entura

THE FUNAFUTI – TUVALU

Power System Study

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Revision history

Revision 0

Revision description			
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1. Brief Summary of Dynamic Study Results

The Funafuti – Tuvalu power system consists of a central diesel power station with three 600 kW diesel generators and smaller distributed smaller solar generators.

This study focuses on understanding the system response for three different renewable penetration scenarios.

Table 1.1: Funafuti Generation Scenarios under Study

Scenario	PV Capacity (kWp)	Battery Storage (kW/kWh)	Diesel Generation (kW)	Operation modes
World Bank Project - 2020	1435	1000/1000	1800[3]	minimum 1 diesel unit running
Scenario 2023	4000	2000/6000	1800	System allows zero diesel operation
Scenario 2025	5000	2500/9000	1800	System allows zero diesel operation

In this study it was assumed that the system will operate with a minimum of 1 DG unit in 2020 where as in 2023 and 2025 it was assumed that the system will be able to operate without any DG unit.

Dynamic studies were carried out only for operation with a minimum of 1 DG in place as a dynamic model for a battery with grid forming capabilities was not available. However, steady state studies were carried out for this case.

It should be noted that no protection relays were included in the model as the purpose of this study is to understand the BESS response to load and generator contingencies. Lack of protection function will show when the frequency/voltage increases or decreases significantly. However, detailed protection coordination study should be carried out to manage appropriate discrimination of diesel generator, solar, BESS and feeder protection system. It was also assumed that there are no controls for the existing solar farms hence curtailment points can only be sent to the proposed solar farms.

The results for the dynamic studies are shown below:

- Loss of largest solar farm

  When the largest solar farm is tripped, the frequency of the network falls quickly. When the battery is available, either charged or charging, it reacts quickly and starts exporting power or reducing its import to improve the frequency of the system. In the subsequent minutes, another DG may be required to be started if the solar plant cannot be reconnected.

  When the battery is unavailable, frequency drops quickly. This could lead to the solar farms to trip and the remaining DG would become overloaded resulting in the frequency dropping even further. Loads would need to be tripped in order to avoid a general blackout. Otherwise, either the number of DGs or the diesels headroom needs to be increased to match the largest PV unit.

If the solar farms manage to remain connected nevertheless the drop in frequency it could be possible to remain stable assuming that the output of the largest solar is lower than or equal to the diesel generation headroom.

It should be noted that due to low inertia of the diesel generations, the rate of change of frequency (RoCoF) is significant under sudden drop in solar generation. This initial RoCoF can be calculated based on

$$RoCoF = \frac{50 * \Delta P}{2 * H}$$

Where ΔP is loss of generation in MW and H is inertia of the system in MWs

Assuming 0.5 s inertia constant of a diesel generator, the initial RoCoF for 200 kW drop in solar when one diesel (600 kW/750 MVA) is running is approximately equal to 6.7 Hz/s.

- Loss of largest load

When the largest load is tripped the frequency within the network drops. The output of the DG in service also drops following this frequency change. When the battery is available it reacts and starts absorbing active power and the frequency increases again. Curtailment set points could be sent to the solar plants to reduce generation if the BESS is close to fully charge until the feeder and load are reconnected

If the battery is charging at maximum import of if the battery is unavailable the frequency will keep increasing and the system will become unstable. The high frequency could cause the solar farms to trip and the frequency would subsequently drop. Unless this solar trip is not controlled and managed, the system could be become unstable at under frequency. Hence, controlled tripping of the solar PV is recommended. Based on above explanation, BESS charging at maximum power could pose a threat to system security, hence recommend to keep some headroom for BESS charging at any time.

- Ramping down

As per the loss of solar case the frequency within the network drops following the solars output drop. The output of the DG unit increases to maximum and the BESS reacts when it is available, either charging or charged. This could lead to the system remaining stable. However if the frequency drops very low due to excessive drop in solar output beyond BESS capability then the solar farms could trip completely..

If the BESS is unavailable the frequency could drop very low and lead to system instability. It is recommended that sufficient diesel machine to be in service to cover MW drop of the solar during cloud moving event.

2. Brief Summary of Steady State Study Results

For this specific steady state study it was assumed that the system in 2023 and 2025 will be able to operate without any DG unit.

2.1 Year 2023

In this study is assumed all the uncontrolled solars are operated and 2 scenarios is considered:

- Scenario 1:

  The batteries are connected to the network and could contribute with the reactive power maximum 0.619 Mvar but the active power is supplied only by solars

- Scenario 2:

  There is no controlled solar in the system and the active and reactive power are supplied by 2 batteries.

As you see in the following network diagrams, in both scenarios in the steady state study, network could operate with no problem in the steady state operation. The levels of the voltage in all buses are reasonable.

Table 2.1: Funafuti Generation Year 2023 under Steady State Study

Steady State Study 2023							
	System Load (kW)	**DG1**	**DG2**	**DG3**	**Uncontrolled Solar (kW)**	**Controlled Solar**	**BESS**
100%solar+ BESS=0	773	0	0	0	320	453	0
	1457	0	0	0	320	1137	0
100%BESS+ Controlled Solar=0	773	0	0	0	320	0	453
	1457	0	0	0	320	0	1137

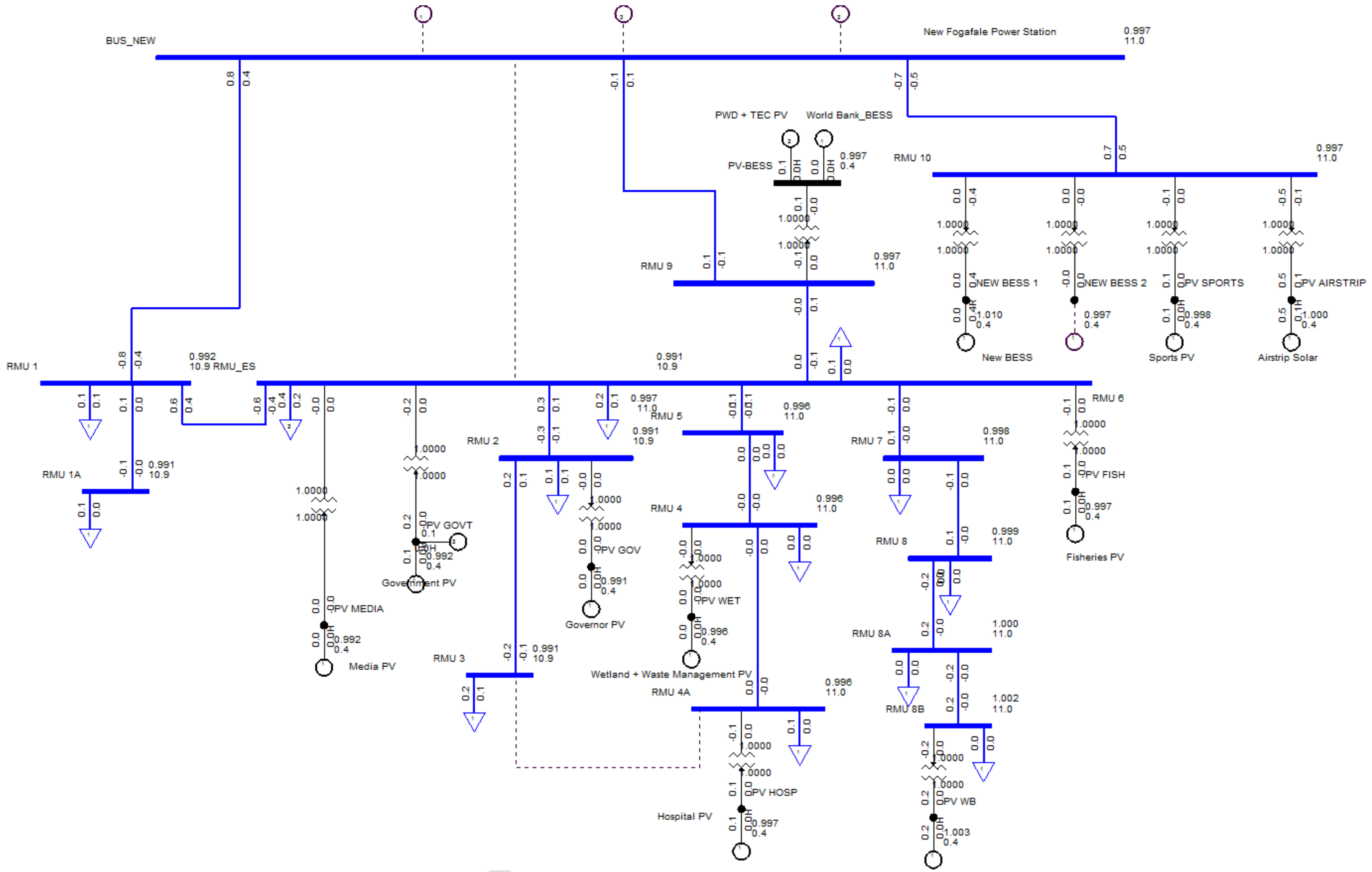

Figure 2.1: Steady State Study 2023 for %100 Solar and BESS=0

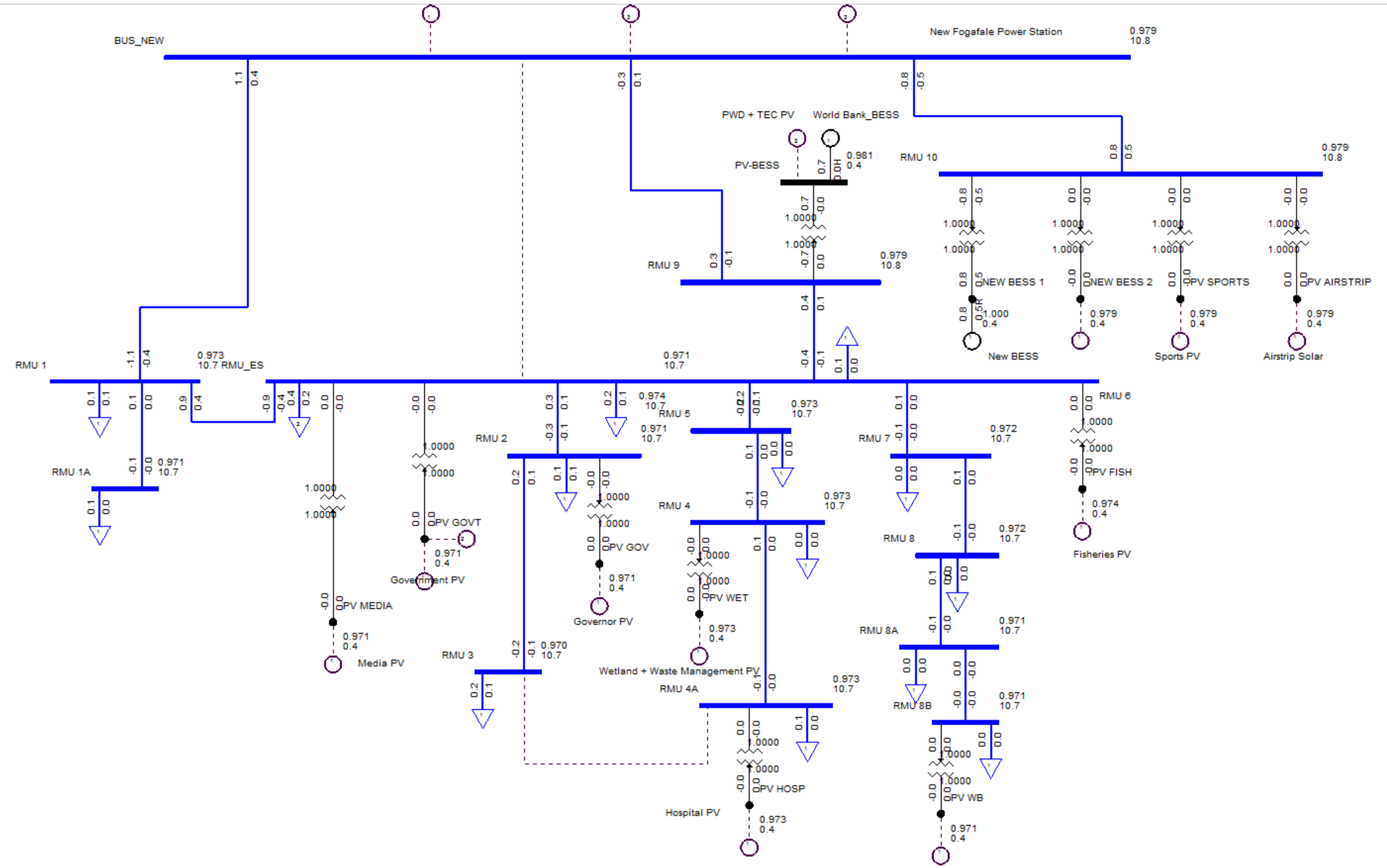

Figure 2.2: Steady State Study 2023 for %100 BESS and Solar=0

2.2 Year 2025

In this study is assumed all the uncontrolled solars are operated and 2 scenarios is considered:

- Scenario 1:

  The batteries are connected to the network and could contribute with the reactive power maximum 0.619 Mvar but the active power is supplied only by solars

- Scenario 2:

  There is no controlled solar in the system and the active and reactive power are supplied by 2 batteries.

As you see in the following network diagrams, in both scenarios in the steady state study, network could operate with no problem in the steady state operation. The levels of the voltage in all buses are reasonable.

