Generator Interconnection Request # GI-2017-5
Combined Feasibility and System Impact Study

54.3 MW Solar Photovoltaic (PV) Generation at Hartsel 230 kV
Park County, Colorado

Public Service Company of Colorado
Transmission Planning
October 20, 2017

A. Executive Summary

Public Service Company of Colorado (PSCo) received an interconnection request (GI-2017-5) for a 54.3 MW solar photovoltaic (PV) generation facility in Park County, Colorado. The proposed Point of Interconnection (POI) is the Hartsel 230 kV bus within the Hartsel 230/115 kV transmission substation (see Figure 1) that is jointly-owned with Intermountain Rural Electric Association (IREA).

The Commercial Operation Date (COD) requested by the Interconnection Customer is March 31, 2019. The backfeed date is assumed to be six months prior to the COD or September 30, 2018.

The proposed solar photovoltaic generating facility consists of 19 SunPower inverters each rated 2.86 MW. Each inverter connects to a pad-mounted step-up transformer which provides voltage transformation for interconnection of the inverter and its associated PV generation source to the medium voltage power collection system within the generating plant. One main step-up transformer provides the final transformation to allow the generating facility to interconnect to the Hartsel 230 kV bus POI via an overhead 230 kV transmission line owned by the Interconnection Customer.

The GI-2017-5 interconnection request was studied as a stand-alone project. The study did not include any other Generator Interconnection Requests (GIR) existing in PSCo's or any affected party's GIR queue, other than the interconnection requests that are considered to be planned resources for which Power Purchase Agreements have been signed. This interconnection request was studied both as Network Resource Interconnection Service (NRIS) and Energy Resource Interconnection Service (ERIS).

For this interconnection request, the Affected Party is Intermountain Rural Electric Association (IREA).

The combined Feasibility and System Impact Study consisted of power flow (steady-state) contingency analysis, transient stability analysis, and short-circuit analysis. One potential thermal

violation was observed as a result of the GI-2017-5 generation addition. The Cabin Creek-Dillon 230kV line (Circuit No. 5007) contingency flow exceeded the 478 MVA rating of the line for an outage of the Tarryall-Hartselt 230kV line as a result of adding the generation facility at the Hartsel Substation. The line rating is limited by substation equipment at the Cabin Creek Substation. The winter normal rating of the line is 478 MVA and the winter emergency rating of the line is 478 MVA. The line has a 764 MVA thermal limit. The branch violation on the PSCo transmission line can be mitigated by re-dispatch and is unlikely to occur as the scenario involves the maximum TOT5 west-to-east flow of 1680 MW coupled with a single contingency. Therefore, it is concluded that no Network Upgrades are required for the GI-2017-5 interconnection to qualify for Network Resource Interconnection Service (NRIS). No circuit-breakers at the Hartsel 230 kV bus or at the neighboring buses were found to be over-dutied[1] due to the proposed interconnection. A stability analysis was performed and the dynamic performance of the system for normally cleared faults was shown to be satisfactory. The proposed generating facility responded as expected; however, 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-024-2.

Cost Estimates

The total estimated cost of the required Interconnection Facilities and Network Upgrades at PSCo's Hartsel Station (in 2017 dollars) is **$1.873 million** and includes:

- $ 0.621 million for PSCo-Owned, Customer-Funded Interconnection Facilities
- $ 1.252 million for PSCo-Owned, PSCo-Funded Network Upgrades for Interconnection
- $ 0.000 million for PSCo-Owned, PSCo-Funded Network Upgrades for Delivery

The estimated time frame to site, design, procure and construct these Interconnection Facilities is 18 months.

Based on this time-frame, the proposed COD of March 31, 2019 is not feasible.

