A Review of the Kiribati PV and BESS Integration Studies

Based on the KINSO 2020 PHC Data

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FEBRUARY 2023

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1 Project Introduction

The island country of Kiribati is located in the central Pacific Ocean and consists of 33 low-lying atoll islands. Of these, 20 remain inhabited. In the 2020 Population and Housing Census conducted by the Kiribati National Statistics Office (KINSO), the area of South Tarawa on the island of Tarawa was reported to be the most populated island in Kiribati having a total population of 63,072. This was over half of the recorded national population of 119,438. Past trends reveal that this is expected to increase over time given its place as the capital and hub of the country. The total number of private households on South Tarawa currently stands at 9,444 with an average household size of 6.5 and a total population of 61,604 making up these households. The average annual population growth rate of 5% in 2020 compared to the national growth rate of 2.2% has made the area one of the most densely populated places in the world. This has been attributed to the impending impacts of climate change and significant increases to urban migration of entire families for employment and education purposes. These factors have all contributed to the increase in electricity demand throughout South Tarawa, the subsequent system overloads, and continued increases to violation of system constraints on the current network resulting in the ongoing power blackouts experienced throughout the island.

In consultation and agreement with the Public Utilities Board (PUB) of Kiribati, this study will combine project proposals submitted to PUB for grid expansion and assess system stability in response to the following changes in the current network;

1. increases in power demand in proportion to the 5% annual population growth rate,
2. increases in electrification coverage,
3. the integration of the proposed 4MW and 2MW to help address present and future demand,
4. the integration of the 5MVA and 2.2MVA BESS to help address PV generation constraints,
5. upgrades to the power grid to accommodate increases in generation and demand,
6. and the addition of two new 550kW reverse osmosis desalination plants to the grid.

This study will be presented in this report in the following sections:

- The Executive Summary section providing concise review of the study findings
- The Project Introduction section providing a brief overview of the report
- The Input Data provides a description of the Kiribati PUB electrical network along with the parameters of all components modelled in this study.
- The Methodology section provides a summary of the procedures used to conduct the steady state studies.
- The Study Results section presents and comments on the obtained study results.
- The Annex section gives detailed tabulated results and single line diagrams.

An important note: There was no grid code available at the time of study for the Kiribati electricity distribution system. Therefore, this study uses best engineering practices and the relevant Australian codes and standards for comparison and evaluation of obtained results.

2 Data for Network Analysis

2.1 Study Activities

The following activities were done as part of the network analysis:

- A review of the PUB network for maximum and minimum loads in 2020, 2030, and 2040.
- Development of the base network model using all network elements provided by PUB in the latest single line diagram.
- Completion of the steady state studies to assess voltage profiles, equipment loading, system losses and short circuit levels after PV and BESS connection.

2.2 Network Single Line Diagram

The single line diagram of the PUB power system was used as a starting point for software modelling on DIgSILENT. This included the existing 11kV network of transmission line types and lengths, generator ratings and location, installed PV systems and their respective ratings, circuit breakers, switches, voltage regulators, and 11/0.415kV transformers. The single line diagram provided by PUB and the modelled version are presented in the Appendix .

2.3 Generators

The current diesel power generation on South Tarawa is provided by six generators. Generators 1, 3, 4, and 5 operate on the 11kV voltage level and are connected directly to the main 11kV grid. These provide the island's generation for base load. Additionally, Generators 2 and 6 are located at Betio PS and Bikenibeu PS respectively and operate on the 0.415kV. These are connected to the grid via 11/0.415kV transformers and provide the backup generation for power or voltage support. This study has not relied on these backup generators for support during normal operation analysis.

Furthermore, there are plans to install 2MW of diesel generation set (800kW minimum capacity) each at Betio PS and at Bikenibeu PS. These have only been included in the analysis for the year 2030 and 2040 as both are expected to be fully functional then. Owing to the surpassing of maximum generation capacity in 2040, this study also sees the need for the addition of an additional 2MW diesel generation and the consequent upgrading of existing generators to 2MW rating. For this study, the parameters of Generator 7 have been applied to all proposed and unaccounted diesel generation sets.

Generator parameters were adopted from the following reports:

1. Kiribati PV and BESS Integration Studies, August 2020.
2. Independent Review of Proposed Power Supply Plan – Steady State Study Prepared for the Finnish Consulting Group and Asian Development Bank Version, Version 1.1, done for South Tarawa Water Supply Project, November 2019.

These have been set to operate at a nominal power factor of 0.85 based on observations carried out on site. The limitations in terms of available active power have been considered based on a power factor of 0.8, as used in a previous study. A summary of the generator nominal, maximum and minimum power is presented in Table 2.1.

Table 2.1. Operational Limits of Power Generators

Generator	Connection Point	Rating (kW)	Maximum (kW)	Minimum (kW)
Generator 1	Betio PS	1250	900	500
Generator 2 - Standby	Betio PS	625	400	350
Generator 3	Bikenibeu PS	1400	1120	500
Generator 4	Bikenibeu PS	1400	1400	500
Generator 5	Bikenibeu PS	1400	1120	500
Generator 6 - Standby	Bikenibeu PS	823	400	350
Generator 7	Betio PS	2000	2000	800

The bus voltage setpoint for Generator 3, 4, and 5 at Bikenibeu PS was used to keep voltage/reactive power within permissible limits. A set point of 1025% was applied prior to the connection of PV and BESS at Bonriki. Generator 1 at Betio PS was operated at 0.85 power factor. Generator 2 at Betio PS and Generator 6 at Bikenibeu PS were kept out of service and only brought into service to keep the voltage profile within accepted limits for the year 2020. The same principle was applied to Generator 7 and the additional generator (denoted Generator 8) at Bikenibeu PS to maintain the voltage profile for the year 2030 and 2040. Generator 3 was set as the network reference generator. Generator control parameters as presented in Table 2.2 were obtained from previous consultant reports submitted by PUB. The information is sufficient to carry out steady state analysis.

Table 2.2. Generator Control Parameters

Generator Data	Gen 1	Gen 2, 6	Gen 3, 4	Gen 5	Gen 7, 8
Nominal Power	1250 kW	823 kW	1400 kW	1400 kW	2000 kW
Nominal Voltage (kV)	11	0.415	11	11	11
Power Factor	0.8	0.8	0.8	0.8	0.8
Active Power Limits - Maximum Value (MW)	0.9	0.6	1.12	1.12	2
Active Power Limits - Minimum Value (MW)	0.5	0.35	0.5	0.5	0.8
Zero Sequence Reactance, x0	0.11	0.037	0.12	0.12	2
Zero Sequence Resistance, r0	0	0	0	0	0
Negative Sequence Reactance, x2	0.26	0.18	0.28	0.28	0.28
Negative Sequence Resistance, r2	0	0	0	0	0
Synchronous Reactances d- xd (pu)	1.3	3.94	1.4	1.4	1.4
Synchronous Reactances q- xq (pu)	1.3	2.36	1.4	1.4	1.4
Transient Reactance d- xd' (pu)	0.32	0.208	0.36	0.36	0.36
Transient Reactance q- xq'(pu)	0.32	0.208	0.36	0.36	0.36
Sub-Transient Reactance d- xd" (pu)	0.23	0.176	0.25	0.25	0.25
Sub-Transient Reactance q- xq" (pu)	0.23	0.186	0.25	0.25	0.25
Time Constant - Td' (s)	0.55	0.18	0.55	0.55	0.55
Time Constant - Td" (s)	0.026	0.018	0.026	0.026	0.026
Time Constant - Tq' (s)	0.55	0.18	0.05	0.05	0.55
Time Constant - Tq" (s)	0.05	0.018	0.05	0.05	0.05
Inertia Constant (sec)	5	5	5	10	5

Generator Data	Gen 1	Gen 2, 6	Gen 3, 4	Gen 5	Gen 7, 8
Governor System Types/Parameter	IEEE - TGOV1	IEEE - TGOV1	IEEE - TGOV1	IEEE - TGOV1	IEEE - TGOV1
Excitation System Type/Parameter	IEEE - ST2A	IEEE - ST2A	IEEE - ST2A	IEEE - ST2A	IEEE - ST2A

2.3.1 Generator Dynamic Modelling

For dynamic control of generator speed and voltage output, a model of the governor and excitation systems were applied to all generators. The governor parameters modelled the generator speed and active power output while the excitation parameters modelled the generator voltage and reactive power output. Given that there were no available data for these controls, the IEEE standard dynamic models available in PowerFactory were used.

2.3.1.1 Assumptions

- Governor model – speed control with internal 16-cylinder combustion engine.
- Excitation model – IEEE type ST2A.
- Same specification for Gen 1, Gen 3, Gen 4 and Gen 5.
- Specifications for Gen 2 and Gen 6 adopted from Gen 3.
- Gen 7 shares the same machine parameters as Gen 3.

2.3.1.2 Turbine Governor

The IEEE TGOV1 is a simple model that mimics governor action and the reheater time constant effect for a steam turbine. This is as also used in Reference 5 and 6. Figure 2.1 shows the TGOV1 turbine generator block diagram while Table 2.3 lists the parameters used.

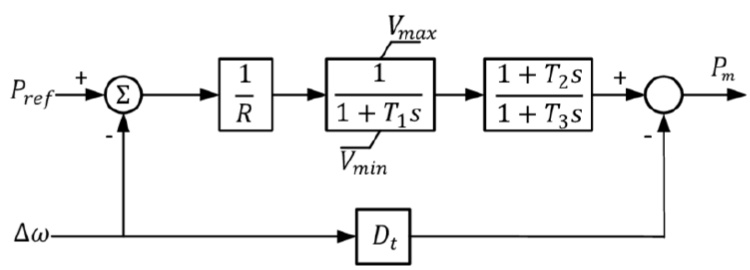


Figure 2.1. TGOV1 Block Diagram

Table 2.3. TGOV1 Turbine Governor Parameters

Name	Value	Unit	Description
T3	2	pu	Turbine Delay Time Constant
T2	1	pu	Turbine Derivative Time Constant
At	1	pu	Turbine Power Coefficient
Dt	0	pu	Frictional Losses Factor
R	0.05	pu	Frictional Losses Factor
T1	0.2	s	Governor Time Constant
PN	0	MW	Turbine Rated Power (=0->PN=Pgnn)
Vmin	0	pu	Minimum Gate Limit
Vmax	1	pu	Maximum Gate Limit

2.3.1.3 Excitation Model

The selected IEEE ST2A exciter model is for a potential source-controlled rectifier excitation system. This model represents a system where excitation power is delivered through a transformer connected to the generator terminals or auxiliary bus and regulated by a controlled rectifier. The maximum exciter voltage is directly related to the generator terminal voltage. The regulator output is added to the compounded transformer output. The block diagram of the IEEE ST2A exciter model is shown in Figure 2.2, while the set of used parameters are shown in Table 2.4.

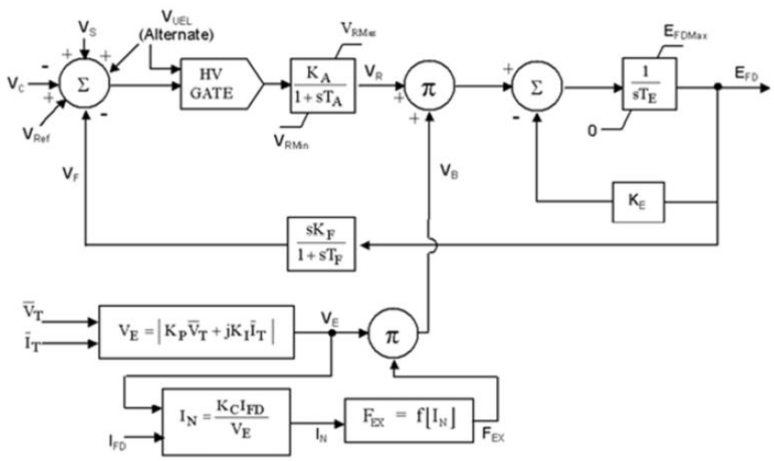


Figure 2.2. IEEE ST2A Block Diagram

Table 2.4. IEEE ST2A Static Exciter Parameters

Name	Value	Unit	Description
Tr	0.02	s	Measurement Delay
Ka	200	pu	Controller Gain
Ta	0.3	s	Controller Time Constant
Te	0.05	s	Exciter Time Constant
Ke	1	pu	Exciter Constant
Kf	0.03	pu	Stabilization Path Gain
Tf	0.5	s	Stabilization Path Time Constant
Kp	1	pu	Voltage Factor
Ki	0.02	pu	Current Factor
Kc	0.1	pu	Excitation Current Factor
Vrmin	-10	pu	Controller Output Minimum
Vrmax	10	pu	Controller Output Maximum
EFDmax	6	pu	Exciter Maximum Output

2.4 Photovoltaic (PV) Systems

The PV generation was modelled using the maximum recorded generation output to offset reliance on diesel generation. This was done on the condition that stable operation was maintained during an N-1 contingency event. The PV operational limits are as listed in the table below.

Table 2.5. PV Generator Operational Limits

Generator	Connection Point	Rating (kW)
K.I.T	RMU53	158.14
Betio Stadium	RMU61	137.2
Police	RMU29	157.6
Nawerewere	RMU42	216.4
Bonriki	RMU39	2200
Bonriki	RMU39	20 x 25
Bikenibeu PS	PV RMU	100 x 4

2.5 PV and Battery Energy Storage System (BESS) at Bonriki

The proposed 4MW PV system and the 5MVA BESS were connected to RMU39 at Bonriki to the low voltage end of a 5MVA, 11/0.415kV transformer. An earlier proposal for a 2.2MVA PV and 2MVA (500kWh) BESS connected to the same RMU39 at Bonriki has also been included in this study. This arrangement has been considered for all analyzed study years.

Like previous studies, the BESS was modelled as a static generator allowing for simulation of BESS power recharging (absorb power from the network) and discharging (release power to the network).

2.6 PV Dynamic Modelling

The dynamic model of the PV systems was adopted from the DIgSILENT software library to model its dynamic responses. The model is presented in Figure 2.3 as a block diagram and includes the PV array, PV controller and active power reduction modules. The parameters of these modules are presented in Table 2.6, Table 2.7, and Table 2.8.

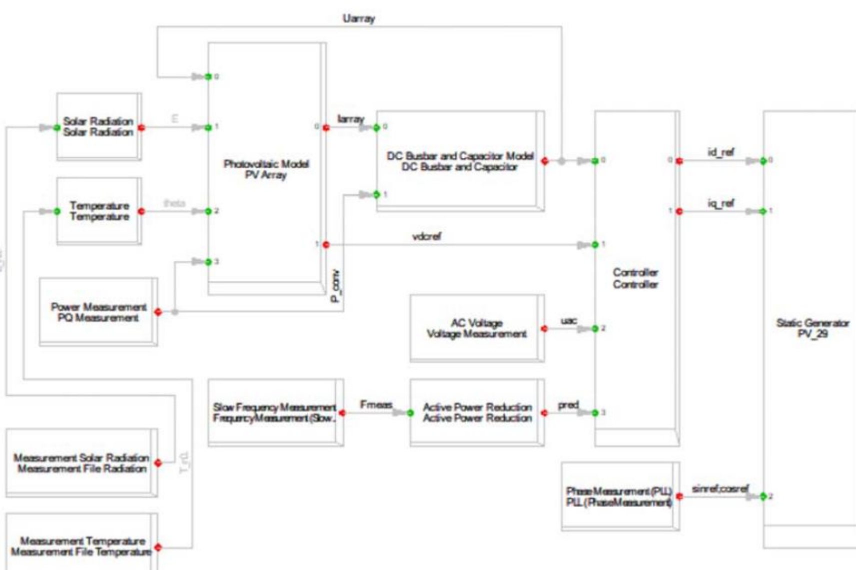


Figure 2.3. PV System Block Diagram

Table 2.6. PV Array Parameters

Name	Value	Unit	Description
U0_stc	43.8	V	Open-circuit voltage of module at STC
Umpp_stc	35	V	MPP voltage of module at STC
Impp_stc	4.58	A	MPP current of module of STC
Isc_stc	5	A	Short-circuit current of module at STC
au	-0.0039	1/K	Temperature correction factor (voltage)
ai	0.0004	1/K	Temperature correction factor (current)
Tr	0	s	Time constant of module
n_series	20		Number of modules in series
n_parallel	140		Number of modules in parallel

Table 2.7. PV Controller Parameters

Name	Value	Unit	Description
Kp	0.005		Gain, Active Power PI-Controller
Tip	0.03	s	Integration Time Constant, Active Power PI-Ctrl
Tr	0.001	s	Measurement Delay
Tmpp	5	s	Time Delay MPP-Tracking
Deadband	0.1	pu	for Dynamic AC Voltage Support
K_FRT	2		Gain for Dynamic AC Voltage Support
i_EEG	0		: 0 = acc. TC2007; 1 = acc. SDLWindV
id_min	0	pu	min. active current limit
iq_min	-1	pu	min. reactive current limit
id_max	1	pu	max. active current limit
iq_max	1	pu	max. reactive current limit
U_min	200	V	minimal allowed DC-voltage
maxAbsCur	1	pu	max allowed absolute current
maxlq	1	pu	max abs reactive current in normal operation

Table 2.8. PV Active Power Reduction Parameters

Name	Value	Unit	Description
fUp	50.2	Hz	Start of Act. Power Reduction
fLow	50.05	Hz	End of Act. Power Reduction
gradient	40	%/Hz	Gradient of Act. Power Reduction
Tfilter	0.01	s	PT1-Filter Time Constant

2.7 BESS Dynamic Modelling

The dynamic model of the BESS systems was adopted from the DIgSILENT software library to model its dynamic responses. The model is presented in Figure 2.4 as a block diagram that includes the BESS controller, frequency controller and the charger controller modules. The parameters of these modules are presented in Table 2.9, Table 2.10, and Table 2.11.

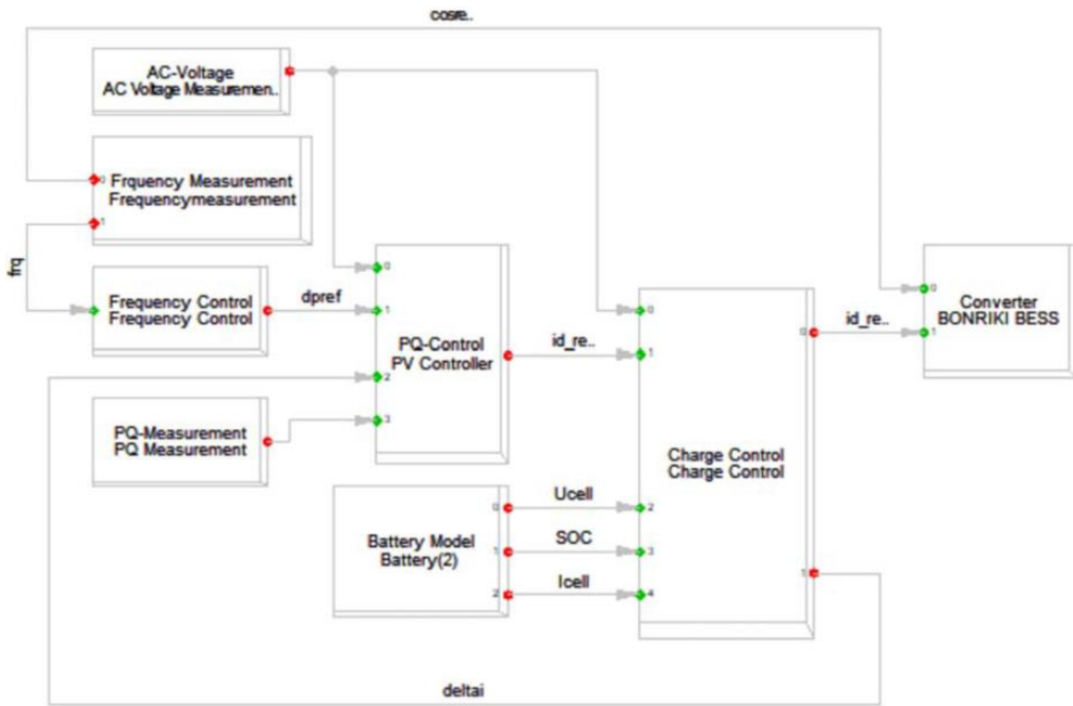


Figure 2.4. BESS System Block Diagram

Table 2.9. BESS PV Controller Parameters

Name	Value	Unit	Description
Tr	0.01	s	Filter time constant, active path
Trq	0.1	s	Filter time constant, reactive path
Kp	2	pu	Proportional gain - id-PI-controller
Tip	0.2	s	Integrator time constant -id-PI-controller
AC_deadband	0	pu	deadband for proportional gain
Kq	1	pu	Proportional gain for AC-voltage support
Tiq	0.002	s	Integrator time constant -iq-I-controller
id_min	-0.4	pu	Max discharging current
iq_min	-1	pu	Min reactive current
id_max	1	pu	Max charging current
iq_max	1	pu	Max charging current

Table 2.10. BESS Frequency Control Parameters

Name	Value	Unit	Description
droop	0.004		0.02/0.04 -> full active power within 1Hz/2Hz
db	0.0002	pu	deadband for frequency control

Table 2.11. BESS Charge Control Parameters

Name	Value	Unit	Description
ChargeCur	0.05	pu	min charging current
minSOC	0	pu	minimal SOC, discharging will be stopped
maxSOC	1	pu	maximal SOC, charging will be stopped
deltau	0.9	pu	threshold for iq preference

2.8 Power Cable Parameters

Power elements on the PUB power grid are connected by medium voltage (11kV) underground cables. The ratings and parameters of these cables are as detailed in Table 2.12.