Table 2.2: Funafuti Generation Year 2025 under Steady State Study

Steady State Study 2025							
	System Load (kW)	**DG1**	**DG2**	**DG3**	**Uncontrolled Solar (kW)**	**Controlled Solar**	**BESS**
100%solar+ BESS=0	804	0	0	0	320	484	0
	1516	0	0	0	320	1196	0
100%BESS+ Controlled Solar=0	804	0	0	0	320	0	484
	1516	0	0	0	320	0	1196

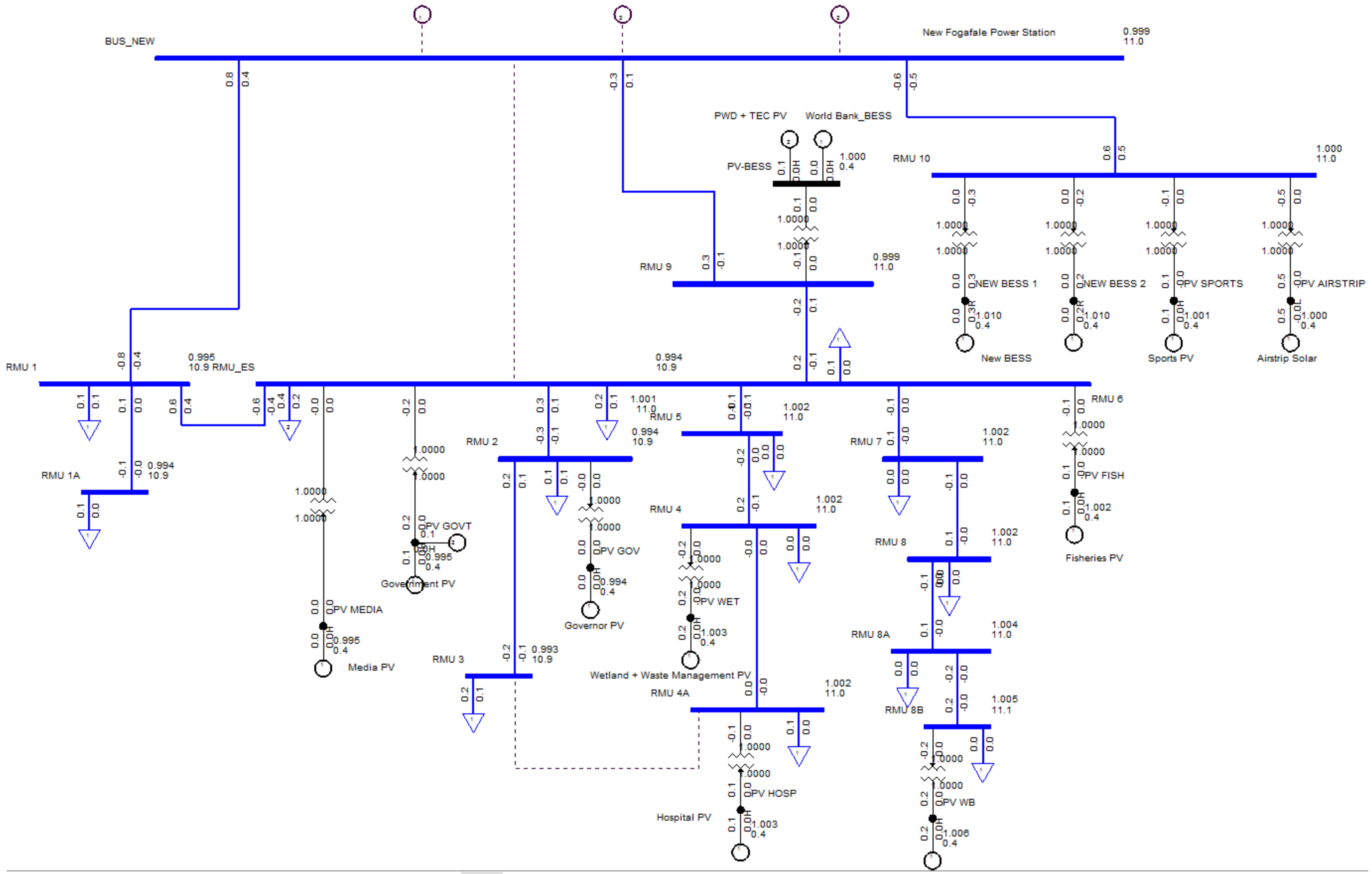

Figure 2.3: Steady State Study 2025 for %100 Solar and BESS=0

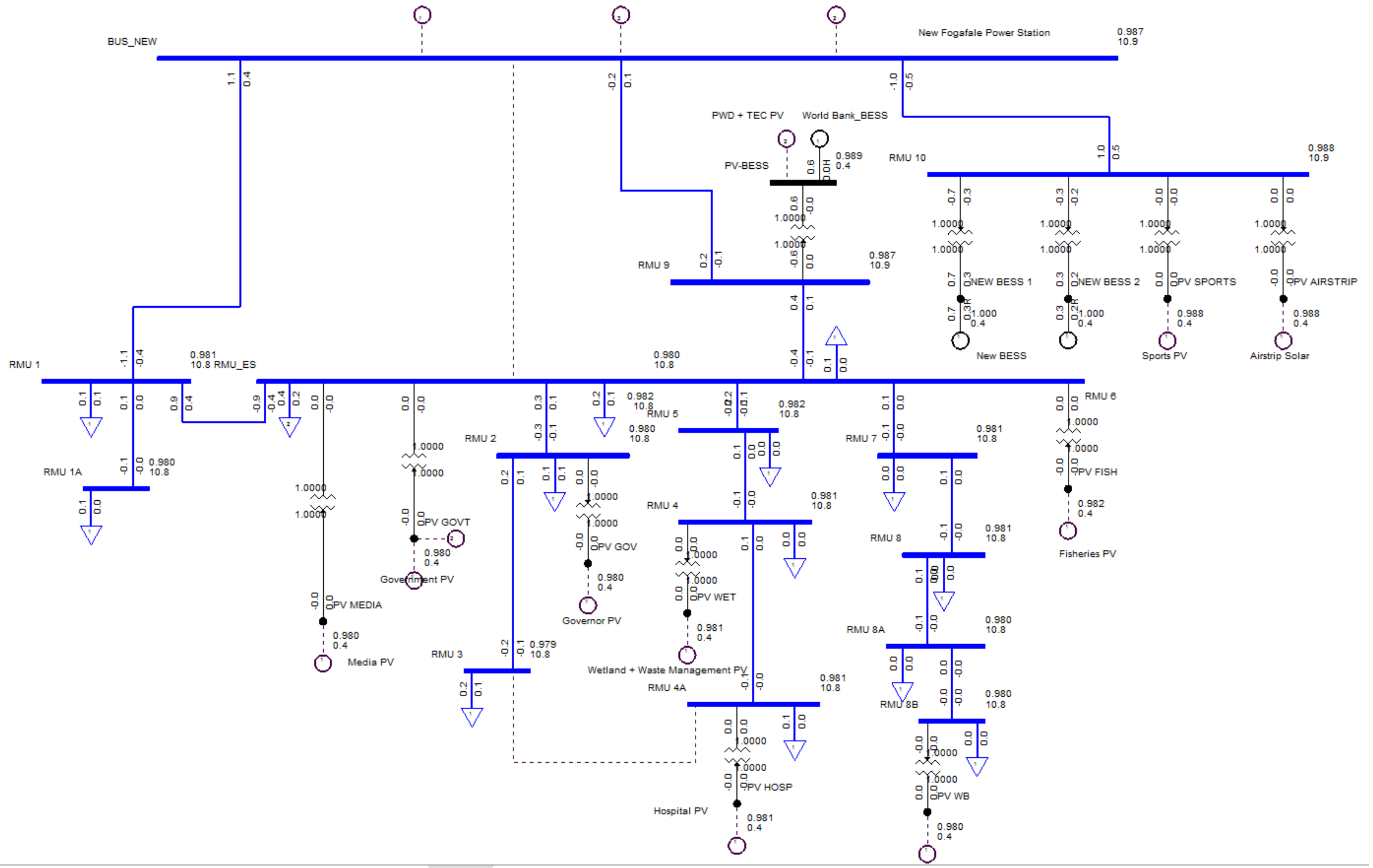

Figure 2.4: Steady State Study 2025 for %100 BESS and Solar=0

3. Key Points for Discussion

Following key points should be noted by project implementation authority when developing specifications and control system for the Funafuti system.

- It should be noted that curtailment of solar and battery is required in all cases in order to avoid excess generation in the system. It is recommended that low voltage ride through and frequency control features of the new solar inverters to be used to assist system recovery.
- It should also be noted that the project relies heavily on an automated control and integration system. Hence control system needs to be properly coordinated with the new solar, diesel generation as well as BESS.
- It is recommended to carry out detailed protection coordination study to manage appropriate discrimination of generator, solar, wind, BESS and feeder protection system
- It is also recommended that low voltage ride through and frequency control features of the new solar inverters to be used to assist system recovery.
- If BESS operate on current controlled mode then there is a minimum short circuit requirement of the BESS need to be considered when dispatching diesel generation.
- Significant RoCoF could occur with single diesel operation (especially contingency is large). Hence, protection system and BESS response need to be designed based on these high RoCoF in the system.
- Current protection system needs to be revisited, especially check the adequacy of fault current at the RMU for protection discrimination.
- New solar inverters could configured to have frequency control functions, especially to control over frequency
- Could consider rotational inertia device to reduce high RoCoF. This can be achieved by high speed flywheel system.
- The risk associated with single diesel operation should be clearly conveyed to TEC.
- It is recommended to carry out detailed protection coordination study to manage appropriate discrimination of diesel generator, solar, BESS and feeder protection system
- When BESS is not available system needs to be operated with adequate MW reserve to avoid voltage collapse especially BESS not available in the system. DGs are required to dispatch such that to cover loss of largest solar or solar MW variation under cloud cover to avoid unwanted load tripping
- The BESS control system should be tuned appropriately in order to avoid very quick or very low response to frequency changes as both these situations could lead to system instability.

- The BESS system should not be fully charged or fully discharged in order to be able to assist in the events of frequency deviations until corrective actions are taken.

Appendices

A Loss of solar plant - 2020

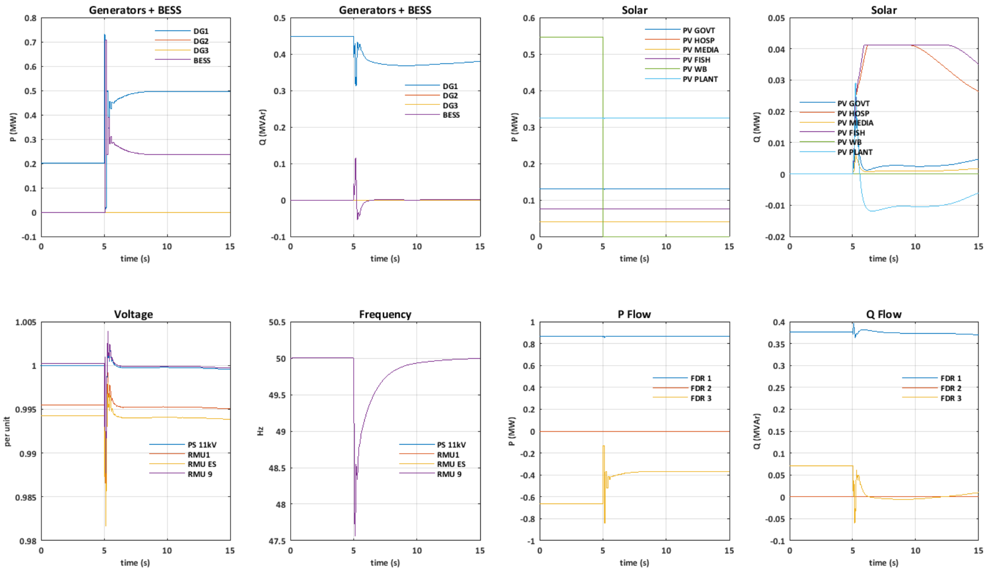

Figure A.1: Peak Load – Battery Charged (System is stable. Minimum frequency goes to 47.5 Hz)

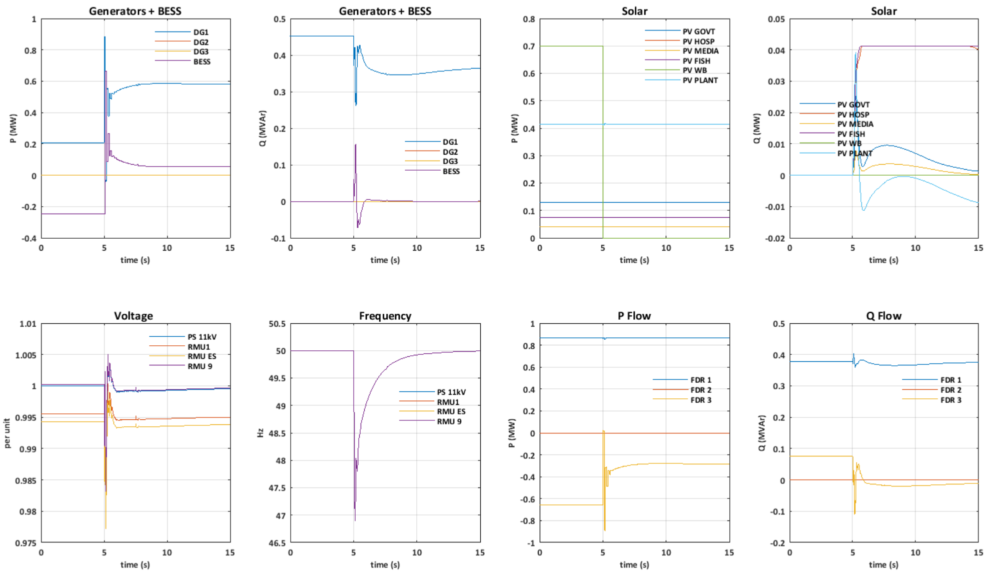

Figure A.2: Peak Load – Battery Charging (System is stable. Minimum frequency goes to 46.8 Hz)

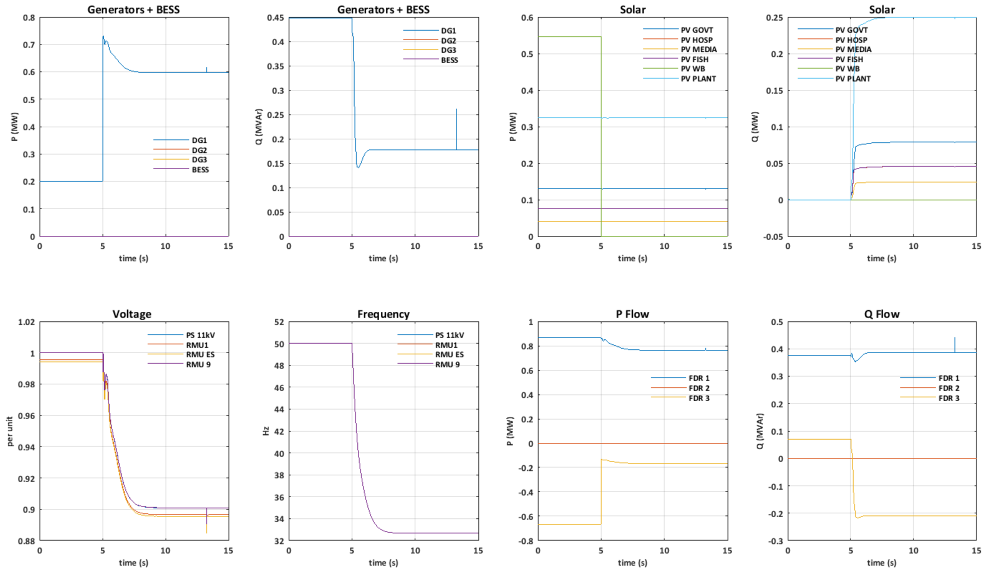

Figure A.3: Peak Load– Battery Unavailable (System is unstable. New solar can be configured to have frequency control function)