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

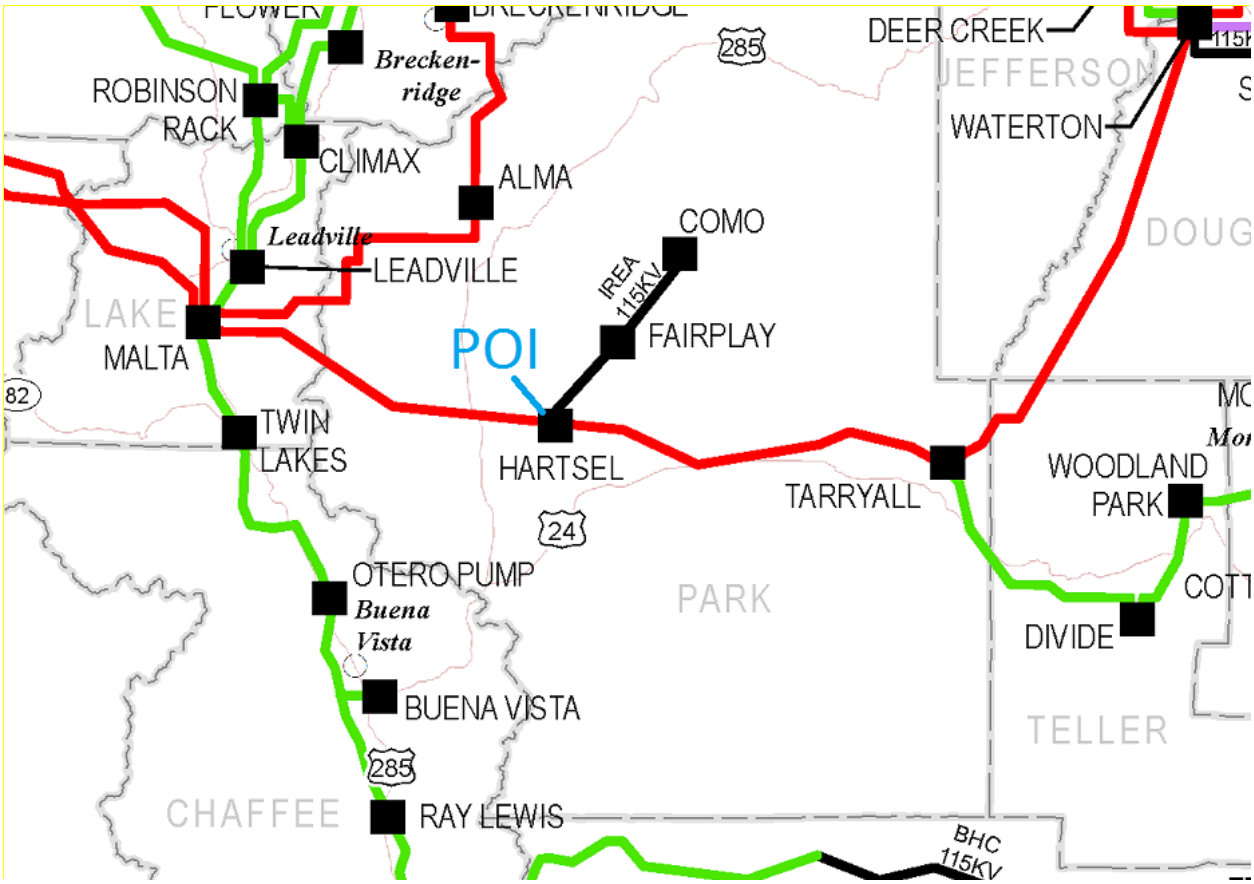


Figure 1 POI - Hartsel Station and Surrounding Transmission System (2017)

B. Introduction

Public Service Company of Colorado (PSCo) received an interconnection request (GI-2017-5) for a 54.3 MW solar photovoltaic (PV) generation facility in Park County, Colorado. The proposed Point of Interconnection (POI) is the PSCo-owned Hartsel 230 kV bus within the jointly-owned (with Intermountain Rural Electric Association (IREA)) Hartsel 230/115 kV transmission substation (see Figure 1).

The Commercial Operation Date (COD) requested by the Interconnection Customer is March 31, 2019 and accordingly the approximate target backfeed date is assumed to be six months prior to the COD or September 30, 2018.

The proposed solar photovoltaic generating facility would consist of 19 SunPower inverters each rated 2.86 MW. Each inverter would be connected to a pad-mounted step-up transformer which provides voltage transformation for interconnection of the inverter and its associated PV generation source to the medium voltage power collection system within the generating plant. One main step-up transformer would provide the final transformation to allow the generating facility to interconnect to the Hartsel 230 kV bus POI via an overhead 230 kV transmission line owned by the Interconnection Customer.

The GI-2017-5 interconnection request was studied as a stand-alone project. The study did not include any other Generator Interconnection Requests (GIR) existing in PSCo's or any affected party's GIR queue, other than the interconnection requests that are considered to be planned resources for which Power Purchase Agreements have been signed. This interconnection request was studied both as Network Resource Interconnection Service (NRIS) and Energy Resource Interconnection Service (ERIS).

For this interconnection request, the Affected Party is Intermountain Rural Electric Association (IREA).

C. Study Scope and Analysis

This interconnection request was studied both as Network Resource Interconnection Service (NRIS)[2] and Energy Resource Interconnection Service (ERIS)[3].

[2] Network 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] Energy Resource Interconnection Service shall mean an Interconnection Service that allows the Interconnection Customer to connect its Generating Facility to the Transmission Provider's Transmission System to be eligible to deliver the Generating Facility's electric output using the existing firm or non-firm capacity of the Transmission Provider's Transmission System on an as available basis. Energy Resource Interconnection Service in and of itself does not convey transmission service.

The combined Feasibility and System Impact Study scope consisted of performing power flow analysis to evaluate the steady-state thermal and/or voltage limit violations in the transmission system resulting from the proposed generator interconnection. The System Impact Study scope also consisted of short circuit analysis to determine any over-dutied circuit breakers due to the proposed generator interconnection. A transient stability analysis was also performed. These analyses help to identify potential Network Upgrades required to deliver the rated output of the proposed generation to load, for both NRIS and ERIS.

PSCo adheres to NERC & WECC System Performance Criteria, as well as internal system performance criteria for transmission system planning studies.

D. Power Flow Study Models

The power flow studies were performed using the Western Electricity Coordinating Council (WECC) approved 2020-21 heavy winter base case ("21hw1ap.sav") in PSS/E 33.6 format.

Important characteristics of the transmission system include the transmission system topology, the size and location of loads, and the generation location and dispatch. One measure of generation dispatch is the flow on certain WECC power transfer paths. The WECC power transfer path that most impacts the Hartsel Substation is the TOT 5 power transfer path. The TOT 5 path is a measure of the power transfers from Western Colorado to Eastern Colorado. The TOT 5 path consists of the following transmission lines:

Line/Transformer	Metered End
-North Park-Terry Ranch kV	Terry Ranch
-Craig-Ault 345 kV	Craig
-Hayden-Gore Pass 230kV	Hayden
-Hayden-Gore Pass 138kV	Gore Pass
-Hopkins-Malta 230kV	Hopkins
-Basalt-Malta 230kV	Basalt
-N. Gunnison-Poncha 115kV	Poncha
-Curecanti-PonchaBR 230kV	Curecanti

The case was re-dispatched to create a high west-to-east flow of 1680 MW on the TOT5 power transfer path. This became the benchmark case and represents the most stressful scenario for high branch flows and low bus voltages. A study case was created from the benchmark case by adding the GI-2017-5 interconnection facility that was dispatched to the full generation output level of 54.3 MW. The facility was modeled using PSS/E modeling data. PSCo's generation in Eastern Colorado was used as the sink for the 54.3 MW generation injection from GI-2017-5.

E. Power Flow Study Process

The study area was defined as Zones 704, 705, 709. Contingency power flow studies for N-1 contingencies were completed on the Benchmark Cases and the Study Cases using PTI's PSSE Ver.33.6 program for contingency analysis. Contingency power flow studies were completed on all power flow models using the PSS®E program, switching out single elements one at a time for all of the elements (lines and transformers) in the study area.

