Provisional Interconnection Study Report
PI-2019-7

Provisional Interconnection Request for GI-2018-23

72 MW Solar Photovoltaic Generating Facility
Tap on the Hartsel – Tarryall 230kV line
Park County, Colorado

Xcel Energy - Transmission Planning West
Xcel Energy
November 18, 2019

Executive Summary

The PI-2019-7 (PI) is the Provisional Interconnection Service Request for the NRIS request GI-2018-23 (GI). The Generating Facility is a 72MW net rated Solar Photovoltaic (PV) Generating Facility that will be located in Park County, Colorado. The Point of Interconnection (POI) for this Generating Facility is a tap on Public Service Company of Colorado (PSCo)'s Hartsel – Tarryall 230kV line. The "PI-2019-7 switching station" may require a Certificate of Public Convenience and Necessity (CPCN).

The proposed COD of the PI facility is December 31, 2022. Accordingly, based on the standard construction schedules, the back-feed date is assumed to be June 30, 2022, approximately six (6) months before the COD. The back-feed and COD of the PI are dependent on the PI-2019-7 switching station being in-service.

PI-2019-7 was studied for Provisional Interconnection Service and the 72 MW rated output of the PI was assumed to be delivered to Public Service Company of Colorado (PSCo) native load, so existing PSCo generation was used as its sink.

The power flow analysis included steady state analysis with TOT5 path flow stressed to a maximum of 1,680MW. The study identified five new overloads on the PSCo system.

The transient stability analysis determined that all generating units are stable (remain in synchronism), display positive damping and the maximum transient voltage dips are within the acceptable dynamic performance criteria.

The short-circuit and breaker duty analysis determined that no breaker replacements are needed at the POI station and/or in neighboring PSCo stations.

The total estimated cost of the PSCo transmission system improvements required for PI-2019-7 to qualify for Provisional Interconnection Service is:

- **$9.992 Million (Tables 8 and 9)**

For PI-2019-7 interconnection:

- **Provisional Interconnection Service (after required transmission system improvements) = 72MW**

The Provisional Interconnection Service results above are contingent upon the transmission system improvements identified in Attachment 1.

Security: The GI-2018-23 request is NRIS. The estimated risk of the potential interconnection facilities and Network Upgrades that might be identified at the conclusion of the GI-2018-23 LGIP is $300 million. Security amount for PI-2019-7 is $300 million.

The Interconnection Customer assumes all risk and liabilities with respect to changes between the Provisional Large Generator Interconnection Agreement and the Large Generator

Interconnection Agreement, including changes in output limits and Interconnection Facilities, Network Upgrades, Distribution Upgrades, and/or System Protection Facilities cost responsibility.

A Certificate of Public Need and Convenience (CPCN) will be required for the construction of the PI-2019-7 Switching Station; any delays in the CPCN approval can cause further delays to the estimated 18 month construction timeframe.

Note: Provisional Interconnection Service in and of itself does not convey transmission service.

Introduction

The PI-2019-7 (PI) is the Provisional Interconnection Service Request for the NRIS request GI-2018-23 (GI). The Generating Facility is a 72MW net rated Solar Photovoltaic (PV) Generating Facility that will be located in Park County, Colorado. The proposed solar photovoltaic generating facility consists of 23 TMEIC 3.36 MW, +/- 0.95 power factor inverters. Each inverter consists of one (1) 630V/34.5 KV, 3.7 MVA, Z=8% pad-mounted step-up transformer. The 34.5 KV collector system in the generating facility will connect to one (1) 63/80/100 MVA, 34.5/230/13.8 KV wye-wye-delta, Z=10% main step-up transformer which will connect to the PSCo transmission system via 250 feet, 230 KV transmission line. The Point of Interconnection (POI) for this Generating Facility is a tap on Public Service Company of Colorado (PSCo)'s Hartsel – Tarryall 230kV line.

The Point of Interconnection (POI) requested for PI-2019-7 will require building a new 230kV switching station in order to accommodate the Generating Facility interconnection. This switching station will be referred to as "PI-2019-7 Switching Station" in this report. A Certificate of Public Convenience and Necessity (CPCN) will be requested for the construction of this switching station.

The geographical location of the transmission system near the POI is shown in Figure 1 below.

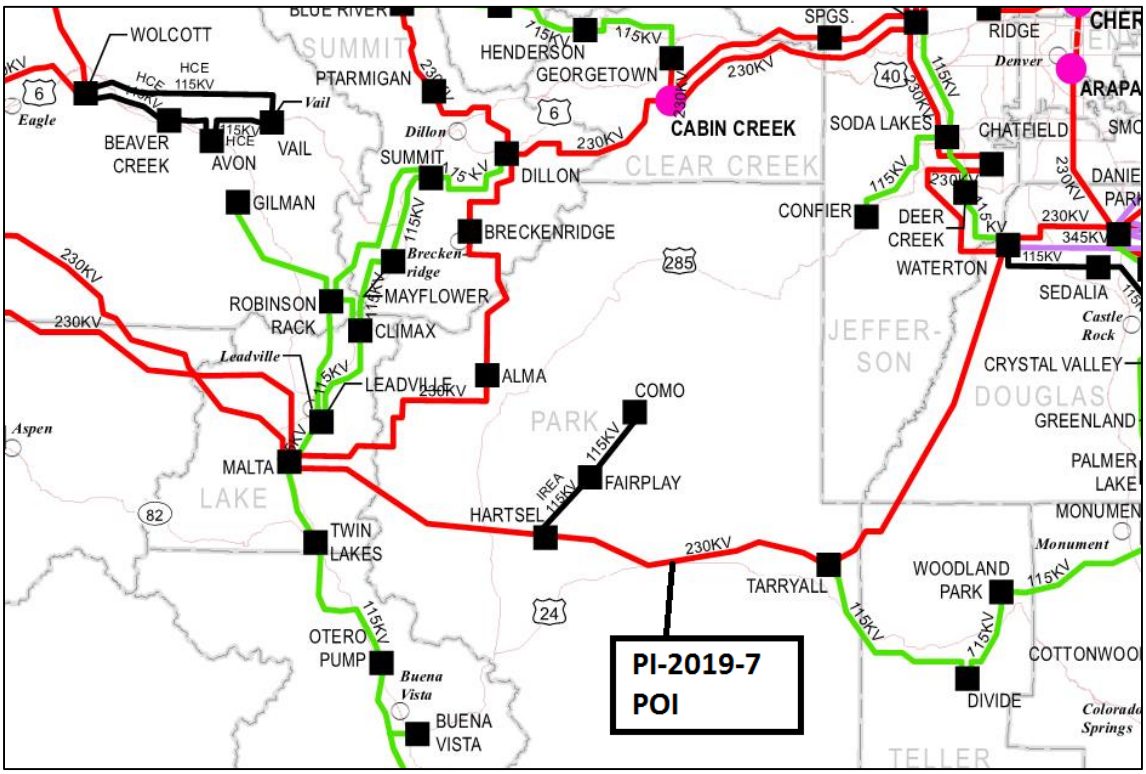


Figure 1 - PI-2019-7 Point of Interconnection and Study Area

The proposed Commercial Operation Date (COD) of the PI facility is December 31, 2022. Accordingly, based on the typical construction timeframes for similar projects, the back-feed date is assumed to be June 30, 2022, approximately six (6) months before the COD.

The main purpose of this study is to determine the system impact of interconnecting 72MW of PV generation on the Hartsel – Tarryall 230kV line. Per the Provisional Interconnection Study Request, PI-2019-7 is studied for Provisional Interconnection Service[1] only. As stated in the PI-2019-7 study agreement, the study assumed GI-2018-23 selects Network Resource Interconnection Service (NRIS)[2]. For this evaluation, the 72 MW rated output of PI-2019-7 is assumed to be delivered to PSCo native load, so existing PSCo generation is used to sink the PI output.

Study Scope and Analysis Criteria

The scope of this report includes steady state (power flow) analysis, transient stability analysis, short circuit analysis, and appropriation level cost estimates (+/- 20% accuracy). The report also identifies the estimated Security[3] for the Provisional Interconnection. The power flow analysis identifies thermal and voltage violations in the PSCo system and the neighboring systems as a result of the interconnection of the GI for Provisional Interconnection. Several single contingencies are studied.

The transient stability analysis verifies that all generating units within the PSCo transmission system and the neighboring systems remain stable (in synchronism), have positive damping, and satisfy acceptable dynamic performance criteria. The short circuit analysis determines the maximum available fault current at the POI and identifies if any circuit breaker(s) within the PSCo station(s) exceed their breaker duty ratings and need to be replaced.

PSCo adheres to applicable NERC Reliability Standards and WECC Reliability Criteria, as well as its internal transmission planning criteria for studies. The steady state analysis criteria are as follows:

P0 - System Intact conditions:

Thermal Loading: <=100% of the normal facility rating

Voltage range: 0.95 to 1.05 per unit

P1-P2-1 – Single Contingencies:

[1] **Provisional Interconnection Service** shall mean an Interconnection Service provided by Transmission Provider associated with interconnecting the Interconnection Customer's Generating Facility to Transmission Provider's Transmission System and enabling that Transmission System to receive electric energy and capacity from the Generating Facility at the Point of Interconnection, pursuant to the terms of the Provisional Large Generator Interconnection Agreement and, if applicable, the Tariff.

[2] **Netowrk Resource Interconnection Service** shall mean an Interconnection Service that allows the Interconnection Customer to integrate its Large Generating Facility with the Transmission Provider's Transmission system (1) in a manner comparable to that in which the Transmission Provider integrates its generating facilities to serve native load customers; or (2) in an RTO or ISO with market based congestion management, in the same manner as all other Network Resources. Network Resource Interconnection Service in and of itself does not convey transmission service.

[3] **Security** estimates the risk associated with the Network Upgrades and Interconnection Facilities that could be identified in the corresponding LGIA.

Thermal Loading: <=100% Normal facility rating
Voltage range: 0.90 to 1.10 per unit
Voltage deviation: <=8% of pre-contingency voltage

The same list of contingencies was run on the benchmark case and the study case, and the results were compared.

For PSCo facilities, thermal violations attributable to the PI include any facilities without a pre-existing thermal violation that (i) resulted in a thermal loading >100% post the GI addition and (ii) contributed to an incremental loading increase of 2% or more to the benchmark case loading. For non-PSCo facilities, thermal violations attributed to the GI include all new facility overloads with a thermal loading of >100% and existing thermal overloads that increased by 1% or more from the benchmark case overload post the GI addition.

The voltage violations that could be assigned to the PI will include new voltage violations or existing voltage violations which resulted in a further variation of 0.1 per unit.

Transient stability criteria require that all generating machines remain in synchronism and all power swings should be well damped following a contingency event. Also, transient voltage performance should meet the following WECC Disturbance-Performance criteria:

- Following fault clearing, the voltage shall recover to 80% of the pre-contingency voltage within 20 seconds for all contingencies
- For all contingencies, following fault clearing and voltage recovery above 80%, voltage at each applicable BES bus serving load shall neither dip below 70% of pre-contingency voltage for more than 30 cycles nor remain below 80% of pre-contingency voltage for more than two seconds.
- For contingencies without a fault, voltage dips at each applicable BES bus serving load shall neither dip below 70% of pre-contingency voltage for more than 30 cycles nor remain below 80% of pre-contingency voltage for more than two seconds.

The study area is the electrical system consisting of PSCo's transmission system and the neighboring transmission systems that are impacted by or that will impact interconnection of the PI. The study area for PI-2019-7 includes WECC designated zones 700, 703, 704, 705, 708, 709, 790 and 791.

System Impact Study Power Flow Case Creation

The Base Case used for the power flow analysis originated from the 2023HS case built for the 2018 TPL1 Work Group of the Colorado Coordinated Planning Group (CCPG). As part of the case build efforts for the TPL1 work group, the case was reviewed by PSCo and neighboring utilities within the CCPG foot print.

