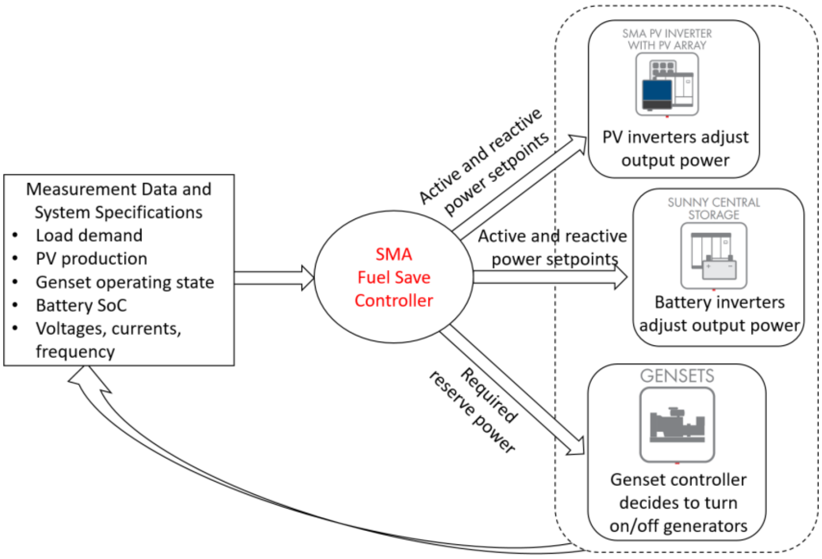
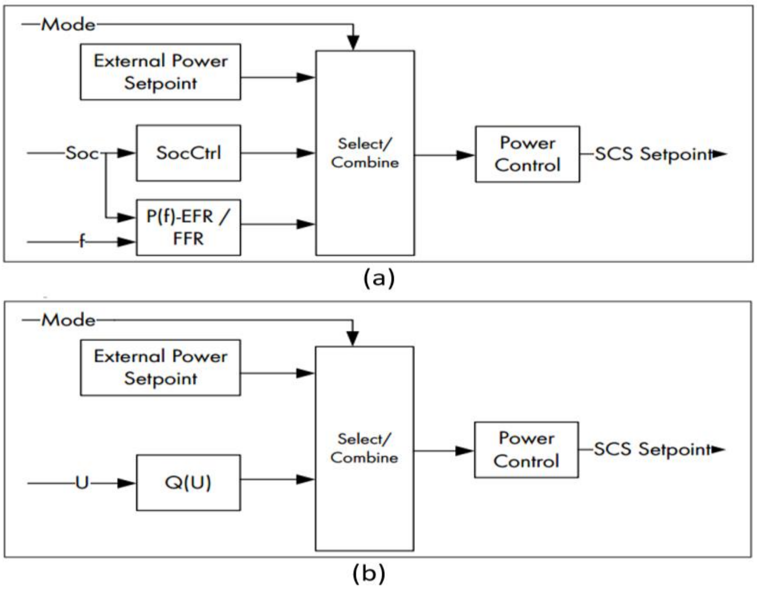


Figure 38. SMA Fuel Save Controller in a diesel-ESS-PV hybrid system when ESS is in grid-parallel mode.

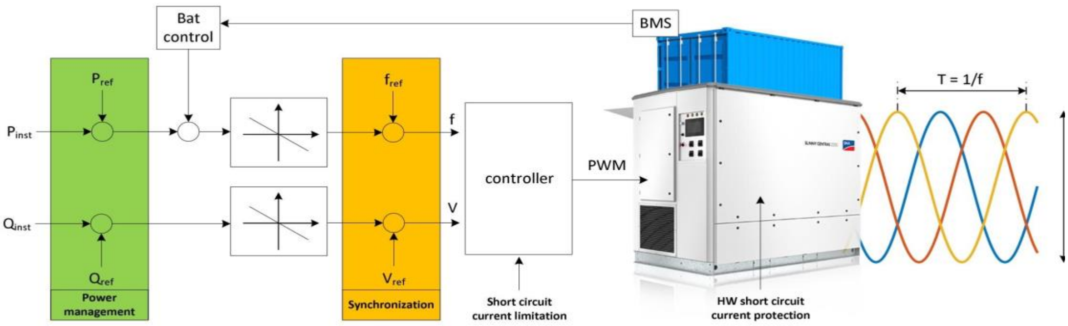
Figure 39 illustrates how the active and reactive power setpoints of ESS can be controlled. For ESS active power, the setpoint can be selected from (1) external setpoint via communication interface or setpoint of a time-profile, or (2) by the frequency-dependent active power control P/f, or combination of (1) and (2). For ESS reactive power, the setpoint can be selected from (1) external setpoint, or (2) reactive power control by the voltage-dependent reactive power control or by power factor or by voltage control or combination of (1) and (2).



Sources: SMA Hybrid Controller, Universal Power Management System.

Figure 39. Active and reactive power setpoints of ESS.

In grid-forming mode, ESS operates as a reference unit which forms and controls the system frequency. In the diesel-ESS-PV hybrid system, ESS operates in grid-forming mode when the diesel-off mode of the system is activated. In diesel-off mode, the loads are served using energy stored in ESS and energy from PV generation as available. The ESS converter employs the P/f and Q/V droops to calculate the frequency and voltage based on the active power and reactive power, respectively. The droops are emulating the behavior of a rotating machine by reducing the frequency when loaded with active power, and vice versa and reducing the voltage when loaded with reactive power and vice versa. The concept of droops for ESS converter is shown in Figure 40. In grid-forming mode, the converters are running as voltage sources, and the load is transferred instantaneously to the battery converters.

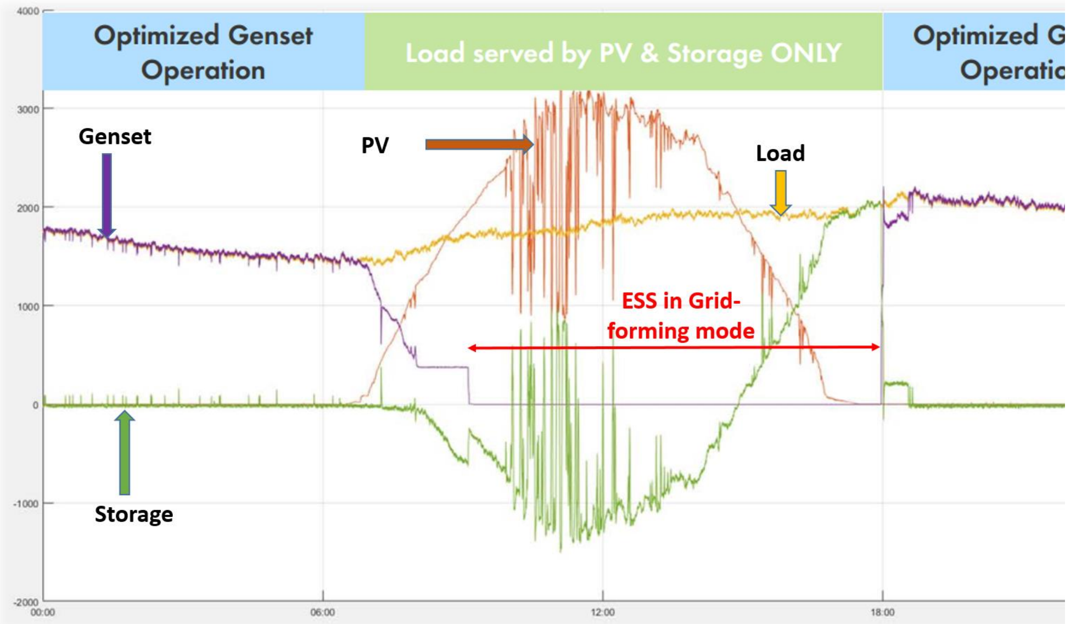


$$f = f_{ref} + kP * (P_{ref} - P_{inst})$$
$$U = U_{ref} + kQ * (Q_{ref} - Q_{inst})$$

Sources: SMA Hybrid Controller, Universal Power Management System.

Figure 40. Droops of ESS converters.

Figure 41 shows the output power of a diesel-ESS-PV hybrid system for a typical day. It is seen that early in the morning and at night when there is no power generated from PV, diesel generators operate as the reference unit to supply the whole load and regulate the system frequency and voltage.



Sources: Sunny Central Storage System, The Solution for 100% Renewable Integration.

Figure 41. Output power of a diesel-ESS-PV in for a typical day

Early in the morning when PV starts to produce some power but insufficient to meet the load, diesel generators keep operating as the main source. When the PV power output increases such that PV and gensets produce some surplus power, gensets keep running at minimum load condition for a certain period before shutdown, while the surplus power is used to charge the ESS. When ESS and PV can securely meet the load and provide the reserve power, gensets are shut down and the diesel-ESS-PV system operates in diesel-off mode, which means ESS now operates in grid-forming mode to control the system frequency and voltage. Now the load is served by PV and storage only. In the late afternoon when the PV generation starts decreasing but the energy stored in ESS is still sufficient to serve the load, ESS keeps operating in grid-forming mode. When the controller sees that the energy stored in ESS is insufficient to meet the load and reserve power, diesel gensets are turned on and the system now operates in diesel-on mode, where diesel generators are the main source to power the load. Now ESS operates in grid-parallel mode, and it is discharged until the minimum SoC (state-of-charge) is reached as shown in Figure 41 after 6 p.m.

4.3.2.2 Micro Controller Dispatch algorithms

The PV-diesel-ESS controller should offer more sophisticated dispatch algorithm since there is high RE penetration level. Here, we analyze the effect of DER dispatch algorithms on the economics. For this analysis, we considered four dispatch algorithms such as load following, cycle charging, diesel-off and diesel-on modes. Load-following and cycle charging algorithm is suggested by HOMER and diesel-off and diesel-on function are functions SMA Hybrid Controller offers.

- **Load Following:** In load following strategy, the algorithm determines whether the renewable energy sources by themselves are capable of supplying the electric load and the required operating reserve. If not, it determines how best to dispatch the diesel generator and energy storage to serve the loads and operating reserve considering the operating cost of DERs (diesel and ESS). The operating cost of dispatchable DERs has two values: a fixed cost per hour, and a variable cost of energy per kilowatt-hour. Using these cost values, the least cost option is chosen to meet the load and the required operating reserve. [Refer to Appendix B1 and B2 for equations used to calculate fixed and variable costs of diesel and ESS]. The next decision is weather when diesel generator charge the ESS. In this strategy, diesel generators are not used to charge the battery bank. Batteries are only charged with renewable energy.

- **Cycle Charging:** Similar to the load following strategy, cycle charging also uses some sort of economic dispatch when it chooses diesel generators to turn on among multiple generators. However, under this strategy, whenever a generator operates, it runs at its maximum rated capacity (or as close as possible without incurring excess electricity) and charges the battery bank with the excess.

- **Diesel off:** The ESS converter has two operating modes, which are grid-parallel mode and grid-forming mode. In this system, if there is any surplus power from diesel generators and PV system due to high PV generation or sudden load disconnections, this surplus power is charged to ESS. When the stored energy in the ESS is enough to supply the load as well as the operating reserve, the diesel generators can be turned off. This saves operation cost due to diesel fuel save and diesel efficiency improvement.
    - **Mode 1 (grid-forming operation of ESS, from 6AM to 6PM):** Mode 1 is when the ESS is in grid forming mode (i.e. the master unit). The ESS unit acts as a master unit and employs V/f control method to maintain voltage and frequency stability in the microgrid.

In this mode, the ESS and RES meet the load demand and the required operating reserve, while the DG remain off.

- **Mode 2 (main generation from diesel generators, from 6PM to 6AM):** In mode 2, the DG is in grid forming mode (i.e. the master unit). The DG uses a droop control method to maintain voltage and frequency stability in the microgrid. The DG and the RES meet the load and the required operating reserve. In this mode of operation, another decision is weather and when to charge the ESS battery using DG.

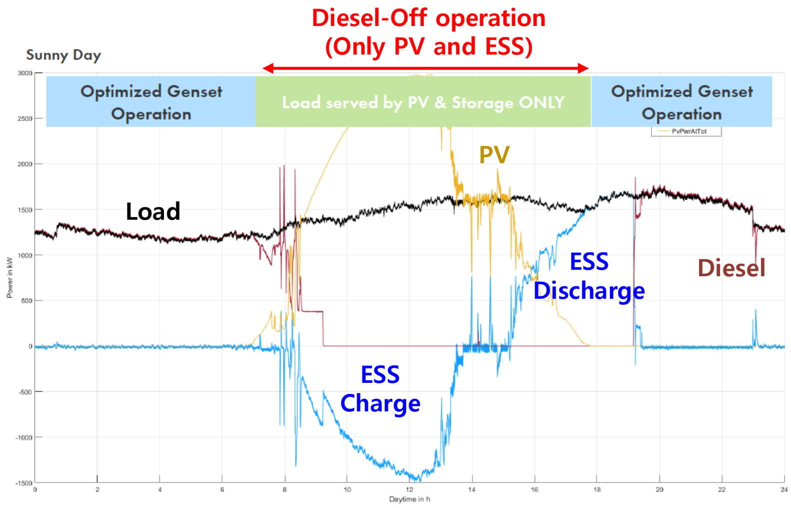


Figure 42. Diesel-off operation for SMA hybrid controller in St. Eustatius island in Caribbean Sea

- **Diesel-on:** In this operation algorithm, the diesel generator is always on to supply the load and the operating reserve. It uses the droop control method to maintain voltage and frequency stability in the microgrid. Because diesel generators must be loaded more than the minimum generation power, PV generation power may sometimes be curtailed.

4.4. Power Network Protection

4.4.1 Distribution line protection scheme

The distribution line is composed of radial and is installed on the concrete pole by 13.8kV three-phase four-wire multiple grounding system. AWG # 2 bare copper conductor is used for distribution line. It has a wire diameter of 33.6 mm² and continuous allowable current is about 130A, so it can supply 3MVA power through this power line.

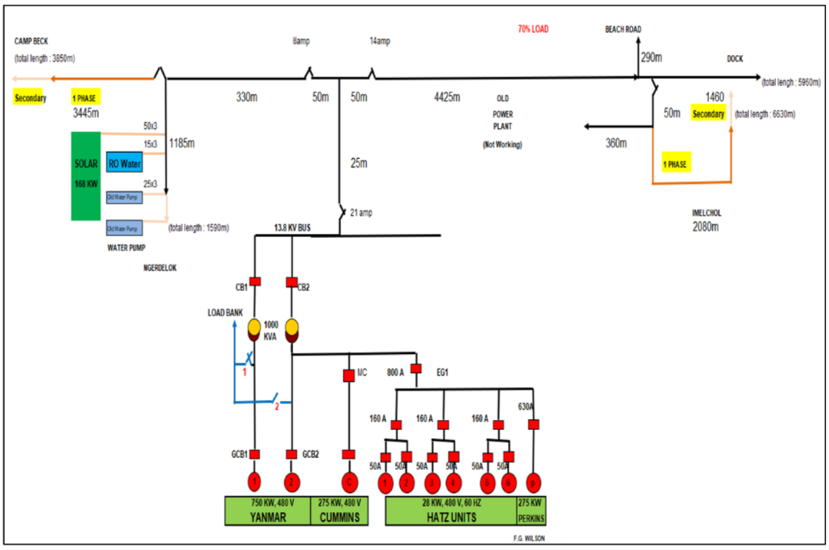


Figure 43. Peleliu power network single line diagram.

The overcurrent relays are installed in the panel of Diesel power plant and these are responsible for the protection of the distribution line fault. There are four COSs (Cut out switch with fuse-link) were installed in the distribution feeder, and they protect the feeder fault in cooperation with the overcurrent relay. The COS is also installed on the primary side of the pole transformer to protect the internal fault of the pole transformer. If a short-circuit fault current is 60 A or higher in the distribution line, the overcurrent relay becomes active and all areas covered by the distribution line may experience power out. But when there is flowing from over the rated current of COS up to 60A as short fault current, fuse-link might be melted down. When the fuse is blown, the power failure time becomes considerably for a long time until fuse is replaced because there is no facility for judging a fault section other than the fuse.

	CT Ratio	**Relay Tap**	**Minimum P.U**	**Remark**
OCR	100/5	3	60A	Min. three phase short fault current: 187A

OCGR	100/5	0.3	6A	Min. one phase earth fault current (30 ohm): 121A
COS on outgoing No. 1 pole	-	-	21A	
COS on No. 1 pole in each branch	-	-	North branch / 14A South branch / 8A	

Table 44. Protection Settings of current network (in 2018).

Figure 44. Over Current Relay for Distribution Feeder.

The below table shows the fault current calculation results. There are four fault types which are three phases short fault current, two phases short fault current, one phase ground fault current (0 ohm) and one phase ground fault current with 30 ohms in each case of diesel power supply only, PV/ESS power supply only and parallel power supply of diesel and PV/ESS to the network. Maximum fault current is the current when the fault occurs at the nearest position of 13.8kV outgoing. On the other hand, minimum fault current is the current when the fault occurs at the end point of three phases or single phase of 13.8kv distribution feeder.

Power Supply	Fault type	17% Penetration Existing network		50% Penetration Upgrade network		75% Penetration Upgrade network		100% Penetration Upgrade network	
		Min(A)	Max(A)	Min(A)	Max(A)	Min(A)	Max(A)	Min(A)	Max(A)
Diesel only	3-phase short circuit	186.75	197.95	185.16	194.74	185.16	194.74		
	2-phase short circuit	121.84	126.55	119.97	123.45	119.97	123.45		
	Phase-to-ground (0 ohm)	153.98	167.39	151.09	162.36	151.09	162.36		
	Phase-to-ground (30 ohm)	121.19	131.05	120.20	128.76	120.20	128.76		
PV/ESS only	3-phase short circuit	49.75	53.36	51.63	53.45	74.24	77.33	120.90	127.63
	2-phase short circuit	18.52	18.59	15.49	15.68	19.87	20.18	27.09	27.64
	Phase-to-ground (0 ohm)	38.77	42.63	35.94	38.72	40.79	43.48	48.60	51.92
	Phase-to-ground (30 ohm)	34.70	38.14	32.65	34.73	36.38	38.75	42.67	45.10
Diesel & PV/ESS parallel	3-phase short circuit			235.12	248.04	256.58	271.70	300.85	321.10
	2-phase short circuit			120.17	124.08	123.23	127.32	128.54	132.92
	Phase-to-ground (0 ohm)			192.29	205.57	197.47	212.75	205.16	221.59
	Phase-to-ground (30 ohm)			141.56	150.42	143.66	154.05	146.95	157.78

Figure 45. Fault current of Peleliu Distribution Network

4.4.2. Operation rating of voltage and frequency

The household voltage of Peleliu Island is 120V, 60Hz. The voltage range is from 105.6V to 132V as shown in the table below, allowing a voltage up to 88%, up to 110%, based on a 120V rated voltage. The frequency holding range is ± 2Hz, allowing 58Hz down to 62Hz and up to 62Hz based on the rated frequency of 60Hz. The table below shows the range and separation time that the distributed power supply should be protected from independent operation when the grid voltage and frequency are exceeded the maintenance range during operation in connection with the distributed power supply.

Category	**Minimum**	**Maximum**	**Maximum Trip Time (cycle)**	
Frequency	58Hz	62Hz	> 62 < 58	0.16
Voltage	105.6V	132V	V < 60 (under 50%) 60 ≤ V ≤ 105.6 (50% ~ 88%) 132 ≤ V ≤ 165 (110% ~ 137%) 165 < V (over 137%)	6 120 120 2

Table 45. Rating of frequency and voltage.

4.4.3 Fault Status and Fault Handling Process

Since the distribution line of Peleliu island is composed of multiple grounding system, short circuit fault and ground fault are simultaneously occurred. A short circuit overcurrent relay (OCR) and a ground fault overcurrent relay (OCGR) are installed to protect the power line in Diesel power plant. OCR or OCGR detects the fault and operates the breaker. Since the peak load to the distribution line is 218kW in 2018, the current flowing in the distribution line is less than 10A.

OCR is set to Tap 3 in the ratio of 100/5, so it operates when a fault current of 60A or more flows. The OCGR is set to Tap 0.5 at 100/5 ratio, and it operates when a ground fault current of 10 A or more flows. If the fault current is large, the protection relay operates, but if the fault current is smaller than relay minimum pick-up current, the cut-out switch (COS) fuse that installed in the distribution line is blown. The fuse rating of the COS that is installed in No. 1 pole on outgoing from power plant is 21A. COS fuse rating of north branch No. 1 pole is 8A.

(a) (b) (c)

Figure 46. COS at (a) Power Plant 1 st pole (b) north branch 1 st pole (c) south branch 1 st pole

Procedures for handling when a fault occurs are described. If a fault occurs in the distribution line and the breaker operates, check whether the fault occurs in which branch line. It is also checked if the North branch line 1 Australian COS and the South branch line 1 Australian COS are fused. If the COS fuse has not been blown, open one of the COSs to see if any breakdown has occurred, then switch on the breaker. If the fault is continuing in a certain branch line, the circuit breaker is tripped while the COS of the branch line is turned on, but the breaker is turned on when the COS is opened. After finding the faulty branch line, the power failure section should be reduced.

In addition to the COS installed on each branch line, one COS is installed in the middle of the line. Therefore, if the COS installed in the middle of the branch line is opened to find the fault occurrence, and the electricity is supplied normally when the COS of the branch line 1 is inputted, it can be seen that the actual fault occurrence period is after the branch COS. After the failure area is reduced, the line is instantaneously inspected, and the electricity is supplied again after checking whether the branches are in contact with each other, whether the transformer is burned down, whether the breaker is damaged or not.

The following table shows the occurrence of power failure in the distribution line for one year, with the most contact with trees and the second with fuse blowing. In case of contact with trees, the average duration of power interruption is about 2 hours. In the case of fuse blowing, the power failure occurs for about 30 minutes. Often, there is a long time of power outage for the removal of tree branches around the wires. Current distribution feeder is completely radial network, so there is not any bypass route to supply the power to the healthy section. In order to reduce the power outage time, a recloser should be installed instead of COS, and a distribution network should be constructed in some sections additionally so as to make loop network.

Date	Times	Reason of Power Outage	Duration
October-17-2017	One	Tree branch took down primary lines	4.5 h
October-17-2017	One	Tree fell on top of primary lines	2.5 h
October-17-2017	One	Fuse link blew out	30 m
October-17-2017	One	Fuse link blew out	30 m
October-17-2017	One	Fuse link blew out	30 m
December-02-2017	One	Unbalance load	2 h
December-07-2017	One	CBS wired HATZ's & Perkins automatic mode	5 h
December-07-2017	One	Testing run Perkins & HATZ	1 h
January-16-2018	One	Main Road to North Dock	6 h
January-21-2018	One	Vegetation Clearance of Primary Lines	8 h

January-23-2018	One	Vegetation Clearance of Primary Lines	8 h
January-25-2018	One	Vegetation Clearance of Primary Lines	8 h
March-09-2018	One	Tree fell and took primary lines down	3 h
June-05-2018	One	Tree branch fell on Primary lines	1 h
September-29-2018	One	Cleared Pine tree from lines	2 h

Table 46. Power outage history of one year.

4.5. Network Design for the Expansion of Renewable Energy

4.5.1 Analysis of power generation and load profile for the past three years

The peak demand profile is analyzed for three years from 2016 to 2018. The peak load, which was 210 kW in 2016, has increased slightly to 215 kW in 2017 and 218 kW in 2018, but the annual growth rate is not large. The three-year data shows that although there are slightly more night peaks than weekly peaks, there is no big difference, and they are rather smooth compared to countries with different load sizes over a day.

Month	**2016**		**2017**		**2018**	
	Day (kW)	**Night (kW)**	**Day (kW)**	**Night (kW)**	**Day (kW)**	**Night (kW)**
One	165	200	176	195	188	205
2	165	200	176	205	175	295
3	182	205	191	200	180	204
4	206	201	195	**215**	204	**218**
5	183	200	195	212	195	214
6	170	188	180	196	183	191
7	**160**	180	180	195	168	192
8	162	182	182	195	203	202

9	184	190	**173**	199	185	194
10	177	189	185	200	**162**	183
11	167	189	195	200	162	183
12	195	**210**	200	200	-	-
Average					**182.27**	**207.36**

Table 47. Peak demand for last three years.

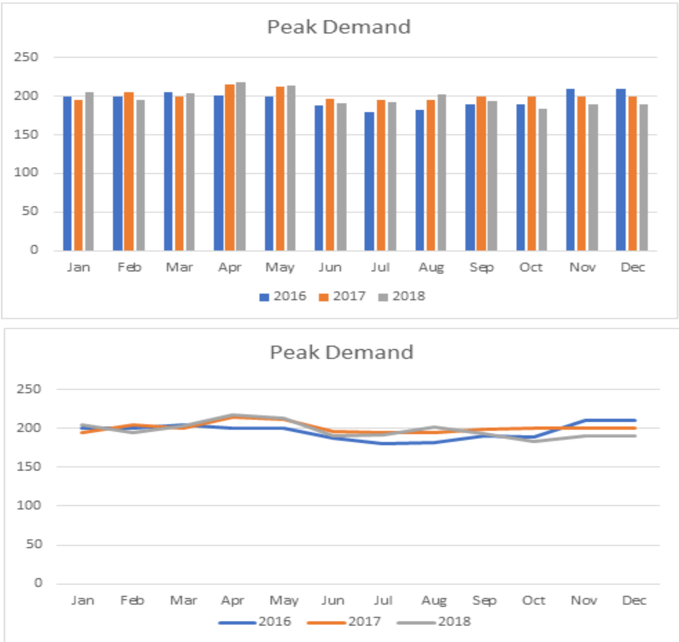
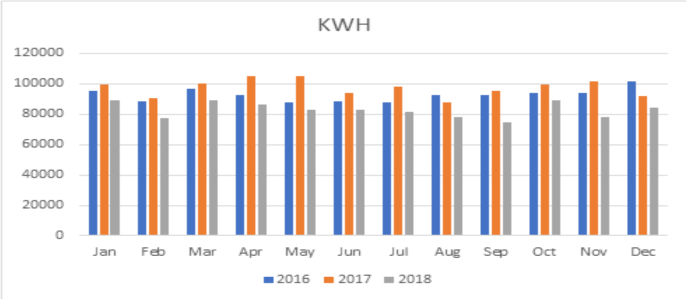


Figure 47. 2016 ~ 2018 Peak Demand Trend.