Table 2.12. Cable Parameters

Name	Cable Type	From	To	Length (km)	I_r (kA)	R_1 (Ω)	X_1 (Ω)	R_0 (Ω)	X_0 (Ω)
Line	NYSEY 3x25RM 6/10kV	RMU50	RMU48	3.034	0.132	2.211	0.385	8.846	1.54
Line 1	NYSEY 3x25RM 6/10kV	RMU49	RMU47	1.278	0.132	0.932	0.162	3.726	0.649
Line 10	NYSEY 3x50RM 6/10kV	RMU38	Terminal	0.63	0.189	0.245	0.072	0.978	0.287
Line 11	NYSEY 3x50RM 6/10kV	RMU38	RMU46	0.53	0.189	0.206	0.06	0.823	0.242
Line 12	NYSEY 3x95RM 6/10kV	RMU46	RMU52	0.7	0.275	0.136	0.072	0.544	0.287
Line 13	NYSEY 3x95RM 6/10kV	RMU52	RMU62A	0.01	0.275	0.002	0.001	0.008	0.004
Line 14	NYSEY 3x25RM 6/10kV	RMU46	RMU39	1.015	0.132	0.74	0.129	2.959	0.515
Line 15	NYSEY 3x25RM 6/10kV	RMU39	RMU44	0.834	0.132	0.608	0.106	2.432	0.423
Line 16	NYSEY 3x50RM 6/10kV	Terminal 1	RMU33	0.01	0.189	0.004	0.001	0.016	0.005
Line 17	NYSEY 3x25RM 6/10kV	RMU44	RMU57	2.44	0.132	1.779	0.31	7.114	1.239
Line 18	NYSEY 3x25RM 6/10kV	RMU57	RMU56	0.85	0.132	0.62	0.108	2.478	0.432
Line 19	NYSEY 3x25RM 6/10kV	RMU56	RMU55	0.61	0.132	0.445	0.077	1.778	0.31
Line 2	NYSEY 3x25RM 6/10kV	RMU48	RMU49	3.381	0.132	2.464	0.429	9.857	1.716
Line 20	NYSEY 3x25RM 6/10kV	RMU55	RMU43	1.21	0.132	0.882	0.154	3.528	0.614
Line 21	NYSEY 3x25RM 6/10kV	RMU43	RMU31	1.184	0.132	0.863	0.15	3.452	0.601
Line 22	NYSEY 3x50RM 6/10kV	RMU31	RMU42	0.79	0.189	0.307	0.09	1.227	0.36
Line 23	NYSEY 3x50RM 6/10kV	RMU42	RMU40	0.74	0.189	0.287	0.084	1.149	0.338
Line 24	NYSEY 3x50RM 6/10kV	Desal2	RMU30	0.3	0.189	0.315	0.092	1.258	0.369
Line 25	NYSEY 3x50RM 6/10kV	RMU30	BIKENIBEU PS	0.75	0.189	0.291	0.086	1.165	0.342
Line 26	NYSEY 3x95RM 6/10kV	Terminal 2	RMU60	0.85	0.275	0.165	0.087	0.66	0.348
Line 27	NYSEY 3x25RM 6/10kV	RMU64	PV RMU3	0.37	0.132	0.27	0.047	1.079	0.0188
Line 28	NYSEY 3x95RM 6/10kV	BIKENIBEU PS	RMU29	0.43	0.275	0.083	0.044	0.334	0.176
Line 29	NYSEY 3x95RM 6/10kV	RMU29	RMU28	0.58	0.275	0.113	0.059	0.45	0.238
Line 3	NYSEY 3x25RM 6/10kV	RMU59	RMU41	0.765	0.132	0.558	0.097	2.23	0.388
Line 30	NYSEY 3x95RM 6/10kV	RMU28	RMU27	0.4	0.275	0.078	0.041	0.311	0.164
Line 31	NYSEY 3x95RM 6/10kV	RMU27	RMU26	0.85	0.275	0.165	0.087	0.66	0.348
Line 32	NYSEY 3x95RM 6/10kV	RMU26	RMU25	0.71	0.275	0.138	0.073	0.551	0.291
Line 33	NYSEY 3x95RM 6/10kV	RMU25	RMU24	2.15	0.275	0.417	0.22	1.67	0.881

Name	Cable Type	From	To	Length (km)	I_r (kA)	R_1 (Ω)	X_1 (Ω)	R_0 (Ω)	X_0 (Ω)
Line 34	NYSEY 3x95RM 6/10kV	RMU24	RMU23	0.7	0.275	0.136	0.072	0.544	0.287
Line 35	NYSEY 3x95RM 6/10kV	RMU23	RMU22	0.99	0.275	0.192	0.101	0.769	0.406
Line 36	NYSEY 3x95RM 6/10kV	RMU22	RMU21	1.6	0.275	0.311	0.164	1.243	0.655
Line 37	NYSEY 3x95RM 6/10kV	RMU21	RMU54	1.78	0.275	0.345	0.182	1.382	0.729
Line 38	NYSEY 3x95RM 6/10kV	RMU54	RMU20	0.007	0.275	0.001	0.001	0.005	0.003
Line 39	NYSEY 3x95RM 6/10kV	RMU20	RMU19	1.25	0.275	0.243	0.128	0.971	0.512
Line 4	NYSEY 3x25RM 6/10kV	RMU41	RMU45	1.059	0.132	0.772	0.134	3.088	0.538
Line 40	NYSEY 3x95RM 6/10kV	RMU19	RMU60	0.85	0.275	0.165	0.087	0.66	0.348
Line 41	NYSEY 3x95RM 6/10kV	RMU17	RMU16	0.834	0.275	0.162	0.085	0.648	0.342
Line 42	NYSEY 3x95RM 6/10kV	RMU16	RMU15	0.67	0.275	0.13	0.069	0.52	0.274
Line 43	NYSEY 3x95RM 6/10kV	RMU15	RMU14	1.708	0.275	0.332	0.175	1.326	0.7
Line 44	NYSEY 3x95RM 6/10kV	RMU14	RMU13	1.26	0.275	0.245	0.129	0.979	0.516
Line 45	NYSEY 3x95RM 6/10kV	RMU13	RMU12	0.59	0.275	0.115	0.06	0.458	0.242
Line 46	NYSEY 3x95RM 6/10kV	RMU12	RMU11	0.28	0.275	0.054	0.029	0.217	0.115
Line 47	NYSEY 3x95RM 6/10kV	RMU11	RMU10	0.27	0.275	0.052	0.028	0.21	0.111
Line 48	NYSEY 3x95RM 6/10kV	RMU10	RMU63	3.74	0.275	0.726	0.383	2.904	1.532
Line 49	NYSEY 3x95RM 6/10kV	RMU63	RMU ROPLANT	0.2	0.275	0.039	0.02	0.155	0.082
Line 5	NYSEY 3x25RM 6/10kV	RMU47	RMU59	1.558	0.132	1.136	0.198	4.542	0.791
Line 50	NYSEY 3x25RM 6/10kV	RMU13	RMU18	0.48	0.132	0.35	0.061	1.399	0.244
Line 51	NYSEY 3x70RM 6/10kV	RMU63	RMU9	0.38	0.23	0.102	0.041	0.41	0.163
Line 52	NYSEY 3x70RM 6/10kV	RMU9	RMU8	0.68	0.23	0.183	0.073	0.733	0.292
Line 53	NYSEY 3x70RM 6/10kV	RMU8	RMU7	0.73	0.23	0.197	0.078	0.787	0.314
Line 54	NYSEY 3x70RM 6/10kV	RMU65	RMU63	1.93	0.23	0.52	0.207	2.08	0.829
Line 55	NYSEY 3x70RM 6/10kV	RMU65	RMU61	0.59	0.23	0.159	0.063	0.636	0.254
Line 56	NYSEY 3x70RM 6/10kV	RMU5	RMU61	0.66	0.23	0.178	0.071	0.711	0.284
Line 57	NYSEY 3x70RM 6/10kV	Desal1	RMU4	0.11	0.23	0.129	0.052	0.517	0.206
Line 58	NYSEY 3x70RM 6/10kV	RMU4	RMU3	0.76	0.23	0.205	0.082	0.819	0.327
Line 59	NYSEY 3x70RM 6/10kV	RMU3	RMU37	0.64	0.23	0.172	0.069	0.69	0.275
Line 6	NYSEY 3x25RM 6/10kV	RMU45	RMU34	0.309	0.132	0.225	0.039	0.901	0.157

Name	Cable Type	From	To	Length (km)	I_r (kA)	R_1 (Ω)	X_1 (Ω)	R_0 (Ω)	X_0 (Ω)
Line 60	NYSEY 3x70RM 6/10kV	RMU37	RMU36	0.005	0.23	0.001	0.001	0.005	0.002
Line 61	NSYEY 3x16RM 6/10kV	RMU37	RMU37_A	0.21	0.056	0.309	0.027	0.491	0.067
Line 62	NYSEY 3x70RM 6/10kV	RMU7	BKL RMU6A	0.42	0.23	0.113	0.045	0.453	0.181
Line 63	NYSEY 3x70RM 6/10kV	RMU6B	BKL RMU6A	0.005	0.23	0.001	0.001	0.005	0.002
Line 64	NYSEY 3x95RM 6/10kV	Terminal 3	RMU17	0.01	0.275	0.001	0.008	0.004	0.001
Line 65	NYSEY 3x95RM 6/10kV	RMU13	Terminal 4	0.01	0.275	0.002	0.001	0.008	0.004
Line 66	NYSEY 3x70RM 6/10kV	RMU2B	RMU6B	0.21	0.23	0.057	0.023	0.226	0.09
Line 67	NYSEY 3x95RM 6/10kV	BKL RMU6A	RMU53	0.76	0.275	0.148	0.078	0.59	0.311
Line 68	NYSEY 3x95RM 6/10kV	RMU53	RMU35	0.005	0.275	0.001	0.001	0.004	0.002
Line 69	NYSEY 3x25RM 6/10kV	PV RMU2	PV RMU3	0.006	0.132	0.004	0.001	0.017	0.003
Line 7	NYSEY 3x95RM 6/10kV	RMU34	RMU62a	0.561	0.275	0.109	0.057	0.436	0.23
Line 70	NYSEY 3x70RM 6/10kV	RMU36	RMU1A	0.11	0.23	0.03	0.012	0.119	0.047
Line 72	NYSEY 3x70RM 6/10kV	RMU5	Desal1	0.37	0.23	0.129	0.052	0.517	0.206
Line 73	NYSEY 3x50RM 6/10kV	RMU40	Desal2	0.51	0.189	0.315	0.092	1.258	0.369
Line 8	NYSEY 3x50RM 6/10kV	RMU32	RMU31	1.49	0.189	0.579	0.17	2.314	0.68
Line 9	NYSEY 3x50RM 6/10kV	RMU32	RMU33	0.9	0.189	0.349	0.103	1.398	0.411

2.9 Power Transformer Parameters

There remains a small selection of transformer units with similar ratings used at each load centre in the PUB power grid. Table 2.13 presents the connection points and the respective ratings for each load centre. The electrical parameters employed in this study are shown in Table 2.14. These were extracted from Reference X and are in line with industry standard practice.

Table 2.13. Transformers in PUB network

Name	Type	HV Side	LV Side	Rating (MVA)
2-Winding TRF	0.5 MVA 11/0.4 kV	RMU39	RMU39_LV	0.5
T PV RMU NO6	0.5 MVA 11/0.4 kV	PV RMU_3	PV RMU3_LV	0.5
T RO	0.2 MVA 11/0.4 kV	RMU ROPLANT	RMU ROPLANT_LV	0.2
T10	0.2 MVA 11/0.4 kV	RMU10	RMU10_LV	0.2
T11	0.5 MVA 11/0.4 kV	RMU11	RMU11_LV	0.5
T12	0.2 MVA 11/0.4 kV	RMU12	RMU12_LV	0.2
T13	0.3 MVA 11/0.4 kV	Terminal 4	RMU13_LV	0.3
T14	0.1 MVA 11/0.4 kV	RMU14	RMU14_LV	0.1
T15	0.2 MVA 11/0.4 kV	RMU15	RMU15_LV	0.2
T16	0.3 MVA 11/0.4 kV	RMU16	RMU16_LV	0.3
T17	0.3 MVA 11/0.4 kV	RMU17	RMU17_LV	0.3
T18	0.5 MVA 11/0.4 kV	RMU18	RMU18_LV	0.5
T19	0.1 MVA 11/0.4 kV	RMU19	RMU19_LV	0.1
T20	0.2 MVA 11/0.4 kV	RMU20	RMU20_LV	0.2
T21	0.1 MVA 11/0.4 kV	RMU21	RMU21_LV	0.1
T22	0.1 MVA 11/0.4 kV	RMU22	RMU22_LV	0.1
T23	0.1 MVA 11/0.4 kV	RMU23	RMU23_LV	0.1
T24	0.2 MVA 11/0.4 kV	RMU24	RMU24_LV	0.2
T25	0.1 MVA 11/0.4 kV	RMU25	RMU25_LV	0.1
T26	0.1 MVA 11/0.4 kV	RMU26	RMU26_LV	0.1
T27	0.2 MVA 11/0.4 kV	RMU27	RMU27_LV	0.2
T28	0.2 MVA 11/0.4 kV	RMU28	RMU28_LV	0.2
T29	0.3 MVA 11/0.4 kV	RMU29	RMU29_LV	0.3
T2A	0.2 MVA 11/0.4 kV	RMU2A	RMU2A_LV	0.2
T2B	0.75 MVA 11/0.4 kV	RMU2B	RMU2B_LV	0.75
T3	0.3 MVA 11/0.4 kV	RMU3	RMU3_LV	0.3
T30	0.2 MVA 11/0.4 kV	RMU30	RMU30_LV	0.2
T31	0.2 MVA 11/0.4 kV	RMU31	RMU31_LV	0.2
T32	0.1 MVA 11/0.4 kV	RMU32	RMU32_LV	0.1
T33	0.2 MVA 11/0.4 kV	RMU33	RMU33_LV	0.2
T34	0.1 MVA 11/0.4 kV	RMU34	RMU34_LV	0.1
T35	0.4 MVA 11/0.4 kV	RMU35	RMU35_LV	0.4
T36	0.2 MVA 11/0.4 kV	RMU36	RMU36_LV	0.2
T37	0.75 MVA 11/0.4 kV	RMU37	RMU37_LV	0.75
T38	0.1 MVA 11/0.4 kV	RMU38	RMU38_LV	0.1

Name	Type	HV Side	LV Side	Rating (MVA)
T4	0.2 MVA 11/0.4 kV	RMU4	RMU4_LV	0.2
T40	0.1 MVA 11/0.4 kV	RMU40	RMU40_LV	0.1
T41	0.05 MVA 11/0.4 kV	RMU41	RMU41_LV	0.05
T42	0.3 MVA 11/0.4 kV	RMU42	RMU42_LV	0.3
T43	0.1 MVA 11/0.4 kV	RMU43	RMU43_LV	0.1
T44	0.1 MVA 11/0.4 kV	RMU44	RMU44_LV	0.1
T45	0.1 MVA 11/0.4 kV	RMU45	RMU45_LV	0.1
T47	0.1 MVA 11/0.4 kV	RMU47	RMU47_LV	0.1
T48	0.1 MVA 11/0.4 kV	RMU48	RMU48_LV	0.1
T49	0.05 MVA 11/0.4 kV	RMU49	RMU49_LV	0.05
T5	0.2 MVA 11/0.4 kV	RMU5	RMU5_LV	0.2
T50	0.1 MVA 11/0.4 kV	RMU50	RMU50_LV	0.1
T52	0.1 MVA 11/0.4 kV	RMU52	RMU52_LV	0.1
T53	0.2 MVA 11/0.4 kV	RMU53	RMU53_LV	0.2
T54	0.5 MVA 11/0.4 kV	RMU54	RMU54_LV	0.5
T55	0.1 MVA 11/0.4 kV	RMU55	RMU55_LV	0.1
T56	0.1 MVA 11/0.4 kV	RMU56	RMU56_LV	0.1
T57	0.1 MVA 11/0.4 kV	RMU57	RMU57_LV	0.1
T59	0.1 MVA 11/0.4 kV	RMU59	RMU59_LV	0.1
T60	0.2 MVA 11/0.4 kV	RMU60	RMU60_LV	0.2
T61	0.2 MVA 11/0.4 kV	RMU61	RMU61_LV	0.2
T62	0.1 MVA 11/0.4 kV	RMU62A	RMU62_LV	0.1
T64	0.1 MVA 11/0.4 kV	RMU64	RMU64_LV	0.1
T65	0.2 MVA 11/0.4 kV	RMU65	RMU65_LV	0.2
T6B	0.5 MVA 11/0.4 kV	RMU6B	RMU6B_LV	0.5
T7	0.2 MVA 11/0.4 kV	RMU7	RMU7_LV	0.2
T8	0.3 MVA 11/0.4 kV	RMU8	RMU8_LV	0.3
T9	0.2 MVA 11/0.4 kV	RMU9	RMU9_LV	0.2
TX STEP UP	0.5 MVA 11/0.4 kV	PV RMU_2	PV RMU2_LV	0.5
VOL_REG	3 MVA 11/11 kV	Terminal 3	Terminal 2	3
Bonriki TX	5.5 MVA 11/0.4 kV	RMU 5.5 PV	RMU 5.5 PV_LV	5.5
Desal1	0.5 MVA 11/0.4 kV	Desal1	Desal1_LV	0.5
Desal2	0.4 MVA 11/0.4 kV	Desal2	Desal2_LV	0.4

Table 2.14. Transformer parameters

Name	Rating (MVA)	HV (kV)	LV (kV)	SC Voltage (%)	Copper Losses (kW)	Ratio X/R	x_1 (pu)	r_1 (pu)	Connection	Zero SC Voltage (%)	Ratio X_0/R_0	x_0 (p.u.)	r_0 (p.u.)
0.05 MVA 11/0.4 kV	0.05	11	0.4	4	1.05	1.621	0.034	0.021	Dyn5	4	1.621	0.034	0.021
0.1 MVA 11/0.4 kV	0.1	11	0.4	6	1.7	3.385	0.058	0.017	Dyn5	6	3.385	0.058	0.017
0.2 MVA 11/0.4 kV	0.2	11	0.4	6	2.9	4.015	0.058	0.015	Dyn5	6	4.015	0.058	0.015
0.3 MVA 11/0.4 kV	0.3	11	0.4	6	3.8	4.63	0.059	0.013	Dyn5	6	4.872	0.059	0.012
0.4 MVA 11/0.4 kV	0.4	11	0.4	6	4.1	5.768	0.059	0.01	Dyn5	6	5.768	0.059	0.01
0.5 MVA 11/0.4 kV	0.5	11	0.4	6	4.7	6.304	0.059	0.009	Dyn5	6	6.304	0.059	0.009
0.75 MVA 11/0.4 kV	0.75	11	0.4	6	7.7	5.768	0.059	0.01	Dyn5	6	6.153	0.059	0.01
3 MVA 11/11 kV	3	11	11	9	24.896	10.799	0.09	0.008	Yyn5	6	7.831	0.06	0.008
5 MVA 11/0.4 kV	5	11	0.4	8.35	11	13	0.083	0.0064	Dyn11	8.35	10.9	0.083	0.0076

2.10 Load Details

The load details were provided by PUB from the year 2018 to 2022. During this period, a peak generation output of 5,587.41kW was recorded on 26 June 2020 (Time - 12:00pm) while the lowest dip in generation was recorded on 19 June 2021 (Time – 4:00am) at 2,031kW. These values have been adopted as maximum and minimum loads respectively in this study. The maximum load of 5,587.41 was used to simulate day loads while the minimum load of 2,031kW was used to simulate night loads.