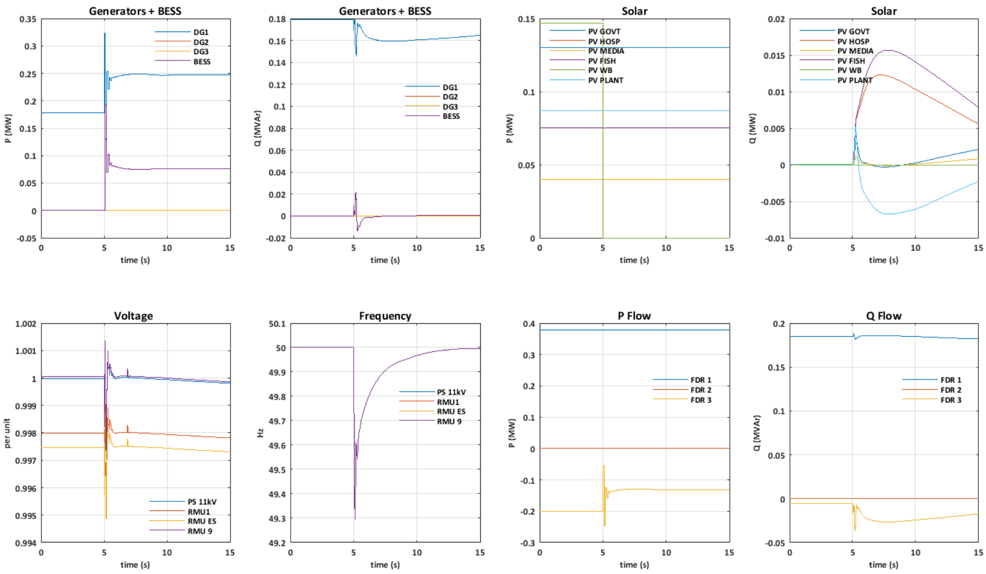

Figure A.4: Min Load – Battery Charged (System is stable. Minimum frequency goes to 49.3 Hz)

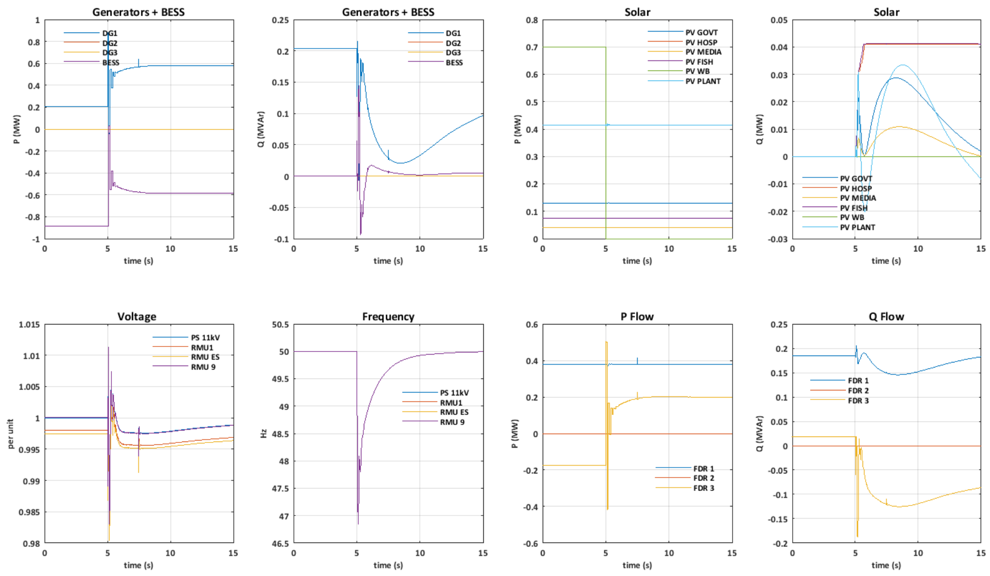

Figure A.5: Min Load – Battery Charging(System is stable. Minimum frequency goes to 46.8 Hz)

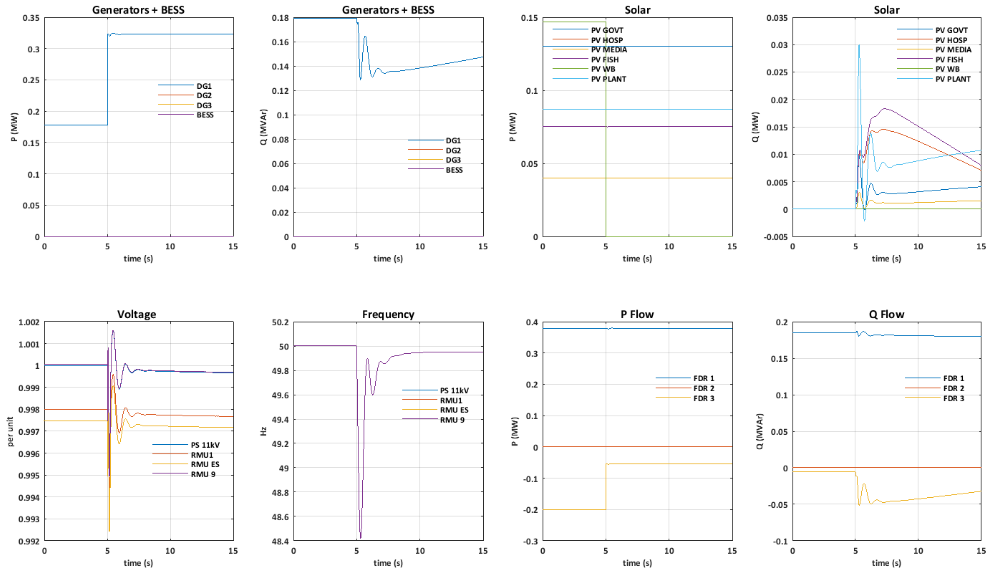

Figure A.6: Min Load – Battery Unavailable (System is stable. Minimum frequency goes to 48.4 Hz)

B Loss of load - 2020

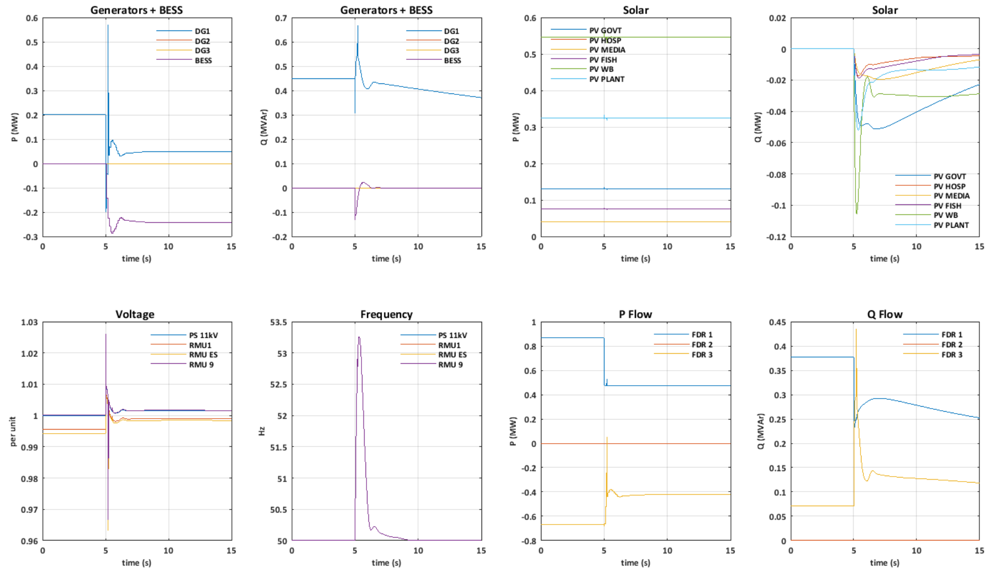

Figure B.1: Peak Load – Battery Charged (System is stable. Minimum frequency goes to 53.3 Hz)

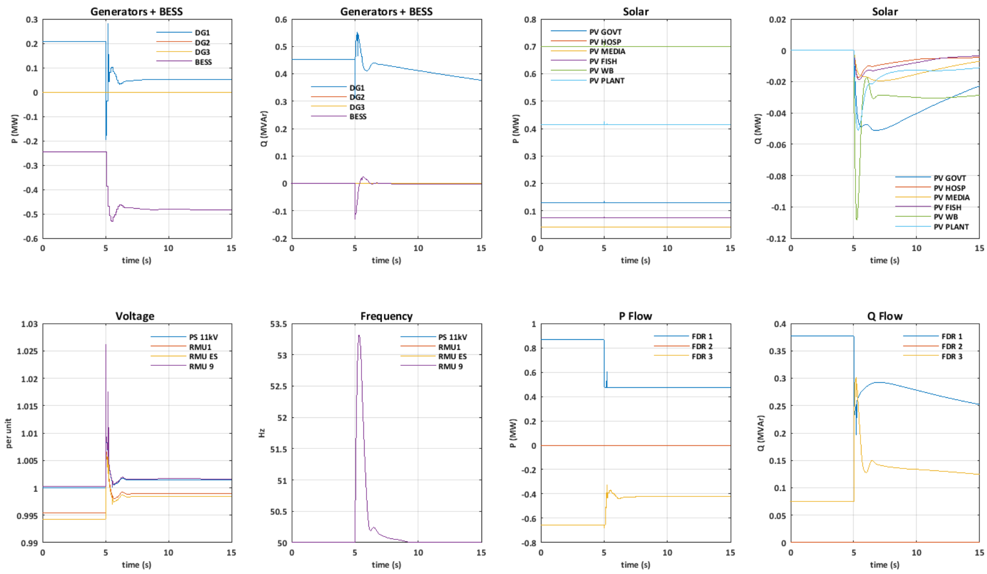

Figure B.2: Peak Load – Battery Charging (System is stable. Minimum frequency goes to 53.3 Hz)

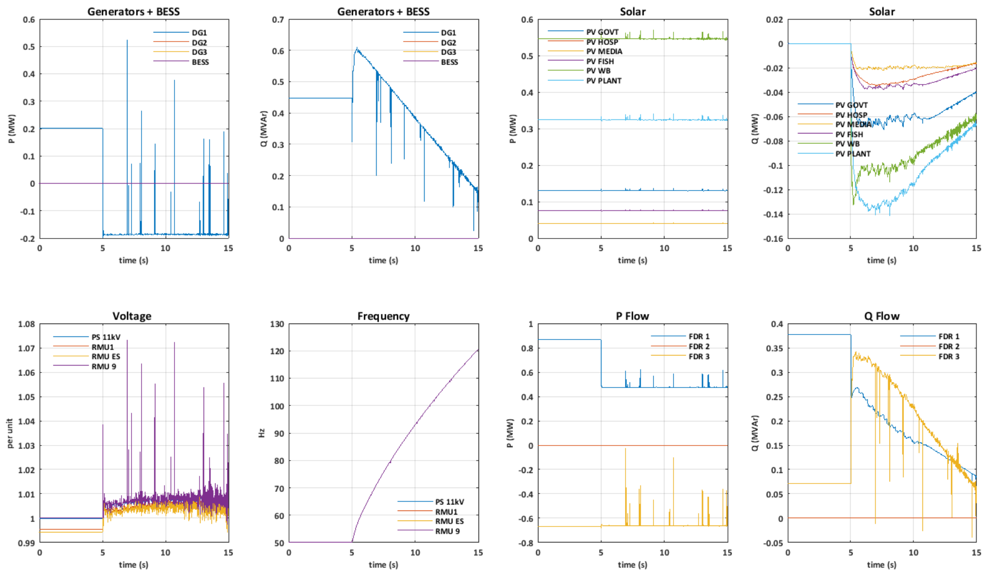

Figure B.3: Peak Load– Battery Unavailable (System is unstable. New solar can be configured to have frequency control function)

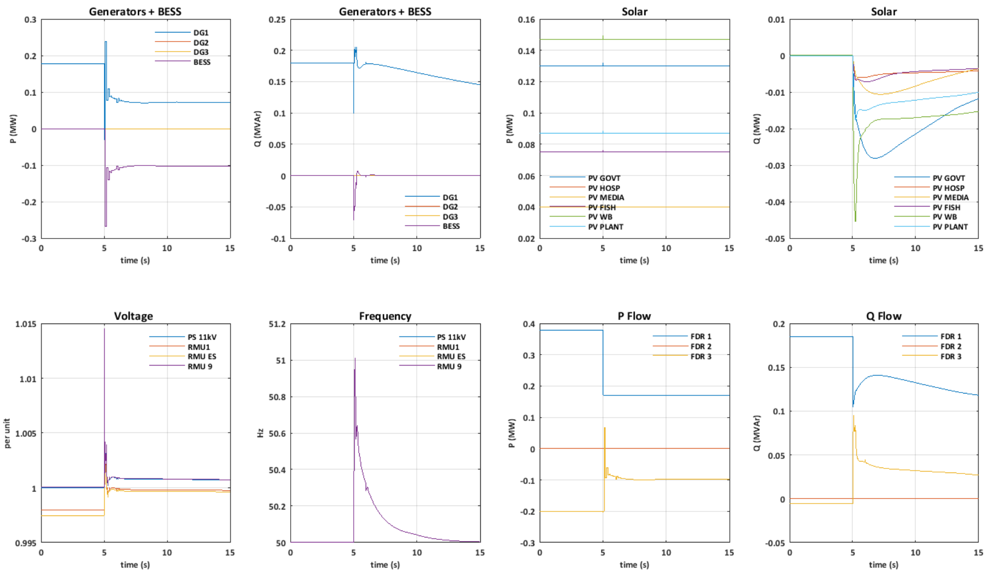

Figure B.4: Min Load – Battery Charged (System is stable. Minimum frequency goes to 51 Hz)