PSCo adheres to all applicable NERC Standards & WECC Criteria for Bulk Electric System (BES) acceptable performance, as well as its internal transmission planning criteria for all studies. During system intact conditions, PSCo's steady-state performance criteria require the transmission bus voltages remain within 0.95 – 1.05 per unit of nominal and the power flows remain below the applicable normal ratings of the transmission facilities. Following a single contingency, the steady state bus voltages must remain within 0.9 – 1.1 per unit of nominal, and the power flows must continue to stay below the applicable normal facility ratings. For N-1 post-contingency system conditions, the applicable normal ratings are the seasonal continuous rating of the transmission facility; however, PSCo allows the use of eight-hour facility ratings for transformers for which it is available. Further, PSCo does not rely on 30-minute emergency ratings of transmission facilities for meeting N-1 system performance in planning studies.

F. Power Flow Contingency Analysis Results

Thermal Analysis:

Table 1. Differential Impact of GI-2017-5 on Facility Loadings

Table 1: Differential Impact of GI-2017-5 on Facility Loadings Summary of Power Flows from Single Contingency Analysis 2020-21 Heavy Winter with a High TOT5 Flow (1680 MW west to east)									
				Facility Loading Without GI-2017-5		Facility Loading With GI-2017-5			
Monitored Facility (Line or Transformer)	Type	Owner	Branch Rating MVA (Norm/Emer)	Flow MVA	Flow % of Rating (Norm/Emer)	Flow MVA	Flow % of Rating (Norm/Emer)	% Change	NERC Single Contingency
Cabin Creek 230-115kV T1	Xfmr	PSCo	66/66	62.6	94.9%/94.9%	62.8	95.1%/95.1%	0.2	Ptarmigan-Dillon 230kV
Cabin Creek-Georgetwn 115	Line	PSCo	120/120	115.4	96.2%/96.2%	118.9	99.1%/99.1%	3.0	Cabin Creek-Dillon 230kV
Georgetwn-Henderson 115kV	Line	PSCo	120/120	120.1	100.1%/100.1%	123.5	102.9%/102.9%	2.8	Cabin Creek-Dillon 230kV
Henderson-Portal 115kV	Line	PSCo	120/120	131.9	109.9%/109.9%	133.5	112.8%/112.8%	2.6	Cabin Creek-Dillon 230kV
Cabin Creek-Dillon 230kV	Line	PSCo	478/478	467.5	97.8%/97.8%	485.2	103.6%/103.6%	5.9	Tarryall-Hartselt 230kV

One potential thermal violation was observed as a result of the GI-2017-5 generation addition. The Cabin Creek-Dillon 230kV line (Ckt #5007) contingency flow exceeded the 478 MVA rating of the line for an outage of the Tarryall-Hartselt 230kV line as a result of adding the generation facility at the Hartsel Substation. The line rating is limited by substation equipment at the Cabin Creek Substation. The winter normal rating of the line is 478 MVA and the winter emergency rating of the line is 478 MVA. The line has a 764 MVA thermal limit. The branch violation on the PSCo transmission line can be mitigated by re-dispatch and is unlikely to occur as the scenario involves the maximum TOT5 west-to-east flow of 1680 MW coupled with a single contingency.

Voltage Analysis:

Table 2. Differential Impact of GI-2017-5 on Bus Voltages

Table 2: Differential Impact of GI-2017-5 on Bus Voltages Summary of Worst Bus Voltages from Single Contingency Analysis 2020-21 Heavy Winter with a High TOT5 Flow (1680 MW west to east)				
Monitored Facility	**Bus Voltage Without GI-2017-5 (p.u.)**	**Bus Voltage With GI-2017-5 (p.u.)**	**% Change**	**NERC Single Contingency**
Blue River 230kV	0.923	0.920	-0.33	Alma-Breckenridge 230kV
Mill 115kV	0.920	0.921	+0.11	Blue River-Mill 115kV line
Portal 115kV	0.930	0.931	+0.11	Blue River-Mill 115kV

The lowest contingency bus voltages occurred at the Blue River 230kV, the Mill 115kV and the Portal 115kV busses. The bus voltages were acceptable after adding the GI-2017-5 generating facility.

G. Voltage Regulation and Reactive Power Capability

The following voltage regulation and reactive power capability requirements 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). Since the POI for this interconnection request is located within Region 1 – Northwest Colorado, the applicable ideal transmission system voltage profile range is 1.01–1.03 per unit at Regulating Buses.

- Xcel Energy's OATT (Attachment N effective 10/14/2016) requires all non-synchronous Generator Interconnections (GI) to provide dynamic reactive power within the power factor range of 0.95 leading to 0.95 lagging at the high voltage side (transmission bus) of the generating station.

- Generating Facilities interconnected to the PSCo transmission system must meet the POI voltage schedule specified by the Transmission Operator, as long as the Generating Facility is on-line and producing power. The Generating Facilities are expected to achieve this by providing dynamic reactive power (MVAR) proportionate to the actual power (MW) output within the 0.95 leading to 0.95 lagging power factor range.

- The Interconnection Customer has the responsibility to determine the type (switched shunt capacitors and/or switched shunt reactors, etc.), the size (MVAR), and the locations of any additional static reactive power equipment needed within the Generating Facility in order to provide the level of dynamic reactive power capability to meet the 0.95 leading to 0.95 lagging power factor standard. The Interconnection Customer may need to perform additional studies for this purpose.

- The Interconnection Customer has the responsibility to ensure that its Generating Facility is capable of meeting the voltage ride-through and frequency ride-through (VRT and FRT) performance specified in NERC Reliability Standard PRC-024-2.

- Prior to commercial operation, the Interconnection Customer must demonstrate to the satisfaction of PSCo Transmission Operator that the Generating Facility can safely and reliably operate within the required power factor and voltage ranges noted above.

H. Stability Analysis

A stability analysis was performed using the WECC 2020-21 heavy winter base case ("21hw2a.sav") in GE format, the associated WECC dynamic data in GE format, and the dynamic data for the proposed facility (that was provided by the Customer) in GE format. The dynamic performance of the system for normally cleared faults was shown to be satisfactory. The proposed generating facility responded as expected; however, 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-024-2. The plot files for the disturbance simulations are provided in Appendix B.

I. Short Circuit Analysis Results

The calculated short circuit levels and Thevenin system equivalent impedances for the POI at the Hartsel 230 kV bus are listed in Table 3 below. The short circuit study work included a preliminary breaker duty analysis. The preliminary breaker duty study did not identify any circuit breakers which would become "over-dutied"[4] due to the proposed generation additions and would require replacement as a result of adding this generation.