PUB raised a concern that previous studies submitted by consultants have used demand growth projections that do not accurately account for actual population growth. This study relies on the population metrics reported by KINSO in the PHC of 2020 to arrive at acceptable demand projections. Progressive electrification is assumed for the years 2020, 2030, and 2040 starting from the current electrification percentage of 92.69%, moving on to 97% in 2030 and then settling at 99% in 2040. Key metrics extracted from the KINSO report and used in this study are shown in the table below.

Table 2.15. Kiribati & Fiji Statistics and Assumed Electrification Coverage.

Key Kiribati Statistics	
Average Kiribati Population Growth Rate (1990-2020)	2.2%
Average South Tarawa Population Growth Rate (1990-2020)	5.0%
Average number of persons per household on South Tarawa	6.5
Fiji rural average max demand per household (kW/HH)*	1.00
Fiji rural average min demand per household (kW/HH)*	0.80
South Tarawa average max demand per household (kW/HH)	0.64
South Tarawa average min demand per household (kW/HH)	0.20
Kiribati Population in 2020	119438
Kiribati Population in 2035 (2.2% growth rate)	165542

Year	Electrification Percentage
2020	92.69%
2025	95.00%
2030	97.00%
2035	98.00%
2040	99.00%

*Data provided by Planning Department of EFL, Fiji

As part of initial load assessments, electrification percentage was applied to an interval period of every 5 years starting at 2020 and ending at 2040. This was used to determine the number of customer connections by applying the percentage to the number of households calculated based on projected population growth over time. Three likely scenarios were identified and assessed to ascertain the most likely demand growth path. The demand growth scenarios were calculated using the following key variables:

Scenario 1 – average annual population growth rate of 2.2% for Kiribati and the average maximum and minimum electricity demand per household for South Tarawa,
Scenario 2 – average annual population growth rate of 5% for South Tawara and the average maximum and minimum electricity demand per household for the area,
Scenario 3 – average annual population growth rate of 5% for South Tarawa and the average rural maximum and minimum electricity demand per household for Fiji,

The projected maximum and minimum demand for each of the three scenarios are shown in Table A, B, and C. By 2040, the projected demand for Scenario 1, Scenario 2, and Scenario 3 will be 9.24MW, 15.89MW, and 24.9MW respectively. This study uses Scenario 2 as a conservative estimate given that the full network expansion required to meet the expected demand in 2040 compares well with the maximum demands of utilities in the Pacific with a customer base of the similar size (Solomon Power – 16MW, UNELCO Vanuatu Limited – 11.85MW). Maximum (day load) and minimum (night load) demands were split into the loading percentages for each designated feeder as shown in Table N. These were as derived and used in Reference

N. Furthermore, a 10-year interval period as opposed to a 5-year interval was used to better highlight significant changes over that period.

Table 2.16. Scenario 1 of Expected Load

Scenario 1 - 2020 to 2040 at 2.2% National Growth Rate, Kiribati Ave Demand						
Year	Time (Years)	Population	No. of Households	No. of Connections	Max Demand (0.64kW/HH)	Min Demand (0.2kW/HH)
2020	0	61604	9444	8754	5,587.41	1,725.00
2025	5	68686	10568	9796	6,252.49	1,930.33
2030	10	76581	11782	11429	7,294.78	2,252.12
2035	15	85384	13136	13005	8,300.69	2,562.67
2040	20	95198	14646	14500	9,254.91	2,857.27

Table 2.17. Scenario 2 of Expected Load

Scenario 2 - 2020 to 2040 at 5% Local Growth Rate, South Tarawa Ave Demand						
Year	Time (Years)	Population	No. of Households	No. of Connections	Max Demand (0.64kW/HH)	Min Demand (0.2kW/HH)
2020	0	61604	9444	8754	5,587.41	1,725.00
2025	5	78625	12097	11213	7,156.91	2,209.55
2030	10	100347	15438	14975	9,558.08	2,950.87
2035	15	128071	19704	19507	12,450.72	3,843.91
2040	20	163454	25147	24896	15,890.35	4,905.83

Table 2.18. Scenario 3 of Expected Load

Scenario 3 - 2020 to 2040 at 5% Local Growth Rate, Fiji Ave Demand						
Year	Time (Years)	Population	No. of Households	No. of Connections	Max Demand (3kW/HH)	Min Demand (1.5kW/HH)
2020	0	61604	9444	8754	5,587.41	1,725.00
2025	5	78625	12097	11213	11,213.00	8,970.40
2030	10	100347	15438	14975	14,975.00	11,980.00
2035	15	128071	19704	19507	19,507.00	15,605.60
2040	20	163454	25147	24896	24,896.00	19,916.80

Table 2.19. Scenario 2 Load Breakdown of Load for Day Operation

Maximum Demand (Day Load)	North Tarawa	Betio	CB1	Bikenibeu PS	Total (0.64kW/HH)
Breakdown	18.71%	13.40%	67.20%	0.69%	100.00%
2020	1045.40	748.71	3754.74	38.55	5,587.41
2030	1788.32	1280.78	6423.03	65.95	9,558.08
2040	2973.09	2129.31	10678.32	109.64	15,890.35

Table 2.20. Scenario 2 Load Breakdown for Night Operation

Minimum Demand (Night Load)	North Tarawa	Betio	CB1	Bikenibeu PS	Total (0.2kW/HH)
Breakdown	**18.41%**	**21.72%**	**58.66%**	**1.21%**	**100.00%**
2020	317.57	374.67	1011.89	20.87	1,725.00
2030	543.25	640.93	1730.98	35.71	2,950.87
2040	903.16	1065.55	2877.76	59.36	4,905.83

The load summary at the RMU level is provided in Table 2.21 for the year 2020, Table 2.22 for the year 2030, and Table 2.23 for the year 2040. Given the high loads expected over each 10-year interval, this table also shows transformer capacity upgrades required to ensure minimal overloads at the customer end.

Table 2.21. 2020 Load Details

Location		Capacity	Maximum 2020		Minimum 2020	
		KVA	KW	KVAr	KW	KVAr
T1	Bikenibeu PS	300	23.0	5.0	15.00	3.3
T2	Betio PS	200	30.0	6.5	25.00	5.5
T3	Kaotitaeka	300	30.0	6.6	3.00	0.7
T4	Betio West	200	60.0	13.1	5.00	1.1
T5	Grave Yard	200	40.0	8.8	21.00	1.1
T6	B.K.L	500	80.9	17.7	48.00	10.5
T7	Lagoon East	200	86.4	18.9	35.00	7.7
T8	Police HQ	300	30.0	13.1	25.00	5.5
T9	Dai Nippon Primary School	200	30.0	6.6	38.67	8.5
T10	Nanonmarie Mwaneaba	200	150.0	32.8	100.00	29.8
T11	Bairiki Stadium	500	200.0	43.8	200.00	43.8
T12	PWO Construction	200	125.7	27.5	56.00	12.3
T13	Bairiki East	300	280.0	61.3	15.00	3.3
T14	Nanikaai	100	90.0	19.7	25.00	5.5
T15	Catholic Head Quarter	200	190.0	41.6	80.00	17.5
T16	USP Teaoraereke	300	280.0	61.3	35.00	7.7
T17	Water Gallery (AVR)	300	280.0	61.3	30.89	6.8
T18	House of Assembly	500	140.0	30.7	55.00	12.0
T19	Banraeaba	100	90.0	19.7	10.00	2.2
T20	Ambo	200	190.0	41.6	24.00	5.3
T21	Taborio	100	95.0	20.8	10.00	2.2
T22	Tangintebu	100	89.0	19.5	10.00	2.2
T23	Eita Village	100	76.0	16.6	10.00	2.2
T24	Church of God	200	168.0	36.8	40.00	8.8
T25	Bwangantebure	100	68.0	14.9	20.00	4.4
T26	Bikenibeu West (CB Primary)	100	89.0	19.5	40.00	8.8
T27	Kiribati Housing Coorperation	200	140.0	30.7	15.00	3.3
T28	F.T.C (Environment)	200	170.0	37.2	15.00	3.3
T29	Bikenibeu Police	300	230.0	50.4	40.00	8.8
T30	E.B.S (KTC)	200	99.9	21.9	20.00	4.4

	Location	Capacity	Maximum 2020		Minimum 2020	
		KVA	KW	KVAr	KW	KVAr
T31	Cray Fish (Roundabout)	200	89.5	19.6	18.00	3.9
T32	Fish Farm	100	22.9	5.0	10.00	2.2
T33	Bonriki Airport	200	78.0	17.1	15.00	3.3
T34	Tanaea	100	46.8	10.2	10.00	2.2
T35	K.P.A	400	32.3	7.1	25.00	5.5
T36	Punjas	200	70.0	15.3	35.00	7.7
T37	Copra Mill	750	60.0	13.1	65.00	14.2
T38	Bonriki Village	100	30.2	6.6	10.00	2.2
T39	Bonriki Water Reservation	500	150.0	32.8	28.00	6.1
T40	Tabaonga	100	48.9	10.7	10.00	2.2
T41	Buota Pump	50	27.0	5.9	10.00	2.2
T42	Nawerewere Hospital	300	25.0	5.5	16.00	3.5
T43	KUC Temaiku (Mother Teresa)	100	69.7	15.3	10.00	2.2
T44	Airfield Runway	100	31.2	6.8	10.00	2.2
T45	Buota Bridge	100	41.5	9.1	10.00	2.2
T46	K.P.A	100	50.0	10.9	16.00	3.5
T47	Abatao KUC	100	28.1	6.2	15.00	3.3
T48	Tabiteuea	100	20.7	4.5	20.00	4.4
T49	End of Abatao	50	10.0	2.2	7.00	1.5
T50	Nabeina	100	23.5	5.1	23.57	5.2
T51	RO Plant	200	30.0	6.6	20.00	2.2
T52	Anraei	100	40.2	8.8	25.00	5.5
T53	K.I.T	200	29.1	6.4	25.00	5.5
T54	New Parliament	500	350.0	76.6	60.00	13.1
T55	RC Temaiku	100	40.6	8.9	10.00	2.2
T56	Temaiku Clinic	100	35.4	7.8	10.00	2.2
T57	Mormon Church Temaiku	100	29.1	6.4	10.00	2.2
T58	Abarao	100	84.0	18.4	60.00	13.1
T59	Buota Village	100	31.2	6.8	10.00	2.2
T60	Antebuka	200	180.0	39.4	25.00	5.5
T61	Betio Stadium	200	40.0	8.8	4.00	0.9
T62	Tabon Tawaana	100	26.0	5.7	10.00	2.2
T64	St Maria	100	15.6	3.4	5.87	1.3
T65	JSS Betio	200	50.0	10.9	20.00	2.2
	Desal 1		405	10.9	405.0	2.2
	Desal 2		324	10.9	324.0	2.2
Total			**6316.4**		**2130.0**	

Table 2.22. 2030 Lood Details for Day & Night Operation

	Location	Capacity	Maximum 2030		Minimum 2030	
		KVA	KW	KVAr	KW	KVAr
T1	Bikenibeu PS	300	50.0	10.9	20.0	4.4
T2	Betio PS	200	40.0	8.6	25.0	5.5
T3	Kaotitaeka	300	180.0	39.4	35.0	7.7
T4	Betio West	200	60.0	13.1	53.0	11.6
T5	Grave Yard	200	40.0	8.8	20.0	4.4
T6	B.K.L	500	40.0	17.5	65.0	14.2
T7	Lagoon East	200	86.78	19.0	35.0	7.7
T8	Police HQ	300	60.0	13.1	25.0	5.5
T9	Dai Nippon Primary School	200	30.0	6.6	38.9	8.5
T10	Nanonmarie Mwaneaba	200	150.0	32.8	50.0	10.9
T11	Bairiki Stadium	500	380.0	83.2	150.0	32.8
T12	PWO Construction	750	520.0	113.9	75.0	16.4
T13	Bairiki East	750	490.0	107.3	171.0	37.4
T14	Nanikaai	300	205.0	44.9	45.0	9.9
T15	Catholic Head Quarter	500	340.0	74.5	100.0	21.9
T16	USP Teaoraereke	500	350.0	76.6	60.0	13.1
T17	Water Gallery (AVR)	500	360.0	78.8	80.0	17.5
T18	House of Assembly	500	323.0	70.7	120.0	26.3
T19	Banraeaba	200	115.0	25.2	60.0	13.1
T20	Ambo	300	190.0	41.6	45.0	9.9
T21	Taborio	300	205.0	44.9	40.0	8.8
T22	Tangintebu	750	420.0	92.0	30.0	6.6
T23	Eita Village	300	180.0	39.4	25.0	5.5
T24	Church of God	300	190.0	41.6	40.0	8.8
T25	Bwangantebure	500	350.0	76.6	40.0	8.8
T26	Bikenibeu West (CB Primary)	200	120.0	26.3	40.0	8.8
T27	Kiribati Housing Coorperation	500	380.0	83.2	105.0	23.0
T28	F.T.C (Environment)	300	205.0	44.9	85.0	18.6
T29	Bikenibeu Police	300	230.0	50.4	120.0	26.3
T30	E.B.S (KTC)	200	99.9	21.9	20.0	4.4
T31	Cray Fish (Roundabout)	200	89.5	19.6	18.0	3.9
T32	Fish Farm	100	65.0	14.2	10.0	2.2
T33	Bonriki Airport	200	105.0	23.0	15.0	3.3
T34	Tanaea	100	76.0	16.6	20.0	4.4
T35	K.P.A	400	50.0	10.9	45.0	9.9
T36	Punjas	200	70.0	15.3	50.0	10.9
T37	Copra Mill	750	350.0	76.6	90.0	19.7
T38	Bonriki Village	100	66.0	14.5	25.0	5.5
T39	Bonriki Water Reservation	500	210.0	46.0	28.0	6.1
T40	Tabaonga	100	48.9	10.7	10.0	2.2
T41	Buota Pump	50	35.0	7.7	10.0	2.2
T42	Nawerewere Hospital	300	205.0	44.9	16.0	3.5

	Location	Capacity	Maximum 2030		Minimum 2030	
		KVA	KW	KVAr	KW	KVAr
T43	KUC Temaiku (Mother Teresa)	100	69.8	15.3	30.0	6.6
T44	Airfield Runway	100	53.0	11.6	30.0	6.6
T45	Buota Bridge	100	65.2	14.3	12.0	2.6
T46	K.P.A	100	50.0	10.9	24.0	5.3
T47	Abatao KUC	100	60.0	13.1	50.0	10.9
T48	Tabiteuea	100	67.0	14.7	20.0	4.4
T49	End of Abatao	50	35.0	7.7	25.0	5.5
T50	Nabeina	100	61.0	13.4	23.3	5.1
T51	RO Plant	200	30.0	6.6	10.0	2.2
T52	Anraei	100	75.0	16.4	25.0	5.5
T53	K.I.T	200	84.0	18.4	40.0	8.8
T54	New Parliament	500	410.0	89.8	120.0	26.3
T55	RC Temaiku	100	60.0	13.1	41.0	9.0
T56	Temaiku Clinic	100	56.0	12.3	30.0	6.6
T57	Mormon Church Temaiku	100	62.0	13.6	10.0	2.2
T58	Abarao	200	130.0	28.5	60.0	13.1
T59	Buota Village	100	70.0	15.3	35.0	7.7
T60	Antebuka	300	180.0	39.4	70.0	15.3
T61	Betio Stadium	200	60.0	13.1	45.0	9.9
T62	Tabon Tawaana	100	54.0	11.8	40.0	8.8
T64	St Maria	100	16.0	3.5	15.7	3.4
T65	JSS Betio	200	50.0	10.9	40.0	8.8
	Desal 1		405.0	303.8	405.0	87.2
	Desal 2		324.0	243	324.0	69.8
Total			**10287.1**		**3679.9**	

Table 2.23. 2040 Load Details for Day & Night Operation

	Location	Capacity	Maximum 2040		Minimum 2040	
		KVA	KW	KVAr	KW	KVAr
T1	Bikenibeu PS	300	50.0	17.5	40.0	8.8
T2	Betio PS	200	60.0	13.1	25.0	5.5
T3	Kaotitaeka	300	180.0	39.4	120.0	26.3
T4	Betio West	200	55.0	12.0	90.0	19.7
T5	Grave Yard	200	160.0	35.0	85.0	18.6
T6	B.K.L	500	230.0	50.4	80.0	17.5
T7	Lagoon East	200	150.0	32.8	34.0	7.4
T8	Police HQ	300	60.0	13.1	25.0	5.5
T9	Dai Nippon Primary School	200	80.0	17.5	46.6	10.2
T10	Nanonmarie Mwaneaba	750	680.0	148.9	134.8	29.5
T11	Bairiki Stadium	500	420.0	92.0	200.0	43.8
T12	PWO Construction	750	680.0	148.9	60.0	13.1
T13	Bairiki East	750	680.0	148.9	183.0	40.1

	Location	Capacity	Maximum 2040		Minimum 2040	
		KVA	KW	KVAr	KW	KVAr
T14	Nanikaai	300	270.0	59.1	45.0	9.9
T15	Catholic Head Quarter	500	480.0	105.1	150.0	32.8
T16	USP Teaoraereke	750	650.0	142.3	230.0	50.4
T17	Water Gallery (AVR)	500	460.0	100.7	80.0	17.5
T18	House of Assembly	500	450.0	98.5	120.0	26.3
T19	Banraeaba	750	680.0	148.9	250.0	54.7
T20	Ambo	300	250.0	54.7	45.0	9.9
T21	Taborio	300	280.0	61.3	40.0	8.8
T22	Tangintebu	750	650.0	142.3	80.0	17.5
T23	Eita Village	500	360.0	78.8	170.0	37.2
T24	Church of God	300	190.0	41.6	90.0	19.7
T25	Bwangantebure	750	480.0	105.1	120.0	26.3
T26	Bikenibeu West (CB Primary)	500	408.3	89.4	40.0	8.8
T27	Kiribati Housing Coorperation	500	460.0	100.7	105.0	23.0
T28	F.T.C (Environment)	500	450.0	98.5	85.0	18.6
T29	Bikenibeu Police	750	550.0	120.4	120.0	26.3
T30	E.B.S (KTC)	200	120.0	26.3	20.0	4.4
T31	Cray Fish (Roundabout)	200	160.0	35.0	60.0	13.1
T32	Fish Farm	100	83.1	18.2	10.0	2.2
T33	Bonriki Airport	300	250.0	54.7	120.0	26.3
T34	Tanaea	100	80.0	17.5	50.0	10.9
T35	K.P.A	400	230.0	50.4	90.0	19.7
T36	Punjas	200	70.0	15.3	50.0	10.9
T37	Copra Mill	750	350.0	76.6	120.0	26.3
T38	Bonriki Village	100	66.0	14.5	25.0	5.5
T39	Bonriki Water Reservation	500	250.0	98.5	28.0	6.1
T40	Tabaonga	100	60.0	13.1	30.0	6.6
T41	Buota Pump	50	35.0	7.7	10.0	2.2
T42	Nawerewere Hospital	300	205.0	44.9	16.0	3.5
T43	KUC Temaiku (Mother Teresa)	500	450.0	98.5	150.0	32.8
T44	Airfield Runway	400	290.0	19.7	30.0	6.6
T45	Buota Bridge	100	80.0	17.5	30.0	6.6
T46	K.P.A	100	60.0	13.1	50.0	10.9
T47	Abatao KUC	100	80.0	17.5	50.0	10.9
T48	Tabiteuea	100	85.0	18.6	20.0	4.4
T49	End of Abatao	50	40.0	8.8	25.0	5.5
T50	Nabeina	100	90.0	19.7	24.2	5.3
T51	RO Plant	200	120.0	26.3	40.0	8.8
T52	Anraei	100	77.0	16.9	25.0	5.5
T53	K.I.T	200	124.3	27.2	50.0	10.9
T54	New Parliament	500	410.0	89.8	120.0	26.3
T55	RC Temaiku	300	167.0	36.6	50.0	10.9
T56	Temaiku Clinic	100	50.0	10.9	30.0	6.6

	Location	Capacity	Maximum 2040		Minimum 2040	
		KVA	KW	KVAr	KW	KVAr
T57	Mormon Church Temaiku	100	90.0	19.7	10.0	2.2
T58	Abarao	500	260.0	56.9	180.0	39.4
T59	Buota Village	100	85.0	18.6	50.0	10.9
T60	Antebuka	500	480.0	105.1	230.0	50.4
T61	Betio Stadium	200	95.0	20.8	80.0	17.5
T62	Tabon Tawaana	100	80.0	17.5	40.0	8.8
T64	St Maria	100	29.6	6.5	19.4	4.2
T65	JSS Betio	200	105.0	23.0	80.0	17.5
	Desal 1		453.0	339.8	453.0	339.8
	Desal 2		369.0	276.8	369.0	276.8
Total			**16682.4**		**5727.83**	

2.11 System Balances

The summary of generation and load balances for the completed models is presented in Table 2.24 for the year 2020, Table 2.25 for the year 2030, and Table 2.26 for the year 2040. These contain the maximum and minimum loading conditions for night and day operations. The BESS and Generator 5 cover demand while also providing reactive power and maintaining voltage profile within permissible limits.