The power consumption is almost similar from January to December because the temperatures are similar throughout the year. However, the power supply from the diesel power plant does not reflect the solar power generation amount, so it may differ from the actual sales power. Photovoltaic power is supplied directly to distribution lines and is not reflected in the diesel power plant power supply data below.



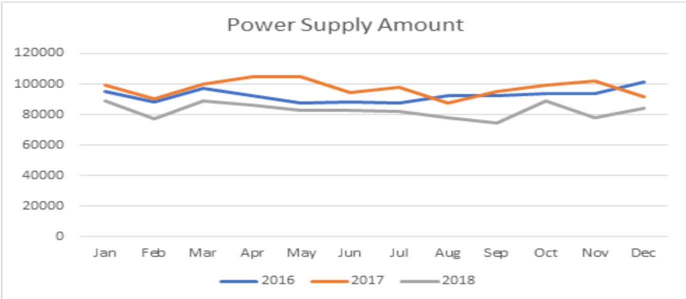


Figure 48. 2016 ~ 2018 Power Supply Trend from Diesel Plant.

4.5.2. Current Network of 2018

The island of Peleliu is mostly populated near the Dock in the north-west of the island, and residents reside only on the western side of the island, so the power line is laid out on one side of the island along the west side road. On the other hand, distribution lines are not installed where people do not live.

Currently there is only one distribution line withdrawn from diesel power plants and it is branching north and south from the first power plant withdrawal number 1. There is a 5.9 km (3-phase) power supply to the Port through the north-west town where many residents live. However, the 2.1km line branching from the 4.4km north line is a single-phase. The southern area has small load, so 1.5km is supplied in three phases from power plant withdrawal to solar power plant and 3.4km branch line from the 330m south line from diesel plant is a single-phase. There are two water pumps installed at near the solar power plant to supply rainwater to the drinking water, and a water pump installed on the way to send the water to the neighboring at high places where the residents reside by pressing the collected water. It is the largest of the load of Peleliu Island to about 64kW. The distribution line network is shown on the map below.

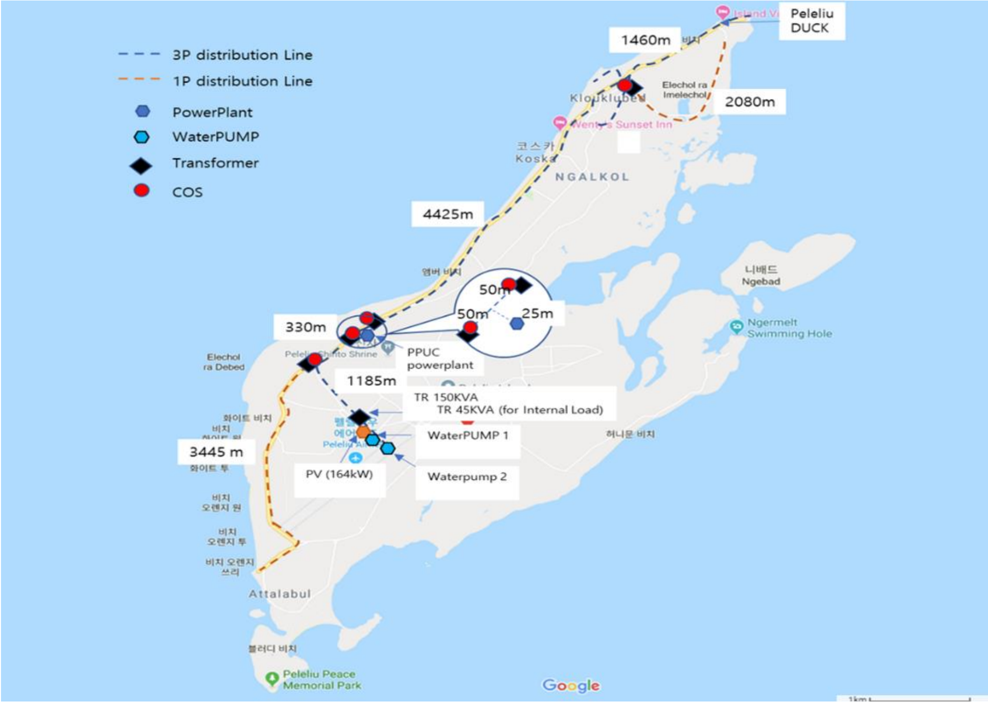


Figure 49. Peleliu Distribution Feeder Route.

The current distribution line is composed of a complete radial structure, so that even if a fault occurs in a section, the entire line is shut down and the power failure continues until the fault is repaired. The lines drawn from the diesel inverters are diverged in a direction completely different from the power plant in the south and the north, and they are constructed with power lines that are not connected to each other at any point, minimizing the construction investment cost.

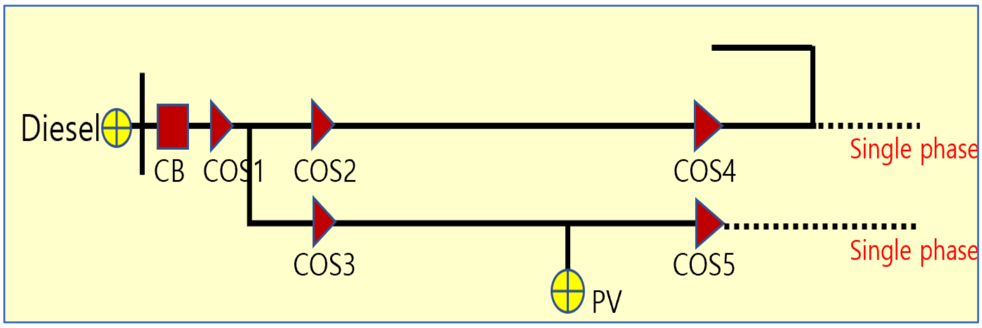


Figure 50. 2018 Distribution Network Configuration.

In order to increase the reliability of the power supply, it is desirable to install a recloser instead of the COS in the middle of the line. To connect the distribution lines to the south and the distribution lines to the north, we need to construct a distribution line of a considerable size, which suggests a simpler method than this. The additional branch line passing through REC4 as shown in the figure below is to be constructed so that an open-loop configuration is made through the switch (SEC2) inside the line by dividing the distribution line branched to the north where the load is concentrated. The normally open point (SEC2) is a normally open switch, and it is operated in such a way that the switch is turned on when necessary and the electricity is supplied to other sections.

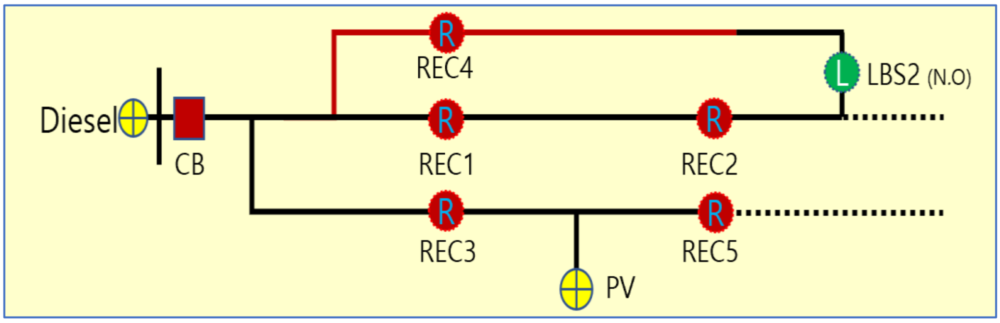


Figure 51. Distribution Network Configuration with reliability upgrade.

4.5.3. Distribution Network from 2025 to 2030

The distribution network diagram of the distribution lines after 2025 is shown in the figure below, when the power of diesel generators is decreased and the proportion of renewable energy source generation exceeds 50%. Since PV and ESS supply the power mainly in the daytime, diesel generator need not to supply the power at full days. Two distribution lines need to be drawn at the PV / ESS power generation complex and the circuit breaker of diesel power plant will be normally turned off in the daytime.

Considering of small peak load, it is enough to have one power line in Peleliu. However, if there is a fault in the power distribution line due to bad weather or the repair of the power breaker, at least two power lines should be backed up each other to make open loop configuration. Each distribution line should have an internal loop configuration capable of flexibly switching some section loads through a switch that is open normally so that electricity can be supplied to other passages when a fault occurs in a specific section. According to the load amount and PV output, CB1 and CB2 can be closed or opened. If CB1, CB2, CB3. CB4 close at the same time, two power sources supply the power to the customers in parallel. If there is a burden of budget, one or two reclosers of each feeder might be accepted. As a sample, REC2 and REC5 can be cancelled to reduce the expense in the below configuration.

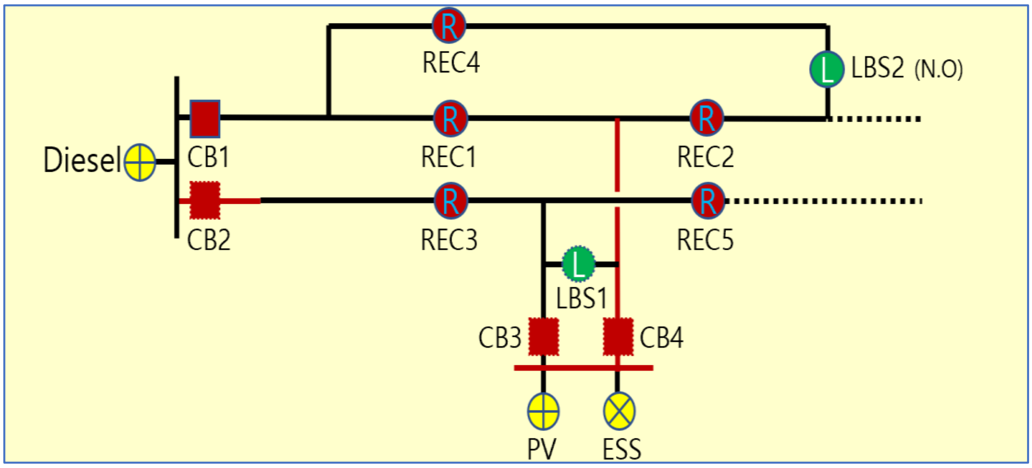


Figure 52. 50% to 100% DG Penetration Level Distribution Network.

4.5.4. Installation place of PV and ESS

In the future, in order to increase the renewable energy ratio to 50% or more, much more solar power generation facilities and energy storage system (ESS) should be installed. The Palauan government says it does not allow other places in Peleliu Island because it does not want to undermine nature and strongly promotes environmental protection. Therefore, it is inevitable to install solar power facilities and energy storage systems by expanding the existing PV power site near. In the view of monitoring and maintenance, it is better to construct ESS facilities near diesel power plant where operator works 24 hours.

Even if the peak load increases by a certain rate every year until 2030, it is only 335kW in maximum and the length of the distribution line is also short, so that the problem of over current in any section, voltage drop and fault current does not arise in any case whether ESS is installed in PV plant near or diesel power plant near.

Figure 53. Placement of PV and ESS Plant.

4.6. Power System Stability Analysis

This chapter presents power system analysis for microgrid system in Peleliu Island. Three major analysis methods are applied here: load flow analysis, fault analysis, and stability analysis. In the load flow analysis, the parameters including voltage, current, and power of generators, transformers, distribution lines are evaluated under different loading conditions. The system stability under different types of fault is verified by the fault analysis. Finally, the transient responses of the system to various switching events such as significant load variations, generator connection and disconnection, and fault events are evaluated in the transient analysis. The main objective of the power system analysis are as follows:

- We can verify that the power system configuration is properly designed through load flow analysis. We can check whether the power flow and line current exceed the rated value of the transformer, distribution line, etc., whether the distribution voltage exceeds the normal range, and the loss of the entire distribution line. In particular, considering the future load increase and the installation capacity of new generators and renewable energy sources, it is examined whether there is a problem in the system design. Therefore, we can use the result of load flow analysis to make a system upgrade plan to reinforce the weakest point in the grid.
- Power system faults without proper protection system can lead to severe power interruptions and blackouts in the grid. Fault analysis calculates the line faulted current for three-phase fault, line-to-line fault, single-phase ground fault and high-impedance

fault. This makes it possible to design protection system as a basic data and to improve the protection system considering future power system configurations and load increases.

- Because the power grid consists of various dynamic equipment such as diesel generators, power converters, renewable energy resources and so on, the analysis on their dynamic response is a complicated work. Transient stability analysis simulates various serious disturbances (load fluctuation, generator dropout, line failure, etc.) to analyze the response dynamics of the overall system. In particular, the main purpose of stability analysis is to check whether fluctuations occurring in voltage and frequency can be securely recovered within the standard required by the system operator within a certain time. Through this, it is confirmed that the system can be restored to a steady state with respect to various disturbances.

Category	**Results**	**Analysis**
Load flow analysis	- Steady state power flow, line current, bus voltages, power factor, line loss	- Check power flow paths in the overall grid - Compare line currents to rated values of transformers and distribution lines - Check voltage regulation and line losses
Fault analysis	- Three-phase fault, Line-to-line fault, Sing-line-to-ground fault, High-impedance fault	- Calculate fault currents according to types of faults and fault location - Design protection system
Stability analysis	- Transient response in power balance, voltage and system frequency variation	- Check dynamic response of dynamic models of generators, power inverters, motors, and their controllers etc. - Check if voltage/frequency variation meet the system's standards - Check if power balance can be securely maintained after severe disturbance in the grid - Design controllers of power system equipment to improve system stability

Table 48. Power system analysis functions and their meanings

For power system analysis, we used PowerFactory software developed by DIgSILENT, which can provide various analysis functions such as load flow analysis, fault analysis and stability analysis.

The distribution line of Peleliu uses AWG2 conductor. Table 49 lists the specifications of two conductor types, which are AWG2 and WO-038. Because we do not have the information about the reactance of AWG2, we used the reactance of WO-038 from Korea Power System Data, which is the closest to AWG2 modeling. The specifications of transformers in terms of ratings, voltages, connection type and % impedance are tabulated in Table 50.

Type	**Cross section (mm^2)**	**Ampacity (A)**	**Thermal limit (^oC)**	**Resistance (Ω/km)**	**Reactance (Ω/km)**
AWG2	33.6	130	90	0.5127	NA
WO-038	38	NA	220	0.484	0.468

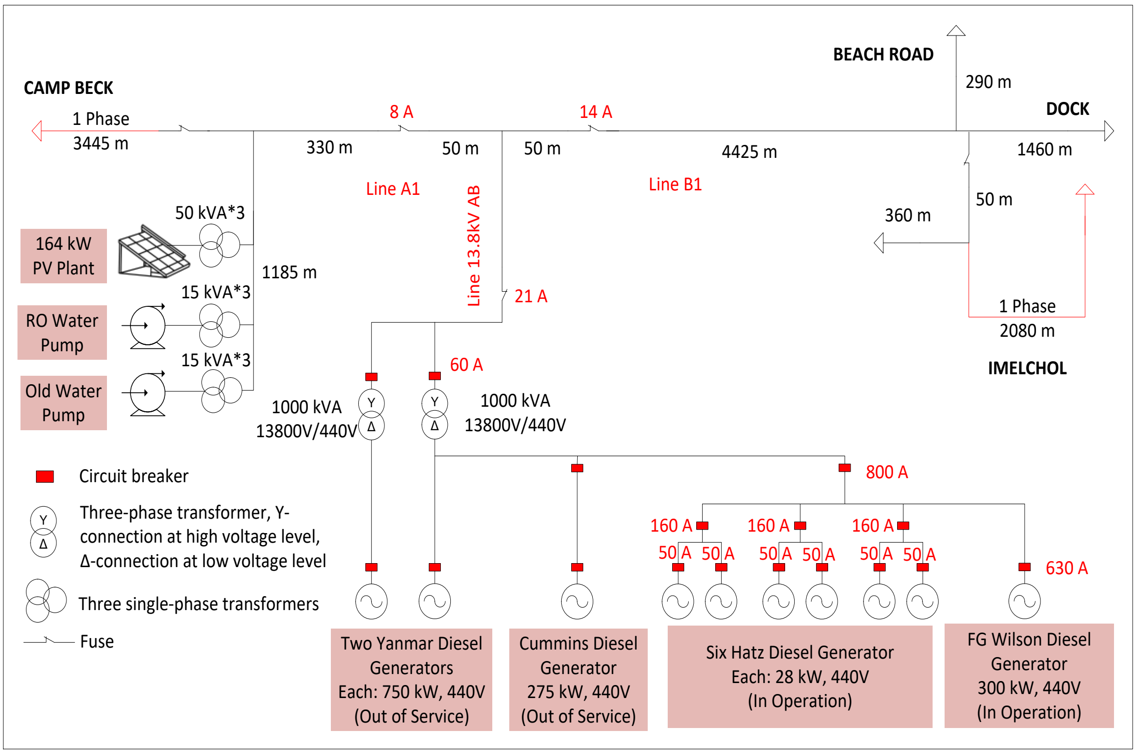
Table 49. Specifications of AWG2 and WO-038 conductors

Rating (kVA)	**Voltages (line-to-line) (V)**	**% Impedance (%)**	**Connection type**
1,000	13,800/440	5.75	Y-Δ
500	13,800/480	1.3	Y-Δ

Table 50. Specifications of transformers

The case of 17% REP is the existing diesel-PV hybrid system of Peleliu Island. The entire electricity demand of Peleliu Island is supplied by six HATZ diesel generators (each of 28 kW), one FG Wilson diesel generator of 300 kW, and a PV plant of 164 kW.

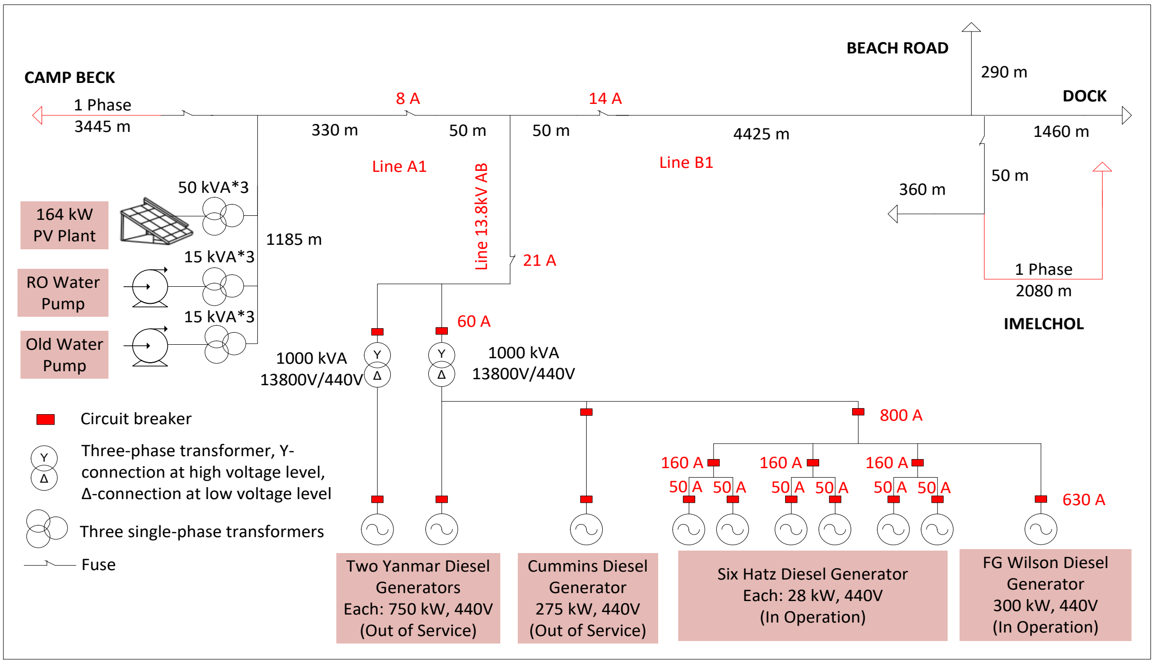
The single-line diagram of the existing Peleliu system is shown in Figure 54. The integrated operation of PV and diesel generators are controlled by the SMA Fuel Save Controller, and diesel generators are controlled by the Woodward EasyGen3000 controller as discussed in previous chapter.



Sources: PPUC

Figure 54. The single-line diagram of the existing diesel-PV hybrid power system.

The existing Peleliu power system is modeled in PowerFactory as in Figure 56.



Sources: PPUC

Figure 55.The single-line diagram of the existing diesel-PV hybrid power system

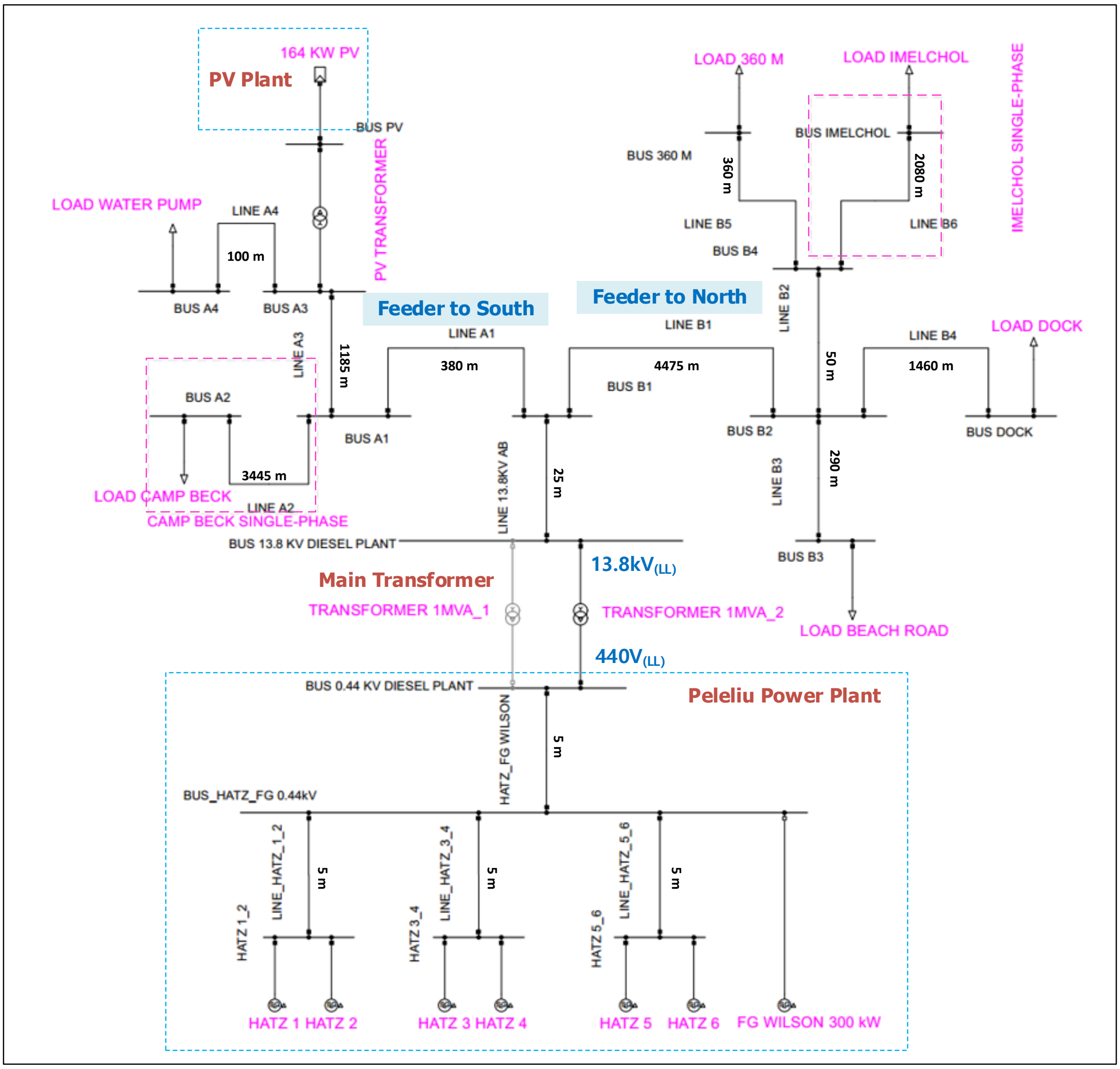


Figure 56. Modeling of Peleliu power system in Power Factory.

The analysis is performed for various configurations with different levels of REP, which includes 17% (the existing system), 50%, 75%, and 100% of REP. The energy mix of each REP level is the same as that obtained in the previous section

To increase the penetration of renewable energy in Peleliu Island, more PV arrays need to be installed and ESS must be integrated. There are two system configurations considered in this report.

- **<u>Configuration1(current configuration)</u>**: The current distribution system configuration in Peleliu
- **<u>Configuration2(upgraded configuration)</u>**: in order to improve the system reliability, configuration 2 is proposed, which is the upgraded system as shown in Figure 57. In

this upgraded configuration, a parallel line is added for the main distribution line to the North side (Load Imelchol) of the island. PV and ESS installed in the South side (near water pumps) can supply power directly to the main distribution line to the North. In addition, reclosers and sectionalizers operate instead of fuses to reduce the outage time.

The power system analysis is conducted for both two configurations. The system modeling of configuration 1 and configuration 2 in PowerFactory is presented in Figure 56 and Figure 59, respectively.