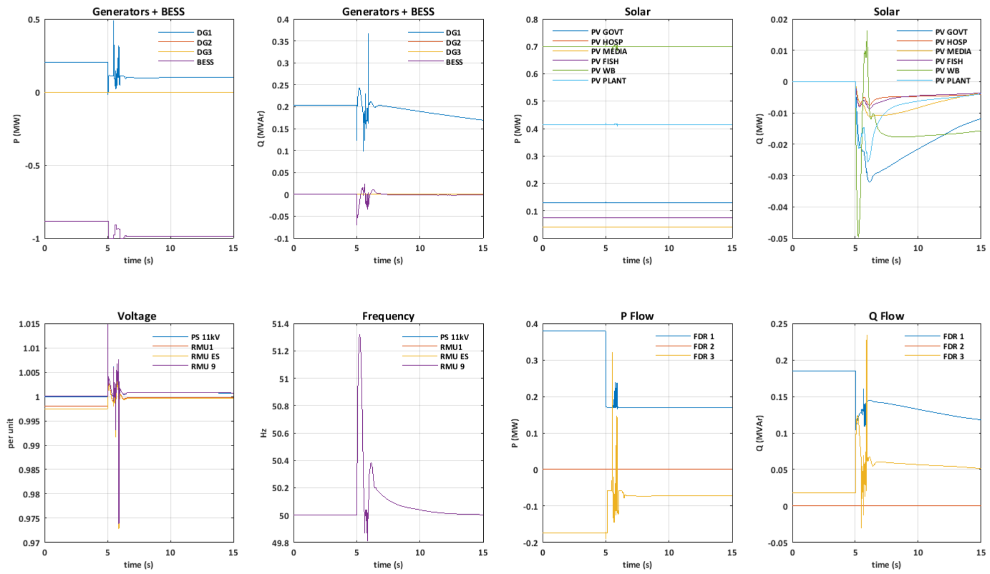

Figure B.5: Min Load – Battery Charging (System is stable. Minimum frequency goes to 51.3 Hz)

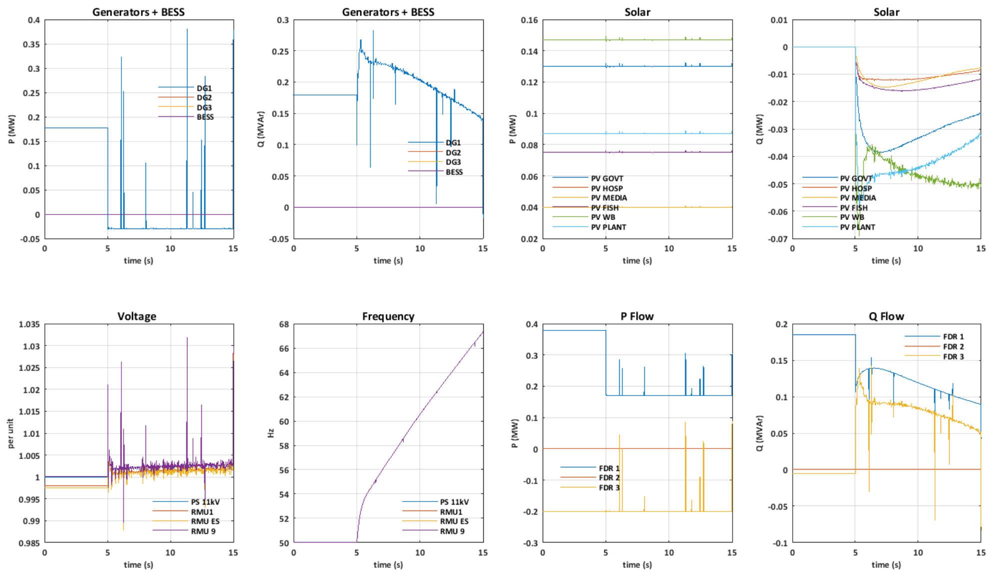

Figure B.6: Min Load – Battery Unavailable (System is unstable. New solar can be configured to have frequency control function)

C Loss of new solar plant - 2023

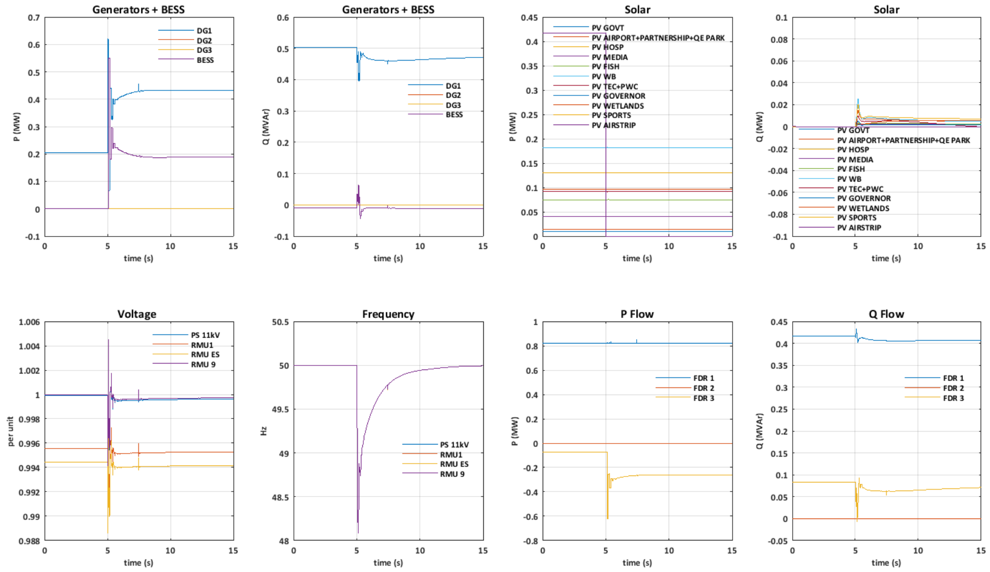

Figure C.1: Peak Load – Battery Charged (System is stable. Minimum frequency goes to 48.1 Hz)

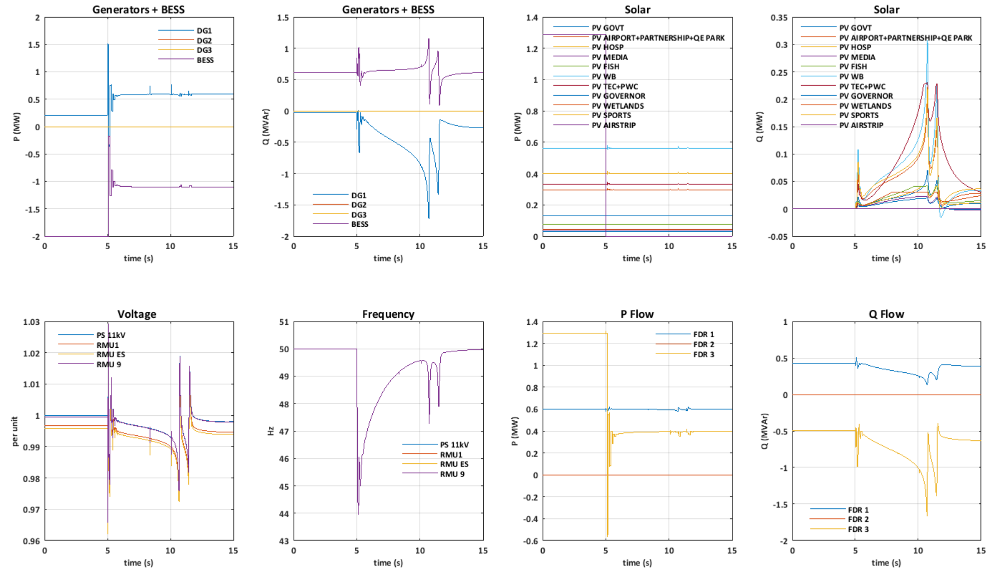

Figure C.2: Peak Load – Battery Charging (System is stable. Minimum frequency goes to 44 Hz)

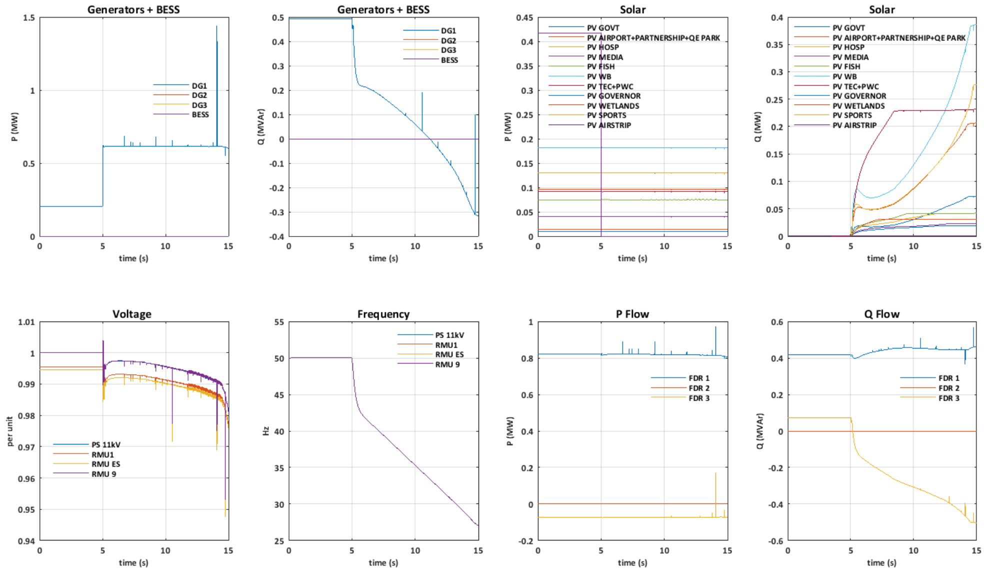

Figure C.3: Peak Load– Battery Unavailable (System is unstable. New solar can be configured to have frequency control function)

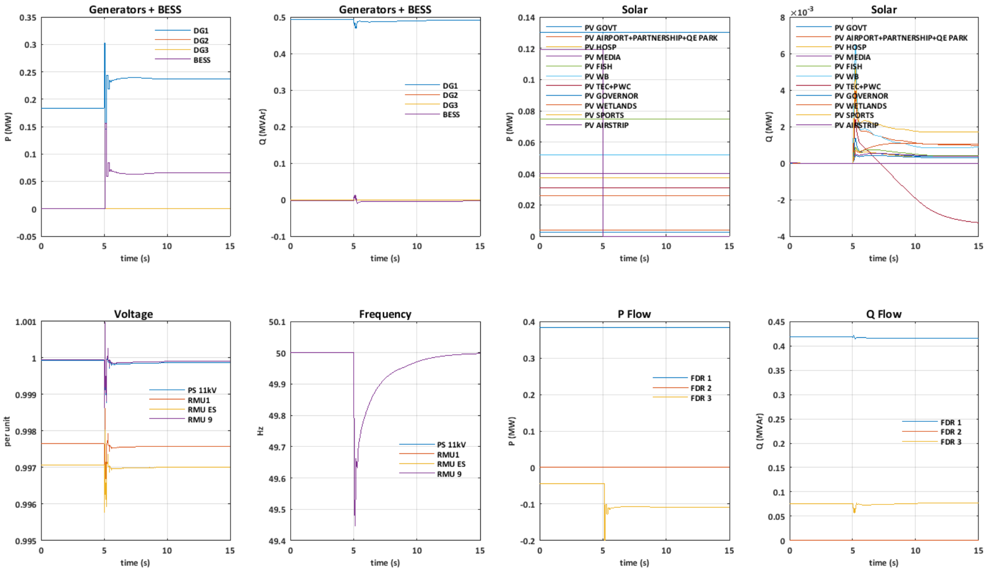

Figure C.4: Min Load – Battery Charged (System is stable. Minimum frequency goes to 49.45 Hz)

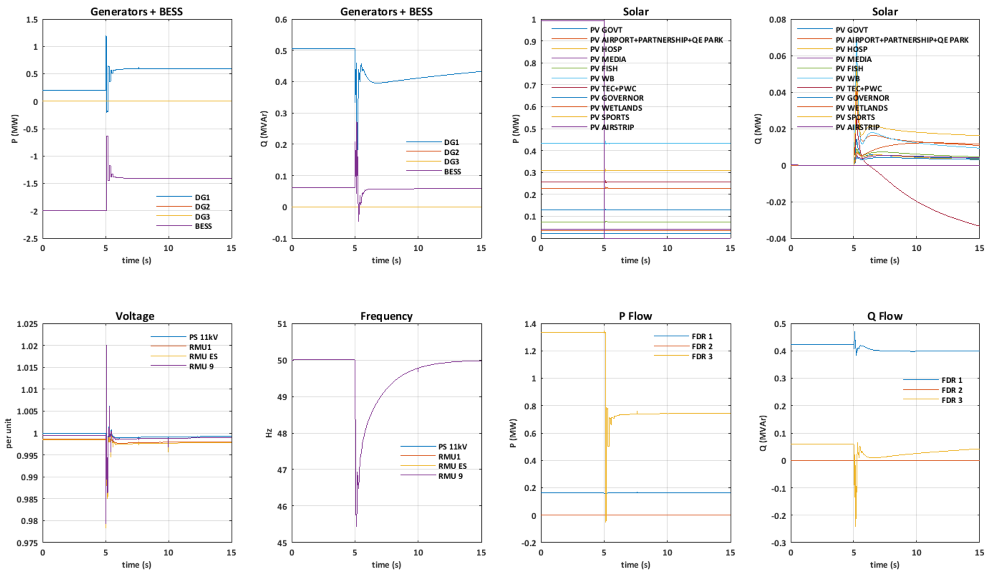

Figure C.5: Min Load – Battery Charging (System is stable. Minimum frequency goes to 45.5 Hz)