All transmission planned projects in PSCo's 10 year transmission plan that are expected to be in-service before July 2023 are modeled in the Base Case, consistent with the case season and year. These projects are described at: (http://www.oasis.oati.com/woa/docs/PSCO/PSCOdocs/Q1_2019_Transmission_Plan.pdf)

The PSCo projects added to the Base Case include the following:

- Shortgrass 345kV Switching Station – ISD 2020
- Shortgrass – Cheyenne Ridge 345kV line – ISD 2020
- Graham Creek 115kV Substation – ISD 2021
- Husky 230/115kV Substation – ISD 2021
- Cloverly 115kV Substation – ISD 2021
- Ault – Husky 230kV line – ISD 2021
- Husky – Graham Creek – Cloverly 115kV line – ISD 2021
- Monument – Flying Horse 115kV Series Reactor – ISD 2021
- Gilman – Avon 115kV line – ISD 2022
- Upgrade Villa Grove – Poncha 69kV Line to 73MVA – ISD 2021
- Upgrade Poncha - Sargent - San Luis Valley 115kV line to 120MVA – ISD 2021
- Increase Waterton – Martin1 tap 115kV line to 159MVA – ISD 2022

The Base Case also modeled PSCo's Poncha - Smeltertown 115kV line closed. Basalt-Hopkins 115kV line was modeled offline.

The following additional changes were made to the Tri-State Generation and Transmission (TSGT) model in the Base Case per further review and comment from TSGT:

- 30MW San Isabel Solar tapping Ludlo Tap – Pinon Canyon 115kV line
- 80MW TSGT_0809 solar facility tapping Gladstone – Walsenburg 230kV line
- Fuller – Vollmer – Black Squirrel 115 kV line modeled at 173 MVA
- Fuller 230/115kV, 100MVA #2 transformer

The following additional changes were made to the Black Hills Energy (BHE) model in the Base Case per further review and comment from BHE:

- Fountain Valley – DesertCove 115kV line was modeled at 222MVA. Planned upgrade project in 1/2021
- Fountain Valley – MidwayBR 115kV line was modeled at 222MVA. Planned upgrade project in 1/2021
- Pueblo West Substation – ISD 1/2021
- Skyline Ranch Substation – ISD 10/2021
- West Station – Greenhorn 115kV line Rebuild – ISD 9/2022

The following additional changes were made to the Colorado Springs Utilities (CSU) model in the Base Case per further review and comment from CSU:

- The Cottonwood – Tesla 34.5kV line is modeled open and Kettle Creek – Tesla 34.5kV line is modeled closed on the CSU system
- Grazing Yak Solar – ISD 2020
- Cottonwood 230/115kV auto-transformer replacement – ISD 2019
- Nixon – Kelker 230kV line upgrade – ISD 2019

The Base Case model includes the existing PSCo generation resources. There were no higher-queued generators in the Provisional Interconnection queue with POI in the same generation pocket and no higher-queued generation in the Generation Interconnection queue which have a Power Purchase Agreement or have received the state approval in the Electric Resource Plan which qualified for inclusion in the Base Case.

The Benchmark Case was created from the Base Case by changing the generation dispatch in the Western part of Colorado to reflect a West to East flows across TOT5. The study modeled the TOT5 path at a maximum of 1,680MW, consistent with how it is studied for the Rocky Mountain Operating Study Group seasonal path studies. This was accomplished by adopting the generation dispatch given in Table 2 below for the study area. In addition, the area interchange schedules from Area 10 (New Mexico), Area 14 (Arizona),and Area 65 (PACE) to Area 70 (PSCo) and Area 73 (Western) were increased to achieve 1680 MW west-to-east on the TOT5 power transfer path.

Table 1 – TOT5 Element Flows with the TOT5 Path Stressed to 1680 MW in the Benchmark Case (MW is Gross Capacity)

benchmark case	Path flow MW
TOT5 path	
Terry Ranch – North Park 230 KV line	166.6
Craig – Ault 345 KV line	529.1
Hayden East – Gore Pass 230 KV line	354.6
Gore Pass – Hayden 138 KV line	82.3
Hopkins – Malta 230 KV line	200.2
Basalt – Malta 230 KV line	81
Poncha – N.Gunnison 115 KV line	45.6
Curecanti – Ponchabr 230 KV line	220.8
Total TOT5 path flow	**1,680**

Table 2 – Study Area Generation with the TOT5 Path Stressed to 1680 MW in the Benchmark Case (MW is Gross Capacity)

Generation	Pgen MW
Craig 1	470
Craig 2	470
Craig 3	478
Hayden 1	202
Hayden 2	285
Bonanza	490
MBPP-1	221
MBPP-2	150
Cabin Creek A	160
Cabin Creek B	160
Blue Mesa 1	40
Blue Mesa 2	40
Morrow 1	72
Morrow 2	72
Elbert-1	90
Elbert-2	90

A Study Case was created from the Benchmark Case by adding the PI-2019-7 interconnection facility at the proposed Point of Interconnection (tap assumed to be at 50% of line length of Hartsel – Tarryall 230KV line). The 72MW output from PI-2019-7 was dispatched pro-rata to the PSCo units outside the study area. The PI-2019-7 facility was modeled using the power flow modeling data provided by the Generation Interconnection Customer.

A power flow analysis was performed, and the results of the Benchmark Case vs Study Case, were compared to determine the impacts of the interconnection of the PI and the Provisional Interconnection Service capacity of PI-2019-7.

The steady state analysis was performed using PTI's PSSE Ver. 33.5.0 program and the ACCC contingency analysis tool.

The transient stability analysis was performed using General Electric's PSLF Ver.21.0_07 program. Three phase faults were simulated for selected single contingencies using standard clearing times. The voltage and frequency of transmission buses in the study area, and the relative rotor angle of generators in the study area were recorded and analyzed. PSLF's DYTOOLS EPCL program was used to simulate the disturbances.

The results of the single contingency analysis (P1 and P2-1) are given in Table 3 below.

Table 3 Power Flow Analysis Results

Note – Thermal overloads for single contingencies are calculated using the normal rating of the facility. All overloads are in red.

Table 3: Differential Impact of PI-2019-7 on Facility Loadings Summary of Power Flows from Single Contingency Analysis 2023 Heavy Summer with a High TOT5 Flow (1680 MW west to east)									
				Facility Loading Without PI-2019-7		Facility Loading With PI-2019-7			
Monitored Facility (Line or Transformer)	**Type**	**Owner**	**Branch Rating MVA (Norm)**	**Flow MVA**	**Flow % of Rating (Norm)**	**Flow MVA**	**Flow % of Rating (Norm)**	**% Change**	**NERC Single Contingency**
CABINCRK 230/115kV Transformer #T1	Xfmr	PSCo	54	57.4	106.3%	58.2	107.9%	1.5%	CABINCRK - DILLON 230 KV line
CABINCRK - DILLON 230 KV line	Line	PSCo	462	529.2	114.5%	536.1	116.0%	1.5%	AULT - CRAIG 345 KV line
HENDERPS - PORTAL 115 KV line	Line	PSCo	120	127.0	105.8%	128.7	107.3%	1.4%	CABINCRK - DILLON 230 KV line
CABINCRK - IDAHOSPG 230 KV line	Line	PSCo	473	607.0	128.3%	615.4	130.1%	1.8%	CABINCRK - LOOKOUT 230 KV line
CABINCRK - LOOKOUT 230 KV line	Line	PSCo	478	603.7	126.3%	612.1	128.0%	1.8%	CABINCRK - IDAHOSPG 230 KV line
IDAHOSPG - LOOKOUT 230 KV line	Line	PSCo	473	586.5	124.0%	594.9	125.8%	1.8%	CABINCRK - LOOKOUT 230 KV line
TARRYALL 230/115 KV transformer	Xfmr	PSCo	100	91.5	91.5%	105.7	105.7%	14.2%	TARRYALL - WATERTON 230 KV line

The results of the single contingency analysis (P1 and P2-1) are given in Table 3. The addition of PI-2019-7 caused several overloads on the PSCo system. The facility overloads impacted by the addition of PI-2019-7 are as follows:

- Cabin Creek 230/115kV Transformer #T1 loading increased from 106.3% to 107.9% (PSCo facility)
- Cabin Creek - Dillon 230 KV line loading increased from 114.5% to 116.0% (PSCo facility)
- Henderps - Portal 115 KV line loading increased from 105.8% to 107.3% (PSCo facility)
- Cabin Creek - Idaho Springs 230 KV line loading increased from 128.3% to 130.1% (PSCo facility)
- Cabin Creek - Lookout 230 KV line loading increased from 126.3% to 128.0% (PSCo facility)

- Idaho Springs - Lookout 230 KV line loading increased from 124.0% to 125.8% (PSCo facility)
- Tarryall 230/115kV transformer loading increased from 91.5% to 105.7% (PSCo facility)

The following table describes the mitigation measures used to address contingency overloads in Table 3. The Cabin Creek – Georgetown 115kV line and Cabin Creek generation reduction are existing TOT5 operating practices that are used by the Path Manager, Western Area Power Administration, when it conducts TOT5 seasonal and planning studies to achieve 1680MW.

Table 4 TOT5 Mitigation Measures to Address Criteria Violations

Monitored Facility (Line or Transformer)	NERC Single Contingency	Mitigation Measure
CABINCRK 230/115kV Transformer #T1	CABINCRK - DILLON 230 KV line	Open the Cabin Creek-Georgetown 115kV line (Existing TOT5 Operating Practice)
CABINCRK - DILLON 230 KV line	AULT - CRAIG 345 KV line	Proposed Project for the PSCo 2021-2025 Capital Budget Process
HENDERPS - PORTAL 115 KV line	CABINCRK - DILLON 230 KV line	Open the Cabin Creek-Georgetown 115kV line (Existing TOT5 Operating Practice)
CABINCRK - IDAHOSPG 230 KV line	CABINCRK - LOOKOUT 230 KV line	Reduce Cabin Creek generation (Existing TOT5 Operating Practice)
CABINCRK - LOOKOUT 230 KV line	CABINCRK - IDAHOSPG 230 KV line	Reduce Cabin Creek generation (Existing TOT5 Operating Practice)
IDAHOSPG - LOOKOUT 230 KV line	CABINCRK - LOOKOUT 230 KV line	Reduce Cabin Creek generation (Existing TOT5 Operating Practice)
TARRYALL 230/115 KV transformer	TARRYALL - WATERTON 230 KV line	Re-Dispatch P-2019-7 to reduce the overload (Proposed TOT5 Operating Practice)

The Cabin Creek-Dillon 230kV contingency overload in table 3 is based on a reduced transmission line rating that is anticipated to begin in 2020-2021 as a result of Xcel Energy changing its line rating methodology. This line de-rate will be reflected in the official FAC-008 publication when that occurs. The line de-rate will become “official” once the FAC-008 ratings are updated. In order for this provisional generator interconnection to achieve its full rating, an uprate of the Cabin Creek-Dillon 230kV transmission line will need to be completed. This is a “planned upgrade under development by PSCo”, and expected to be completed before 2022. If this project is delayed, the PI output will be limited based on the firm and non-firm capacity available on the system.

The Tarryall 230-115kV transformer contingency overload occurs due to the combination of very high TOT5 west-to-east flows and PI-2019-7 project at its maximum output and an outage of the Tarryall-Waterton 230kV line. Similar to the existing Operating Practices developed for high TOT5, re-dispatching the PI-2019-7 generation will be proposed as a new TOT5 operating practice. The PI output will be limited based on existing firm and non-firm capacity available on the system.

Voltage Regulation and Reactive Power Capability

The Interconnection Customer is required to interconnect its Large Generating Facility with PSCo's Transmission System in accordance with the *Xcel Energy Interconnection Guidelines for Transmission Interconnected Producer-Owned Generation Greater Than 20 MW* (available at: http://www.transmission.xcelenergy.com/staticfiles/microsites/Transmission/Files/PDF/Interconnection/Interconnections-POL-TransmissionInterconnectionGuidelineGreat20MW.pdf).