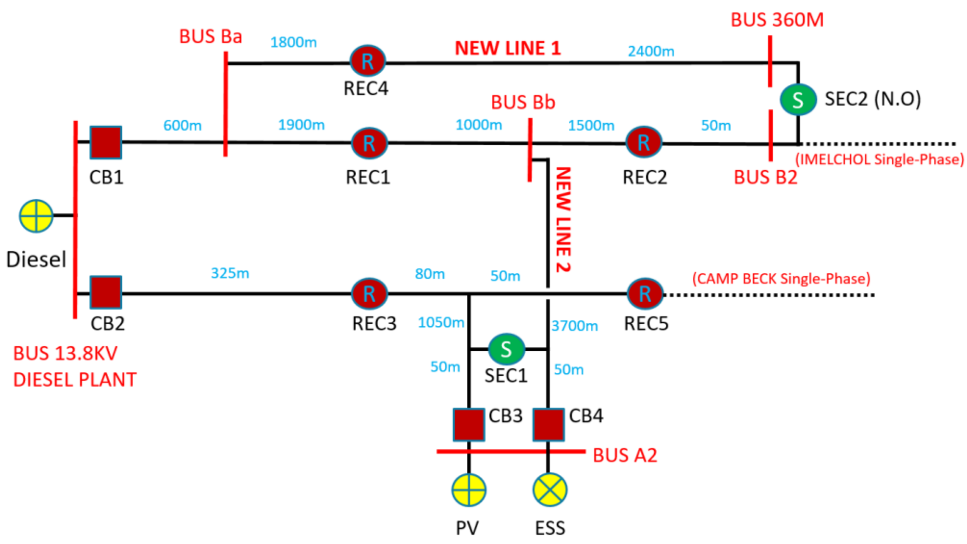


Figure 57. Upgraded power system for Peleliu Island (configuration 2)

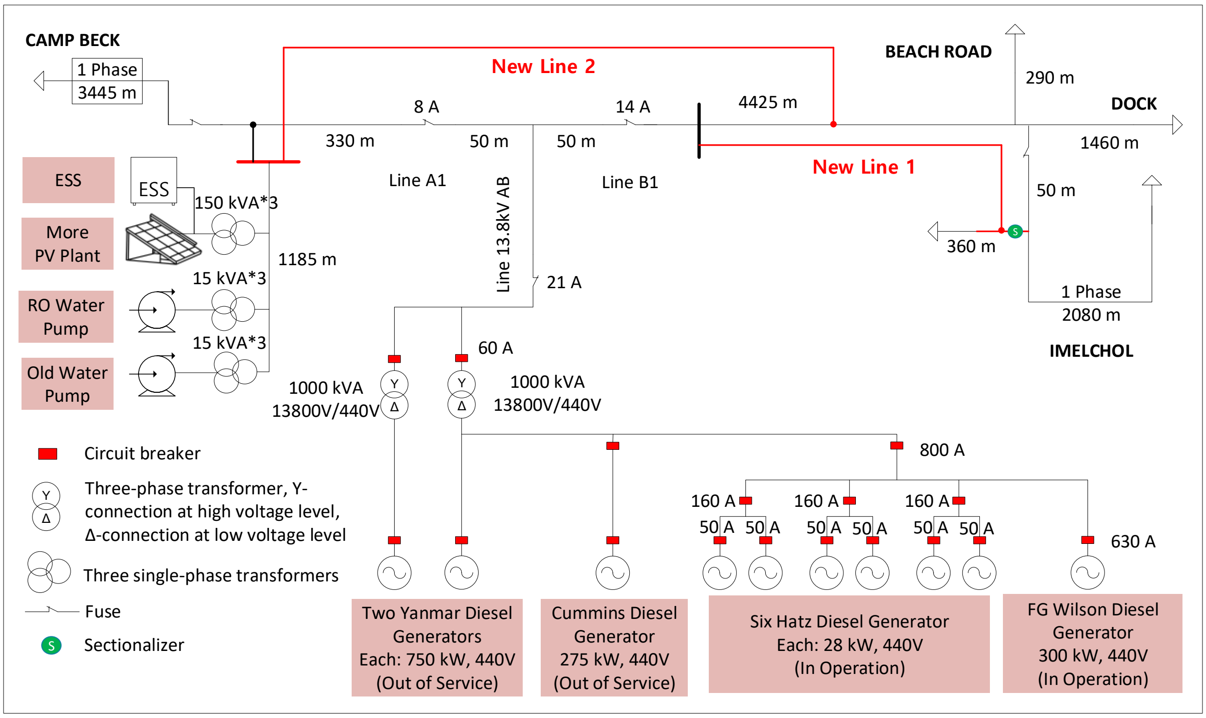


Figure 58. The single-line diagram of upgraded power system for Peleliu Island (configuration 2)

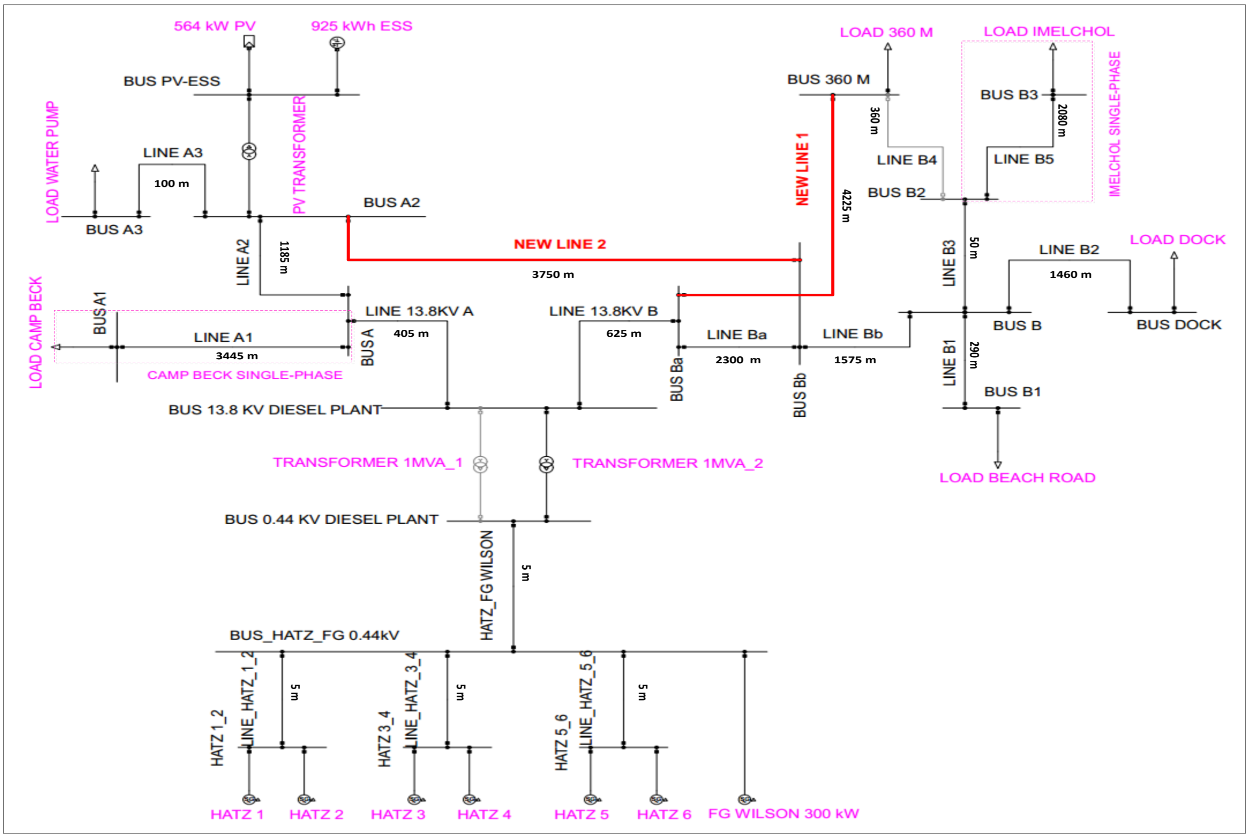


Figure 59. Modeling of Peleliu power system for configuration 2 in PowerFactory

4.6.1. Load Flow Analysis

Load flow analysis is the most important and essential method for investigating problems in power system operation and planning. Based on the specified generation status and transmission network structure, load flow analysis resolves normal operation with bus voltages and branch power flows in the power system.

In this report, the Peleliu microgrid system is simulated for various loading conditions in the total load demand, PV output power, and the number of operating diesel generators. The purposes of load flow analysis are to check

- Power balance between demand and generation capacity (power balance stability)
- Power losses of the whole system
- Transformer capacity during maximum loading condition
- Distribution line ampacity during maximum loading condition
- Ampacity of fuses and circuit breakers
- Voltage level at the end of distribution lines (undervoltage or overvoltage problems)

We run 4 cases according to REP levels (17%, 50%, 75% and 100%) with multiple scenarios in each case. The detailed scenarios are different for four cases because the operating conditions are all different each other but the main idea is to check the normal steady-state operations and any violations from the normal range.

Overall results of load flow analyses for all cases and configurations are summarized. REP 17% is the current state of Peleliu island, which employs only PV and diesel gensets. For higher REP such as 50%, 75% and 100%, more new PV panels and ESS should be installed. We chose the location of the new PV and ESS at the same bus at the low-voltage side of three-phase PV transformer. Because of the higher PV penetration, a new transformer for the PV plant with higher capacity must be installed. From the result of load flow analysis, we can suggest that a 500kVA transformer should be installed for the PV-ESS plant. In addition, we proposed a new upgraded configuration for the Peleliu distribution system.

For the load flow study, following conditions are considered

- A 500kVA transformer is installed for the PV-ESS plant.
- The new PV and ESS will be installed at the same bus with the existing 164kW PV.

Configurations are defined as follows:

- Configuration 1: the current configuration of Peleliu distribution system (Figure 54)
- Configuration 2: the upgraded configuration for additional distribution lines (Figure 58)

Table 51 and Table 52 summarize the load flow analysis for configurations 1 and 2, respectively. Both configurations are stable under minimum and maximum loading conditions. There are no undervoltage and overvoltage problems.

In all configurations, the maximum loaded capacity of the 1,000kVA main transformer is less than 50% of its capacity. For the 50%, 75%, and 100% REP cases, it is suggested that a 500kVA transformer should be installed for the PV-ESS plant. The maximum loaded capacity of this 500kVA transformer in both configurations is smaller than 75% of its rated capacity.

For configuration 1, the fuse for Line A must be upgraded because the maximum current flowing on this line is 11.294 A, which is greater than the rated current of the existing fuse of 8 A. The voltage profiles of the two configurations under different loading conditions are approximately the same. However, configuration 2 has some advantages. Firstly, the outage time will be reduced with the operation of reclosers and sectionalizers.

Secondly as analyzed, the power from diesel power plant is equally distributed on Line 13.8kV A and Line 13.8kV B, which distribute the power to the two sides of Peleliu Island. Currently the load of the north and south sides is not equal, with 70% of the load is on the north side. With configuration 2, circuit breakers with the same rated capacity can be used for Line 13.8kV A and Line 13.8kV B.

Scenario	**Voltage (p.u.)**		**Maximum current (A)**			**Maximum loaded capacity (kVA)**	
	Max.	**Min.**	**Line AB**	**Line A**	**Line B**	**1000kVA Transformer**	**PV plant Transformer**
17%	1.012	0.983	17.211 (13.24%)	6.549 (5.04%)	12.711 (9.78%)	415.04 (41.5%)	150.00 (100%)
50%	1.020	0.983	17.211 (13.24%)	11.280 (8.68%)	12.849 (9.88%)	415.04 (41.5%)	355.33 (71.07%)
75%	1.030	0.983	17.211 (13.24%)	11.286 (8.68%)	12.899 (9.92%)	415.04 (41.5%)	355.86 (71.17%)
100%	1.034	0.983	17.211 (13.24%)	11.294 (8.69%)	12.914 (9.93%)	415.04 (41.5%)	356.22 (71.24%)

*The transformer of PV plant is 150kVA in the 17% REP case, and is 500kVA in the other cases.

Table 51. Summary of load flow analysis for configuration 1 (the existing configuration)

Scenario	Voltage (p.u.)		Maximum current (A)				Maximum loaded capacity (kVA)	
	Max.	Min.	Line A	Line B	Line Bb	New Line 2	1000kVA Transformer	500kVA Transformer
50%	1.018	0.987	8.280 (6.37%)	8.345 (6.42%)	9.687 (7.45%)	11.448 (8.81%)	410.75 (41.08%)	341.69 (68.34%)
75%	1.027	0.987	8.280 (6.37%)	8.345 (6.42%)	9.487 (7.30%)	11.520 (8.86%)	410.75 (41.08%)	342.24 (68.45%)
100%	1.030	0.987	8.280 (6.37%)	8.345 (6.42%)	9.519 (7.32%)	11.581 (8.91%)	410.75 (41.08%)	343.05 (68.61%)

Table 52. Summary of load flow analysis for configuration 2 (the upgraded configuration)

4.6.2. Fault Current Analysis

Fault current calculation is generally performed for selecting protective equipment. If a short-circuit fault occurs in the power system, a fault current as shown in Figure 60 is generated. The first time an accident occurs, the current suddenly increases. This occurs because the impedance of the system is reduced as the accident occurs, but the output of the generator cannot change suddenly.

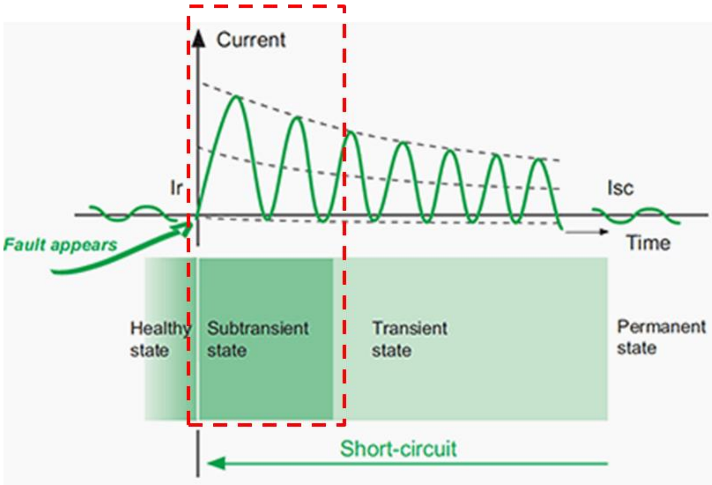


Figure 60. Fault current of three-phase short-circuit fault

The effective value (rms) of the fault current is obtained as $I_{f,rms} = E_{rms}/Z_{eq}$ when E_{rms} is the rated voltage of the sources and the equivalent impedance of this system is Z_{eq} from the source to the faulted location. As shown in the Figure 60, the magnitude of the current varies with time, and the changing value depends on the grid time constant X / R ratio. The fault current value required to select the breaker capacity is the fault current value for 1/2 cycle (initial symmetrical short-circuit current) and 3 ~ 5 cycle (symmetrical short-circuit breaking current). The calculation method of the fault current can be performed in PowerFactory, the power system analysis program used in this report.

Symmetrical and asymmetrical short-circuit currents distinguish symmetric and asymmetric symmetry around the X-axis of an AC waveform. When the current waveform is symmetrical with respect to the X-axis, it is called a symmetrical current. When the current waveform is asymmetrical with respect to the X-axis, it is called asymmetry. In general, the short-circuit current is asymmetrical within the initial few cycles after a short-circuit fault occurs and gradually changes symmetrically.

PowerFactory provides short-circuit calculations for single and multiple faults. As short-circuit calculations are needed for a variety of purposes, the short-circuit calculation in PowerFactory supports different representations and calculation methods based on a range of international standards, as well as the superposition method (also known as the Complete Method).

- Support of IEC 60909 (including 2016 edition), IEEE 141/ANSI C37, VDE 0102/0103, G74 and IEC 61363 norms and methods
- Complete superposition method, including dynamic voltage support of generators connected via power electronics

Category	**Features**
Initial symmetrical short-circuit current	- The first 1/2 cycle current - Defined as momentary current according to ANSI/IEEE - Used for instantaneous current setting for relay
Symmetrical short-circuit breaking current	- Short-circuit fault current when breaker contact is opened (at 3~5 cycles after the fault) - Defined as Interrupting Current according to ANSI/IEEE - Used for selection of high-voltage breakers
Steady-state short-circuit current	- Short-circuit fault current at the time of protection relay operation (e.g. 30 cycles) - Used for time-delayed setting for relay

Table 53. Classification of short-circuit current according to time scale

In this section, various fault calculations are done at different locations in order to check the rated current of protective devices such as circuit breakers, fuses, and relays. Short circuit tests are simulated at various points. The points where short circuit tests have been performed as follows:

- 13.8kV Diesel Plant Bus (3-Phase): the high-voltage side of the main transformer
- 13.8kV PV Plant Bus (3-Phase): the high-voltage side of the PV transformer
- 13.8 kV Load Bus (3-Phase): the farthest end of the 3-phase lines of the Northern area
- IMELCHOL Bus (1-Phase): the farthest end of the single-phase line of the Northern area
- CAMP BECK Bus (1-Phase): the farthest end of the single-phase line of the Southern area

We performed four types of short-circuit tests and measured the short-circuit currents accordingly. We have 60A OCR (over-current relay) and 10A OCGR (over-current ground relay) at the main step-up transformer side. Short-circuit analysis determines whether the mentioned protective devices are feasible or not if short circuit event happens at any described point. Short-circuit tests are listed as follows:

- Three-phase short-circuit
- Two-phase line-to-line short-circuit
- Single-phase-to-ground short circuit (Fault resistance: 0 ohm)
- Single-phase-to-ground short circuit (Fault resistance: 30 ohm)

To calculate the short-circuit currents from synchronous diesel generators, we obtained the information about the subtransient (Xd'') reactance and stator resistance (Rstr) of Hatz and FG Wilson diesel gensets from manufacturer's manual as shown in Figure 61.

- For FG Wilson: Xd'' = 0.096 p.u. and Rstr = 0.004 p.u.
- For Hatz gensets: Xd'' = 0.08 p.u. and Rstr = 0.004 p.u.

Potenza resa Rating power [kVA]		Reattanze e costanti di tempo (230/400V 50Hz) Reactances and time constants (230/400V 50Hz)							
50Hz	60Hz	ρcc	X_d	X'_d	X''_d	X_q	T'_{do} [ms]	T'_d [ms]	T''_d [ms]
20	24	0.57	242%	19%	9%	133%	103	7	5
25	30	0.57	240%	20%	9%	134%	101	8	5
30	36	0.58	243%	19%	8%	135%	125	10	5
35	42	0.58	240%	18%	7%	133%	147	11	6
42	50	0.60	253%	20%	8%	141%	180	14	8
50	60	0.62	255%	20%	7%	146%	188	14	9
60	72	0.63	260%	21%	7%	148%	195	15	9

From catalogue of Hatz genset

Alternator Performance Data:	60 Hz		
Data Item	480/277V 240/139V	380/220V	440/254V 220/127V
Motor Starting Capability* kVA	683	457	589
Short Circuit Capacity** %	300	300	300
Reactances: Per Unit			
Xd	2.962	4.201	3.525
X'd	0.136	0.192	0.161
X"d	0.081	0.115	0.096

From datasheet of FG Wilson P375-3

Figure 61. Fault characteristics of diesel gensets of Peleliu Island

Other than diesel gensets, the fault contribution from inverter-interfaced energy resources such as PV panels and ESS can be calculated from the maximum fault current characteristics. Normally, the maximum sub-transient fault current of the inverters is 1.2~2.0 times larger than the rated current.

Since the Peleliu microgrid employs the inverters and controllers made by SMA, we use the maximum current of SMA inverter (Imax) obtained from manufacturer's resource as follows and the fault current will be 1.4 times of Imax.

- PV Inverter (SMA SUNNY TRIPOWER 20000TL-US): $I_{max} = 24A$
- ESS Inverter (SMA SUNNY TRIPOWER STORAGE 60): $I_{max} = 109A$

Technical data	Sunny Tripower 12000TL-US	Sunny Tripower 15000TL-US	Sunny Tripower 20000TL-US	Sunny Tripower 24000TL-US	Sunny Tripower 30000TL-US
Output (AC)					
AC nominal power	12000 W	15000 W	20000 W	24000 W	30000 W
Max. AC apparent power	12000 VA	15000 VA	20000 VA	24000 VA	30000 VA
Output phases / line connections	3 / 3-N-PE				3 / 3-N-PE, 3-PE
Nominal AC voltage	480 / 277 V WYE				480 / 277 V WYE, 480 V Delta
AC voltage range	244 V...305 V				
Rated AC grid frequency	60 Hz				
AC grid frequency / range	50 Hz, 60 Hz / -6 Hz...+5 Hz				
Max. output current	14.4 A	18 A	24 A	29 A	36.2 A
Power factor at rated power / adjustable displacement	1 / 0.0 leading...0.0 lagging				
Harmonics	< 3%				

i_p	I_k''	I_k
up to 5 x i_{max}	up to 1.4 x I_{max}	1.0 x I_{max}

The maximum sub-transient fault current of SMA inverter:

$I_{fault} \approx 1.4 \times I_{max}$

<SUNNY TRIPOWER 12000TL-US / 15000TL-US / 20000TL-US / 24000TL-US / 30000TL-US Data sheet>

Figure 62. Fault current contribution for SMA PV inverter (Sunny Tripower 20000TL-US)

Then, we can roughly estimate the three-phase fault current (I_{fault}) as follows where $V_{nominal}$ is the nominal voltage; Z_{gen}, Z_{line}, and Z_{fault} are the equivalent subtransient impedance of diesel genset, the line impedance from the generator to the fault location, and the fault impedance, respectively. If there are multiple generators, we can apply superposition theorem to approximately calculate the total fault current.

$$I_{fault} \approx \frac{V_{nominal}}{Z_{gen} + Z_{line} + Z_{fault}}$$

In addition, impedances of the system along with the fault location and distances of lines in order to have intuition about the fault current values are shown in Figure 63.

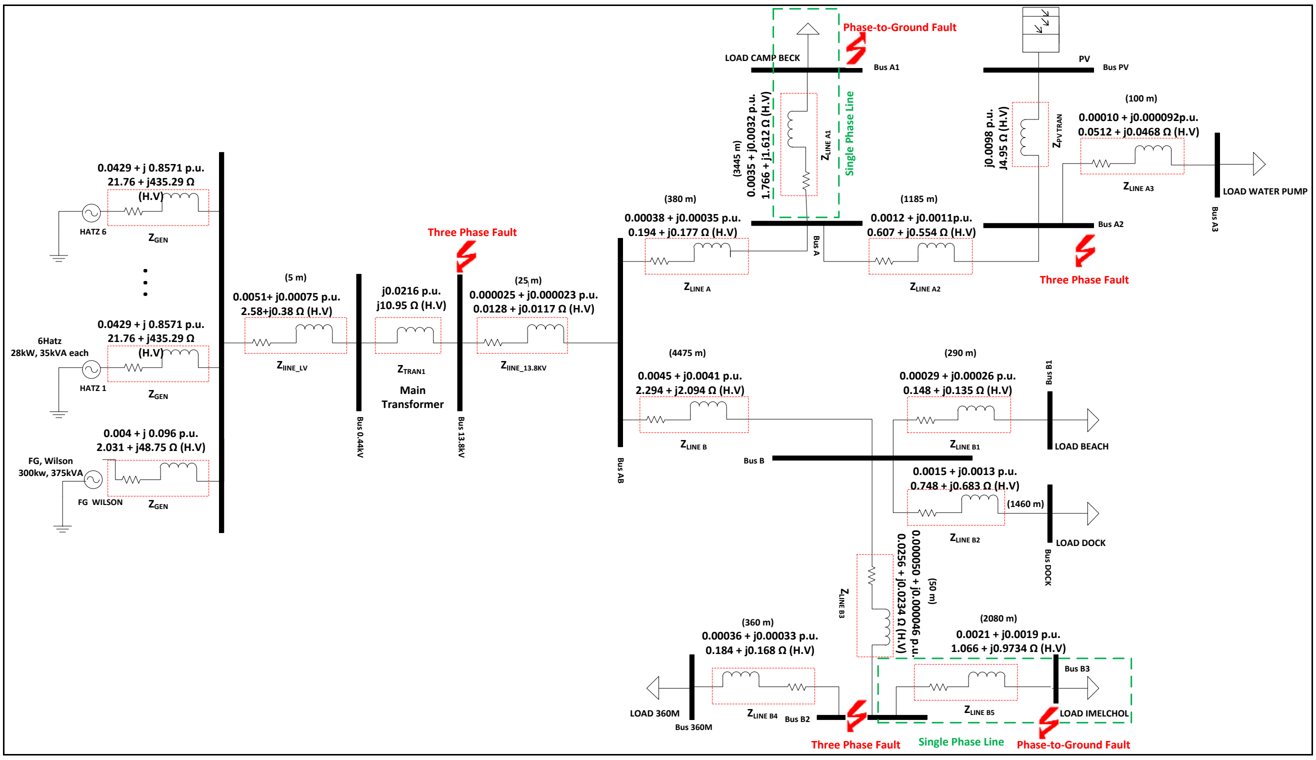


Figure 63. Fault locations and fault impedance diagram of the whole power system

Table below summarizes the minimum and maximum values of short-circuit current for all four REP penetration levels 17%, 50%, 75% and 100%. For scenario 1, it shows that the fault current values provided by diesel gensets are big enough for the OCR and OCGR relay settings (OCR 60A and OCGR 10A) at the main step-up transformer. For scenario 2, the fault current provided by PV and ESS inverters are smaller than that of diesel generators. Basically, inverters have internal protection system so that they can protect themselves. However, for more safe operation, relevant protective system for PV inverters and ESS should be coordinated to other protective devices in the grid accordingly.

No.	**Short Circuit Type**	**17%**		**50%**		**75%**		**100%**	
		Config. 1 (existing)		**Config. 2 (upgraded)**		**Config. 2 (upgraded)**		**Config. 2 (upgraded)**	
		Min(A)	**Max(A)**	**Min(A)**	**Max(A)**	**Min(A)**	**Max(A)**	**Min(A)**	**Max(A)**
1	3-phase short circuit	186.75	197.95	185.16	194.74	185.16	194.74	185.16	194.74
	2-phase short circuit	121.84	126.55	119.97	123.45	119.97	123.45	119.97	123.45
	Phase-to-ground (0 ohm)	153.98	167.39	151.09	162.36	151.09	162.36	151.09	162.36
	Phase-to-ground (30 ohm)	121.19	131.05	120.20	128.76	120.20	128.76	120.20	128.76
2	3-phase short circuit	49.75	53.36	51.63	53.45	74.24	77.33	120.90	127.63

	2-phase short circuit	18.52	18.59	15.49	15.68	19.87	20.18	27.09	27.64
	Phase-to-ground (0 ohm)	38.77	42.63	35.94	38.72	40.79	43.48	48.60	51.92
	Phase-to-ground 30 ohm)	34.70	38.14	32.65	34.73	36.38	38.75	42.67	45.10
3	3-phase short circuit	231.09	248.61	235.12	248.04	256.58	271.70	300.85	321.10
	2-phase short circuit	122.37	127.89	120.17	124.08	123.23	127.32	128.54	132.92
	Phase-to-ground (0 ohm)	194.58	213.29	192.29	205.57	197.47	212.75	205.16	221.59
	Phase-to-ground (30 ohm)	141.51	154.33	141.56	150.42	143.66	154.05	146.95	157.78

Table 54. Summary Table for Fault Analysis

4.6.3. Stability Analysis

A microgrid operating in equilibrium is considered steady-state values satisfying operational constraints, such as acceptable ranges of currents, voltages, and frequency. Such a microgrid is stable if, after being subjected to a disturbance, all state variables recover to steady-state values which satisfy operational constraints, and without the occurrence of involuntary load shedding. In this context, disturbances represent any exogenous inputs, and may correspond to load changes, component failures, or operational mode/set-point adjustments. If the disturbances are considered small, such as minor load fluctuations, it is referred as small-disturbance stability. Otherwise, the system would be called large-disturbance stable with large disturbances such as component failures, transition between grid-connected and islanded modes of operation.