Table 3 – Short Circuit Levels at the Hartsel 230 kV POI

	Without Proposed Generation	With Proposed Generation
Three Phase Current	5914A	6147A
Single Line to Ground Current	5155A	6043A
Positive Sequence Impedance	2.576+j22.307 ohms	2.576+j22.307 ohms
Negative Sequence Impedance	2.585+j22.303 ohms	2.585+j22.303 ohms
Zero Sequence Impedance	4.730+j32.030 ohms	3.350+j26.332 ohms

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

J. Cost Estimates and Assumptions

PSCo Engineering developed scoping level cost estimates for Interconnection Facilities and Network/Infrastructure Upgrades required for the interconnection of the Interconnection Customer's proposed generation facility. The cost estimates are in 2017 dollars with escalation and contingencies applied. AFUDC is not included. These estimated costs include all applicable labor and overheads associated with the siting support, 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 Interconnection Facilities and Network/Infrastructure Upgrades is **$1,873,000.** The following tables (Table 4 through Table 6) list the system improvements required to accommodate the interconnection and the delivery of the Customer's 54.3 MW solar facility generation output. System improvements are subject to revision as a more detailed and refined design is produced.

Figure 2 in Appendix A is a preliminary one-line of the proposed interconnection. The Point of Interconnection (POI) will be a tap on the Hartsel Substation 230kV bus.

Table 4 – PSCo Owned; Customer Funded Transmission Provider Interconnection Facilities

Element	Description	Cost Estimate (Millions)
PSCo's Hartsel 230kV Transmission Sub Station	Interconnect Customer to the Hartsel Sub 230kV bus. The new equipment includes; • One (1) motor operated 230kV disconnect switch • Three (3) 230kV combination CT/PT metering units • One (1) 230kV CCVT • Power Quality Metering (230kV line from Customer) • Three (3) surge arresters • Two (2) relay panels • Associated bus, wiring and equipment • Associated foundations and structures • Associated transmission line communications, relaying and testing	**$0.568**
	Transmission line tap into the substation. Conductor, hardware, and installation labor.	**$0.053**
	Total Cost Estimate for PSCo-Owned, Customer-Funded Interconnection Facilities	**$0.621**
Time Frame	**Design, procure and construct**	**18 Months**

Table 5 – PSCo Owned; PSCo Funded Network Upgrades for Interconnection

Element	Description	Cost Estimate (Millions)
PSCo's Hartsel 230kV Transmission Sub Station	Interconnect Customer to the Hartsel Sub 230kV bus. The new equipment includes; • One (1) 230kV circuit breaker • Two (2) 230kV gang switches • Associated communications, supervisory and SCADA equipment • Associated line relaying and testing • Associated bus, miscellaneous electrical equipment, cabling and wiring • Associated foundations and structures • Associated road and site development, fencing and grounding	**$1.167**
	Siting and Land Rights support for permitting construction.	**$0.085**
	Total Cost Estimate for PSCo-Owned, PSCo-Funded Interconnection Facilities	**$1.252**
Time Frame	**Design, procure and construct**	**18 Months**

Table 6 – PSCo Owned; Network Upgrades for Delivery

Element	Description	Cost Estimate (Millions)
NA	None identified	**NA**
	Total Cost Estimate for PSCo Network Upgrades for Delivery	**$0**
Duration	**Design, procure, permit and construct**	**NA**
	Total Project Estimate	**$1.873**

Cost Estimate Assumptions

- Scoping level project cost estimates for Interconnection Facilities were developed by PSCo Engineering.
- Estimates are based on 2017 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 is included.
- Lead times for materials were considered for the schedule.
- 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).
- Line and substation bus outages will be necessary during the construction period. Outage availability could potentially be problematic and extend the requested backfeed date.
- This project is completely independent of other queued projects and their respective ISD's.
- A CPCN will not be required for the interconnection facilities construction.
- The Customer will string OPGW fiber into substation as part of the transmission line construction scope.
- 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.
- Power Quality Metering (PQM) will be required on the Customer's 230kV line terminating into Proposed Switching Station.
- The Customer's Generation Facility is not in PSCo's retail service territory. Therefore, no costs for retail load metering are included in these estimates.

K. Study Conclusion

Based on the study results, it is concluded that no Network Upgrades are required for the GI-2017-5 interconnection to qualify for Network Resource Interconnection Service (NRIS). No circuit-breakers were found to be over-dutied due to the proposed generation addition and would require replacement as a result of adding this generation. However, due to the 18 month time-frame estimated to design, procure and construct the Interconnection Facilities, the proposed COD of March 31, 2019 is not feasible.