Table 2.24. 2020 System Balance

	Type	2020					
		Day			Night		
		kW	KVAr	PF	kW	KVAr	PF
.	Diesel	900	557.8	0.85	700	433.8	0.85
No.2	Diesel	-	-	-	-	-	-
No.3	Diesel	1381	668.8	0.90	-	-	-
No.4	Diesel	1250	774.7	0.85	-	-	-
No.5	Diesel	1200	743.7	0.85	1053	-593.9	0.871
No.6	Diesel	-	-	-	-	-	-
No.7	Diesel	-	-	-	-	-	-
Bonriki 5	PV	-	-	-	-	-	-
PV_29_KGV	PV	159	-	1	-	-	-
PV_39_STWSP	PV	-	-	-	-	-	-
PV_39_Vergnet	PV	419	-	1	-	-	-
PV_42_TCH	PV	157	-	1	-	-	-
PV_53_KIT	PV	117	-	1	-	-	-
PV_61_BSC	PV	100	-	1	-	-	-
PV_2_PEC	PV	280	-	1	-	-	-
2MVA BESS	BESS	-	-	-	-	-	-
5MVA BESS	BESS	-	-	-	-	-	-
Total		5870.92	2665.67		1753.00	-158.51	
Load		6316.40	3468.70	-	2130.00	1320.06	-
Losses		283.52	-801.5	-	28.0	-1227.6	
Compensation			**-**	**-**			

Table 2.25. 2030 System Balance

	Type	2030					
		Day			Night		
		kW	KVAr	PF	kW	KVAr	PF
No.1	Diesel	900	557.8	0.85	700.0	433.8	0.85
No.2	Diesel	591	366.3	0.85	-	-	-
No.3	Diesel	778	400.3	0.89	720.0	-427.2	0.86
No.4	Diesel	1250	774.7	0.85	600.0	371.8	0.85
No.5	Diesel	1200	743.7	0.85	-	-	-
No.6	Diesel	1800	1115.54	0.85	-	-	-
No.7	Diesel	-	-	-	-	-	-
Bonriki 5	PV	4000	-	1	-	-	-

	Type	2030					
		Day			Night		
		kW	KVAr	PF	kW	KVAr	PF
PV_29_KGV	PV	159	-	1	-	-	-
PV_39_STWSP	PV	2000	-	1	-	-	-
PV_39_Vergnet	PV	419	-	1	-	-	-
PV_42_TCH	PV	157	-	1	-	-	-
PV_53_KIT	PV	117	-	1	-	-	-
PV_61_BSC	PV	100	-	1	-	-	-
PV_2_PEC	PV	280	-	1	-	-	-
2MVA BESS	BESS	-1000	-	1	500.0	0.0	1.00
5MVA BESS	BESS	-2000	-	1	1000.0	0.0	1.00
Total		10746.21	3958.3		3520.0	230.2	
Load		10287.08	6387.8		3679.9	2280.6	-
Losses		459.1	-1093.4		136.1	-1282.0	-
Compensation			1250.0			-	

Table 2.26. 2040 System Balance

	Type	2040					
		Day			Night		
		kW	KVAr	PF	kW	KVAr	PF
No.1	Diesel	900.0	557.77	0.85	1100.0	681.7	0.85
No.2	Diesel	1700.0	1053.57	0.85	-	-	-
No.3	Diesel	986.3	505.29	0.89	763.0	-472.9	0.85
No.4	Diesel	1250.0	774.68	0.85	-	-	-
No.5	Diesel	1800.0	1115.54	0.85	1000.0	619.7	0.85
No.6	Diesel	1700.0	1053.57	0.85	-	-	-
No.7	Diesel	1800.0	1115.54	0.85	1000.0	619.7	0.85
No.8	Diesel	-	-	-	-	-	-
Bonriki 5	PV	6000.0	-	1	-	-	-
PV_29_KGV	PV	159.0	-	1	-	-	-
PV_39_STWSP	PV	4000.0	-	1	-	-	-
PV_39_Vergnet	PV	419.0	-	1	-	-	-
PV_42_TCH	PV	157.0	-	1	-	-	-
PV_53_KIT	PV	117.0	-	1	-	-	-
PV_61_BSC	PV	100.0	-	1	-	-	-
PV_2_PEC	PV	280.0	-	1	-	-	-
2MVA BESS	BESS	-2000.0	-	1	1000.0	0.0	1.00
5MVA BESS	BESS	-1700.0	-	1	1000.0	0.0	1.00
Total		17668.3	6176.0		5863.0	1450.8	
Load		16682.4	10346.6		5727.8	3557.06	
Losses		1004.6	-3.8		134.6	-2106.28	
Compensation			3000.0		-		

3 Methodology for Grid Integration Study

Steady state studies were completed to determine system performance following the integration of a 4MW PV and 5MVA BESS system at Bonriki with projected load growth up to year 2040. Load flow studies, contingency analysis studies, and short circuit calculations were performed to asses equipment loading and the voltage profile along the power grid. The study follows the requirements outlined in the Australian Standards as shown in Table X given that PUB does not strictly adhere to any particular set of standards, regulations, or grid codes. This is also as followed in Reference X. This study sets voltage limits of 0.9 p.u. and 1.1 p.u. under normal conditions and an N-1 contingency event.

Table 3.1. Study Assessment Criteria

Assessment	Criteria
Thermal capacity (not derated)	Equipment thermal loading ≤ Equipment thermal rating
Thermal capacity (derated)	Equipment thermal loading ≤ 80% of Equipmet thermal rating
Bus Voltage Limits	0.9 p.u. (9.9kV) ≤ Bus Voltage ≤ 1.1 p.u. (12.1kV)
AVR Maximum Loading Limits	3MVA (1 p.u.)
11kV Bus Fault Levels	13.1 kA (250MVA)

Four contingency scenarios used in Reference X have been adopted in this study to assess PV and BESS integration at Bonriki. Grid assessment was done for night and day loading levels for the year 2020, 2030, and 2040. A summary of these contingency scenarios is shown in Table X.

Table 3.2. Summary of Contingency Scenarios

	Contingency 1	Contingency 2	Contingency 3	Contingency 4
Demand	Maximum	Maximum	Maximum	Minimum
Operation Period	Day	Day	Day	Night
Network Description	2020, 2030, 2040	2020, 2030, 2040	2020, 2030, 2040	2020, 2030, 2040
PV Operation	All PV & Bonriki 4MW PV in service	All PV & Bonriki 4MW PV in service	All PV & Bonriki 4MW PV in service	All PV out of service
BESS Status	Recharging	Recharging	Recharging	Discharging
Contingency Description	Loss of 5MVA BESS	Loss of Generator No. 4 at Bikenibeu PS	Loss of Generator 1 at Betio PS	Loss of Generator 5 at Bikenibeu PS

3.1 Short Circuit Current Calculations

Simulations and assessments carried out in this study seek to show that calculated fault levels are within the circuit breaker withstand limits. These have been assessed for both three- and single-phase faults and calculated using the IEC 60909 standard procedure. Results from this procedure may be higher than actual recorded fault levels giving a safety buffer for plant and equipment ratings. Maximum loading scenario was considered with Generator 1, 3, 4, 5, and 7 in service to simulate the highest fault contribution as a result of a high number of diesel generators put in service. These were calculated based on normal running arrangement and compared to the circuit breaker and switchboard ratings.

3.2 Dynamic Analysis

While this study only focuses on steady-steady analysis, a later stage will focus on conducting dynamic analysis to understand generator response and ability to return to stable operation following severe disturbance to the power grid. These responses will be simulated based on the disturbances outlined in the table below.

Table 3.3. Disturbances considered for Dynamic Analysis

Disturbance	Description
1	Increase the highest load by 80%
2	Loss of highest load
3	Loss of Generator 5 at Bikenibeu power station

Power grid recovery during the disturbance will be assessed using the following indices:

- Rotor angle stability
- Frequency deviation
- Active and reactive power recovery
- Voltage profile recovery

4 Study Results

The steady-state analysis was completed for all years considering integration of PV and BESS. Although these remain to be installed and put in service, PV and BESS systems have been included in the contingency and short-circuit analysis for the year 2020 to assess power grid system responses based on the current maximum and minimum load conditions. This is important should integration of these systems to the power grid be completed within the next few years and prior to 2030. The PV plants were operated at the maximum generation capacity recorded to date and put in service to offset diesel fueled generation. Diesel generators were operated at the maximum derated capacities as advised by PUB as shown in Table 2.1. Load flow studies, contingency scenarios and short-shirt calculation results are presented in the following subsections.

4.1 Load Flow Results

4.1.1 System Operation – Year 2020

System operation during the day considers all available diesel generation, PV, and BESS systems to be in service. Generator 2 and Generator 6 were kept out of service as backup while Generator 7 was not considered as it remains to be installed. System operation at night considers only Generator 1 at Betio PS and Generator 5 at Bikenibeu PS in service. Initial load flow analysis show voltage drop falling below the accepted -10% limit for a number of elements (red lines) connected along the feeder linking Betio PS to Bikenibeu PS. These may also be attributed to an increased reactive power transfer from the diesel generators.

The PUB grid consists of a single 11kV feeder that spans the whole length of South Tarawa from Bonriki all the way to Betio PS. This radial structure of the has limited the possibility of a centralized supply mainly due to voltage drops experienced on the long lines. The voltage profile in Figure 4.1 show a voltage drop of more than 10% on the portion of the feeder that lies between Bikenibeu and Betio. The existing 11kV cable along this area and on other parts of the feeder also do not have sufficient capacities to transfer the required power over that distance. The outlined study scenarios take these system characteristics into account and propose mitigation strategies.

Solutions proposed in the short-term (2020) consider operational actions such as switching on existing generators, tap adjustment of transformers or curtailment of BESS and PV plants due to time limitations. Mid-term (2030) and Long-term (2040) solutions consider more capital intensive actions that include new installations and upgrades to existing equipment.

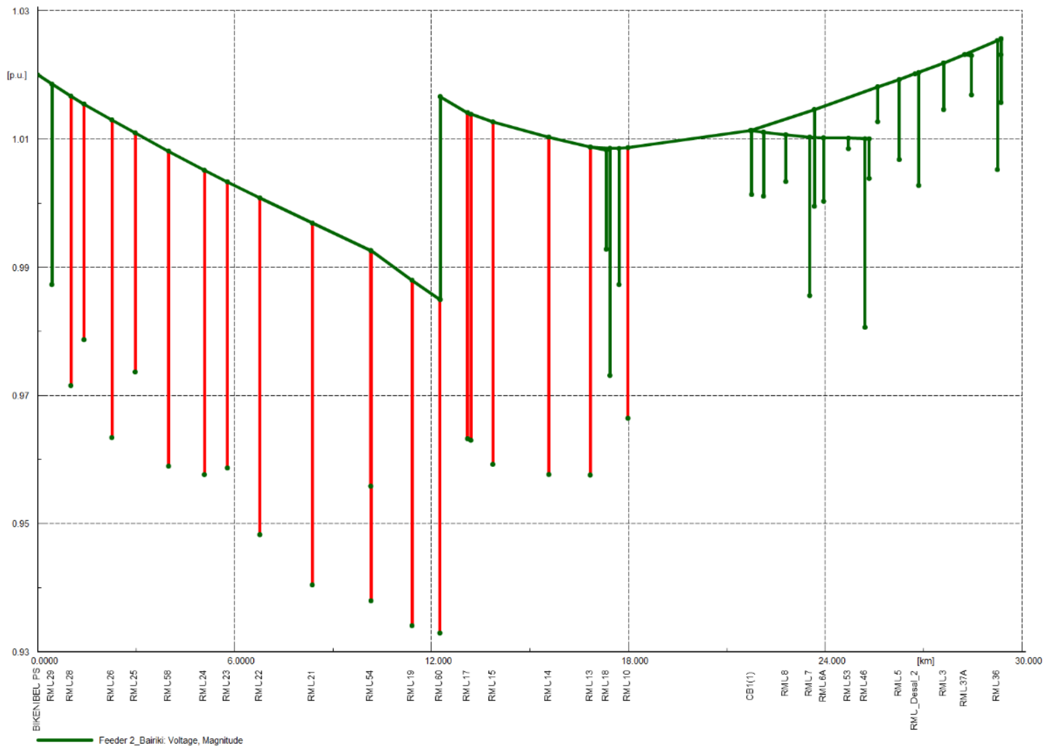


Figure 4.1. Voltage Profile on Feeder from Bikenibeu PS to Betio PS

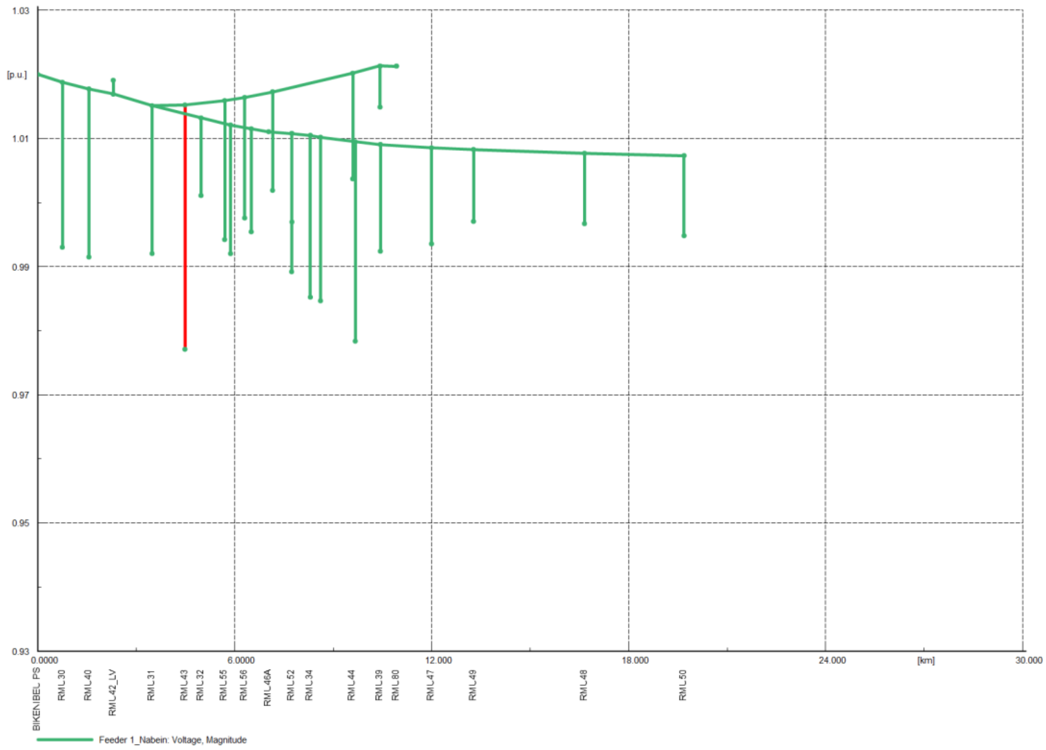


Figure 4.2. Voltage Profile on Feeder from Bikenibeu PS to Nabeina

The 2020 voltage profiles shown for the feeder to Betio (Figure 4.1) and Nabeina (Figure 4.2) are within the permissible operation limits. Generator 2 improves voltage profile when in service as shown in Figure 4.3, however, this will not be required at present given that the voltage profile is already within permissible limits. This will be required as demand continues to grow over time. A preferred short-term solution would be to install a capacitor bank to improve voltage profile and avoid putting Generator 2 in service. Figure 4.4

shows the summary of transformer loading before and after Generator 2 is brought in service. The majority of transformers fed by the 11kV underground cable running between Bikenibeu PS and Betio PS are overloaded. The most loaded transformers are shown Table 4.1.