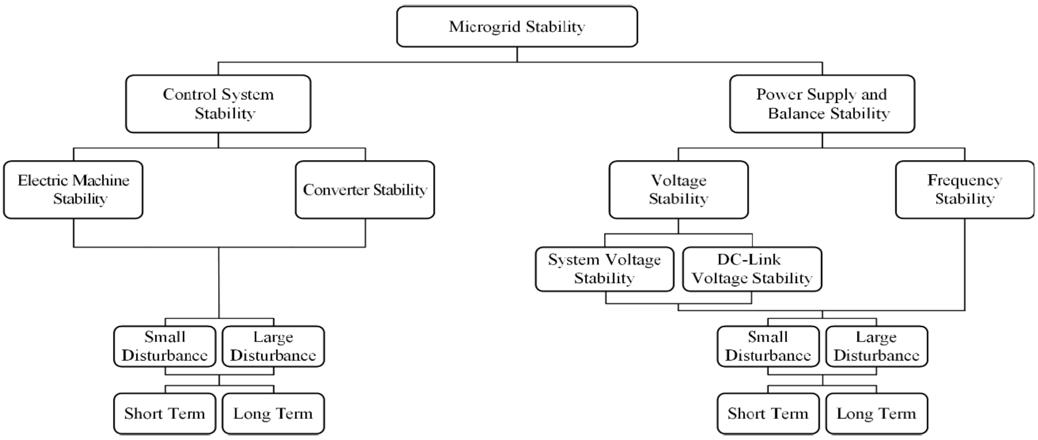


Figure 64. Classification of stability in microgrids
(IEEE Technical report PES-TR66: Microgrid stability definitions, analysis, and modeling)

Frequency regulation is a major concern in islanded microgrids, due to their low system inertia and high share of intermittent RES. Frequency instability can be triggered for a variety of reasons in microgrids. For example, a large load increase accompanied by inadequate system response can result in a fast decay of frequency, leading to a system blackout triggered by the protection scheme. Poor coordination of multiple frequency controllers and power sharing among DERs may trigger small-perturbation stability issues resulting in undamped frequency oscillations in the span of a few seconds to a few minutes. In addition, insufficient generation reserve can also lead to the steady-state frequency being outside acceptable operating ranges, activating under-frequency load tripping relays.

In microgrids, the feeders are relatively short, resulting in relatively small voltage drops between the sending and receiving ends of the feeders. The limits of DERs and the sensitivity of load power consumption to supplied voltage are critical factors in voltage instability. Depending on the system response and load characteristics, a voltage instability may occur following a large disturbance, such as sudden change in the demand and/or output of RES, or a generator outage.

Category	**Control System Stability**		**Power Supply and Balance Stability**	
Subcategory	**Electric Machine Stability**	**Converter Stability**	**Voltage Stability**	**Frequency Stability**
Root Cause	- Poor controller tuning	- Poor controller tuning - PLL bandwidth - PLL failure - Harmonic instability	- DERs power limits - Inadequate reactive power supply - Poor reactive power sharing - Load voltage sensitivities - DC link capacitor	- DERs active power limits - Inadequate active power supply - Poor active power sharing.
Manifestation	- Undamped oscillations - Aperiodic voltage and/or frequency increase/decrease	- Undamped oscillations - Low steady-state voltages - High frequency oscillations	- Low steady-state voltages - Large power swings - High dc-link voltage ripples	- High rate of change of frequency - Low steady-state frequency - Large power and frequency swings

Table 55 Characteristics of various types of stability issues in microgrids (IEEE Technical report PES-TR66)

The operation of the microgrid should always be operated in a normal state but disturbances such as unexpected generator trip, abrupt load change, and ground fault will occur. When a disturbance occurs, each power device has dynamic characteristics, resulting in electromechanical fluctuations. It is the purpose of the transient stability analysis to check the degree of electromechanical fluctuation and to check whether the degree falls within the specified limits and whether stable operation is possible after disturbance. There are several reasons why transients occur in the system, as follows:

- Instantaneous output changing, starting and stopping in power generation

- Connection/Disconnection of renewable energy resources
- Sudden changes in load demand
- Short-circuit faults in the distribution lines

These disturbances limit the permissible voltage and frequency in transient states because they can cause problems such as power failure, load shedding, low voltage, flicker, and equipment damage in all systems. In this study, it is necessary to comply with the regulation of PPUC (Palau Public Utilities Corporation) as listed in table below. In this analysis, we examine the power, voltage, and frequency responses to different disturbances, such as load variations, short-circuit, and disconnection and reconnection of DER.

Parameter	Minimum	Maximum
Frequency	58Hz	62Hz
Voltage	88%	110%

Table 56 Regulation for frequency / voltage protection setting limits

Table above summarizes the overall stability analysis for 17%, 50%, 75%, and 100% REP penetration. There scenarios were considered. Scenario 1 considers abrupt load variations. Scenario 2 considers PV disconnection and reconnection. Scenario 3 considers three-phase short-circuit fault. For the 17% REP case which is the existing system, the stability is formed by diesel generators. For the 50% REP case, scenario 1 considers stability formed by ESS converter, while scenarios 2 and 3 consider stability formed by diesel generators. For the 75% REP case, scenarios 1 and 2 consider stability formed by ESS converter, while scenario 3 considers stability formed by diesel generators. For the 100% REP case, the stability is formed by ESS converter because diesel generators are back-up sources.

The results indicate that the system is stable under various disturbances such as load variations, PV disconnection and reconnection, and short-circuit fault. Compared to the case when the system is controlled by diesel gensets, the upper and lower peaks in voltage and frequency responses are significantly smaller when the system is controlled by ESS converter. Under the control of ESS converter, the system frequency is control constantly at 60 Hz, the voltage and frequency responses reach steady-state operation after disturbances more quickly.

Parameter	REP	17%			50%			75%			100%		
		1	2	3	1	2	3	1	2	3	1	2	3
Voltage	Transient max (p.u.)	0.973	0.898	0.022	1.003	0.942	0.085	1.003	0.998	0.127	1.003	0.999	0.167
	Steady-state (p.u.)	0.996	0.993	1.000	1.003	0.995	0.997	1.003	0.999	0.997	1.003	0.999	0.999
	Settling time (s)	1.20	1.59	0.96	0.22	0.79	0.32	0.00	0.00	0.70	0.00	0.00	0.38
Frequency	Transient max (Hz)	58.96	58.28	59.72	59.95	57.85	59.39	59.98	59.92	59.19	59.99	59.95	59.89
	Steady-state (Hz)	59.75	59.60	60.00	60.00	59.48	60.00	60.00	60.00	60.00	60.00	60.00	60.00
	Settling time (s)	0.68	0.79	0.00	0.00	1.79	0.76	0.00	0.00	1.62	0.00	0.00	0.00

Table 57. Summary of transient stability analysis

5. Implementation Plan for Peleliu Project

5.1. Project Overview

According to various suggestions and scenarios presented in chapter 4, we have prudently discussed with PPUC about what should be included in the projects. The project includes the following suggestions.

First, capacity of RE is increased to 50%, which is the most economical LCOE size according to technical design. Considering there is already 164kW PV installed, capacity of ESS and PV installed in RE 50% scenario will be about PV 400kW and ESS 1MWh.

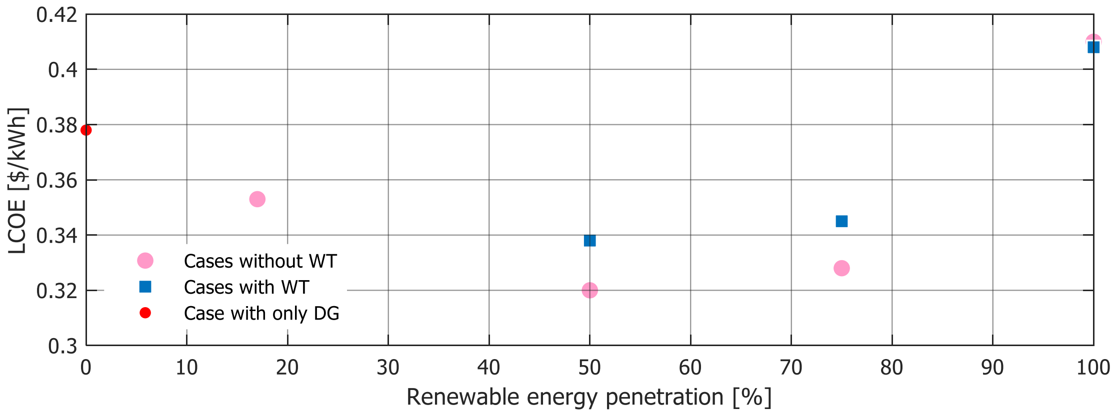


Figure 65 Simulations of scenarios according to RE Penetration

Component	Optimal size	Units
PV	564	kW
ESS	925	kWh
ESS Inverter	200	kW
FG Wilson generator	300	kW
HATZ generator	168	kW

Table 58. RE 50% System architecture.

Second, a microgrid controller design for a higher renewable energy penetration is required. Current fuel save controller cannot control ESS. To control PV, diesel and ESS, the following feature should be added to controller.

- **Voltage and Frequency Control**: Both diesel generator and ESS can be main controller for voltage and frequency control. ESS converter should offer both grid-parallel mode and grid-forming mode.
- **Dispatch Algorithm:** More sophisticated dispatch algorithm should be applied such as load following, cycle charging, and diesel-on/off.

Third, distribution line should be upgraded aligned with a higher renewable energy penetration level. In RE 50% scenario, PV and ESS supply the power mainly in the daytime, diesel generators do not need to supply the power at full days. Two distribution lines need to be drawn at the PV / ESS power generation complex and the circuit breaker of diesel power plant will be normally turned off in the daytime. In order to increase the reliability of the power supply, it is desirable to install a recloser instead of the COS in the middle of the line.

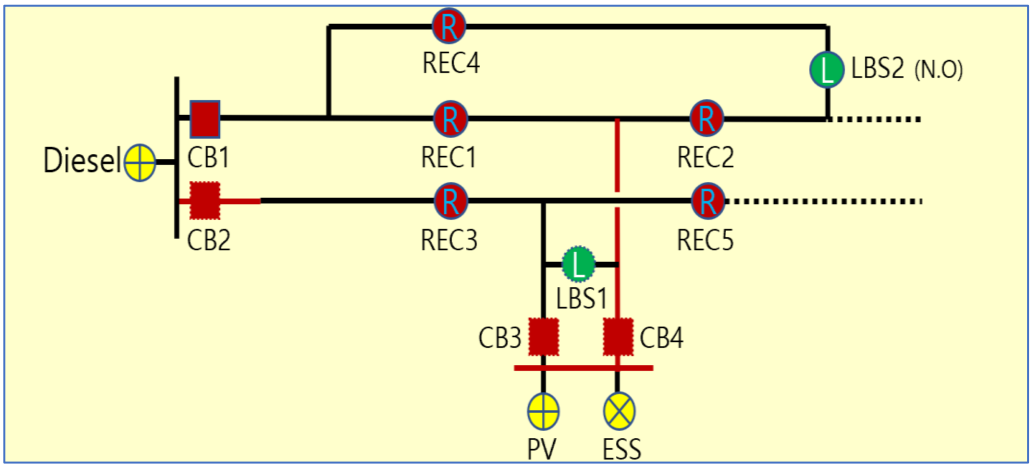


Figure 66. 50% to 100% DG Penetration Level Distribution Network.

5.2. Land

Site for additional PV and ESS would be better at the site where previous PV has been installed. It is south of the island. There is 64kW PV (2013, installed by Japan) and 100kW PV (2016, installed by UAE)

	
Location of site	**Photo of site**

Table 59. Site Information

For the site in google map is as below. Potential sites are designated by PPUC. However, sites are not enough for 400kW PV and 1MWh ESS. PPUC will look for additional sites near potential sites. The final site for solar PV expansion and ESS need to be selected from those two potential sites shown in Figure 68.

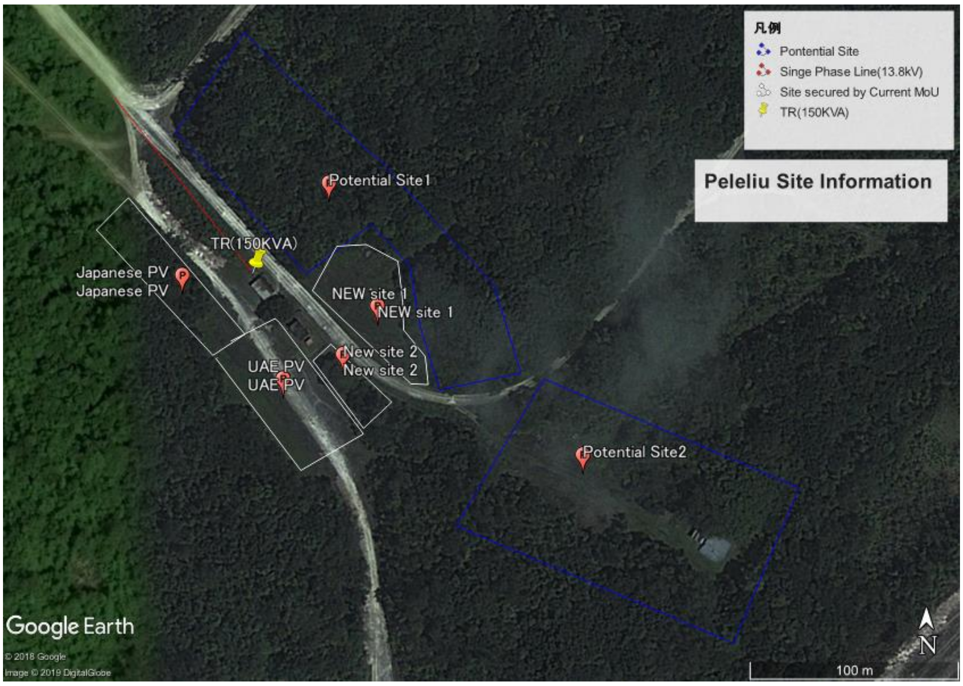
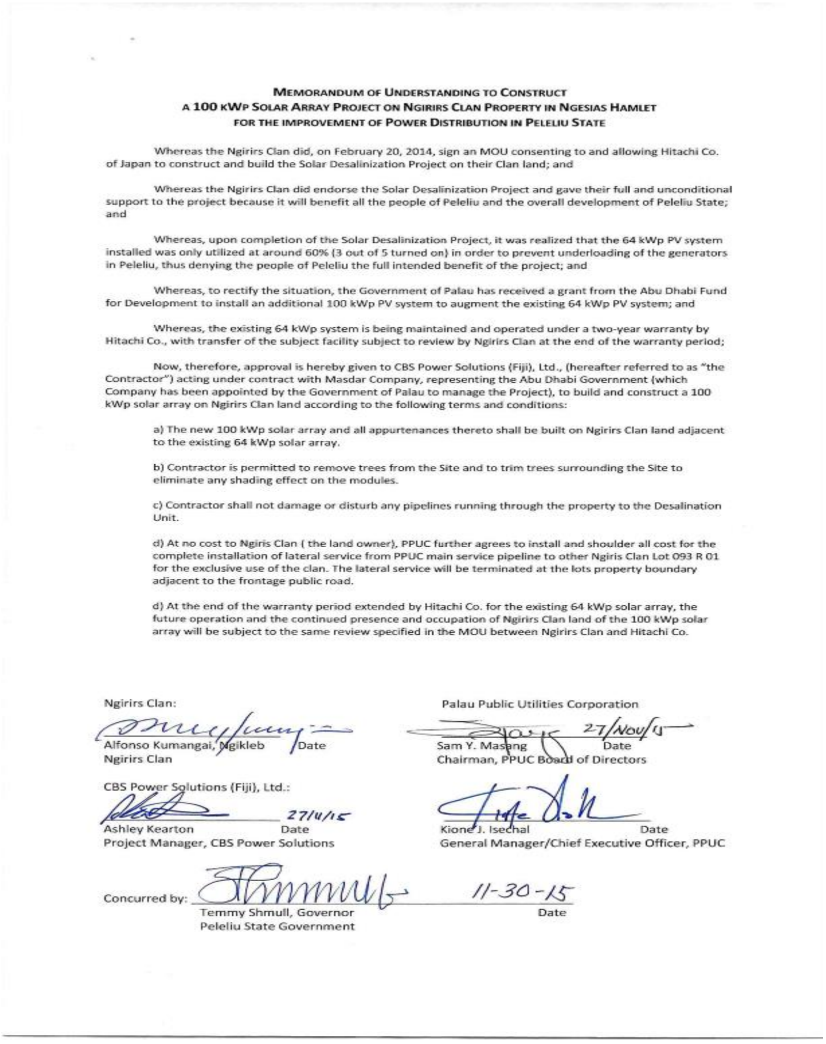


Figure 67. Site Location in Google

The area including Japan PV, UAE PV and potential PV sites 1 and 2 has already been consent by land-owner with Memorandum of Understanding (MOU). Though an MOU is not binding, it is expected that the land arrangement will be completed without problem. In MOU it specified rights for

- The new 100kWp solar array and all appurtenances there to build on Nigiris Clan land near existing 64kWp array
- Permission to remove tees from sites

Existing MOU only covers previous power plants. New MOU for PV and ESS with owners is required. Furthermore, it is recommended to sign the legally binding contract such as Land Lease Agreement.



MEMORANDUM OF UNDERSTANDING TO CONSTRUCT
A 100 KWP SOLAR ARRAY PROJECT ON NGIRIRS CLAN PROPERTY IN NGESIAS HAMLET
FOR THE IMPROVEMENT OF POWER DISTRIBUTION IN PELELIU STATE

Whereas the Ngirirs Clan did, on February 20, 2014, sign an MOU consenting to and allowing Hitachi Co. of Japan to construct and build the Solar Desalinization Project on their Clan land; and

Whereas the Ngirirs Clan did endorse the Solar Desalinization Project and gave their full and unconditional support to the project because it will benefit all the people of Peleliu and the overall development of Peleliu State; and

Whereas, upon completion of the Solar Desalinization Project, it was realized that the 64 kWp PV system installed was only utilized at around 60% (3 out of 5 turned on) in order to prevent underloading of the generators in Peleliu, thus denying the people of Peleliu the full intended benefit of the project; and

Whereas, to rectify the situation, the Government of Palau has received a grant from the Abu Dhabi Fund for Development to install an additional 100 kWp PV system to augment the existing 64 kWp PV system; and

Whereas, the existing 64 kWp system is being maintained and operated under a two-year warranty by Hitachi Co., with transfer of the subject facility subject to review by Ngirirs Clan at the end of the warranty period;

Now, therefore, approval is hereby given to CBS Power Solutions (Fiji), Ltd., (hereafter referred to as "the Contractor") acting under contract with Masdar Company, representing the Abu Dhabi Government (which Company has been appointed by the Government of Palau to manage the Project), to build and construct a 100 kWp solar array on Ngirirs Clan land according to the following terms and conditions:

a) The new 100 kWp solar array and all appurtenances thereto shall be built on Ngirirs Clan land adjacent to the existing 64 kWp solar array.

b) Contractor is permitted to remove trees from the Site and to trim trees surrounding the Site to eliminate any shading effect on the modules.

c) Contractor shall not damage or disturb any pipelines running through the property to the Desalination Unit.

d) At no cost to Ngiris Clan (the land owner), PPUC further agrees to install and shoulder all cost for the complete installation of lateral service from PPUC main service pipeline to other Ngiris Clan Lot 093 R 01 for the exclusive use of the clan. The lateral service will be terminated at the lots property boundary adjacent to the frontage public road.

d) At the end of the warranty period extended by Hitachi Co. for the existing 64 kWp solar array, the future operation and the continued presence and occupation of Ngirirs Clan land of the 100 kWp solar array will be subject to the same review specified in the MOU between Ngirirs Clan and Hitachi Co.

Ngirirs Clan:
Alfonso Kumangai, Ngikleb / Date
Ngirirs Clan

Palau Public Utilities Corporation
27/Nov/15
Sam Y. Masang / Date
Chairman, PPUC Board of Directors

CBS Power Solutions (Fiji), Ltd.:
27/11/15
Ashley Kearton / Date
Project Manager, CBS Power Solutions

Kione J. Isechal / Date
General Manager/Chief Executive Officer, PPUC

Concurred by: 11-30-15
Temmy Shmull, Governor / Date
Peleliu State Government

Figure 68. MoU of current sites

Cadastral map of Peleliu grid is as below, PPUC has currently rights to use 093R01, 087 R 06, 087 R 07, 087 R 08, 087 R 09 under the written MOU. Additional sites are located either remaining area in 093 R 01 or south of 087 R 07 where water pump is located on.

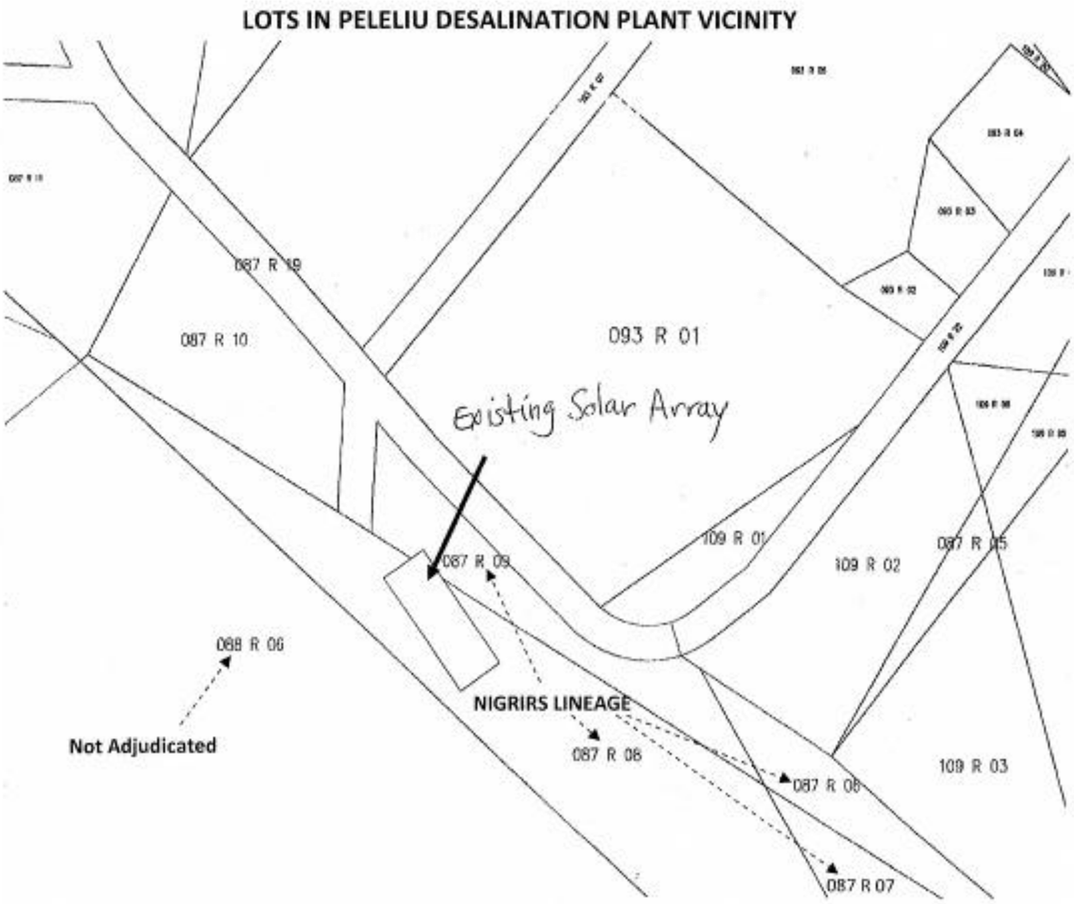


Figure 69. Cadastral Map of Peleliu Sites

5.2. Permission Plan

Site for PV and ESS needs construction permit by Peleliu state government. As it is explained in chapter 2, Construction permit is comprehensive permit which requires clearances from 4 other departments. Among 4 of them, Environmental Quality Preservation Board (EQPB) clearance is the most difficult ones. National Bureau of Land and Survey: For Public land should be cleared by the Koror State Public

- Land Authority. Private land should be cleared by the National Bureau of Land and Survey. The authority will inspect the land to confirm ownership and to verify the boundaries.
- Public Works: The Public Works Authority checks the plumbing system and the distance between the building and the land space boundary. The Public Works Authority checks the plumbing system, and the distance between the building and the land space boundary.
- Bureau of Arts and Culture: Any negative affect to any historical sites should be

identified

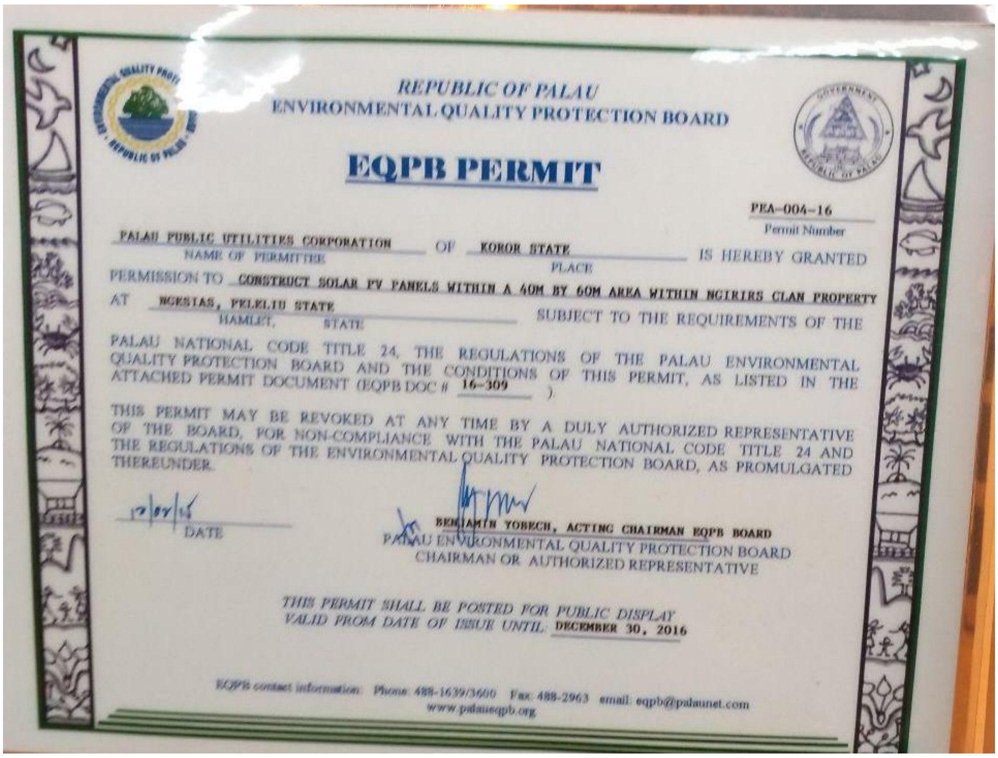
- Environmental Quality Preservation Board (EQPB): Environment Assessment for Environment Impact Assessment is required.