Appendix A – Engineering Drawings

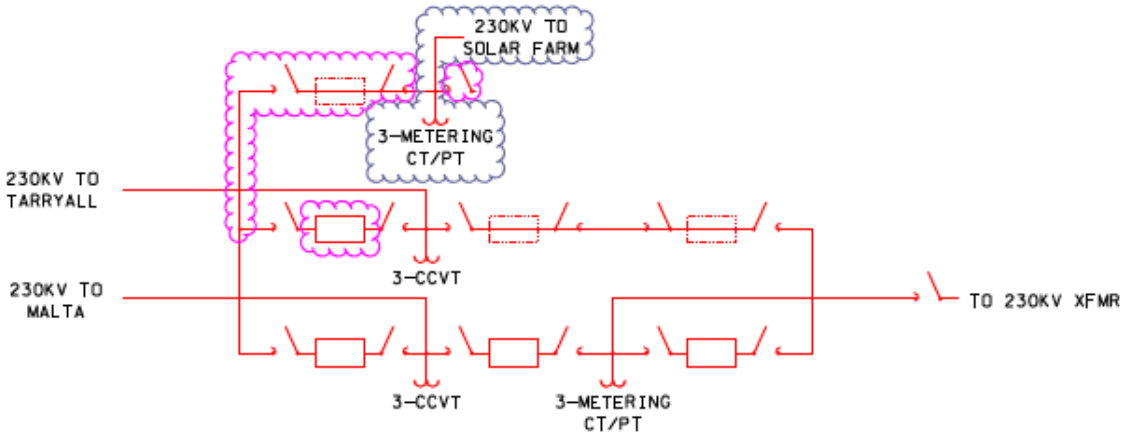
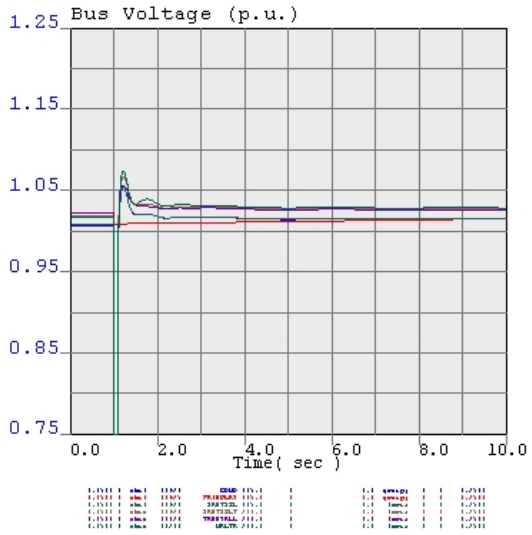
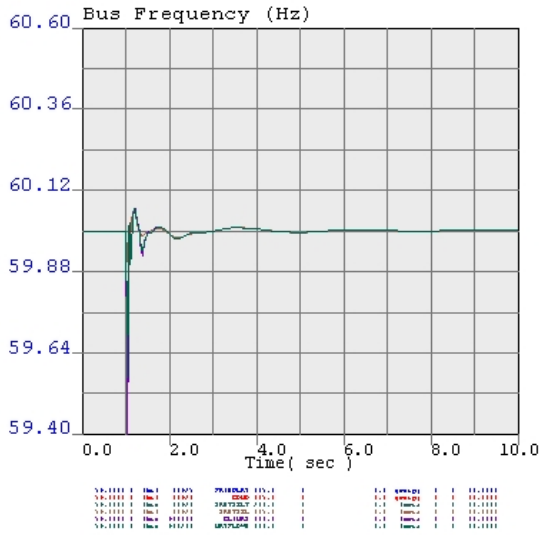


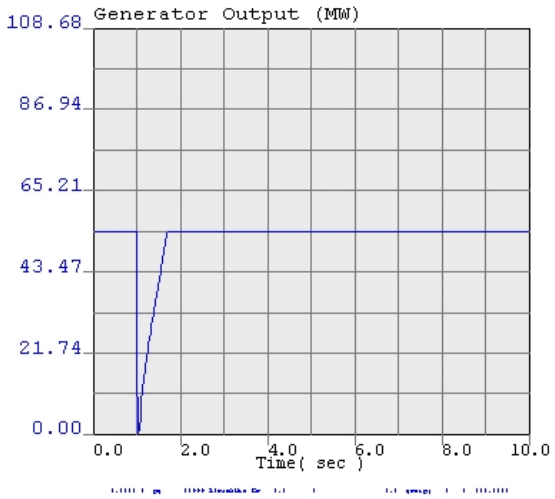
Figure 2: One-Line of Proposed GI-2017-5 Interconnection at the Hartsel 230 kV Station

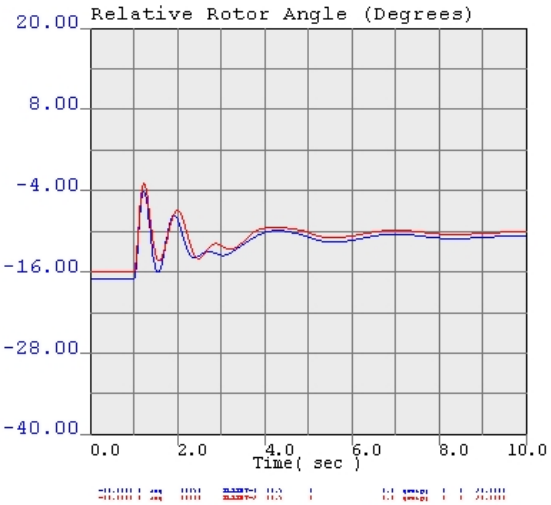
Appendix B – Transient Stability Plots

3ph fault at Hartsel end of Hartsel-Tarryall 230kV at 1 sec. After 5 cycles, trip line to clr fault.