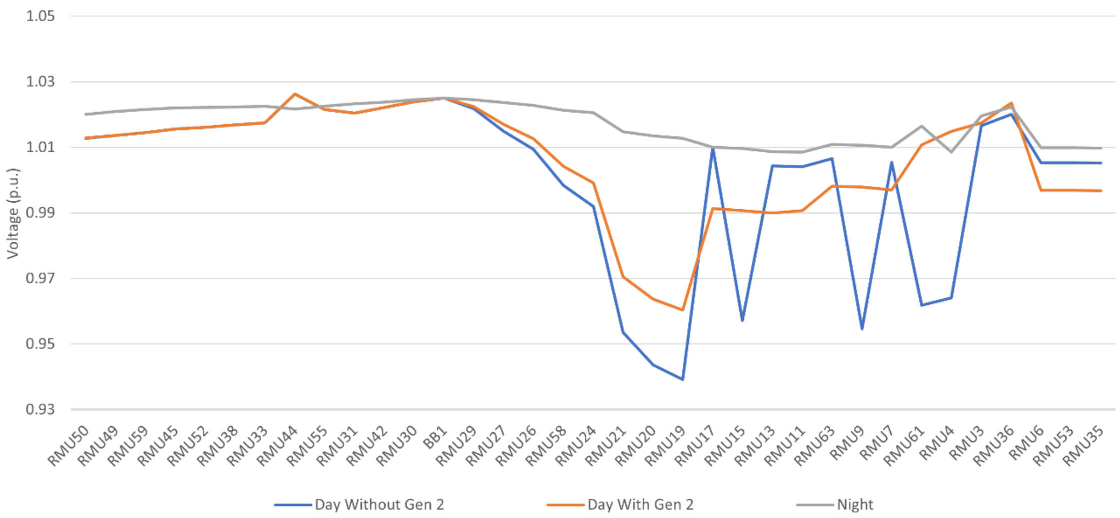


Figure 4.3. Year 2020 System Voltage Profile

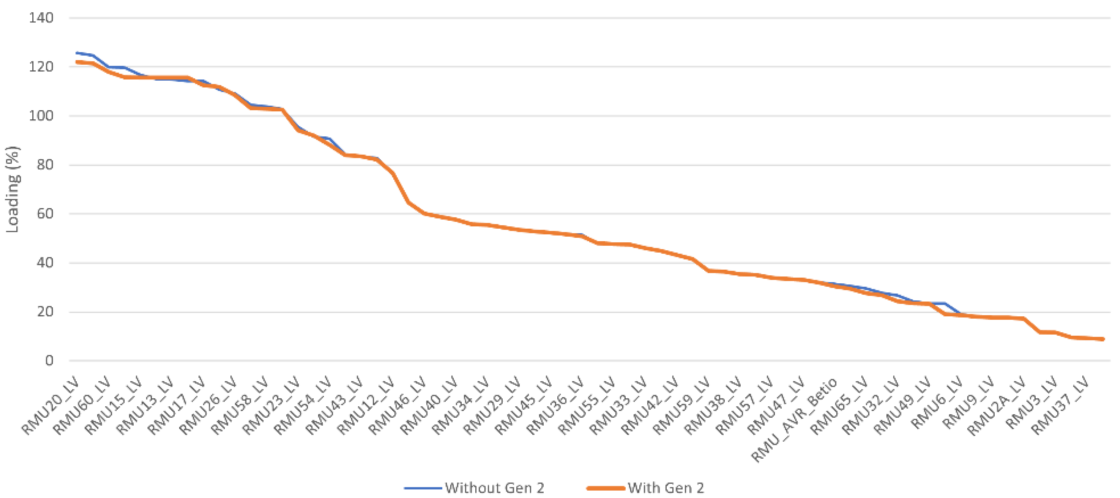


Figure 4.4. Year 2020 System Loading Profile

Table 4.1. Year 2020 - Most Loaded Elements

HV-Side	LV-Side	Loading Before Gen 2 (%)	Loading After Gen 2 (%)
RMU20	RMU20_LV	125.7687	121.9422
RMU21	RMU21_LV	124.6839	121.4234
RMU60	RMU60_LV	119.8991	118.0632
RMU19	RMU19_LV	119.7209	115.7706
RMU15	RMU15_LV	116.7679	115.7456
RMU22	RMU22_LV	115.1271	115.7315
RMU13	RMU13_LV	114.9541	115.6213
RMU16	RMU16_LV	114.2609	115.6045
RMU17	RMU17_LV	114.2296	112.5912

HV-Side	LV-Side	Loading Before Gen 2 (%)	Loading After Gen 2 (%)
RMU14	RMU14_LV	110.8248	111.8002
RMU26	RMU26_LV	109.1132	108.561
RMU24	RMU24_LV	104.4614	103.2693
RMU58	RMU58_LV	103.8973	102.9676
RMU28	RMU28_LV	102.8229	102.594
RMU23	RMU23_LV	95.54309	94.05723
RMU10	RMU10_LV	91.52704	92.02495

4.1.2 System Operation – Year 2030

The proposed changes for 2020 were applied to the year 2030. Increase in demand required all generators, except Generator 7, to be put in service. Proposed 4MW and 2.2MW PV power plants at Bonriki were also included along with the respective 5MVA and 2.2MVA BESS. Proposed seawater reverse osmosis desalination plants rated at 500kVA each were also installed between RMU30 and RMU40 and between RMU4 and RMU5. A 0.75MVA 11/0.415kV transformer was installed at each location of the desalination plants to transfer power from the grid to the plant. Two 2.5MVA 11/0.415kV transformers were installed in parallel for the 4MW PV power plant and one 2.5MVA 11/0.415kV transformer was installed for the 2.2MW PV power plant. The underground cables running from Bikenibeu PS to RMU39, from Bikenibeu PS to RMU31 were also all upgraded to the 240sqmm sized cables.

An increase in load and PV generation led to the increase in reactive power transfer along the line and poor power factor. The study found that the connection of a 1.25MVar capacitor bank at RMU17 improved voltage profile, reduced reactive power transfer, and subsequently raised the overall power factor to 0.85 at Bikenibeu PS and Betio PS to

Voltages remain within permissible limits as shown in the Figure 4.5 while overall equipment loading decreases as shown in Figure 4.6. The overall load growth resulted in an increase in the number of overloaded RMUs. These have been upgraded to cater to the 2030 load.

Figure 4.5. Year 2030 System Voltage Profile

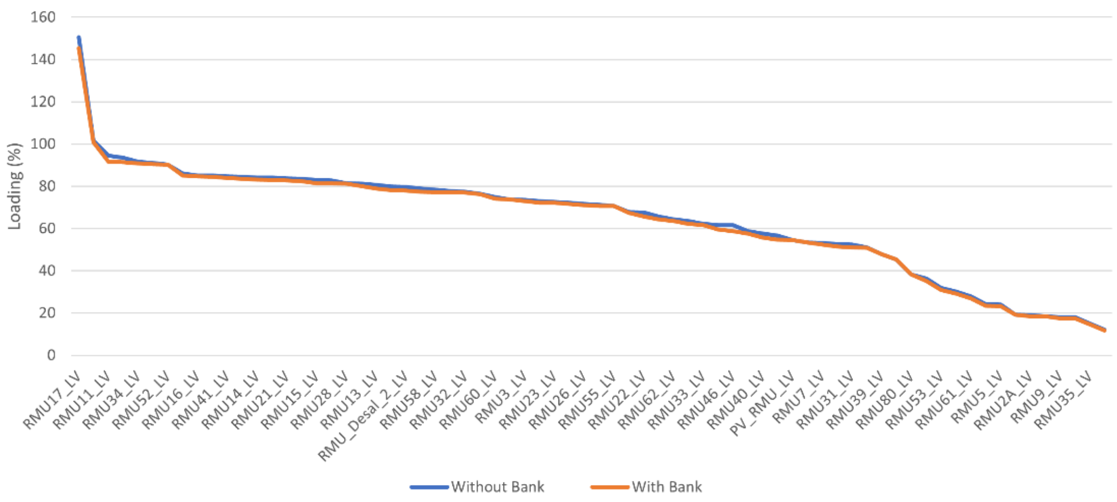


Figure 4.6. 2030 System Loading Profile

Table 4.2. Year 2030 - Most Loaded Elements

HV-Side	LV-Side	Loading Before Gen 2 (%)	Loading After Gen 2 (%)
RMU17	RMU17_LV	150.5612	145.3338
RMU54	RMU54_LV	100.8538	100.8538
RMU11	RMU11_LV	91.68935	91.68935

4.1.3 System Operation – Year 2040

Finally, system performance for the year 2040 also showed that the voltage profile can be kept within the permissible ±10% limits (Figure 4.7). This assessment was performed following upgrades to increase the rated capacities of overloaded transmission lines and transformers. All diesel generators were also increased to 2MW rated capacity to meet projected load of 2040. An additional generator labelled Generator 8 was connected at Bikenibeu to provide backup generation. The connection of a 3MVar capacitor bank to RMU17 improved the voltage profile but was not able to solve overloading all RMUs as this was due to overall load growth. It is suggested that the capacitor bank capacity be increased from 1.25MVar to 3MVar between 2030 and 2040.

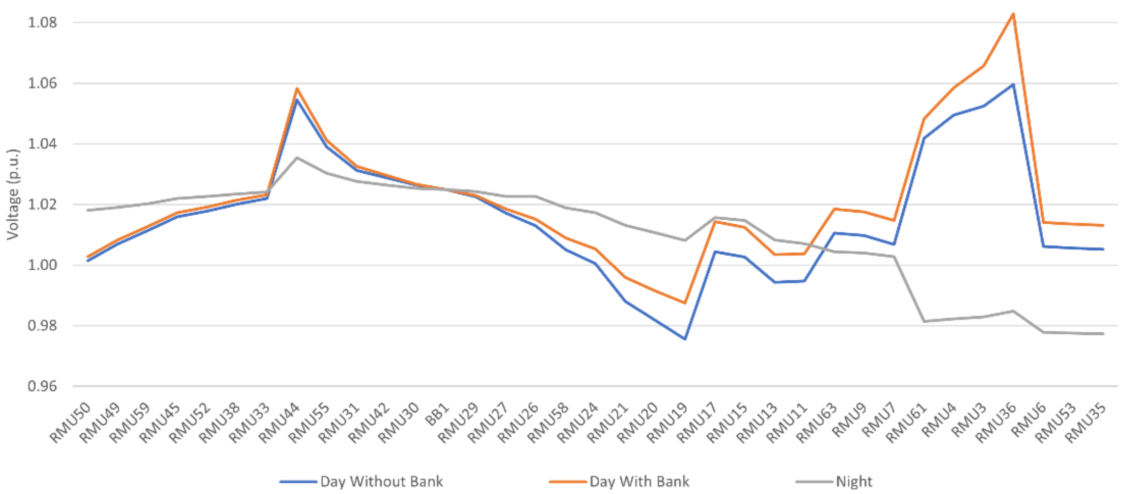


Figure 4.7. Year 2040 System Voltage Profile

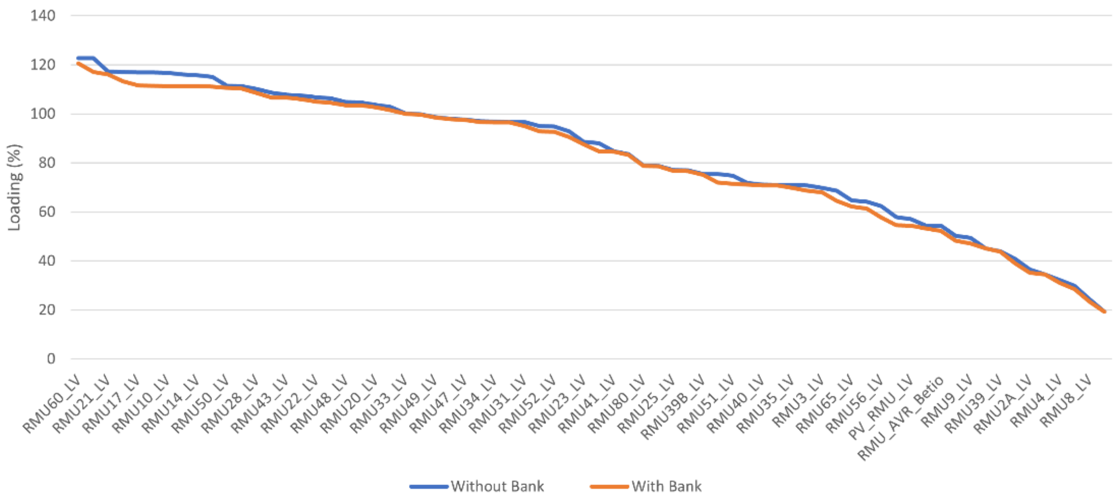


Figure 4.8. Year 2040 System Loading Profile

Table 4.3. Year 2040 - Most Loaded Elements

HV-Side	LV-Side	Loading %	Loading %
RMU60	RMU60_LV	122.7675	120.6677
RMU15	RMU15_LV	122.7361	117.0127
RMU21	RMU21_LV	117.2514	116.0323
RMU12	RMU12_LV	117.068	113.3541
RMU17	RMU17_LV	116.9457	111.6653
RMU13	RMU13_LV	116.923	111.3692
RMU10	RMU10_LV	116.8117	111.3546
RMU18	RMU18_LV	116.1259	111.2496
RMU14	RMU14_LV	115.7907	111.2108
RMU19	RMU19_LV	115.1547	111.1605
RMU50	RMU50_LV	111.3773	110.5896
RMU27	RMU27_LV	111.3477	110.3129
RMU28	RMU28_LV	110.0554	108.4259
RMU16	RMU16_LV	108.556	106.6058
RMU43	RMU43_LV	107.7646	106.5966
RMU57	RMU57_LV	107.493	105.9642
RMU22	RMU22_LV	106.7873	104.998
RMU11	RMU11_LV	106.2713	104.4959
RMU48	RMU48_LV	104.794	103.5657
RMU59	RMU59_LV	104.6506	103.4806
RMU20	RMU20_LV	103.7159	102.6794
RMU54	RMU54_LV	102.7498	101.4728
RMU33	RMU33_LV	100.1085	99.96853
RMU32	RMU32_LV	99.7735	99.63426
RMU49	RMU49_LV	98.75129	98.48708
RMU26	RMU26_LV	98.06264	97.91918
RMU47	RMU47_LV	97.61505	97.47363
RMU45	RMU45_LV	97.08433	96.70086

HV-Side	LV-Side	Loading %	Loading %
RMU34	RMU34_LV	96.83862	96.60124
RMU62	RMU62_LV	96.73853	96.50563
RMU31	RMU31_LV	96.64246	94.97525
RMU5	RMU5_LV	95.1051	92.92406
RMU52	RMU52_LV	94.86428	92.71836
RMU7	RMU7_LV	92.8493	90.48894

4.2 Contingency Analysis Results

4.2.1 Contingency 1 – Loss of 5MVA BESS at Bonriki

Contingency 1 assesses the worst-case scenario of losing the proposed 5MVA BESS at Bonriki for the year 2020, 2030, and 2040. A similar set of remedial actions is also required for this to keep the system parameters within the permissible limits and closest to the nominal values. The summary of remedial actions for this scenario is presented in Table 4.4.

Table 4.4. Loss of 5MVA BESS at Bonriki - Remedial Actions

Action	2020	2030	2040
1	Switch off 4MW PV	Switch off 4MW PV	Switch off 4MW PV
2	2.2MVA BESS limited to 1MW charging	2MVA BESS limited to 500kW charging	Upgrade 2MVA BESS to 5MVA
3	Switch off Generator 6	Switch on Gen 4 & Gen 7	Expand 4MW PV to 6MW PV
4	Switch on 300kVar capacitor bank at RMU17	Switch on 400kVar capacitor bank at RMU17	Expand 2MW PV to 4MW PV
5	-	-	2.2MVA BESS limited to 500kW charging
6	-	-	Switch on Gen 4, Gen 7, and Gen 8
7	-	-	Switch on 2MVar capacitor bank at RMU17

The loss of the 5MVA BESS will require the 4MW PV to be switched off. This is important as it is not possible to evacuate 4MW of power from Bonriki without significantly overloading the power grid. As an alternative, other PV systems could be switched off while the 2.2MVA BESS is kept in service. This study considers the disconnection of the 4MW PV as a remedial action to the 5MVA BESS going out of service.

Figure D shows that by applying the remedial actions the voltage profile was kept within permissible limits. Overloaded RMUs was recorded for 2020 due to low-capacity expansion. Upgrade of RMUs is necessary in the near-term and by the year 2030 and 2040 to cater to the expected load growths.

Figure 4.9. Loss of 5MVA BESS - System Voltage Profile

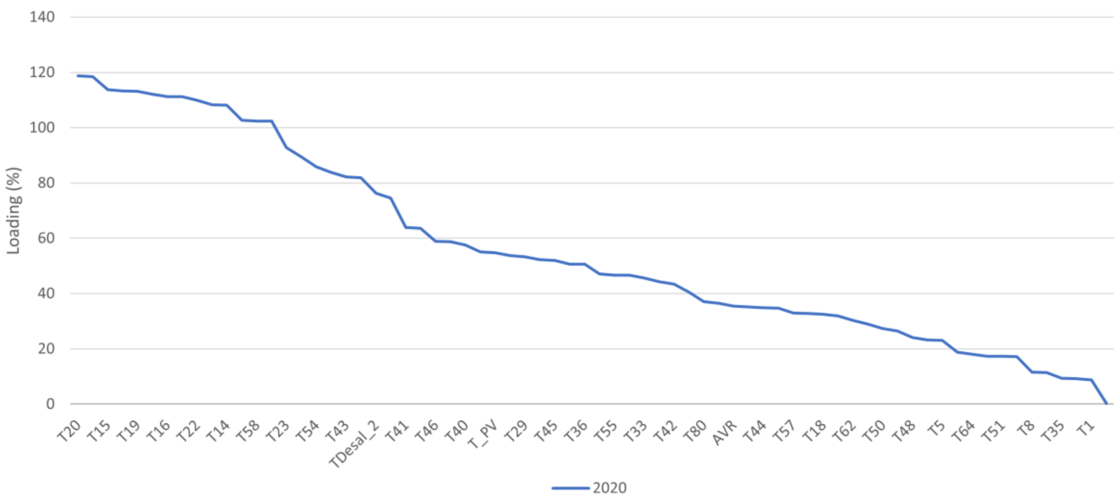


Figure 4.10. Loss of 5MVA BESS - Year 2020 System Loading

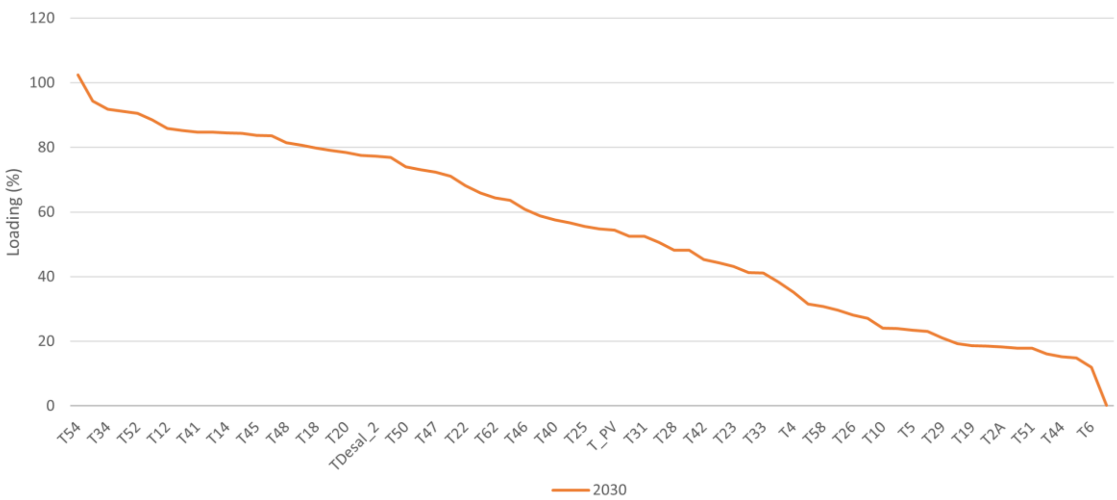


Figure 4.11. Loss of 5MVA BESS - Year 2030 System Loading

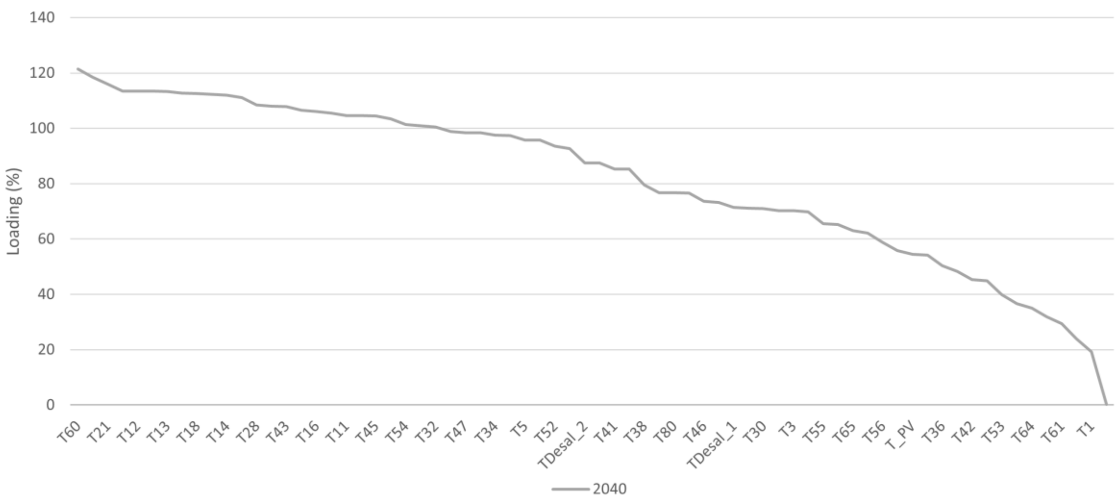


Figure 4.12. Loss of 5MVA BESS - Year 2040 System Loading

Upon implementing the suggested remedial actions following the outage of the 5MVA BESS, the diesel generators will continue to operate within their set limits and power factors. A summary of the generation dispatch is shown in Table 4.5.