Accordingly, the following voltage regulation and reactive power capability requirements at the POI are applicable to this interconnection request:

- To ensure reliable operation, all Generating Facilities interconnected to the PSCo transmission system are expected to adhere to the *Rocky Mountain Area Voltage Coordination Guidelines (RMAVCG)*. Accordingly, since the POI for this interconnection request is located within West slope - Region 1 defined in the *RMAVCG*; the applicable ideal transmission system voltage profile range is 1.01 – 1.03 per unit at regulated buses and 1.0 – 1.03 per unit at non-regulated buses.
- Xcel Energy's OATT (Attachment N effective 10/14/2016) requires all non-synchronous Generator Interconnection Customers to provide dynamic reactive power within the power factor range of 0.95 leading to 0.95 lagging at the high side of the generator substation. Furthermore, Xcel Energy requires every Generating Facility to have dynamic voltage control capability to assist in maintaining the POI voltage schedule specified by the Transmission Operator as long as the Generating Facility does not have to operate outside its 0.95 lag – 0.95 lead dynamic power factor range capability.
- It is the responsibility of the Interconnection Customer to determine the type (switched shunt capacitors and/or switched shunt reactors, etc.), the size (MVAR), and the locations (34.5kV or 230kV bus) of any additional static reactive power compensation needed within the generating plant in order to have adequate reactive capability to meet the +/- 0.95 power factor and the 1.0 – 1.03 per unit voltage range standards at the POI. Finally, it is the responsibility of the Interconnection Customer to compensate their generation tie-line to ensure minimal reactive power flow under no load conditions.

The Interconnection Customer is required to demonstrate to the satisfaction of PSCo Transmission Operations prior to the commercial in-service date of the generating plant that it can safely and reliably operate within the required power factor and voltage ranges (noted above).

According to the modeling data provided by the Customer, PI-2019-7 generator has the following modeling parameters:

- Solar PV: Pmax =77.2MW (not to exceed 72MW at the POI), Pmin =0, Qmax = 24.9Mvar, Qmin = -24.9Mvar

In addition, PI-2019-7 models a 12Mvar shunt capacitor bank on the 34.5kV bus.

Table 5 - Reactive Capability Evaluation

Gen MW/Mvar	Shunt Mvar	Gen Voltage (p.u.)	High Side Main Station Transformer Voltage (p.u.)	High Side MW	High Side Mvar	High Side Power Factor	POI Voltage (p.u.)	Lead/lag	POI MW	POI MVar	POI power Factor
73.2 MW /24.9 Mvar	12	1.042	1.016	72	22.4	0.955	1.016	lag	72	22.4	0.955
73.2 MW/-10.1 Mvar	0	0.974	0.995	72	-23.6	0.950	0.995	Lead	72	-23.6	0.950
7.3 MW/2.0 Mvar	12	0.985	1.002	7.3	2.4	0.950	1.002	Lag	7.3	2.4	0.950
7.3 MW/-2.9 Mvar	0	1.001	1	7.3	-2.4	0.950	1	Lead	7.3	-2.4	0.950
73.1 MW /24.9 Mvar	12	1.042	1.016	72	22.4	0.955	1.016	Lag	72	22.4	0.955
73.2 MW/-24.9 Mvar	0	0.975	0.986	71.9	-40.6	0.871	0.986	Lead	71.9	-40.6	0.871
0 MW /-9.1 Mvar	12	1.006	1	72	-9.8	0.991	1	Lead	72	-9.8	0.991

From the analysis in Table 5, the Generating Facility is not capable of meeting 0.95 PF at the high side of the main step-up transformer for the 72MW output (see the row highlighted in red). It is the responsibility of the Interconnection Customer to determine the type (switched shunt capacitors and/or switched shunt reactors, etc.), the size (MVAR), and the locations (34.5kV or 230kV bus) of additional static reactive power compensation needed within the generating plant in order to have adequate reactive capability to meet the +/- 0.95 power factor at the high side of the main step-up transformer prior to COD of the PI.

Transient Stability Study Results

Table 6 Transient Stability Analysis Results

Stability Scenarios						
#	Fault Location	Fault Type	Facility Tripped	Clearing Time (cycles)	Post-Fault Voltage Recovery	Angular Stability
1	Line-end fault at PI-2019-7 POI on Tarryall - PI-2019-7 POI 230 KV line	3ph	PI-2019-7 POI – TARRYALL 230 KV line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
2	Line-end fault at Hartsel on Hartsel - Malta 230 KV line	3ph	MALTA - HARTSELT 230 KV line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
3	Line-end fault at Tarryall on Tarryall - Waterton 230 KV line	3ph	TARRYALL – WATERTON 230 KV line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
4	Line-end fault at Malta on Alma - Malta 230 KV line	3ph	MALTA – ALMA 230 KV line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
5	Line-end fault at Malta on Basalt - Malta 230 KV line	3ph	MALTA – BASALT 230 KV line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
6	Line-end fault at Malta on Hopkins - Malta 230 KV line	3ph	MALTA – HOPKINS 230 KV line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
7	Line-end fault at Malta on Mt. Elbert - Malta 230 KV line	3ph	MALTA – MT. ELBERT 230 KV line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping
8	Line-end fault at Hartsel on Hartsel - PI-2019-7 POI 230 KV line	3ph	HARTSELT – PI-2019-7 230 KV line	Primary (5.0)	Maximum transient voltage dips within criteria	Stable with positive damping

The results of the transient stability analysis are given in Table 6. The following results were obtained for the disturbances analyzed:

- ✓ No machines lost synchronism with the system
- ✓ No transient voltage drop violations were observed
- ✓ Machine rotor angles displayed positive damping

Transient stability plots showing surrounding bus voltages, bus frequencies, generator terminal voltages, generator relative angles, generator speeds, and generator power output for each of the disturbances runs for each study scenario have been created and documented in Appendix A. Furthermore, it is the responsibility of the Interconnection Customer to ensure that its generating facility is capable of meeting the voltage ride-through and frequency ride-through (VRT and FRT) performance specified in the NERC Reliability Standard PRC-024.

Short Circuit and Breaker Duty Analysis

The calculated short circuit levels and Thevenin system equivalent impedances at the PI-2019-7 230kV Switching Station POI are shown in Table 7.

Table 7 – Short Circuit Parameters at the PI-2019-7 at POI

	Before the PI-2019-7 Interconnection	After the PI-2019-7 Interconnection
Three Phase Current	5861A	5973A
Single Line to Ground Current	4685A	5166A
Positive Sequence Impedance	2.554+j22.536 ohms	2.554+j22.536 ohms
Negative Sequence Impedance	2.571+j22.541 ohms	2.571+j22.541 ohms
Zero Sequence Impedance	6.802+j39.071 ohms	11.979+j36.077 ohms

The preliminary breaker duty study did not identify any circuit breakers that became over-dutied"[2] as a result of adding this generation.

[2] "Over-dutied" circuit breaker: A circuit breaker whose short circuit current (SCC) rating is less than the available SCC at the bus.

Costs Estimates and Assumptions

PSCo Engineering developed Appropriations level cost estimates (AE) for Interconnection Facilities and Network/Infrastructure Upgrades required for the interconnection of the Interconnection Customer's proposed generation facility. The cost estimates are in 2019 dollars with escalation and contingencies applied. AFUDC is not included. These estimated costs include all applicable labor and overheads associated with the siting, engineering, design, and construction of these new PSCo facilities. This estimate does not include the cost for any Customer owned equipment and associated design and engineering.

The estimated total cost for the required upgrades is **$9,992,000.**

Figure 2 below is a conceptual one-line of the "PI-2019-7 Switching Station" at the Point of Interconnection, which will be a tap on the Hartsel-Daniels Park 230kV Transmission line.

The Tables 8 and 9 list the improvements required to accommodate the interconnection and the delivery of the customer's 72MW PV generation facility generation output. The cost responsibilities associated with these facilities shall be handled as per current FERC guidelines. System improvements are subject to revision as a more detailed and refined design is produced.

The Transmission Provider has specified and estimated the cost of the equipment, engineering, procurement and construction work needed to interconnect PI-2019-7. The results of the engineering analysis for facilities owned by the Transmission Provider are appropriation level estimates and are summarized in Tables 8 and 9.

Table 8: "Transmission Provider's Interconnection Facilities" includes the nature and estimated cost of the Transmission Provider's Interconnection Facilities and an estimate of the time required to complete the construction and installation of such facilities.

Table 9: "Network Upgrades Required for Interconnection Service includes the nature and estimated cost of the Transmission Provider's Network Upgrades necessary to accomplish the interconnection and an estimate of the time required to complete the installation of such facilities.

Upgrades identified in Tables 8 and 9 are illustrated in Figure 2 in the Appendix which shows the physical and electrical connection of the Interconnection Customer's Generating Facility to the Transmission Provider's Transmission System. The one-line diagram also identifies the electrical switching configuration of the interconnection equipment, including, without limitation: the transformer, switchgear, meters, and other station equipment.

Conclusion:

The total estimated cost of the PSCo transmission system improvements required for PI-2019-7 to qualify for Provisional Interconnection Service is:

- **$9.992 Million (Tables 8 and 9)**

For PI-2019-7 interconnection:

Provisional Interconnection Service (after completion of required transmission system improvements) = 72MW

In case the completion of required transmission enhancements on the cabin Creek – Dillon 230kV line and Tarryall 230/115kV transformer are delayed for any reason, the maximum output PI-2019-7 may be limited based on generation dispatch and available firm or non-firm capacity on the transmission system.

The Provisional Interconnection Service results above are contingent upon the transmission system improvements identified in Attachment 1.

The net generation output of the generation facility at the POI shall not exceed 72MW at any time, which will be monitored by PSCo and limited by the Plant Controller at all times.

Security: The GI-2018-23 request is NRIS. The estimated risk of the potential interconnection facilities and Network Upgrades that might be identified at the conclusion of the GI-2018-23 LGIP is $300 million. Security amount for PI-2019-7 is $300 million.
The Interconnection Customer assumes all risk and liabilities with respect to changes between the Provisional Large Generator Interconnection Agreement and the Large Generator Interconnection Agreement, including changes in output limits and Interconnection Facilities, Network Upgrades, Distribution Upgrades, and/or System Protection Facilities cost responsibility.

Note: Provisional Interconnection Service in and of itself, does not convey transmission service.