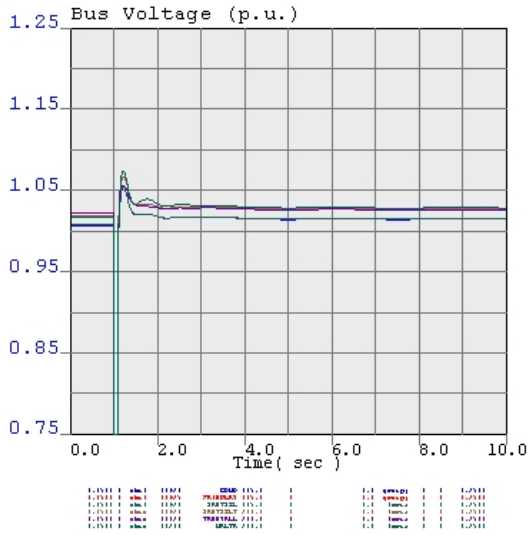


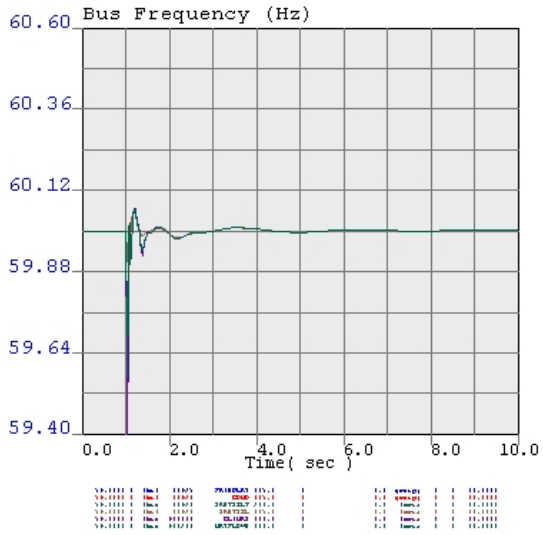


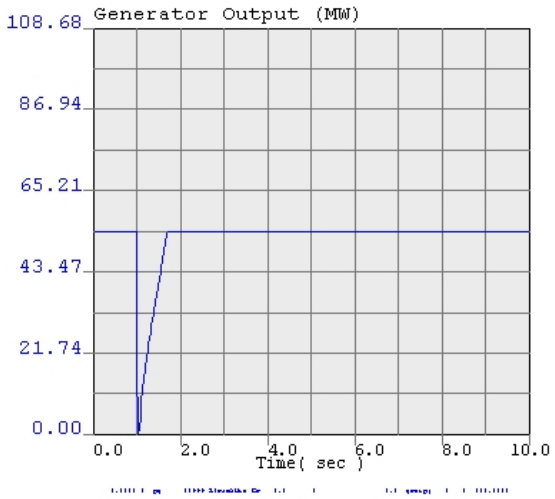


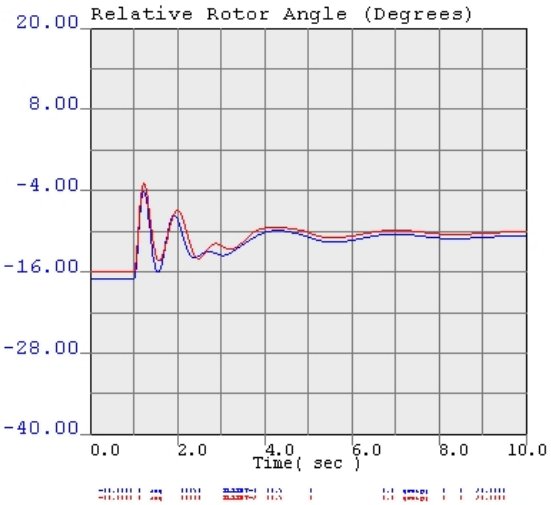
line_6
line MALTA to HOPKINS 230 ck 1
August 19, 2016

3ph fault at Hartselt end of Hartselt-Malta 230kV at 1 sec. After 5 cycles, trip line to clr fault.



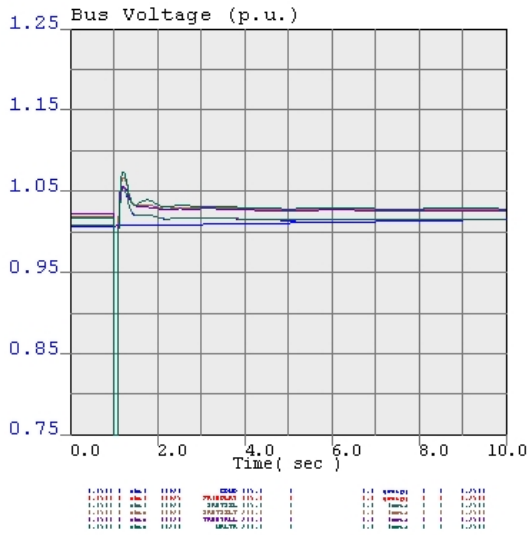


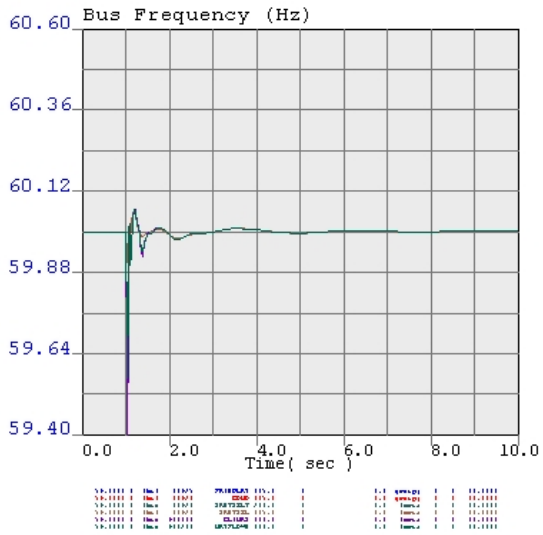


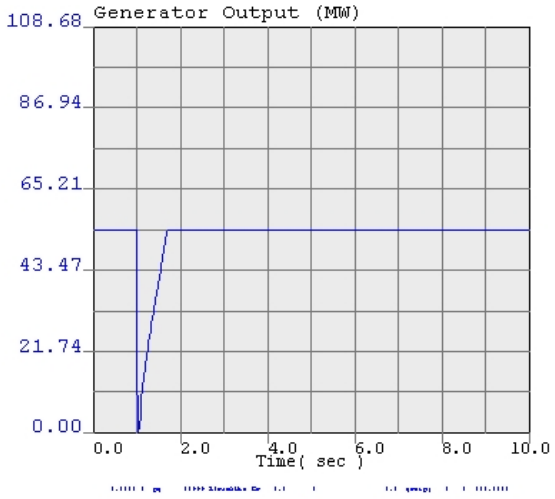


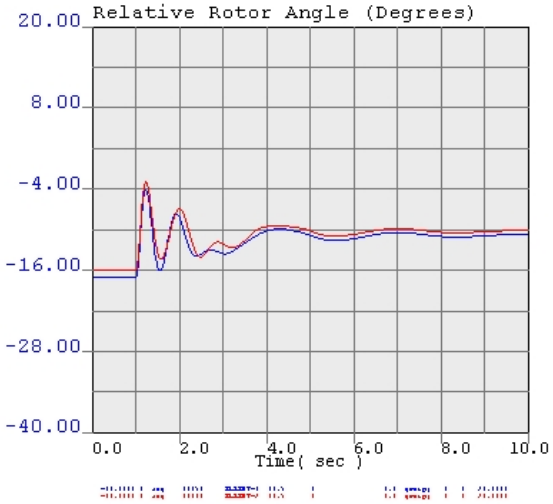
line_6
line MALTA to HOPKINS 230 ck 1
August 19, 2016

3ph fault at Tarryal end of Tarryal-Watertn 230kV at 1 sec. After 5 cycles, trip line to clr fault.