Table 4.5. Loss of 5MVA at Bonriki - Generation Dispatch

	Type	2020			2030			2040		
		Day			Day			Night		
		kW	KVAr	PF	kW	KVAr	PF	kW	KVAr	PF
No.1	Diesel	900	558	0.85	900	558	0.85	1200	744	0.85
No.2	Diesel	-	-	-	-	-	-	1200	744	0.85
No.3	Diesel	779	483	0.85	1076	624	0.87	1734	1006	0.87
No.4	Diesel	-	-	-	1250	775	0.85	1800	1116	0.85
No.5	Diesel	1200	744	0.85	1200	744	0.85	1900	1178	0.85
No.6	Diesel	1500	930	0.85	1800	1116	0.85	1900	1178	0.85
No.7	Diesel	-	-	-	1800	1116	0.85	1200	744	0.85
No.8	Diesel	-	-	-	-	-	-	1800	1116	0.85
New 5MVA	PV	-	-	-	-	-	-	-	-	-
KGV	PV	159	-	1	159	-	1	159	-	1
New 2.2MVA	PV	2000	-	-	2000	-	-	4000	-	1
UAE	PV	419	-	1	419	-	1	419	-	1
TCH	PV	157	-	1	157	-	1	157	-	1
KIT	PV	117	-	1	117	-	1	117	-	1
BSC	PV	100	-	1	100	-	1	100	-	1
PEC	PV	280	-	1	280	-	1	280	-	1
New 2MVA	BESS	-1000	-	-	-500	-	1	-500	-	1
New 5MVA	BESS	-	-	-	-	-	-	-	-	-
Total		6611	2714		10758	4931		17466	7823	
Load		6316	3920	-	10287	6388	-	16682	10357	-
Losses		295	916	-	471	-1028	-	784	-534	-
Compensation			290	-		428	-		2000	-

4.2.2 Contingency 2 – Loss of Generator 4 at Bikenibeu PS

The second contingency considers the loss of Generator 4 at Bikenibeu PS for the year 2020, 2030, and 2040. The summary of remedial actions for each loading scenario, similar to contingency 1, is shown in Table 4.6.

Table 4.6. Loss of 5MVA BESS - Remedial Actions

Action	2020	2030	2040
1	5MVA BESS limited to 3.5MW charging	5MVA BESS limited to 500kW charging	5MVA BESS limited to 1.8MW charging
2	2.2MVA BESS limited to 1.5MW charging	2MVA BESS limited to 500kW charging	2.2MVA BESS limited to 1MW charging
3	Switch on 300kVar capacitor bank at RMU17	Switch on 2.75MVar capacitor bank at RMU17	Upgrade 2MVA BESS to 5MVA
4	-	-	Expand 4MW PV to 6MW PV
5	-	-	Expand 2MW PV to 4MW PV
6	-	-	Switch on Gen 2, Gen 7, and Gen 8
7	-	-	Switch on 3.8MVar capacitor bank at RMU17

Figure 4.13 shows that by applying the remedial actions the voltage profile can be kept within permissible limits. Overloaded RMUs were recorded for 2020 due to low-capacity expansion. Upgrade of RMUs will be necessary in the near-term and by the year 2030 and 2040 to cater to the expected load growths.

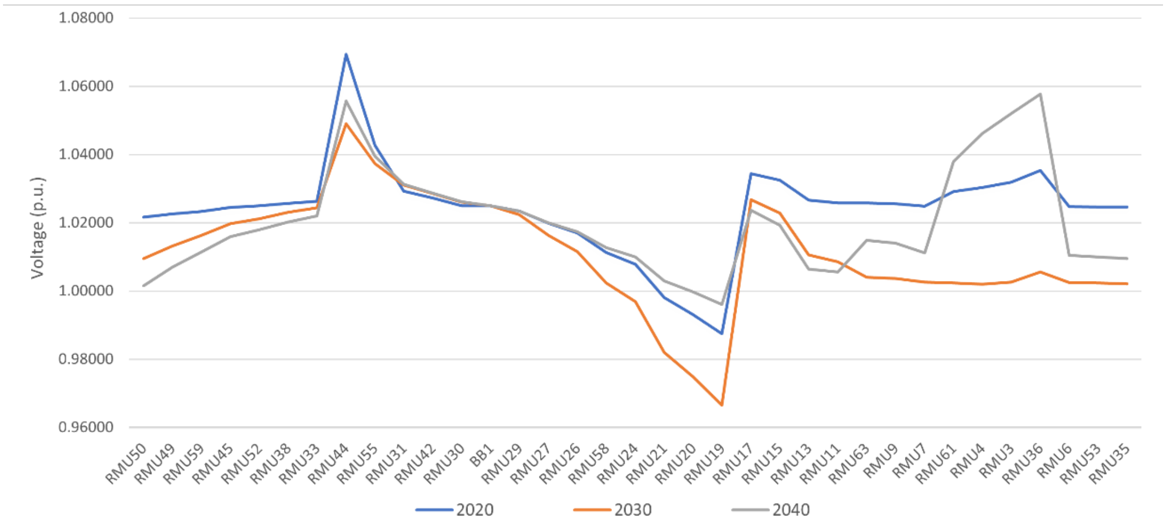


Figure 4.13. Loss of Generator 4 at Bikenibeu PS - System Voltage Profile

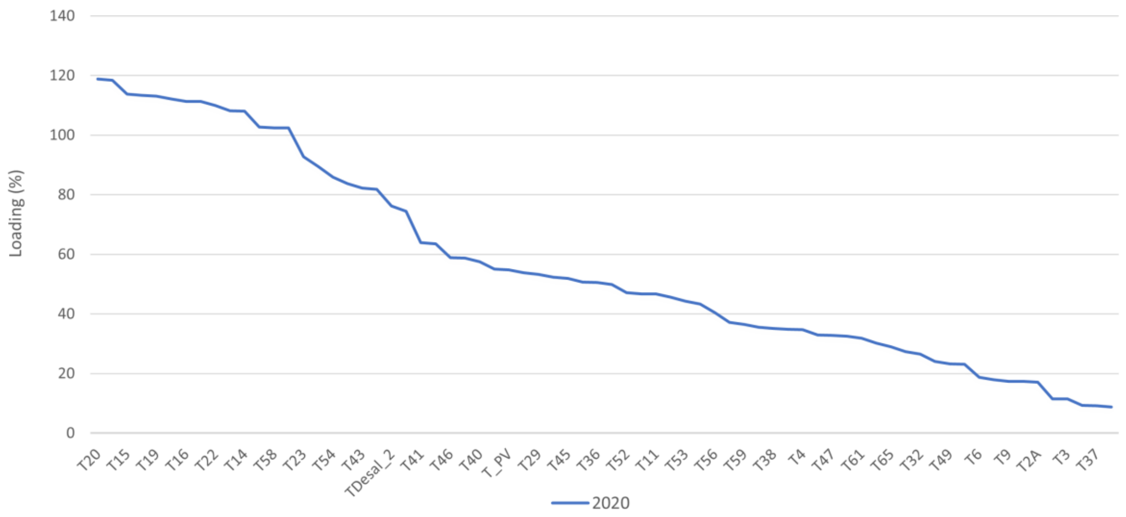


Figure 4.14. Loss of Generator 4 at Bikenibeu PS - Year 2020 System Loading Profile

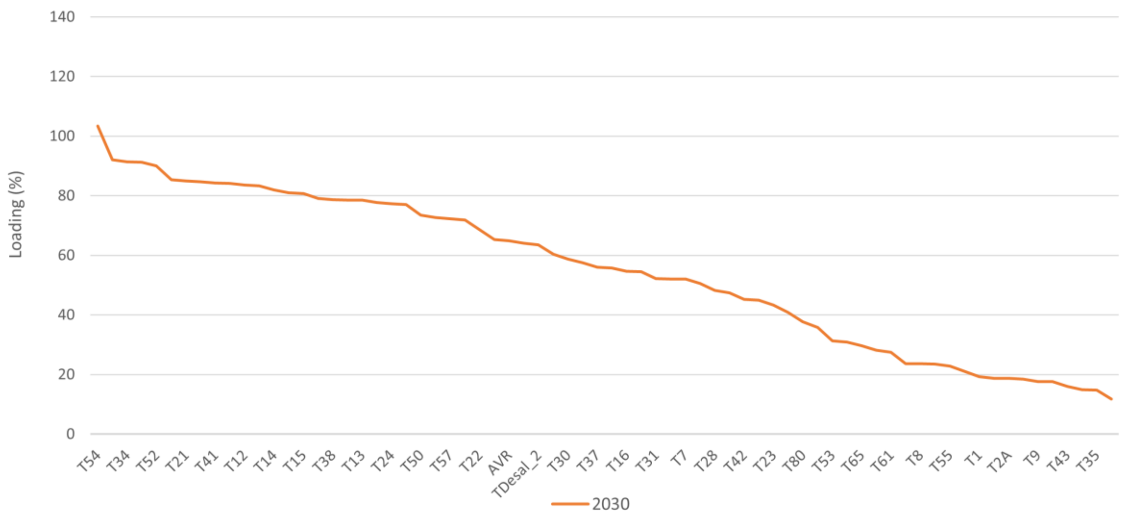


Figure 4.15. Loss of Generator 4 at Bikenibeu PS - Year 2030 System Loading Profile

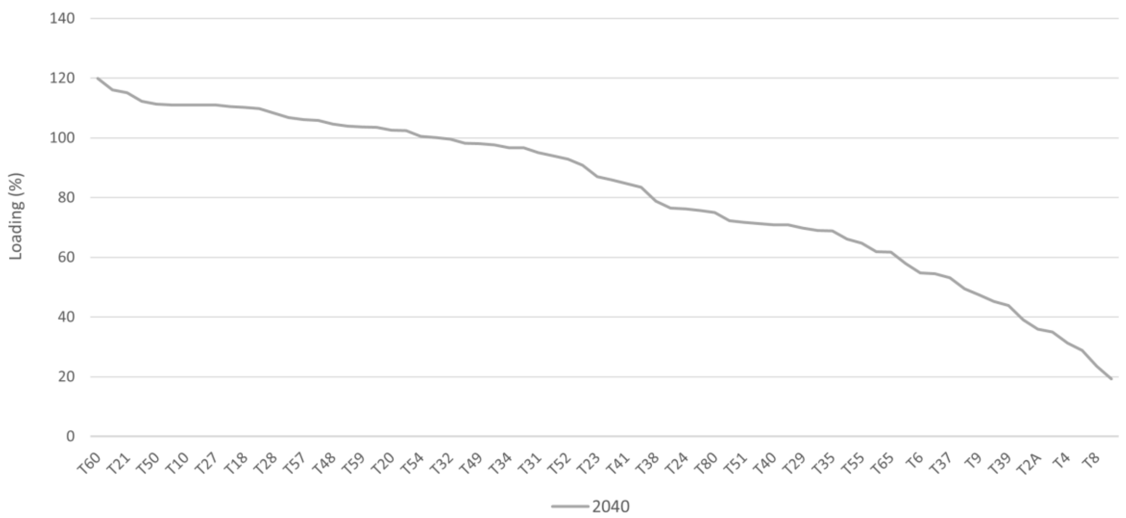


Figure 4.16. Loss of Generator 4 at Bikenibeu PS - Year 2040 System Loading Profile

Upon implementing the suggested remedial actions following the loss of Generator 4 at Bikenibeu PS, the generators can be expected to operate within their set limits and power factor. A summary of the generation dispatch is shown in Table 4.7.

Table 4.7. Loss of Generator 4 at Bikenibeu PS - Generation Dispatch

	Type	2020			2030			2040		
		Day			Day			Night		
		kW	KVAr	PF	kW	KVAr	PF	kW	KVAr	PF
No.1	Diesel	900	558	0.85	900	558	0.85	1200	744	0.85
No.2	Diesel	-	-	-	-	-	-	1200	744	0.85
No.3	Diesel	779	483	0.85	859	498	0.87	1783	1119	0.85
No.4	Diesel	-	-	-	-	-	-	-	-	-
No.5	Diesel	1200	744	0.85	1200	744	0.85	1900	1178	0.85
No.6	Diesel	1500	930	0.85	1800	1116	0.85	1900	1178	0.85
No.7	Diesel	-	-	-	-	-	-	1200	744	0.85
No.8	Diesel	-	-	-	-	-	-	1800	1116	0.85
New 5MVA	PV	4000	-	1	4000	-	1	6000	-	1
KGV	PV	160	-	1	159	-	1	159	-	1
New 2.2MVA	PV	2000	-	1	2000	-	-	4000	-	1
UAE	PV	422	-	1	419	-	1	419	-	1
TCH	PV	158	-	1	157	-	1	157	-	1
KIT	PV	118	-	1	117	-	1	117	-	1
BSC	PV	101	-	1	100	-	1	100	-	1
PEC	PV	282	-	1	280	-	1	280	-	1
New 2MVA	BESS	-1500	-	1	-500	-	1	-1000	-	1
New 5MVA	BESS	-3500	-	1	-500	-	1	-1800	-	1
Total		6658	2156		10991	2915		19415	6272	
Load		6316	3920		10287	6388	-	16682	10357	-
Losses		341	-917		704	-723	-	2733	-103	-
Compensation			289			2750	-		3800	-

4.2.3 Contingency 3 – Loss of Generator 1 at Betio PS

The third contingency considers the loss of Generator 1 at Betio PS for the year 2020, 2030, and 2040. The summary of remedial actions for each loading scenario, similar to contingency 1, is shown in Table 4.8.

Table 4.8. Loss of Generator 4 at Bikenibeu PS - Remedial Actions

Action	2020	2030	2040
1	Switch on Gen 2	Switch on Gen 2 and Gen 7	5MVA BESS limited to 1.8MW charging
2	5MVA BESS limited to 3.5MW charging	5MVA BESS limited to 500kW charging	2MVA BESS limited to 1MW charging
3	2.2MVA BESS limited to 1.6MW charging	2.2MVA BESS limited to 500kW charging	Upgrade 2MVA BESS to 5MVA

Action	2020	2030	2040
4	Switch on 300kVar capacitor bank at RMU17	Switch on 3MVar capacitor bank at RMU17	Expand 4MW PV to 6MW PV
5	-	-	Expand 2MW PV to 4MW PV
6	-	-	Switch on Gen 2, Gen 5, Gen 7, and Gen 8
7	-	-	Switch on 4MVar capacitor bank at RMU17

Figure 4.17 shows that by applying the remedial actions the voltage profile was kept within permissible limits. Overloaded RMUs was recorded for 2020 due to low-capacity expansion. Upgrade of RMUs will be necessary in the near-term and by the year 2030 and 2040 to cater to the expected load growths.

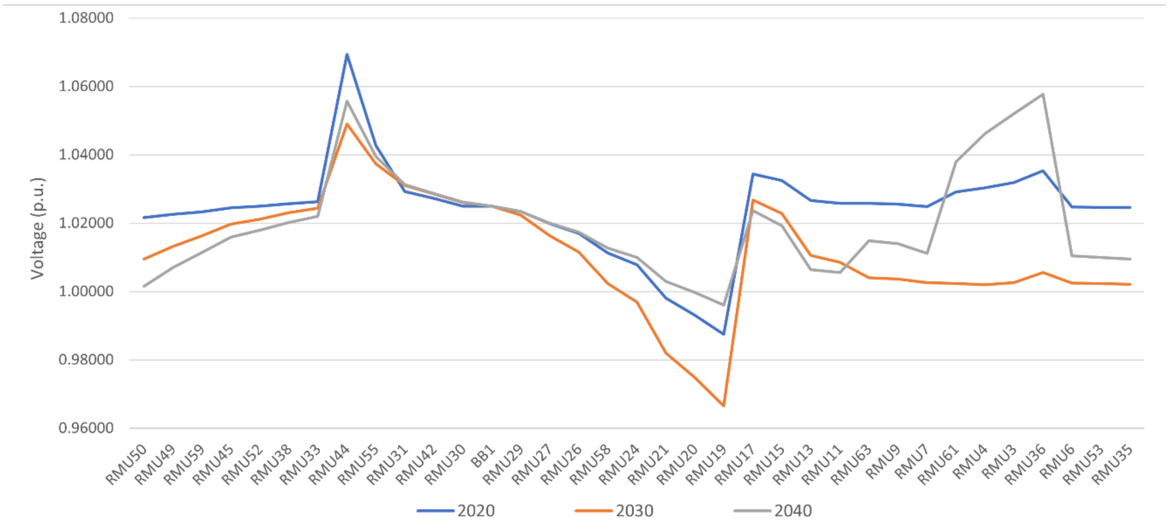


Figure 4.17. Loss of Generator 1 at Betio PS - System Voltage Profile

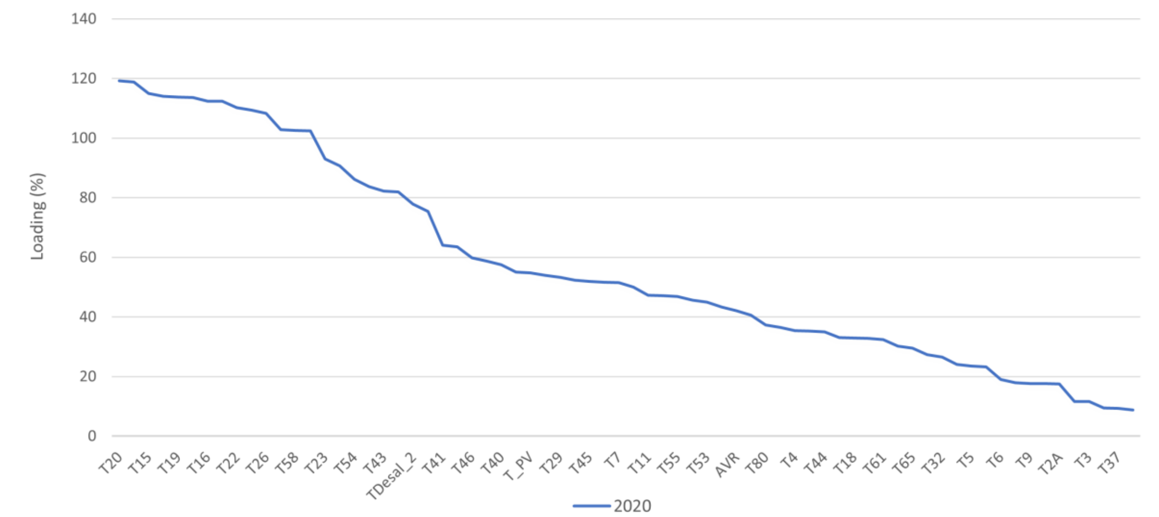


Figure 4.18. Loss of Generator 1 at Betio PS - Year 2020 System Loading Profile

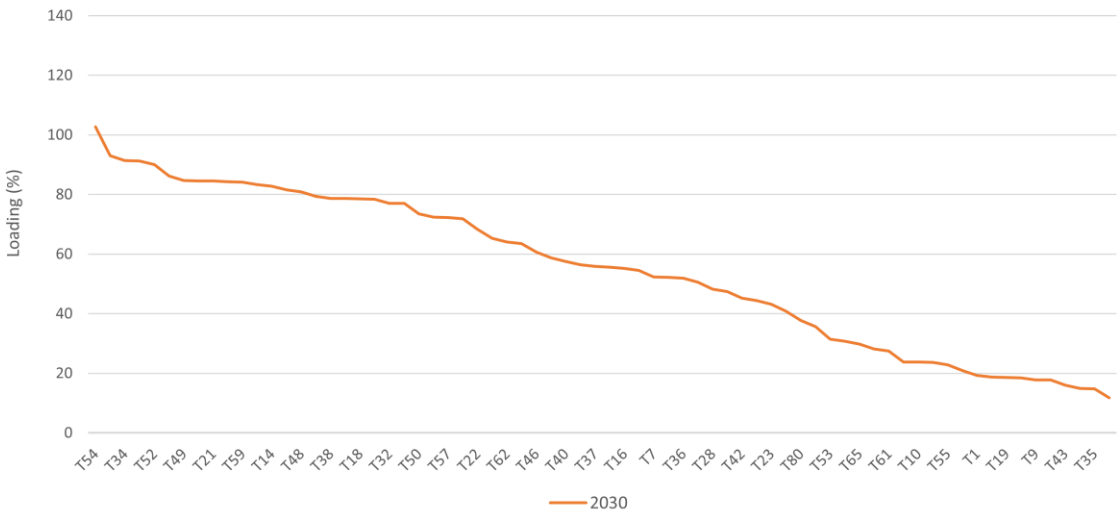


Figure 4.19. Loss of Generator 1 at Betio PS - Year 2030 System Loading Profile

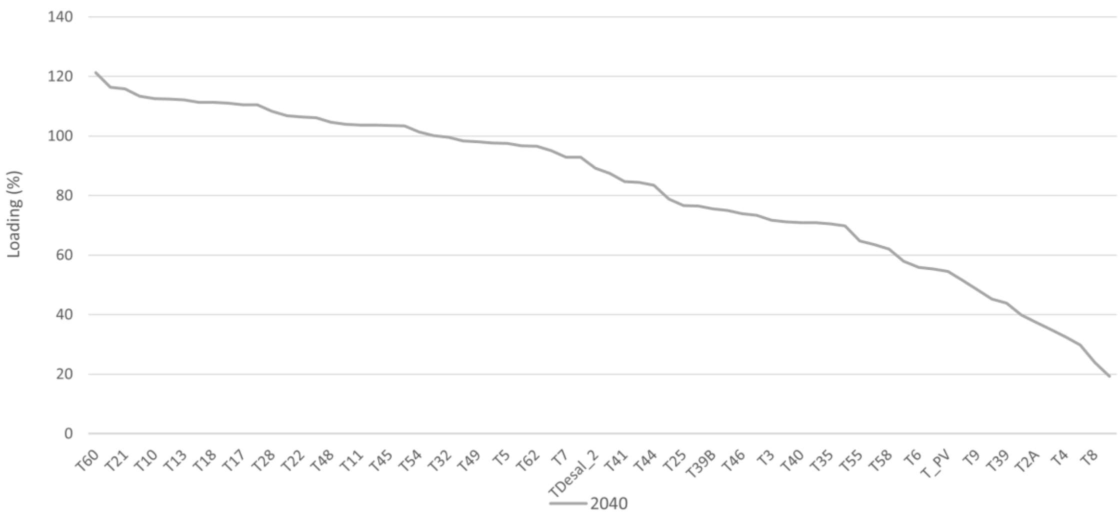


Figure 4.20. Loss of Generator 1 at Betio PS - Year 2040 System Loading Profile

Upon implementing the suggested remedial actions following the loss of Generator 1 at Betio PS, the generators can be expected to operate within their set limits and power factor. A summary of the generation dispatch is shown in Table x.