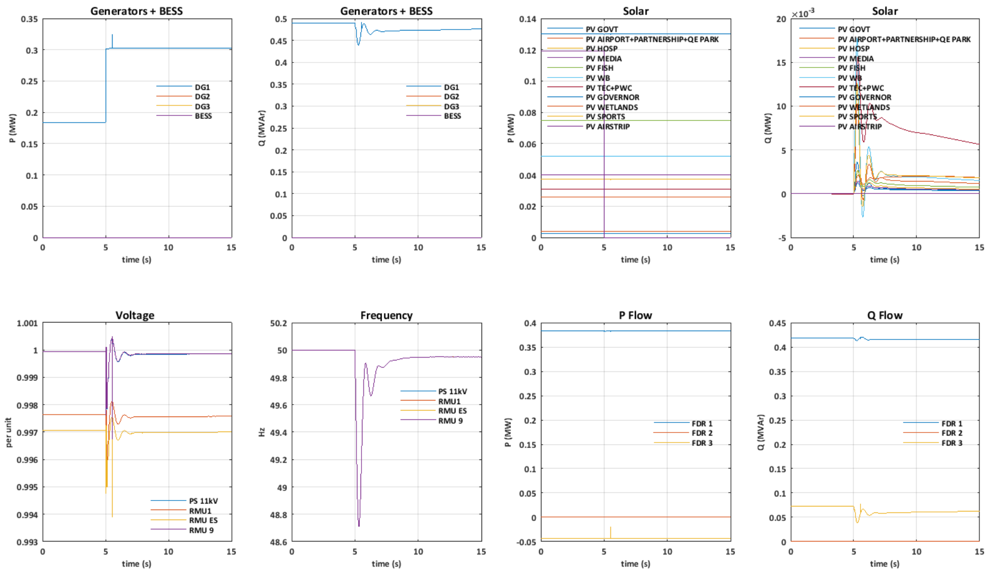

Figure C.6: Min Load – Battery Unavailable (System is stable. Minimum frequency goes to 48.7 Hz)

D Loss of load - 2023

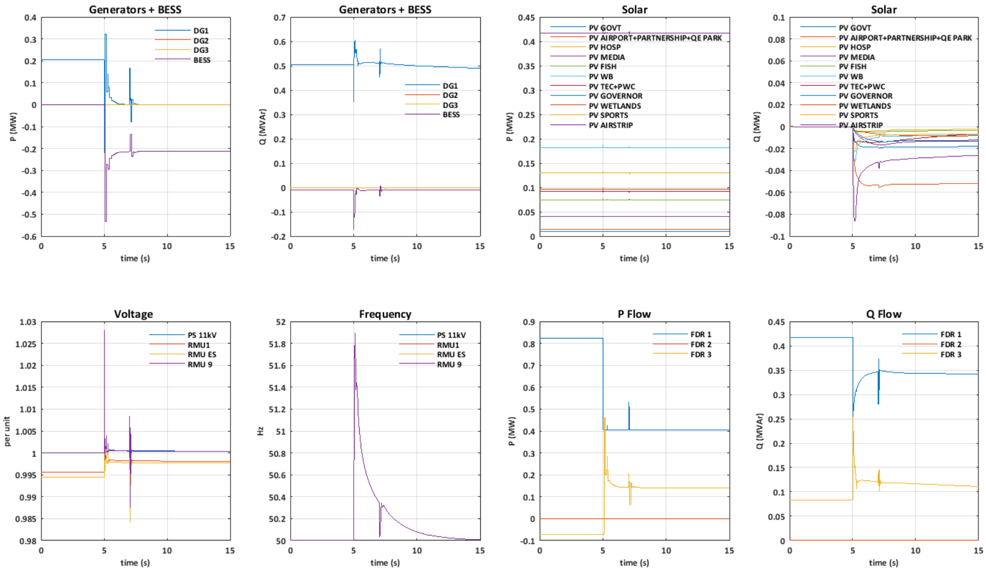

Figure D.1: Peak Load – Battery Charged (System is stable. Minimum frequency goes to 51.9 Hz)

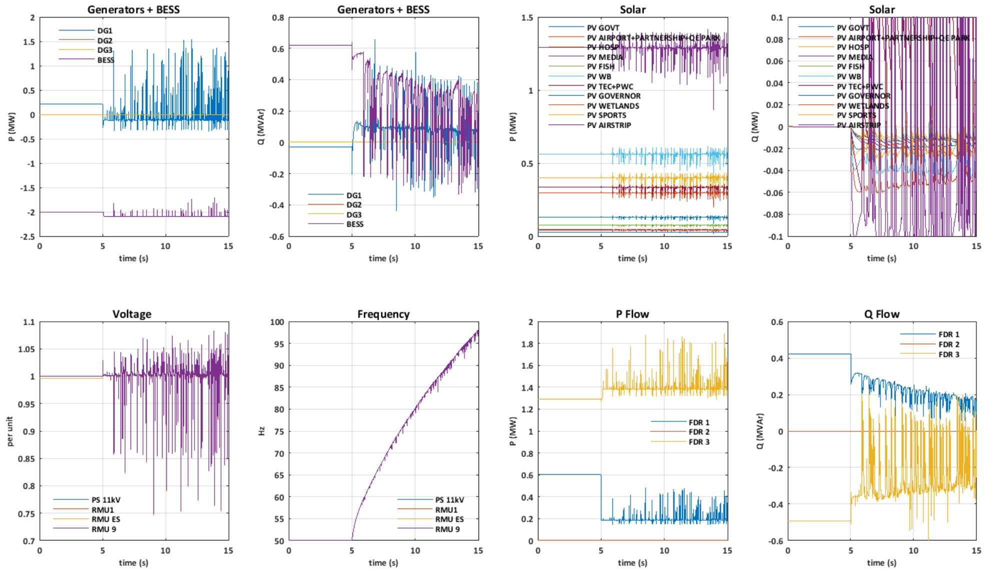

Figure D.2: Peak Load – Battery Charging (System is unstable. New solar can be configured to have frequency control function)

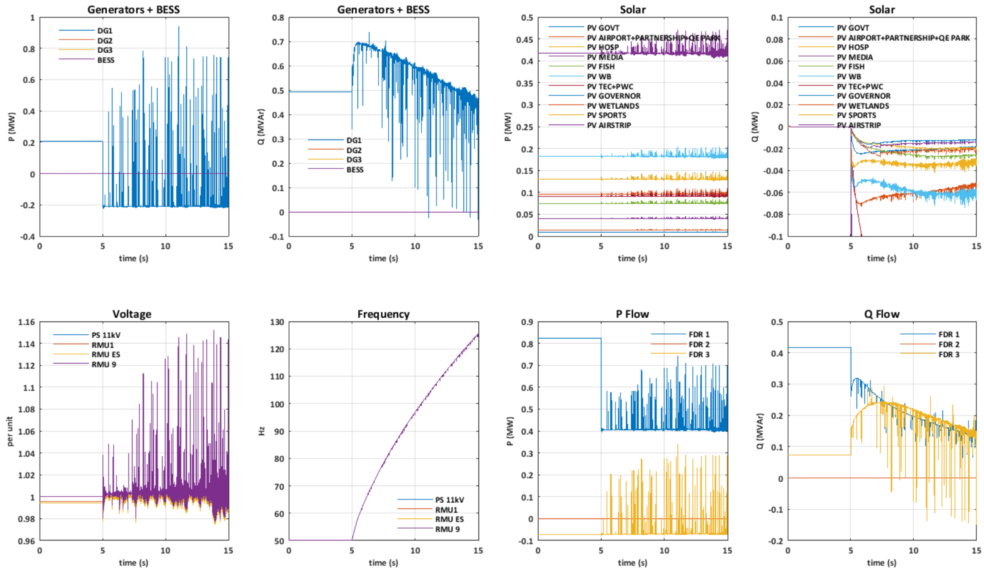

Figure D.3: Peak Load– Battery Unavailable (System is unstable. New solar can be configured to have frequency control function)

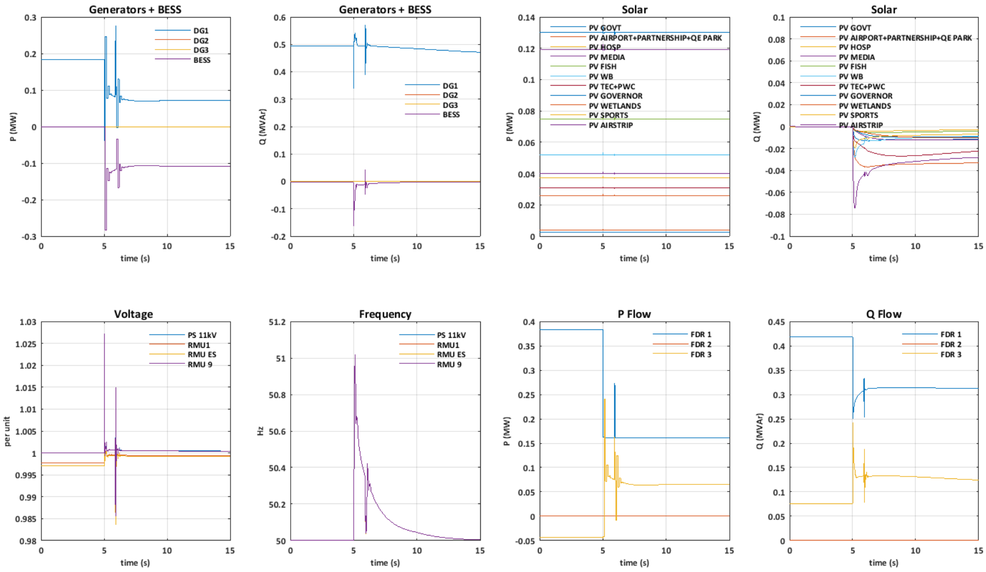

Figure D.4: Min Load – Battery Charged (System is stable. Minimum frequency goes to 51 Hz)

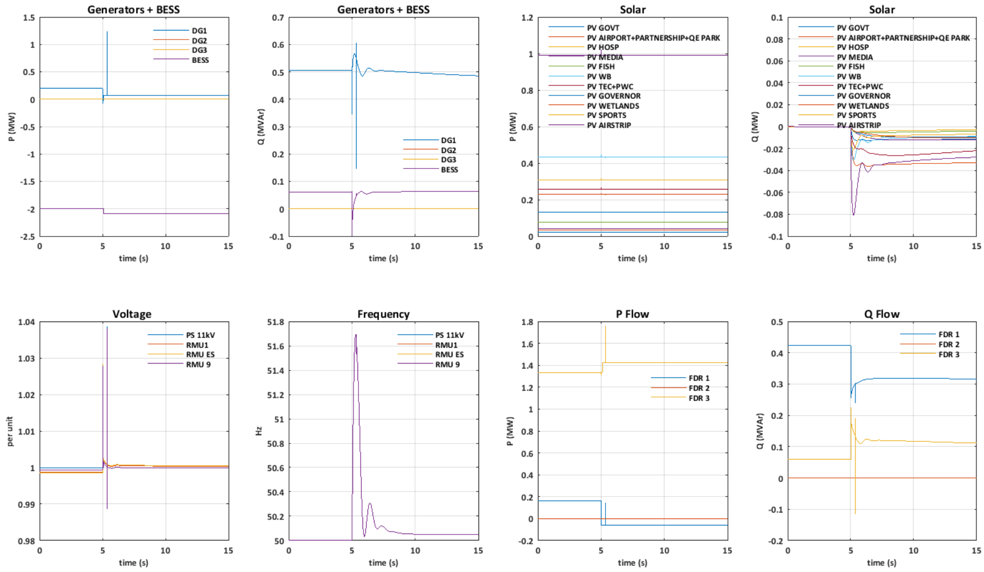

Figure D.5: Min Load – Battery Charging (System is stable. Minimum frequency goes to 51.7 Hz)

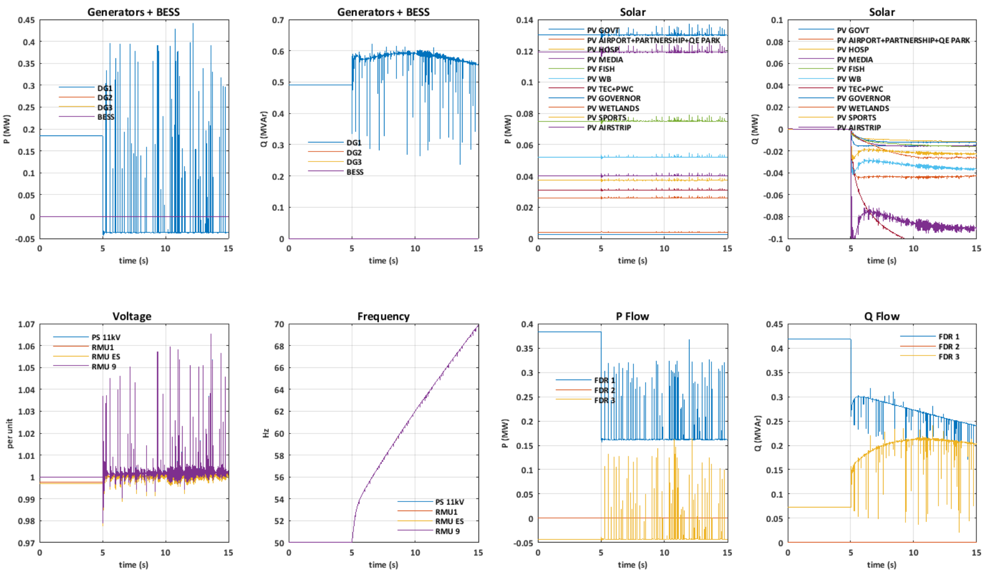

Figure D.6: Min Load – Battery Unavailable (System is unstable. New solar can be configured to have frequency control function)