5.2.1. Clearance form Environment Quality Permission Board (EQPB)

For any development activities related to earth-moving, public drinking water system, marine and freshwater discharge, solid waste management, and air pollution, EQPB clearance is required. As explained in chapter 2, EQPB clearance has 3 parts.

- EQPB clearance: It is necessary for every project.
- Environmental Assessment: If project triggers conditions stated in EQPB regulati on 2401-61-03, a separate Environmental Assessment should be conducted.
- Environmental Impact Assessment: It is required for the project which has seri ous impact on Palau national environment.

UAE 100kW PV project in 2016 did not take EA since Land was flat land, there is not much possibility on environment impact.



REPUBLIC OF PALAU
ENVIRONMENTAL QUALITY PROTECTION BOARD

EQPB PERMIT

PEA-004-16
Permit Number

PALAU PUBLIC UTILITIES CORPORATION (NAME OF PERMITTEE) OF KOROR STATE (PLACE) IS HEREBY GRANTED PERMISSION TO CONSTRUCT SOLAR PV PANELS WITHIN A 40M BY 60M AREA WITHIN NGIRIRS CLAN PROPERTY AT NGESIAS, PELELIU STATE (HAMLET, STATE) SUBJECT TO THE REQUIREMENTS OF THE PALAU NATIONAL CODE TITLE 24, THE REGULATIONS OF THE PALAU ENVIRONMENTAL QUALITY PROTECTION BOARD AND THE CONDITIONS OF THIS PERMIT, AS LISTED IN THE ATTACHED PERMIT DOCUMENT (EQPB DOC # 16-309).

THIS PERMIT MAY BE REVOKED AT ANY TIME BY A DULY AUTHORIZED REPRESENTATIVE OF THE BOARD, FOR NON-COMPLIANCE WITH THE PALAU NATIONAL CODE TITLE 24 AND THE REGULATIONS OF THE ENVIRONMENTAL QUALITY PROTECTION BOARD, AS PROMULGATED THEREUNDER.

12/07/16
DATE

BENJAMIN YOBECH, ACTING CHAIRMAN EQPB BOARD
PALAU ENVIRONMENTAL QUALITY PROTECTION BOARD
CHAIRMAN OR AUTHORIZED REPRESENTATIVE

THIS PERMIT SHALL BE POSTED FOR PUBLIC DISPLAY
VALID FROM DATE OF ISSUE UNTIL DECEMBER 30, 2016

EQPB contact information: Phone: 488-1639/3600 Fax: 488-2963 email: eqpb@palaunet.com
www.palaueqpb.org

Figure 70.EQPB permission for previous project

For this project, only EQPB clearance is expected. However, there is possibility for Environment Assessment(EA). These are requirements for EQPB clearance

A. State Building Permit application
B. Land use right (Certificate of Ownership or Lease Agreement)
C. Project Plan (Floor Plan, Grading Leveling)
D. Septic Tank & Leaching Field Plan (if necessary)
E. Historical Preservation Office (HPO Clearance)
F. Unexploded Ordnance (UXO) Clearance
G. Erosion & Sedimentation Control Plan (ESCP)
H. List of Refrigeration & Air Condition Equipment (if necessary)
I. List of Refrigerants & Freons (if necessary)

5.3. Construction Plan

5.3.1. Product standard

General product standard PPUC requires is as below. This standard is from PPUC RFP for Independent Power Plant (IPP) proposal in February 2019.

Category	Standard
PV Module	PV module must meet - Underwriters Laboratories (UL) Standard 1701: Flat Plat Photovoltaic Modules and Panels. or both - IEC 61730-1: Photovoltaic (PV) Module Safety Qualification Part 1: Requirements for Construction - IEC 61730-2 Photovoltaic (PV) Module Safety Qualification Part R: Requirements for Construction (or EN 61730-1 and EN61730-2). Crystalline silicon PV modules shall comply with IEC 61215: Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval. Thin film PV modules shall comply with IEC 61646: Thin Film terrestrial photovoltaic (PV) modules - Design qualification and type approval. Modules are to be capable of withstanding local climactic conditions, considering that Palau has a tropical marine climate and experiences occasional hurricanes/typhoons, severe, tropical storms, year-round high humidity and

	salinity. Modules must meet the following specific requirements: - Metals used on the module shall be marine grade aluminum or marine grade, stainless steel; - Modules shall be certified to hail testing according to IEC 61215 - Modules shall be certified to cyclic pressure testing according to IEC 61215
Mounting Structure	All mounting structures will have a design life of at least 20 years and will be either marine grade aluminum or marine grade stainless steel. Galvanized steel is not acceptable. All hardware used for mounting panels to the structures and the structures to their supports must be marine grade stainless steel. There must be no direct contact between aluminum and other materials that can cause electrolytic corrosion of either material. Mounting structures are to meet the design requirements of relevant Palau/US structural standards noting that Palau is in a tropical hurricane/typhoon zone for wind zoning purposes. Mounting structure must be certified by the manufacturer as suitable for hurricane regions at minimum, and installation must be completed in accordance with manufacturer's instructions. Ground mounted arrays must utilize concrete foundations and metal frames. The installations must be designed to meet the requirement of surviving a 150 km per hour continuous wind load with gusts to 200 km per hour. All structures must be able to resist at least 20 years of outdoor exposure in the location's harsh tropical marine environment without any appreciable corrosion or structural fatigue.
Inverter	Inverters should be suitable for connection to Palau's central grid via transformers The inverter shall meet either: - UL Standard 1741: Standard for Inverter, Converters, Controllers and Interconnection System Equipment for use with Distributed Energy Resources (Suitable for PV Systems and Wind Systems), and - Institute of Electrical and Electronic Engineer (IEEE) Standard 1547-

	2003: IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems. For PV systems only: - IEC 62109: Safety of Power Converters for use in Photovoltaic Power Systems (Part 1: General Requirements, Part 2: Particular Requirements for Inverters) Inverter total harmonic distortion must be less than 3% at unity power factor.
ESS	Energy Storage System must comply with standards and safety requirements of UL 9540. - This is important to ensure hazardous and/or flammable materials are handled and contained accordingly with the appropriate safeguards in place. - Housing structures for highly flammable and hazardous materials must include flame-retardant materials and fire-suppressing agents where necessary. Design must take into consideration weather conditions such as heat, humidity, cloud cover, rain, and other factors specific to the region.

Table 60. Product Standard (PPUC RFP,2019)

5.3.2. Logistics Plan

To ensure timely delivery and construction, a well planned logistics is very important. According to previous transportation project, Guam and Hong Kong are main transfer port for Palau. Example route can be

- Busan- Guam- Palau
- China-Hong Kong- Palau

In Port of Koror, an external customs clearance agent should be hired to manage customs process. These are some important custody processes specified by customs office of Republic of Palau. However, it is necessary to hire customs clearance agent to avoid risk. The important rule suggested by custody is as below:

- Cargo shall be retained at the place of unloading until import tax has been paid. (PNCA-40 §1304(e))
- Goods in the physical possession of the terminal operator exceeding ninety (90) days from the date of import will be transferred by the terminal operator to the Division of Customs for safekeeping and storage.

- No one shall release or turn over to a consignee any merchandise being imported into the Republic without prior official written permission. (PNCA-40 § 1304(f)).

A local clearing agent should be hired to clear the containers through customs and deliver them to site by truck. Containers are emptied by forklift and the materials stored in the storage areas.

Vessels can only sail to the main Island (Koror). A Barge has to be hired with a side lifer to transport the goods from Koror to Peleliu.

Figure 71. Cargo ship in Peleliu Port

The sail time is only one hour to each of the Islands from Koror. However, goods must be unloaded from the vessel and loaded onto the barge. This adds additional time to the full duration of the transportation.

5.3.3. Civil work

5.3.3.1. Erosion and Sediment Control Plan

Due to tropical climate in Palau, most soils in Palau are classified as highly erodible by USDA-NRCS. ESC practices are not properly installed or maintained. According to Palau Environmental Quality Protection Act, Erosion and Sediment Control (ESC) Standards Manual is compiled with by all contractors.

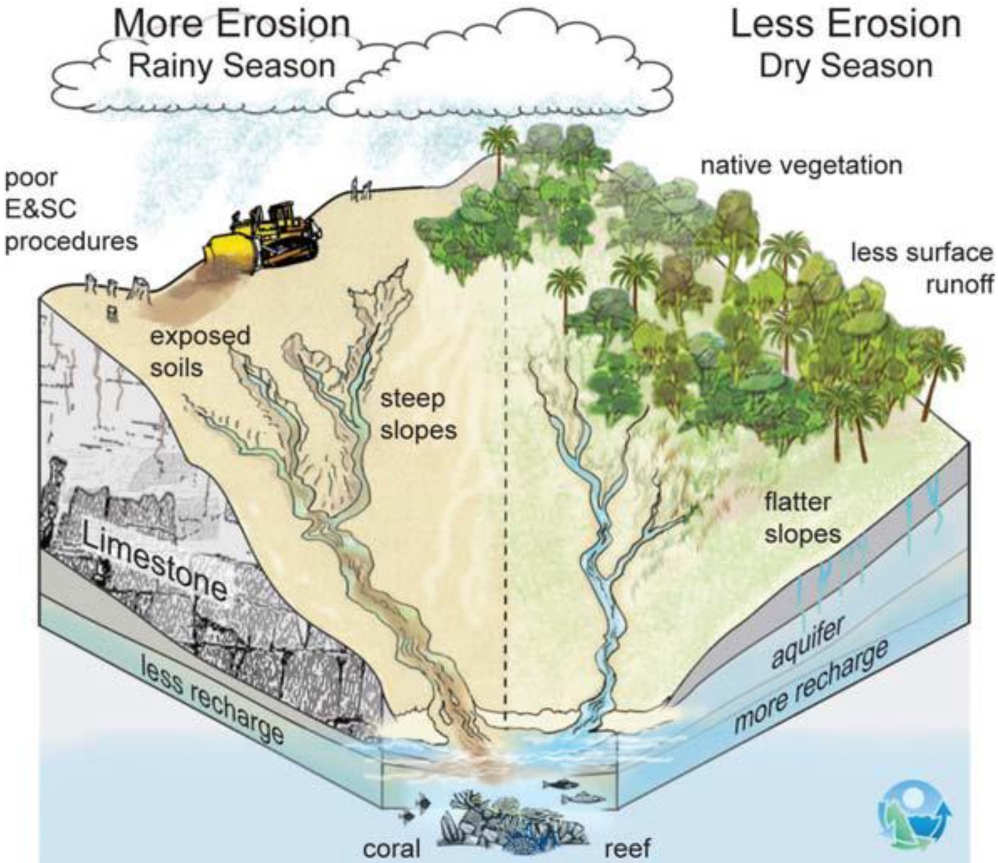


Figure 72. Diagram of Erosion

ESC manual is open in EQPB homepage (https://www.palaugov.pw/eqpb) and standard steps of ESC are as below:

① Hold preconstruction meeting

② Mark limits of disturbance to protect waterway buffer, existing vegetation, and other resources

③ Clear/grub areas necessary to construct ESC practices

④ Stabilize construction entrance and install necessary perimeter controls and diversions

⑤ Install temporary sediment trapping devices and runoff conveyance systems

⑥ Complete clearing and rough grading where necessary (minimized and phased)

⑦ Provide temporary stabilization with vegetation or mulch for inactive, disturbed areas

⑧ Construct utilities, roads, and buildings

⑨ Convert/install permanent stormwater practices

⑩ Remove temporary ESC devices

⑪ Stabilize with permanent vegetation

5.3.3.2. Unexploded Ordnance (UXOs) Clearance Plan

Peleliu was a fierce battleground between the Japanese and the United States of America in World War II. As a result, to this day Unexploded Ordnance (UXOs) can be found throughout the islands of Palau. If disturbed or handled incorrectly, these UXOs may explode, and may pose a risk to public safety. EQPB regulation enforces UXOs clearance in all earth-moving application.

To mitigate the risk, expert contractors should be hired to identify and remove any potentially hazardous UXOs found on any of the sites to be used for the project. The expert contractor can make recommendations on all aspects, such as future ERW, removal and land mine clearing activities, funding needs, or the adequacy of financial controls and value-for-money.

In previous UAE project in Peleliu, explosive ordnance disposal and battleground clearance were conducted.

Type of Clearance	Explanation
Explosive Ordnance Disposal	Explosive Ordnance disposal involves the detection, identification, evaluation, render safe, recovery and disposal of explosive items.
Battle Area Clearance	This will ensure that all items of ERW are safely removed and destroyed including cluster munitions, small arms/light weapons and aircraft bombs.
Land Mine Verification & Area Reduction	The process of minefield verification and area reduction, so that the limits of suspected contaminated search areas may be safely defined. Once a hazardous area has been delineated, Cleared Ground can also carry out minefield marking tasks.

Table 61. Typical type of Ordnance Clearance

5.3.4. Electrical Construction

There is enough land for 676 PV arrays which are 256.88kW. However, there should be more space for 150kW PV and sites for ESS. Since the design is very tight, there should be some extra space for contingency.

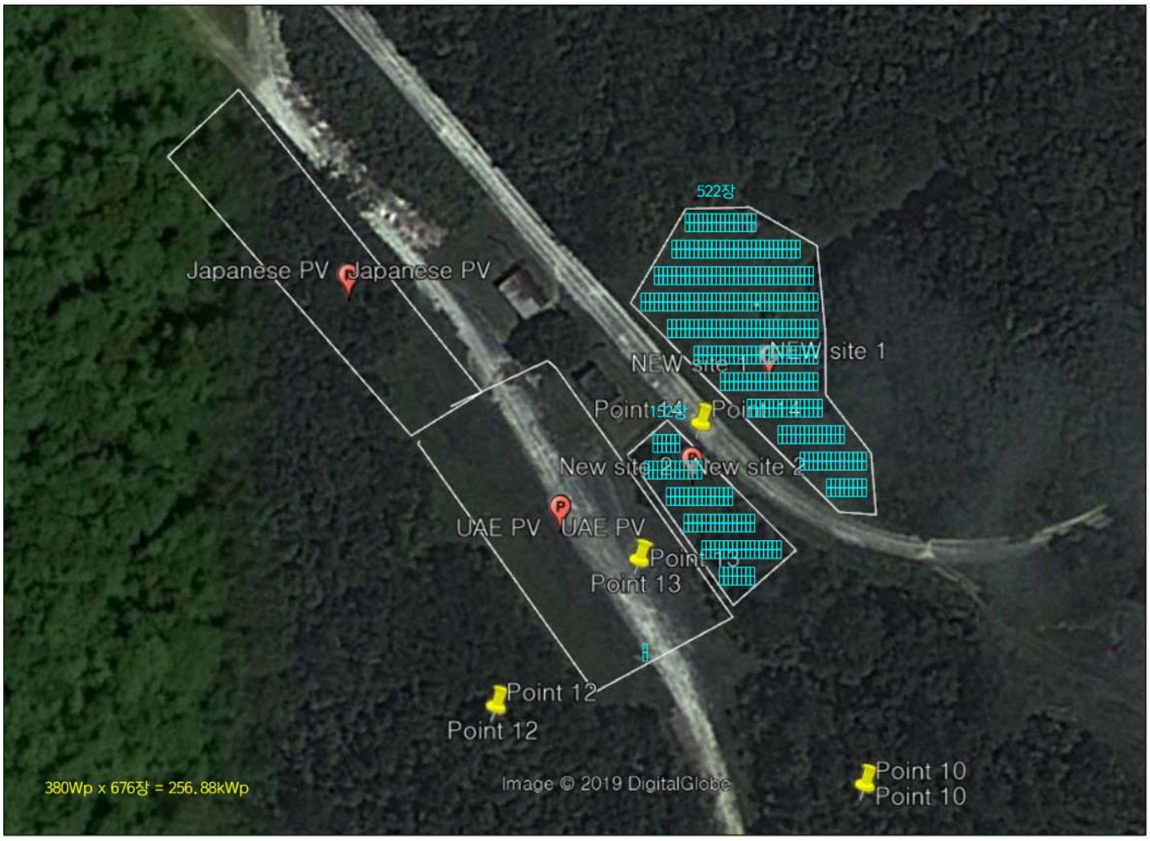


Figure 73. PV arrays in existing site

5.3.5. Commissioning Plan

There is 13.8kV through three 50kVA (150kVA) single-phase transformers and connected to distribution lines. Three transformers are close to potential sites. However, distance of connection point might be longer to potential site.

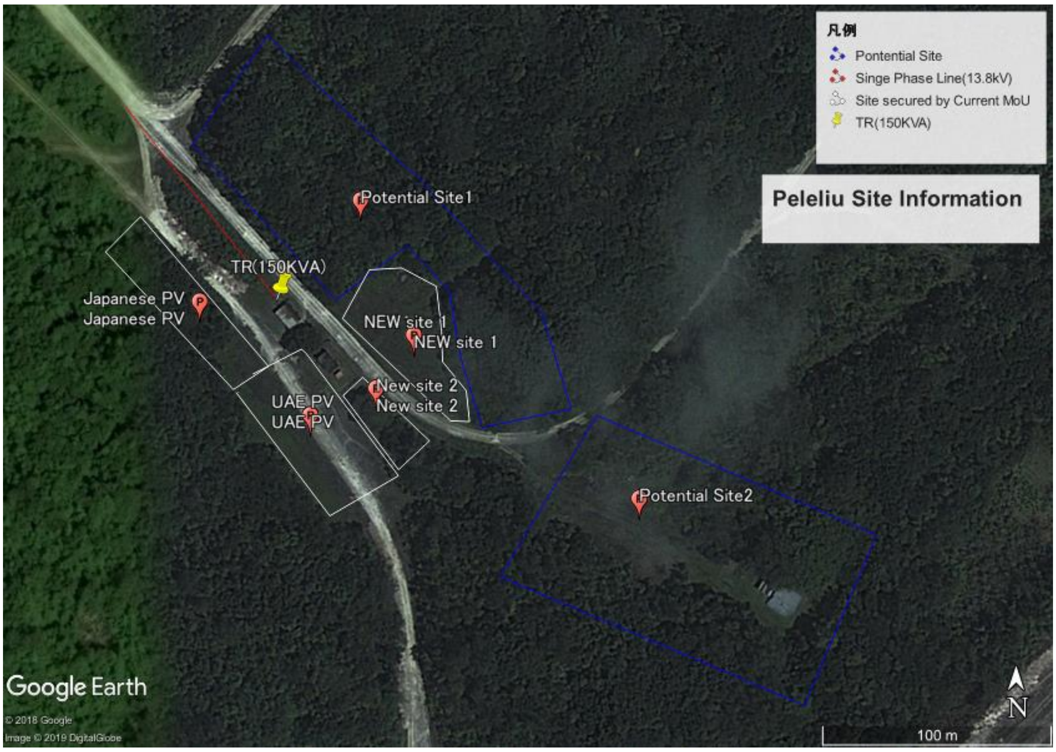


Figure 74. Photo of commission Plan

Because of the higher PV penetration, a new transformer for the PV plant with higher capacity must be installed. From the result of load flow analysis, we can suggest that a 500kVA transformer should be installed for the PV-ESS plant. In addition, we propose a new upgraded configuration for the Peleliu distribution system.

PPUC has own guideline called "Guidelines Standards and Regulations for Renewable Energy Generation Systems Connecting to the Palau Central Grid. This is established under the regulations below:

- The USA 2011, National Electrical Code®; and
- IEEE 1547: Standards for Interconnecting Distributed Resources with Electric Power Systems.

The guideline is originally used for RE generation system under 100kVA and further negotiation is required based on this guideline. However, PPUC confirms that this guideline is used for all existing PV plant without negotiation. A negotiation might be necessary for this project since there is ESS. However, the negotiation is also conducted based on PPUC guideline and superior guideline such as USA NEC 2011 or IEEE-1547 might be required.

5.4. Operation & Maintenance Plan

Standard Operation &Maintenance (O&M) manual is necessary to keep the system operating at its full capacity with minimum downtime. When designing standard O&M manual, it is necessary to consider the following issues:

- Manual needs to be concise and correct in a proper language so that local operators read, understand, and practice without any difficulties
- Manual needs to be designed for training purpose of local O&M staff
- A clear definition and assignment of responsibility of the management of manual to local O&M staff

"Installation, Operation and Maintenance of Solar PV Microgrid-A handbook for technicians" by GSES (global sustainable energy solutions) and CLEAN (Clean Energy Access Network) suggested details of Micro-grid O&M. A detailed content of O&M manual is presented in table below

Weekly	Clean PV array from dust Use clean water and avoid hard water
	Observe battery state of charge (SOC). In case of VRLA battery use voltmeter to measure voltage to check corresponding SOC
Monthly	If flooded, check the electrolyte level of lead acid batteries Wipe out electrolyte residues from the top of the battery
	Inspect all terminals for corrosion and loosened cable connections. Clean and tighten as necessary. After cleaning, add anti-oxidant to exposed wire and terminals
	Check if new loads have been added and system is over-loaded
	Inspect array for broken modules If any, replace with appropriate modules
Annually	Check array wiring for physical damage and wind chafing
	Check array mounting hardware for tightness
	Inspect inverter and remove dust. Inspect system wiring for poor connections and check signs of excessive heating Inspect controller for proper operation
	Verify output from the array

Table 62.Example manual of Mini-grid GSES (global sustainable energy solutions), CLEAN (Clean Energy Access Network) (2015)

IEEE 2030.3™-Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications" suggests "periodic function test". A periodic function test shall be performed to verify that all interconnection-related protective functions and associated batteries are functioning properly after a certain time of operation. The periodic test includes: an SOC test, response time test, ramp-rate test, harmonics test, response to voltage, abnormal test, response to frequency abnormal test, etc.

A written periodic test procedure shall be agreed by the ESS owner and the EPS operator. The test interval shall be specified by the manufacturer, system integrator, or ESS operator. Written test reports or a log for inspection shall be maintained. Corresponding type tests on related components shall be performed in the case of the following conditions:

A. Change of ESS functional software or firmware
B. Modification, replacement, or repair on ESS hardware components causing changes in ESS configuration.

5.5. Project Financial Feasibility

5.5.1. Method of Financial Feasibility Analysis

A cost-benefit analysis model is the procedure of the decision on whether to invest resources or not in the public sector by relying on the economic feasibility result. When total benefit obtained through project performance is bigger than the required total cost, the cost-benefit analysis judges it as economically reasonable. Only when the condition that total benefit is bigger than total cost is met, the conclusion that a project has economic efficiency is made by the cost-benefit analysis. Generally, cost-benefit analysis is used for an ODA project which is in pursuit of social purposes of poverty alleviation and sustainable development in a developing nation. The ODA project sets detailed socio-economic goals to be achieved both by direct and indirect ways by a proposed project. The cost-benefit analysis is the process of verifying economic efficiency of a project by setting up the goals and expected effect (results) pursued by the project, and indicators for evaluating them, and carrying out the cost-benefit analysis targeting the pre-selected alternative based on that the relevant agency involved in the analysis understands a recipient country’s problems and selects a project to solve them.

There are basically three methods of financial feasibility to analyze cost and benefit, which are B/C (Benefit/Cost) ratio, Net Present Value (NPV) Standard, and Internal Rate of Return (IRR) Standard.

- **Benefit Cost Ratio**: It is necessary to arrange a desirable standard or indicator in order to perform reasonable decision-making under constraining factors. Among these decision-making standards, it is advisable to take into account the Benefit Cost Ratio first. The Benefit/Cost ratio is identified through the division of the present value of benefit by the present value of cost after converting the cost and benefit, which are to appear in the future, to the present value by applying a selected discount rate. In other words, the ratio of the discounted amount of total cost and total benefit is called B/C ratio. Generally, the evaluation is that the higher the B/C ratio of a project, the higher the economic feasibility of a project.

$$\frac{B}{C} = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}}$$

- **Net Present Value (NPV) Standard**: Secondly, it is possible to use the estimated result of the Net Present Value (NPV) for decision-making. The NPV is the converted present value of the sum of net benefits coming about over the whole period of an investment project; namely, it means the added value by converting the value found by subtracting total cost from total benefit into the present value. When the net present value comes out in a positive number (≥0), the project is evaluated as having economic feasibility.

$$NVP = \sum_{t=0}^{n} \frac{B_t}{(1+R)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+R)^t}$$

- **Internal Rate of Return (IRR) Standard**: The internal rate of return (IRR) is an estimated rate of return under the premise that a project is going smoothly, referring to the discount rate, while making the present value zero by coinciding the present value of benefit with the present value of cost over the whole period of a project. When the internal rate of return is larger than the social discount rate, the relevant project is judged as having economic feasibility. Therefore, the bigger the internal rate of return of a project, the higher the probability of a project's being judged as having high economic feasibility, which is best suited in deciding the priority between competing projects.

$$\sum_{t=0}^{n} \frac{B_t}{(1+R)^t} = \sum_{t=0}^{n} \frac{C_t}{(1+R)^t}$$

The table below compares the characteristics and merits and demerits of cost & benefit analysis standards.