Table 4.9. Loss of Generator 1 at Betio PS - Generation Dispatch

	Type	2020			2030			2040		
		Day			Day			Night		
		kW	KVAr	PF	kW	KVAr	PF	kW	KVAr	PF
No.1	Diesel	-	-	-	-	-	-	-	-	-
No.2	Diesel	600	372	0.85	600	372	0.85	1200	744	0.85
No.3	Diesel	1061	639	0.86	1088	601	0.88	1276	791	0.85
No.4	Diesel	1250	775	0.85	1200	744	0.85	1800	1116	0.85
No.5	Diesel	-	-	-	-	-	-	1900	1178	0.85
No.6	Diesel	1600	992	0.85	1000	620	0.85	1900	1178	0.85
No.7	Diesel	-	-	-	800	496	0.85	1200	744	0.85
No.8	Diesel	-	-	-	-	-	-	1800	1116	0.85

	Type	2020			2030			2040		
		Day			Day			Night		
		kW	KVAr	PF	kW	KVAr	PF	kW	KVAr	PF
New 5MVA	PV	4000	-	1	4000	-	1	6000	-	1
KGV	PV	159	-	1	159	-	1	159	-	1
New 2.2MVA	PV	2000	-	1	2000	-	1	4000	-	1
UAE	PV	419	-	1	419	-	1	419	-	1
TCH	PV	157	-	1	157	-	1	157	-	1
KIT	PV	117	-	1	117	-	1	117	-	1
BSC	PV	100	-	1	100	-	1	100	-	1
PEC	PV	280	-	1	280	-	1	280	-	1
2MVA (2040 - 5MVA)	BESS	-1600	-	1	-500	-	1	-1000	-	1
5MVA	BESS	-3500	-	1	-500	-	1	-1800	-	1
Total		6690	2777		10920	2832		19508	5748	
Load		6316	3920		10287	6388		16682	10357	
Losses		373	855		633	708		2825	153	
Compensation			287			2848			4000	

4.2.4 Contingency 4 – Loss of Generator 5 at Bikenibeu PS (Night Operation)

The fourth contingency considers the loss of Generator 1 at Betio PS for the year 2020, 2030, and 2040. The summary of remedial actions for each loading scenario, similar to previous scenarios, is shown in Table 4.10.

Table 4.10. Loss of Generator 5 at Bikenibeu PS - Night Operation

Action	2020	2030	2040
1	2MVA BESS limited to 200kW discharging	2MVA BESS limited to 300kW discharging	2MVA BESS limited to 2.5MW discharging
2	5MVA BESS limited to 300kW discharging	5MVA BESS limited to 300kW discharging	5MVA BESS limited to 1MW discharging
3	-	Switch on Gen 5	-

Figure 4.21 shows that by applying the remedial actions the voltage profile was kept within permissible limits. Overloaded RMUs was recorded for 2020 due to low-capacity expansion. Upgrade of RMUs will be necessary in the near-term and by the year 2030 and 2040 to cater to the expected load growths.

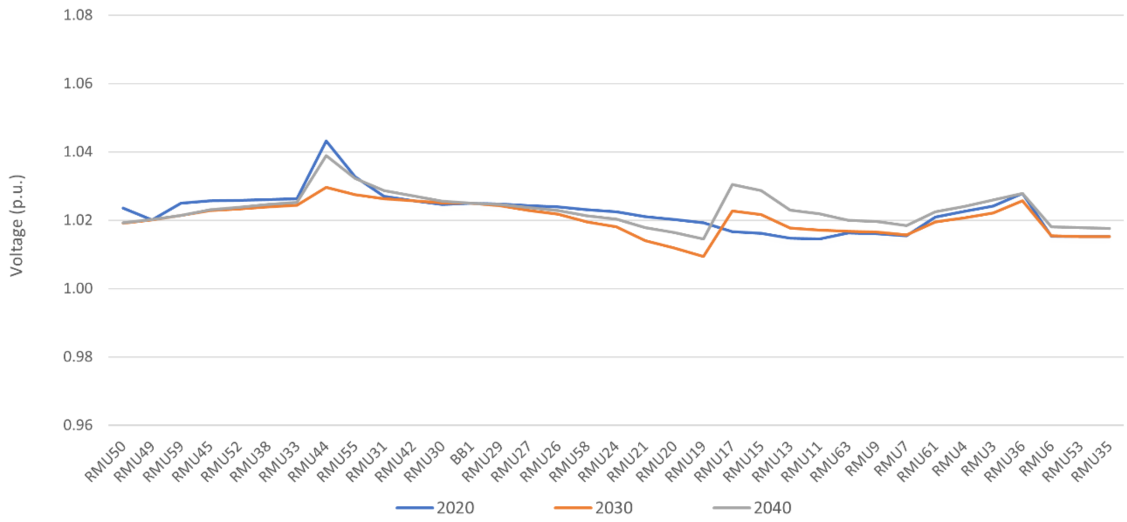


Figure 4.21. Loss of Generator 5 at Bikenibeu PS during night - System Voltage Profile

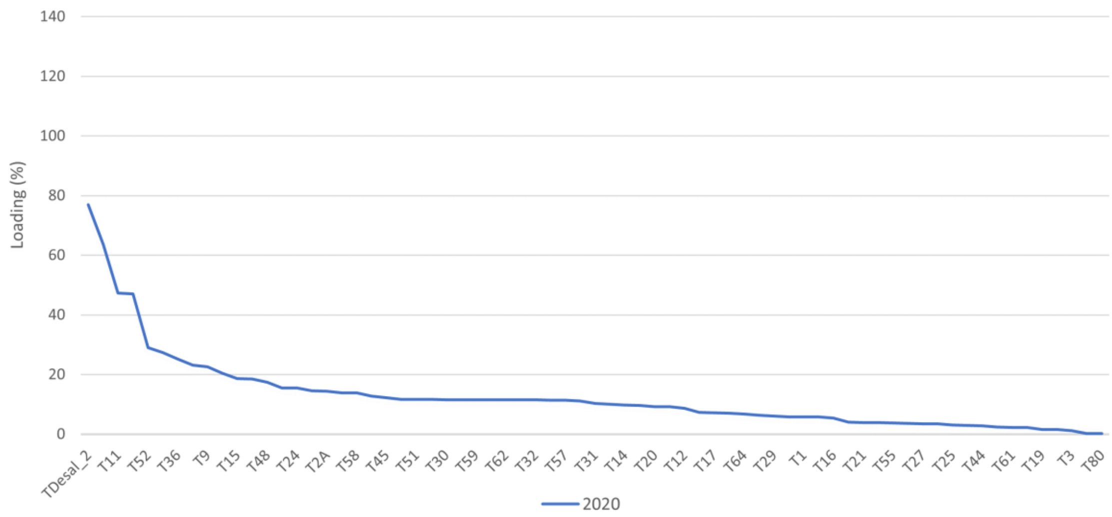


Figure 4.22. Loss of Generator 5 at Bikenibeu PS during night - Year 2020 System Loading Profile

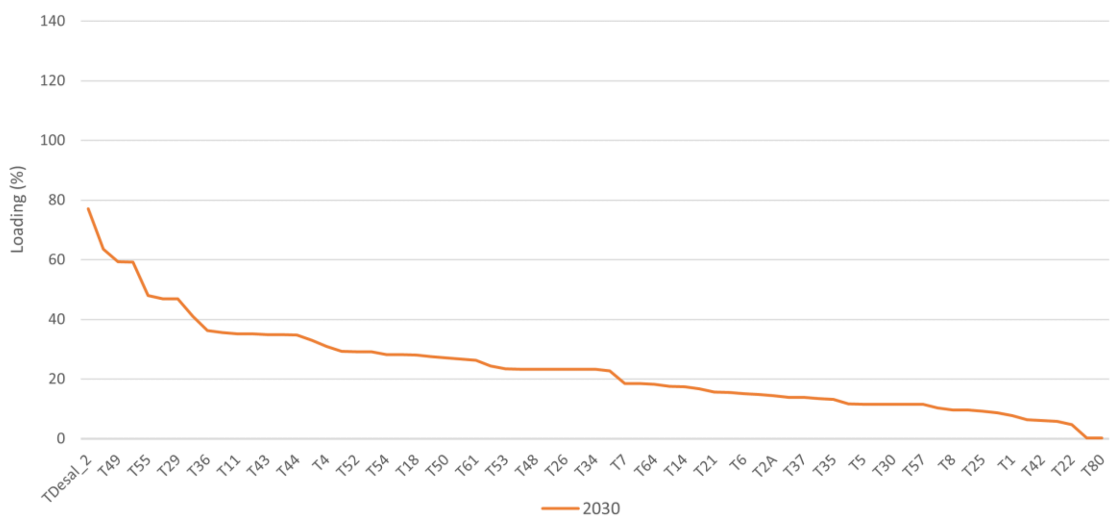


Figure 4.23. Loss of Generator 5 at Bikenibeu PS during night - Year 2030 System Loading Profile

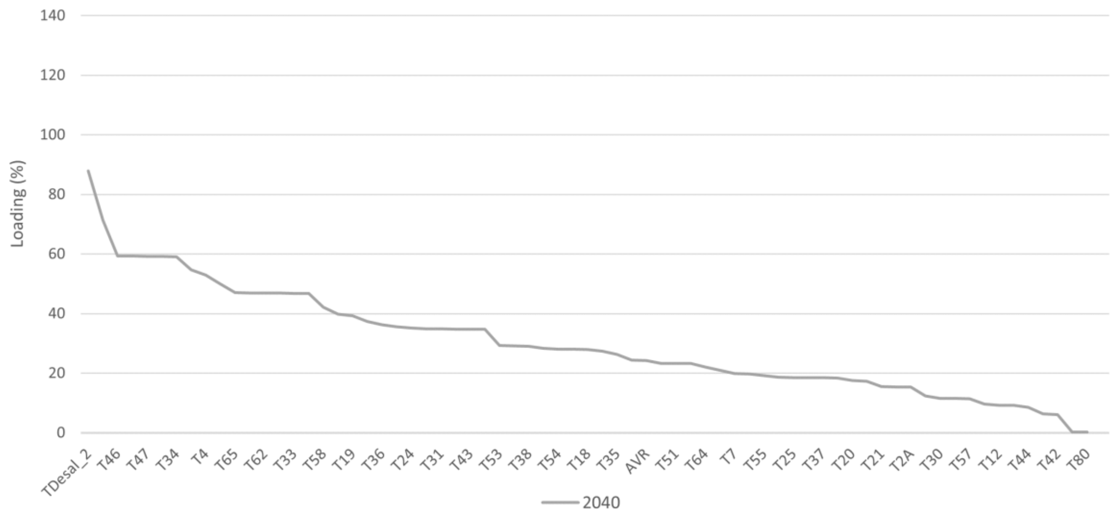


Figure 4.24. Loss of Generator 5 at Bikenibeu PS during night - Year 2040 System Loading Profile

Upon implementing the suggested remedial actions following the loss of Generator 1 at Betio PS, the generators can be expected to operate within their set limits and power factor. A summary of the generation dispatch is shown in Table 4.11.

Table 4.11. Loss of Generator 5 at Bikenibeu PS during night - Generation dispatch

	Type	2020			2030			2040		
		Day			Day			Night		
		kW	KVAr	PF	kW	KVAr	PF	kW	KVAr	PF
No.1	Diesel	900	558	0.85	900	558	0.85	1200	744	0.85
No.2	Diesel	-	-	-	-	-	-	-	-	-
No.3	Diesel	1105	-653	0.86	1109	-832	0.8	1200	718	0.86
No.4	Diesel	-	-	-	-	-	-	-	-	-
No.5	Diesel	-	-	-	1150	713	0.85	-	-	-
No.6	Diesel	-	-	-	-	-	-	-	-	-
No.7	Diesel	-	-	-	-	-	-	-	-	-
No.8	Diesel	-	-	-	-	-	-	-	-	-
New 5MVA	PV	-	-	-	-	-	-	-	-	-
KGV	PV	-	-	-	-	-	-	-	-	-
New 2.2MVA	PV	-	-	-	-	-	-	-	-	-
UAE	PV	-	-	-	-	-	-	-	-	-
TCH	PV	-	-	-	-	-	-	-	-	-
KIT	PV	-	-	-	-	-	-	-	-	-
BSC	PV	-	-	-	-	-	-	-	-	-
PEC	PV	-	-	-	-	-	-	-	-	-
2MVA (2040 – 5MVA)	BESS	200	41	0.98	300	61	0.98	2500	508	0.98
5MVA	BESS	300	61	0.98	300	61	0.98	1000	203	0.98
Total		2505	-552		3759	2		5900	2173	
Load		2443	1515		3680	2282		5728	3557	
Losses		62	-2067		80	-2280		172	-1384	
Compensation			-			-			-	

4.3 Short Circuit Current Results

The three phase and single line to ground fault levels were calculated for normal system operation and at maximum loading conditions. The results show for all years were seen to be well below the 13.1kA maximum allowable short circuit current rating for 11kV equipment and require no further mitigation. The network fault level profiles for each year are shown in the figures below.

Figure 4.25. Short Circuit Current Results - Year 2020

Figure 4.26. Short Circuit Current Results - Year 2030

Figure 4.27. Short Circuit Results - Year 2040

5 Recommendations and Conclusions

The completed steady-state studies analyse the PUB electrical system post connection of the proposed 4MW PV and 5MVA BESS system at Bonriki, the proposed 2MW PV and 2MVA BESS system also at Bonriki, and the two proposed 546kW reverse osmosis desalination plants to be connected between RMU30 and RMU40 and between RMU4 and RMU5. The most important contingency conditions have been presented in Section 4.2. A summary of the remedial actions of the observed disturbances is shown in Table 5.2.

Table 5.1. Summary of Suggested Actions and Network Modifications

Equipment	Action	Time
RMU29, RMU28, RMU27, RMU26, RMU25, RMU24, RMU23, RMU22, RMU21, RMU54, RMU20, RMU19, RMU60, RMU17, RMU16, RMU15, RMU14, RMU18, RMU13, RMU12, RMU11, RMU10	Experience overloads that range from -10% to beyond 20% of rated capacity. Upgrade each RMU to ensure load is at 50-60% of rated capacity for optimal performance. Alternatively, install additional ring main units to lower rating on each RMU to within 50-60% of rated capacity. It is suggested that this be implemented for all RMUs along the line from Bikenibeu PS to C/B 1 at Betio.	2023-2030
XLPE 3C x 25sqmm, XLPE 3C x 50sqmm on feeder to Bonriki PV & BESS site	Experience overloads that range from -10% to beyond 20% of rated capacity when 4MW PV, 2.2MW PV, 5MVA BESS, and 2MVA BESS are connected. Limited transmission capacity from Bonriki to high load centers. It is suggested that these cables be upgraded to XLPE 3C x 240sqmm.	2023-2030
XLPE 3C x 25sqmm, XLPE 3C x 50sqmm XLPE 3C x 70sqmm on feeder to Bonriki PV & BESS site	Limited transmission capacity. Experience overloads that range from -10% to beyond 20% of rated capacity as a result of high demand from load centers between Bikenibeu PS and Betio PS. It is suggested that these cables be upgraded to XLPE 3C x 240sqmm.	2023-2035
RMU30, RMU40, RMU42, RMU31, RMU32, RMU33, RMU38, RMU26, RMU27, RMU56, RMU57, RMU44, RMU39, RMU52, RMU62, RMU34, RMU45, RMU41, RMU59, RMU47, RMU49, RMU48, RMU50	Experience overloads that range from -10% to beyond 20% of rated capacity. Upgrade each RMU to ensure load is at 50-60% of rated capacity for optimal performance. Alternatively, install additional ring main units to lower rating on each RMU to within 50-60% of rated capacity. It is suggested that this be implemented for all RMUs along the line from Bikenibeu PS to C/B 1 at Betio.	2031-2040
Gen 2, Gen 4, Gen 5, Gen 6	2040 load is expected to be 3 times of current maximum load. Diesel generators do not have the capacity for this. It is suggested that the selected generators be upgraded to 2MW maximum rated output to cater to 2040 expected load. These will be supported by a total of 6MW PV and 7MVA BESS systems installed at Bonriki.	2040

Equipment	Action	Time
Gen 8	All diesel generators will be in service in 2040. There will be no backup generator available to maintain an N-1 contingency. It is suggested that an additional 2MW generator be installed at Bikenibeu PS to provide this service.	2040
2.2MW PV & 2MVA BESS	Total combined generation output of the installed and proposed diesel generators and the proposed PV and BESS systems do not have the capacity to meet the 2040 calculated load. It is suggested that these be expanded to 4MW PV & 5MVA BESS to meet the 2040 load.	2040
3MVar Capacitor Bank	Install 3MVar capacitor bank connected at RMU17 to provide local voltage support	2030
4MVar Capacitor Bank	Upgrade 3MVar capacitor bank to 4MVar capacitor bank connected at RMU17	2040