E Solar Farms Ramping Down – 2023

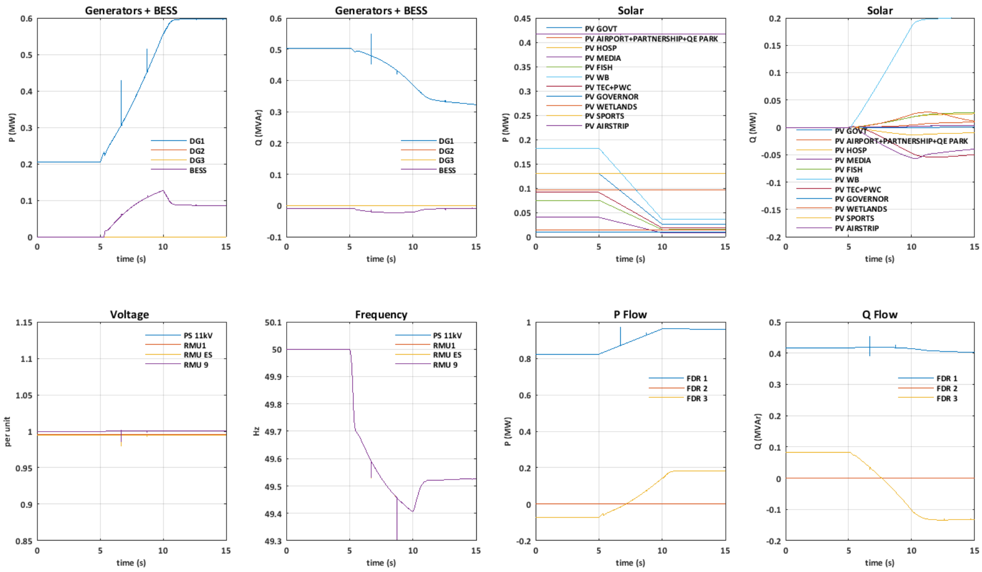

Figure G.1: Peak Load – Battery Charged (System is stable. Minimum frequency goes to 49.4 Hz)

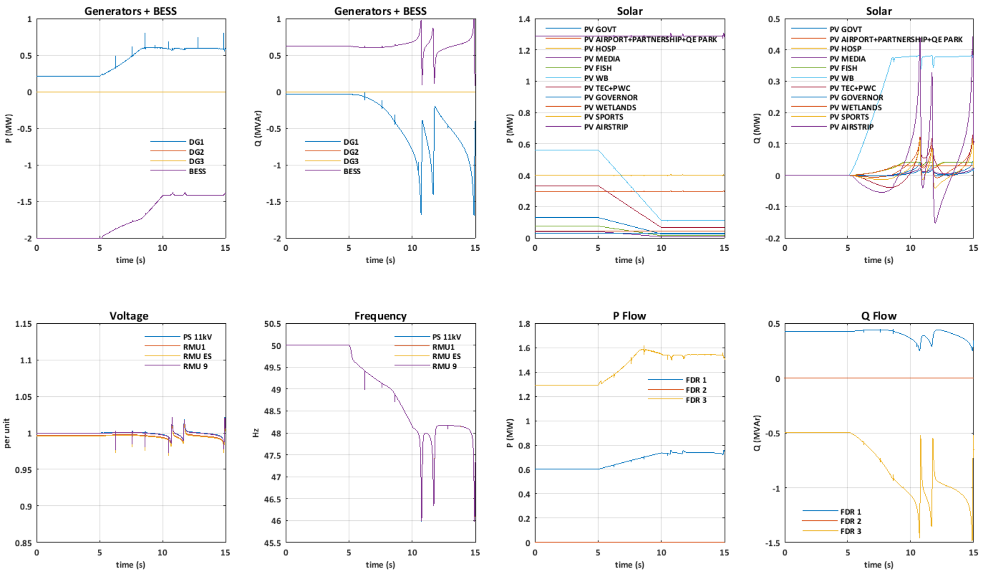

Figure G.2: Peak Load – Battery Charging (System is unstable. New solar can be configured to have frequency control function)

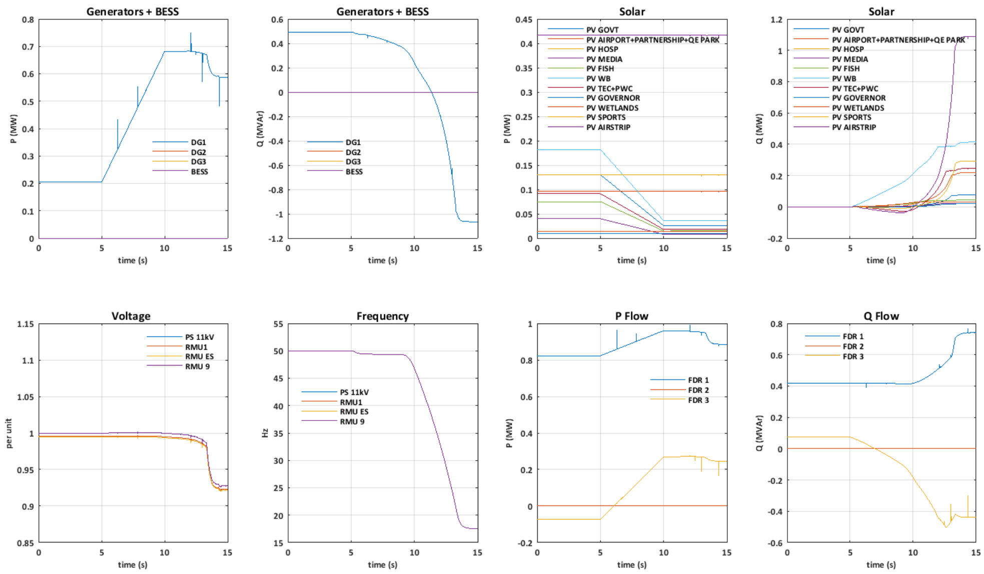

Figure G.3: Peak Load – Battery Unavailable (System is unstable. New solar can be configured to have frequency control function)

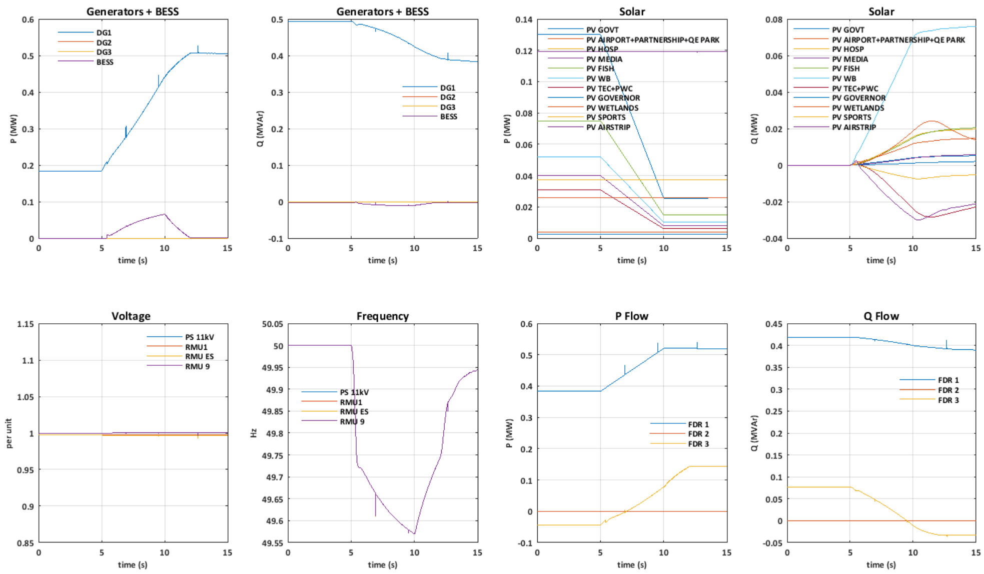

Figure G.4: Min Load – Battery Charged (System is stable. Minimum frequency goes to 49.55 Hz)

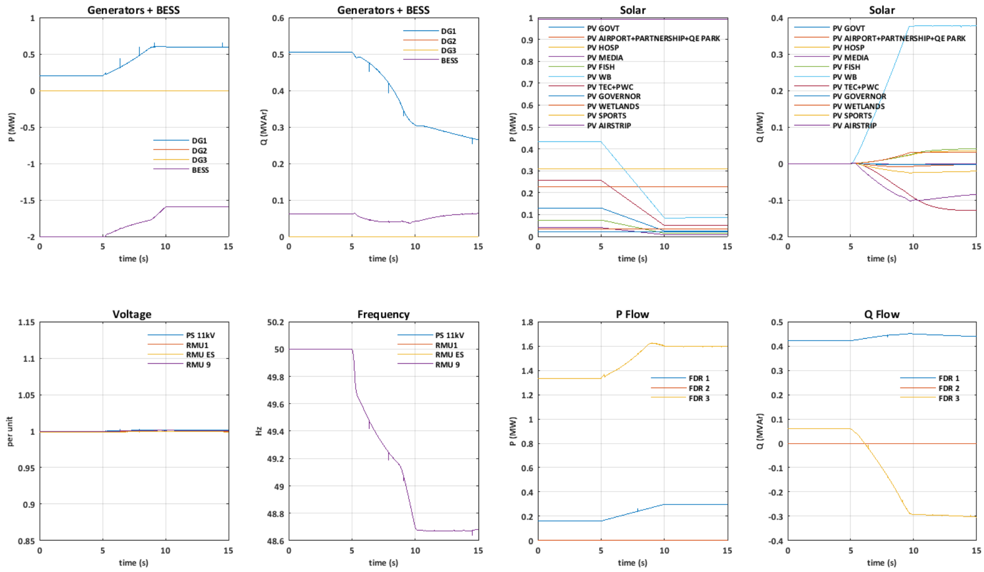

Figure G.5: Min Load – Battery Charging (System is stable. Minimum frequency goes to 48.7 Hz)

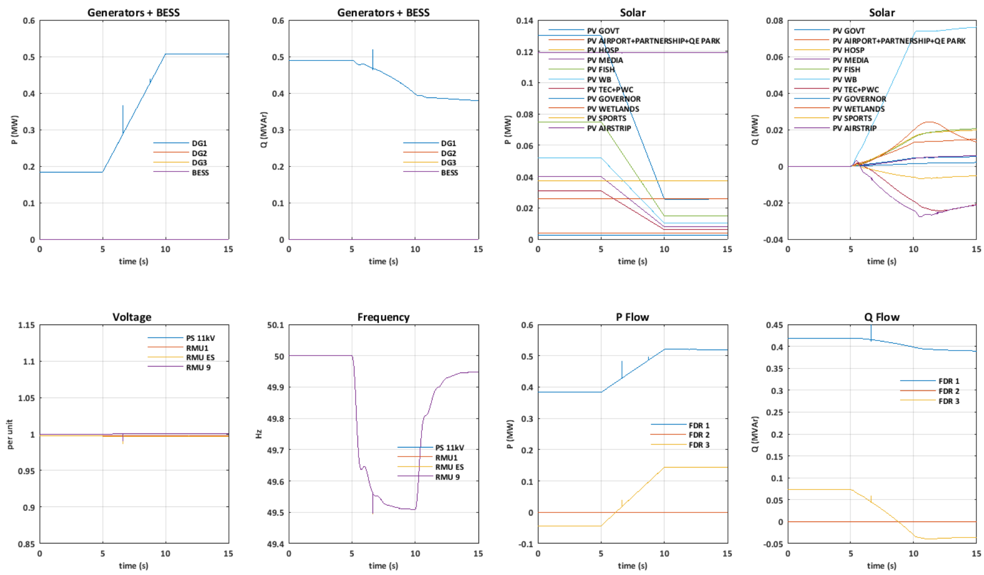

Figure G.6: Min Load – Battery Unavailable (System is stable. Minimum frequency goes to 49.5 Hz)

F Loss of new solar plant – 2025

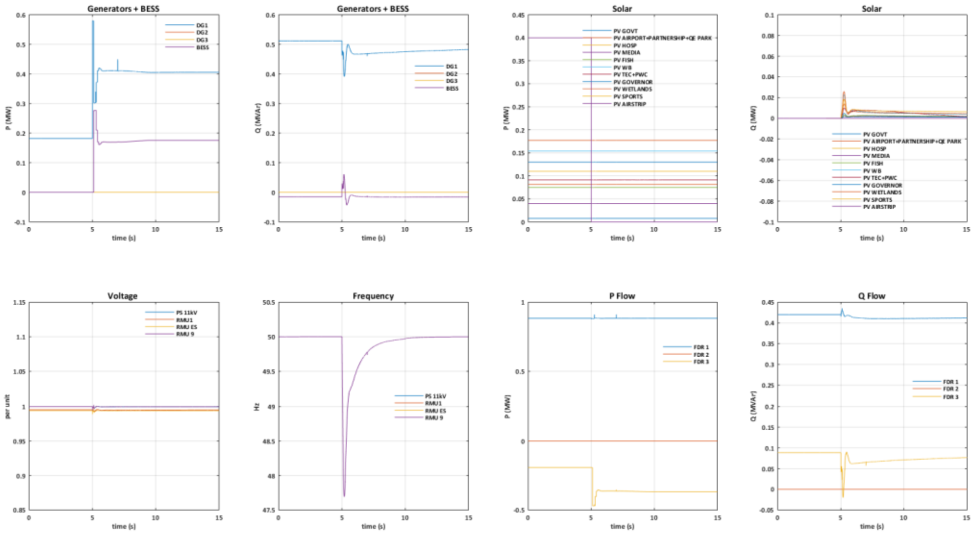

Figure F.1: Peak Load – Battery Charged (System is stable. Minimum frequency goes to 47.7 Hz)

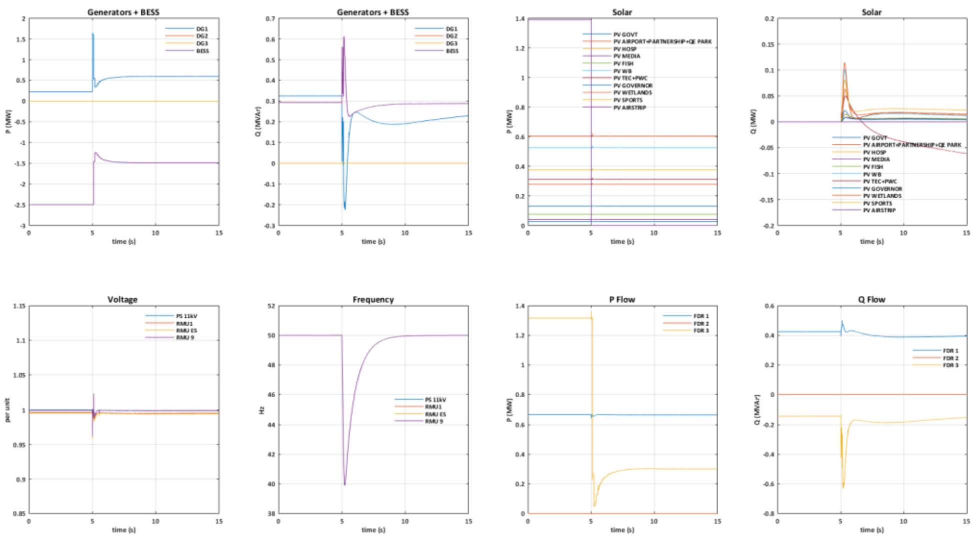

Figure F.2: Peak Load – Battery Charging (System is stable. Minimum frequency goes to 40 Hz)