Table 8 – Transmission Provider's Interconnection Facilities

Element	Description	Cost Est. (Millions)
PI-2019-7 230kV switching station on PSCo's Hartsel-Tarryall 230kV Line	Interconnect Customer to tap the Hartsel-Tarryall 230kV line at a new switching station. The new equipment includes: • One 230kV dead-end and one girder • Three 230kV arresters • One 230kV 2000A Switch • One set (of three) high side metering units • Fiber communication equipment • Station controls • Associated electrical equipment, bus, wiring and grounding • Associated foundations and structures • Associated transmission line communications, fiber, relaying and testing.	$0.870
	Transmission line tap into substation:	$0.055
	Siting and Land Rights support for siting studies, land and ROW acquisition and construction	$0.020
	Total Cost Estimate for Transmission Providers Interconnection Facilities	**$0.945**
Time Frame	**Site, design, procure and construct**	**18 Months**

Table 9 – Network Upgrades Required for Interconnection Service

Element	Description	Cost Est. (Millions)
PI-2019-7 230kV switching station on PSCo's Hartsel-Tarryall 230kV Line	Install a new three position ring bus switching station on the Hartsel-Tarryall 230kV Line. The new equipment includes: • Three 230kV 3000A circuit breakers • Nine 230kV 2000A disconnect switches (assume all switch stands will be installed) • Six 230kC CCVT's • Two Line Traps • Six 230kV Surge Arrestors • Four Dead-ends / 2 DE girder • One Electrical Equipment Enclosure (EEE) • Station controls and wiring • Associated electrical equipment, bus wiring, and grounding • Associated foundations and structures	$7.042
	Install required communications in the EEE at the new switching station	$0.321
	Update primary line relaying on the line to PI-2019-7	$0.331
	Update primary and secondary line relaying and associated breaker fail on the line to PI-2019-7	$0.616
	Re-terminate the transmission line into the new switching station	$0.717

	Siting and Land Rights support for substation construction	$0.020
	Total Cost Estimate for Network Upgrades for Interconnection	**$9.047**
Time Frame	**Site, design, procure and construct**	**12 Months**

Cost Estimate Assumptions

- Appropriations level project cost estimates (AE) for Interconnection Facilities were developed by PSCo Engineering. A level of accuracy of ±20% is specified for AE's.
- Estimates are based on 2019 dollars (appropriate contingency and escalation applied).
- "Allowance for Funds Used During Construction" (AFUDC) has been excluded.
- Labor is estimated for straight time only – no overtime included.
- Lead times for materials were considered for the schedule.
- The Solar Generation Facility is not in PSCo's retail service territory. Therefore, no costs for retail load metering are included in these estimates.
- PSCo (or it's Contractor) crews will perform all construction, wiring, testing and commissioning for PSCo owned and maintained facilities.
- The estimated time to design, procure and construct the interconnection facilities is approximately 18 months after authorization to proceed has been obtained.
- A CPCN will be required for the interconnection facilities construction. The CPCN process is expected to take up to 18 months in addition to the 18 months construction timeframe, resulting in an estimate total time from project initiation to construction would take a total 36 months.
- Customer will string OPGW fiber into substation as part of the transmission line construction scope.
- Breaker duty study determined that no breaker replacements are needed in neighboring substations.
- Line and substation bus outages will be necessary during the construction period. Outage availability could potentially be problematic and extend requested backfeed date due.
- Power Quality Metering (PQM) will be required on the Customer's 230 kV line terminating into PI-2019-7 Substation.
- The Customer will be required to design, procure, install, own, operate and maintain a Load Frequency/Automated Generation Control (LF/AGC) RTU at their Customer Substation. PSCo / Xcel will need indications, readings and data from the LFAGC RTU.

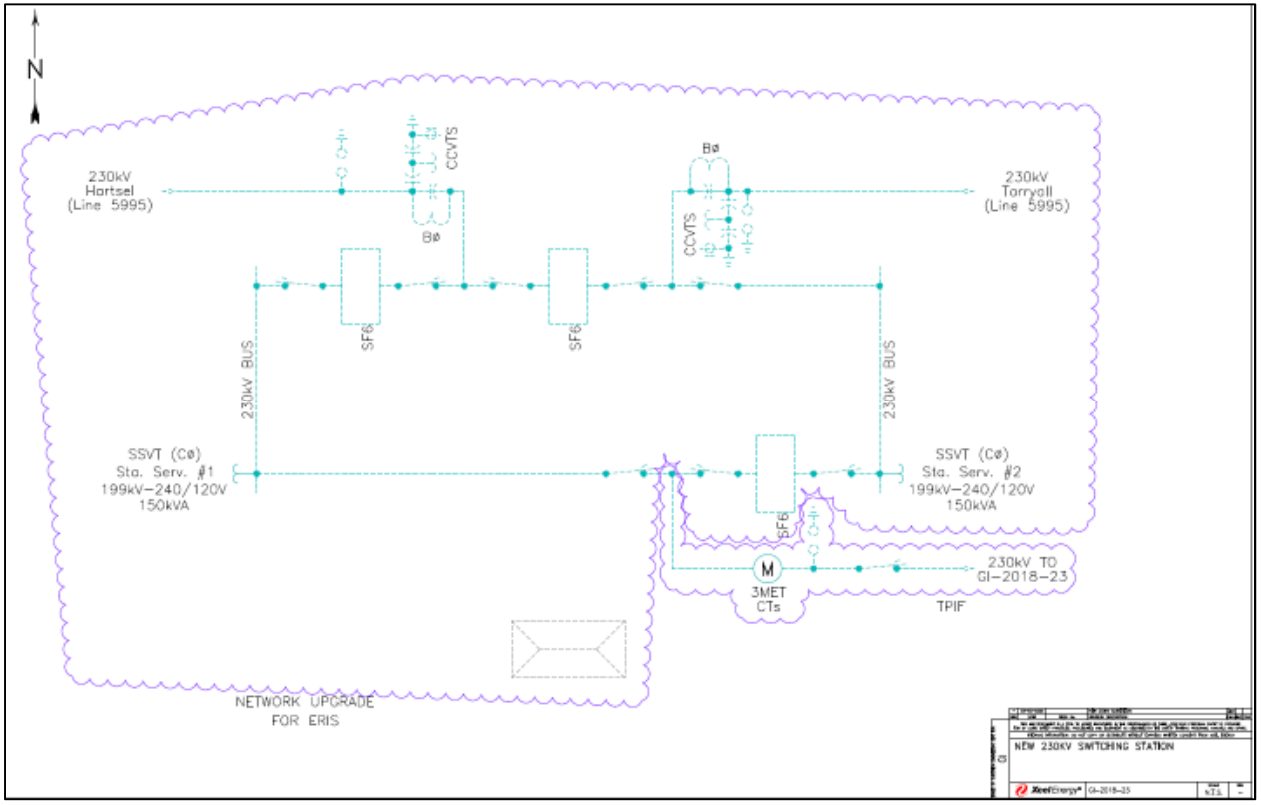


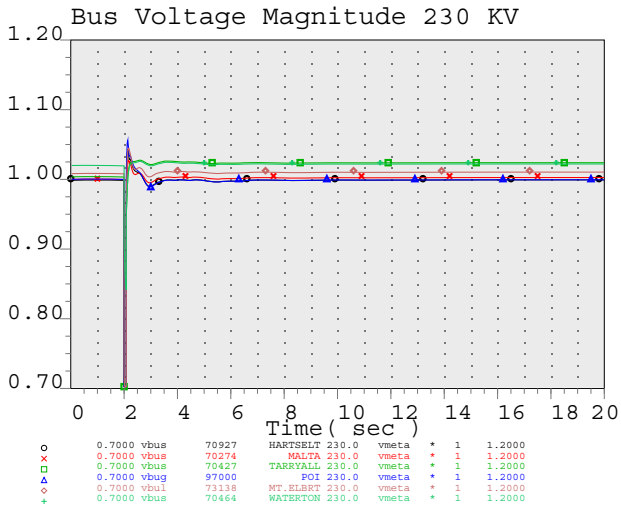
Figure 2 – Preliminary One-line of the PI-2019-7 230kV Switching Station (Tap on the Hartsel–Tarryall 230kV Line)

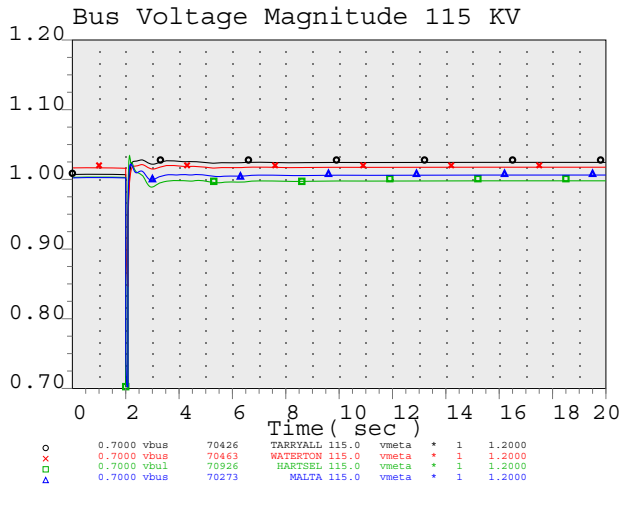
Attachment 1 – Contingent Facilities Assigned to PI-2019-7

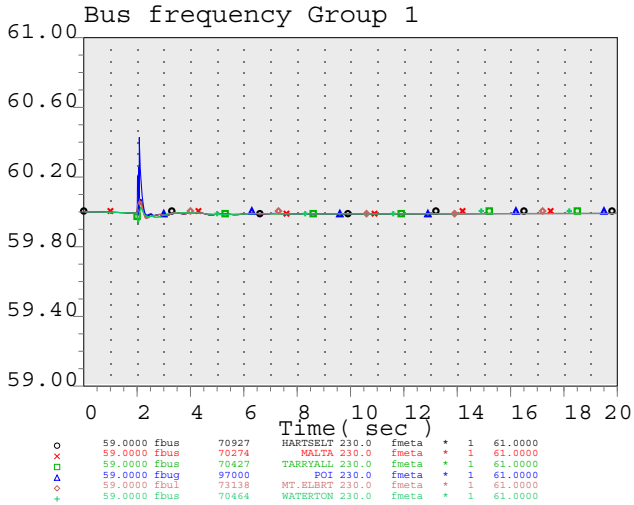
The following is the list of the unbuilt Interconnection Facilities and Network Upgrades upon which the PI-2019-7 request's costs, timing, and study findings are dependent, and if delayed or not built, could cause a need for re-studies of the Interconnection Request or a reassessment of the Interconnection Facilities and/or Network Upgrades and/or costs and timing. PI-2919-7's maximum allowable output may be decreased if these Contingent Facilities are not in-service.

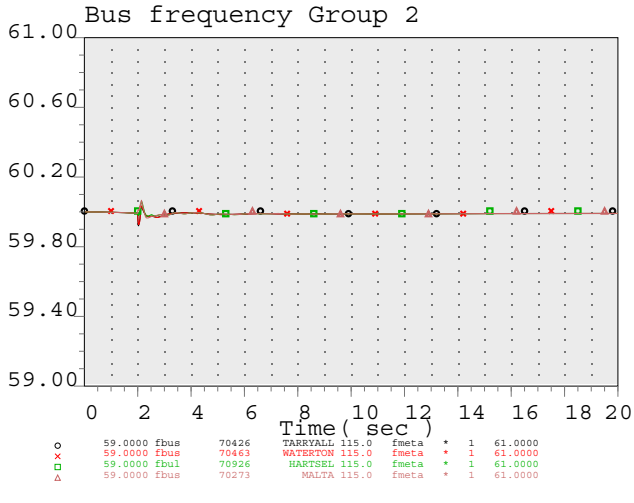
- Cabin Creek-Dillon 230kV Uprate
- Tarryall 230-115kV Operating Practice