Table 5.2. Summary of Corrective Actions for the most important disturbances

Loss of 5MVA BESS at Bonriki - Remedial Actions	2020	2030	2040
1	Switch off 4MW PV	Switch off 4MW PV	Switch off 4MW PV
2	2MVA BESS limited to 1MW charging	2MVA BESS limited to 500kW charging	Upgrade 2MVA BESS to 5MVA
3	Switch off Generator 6	Switch on Gen 4 & Gen 7	Expand 4MW PV to 6MW PV
4	Switch on 300kVar capacitor bank at RMU17	Switch on 400kVar capacitor bank at RMU17	Expand 2MW PV to 4MW PV
5	-	-	2MVA BESS limited to 500kW charging
6	-	-	Switch on Gen 4, Gen 7, and Gen 8
7	-	-	Switch on 2MVar capacitor bank at RMU17
Loss of Gen 4 at Bikenibeu PS - Remedial Actions	**2020**	**2030**	**2040**
1	5MVA BESS limited to 3.5MW charging	5MVA BESS limited to 500kW charging	5MVA BESS limited to 1.8MW charging
2	2MVA BESS limited to 1.5MW charging	2MVA BESS limited to 500kW charging	2MVA BESS limited to 1MW charging
3	Switch on 300kVar capacitor bank at RMU17	Switch on 2.75MVar capacitor bank at RMU17	Upgrade 2.2MVA BESS to 5MVA
4	-	-	Expand 4MW PV to 6MW PV
5	-	-	Expand 2MW PV to 4MW PV

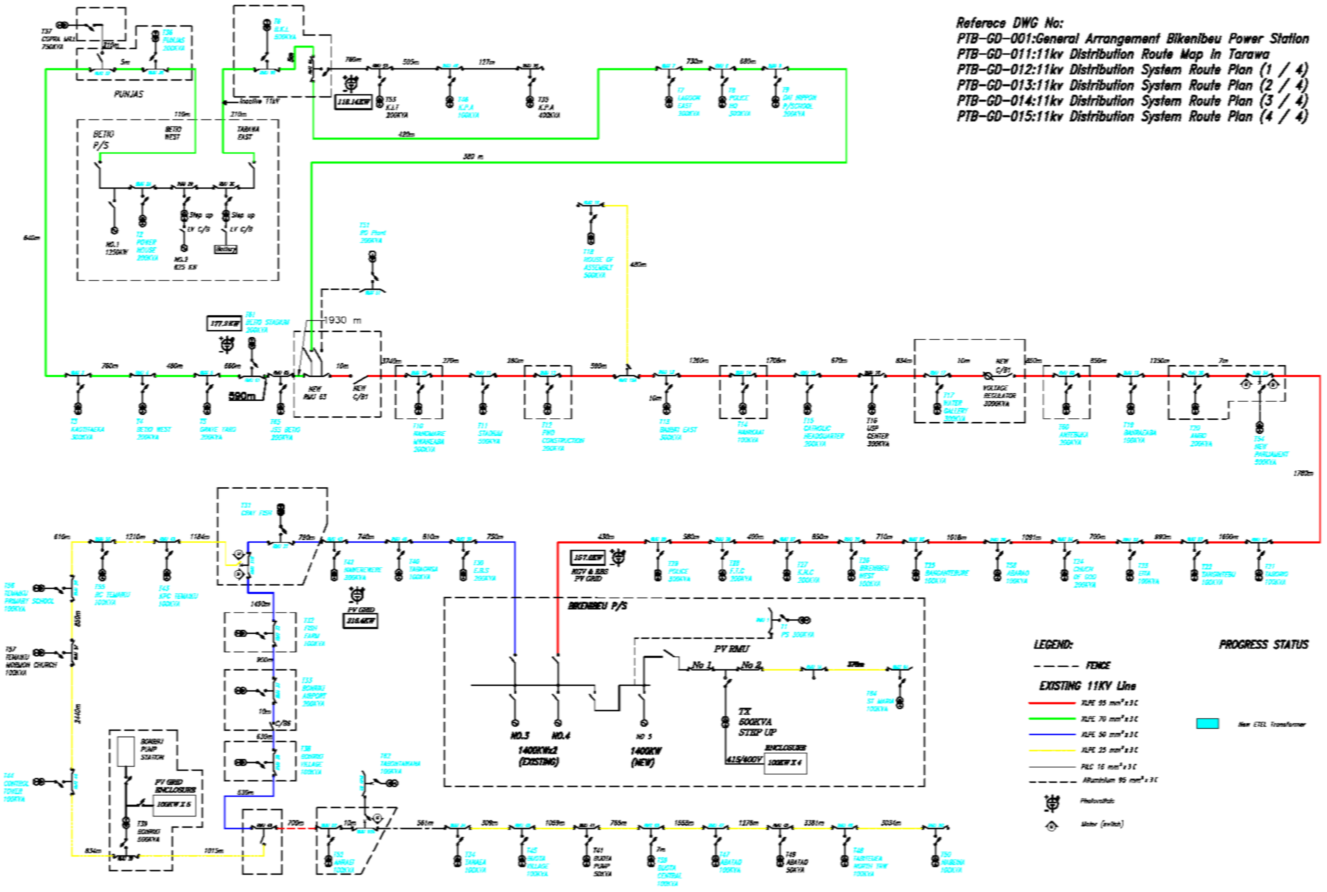
6	-	-	Switch on Gen 2, Gen 7, and Gen 8
7	-	-	Switch on 3.8MVar capacitor bank at RMU17
Loss of Gen 1 at Betio PS - Remedial Actions	**2020**	**2030**	**2040**
1	Switch on Gen 2	Switch on Gen 2 and Gen 7	5MVA BESS limited to 1.8MW charging
2	5MVA BESS limited to 3.5MW charging	5MVA BESS limited to 500kW charging	2MVA BESS limited to 1MW charging
3	2MVA BESS limited to 1.6MW charging	2MVA BESS limited to 500kW charging	Upgrade 2MVA BESS to 5MVA
4	Switch on 300kVar capacitor bank at RMU17	Switch on 3MVar capacitor bank at RMU17	Expand 4MW PV to 6MW PV
5	-	-	Expand 2MW PV to 4MW PV
6	-	-	Switch on Gen 2, Gen 5, Gen 7, and Gen 8
7	-	-	Switch on 4MVar capacitor bank at RMU17
Loss of Gen 5 at Bikenibeu PS during night - Remedial Actions	**2020**	**2030**	**2040**
1	2MVA BESS limited to 200kW discharging	2MVA BESS limited to 300kW discharging	2MVA BESS limited to 2.5MW discharging
2	5MVA BESS limited to 300kW discharging	5MVA BESS limited to 300kW discharging	5MVA BESS limited to 1MW discharging
3	-	Switch on Gen 5	-

6 References

No	Document	Description	Filename
1	11kV Distribution Network in Tarawa	PUB Single Line Diagram	PUB 11kV SLD 2022.pdf
2	Kiribati Population Housing Census 2020	Kiribati Population Statistics	KINSO PHC 2020.pdf
3	“Independent Review of Proposed Power Supply Plan – Steady State Study Prepared for the Finish Consulting Group and Asian Development Bank”, Version 1.1, done for South Tarawa Water Solar Project, on 27th November 2019	South Tarawa Water Supply Project Steady State Studies.	STWSP – Power Supply Review – Steady State Study V1.1.pdf
4	Inception Report – Independent Review of Power Supply Plan – Dynamic Study Prepared for the Asian Development Bank	South Tarawa Water Supply Project	STWSP – Power Supply Review – Dynamic Study Review V1.0.pdf
5	Kiribati PV and BESS Integration Study, August 2020	Assessment of PV and BESS Integration on South Tarawa	PV and BESS Integration Study on South Tarawa.pdf
6	Maximizing PV Integration at Kiribati Distribution System, November 2020	Maximizing PV Integration on South Tarawa	Kiribati Distribution Network Study Rev 6.pdf

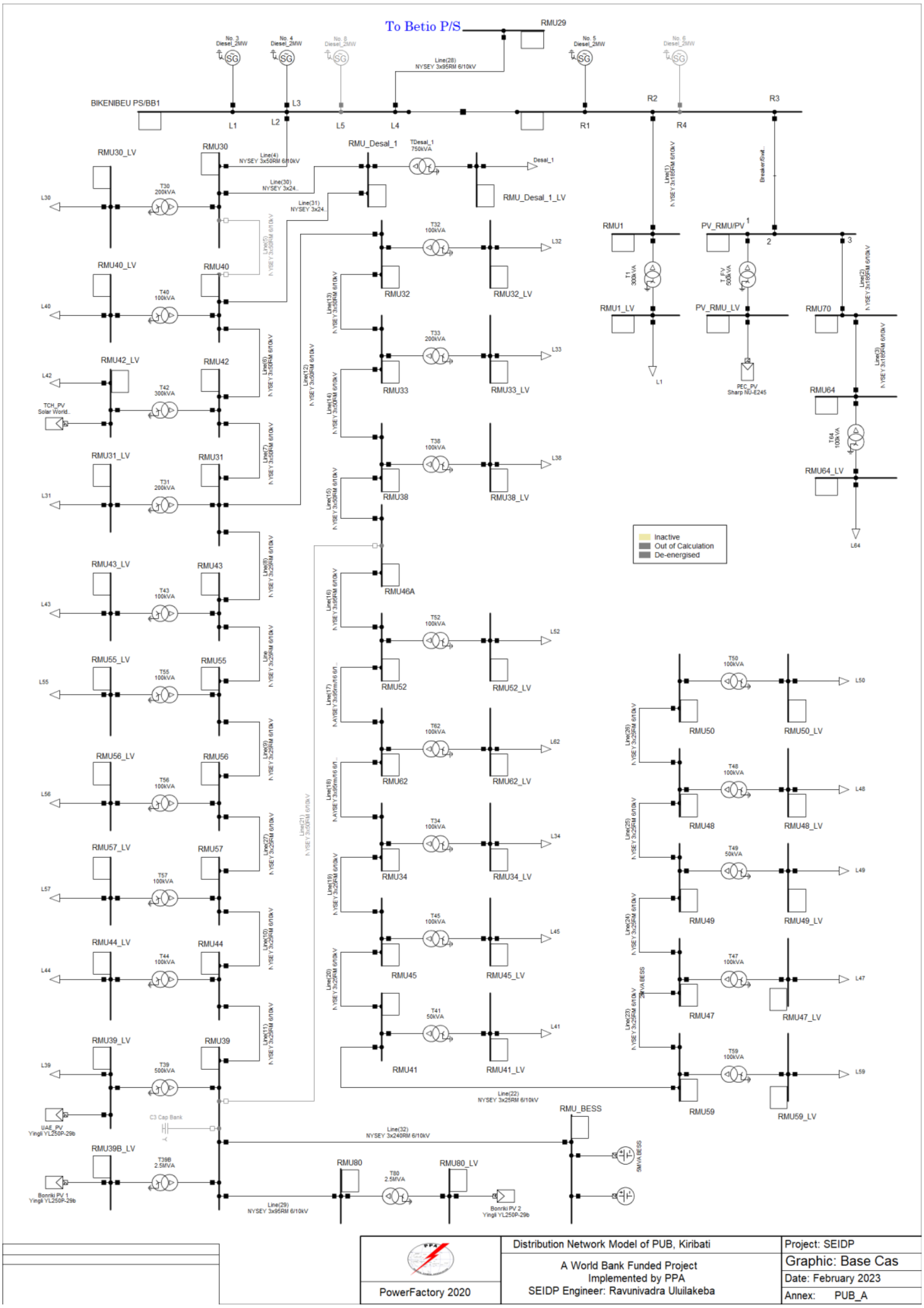
7 Appendices

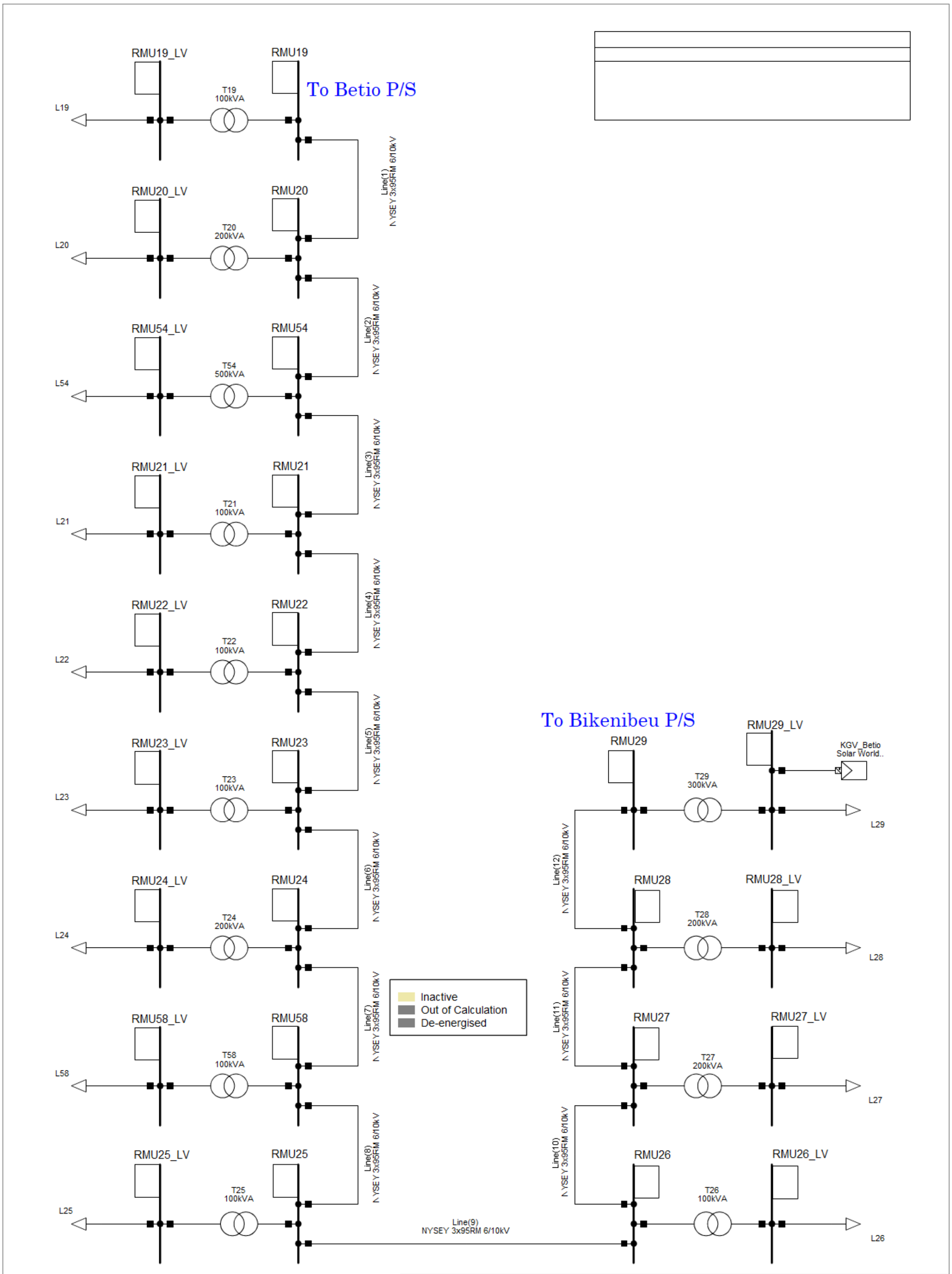
7.1 Network Single Line Diagram



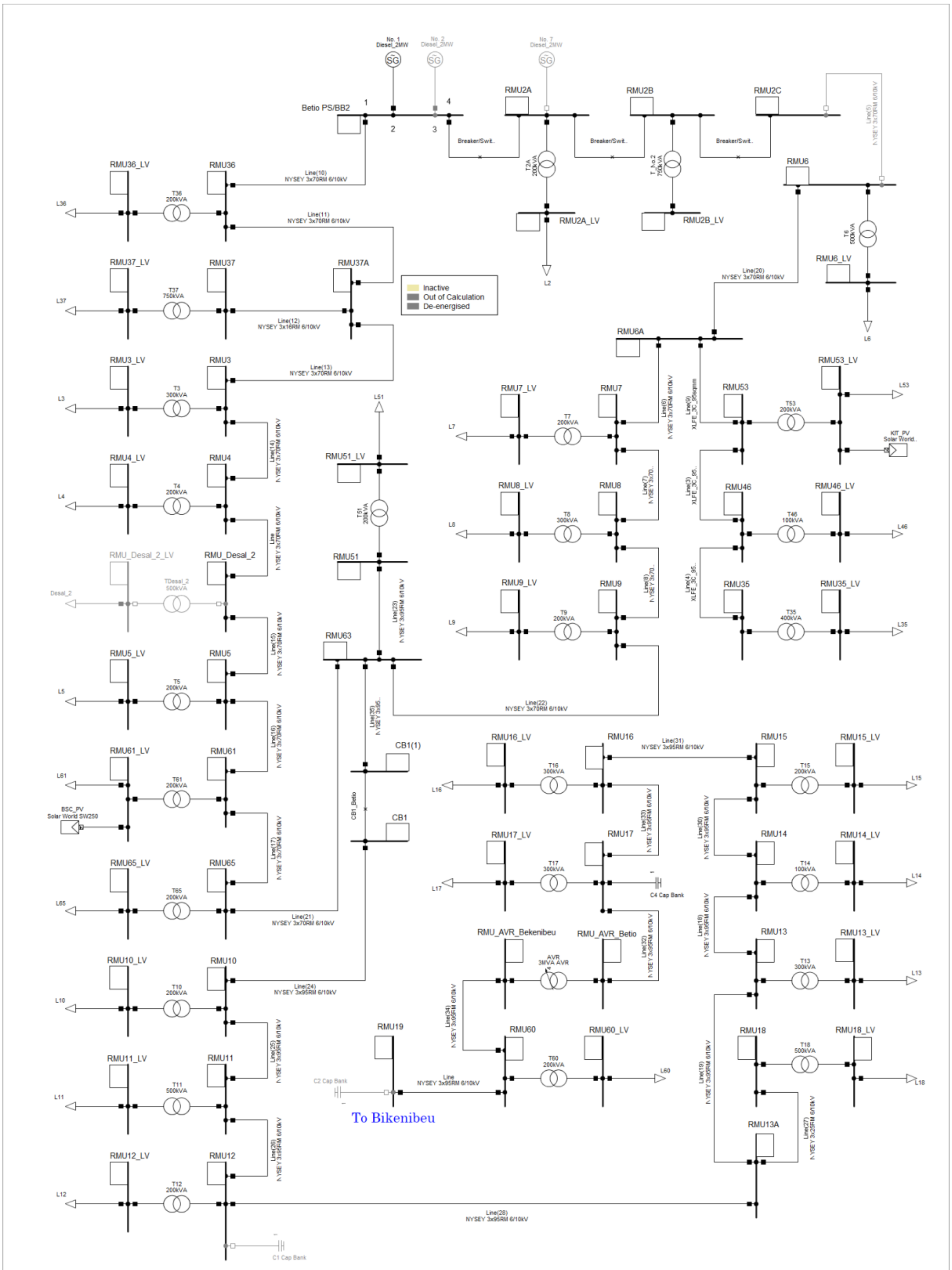
Drawn by I.Tamaroa	**PUB** PUBLIC UTILITIES BOARD		ELECTRICAL ENGINEERING DEPARTMENT
Check by Ioata Reemon			11 KV Distribution Network in Tarawa
Approved by Ioata Reemon			
Date modified 27/09/2022	Phone: (686) 26292 Fax: (686) 26106 P.O.Box 443 E-Mail pub@tski.net.ki Betio, Tarawa. Kiribati		Scale | Drawing No : LD 1 | Sheet No 1 | A3

7.2 Software Network Model





PowerFactory 2020	Distribution Network Model of PUB, Kiribati A World Bank Funded Project Implemented by PPA SEIDP Engineer: Ravunivadra Uluilakeba	Project: SEIDP Graphic: Base Cas Date: February 2023 Annex: PUB_B



PowerFactory 2020	Distribution Network Model of PUB, Kiribati A World Bank Funded Project Implemented by PPA SEIDP Engineer: Ravunivadra Uluilakeba	Project: SEIDP Graphic: Base Cas Date: February 2023 Annex: PUB_C