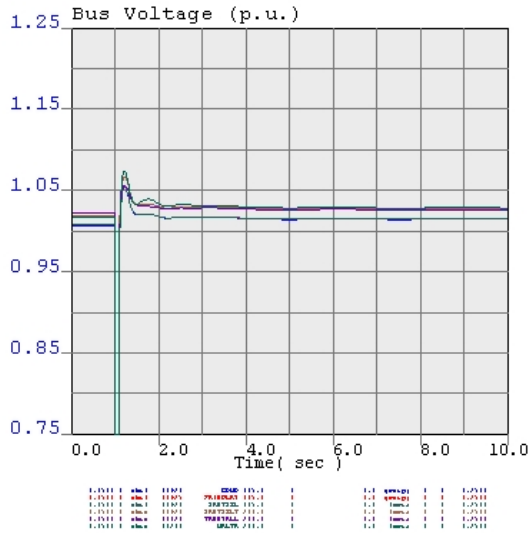


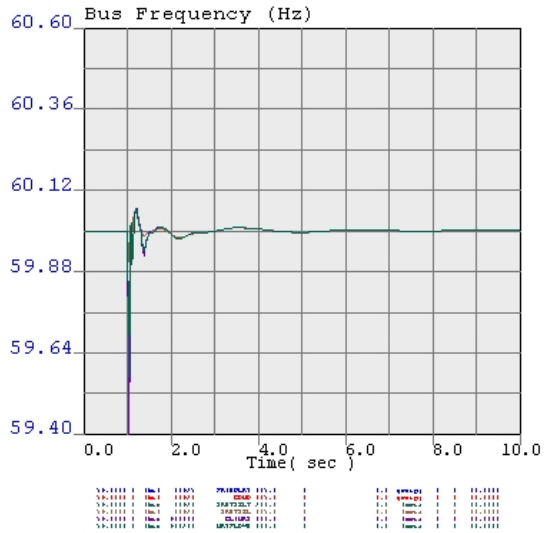


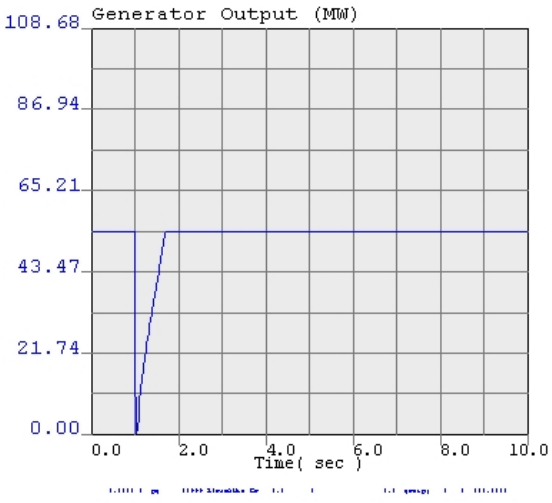


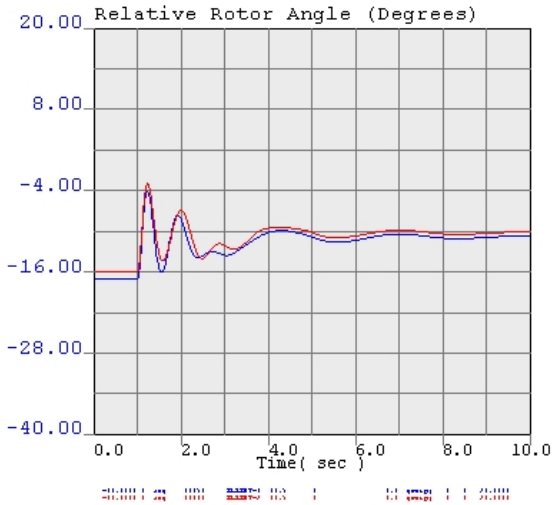
line_6
line MALTA to HOPKINS 230 ck 1
August 19, 2016

3ph fault at Malta end of Malta-Alma 230kV at 1 sec. After 5 cycles, trip line to clr fault.