Analysis Technique	**Judgment Standard**	**Merits**	**Demerits**
Benefit/Cost Ratio(B/C)	More than B/C 1	- Easy for understanding, available for project size consideration	- No significance in decision on the priority order of projects

Net present value (NPV)	NPV Positive	- Proposal of a clear standard in time of alternative selection - Suggestion of the present value of the benefit which is to come up in the future -Consideration of marginal net present value	- There is a likelihood of error occurrence due to the lack of standardization of project size in time of the decision on priority order of alternatives
Internal rate of return (IRR)	IRR > Capital financing cost	- Available for project profitability measurement - Easy for comparison with other alternatives - Easy to understand the evaluation process & result - Available for calculation despite no prior knowledge of the social discount rate	- No consideration to absolute size of a project. - Embedded is the possibility of simultaneous deduction of several internal rates of return. - Impossible to apply the internal rate of return standard to a project having budgetary restrictions, or projects in mutually competitive relations (mutually exclusive)

Table 63.Comparison of Cost & Benefit Analysis Standard

As the standard of Cost & Benefit Analysis for the project, the Benefit/Cost Ratio Analysis (B/C Ratio Analysis), which is judged as the most reasonable in the application to a single project without alternatives, is applied. The value for B/C Ratio Analysis only includes estimated direct financial value without estimating monetary value from carbon emissions reduction or any other qualitative factors. However, qualitative factors including carbon emissions reduction are considered also benefits from the Peleliu project aligned with the proposed solution.

5.5.2. Discount Rate Scenario

Homer, which is basic tool which is used to analyze economic feasibility of this project, discount rate of 8% as default. which is typically used in renewable energy. However, MDBs such as world bank or IDB suggested different discount rate for project in developing countries.

"Design of development" which is published in 1958 in World Bank, uses a rate of 10% as the appropriate cost of capital for evaluating projects in developing countries. Its original source is the ECLAC Manual on Development Projects. Since then, various World Bank projects were evaluated at rates of 10% and 12%. (world Bank 1958). Recent World Bank document "Guidelines for Economic Analysis of Power Sector Projects" also uses either 10% or 12%(World Bank 2015) as discount rate. Therefore, According to Homer default discount rate and World Bank suggested, this study generates 3 B/C ratio scenarios

- 12% discount scenario(World Bank Suggested)
- 10% discount scenario(World Bank Suggested)
- 8% discount scenario(Homer default value)

5.5.3. Project's Cost and Benefit Sensitivity Test

In order to analyze B/C Ratio, conditions to identify items and calculate the value for benefit and cost should be defined on the basis of implementation plan including proposed solution to expand RE in Peleliu Island.

For the Peleliu project, RE penetration rate of 50% scenario is proposed with additional capacity of 400kW PV, 925kWh ESS, and 200kW ESS inverter. Capital cost for the additional capacity of solar power system consists of $800,000 for PV, $462,500 for ESS and $60,000 for ESS inverter, with the total amount of $1,322,500.

Peleliu project is carried out on the condition that:

- newly designed and constructed solar power system is being operated for 25 years:
- electricity tariff rates remain the same (revenue will be increased according to increase capacity with implementing 400 kW PV. But current average tariff is lower than LCOE, so there is no need to account for revenue in the cost and benefit analysis)
- LCOE is reduced from 0.353 $/kWh to 0.320 $/kWh:
- solar PV supplies electricity up to 50% of total power supply as proposed with replacing 33% of energy source from diesel to solar:
- solar power operates 3.8 hours/day, so power supply from newly implemented solar power system produces 554,800 kW/year:
- carbon emission is reduced from 845 ton of CO2/year to 482 ton of CO2/year with annual reduction of 363 ton of CO2:
- fuel consumption is reduced from 320,837 liter/year to 182,867 liter/year with annual reduction of 137,970 liter/year:
- salvage cost is not considered because it has already been applied to calculate LCOE.

Financial feasibility analysis is conducted with applying B/C ratio and here is the summary of items and NPVs applied to B/C ratio analysis.

Scenario	Benefit	Amount	Cost	Amount	B/C Ratio
Scenario 1	Benefit 1+ Benefit 2 Discount Rate 12%	1,155,488	Cost 1+Cost 2	1,362,563	0.848024873
Scenario 2	Benefit 1+ Benefit 2 Discount Rate 10%	1,337,272	Cost 1+Cost 2	1,375,127	0.972471556
Scenario 3	Benefit 1+ Benefit 2 Discount Rate 8%	1,572,658	Cost 1+Cost 2	1,392,067	1.129728507

Table 64 Summary of .B/C ratio Sensitivity Test

The result of B/C ratio varies on discount rates. For discount rate 10% and 12% scenarios , B/C ratio is below 1 since benefit of O&M and fuel cost saving decreases. Detailed of analysis are in 3 tables below. Moreover, excel sheet for B/C ratio is attached in appendix.

Item	Description	Amount(USD)	Remark
Benefit			
Benefit 1	Savings of O&M Cost for 25 years	62,549	USD
Benefit 2	Savings of Fuel Cost for 25 years	1,092,939	USD
Sub-total		1,155,488	USD
Cost			
Cost 1	Increased Capital investment for 25 years	1,322,500	USD
Cost 2	Increased Replacement Cost for 25 years	40,063	USD
Sub-total		1,362,563	USD

Table 65.B/C scenario for 12% discount rate

Item	Description	Amount (USD)	Remark
Benefit			
Benefit 1	Savings of O&M Cost for 25 years	72,389	USD
Benefit 2	Savings of Fuel Cost for 25 years	1,264,882	USD
Sub-total		1,337,272	USD
Cost			
Cost 1	Increased Capital investment for 25 years	1,322,500	USD
Cost 2	Increased Replacement Cost for 25 years	52,627	USD
Sub-total		1,375,127	USD

Table 66. B/C scenario for 10% discount rate

Item	Description	Amount (USD)	Remark
Benefit			
Benefit 1	Savings of O&M Cost for 25 years	85,131	USD
Benefit 2	Savings of Fuel Cost for 25 years	1,487,526	USD
Sub-total		1,572,658	USD
Cost			
Cost 1	Increased Capital investment for 25 years	1,322,500	USD
Cost 2	Increased Replacement Cost for 25 years	69,567	USD
Sub-total		1,392,067	USD

Table 67. B/C scenario for 10% discount rate

5.5.3. Project's Socio-Economic Benefits

In addition to the quantifiable benefits presented through financial analysis, there are other benefits that the proposed solution could deliver to the local utility company and community. These qualitative benefits are categorized into environment, economy and society as Figure 75.

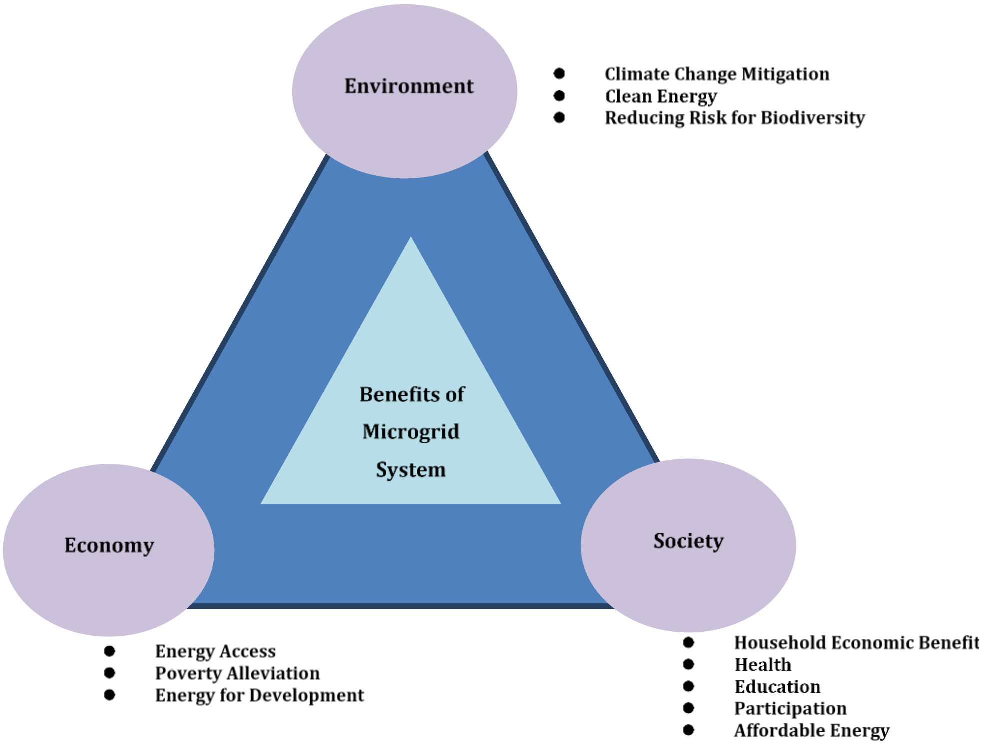


Figure 75. Benefits of Microgrid System

- **Environment**: At environment perspectives, there are three benefits of climate change mitigation, increase penetration of clean energy and risk reduction for biodiversity. All energy sources (fossil fuels as well as renewable energies) have some effect on our environment. Even though renewable energy sources are considered environmentally preferable to conventional sources (and, when replacing fossil fuels, has significant potential to reduce greenhouse gas emissions), it is still important to understand the impacts linked to the production of power from renewable sources. The type and intensity of environmental impacts always vary depending on the specific technology used, the geographic location, and a number of other factors. However, increase of renewable energy penetration could be the solution to mitigate climate change Peleliu Island is facing. Palau including Peleliu is internationally renowned for its biological significance to the Earth's natural environment. Although Palau may not be considered one of the most biologically diverse countries in the world in terms of sheer number of species, Palau is home to a substantial number of species in terms of exclusivity. Palau's biological significances are presented as: one of the largest portions of species that occur nowhere else in the world: supports more coral, fish, and other invertebrates per unit area of marine habitat than any other place on Earth: home to the most isolated Dugon population in the world: the most plant and animal species in Micronesia: home to seven of the nine species of giant clams: home to the largest natural lake in Micronesia: Ngermeduu Bay as the largest estuary in Micronesia: one of the largest undisturbed tropical rainforests in Micronesia: and the largest number of resident bird species in Micronesia. Hence, the value to preserve biodiversity in Palau is priceless. One of the most important factors for environmental benefits is carbon emissions reduction, which could be achieved by increase of renewable energy penetration regardless of other potential negative impact considered and managed with utmost care.

- **Economy**: Economic benefits apart from financial benefits come from increased energy access, poverty alleviation caused by promotion of various industries and increased income accordingly, and energy for development in balanced manner. Energy access itself is not a panacea to rural poverty issues. A successful intervention has the potential to stimulate development by modernizing existing needs and introducing new services. Individually, energy access has the potential to alleviate poverty through stimulating rural livelihood options. This can occur via the establishment of new energy-based industries, creating employment in manufacturing, construction and maintenance. Energy access can allow households to engage in a more diverse range of income-generating activities as well as make pre-existing activities more efficient. With the necessary infrastructure to ensure sustainability, new livelihoods developed via energy access can have a huge impact on long term poverty reduction.

- **Society**: There are various benefits at society perspectives such as household economic benefit, health, education, participation and affordable energy, which are likely to be overlapped with economic benefits and created in line with environmental benefits. Building, operating, and maintaining mini-grids have generated positive social impacts in addition to economic benefits. They will directly impact on labour market, which requires skilled resources with higher income and contributes to diversify jobs and employment conditions. They also encourage integrated government cooperation and the participation of the private sector in all aspects of mini-grid implementation. Rural communities in developing nations stand to benefit greatly from electrification and the opportunities that come with it. Affordable and clean energy is a requirement in developing countries and inclusive implementation has been shown to generate a positive impact. The process of sharing power and resources to achieve a common goal helps to bring communities together to invest in future progress. Modern energy access has the potential to improve health in rural areas both directly by powering healthcare facilities and indirectly by providing cleaner fuel sources and reducing hard labor activities. The inefficient combustion of solid fuels combined with inadequate ventilation contributes to poor health in many households. These high levels of indoor air pollution often result in decreased pulmonary function, particularly amongst women and children. According to the WHO, approximately 2.6 million premature deaths are attributable annually to household air pollution, making it the second largest environmental health risk factor in the world. The impacts of energy access also have positive impacts on education. Improved energy resources can reduce the time and labor required to achieve certain tasks such as collecting fire wood and water as well as mechanizing many activities. This could lead to increased enrolment of children in schools, since they no longer have to spend so much time assisting with household duties. In addition, access to lighting in the home increases the time available for study and hence may positively impact achievement levels. Lighting at the schools themselves can remove restrictions on school times making night classes a viable possibility or allowing schools to double as community centers in the evenings. Electrification can also affect education infrastructure through the integration of modern resources such as computers and internet access. A decentralized approach applied to Peleliu project to energy interventions led by local needs and contexts is necessary, particularly with smaller communities and rural populations. Starting with the people and not the technology can lead to improved and more widely disseminated energy technologies. Even Principle 10 of the Rio summit on the environment states that "Environmental issues are best handled with the participation of all concerned citizens. Each individual should have information and the opportunity to participate in decision making processes." Employing a participatory approach is necessary in every aspect of ensuring the success of an energy project. In the Pacific, the Talanoa framework serves as a dialogue platform which encourages inclusive, participatory, and transparent communication between the stakeholders of a project and between nations in the Pacific. The overall social benefits could be reflected in improvement of living standard and inclusive society.

Figure 76. Natural Environment and Biodiversity in Peleliu Island

It cannot be emphasized to present one of the most significant qualitative benefits as carbon emissions reduction. With carrying out this Peleliu project, carbon emissions are reduced to 482 ton/year through reducing fuel consumption of 137,970 liter/year. Carbon price cannot be forecasted precisely, so estimated monetary value for carbon emissions reduction as for now does not provide significant difference for decision-making.

5.6.Commercial-Scale Project Development Plan

5.6.1.Approach of Commercial-Scale Microgrid Project Development in PICTs

It was one of the key purposes of this feasibility study to design Peleliu microgrid project scalable and applicable to a commercial-scale project which puts small multiple microgrid projects together into one commercial and bankable project as to attract private sector. This chapter discuss the approach and strategic plan to develop a commercial scale microgrid project which will be built on the technical and operational concept of Peleliu project.

5.6.1.1. Categorization of PICTs

The issues surrounding a microgrid project in the PICTs are multi-dimensional, technological, socio-economic, geographic and demographic. Hence, the solutions to address those issues require in-depth knowledge, hands-on experiences and collaboration within different fields. Creating a sustainable microgrid project might raise multi-sectoral issues that need integrated approach and solution.

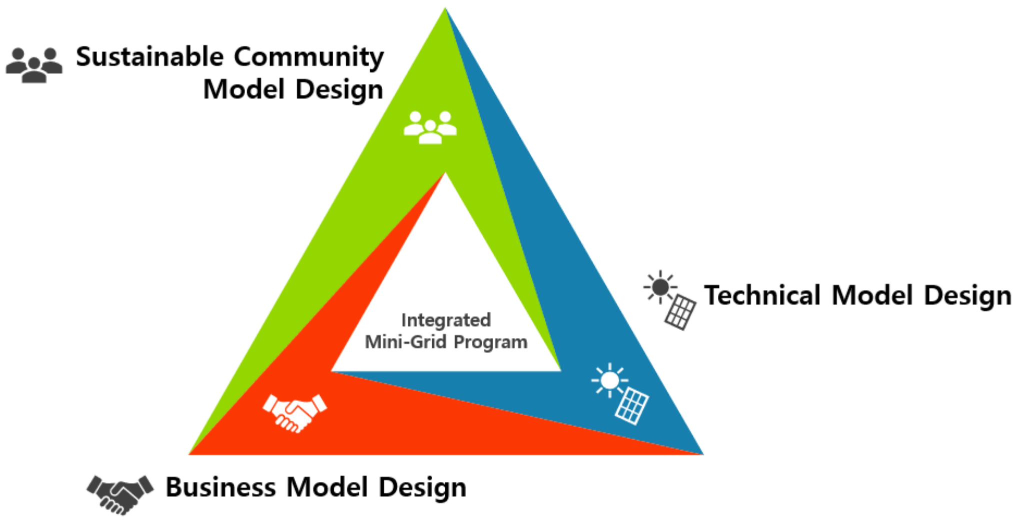


Figure 77. Approach of Microgrid Project Development

Different conditions of Islands in different groups in PICTs are expected to determine different approach to drive energy infrastructure transformation. Accordingly, islands in different groups need different sets of technical and business models for microgrid project design. The following table presents a tentative grouping and characteristics of each island group in PICTs and suggests different technical and business model for each group. The following categorization of PICTs islands and design approach is quoted from Mini-grid Market and Industry Assessment Report in PICTs, UNIDO, 2018

	Main Islands (Group A)	Outer Islands (Group B)	Remote Islands (Group C)
Existing Power System and Environment	Centralized grid operated by a public utility corporation Size of average load larger than 10MW in most main Islands Still majority of power generation based on diesel	Small grid operated by a public utility or a private company Size of average load varies in the range of several hundred kW to several MW Mostly diesel-based generation	No reliable power system or small independent power system on diesel base Size of average load in most cases less than one hundred kW
Constraints and Conditions for Commercial Scale Mini-grid Projects	Dominant and monopolistic position of existing utility	High demand of mini-grid with RE and ESS Economies of scale needed to make a bankable commercial project	Challenging logistics conditions for delivery and construction Poor local capacity for construction and O&M
Feasible technical Model	Grid tied RE systems utilizing local RE sources ESS for voltage support and frequency regulation as RE increases	Hybrid of mini-grid systems with RE, ESS and diesel to reduce the dependency of diesel	SHS (Small Solar Home System) or Hybrid mini-grid system
Feasible Business Model	IPP with private funding	Community or private business model with a blended funding that includes concessional loan from public sector	Public program
Technical System Design	Diesel as the main power source responsible for CVCF with RE supporting PQ function	RE as the main power source responsible for CVCF with diesel supporting PQ function	Small solar home system, or mini-grid with RE as the main source but with: no CVCF or PQ functions. Black out or supply interruption allowed
	Grid stability as RE penetration increases	High level of engineering requirements for mini-grid	

Key Problems and Solutions		design Effective O&M platform Incentives to attract private participation Innovative business model to achieve economies of scale of a project, and Blended financing model for risk sharing between public and private companies	
Recommended Tasks	Determined capabilities of local communities Data base of mini-grid projects, including record of troubles, for knowledge accumulation and knowledge sharing Integrated O&M platform Effective Public and Private Partnership (PPP) model to encourage private participation (to modify and apply UNESCAPE's "5Ps Model) Blended financing and incentive tools for risk sharing between public and private companies Win-win collaboration between foreign technology companies and local enterprises for customization and localization of key equipment, and local capacity building		

Table 68. Categorization of PICT Islands

5.6.1.2. Concept of a Commercial Scale Microgrid Project in PICTs

Microgrid project for outer islands categorized into Group B has better potential to be carried out as a commercial-scale project with putting multiple microgrid projects together as to attract private sector and funding sources.

The characteristics of islands belonging to Group B are that there are small grids operated by a public utility or a private company, size of average load varies in the range of several hundred kW to several MW, electricity is mostly supplied through diesel-based generation. They have high demand of mini-grid with renewable energy and ESS, but economies of scale are required to develop a bankable commercial project. Hence, there is little potential to develop and execute mini-grid project in each island especially with attracting participation from private sector. However, private utility companies operate in some islands, so it is worth structuring technical and business model for development, financing and operation based on public and private partnership.

Considering roles of integrated technology and financing under the Paris Agreement, viable technical and business model could be developed and implemented with bundling multiple small microgrid projects into one commercial project. Paris Agreement emphasizes that developed country parties shall provide financial resources to assist developing country parties with respect to both mitigation and adaptation in continuation of their existing obligation under the Convention. It also states that the provision of scaled-up financial resources should aim to achieve a balance between adaptation and mitigation, taking into account country-driven strategies, and the priorities of developing country.

The Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE) has been already established under the umbrella of the Framework for Action on Energy Security in the Pacific (FAESP) to play a significant role as a regional centre of excellence to support the Pacific Island Countries and Territories (PICTs) in the mitigation of existing barriers for the creation of sustainable energy markets. So, PICTs demonstrates that they are actively participating to cope with Paris Agreement and should be supported by developed country parties, especially for financing in consideration of climate change and biodiversity.

There are increasing number of renewable energy projects in developing countries, which are developed, constructed and even operated by private sector, Independent Power Producer (IPP) based on Power Purchase Agreement (PPA) which is the basic, but unique type of Public Private Partnership (PPP) in energy sector. IPP finances renewable energy projects mainly from International Finance Corporation (IFC), Inter-American Development Bank (IDB) Invest and other international finical institutes which provide loans for the projects in developing countries. However, terms of conditions are not still intricate and strict to both IPPs and countries with low credit rate and require more responsibility from IPPs and countries including higher ratio of equity investment. Hence, blended financing model with public concessional fund needs to be considered. It should be well structured and tailored in alignment with nature, objectives and plan for each project.

Technical system of a bundled commercial project for islands in Group B is designed to make renewable energy the main power source responsible for CVCF with diesel support PQ function. With the proposed technical system design, integrated operation and maintenance model is suggested to reduce total cost and constraints of operation of microgrid projects, and achieve sustainability in outer islands.

5.6.2. Funding Model for Commercial Scale Microgrid Project

A Blended Financing could be considered in case that a project's financial feasibility is not good enough to justify a commercial financing. Blended Finance is defined by World Economic Forum and OECD as 'the strategic use of development finance and philanthropic funds to mobilize private capital flows to emerging and frontier markets. Blended Finance deliberately channels private investment to sectors of high-development impact while at the same time delivering risk-adjusted returns.

Blended Finance is an approach to structured finance that enables development and philanthropic funding to mobilize private capital into a project or company that promotes development outcomes, by mitigating risk and/or ensuring commercial risk adjusted returns. Blended Finance attempts to achieve similar goals to Impact Investing (intentional approach to create societal and financial impacts) by using a structuring approach to "blend" the different intents of a range of investor motivations to achieve these development objectives at scale. Method of blended finance could be in Figure 76.

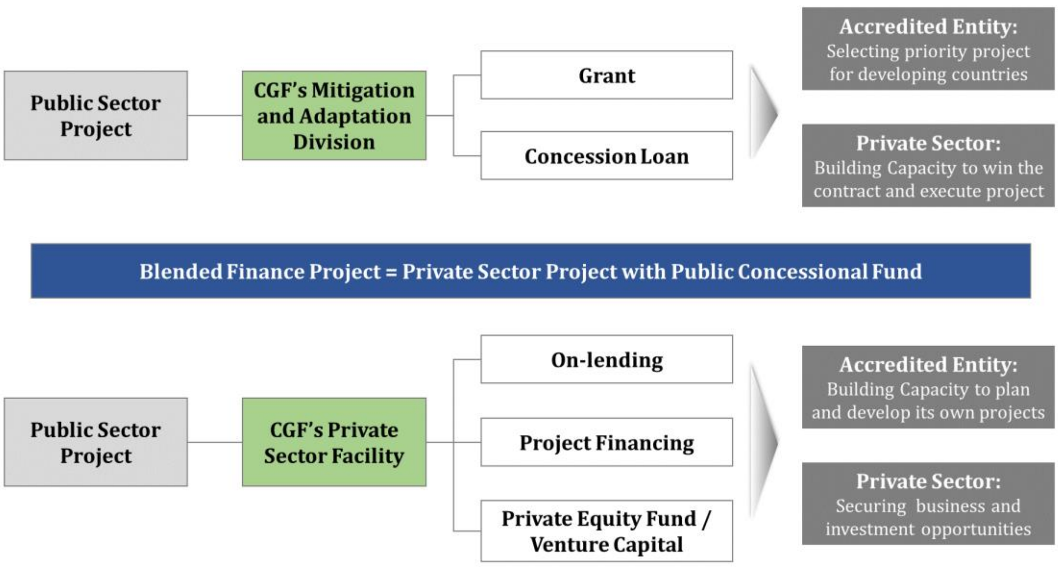


Figure 78.Structure of Blended Finance (WEF-OECD 2015)

Blended financing model is applied for private sector projects supported by GCF's Private Sector Facility or any other public concessional funding organizations. Public concessional funding organizations work with commercial or specialized bank for on-lending, project financing, private equity fund and venture capital. According to Green Climate Fund Analysis conducted by KPMG in 2018, international AE such as Green Climate Fund (GCF) focuses on projects with higher impact, which are replicable and scalable.

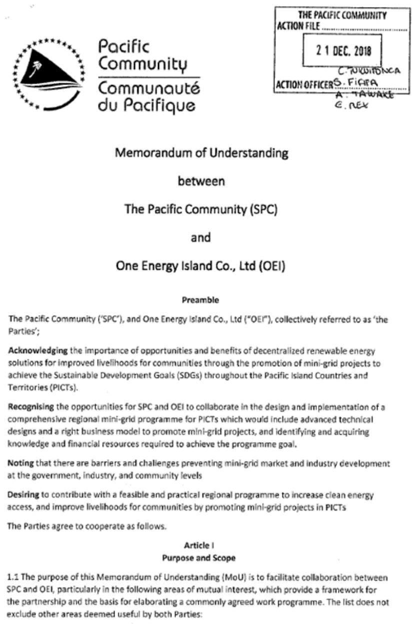
There have been many cases which demonstrates successful implementation and operation of microgrid systems in islands. Once microgrid project at Peleliu Island is successfully implemented and operated as planned and designed without significant issues, a commercial project plan for islands belonging to Group B stands out and attracts attention from both international Accredited Entity (AE) and private sector. Then blended financing model could be applied for funding with terms and conditions in favor of the project.

5.6.3.Key Public and Private Partnership Entities

5.6.3.1.PICTs

SPC (Secretary of Pacific Community) is the regional hub of PICTs for the sustainable community development of this region. In February 2019, SPC was designated as a GCF's AE (Accredited Entity) in particular for the following modalities: small amounts (up to 50m USD); fiduciary: basic + project management + grant; medium ESS risk (cat B). This is a recognition of SPC's track records and strengths in supporting for PICTs to address their priority climate change issues among which: food security, water security, health adaptation, low emission transportation, energy efficient infrastructure, disaster risk management, coastal erosion and more generally climate smart sustainable development.