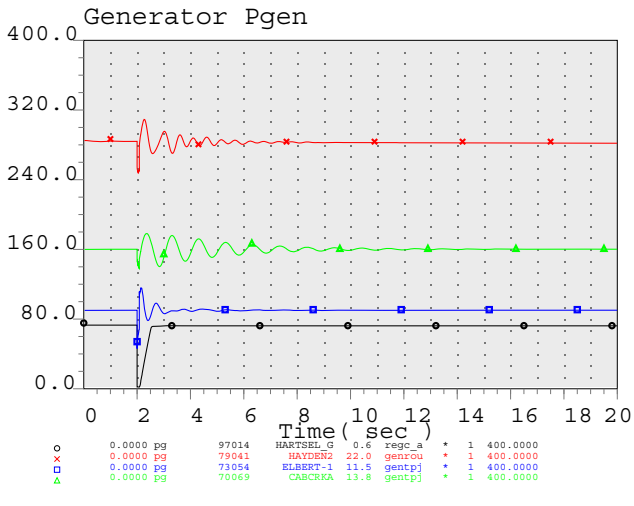
APPENDIX A
Transient Stability Plots

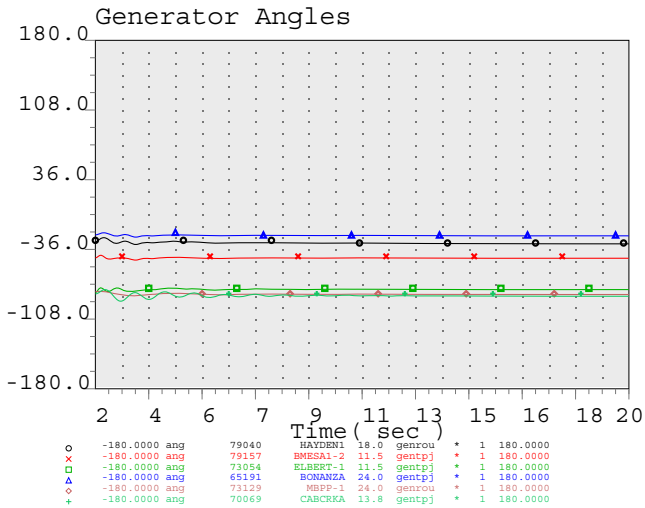






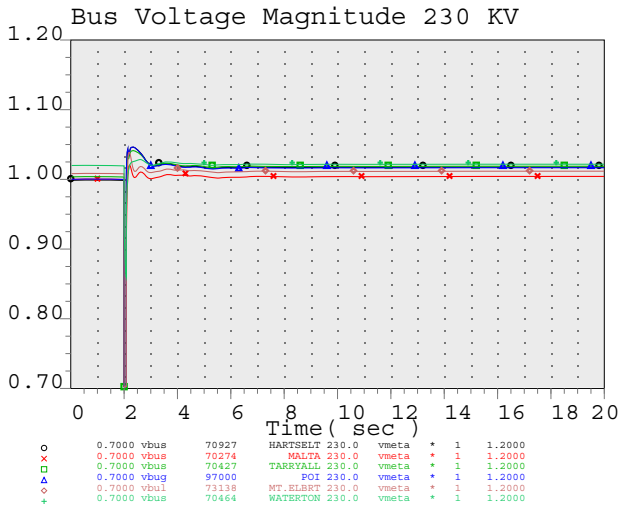


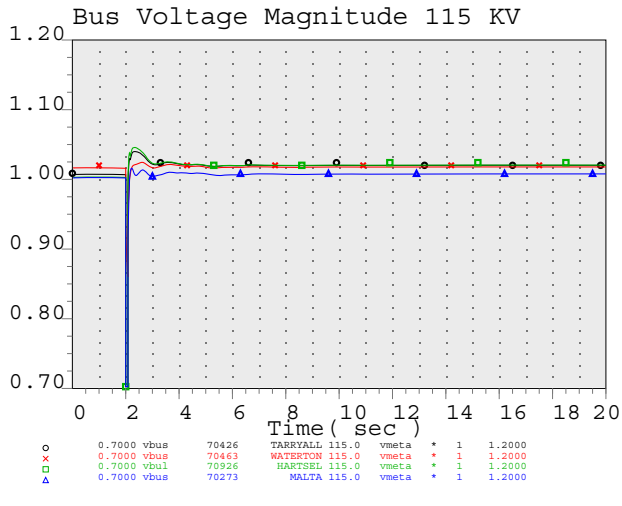


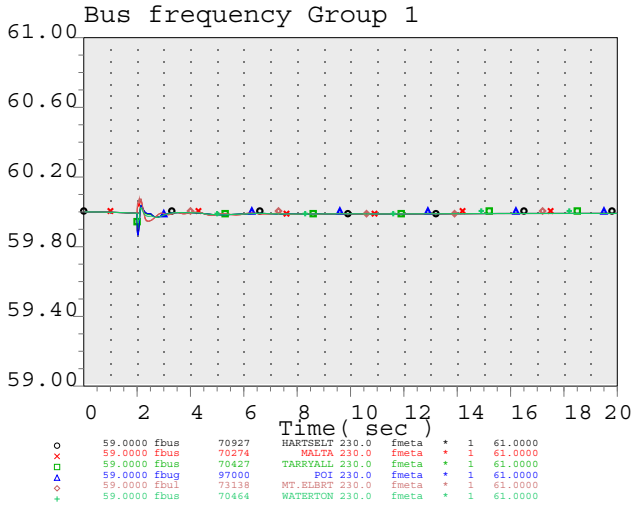


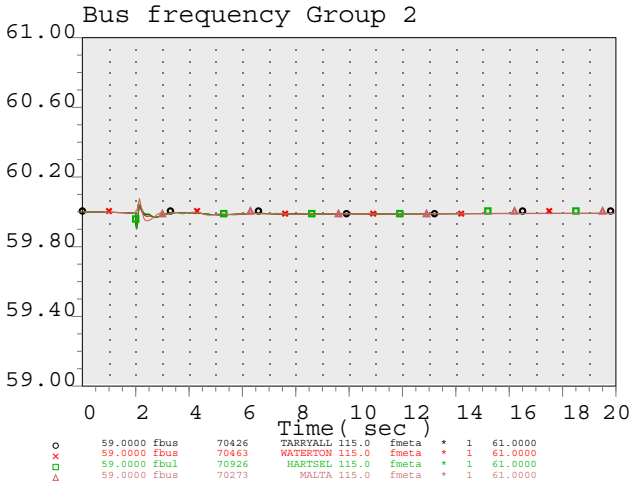
Solar PV - 72 MW

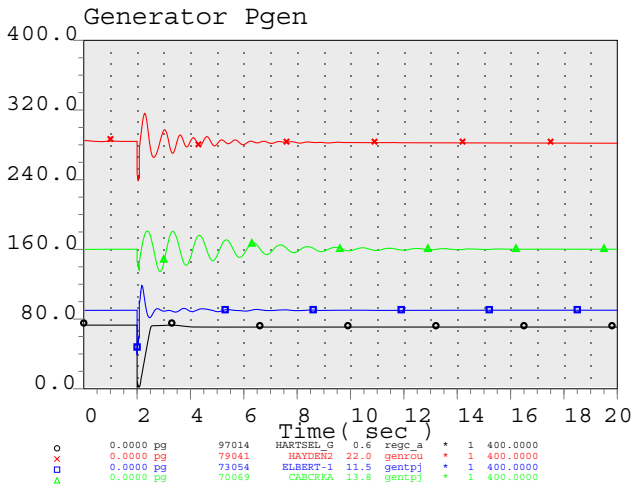
Fault: 3-ph 5 cycle line end fault on Tarryall - PI-2019-7 POI 230kV line at PI-2019-7 POI 230kV
Outage: Tarryall - PI-2019-7 POI 230kV line

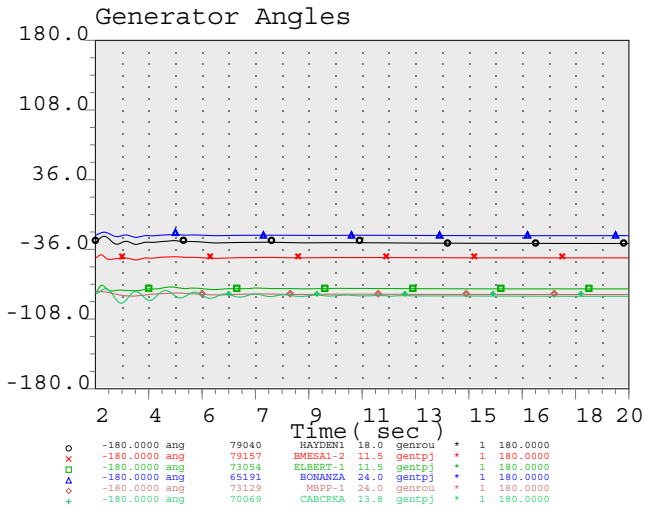






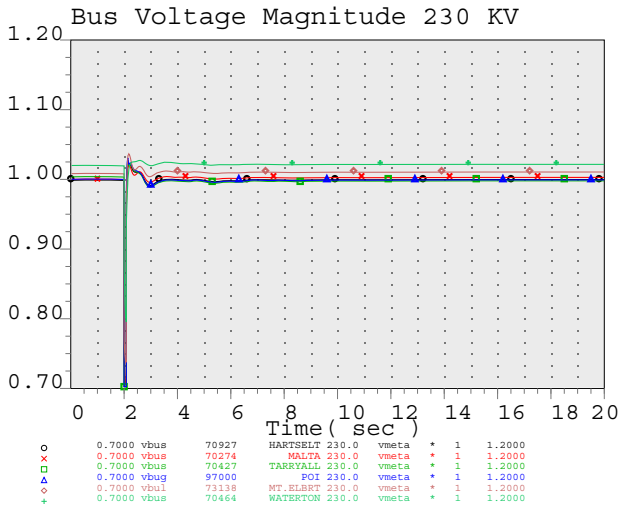


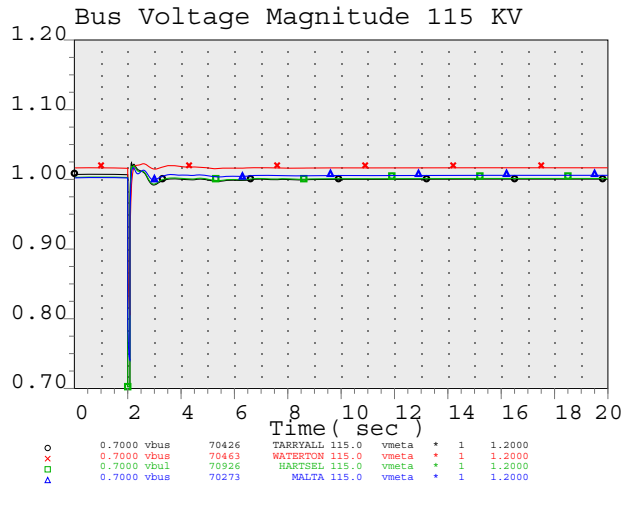


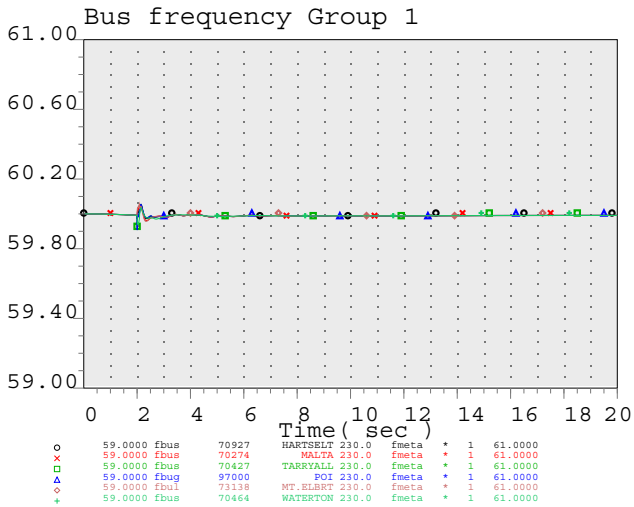


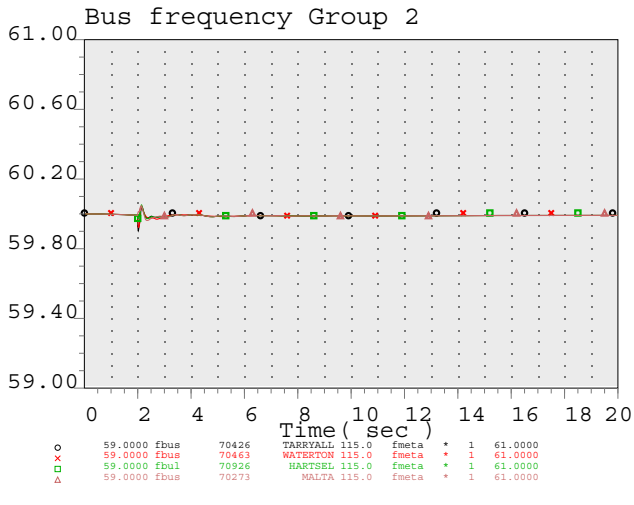
Solar PV - 72 MW

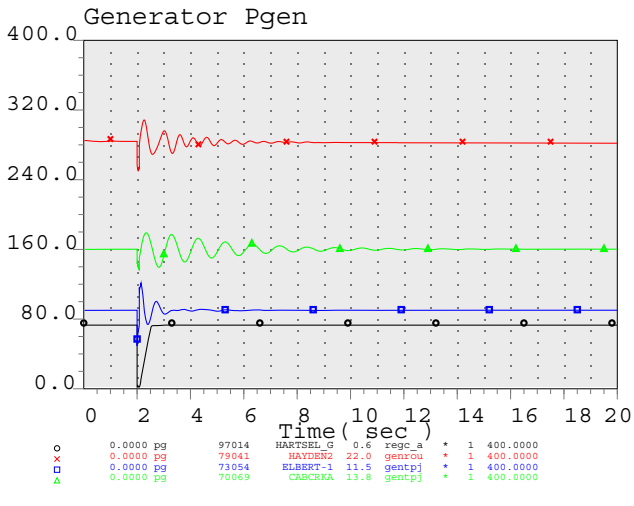
Fault: 3-ph 5 cycle line end fault on Malta - Hartsel 230kV line at Hartsel 230kV
Outage: Malta - Hartsel 230kV line