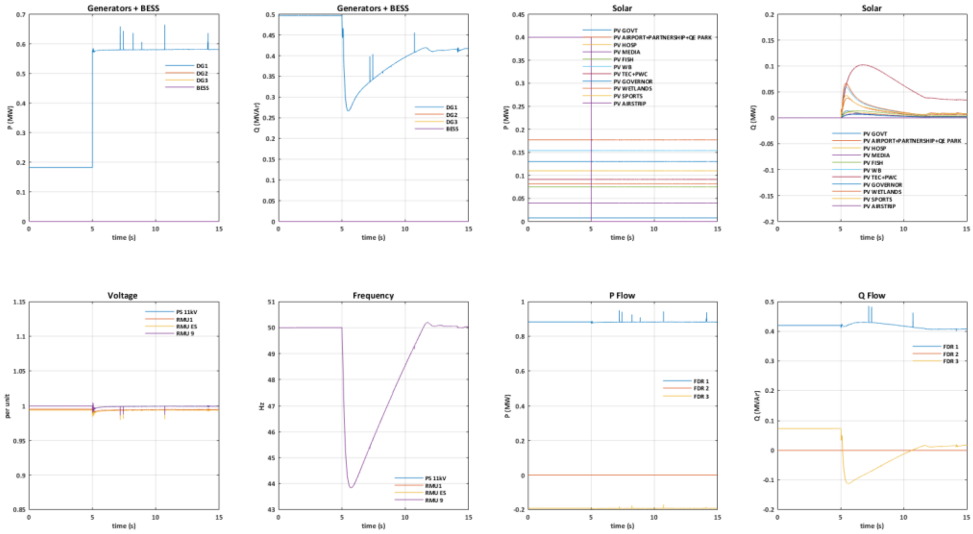

Figure F.3: Peak Load– Battery Unavailable (System is stable. Minimum frequency goes to 44 Hz)

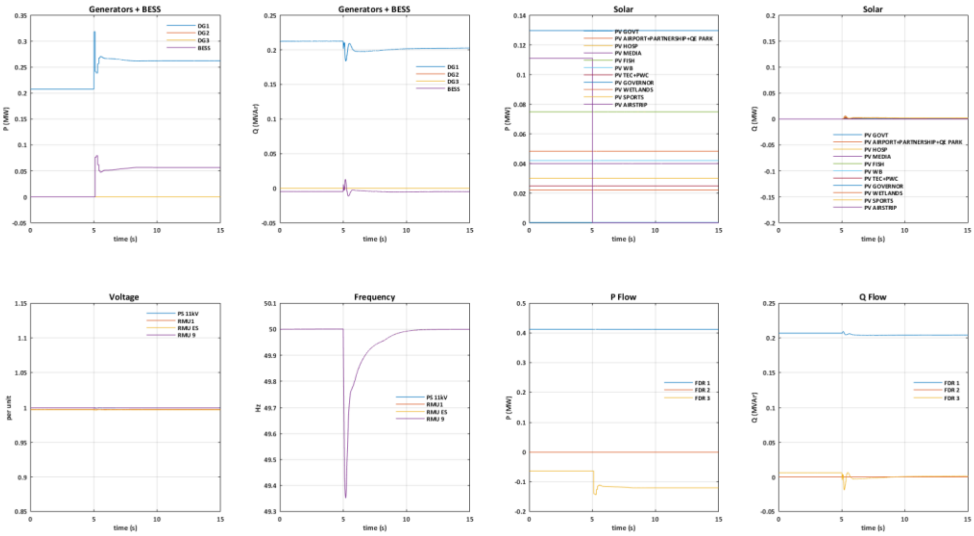

Figure F.4: Min Load – Battery Charged (System is stable. Minimum frequency goes to 49.35 Hz)

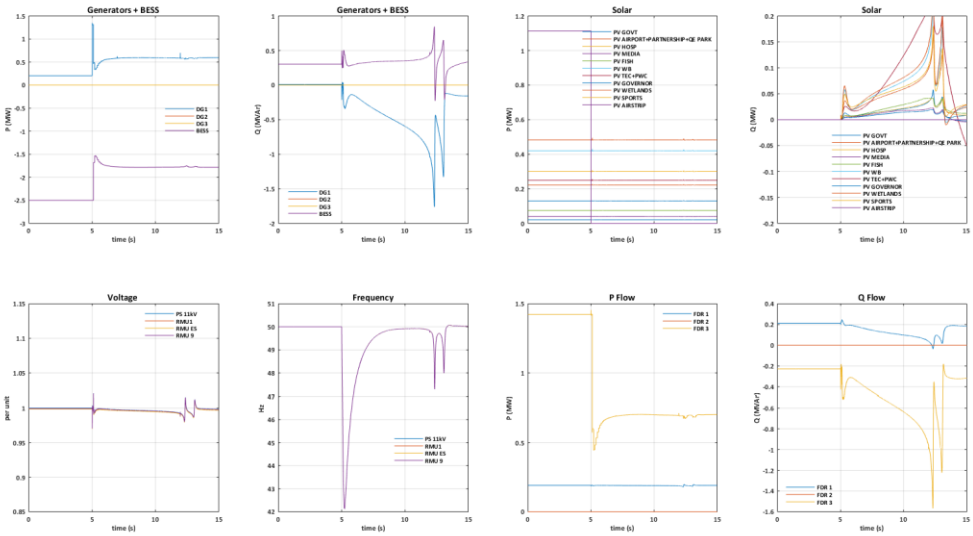

Figure F.5: Min Load – Battery Charging (System is stable. Minimum frequency goes to 42 Hz)

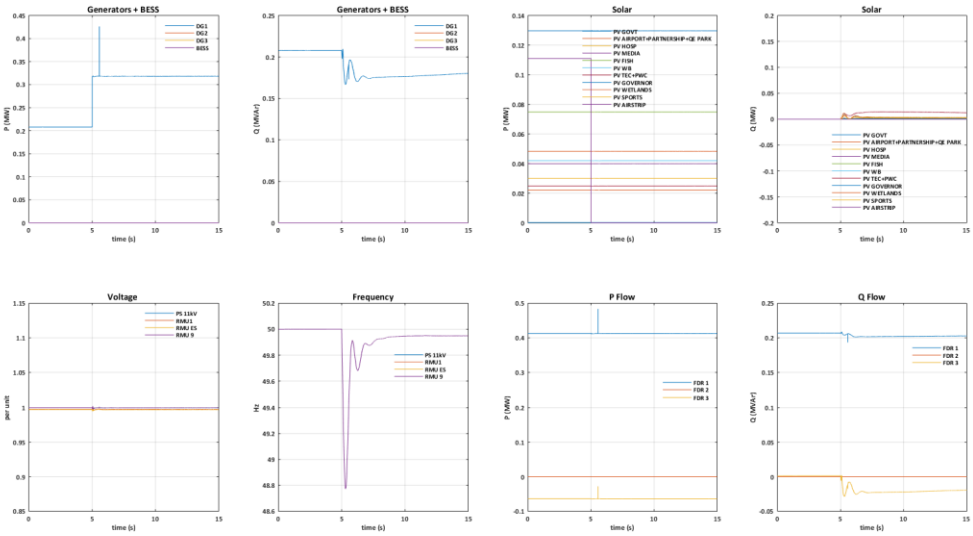

Figure F.6: Min Load – Battery Unavailable (System is stable. Minimum frequency goes to 48.8 Hz)

G Loss of load - 2025

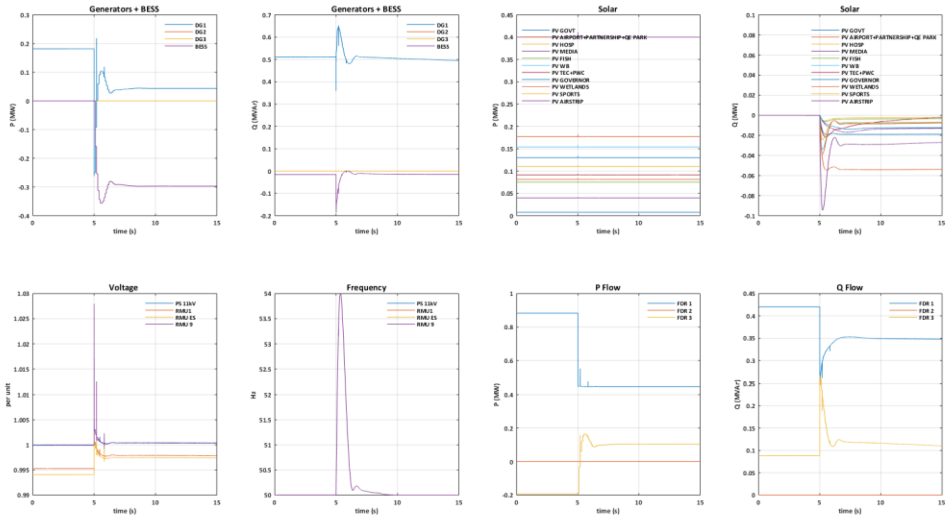

Figure G.1: Peak Load – Battery Charged (System is stable. Minimum frequency goes to 54 Hz)

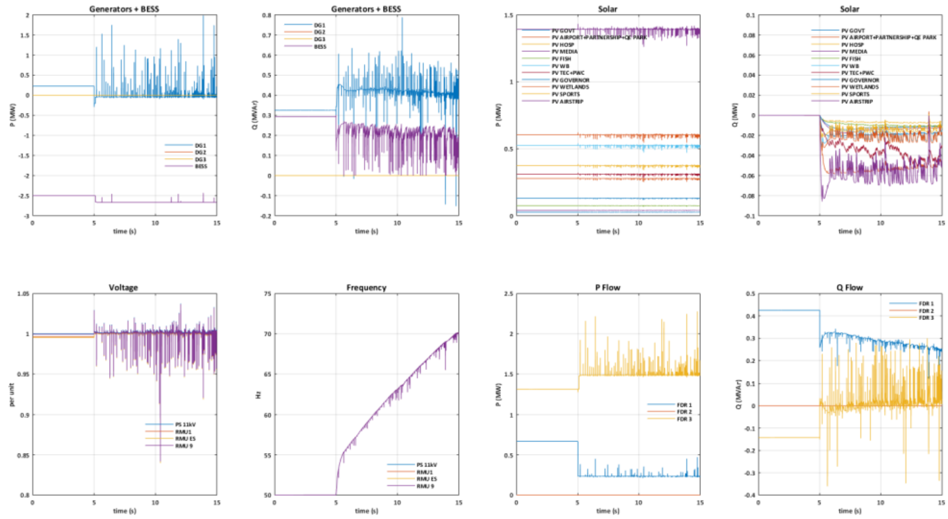

Figure G.2: Peak Load – Battery Charging (System is unstable. New solar can be configured to have frequency control function)

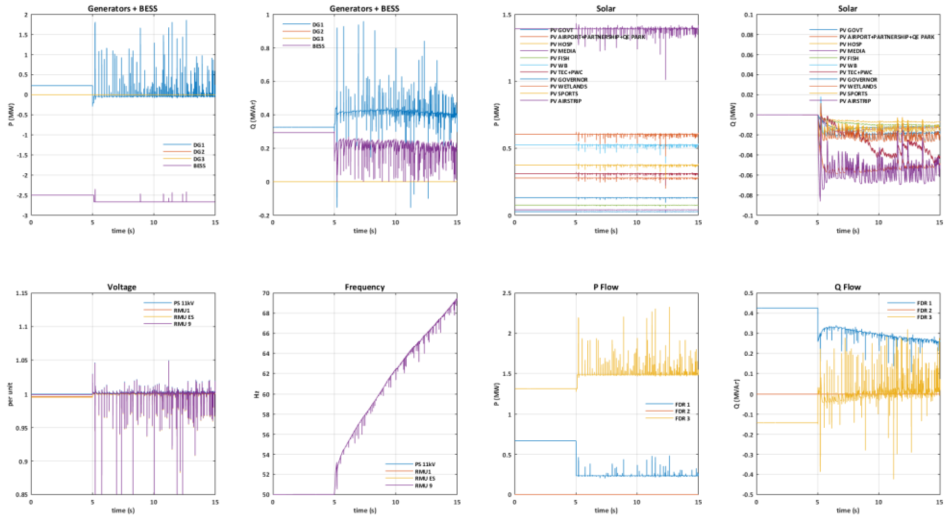

Figure G.3: Peak Load– Battery Unavailable (System is unstable. New solar can be configured to have frequency control function)

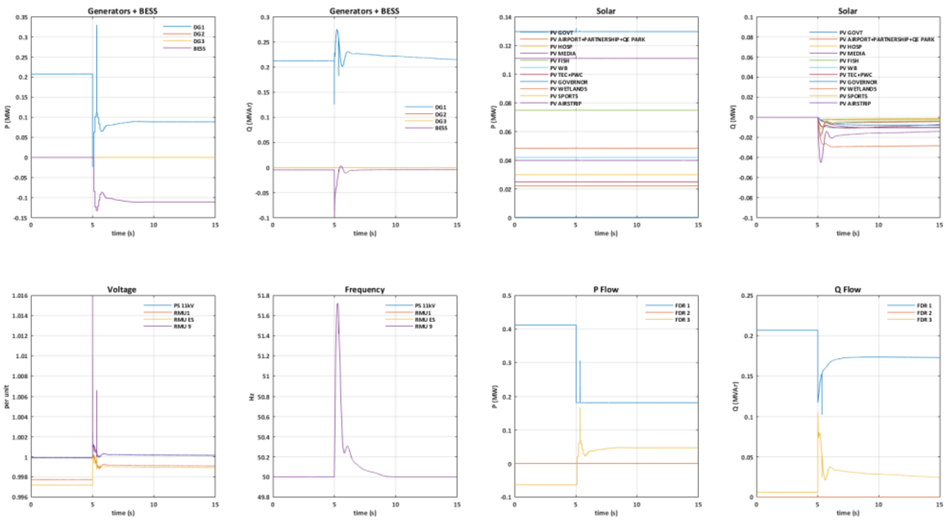

Figure G.4: Min Load – Battery Charged (System is stable. Minimum frequency goes to 51.7 Hz)