One Energy Island (OEI) signed the Memorandum of Understanding (MOU) with SPC to collaborate in the design and implementation of a comprehensive regional mini-grid programme for PICTs which should include advanced technical designs and a right business model to promote mini-grid projects, and identifying and acquiring knowledge and financial resources required to achieve the programme goal. The purpose of the MOU is to facilitate collaboration between SPC and OEI, particularly in the areas of mutual interest including market intelligence, capacity building and PPP, technical advancement and mini-grid project promotion, which provide a framework for the partnership and the basis of elaborating a commonly agreed work programme.


Pacific Community
Communauté du Pacifique

THE PACIFIC COMMUNITY
ACTION FILE
21 DEC. 2018
ACTION OFFICER

Memorandum of Understanding

between

The Pacific Community (SPC)

and

One Energy Island Co., Ltd (OEI)

Preamble

The Pacific Community ('SPC'), and One Energy Island Co., Ltd ("OEI"), collectively referred to as 'the Parties';

Acknowledging the importance of opportunities and benefits of decentralized renewable energy solutions for improved livelihoods for communities through the promotion of mini-grid projects to achieve the Sustainable Development Goals (SDGs) throughout the Pacific Island Countries and Territories (PICTs).

Recognising the opportunities for SPC and OEI to collaborate in the design and implementation of a comprehensive regional mini-grid programme for PICTs which would include advanced technical designs and a right business model to promote mini-grid projects, and identifying and acquiring knowledge and financial resources required to achieve the programme goal.

Noting that there are barriers and challenges preventing mini-grid market and industry development at the government, industry, and community levels

Desiring to contribute with a feasible and practical regional programme to increase clean energy access, and improve livelihoods for communities by promoting mini-grid projects in PICTs

The Parties agree to cooperate as follows.

Article I
Purpose and Scope

1.1 The purpose of this Memorandum of Understanding (MoU) is to facilitate collaboration between SPC and OEI, particularly in the following areas of mutual interest, which provide a framework for the partnership and the basis for elaborating a commonly agreed work programme. The list does not exclude other areas deemed useful by both Parties:

Figure 79.MOU between SPC and OEI (21 December 2018)

Pacific Centre for Renewable Energy and Energy Efficiency (PCREEE) was established in 2017 as a knowledge hub with a focus on information exchange regarding regional interventions, tools, and methodologies in a partnership with the private sector, international donors, and the Pacific Island Countries and Territories. PICTs have growing attention and need for RE development and have set forth ambitious goals. PCREEE is closely working with SPC in sustainable community development in PICTs by promoting renewable energies.

December 2018, One Energy Island (OEI) signed an MOU with SPC and PCREEE for collaboration of mini-grid program development in PICTs. The MOU was signed subsequently after OEI successfully completed with "Consultancy Services for the Design of a Sub-Regional Renewable Energy Mini-grid Program for Pacific Island Countries and Territories." During the last week of June 2019 in Suva, Fiji, SPC and PCREE plan to hold an annual workshop for the topic of sustainable energy infrastructure development in PICTs. One Energy Island has been invited to present the Peleliu microgrid project, its technical design and development plan.

5.6.3.2.Korean Government

Korea Energy Agency (KEA) and Korea Institute of Energy Technology Evaluation and Planning (KETEP) are the main players in renewable energy in public sector.

Since its establishment in 1980, KEA has been at the forefront of efficient and rational energy use in Korea, as a silent guardian of Korea's sound economic development and better quality of life. From energy audit service, identifying energy saving potential in energy intensive businesses, to systematical optimization of building and industrial energy consumption pattern using ICT, KEA has led the transformation into a low energy consumption society with efficient energy use culture. In an effort to secure energy sources in resource-deprived country, KEA also paved a road for development and dissemination of renewable energy including solar and wind energy, while playing a pivotal role in climate change response and national greenhouse gas reduction. KETEP develops mission to contribute to the realization of the national energy vision by leading technological innovation and vision to become an energy R&D specialist institution that cultivates the world's highest levels of energy competitiveness. And it sets management goals to achieve more than double competitiveness in energy technology by 2025 with reducing the technological gap from 3.7 years to 1.5 years; increasing the ROI by 50% (compared to 2014); and achieving a 35% commercialization rate by leveraging core value of creativity and innovation, fairness and transparency, challenge and growth, and communication and cooperation.

KEA strives to strengthen the foundation of international cooperation on energy efficiency through bilateral and multilateral cooperation with other international organizations. The goal is to be an information hub for energy and climate change that can facilitate exchange of information through active participation in international cooperation projects. KEA also aims to heighten its country reputation in multilateral organizations and have stronger initiative for cooperation. KEA implements cooperation projects with developing countries to build infrastructure for climate change adaptation and lay foundation of relative businesses, which enables KEA to maintain good relations with those countries.

KETEP pursues Global Technology Exchange and Cooperation Project for both bilateral and multilateral cooperation in energy technology fields. For bilateral cooperation, it carries out projects based on MOU with exploring joint research topics through Government-to-Government (G2G) joint planning meetings and Energy Technology Joint workshops, and hosting Energy Technology Network Workshop to boost exchanges in the private sector. For multilateral cooperation, it actively works on activities for the Committee on Energy Research and Technology (CERT), participates in the 15 Technology Collaboration Programmes (TCPs) under the End-Use Working Party (EUWP), Working Party on Fossil Fuels (FFWP) and the Cross-cutting working group, and explores joint tasks by operating a domestic council for each TCP. Its four innovative challenge areas smart grids, off-grid access to electricity, carbon capture, and clean energy materials.

Based on international collaborative direction to support developing countries by both KEA and KETEP, they are in discussion to support Peleliu microgrid project as a pilot scale project in PICTs. KEA has conducted many feasibility studies continuously to find the opportunities for renewable energy to work with developing countries and contribute to meet their needs and supporting challenges they are facing. KETEP also promotes official development assistance (ODA) under the global technology and exchange program and seeks for opportunities of renewable energy projects, through which it pursues not only contribute to implement sustainable renewable energy and improve energy access, but transfer knowledge and experiences accumulated by implementing microgrid projects successfully in Korea, especially small island with inhabitants. A proposal to raise the fund for the Peleliu microgrid pilot project will be submitted to KETEP's evaluation session in May 2019. KEA and KETEP will review this feasibility study and proposal with prudence, evaluate the results including quantitative and qualitative feasibility focusing on benefits, and make the final decision whether to carry out this project. They consider the pilot project good opportunities to demonstrate advanced microgrid technologies all around the world and promote scaling-up microgrid in small islands.

5.6.4.Next Step

During SPC/PCREE annual workshop in June 2019, feasibility study on the Peleliu microgrid project will be present to share the results of feasibility study, detailed project plan including financing with selecting SPC as GCF's AE, demonstration plan and emphasize significant meaning of the project at various perspectives. Main audiences will be from energy sector in PICTs.

Subsequently, a discussion will be held among SPC/PCREE, Korean government including relevant ministries and major energy agencies, and private sectors to identify more opportunities of microgrid initiatives and develop commercial scale microgrid projects.

In the meantime, to accelerate appraisal process for the Peleliu project, the funding proposal will be prepared by OEI in collaboration with SPC/PCREEE and submitted to GCF by SPC.

5.7. Project Design Matrix (PDM)

The Project Design Matrix (PDM) is structured below to approach the actual project to be implemented. It includes the planning, implementing and evaluation of the microgrid system to be implemented on Peleliu island.

	Project Summary	Indicators	Means of Verification	Risks/ Assumptions
Goal	• To achieve sustainable power systems with increased renewable energy in Peleliu Island • To increase performance of renewable systems • To continue to reduce greenhouse gas emissions	• Contribution to renewable energies to power generation • Quality of electricity supply in Peleliu Island • Savings of diesel fuel and carbon emissions reduction	• Renewable energy target for Peleliu's SDGs • Peleliu Island power system operational report • PPUC annual report and sustainability report	• Changes in policy and SDGs target for renewable energy • Flawed technical analysis and design due to limited availability of input data • Natural disaster impacting power system generation and operation
Outcome	• Increased renewable energy penetration rate over 50%, which is 564 kW • Improved control of fault troubles and frequency and voltage • Reduced diesel consumption to 182,867 liter/year • Reduce carbon emissions to 482 ton/year • Trained skilled resources for solar power operation and maintenance	• Generation of electricity from renewable energy sources • Troubles on the grid including black-out, and frequency and voltage volatility • Quantity of diesel fuel consumption and cost reduction	• Peleliu Island power system operational report • PPCU annual report and sustainability report	• Flawed technical analysis and design due to limited availability of input data • Natural disaster impacting power system generation and operation • Lack of skilled resources for new technologies and installed system operation
Outputs	• Developed design and construction plan • Implemented 400 kW PV, 1 MW ESS and 200 kW ESS inverter • Developed manual and trained engineers for operation and maintenance	• Peleliu's power system (physical asset of newly implemented solar power system in operation) • Manual in use for operation and maintenance • Number of skilled engineers trained	• Project reports including inception report, interim report, final report and monitoring and evaluation report • Project documents including training plan and report and manual for operation and maintenance	• Delays in permits and licenses, especially UXOs clearance • Natural disaster impacting power system construction and equipment transportation • Lack of skilled resources working with the project
Activities	• To develop detailed design, procure equipment, and construct microgrid in Peleliu Island • To implement 400 kW PV, 1MW ESS and 200 kW ESS inverter • To prepare manuals and provide training for operation and maintenance and	**Input** • Donor organization and/or country - Funding for the project - Engineering and construction for solar power system - Supplies of key equipment including 400 kW PV, 1MW ESS, 200 kW ESS inverter, etc. - Test on system operation - Training by dispatched experts in Peleliu and inviting in donor country • Recipient Country - Construction site for solar power plant - Preparation and provision of required information, human resources, working space and transportation for equipment - Pre-environmental impact assessment and tariff exemption for imported equipment - Support for permits and licenses for construction and operations		• Funding with the favorable terms and conditions to recipient country and project in timely manner • Accuracy of system design • Proper project management in place **Precondition** • Secured land for solar power plant and • Pre-environmental impact assessment without any issues

6. Mini-grid Expansion Strategy to PICTS countries

6.1. Independent Power Plant Movement in PICTs

6.1.1. General Environment and Trend of Mini-grid Market in PICTs

Like other countries, transition to renewable energy is inevitable movement in PICTs Countries. Furthermore, PICTs countries have higher motivation for renewable energy transition since 13 countries are considered small island developing states (SIDS) according to the United Nations Department of Economic and Social Affairs (UN DESA),

In terms of the Renewable Energy Contribution percent and the stated 2020 goals, all countries have established goals for 2020 with the exception of Papua New Guinea. However, it remains unlikely that any of the listed countries will reach their stated goals with the possible exception of Fiji.

Country	Electrification Ratio (%)	RE Contribution (%)	2020 RE Goal (%)
Cook Islands	-	-	100%
Fiji	100	59	100%
Kiribati	48.1	2.6	10%
Marshall Islands	90	<1	20%
Micronesia (F.S.)	71.7	-	30%
Nauru	99.2	<1	50%
Palau	99.8	<1	20%
Papua New Guinea	20.3	35	No Target
Samoa	97.9	41	10%
Solomon Islands	35.1	<1	50%
Tonga	95.3	<1	50%
Tuvalu	98.5	3	100%
Vanuatu	34.5	19	65%

Table 68. PICTSs Countries RE goals (Data from different sources. World Bank Data (2014), Power Access and CO2 Emission. World Bank Data (2015), PPA (2011), RE rate, IRENA (2013), Pacific Lighthouses, French Development Agency (2014), Renewable Energy in Pacific Islands)

In order to accomplish the goals, set forth regarding Renewable Energy and Energy Efficiency, it was acknowledged that there was a need for regional organizations to pool together their resources in order to more efficiently work towards a more prosperous energy environment in the Pacific. The major organizations working to this end are:

- **The Pacific Community (SPC):** The SPC provides technical assistance, training and research services to the member countries in areas such as health, fisheries, human development and agriculture. Especially in recent years, sharing and promoting regional cooperation.
- **Pacific Center for Renewable Energy and Energy Efficiency (PCREEE):** PCREEE was established as a consultation and implementation body for the renewable energy and energy efficiency dissemination of the island countries in the South Pacific region as a part of the SPC, the Sustainable Energy Island and Climate Resilience Initiative (SIDS DOCK) and the United Nations Industrial Development Organization (UNIDO) Argument.
- **The University of the South Pacific (USP)** – Is a Public research organization with locations in Fiji, Samoa, Vanuatu, the Cook Islands, Kiribati, Marshall Islands, Nauru, Niue, The Solomon Islands, Tokelau, Tonga, and Tuvalu. As a public organization owned by the 12 previously mentioned governments, the USP promotes various programs and research grants regarding the Pacific Community and its members.
- **Pacific Power Association (PPA)** – Is an inter-governmental agency that promotes technical training, the exchange of information, and dissemination of technical expertise in order to benefit member countries in energy sector.

Even though, active goals set by PICTs countries, RE transition has not been easy. Most of generation in PICTs are heavily rely on fossil fuels such as diesel. The lack of appropriate policies, capacities, knowledge, finance and a stimulating business environment are constraints that restrict the growth of the energy market.

Most utility industry in PICTs are vertically integrated: generation, transmission, distribution and sales are monopolized by state-owned public utility corporation. This vertical structure very natural considering many PICTs countries are developing countries. “Competitive Electricity Markets: Design, Implementation, Performance” (Elsevier Science, 2008) explains that historically most electricity industries world-wide are vertically integrated, but these industries are not being liberalized. However, within vertical integration structure of PICTs electricity industry, most RE projects driven by public utility or government are not very scalable to meet national RE goals. Table 69 shows RE projects completed in PICTs. Most projects rely on international grant and sizes are small to contribute national RE goals.

Classification	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Project Type	Solar PV mini grid	Solar PV mini grid with Diesel	Solar PV/ Diesel hybrid mini	Solar PV/ Wind / Diesel hybrid mini	Solar PV/ Diesel hybrid mini	Solar PV/ Diesel hybrid mini

		back up	grid	grid	grid	grid
Location	Kauma (Abemama), Kiribati	Kiritimati island, Kiribati	Kadavu island, Fiji	Nabouvalu , Fiji	Kadavu island, Fiji	Vava'u island, Tonga
Business Year	2014	2014	2015	1997	2017	2013
Scope and Major Composition	42.525 kW_p sola PV (180 x 235 W_p) + 3488.3AH C_{10} Battery + 18 kWinverter (3 phase) with Diesel backup.	16.215 kW_p solar PV + 2150AH C_{10} battery + 12 kW inverter	249 kW_p solar PV + 2 x 23 kW Hatz twinpacks low load diesel generators	37.4 kW_p solar PV + 8 x 6.7 kW Bergey wind + 50 kW battery + 2 x 100 kVA diesel generators	30 kW_p solar PV + 32 kVA diesel generators -	420 kW_p Solar PV+ 930 kW Diesel + 100 kW Battery
Funding	A component of EU 10th European Development Funding (EDF)- Total 4.1 Million Euros	A component of EU 10th European Developmen t Funding (EDF)- Total 4.1 million Euros	UAE Pacific Partnership Fund (Total 5 million USD for 3 projects in Fiji)	MOFA, Japan (F$ 800,000) + FDoE , Fiji F$ 230,000	Korea Government (1.5 M USD) + Fiji Government (500, 000 FJD)	UAE partnership Fund

Table 70. Previous Public Mini-grid project in PICTs

This is mainly because financial sources in PICTs countries are limited. Both government budget is limited. For government budget, PICTs countries highly rely on ODA: most of the renewable energy projects in the Pacific are either donor funded or constructed using loans from international partner. Meanwhile for private sectors are not mature enough to project-finance power plant for long period (More than 10 years).

Country	ODA US$ in millions	ODA Received per Capita	Population (2012)	Land area (km2)	GDP per capita (WB)		GDP growth rate per capita (WB)	
					US$	Year	%	Year
Cook Island	8.09	536.22	15,087	237	15,002	2014	6.2	2014
Fiji	102.48	114.87	855,545	18,273	4,922	2015	5.56	2015
Kiribati	64.95	577.81	106,886	811	1,424	2015	3.5	2015
Marshall Is.	57	1,076.72	53,679	181	3,386	2015	0.63	2015
Micronesia (F.S.)	81.39	779.35	102,948	701	3,016	2015	3.77	2015
Nauru	31.25	2505	10,292	21	8,053	2015	2.81	2015
Palau	13.93	654.36	17,445	444	13,501	2015	9.36	2015
PNG	589.74	74.46	7,229,077	462,840	2,183	2015	8.53	2014
Samoa	93.72	483.69	187,610	2,785	4,149	2015	1.63	2015

Solomon Is.	190	323.47	587,068	30,407	1,922	2015	3.73	2015
Tonga	68.4	643.1	103,276	650	4,094	2015	3.71	2015
Tuvalu	49.65	4,513.23	10,732	26	2,970	2015	2.64	2015
Vanuatu	186.56	705.06	257,031	12,281	2,806	2015	-0.8	2015
Average	**118.24**	**999.03**	**-**	**-**	**5,187**	**-**	**3.94**	**-**

Table 71.Economic Structure of PICTs (World Bank)

6.1.2. Latest Renewable Energy IPP Projects Announced in PICTs

Recently electricity industry of PICTs countries is deregulated, and Independent Power Producers are invited to submit IPP proposals by some of countries in PICTs. The followings are examples.

- Tonga 6MW solar project in 2018
- Palau RE 45%(30MW~40MW) Solar+ESS IPP proposal in 2019

There are many motivations for electricity market deregulation and IPP, but main reasons for PICTs to adopt IPP scheme in energy transition are 1) to invite necessary funds for RE investment through the use of private funds, 2) to grow local renewable energy industry and market, and most of all 3) to achieve sustainability of mini-grid projects by allowing roles and responsibility of private companies in life-time operations of mini-grid projects (JICA 2018).

6.2. Palau Independent Power Producer Request of Proposal

Palau has announced to achieve 45% of renewable energy contribution by 2025. As the major implementation step, in February 2019, Palau Public Utilities Corporation (PPUC) announced Independent Power Producer (IPP) Request of Proposal (RFP). The PV generation facilities, energy storage systems, and provisions for grid stability (collectively referred to as the Project) are to be designed, financed, procured, installed, grid-connected, commissioned, owned, operated, and maintained by the IPP for the duration of the Power Purchase Agreement (PPA).

The Palau IPP project is one of the first IPP projects not only in PICTs but small island nations in the world. The project is significant particularly in terms of the size of grid, ratio of renewable energy contribution target, and technical challenges that the RFP requires to prospecting participants. The summary of RFP is as below.

Category	Value
Palau National Energy Policy	20% of RE by end of FY 2020 45% of RE by end of FY 2025
PPA conditions	Fixed-rate, 20-year (option for extending 5 years)

Commercial Operation Date	Within 12 months from PPA sign
Prediction of generation/load in central grid	89.4Gwh generation and 12.5 MW in 2018 96.9GWh generation and 14.6 MW in 2020 115.1GWh generation and 18.2MW in 2025 * This will be reference for carbon-free rate
T/D line	47 linear miles of 34.5KV transmission line 114 linear miles of 13.8KV distribution line
Sites	Sites are not limited, bidder can choose sites in central grid
Language/Currency	English/U.S. Dollars
Closing Date	Package A- 2019.4.10. Package B- 2019.5.31. Package C- 2019.5.31.

Table 72.Palau IPP RFP summary (PPUC 2019)

RFP designated to submit 3 packages (scenarios) for IPP. PPUC will choose which scenario is the best in negotiation stage.

Package A	Package A: 20% by end of FY 2020. Supply a minimum of 20.0 GWh's and a maximum of 23.0 GWh's to the K/B Grid by the end of fiscal year 2020
Package B	20% by end of FY 2020 and up to 45% by end of FY 2025. Supply a minimum of 52.0 GWh's and a maximum of 55.0 GWh's to the K/B Grid by the end of fiscal year 2025
Package C	45% by end of FY 2020. Supply a minimum of 52.0 GWh's and a maximum of 55.0 GWh's to the K/B Grid by the end of fiscal year 2020

Table 73. 3 packages in Palau RFP (PPUC 2019)

Palau IPP RFP also requires careful capacity determination and grid stability as Peleliu technical design.

① ESS is necessary to meet RE target more than 20% but cost of ESS affects project profitability. Therefore, capacity should be carefully determined.

② Since grid system in PICTs is small, but size of IPP should be large enough to be bankable. The IPP accounts for a significant proportion in electricity generation in total grid. IPP proposed by Palau RFP accounts for 20%~45% of total electricity generation in Palau. Therefore, careful grid-stability analysis should be done.

6.3. Pre-Feasibility Study of Palau IPP Project

6.3.1. Decision to Conduct a Pre-FS for the IPP Project

In January 2019, the consortium of the Feasibility Study of Peleliu Mini-grid project acknowledged the PPUC's plan for the IPP Project at the Palau main islands. And subsequently the consortium reported to Korea Energy Agency and discussed if this Feasibility Study should expand its scope to conduct a Pre-FS for the IPP project on a purpose of providing detailed preparatory information to Korean companies who might be interested in participating in the IPP project. As a result, an additional pre-FS was approved and conducted for the IPP project with an extension of the original feasibility study period from 9 months (Jun 2018 to Fed 2019) to 10 months (Jun 2018 to Mar 2019).

6.3.2. Palau Main Island Grid Analysis

The Most of load are in Koror which is south part of main island. Figure below is Koror-Babeldaob grid (K/B grid) which connect Koror (South) and Babeldaob. Even though Babeldaob is much bigger island than Koror, most of load is concentrated on Koror. 34.5 kV (High-Voltage, blue), 13.8kV, 7.967 kV (Middle-Voltage, red) 240/480, 277/480, 240,120/240, 120 (Low-Voltage).

There are two main power plants in K/B grid.

- Malakal Power Plant: Main power plant located on south of Koror.
- Aimeliik Power Plant: Sub Power Plant located Aimeliik which is one of the state in Babeldaob.

Figure 80. Koror-Babeldaob grid in Palau Main Island(PPUC, 2019)

Table below is diesel power plant status of Nigata 14 and 15 in Malakal Power Station which is the main generators running all the time. Mitsubishi 6 and 7 take turns in five days. For example, in 2016.1.9~1.14 Mistubishi 6 runs and 2016.1.14~19 Mistubishi 7 runs.

	Name	**Capacity(kW)**	**Voltage(kV)**	**Installation Year**
Malakal	Mitsubishi 12	3,400	13.8	1997
	Mitsubishi 13	3,400	13.8	1997
	Wartsila 1	2,000	13.8	1996
	Caterpillar 1	1,825	0.48	2006
	Caterpillar 2	1,825	0.48	2006
	Niigata 14 (Main)	**5,000**	**6.6**	**2005**
	Niigata 15 (Main)	**5,000**	**6.6**	**2005**

	Mitsubishi 1	500	0.48	2012
	Mitsubishi 2	500	0.48	2012
	Mitsubishi 3	500	0.48	2012
	Mitsubishi 4	500	0.48	2012
Aimeliik	**Mitsubishi 6 (Main)**	**5,000**	**13.8**	**2013**
	Mitsubishi 7 (Main)	**5,000**	**13.8**	**2013**
	CAT 3516	2,000	0.48	2012

Table 74.Diesel Power Plant Status (JICA, 2018)

In details, Figure 81 is diesel generation example in 2016. Load is about 10MW. Nigata 14, Nigata 15, Mitubishi 6 supply the load. Between 2am and 8am, when load is relatively low, one of Nigata generators stop for maintenance.

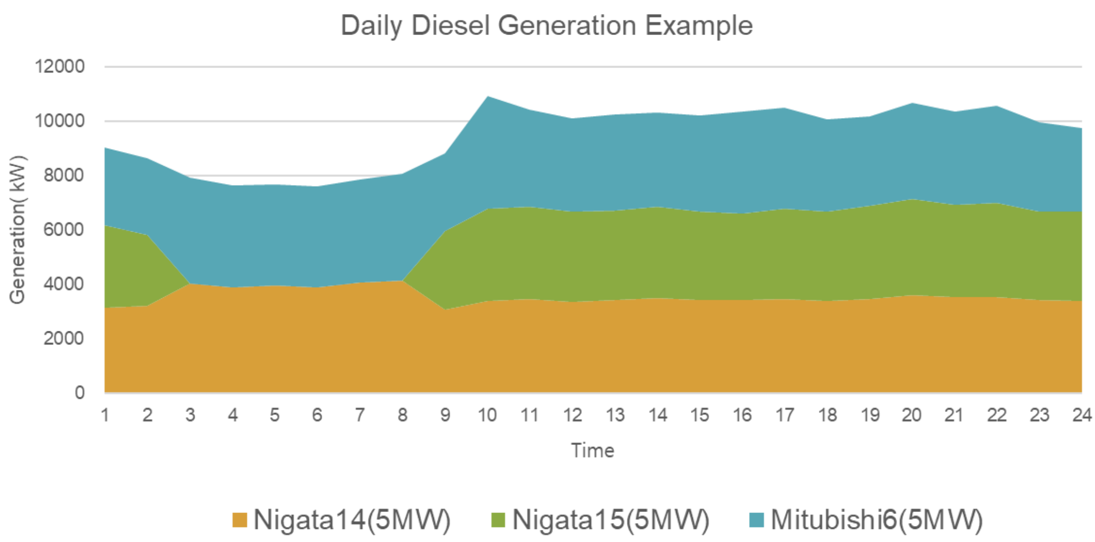


Figure 82. Daily Diesel Generation Example

6.3.3. Capacity Determination Analysis

PV and ESS capacity have been determined by following steps. For this analysis, we only consider package A and C which is RE 20% and 45%. The analysis is basically done by using Homer, like

Peleliu technical design.

① PPUC provides 2016/2017 hourly load data, and prediction 2020 load. Escalation rate is determined by estimated annual generation.

② According to RFP, there is minimum and maximum output of RE. Therefore, PV+ESS should meet minimum and maximum output stated in RFP.

- For 20%, a minimum of 20.0 GWh's and a maximum of 23.0 GWh'
- For 45%, minimum of 52.0 GWh's and a maximum of 55.0 GWh's

③ Dispatch strategy is load-following strategy. There are two main dispatch strategies in Homer: load-following and cycle-charging. Load-following strategy is more adequate strategy for IPP.