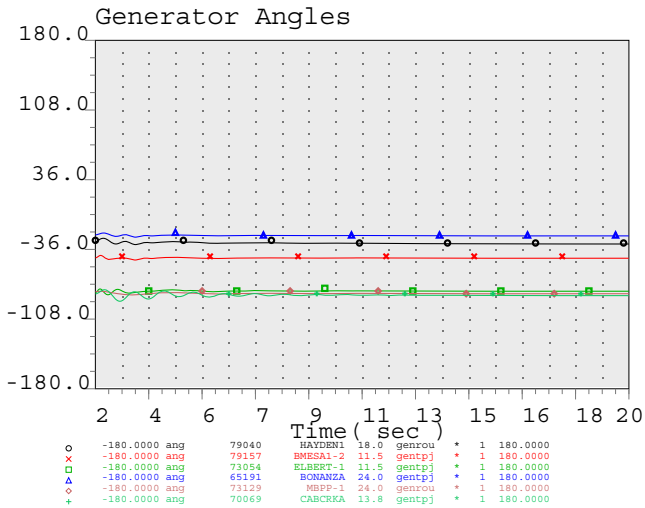






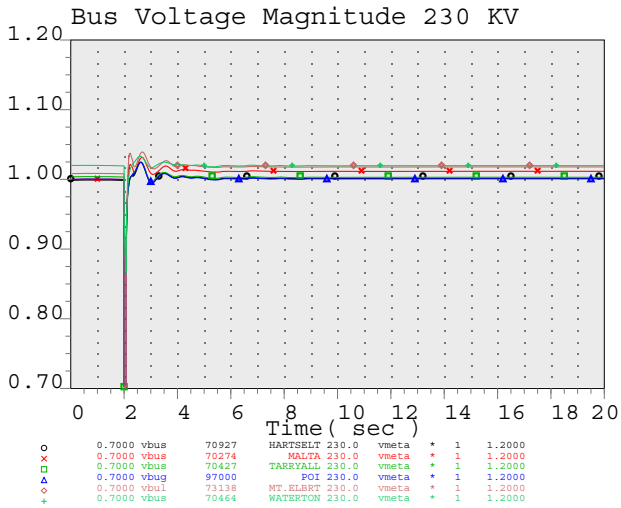


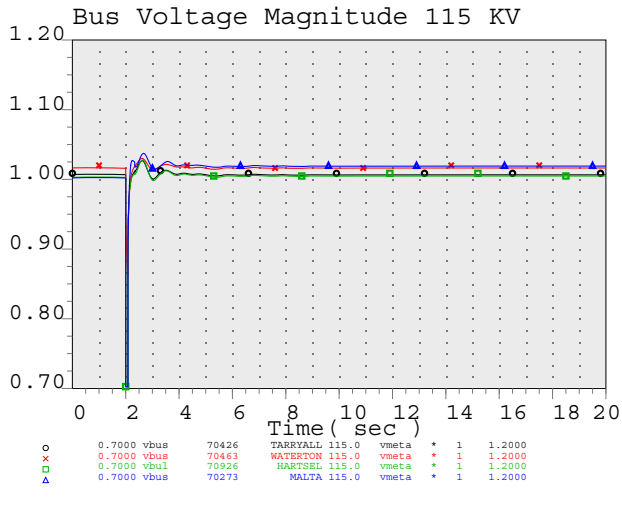


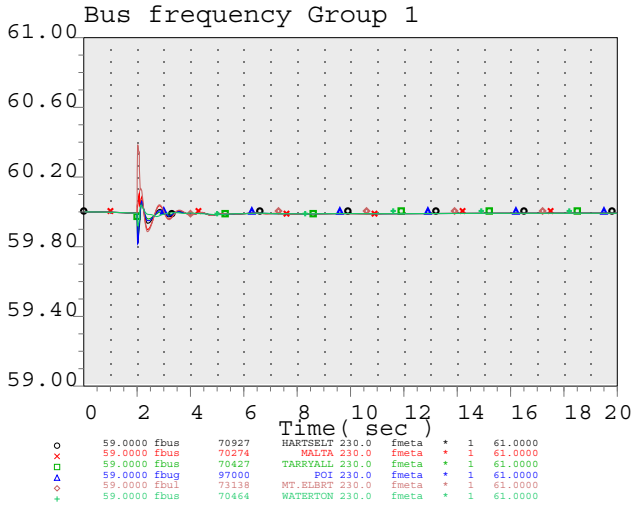


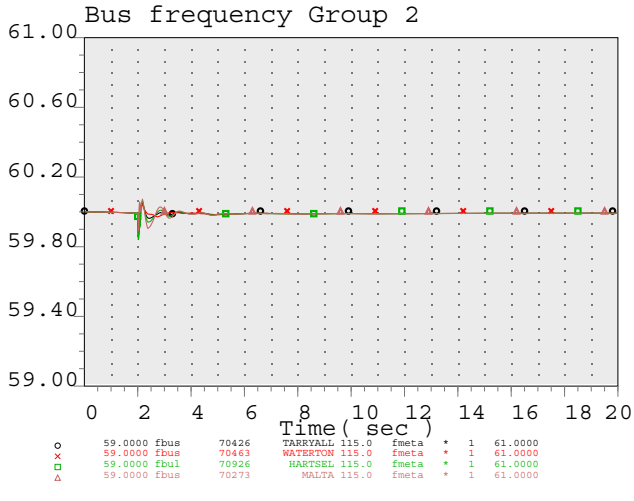
Solar PV - 72 MW

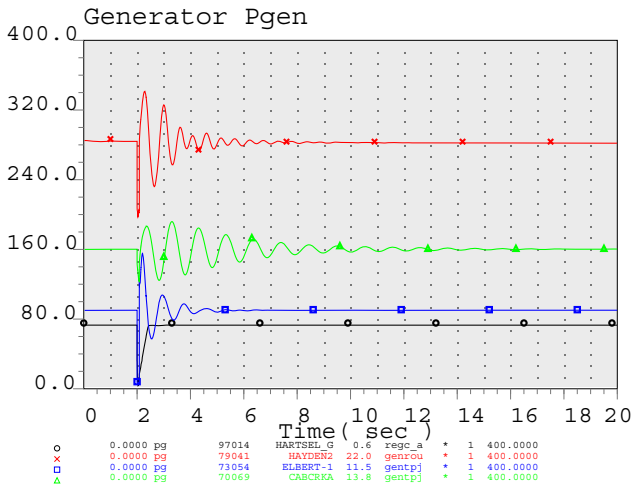
Fault: 3-ph 5 cycle line end fault on Tarryall - Waterton 230kV line
at Tarryall 230kV
Outage: Tarryall - Waterton 230kV line