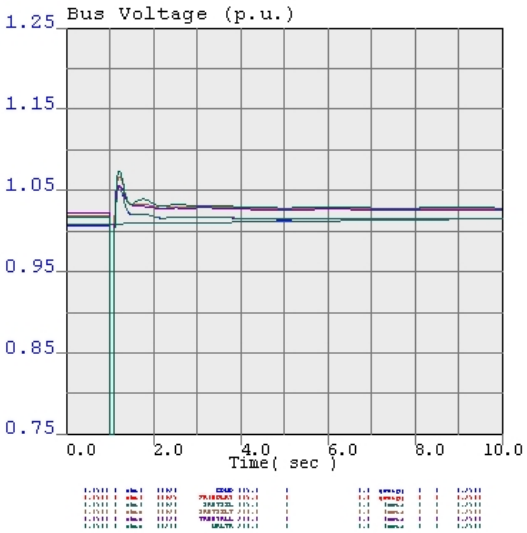


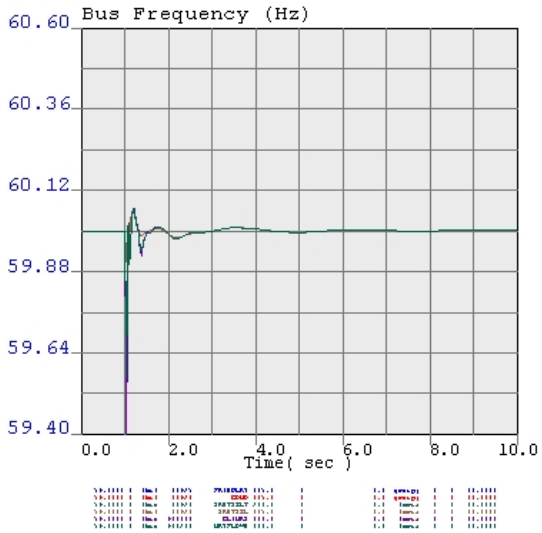


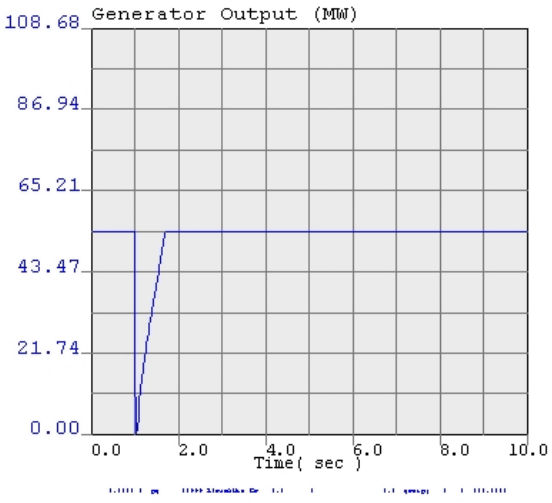


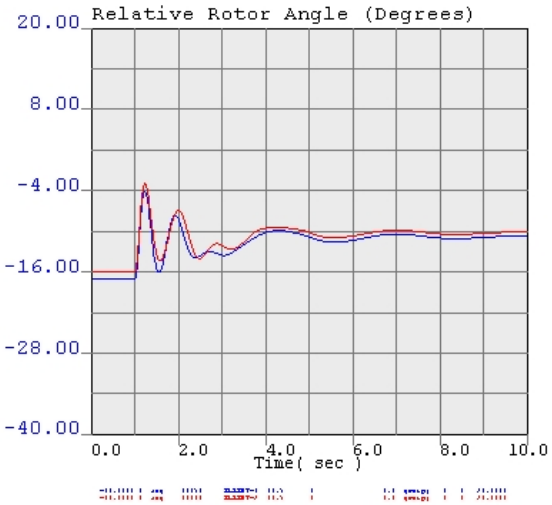
line_6
line MALTA to HOPKINS 230 ck 1
August 19, 2016

3ph fault at Malta end of Malta-Basalt 230kV at 1 sec. After 5 cycles, trip line to clr fault.









line_6
line MALTA to HOPKINS 230 ck 1
August 19, 2016

gi-run-line_6.chf

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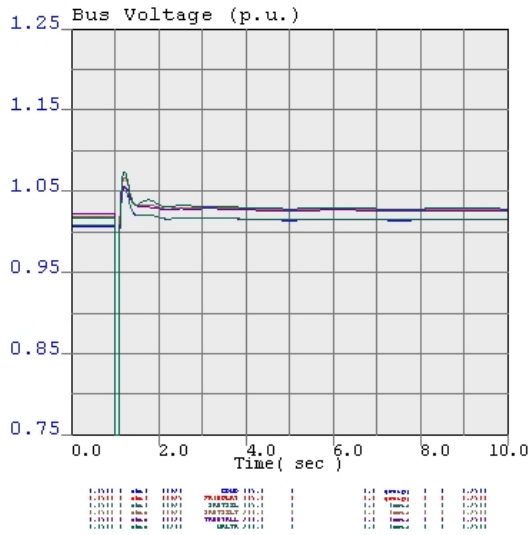
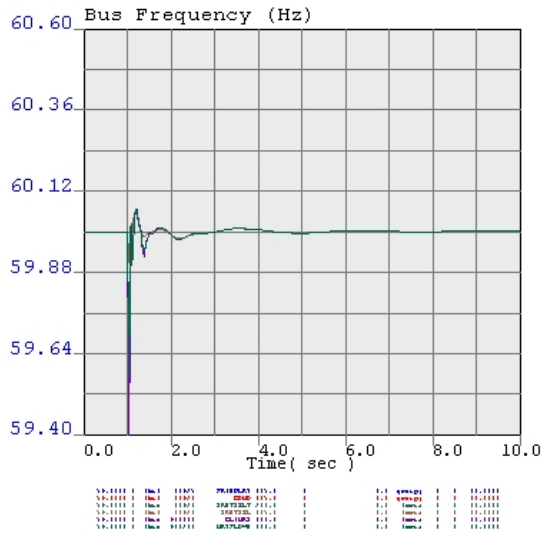
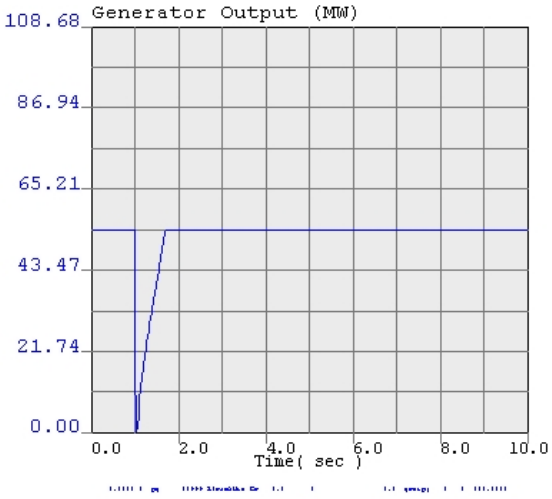
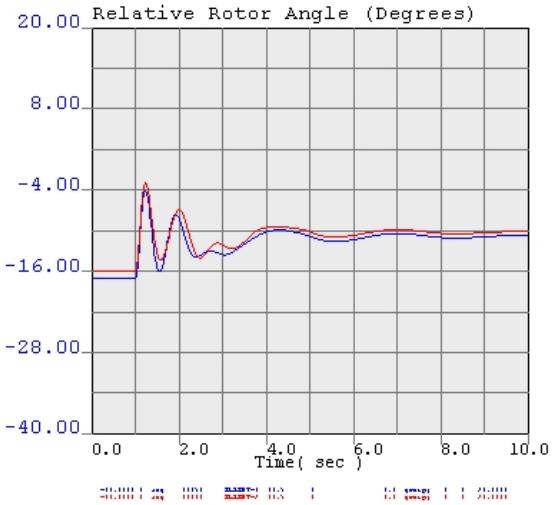
Thu Oct 19 23:35:55 2017

3ph fault at Malta end of Malta-Hopkins 230kV at 1 sec. After 5 cycles, trip line to clr fault.









line_6
line MALTA to HOPKINS 230 ck 1
August 19, 2016