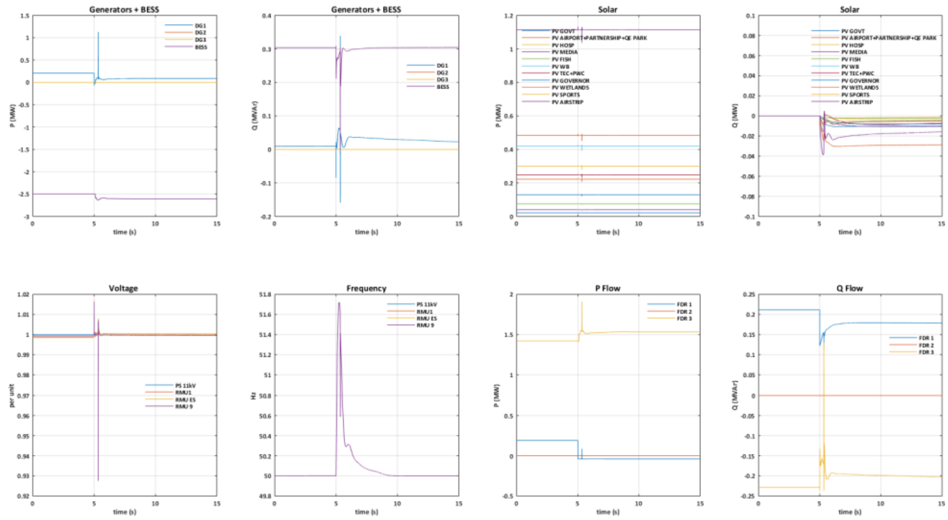

Figure G.5: Min Load – Battery Charging (System is stable. Minimum frequency goes to 51.7 Hz)

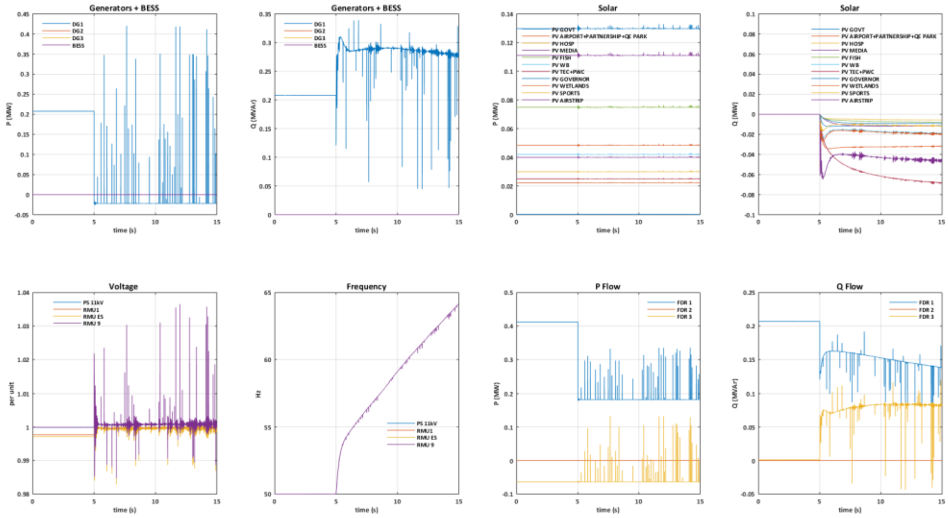

Figure G.6: Min Load – Battery Unavailable (System is unstable. New solar can be configured to have frequency control function)

H Solar Farms Ramping Down – 2025

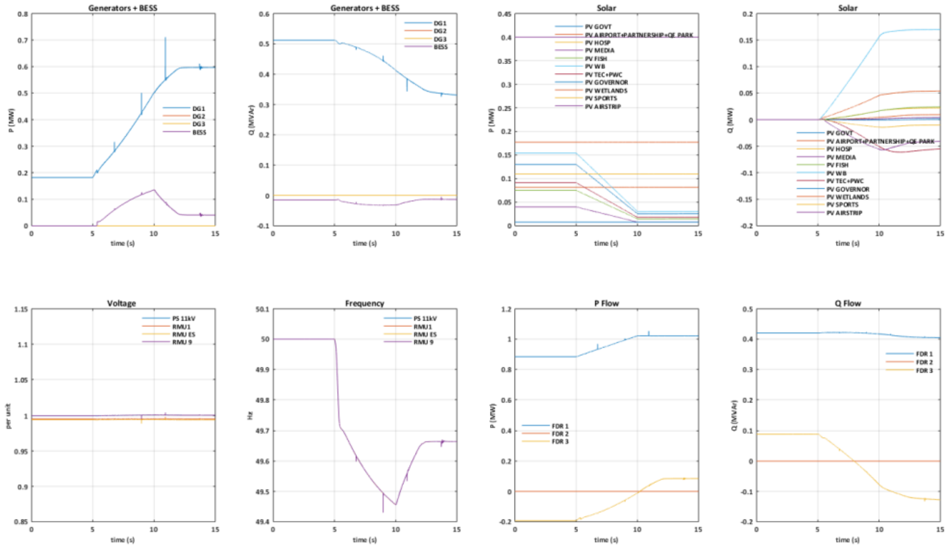

Figure G.1: Peak Load – Battery Charged (System is stable. Minimum frequency goes to 49.45 Hz)

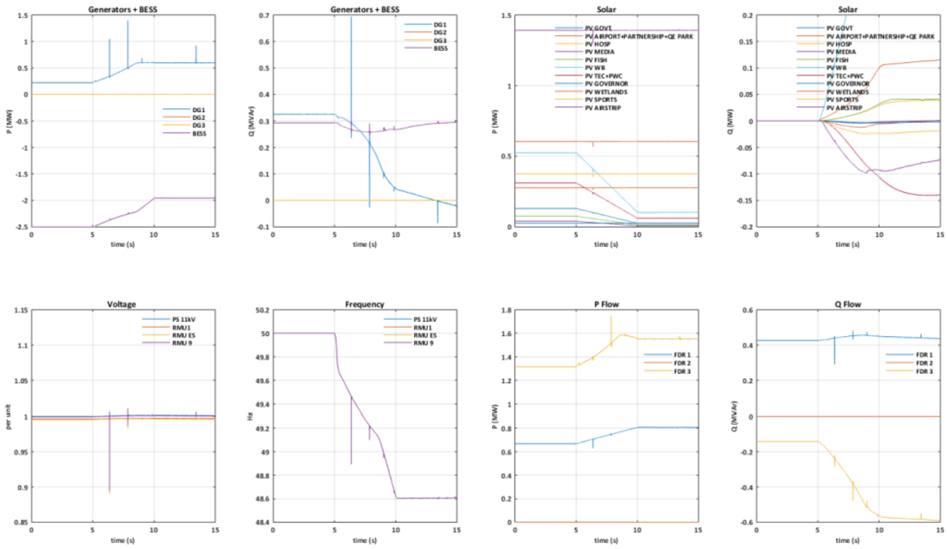

Figure G.2: Peak Load – Battery Charging (System is stable. Minimum frequency goes to 48.5 Hz)

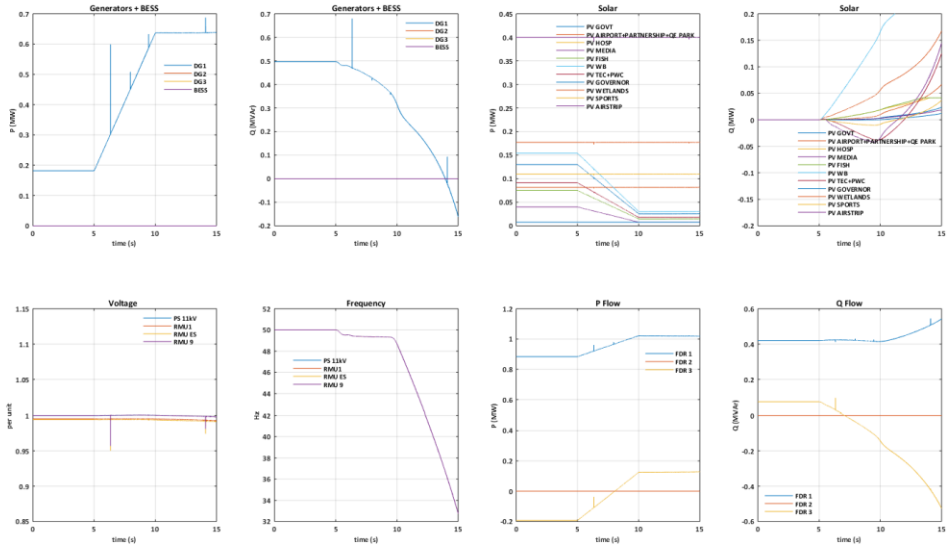

Figure G.3: Peak Load – Battery Unavailable (System is unstable. New solar can be configured to have frequency control function)

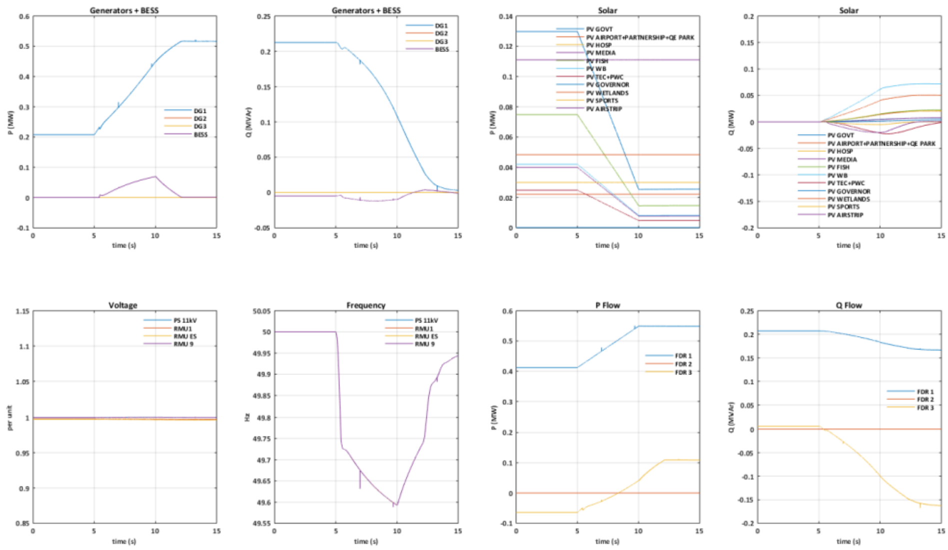

Figure G.4: Min Load – Battery Charged (System is stable. Minimum frequency goes to 49.6 Hz)

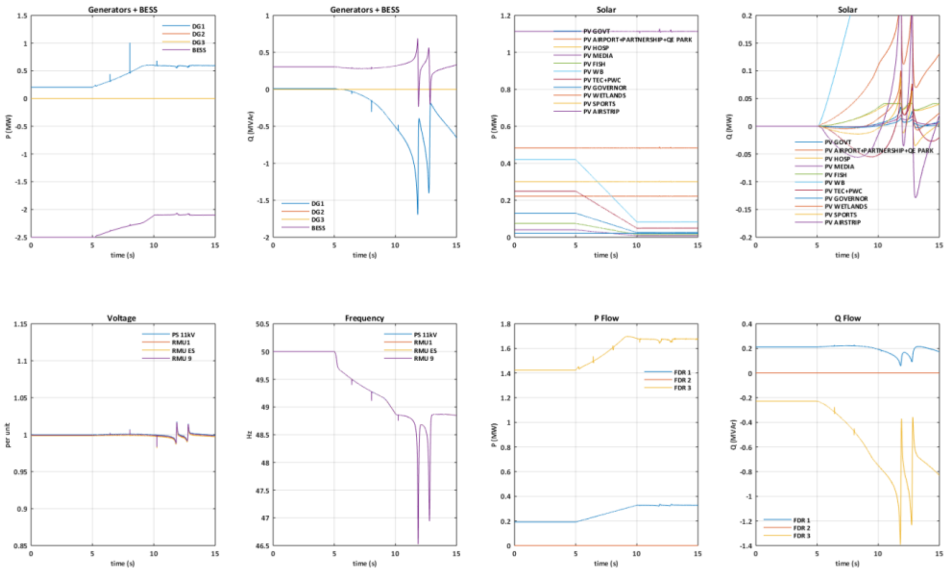

Figure G.5: Min Load – Battery Charging (System is stable. Minimum frequency goes to 46.5 Hz)

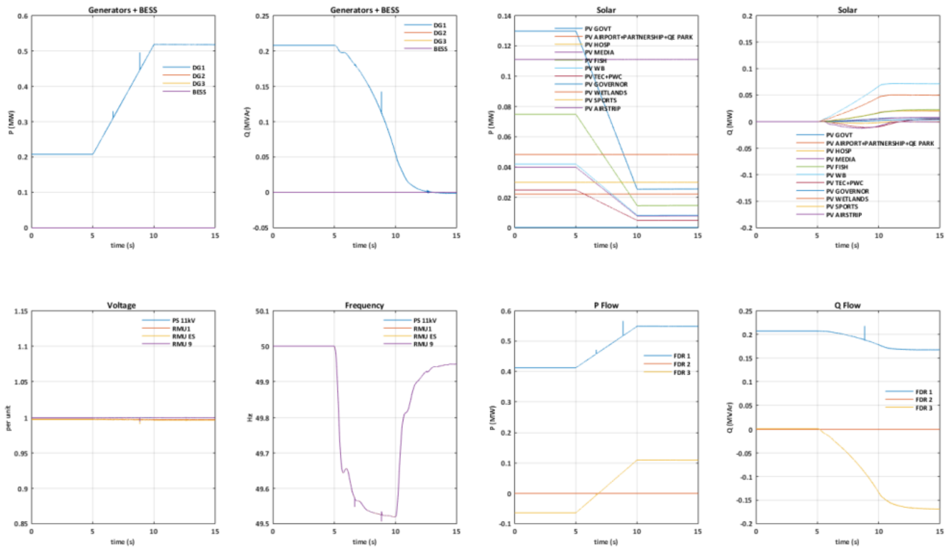

Figure G.6: Min Load – Battery Unavailable (System is stable. Minimum frequency goes to 49.5 Hz)