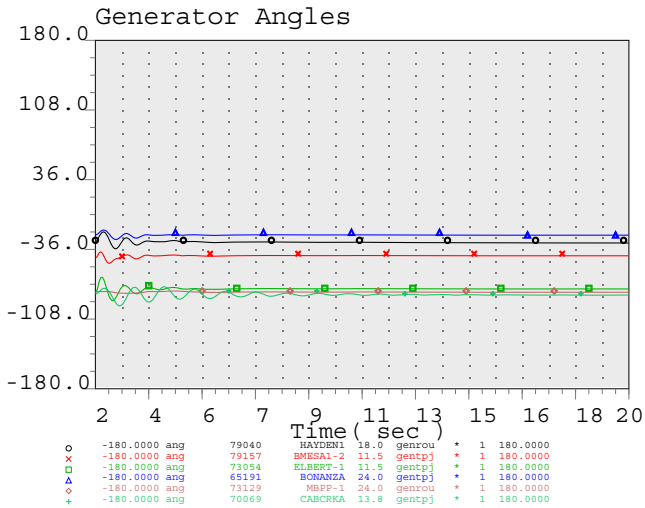






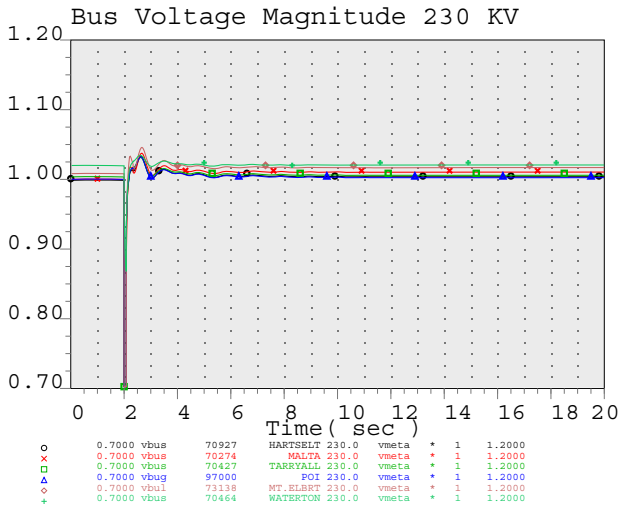


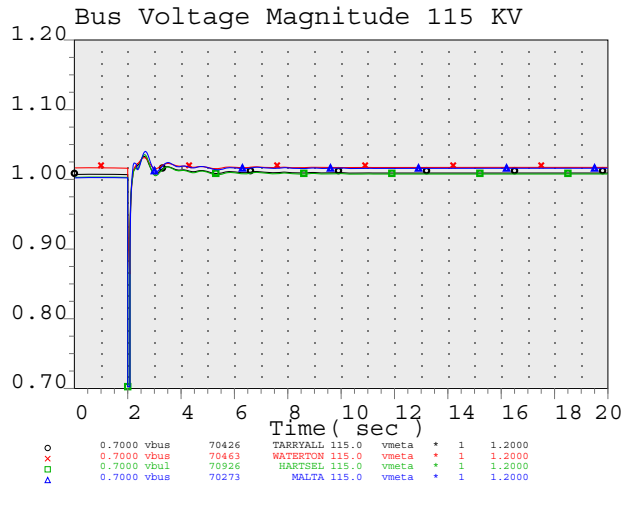


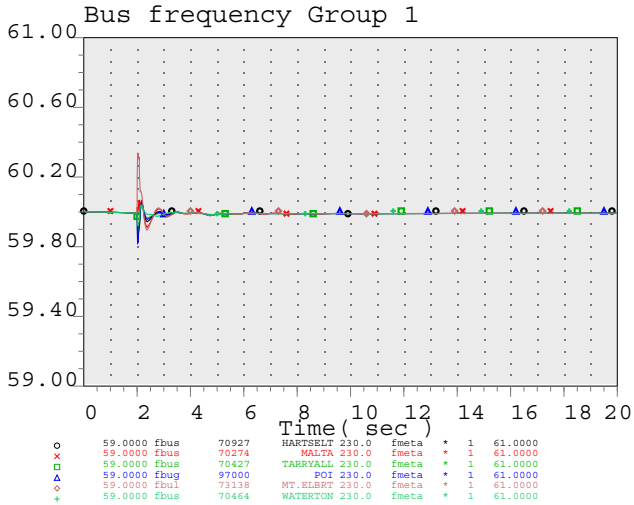


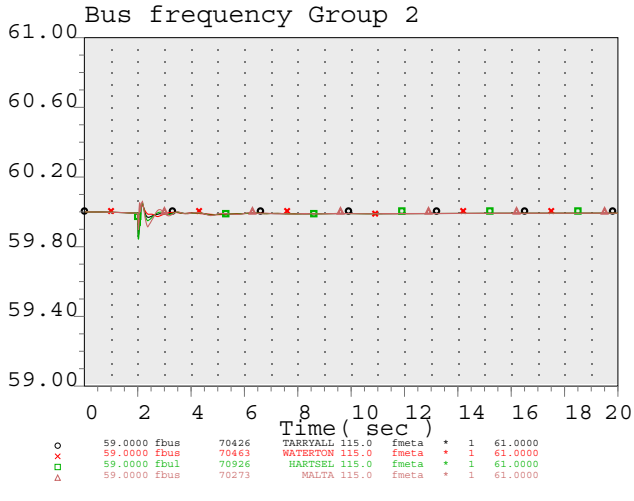
Solar PV - 72 MW

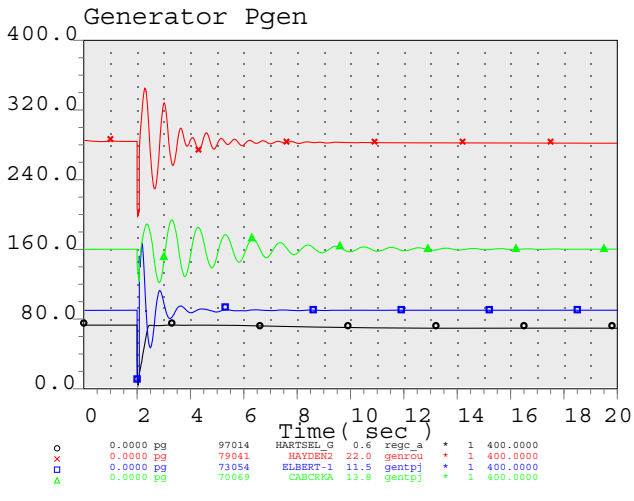
Fault: 3-ph 5 cycle line end fault on Malta - Alma 230kV line
at Malta 230kV
Outage: Malta - Alma 230kV line

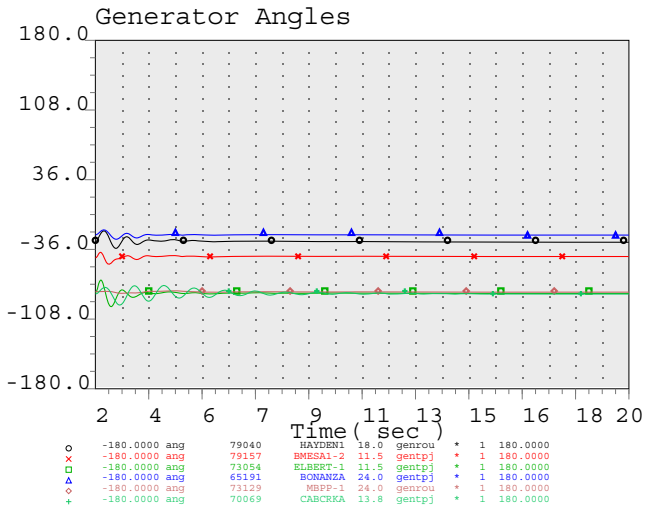






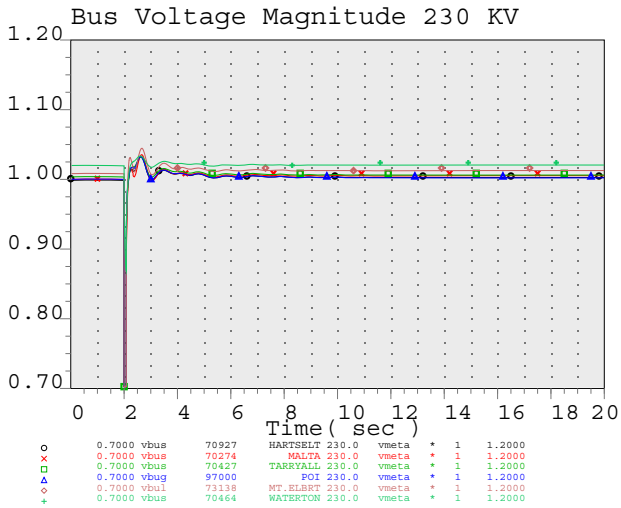


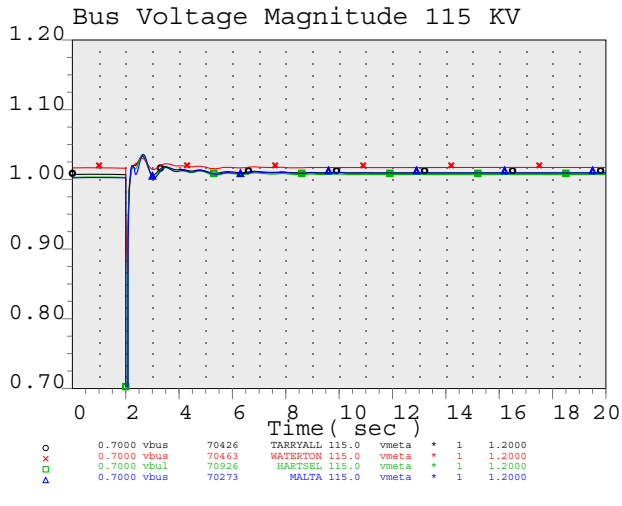


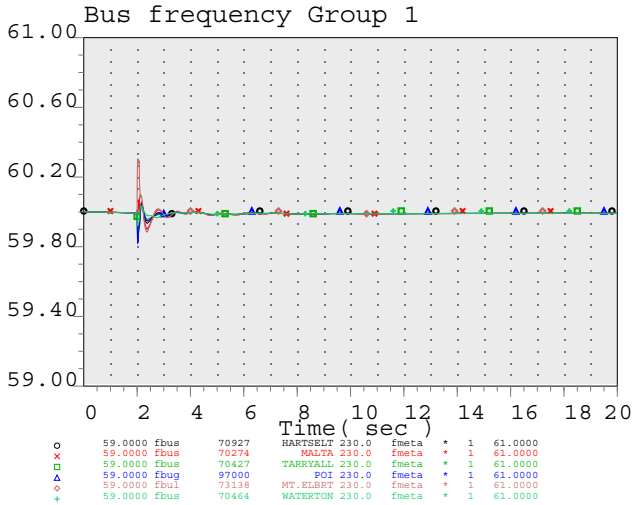


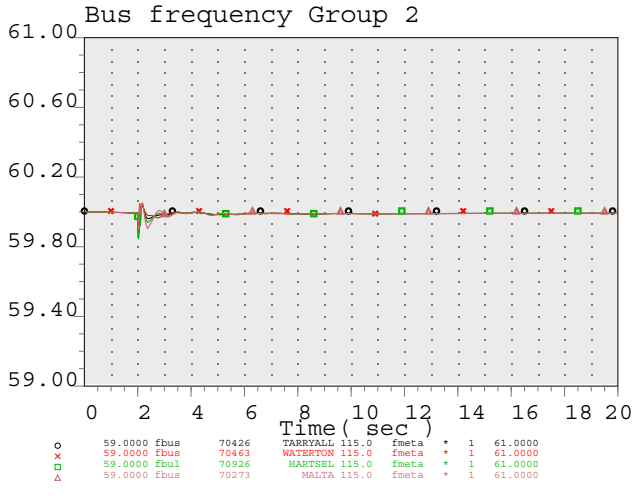
Solar PV - 72 MW

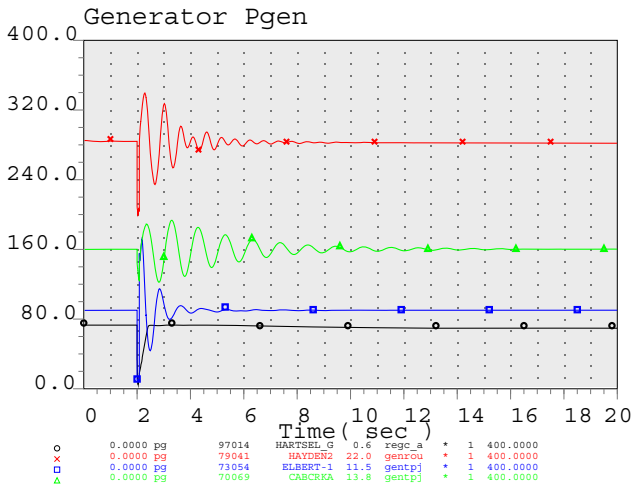
Fault: 3-ph 5 cycle line end fault on Malta - Basalt 230kV line
at Malta 230kV
Outage: Malta - Basalt 230kV line