④ Diesel Operating Reserve

- Diesel should be ready to meet operating reserve, which means that 2 diesel power plants (10MW) have to run at least 30% which is mandatory by product manual (JICA 2018).

The result for capacity determination is as below.

RE Contribution	Diesel	PV	ESS	Inverter
RE 20%	20MW	17.5MW	15MWh	8MW
RE 45%	20MW	38.5MW	42.5MWh	10.5MW

Table 75.Resut of Homer ESS +PV Capacity Determination

6.3.4. Grid Stability Analysis

Separate grid stability study should be done for each package. However, JICA 2018 report shows power and voltage flow in 2016 which is similar to current system. Some clues can be identified in current system.

Power flow analysis in JICA report, Aimlik Power Plant takes main role to supply power. Airai substation is main-substation which supplies power to airport and downtown of Koror: about 7MW load flow into Airai Station. Moreover, about 1MW load flows to northern side of Aimeliik power station where most of Babeldaob area is located. Therefore, to control voltage and reduce transmission loss, it is better if IPP is located close to Airai substation.

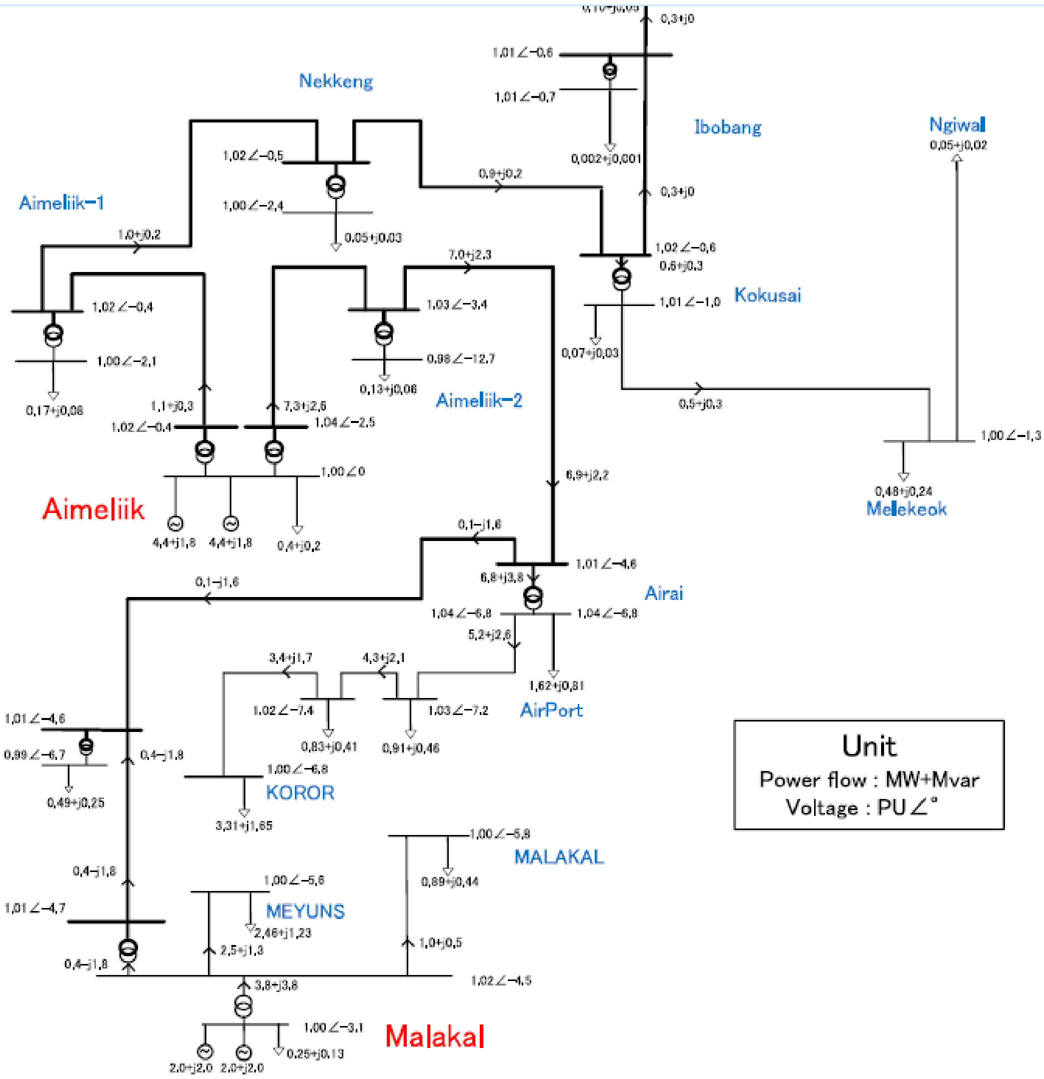
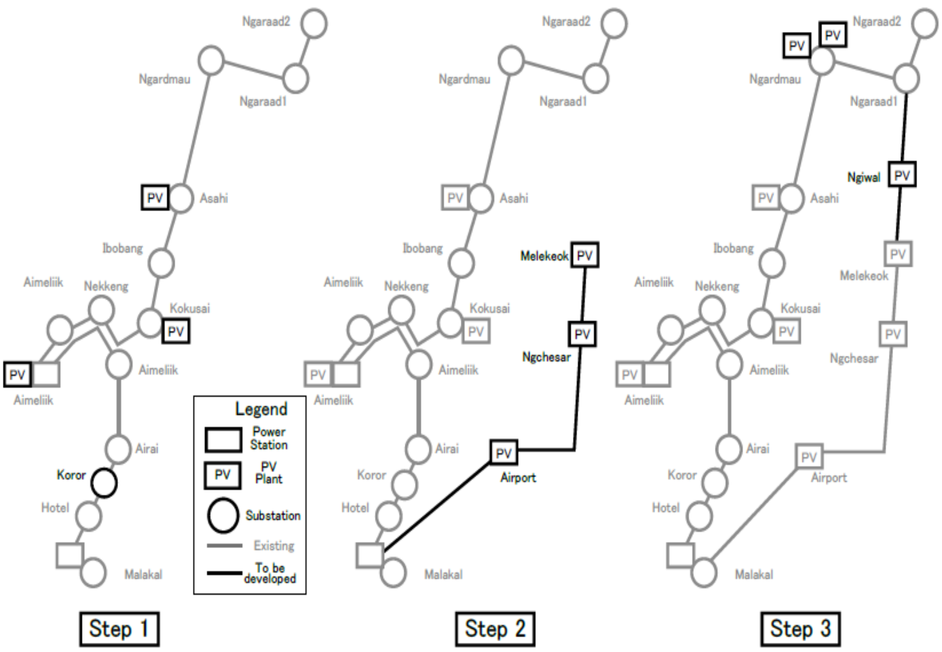


Figure 83. Power Flow Analysis in 2016(JICA,2018)

At present, only one circuit of 34.5 kV transmission line interconnects these two power stations. JICA analyzed that it was very fragile to fault current. It means that if any faults happen in this line, the power system shall be totally separated into two systems. JICA suggested open-loop distribution line system to back-up other grids.

Details of implementation plan is in chapter 3. The basic diagram for distribution line upgrade is in figure below. However, budget for distribution line reinforcement is not planned yet. Therefore, IPP grid stability should be done based on existing grid.



Source: JICA Project Team

Figure 84.3-step distribution line reinforcement plan (JICA,2018)

6.3.5. Land Survey

A survey to identify and assess site candidates has been conducted. As a result, total 31 candidate sites are identified in total 4.6 million square meters, each of which has good access condition and grid-connection point.

Province	Lot	Area (m2)	Capacity Estimates (KW Solar PV)
Aimelik	1	533,677	56,000
	2	23,900	2,100
Ngatpang	1	457,183	50,000
	2	115,115	12,500
	3	64,031	6,400
	4	28,517	2,500
	5	21,600	2,300

	6	102,548	10,800
	7	130,202	13,000
	8	119,884	11,000
	9	355,360	38,000
Ngaremlengui	1	103,811	11,000
	2	127,974	13,000
Ngardamu	1	153,865	15,000
	2	156,462	16,000
	3	53,856	5,500
	4	21,600	17,000
	5	44,617	4,000
	6	58,844	5,000
Ngaraard	1	69,374	7,000
	2	36,320	3,000
	3	75,211	7,000
Ngiwal	1	231,600	23,000
	2	177,710	18,000
	3	35,829	3,000
Melekeok	1	10,048	800
	2	246,336	26,000
	3	321,486	35,000
	4	348,422	35,000
Nchesar	1	264,278	28,000
Airai	1	107,722	10,000
Total			

Table 76.Site Survey Results with Capacity Estimates of Solar PV

Also, visible ground condition of each candidate sites is good without necessity of major civil work and deforestation. The following picture is the actual photo image of a candidate site.

Figure 85. Visible Ground Condition of Candidate Sites

Separately, a “Title Search” is being conducted with a hired lawyer in Palau. The Title Search is expected to provide detailed information of ownership of each of the candidate sites, and regulatory issues concerning land development.

6.3.6. Financial Feasibility Analysis

6.3.6.1. Project IRR Estimate

The most important thing in financial feasibility analysis in IPP is that Power Purchase Agreement (PPA) price. In RFP, proposed price should be fixed-rate price. Target price is determined based on current diesel variable cost. Since diesel generators are already installed more than peak-load and should be conserved for operating reserve, PPA price should be competitive to current diesel variable cost.

According to JICA 2018 report, PPUC tariff consists of energy rate and fuel rate. Energy rate is operation and maintenance cost of the following price list and has not changed at the same price since 2012, fuel rate has been reviewed and changed every quarter according to the change of the diesel price level. Therefore, fuel rate is appropriate indicator for diesel variable cost.

Category	Per kWh	Energy rate	Fuel rate	Total Rate
Residential	0-150	0.02	0.177	0.197
	151-500	0.094	0.177	0.271
	501+	0.143	0.177	0.32
Commercial/ Government	0-150000	0.143	0.177	0.32
	150001-250000	0.133	0.177	0.31
	250001+	0.123	0.177	0.3

Table 77.Tariff Table in 2018.1.1 (PPUC)

According to PPUC, the historical trend of fuel rate varies between 0.15~0.2$/kWh. From PPUC's interest and perspective, it is reasonable to consider that PPA price should be competitive with the fuel rate.

Category	2017.04.01	2017.07.01	2018.01.01
Fuel Rate($/kwh)	0.152	0.191	0.177

Table 78. Fuel rate change

There are several methods for assessment of the project's financial feasibility: Benefit/Cost (B/C) Ratio, Net Present Value (NPV), Internal Rate of Return (IRR), and Levelized Cost of Electricity (LCOE). Considering preliminary analysis, Project IRR is adequate method since it does not require discount rate and debt cost. JICA 2018 report suggested target IRR between 10% to 15% for the project, which is considered to be too high for international RE project considering the business risk of power development and the current market interest rate level. Considering Palau economic status, the target non-levered project IRR for the project was set as 10%. In order to meet a recommended PPA price target, an IRR simulation should be conducted in the following way.

First, three cases for the value of the target PPA price are set as in the following table. The numerical values of the target PPA price is not disclosed in this report. Instead, the values are described not as a real number but as A, B, and C in the following table because the recommended values of the target PPA price could be actually adopted by a Korean company or consortium later in an official proposal to PPUC.

Criteria	Scenario1	Scenario2	Scenario3
Target PPA($/kWh)	A	B	C

Table 79. IRR Scenarios

Other assumptions for IRR analysis are as below:

- Total capex budget is set 70 million USD.
- Operational period is set for 20 years.
- O&M cost is set for $9/kWp (Solar PV)
- Land lease price is set as $10/kWp (Solar PV).
- ESS replacement cost is set as 50% of initial ESS cost.

The IRR simulation adopted System Advisor Model (SAM) which is tools for performance and financial model used for IRR analysis. SAM is developed by NREL and conducts performance predictions and financial analysis. Comparing to Homer, SAM is more adequate tool for financial analysis. The result from SAM simulation is in the below table.

PPA Scenarios	**Project IRR Estimate**
A $/kWh	8.61%
B$/kWh	9.57%
C$/kWh	10.51%

Table 80. Result of IRR scenarios

6.3.6.2 Drafting Power Purchase Agreement

Power Purchase Agreement (PPA) is the most important agreement in IPP business since all revenue from IPP is generated by PPA. PPA should be "bankable" which means that PPA should meet evaluation criteria by lender. This chapter presents general structure of PPA suggested by both world bank and JICA and analyzes adequate PPA guideline for Palau IPP and other countries.

- Concessions for infrastructure A guide to their design and award (World Bank, 1996)
- JICA 2018 report chapter 8
- General term for bankable PPA guided by Word Bank (1996) and JICA (2018) are as below.

Terms	**Explanation**
Tariff	If energy source is dispatchable, capacity cost must be consider to compensate to follow since solar spot price+ capacity price. If energy source is not dispatchable such as RE, fixed-rate is usually applied.
Minimum/Maximum Output	Most PPA require minimum and maximum output of power plant, Palau RFP also suggests minimum and maximum output.

	- If supplier do not meet minimum amount, supplier has to pay penalty for unmet capacity. Usually, minimum output activates as deemed generation article as below. - If supplier produce over maximum output, purchaser do not have to purchase for exceed amount
Deemed Generation	Purchaser must pay for generation that would have been available. If purchaser do not accept electricity which supplier would have been produced, purchaser should either pay capacity cost. In RE generation, this usually aligned with minimum/generation output. Minimum generation output is deemed to generate. Even though purchaser need below minimum output due to dispatch order, low demand, purchaser should pay at least minimum generation output. On the other hand, supplier has penalty if they supply less than minimum/generation.
Deemed Commissioning	After commercial operation date which party agrees upon, power plants are deemed commissioned. There are many cases that either parties are not ready for commissioning until commercial operation date such as - Construction delay from supplier side. - Transmission preparation delay from purchaser side Either member of party who are responsible for delay has to compensate the other one
Change in Law	The PPA should address the impact on the tariff in the event of change in applicable law or its interpretation that affects the supplier. To be bankable, change in law should not affect cash flow of supplier.
Force Majure	PPA should clearly classify force majeure events, specifying the impact of each event on the obligations of the parties. Example of force majeure might be: - Specified nonpolitical events such as natural disasters, labor difficulties, and contractor failure - Domestic political events including war, revolution, terrorism, political sabotage - Foreign political events
Termination and Buyout Price	In the event of default, the non-defaulting party will have the rights, subject to certain cure rights for the defaulting party and lenders and other limitations, as to terminate the agreement and exercise certain other rights.

Table 81.General Structure of PPA (World Bank 1996, JICA 2018)

Both JICA and World Bank suggest that PPA may include government guarantee of PPA.

Government guarantee should cover any breach of contract by utilities. Since there is a risk of utility liquidation, government guarantee is essential especially in developing countries.

JICA 2018 suggested guarantee from international organization such as Political Risk Insurance (PRI) against the specific risks of transfer and convertibility, expropriation, war and civil disturbance, and breach of contract. Multilateral Investment Guarantee Agency (MIGA) provides PRI. PRI from MIGA often requires government guarantee. PRI can ensure payment or any compensation of breach of contract in PPA. However, PRI only guarantee breach of contract which is written on PPA.

6.3.7. Project Financing Plan

A project financing specialist from KORAMCO is invited and provides consultancy on the project financing for the IPP Project. KORAMCO (www.koramco.co.kr) is a domestic private fund specialized in real-estate and infrastructure investments both home and overseas. As or the end of 2017, KORAMCO manages about US 4 billion dollars investment portfolios. KORAMCO has been working to launch a fund to invest in energy projects in PICTs.

The ideal project financing structure was considered to be 30% equity and 70% non-resource project loan. For the equity financing, both strategic investor and financial investor should be considered to be invited. The design for equity and loan financing was suggested as below

- Equity (30%)
  - Equity of Strategic Investor (SI) (up to 50% of Equity),
  - Preferred share of Financial Investor (FI) or Equity (up tod 50% of Equity)
- Loan (70%)

Financing Conditions	Government guarantee for PPA.
Financing Source	International Financial Institutes supporting Asia-Pacific Region such as ADB (PSOD), AIIB and IFC.
Expected Terms and Conditions	Senior: 7 ~ 8%

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B/C ratio Calculation

Financial Feasibility Analysis_B/C Ratio

(Case1: Current, Case 2: Proposed)

Scenario	Benefit	Amount	Cost	Amount	B/C Ratio
Scenario 1	Benefit 1+ Benefit 2 Discount Rate 12%	1,155,488	Cost 1+Cost 2	1,362,563	0.848024873
Scenario 2	Benefit 1+ Benefit 2 Discount Rate 10%	1,337,272	Cost 1+Cost 2	1,375,127	0.972471556
Scenario 3	Benefit 1+ Benefit 2 Discount Rate 8%	1,572,658	Cost 1+Cost 2	1,392,067	1.129728507

Scenario 1(Discount Rate 12%)

Item	Description	Amount (USD)	Remark
Benefit			
Benefit 1	Savings of O&M Cost for 25 years	62,549	USD
Benefit 2	Savings of Fuel Cost for 25 years	1,092,939	USD
Sub-total		1,155,488	USD
Cost			
Cost 1	Increased Capital investment for 25 years	1,322,500	USD
Cost 2	Incrased Replacement Cost for 25 years	40,063	USD
Sub-total		1,362,563	USD

Scenario 2(Discount Rate 10%)

Item	Description	Amount (USD)	Remark
Benefit			
Benefit 1	Savings of O&M Cost for 25 years	72,389	USD
Benefit 2	Savings of Fuel Cost for 25 years	1,264,882	USD
Sub-total		1,337,272	USD
Cost			
Cost 1	Increased Capital investment for 25 years	1,322,500	USD
Cost 2	Incrased Replacement Cost for 25 years	52,627	USD
Sub-total		1,375,127	USD

Scenario 3(Discount Rate 8%)

Item	Description	Amount (USD)	Remark
Benefit			
Benefit 1	Savings of O&M Cost for 25 years	85,131	USD
Benefit 2	Savings of Fuel Cost for 25 years	1,487,526	USD
Sub-total		1,572,658	USD
Cost			
Cost 1	Increased Capital investment for 25 years	1,322,500	USD
Cost 2	Incrased Replacement Cost for 25 years	69,567	USD
Sub-total		1,392,067	USD

Detailed result for cases(Case1: Current, Case 2: Proposed)

Case1(Discount Rate 12%)

Component	Capital	Replacement	O&M cost	Fuel	Total (excluding Salvage)
PV	$ 328,000	$ -	$ 12,863	$ -	$ 340,863
FG Wilson	$ 150,000	$ 33,998	$ 323,365	$ 1,505,789	$ 2,013,151
HATZ	$ 84,000	$ 13,987	$ 145,639	$ 1,035,747	$ 1,279,373
Total	$ 562,000	$ 47,985	$ 481,867	$ 2,541,535	$ 3,633,387

Component	Capital	Replacement	O&M cost	Fuel	Total (excluding Salvage)
PV	$ 1,128,000	$ -	$ 44,235	$ -	$ 1,172,235
ESS	$ 462,500	$ 54,185	$ 72,549	$ -	$ 589,234
ESS Inverter	$ 60,000	$ 10,962	$ -	$ -	$ 70,962
FG Wilson	$ 150,000	$ 22,902	$ 255,388	$ 1,173,090	$ 1,601,381
HATZ	$ 84,000	$ -	$ 47,145	$ 275,506	$ 406,651
Total	$ 1,884,500	$ 88,048	$ 419,318	$ 1,448,596	$ 3,840,463

Case 2(Discount Rate 10%)

Component	Capital	Replacement	O&M cost	Fuel	Total (excluding Salvage)
PV	$ 328,000	$ -	$ 14,886	$ -	$ 342,886
FG Wilson	$ 150,000	$ 43,047	$ 374,237	$ 1,742,683	$ 2,309,967
HATZ	$ 84,000	$ 17,813	$ 168,552	$ 1,198,693	$ 1,469,057
Total	$ 562,000	$ 60,860	$ 557,675	$ 2,941,375	$ 4,121,911

Component	Capital	Replacement	O&M cost	Fuel	Total (excluding Salvage)
PV	$ 1,128,000	$ -	$ 51,195	$ -	$ 1,179,195
ESS	$ 462,500	$ 68,246	$ 83,963	$ -	$ 614,708
ESS Inverter	$ 60,000	$ 14,364	$ -	$ -	$ 74,364
FG Wilson	$ 150,000	$ 30,878	$ 295,567	$ 1,357,644	$ 1,834,088
HATZ	$ 84,000	$ -	$ 54,562	$ 318,849	$ 457,411
Total	$ 1,884,500	$ 113,487	$ 485,286	$ 1,676,493	$ 4,159,766

Case 3(Discount Rate 8%)

Component	Capital	Replacement	O&M cost	Fuel	Total (excluding Salvage)
PV	$ 328,000	$ -	$ 17,507	$ -	$ 345,507
FG Wilson	$ 150,000	$ 54,742	$ 440,110	$ 2,049,429	$ 2,694,281
HATZ	$ 84,000	$ 22,786	$ 198,220	$ 1,409,686	$ 1,714,692
Total	$ 562,000	$ 77,528	$ 655,837	$ 3,459,115	$ 4,754,480

Component	Capital	Replacement	O&M cost	Fuel	Total (excluding Salvage)
PV	$ 1,128,000	$ -	$ 60,206	$ -	$ 1,188,206
ESS	$ 462,500	$ 86,320	$ 98,742	$ -	$ 647,562
ESS Inverter	$ 60,000	$ 18,915	$ -	$ -	$ 78,915
FG Wilson	$ 150,000	$ 41,860	$ 347,592	$ 1,596,616	$ 2,136,068
HATZ	$ 84,000	$ -	$ 64,166	$ 374,973	$ 523,139
Total	$ 1,884,500	$ 147,095	$ 570,706	$ 1,971,588	$ 4,573,889

Annual Replacement Cost

Replacement cost and Schedule is provided by Homer

Case1(Current Situation)

Replacement Cost	Discount Rate	Life Time(Year)	Total NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
FG Wilson Replacement Cost	12%	13.0976	$ 33,998	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 150,000	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
Hatz Replacement Cost		13.419	$ 13,987	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 64,000		$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
FG Wilson Replacement Cost	10%	13.0976	$ 43,047	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 150,000	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
Hatz Replacement Cost		13.419	$ 17,813	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 64,000		$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
FG Wilson Replacement Cost	8%	13.0976	$ 54,742	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 150,000	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
Hatz Replacement Cost		13.419	$ 22,786	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 64,000		$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –

Case2(Proposed)

Replacement Cost	Discount Rate	Life Time(Year)	Total NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
ESS	12%	12.80437	$ 54,185	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 231,250	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
ESS Converter		15	$ 10,962	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 60,000	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
FG Wilson Replacement Cost		16.5837	$ 22,902	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 150,000	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
Hatz Replacement Cost			$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
ESS	10%	12.80437	$ 68,246	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 231,250	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
ESS Converter		15	$ 14,364	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 60,000	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
FG Wilson Replacement Cost		16.5837	$ 30,878	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 150,000	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
Hatz Replacement Cost			$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
ESS	8%	12.80437	$ 86,320	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 231,250	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
ESS Converter		15	$ 18,915	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 60,000	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
FG Wilson Replacement Cost		16.5837	$ 41,860	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ 150,000	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –
Hatz Replacement Cost			$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –	$ –

Annual O&M Cost

O&M cost and Schedule is provided by Homer

Case1(Current Situation)

Annual O&M Cost Scenario	Discount Rate	Total NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV O&M Cost	12%	$ 12,863	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640
FG Wilson O&M Cost		$ 323,365	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229
Hatz O&M Cost		$ 145,639	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569

Annual O&M Cost Scenario	Discount Rate	Total NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV O&M Cost	10%	$ 14,886	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640
FG Wilson O&M Cost		$ 374,237	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229
Hatz O&M Cost		$ 168,552	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569

Annual O&M Cost Scenario	Discount Rate	Total NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV O&M Cost	8%	$ 17,507	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640	$ 1,640
FG Wilson O&M Cost		$ 440,110	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229	$ 41,229
Hatz O&M Cost		$ 198,220	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569	$ 18,569

Case2(Proposed)

Annual O&M Cost Scenario	Discount Rate	Total NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV O&M Cost	12%	$ 44,235	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640
BESS O&M Cost		$ 72,549	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250
FG Wilson O&M Cost		$ 255,388	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562
Hatz O&M Cost		$ 47,145	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011

Annual O&M Cost Scenario	Discount Rate	Total NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV O&M Cost	10%	$ 51,195	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640
BESS O&M Cost		$ 83,963	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250
FG Wilson O&M Cost		$ 295,567	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562
Hatz O&M Cost		$ 54,562	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011

Annual O&M Cost Scenario	Discount Rate	Total NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV O&M Cost	8%	$ 60,206	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640	$ 5,640
BESS O&M Cost		$ 98,742	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250	$ 9,250
FG Wilson O&M Cost		$ 347,592	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562	$ 32,562
Hatz O&M Cost		$ 64,166	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011	$ 6,011

Annual Fuel Cost

Fuel import price(Provided by PPUC)*Fuel consumption rate(provided by manual)*Fuel consumption scenario(provided by Homer)

Case1(Current)

Annual Fuel Cost Scenario	Discount Rate	Total NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
FG Wilson Fuel Cost	12%	$ 1,505,789	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988
Hatz Fuel Cost		$ 1,035,747	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058
FG Wilson Fuel Cost	10%	$ 1,742,683	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988
Hatz Fuel Cost		$ 1,198,693	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058
FG Wilson Fuel Cost	8%	$ 2,049,429	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988	$ 191,988
Hatz Fuel Cost		$ 1,409,686	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058	$ 132,058

Case2(Proposed)

Annual Fuel Cost Scenario	Discount Rate	Total NPV	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
FG Wilson Fuel Cost	12%	$ 1,173,090	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569
Hatz Fuel Cost		$ 275,506	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127
FG Wilson Fuel Cost	10%	$ 1,357,644	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569
Hatz Fuel Cost		$ 318,849	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127
FG Wilson Fuel Cost	8%	$ 1,596,616	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569	$ 149,569
Hatz Fuel Cost		$ 374,973	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127	$ 35,127