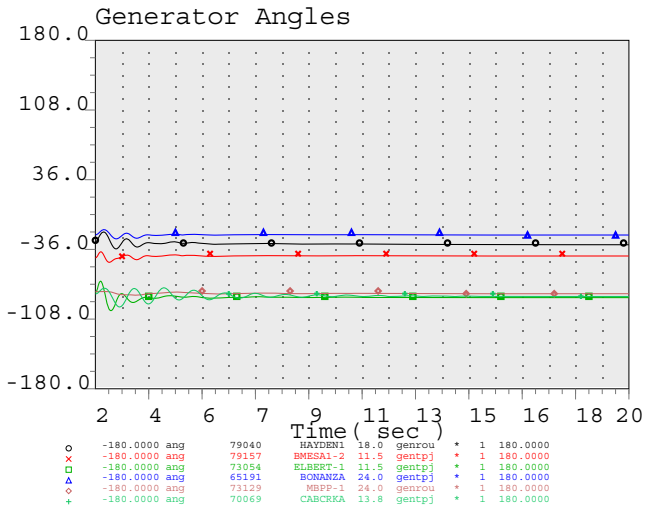






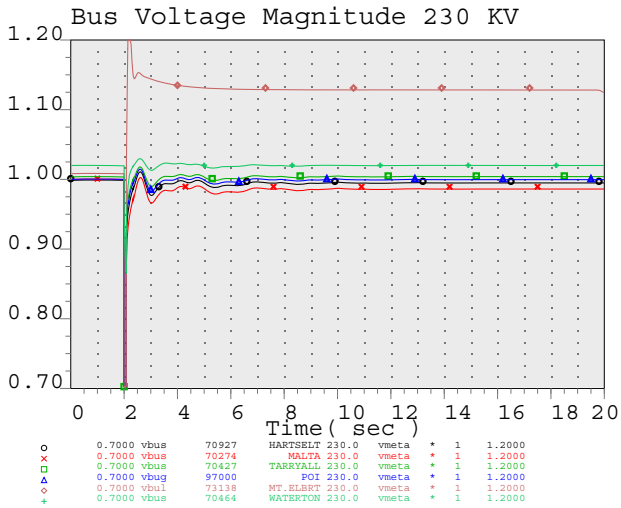


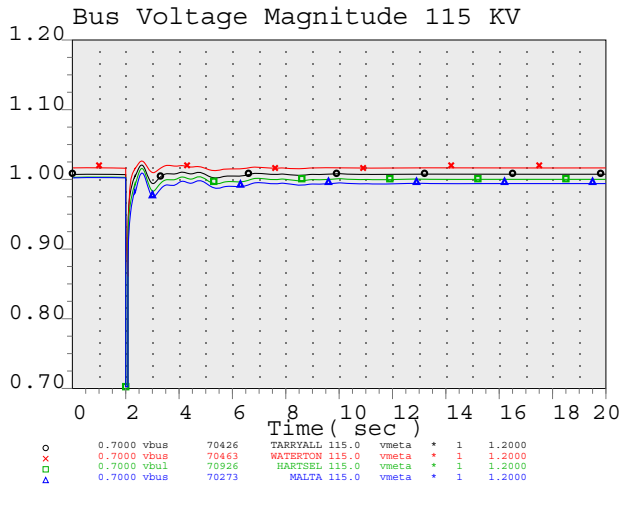


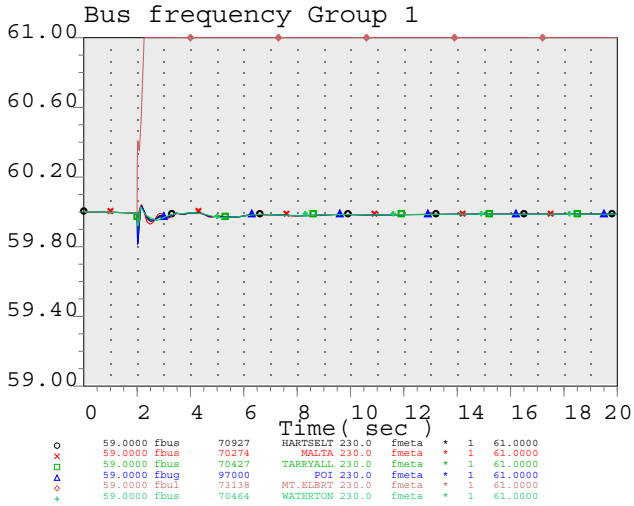


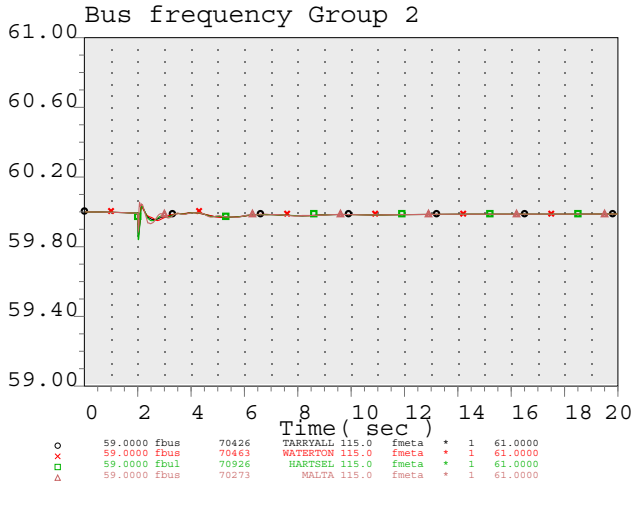
Solar PV - 72 MW

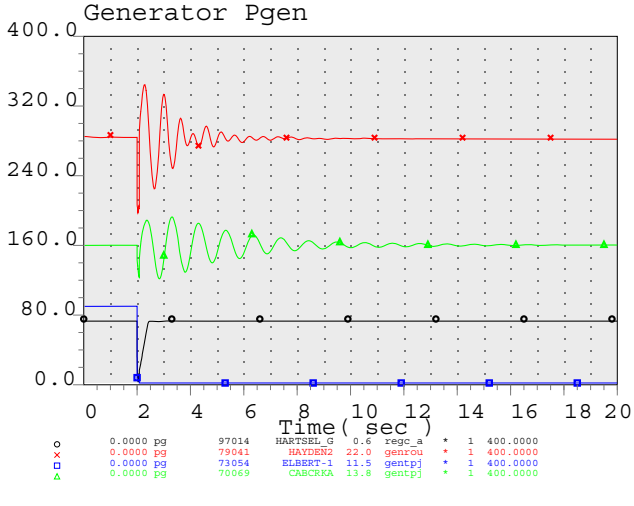
Fault: 3-ph 5 cycle line end fault on Malta - Hopkins 230kV line
at Malta 230kV
Outage: Malta - Hopkins 230kV line

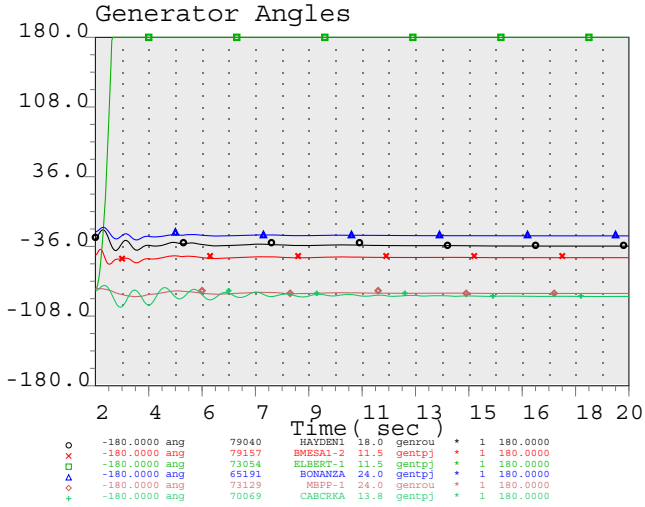






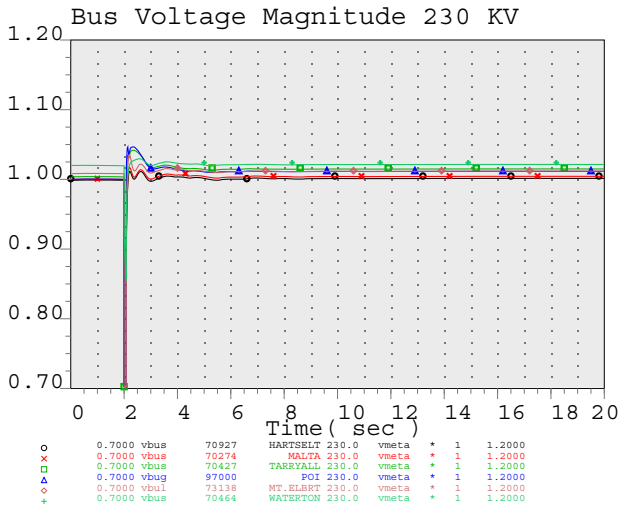


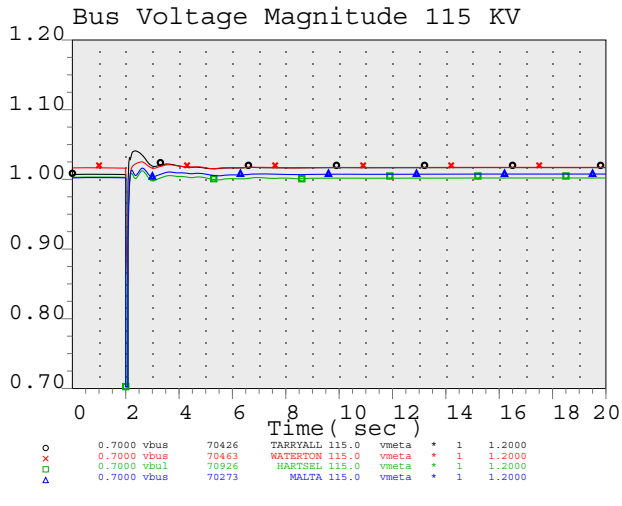


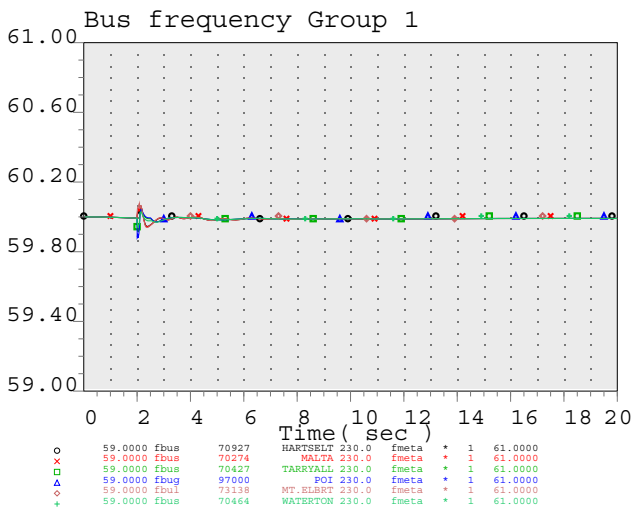


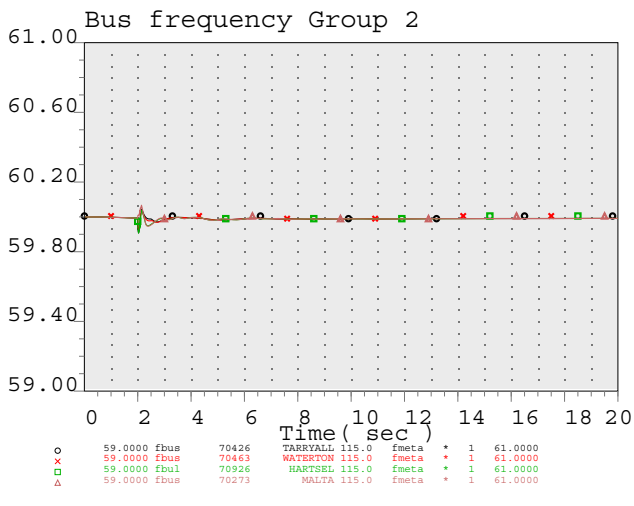
Solar PV - 72 MW

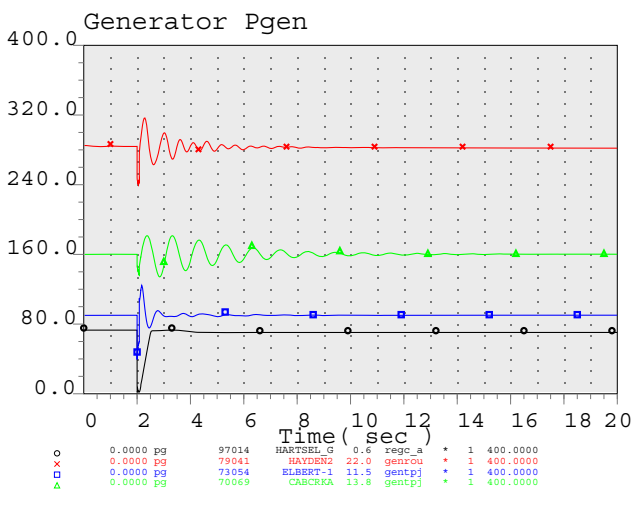
Fault: 3-ph 5 cycle line end fault on Malta - Mt. Elbert 230kV line at Malta 230kV
Outage: Malta - Mt. Elbert 230kV line

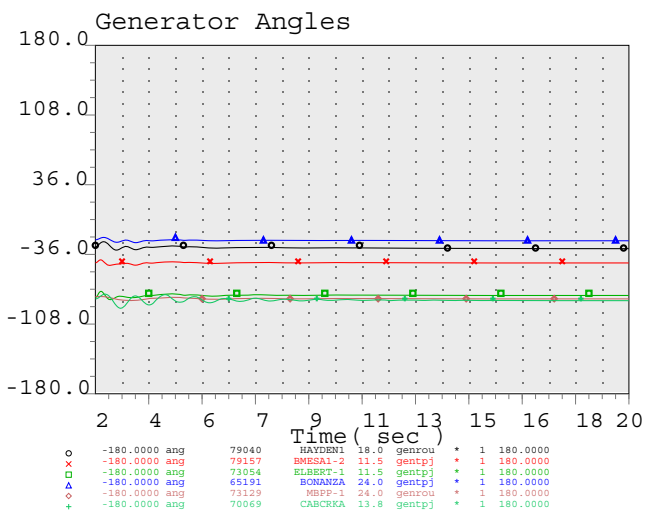












Solar PV - 72 MW

Fault: 3-ph 5 cycle line end fault on Hartsel - PI-2019-7 POI 230kV line at Hartsel 230kV
Outage: Hartsel - PI-2019-7 POI 230kV line