Interconnection System Impact Study Report
Request # GI-2008-23

34 MW Solar Generation Ranch at Hartsel, Colorado

Public Service Company of Colorado
Transmission Planning
August 19, 2010

Executive Summary

Public Service Company of Colorado received an interconnection request (GI-2008-23) to install a 34 MW solar photovoltaic (PV) generation facility at Hartsel, Colorado. The proposed interconnection point is the Hartsel 230 kV substation. This substation is connected to lines terminating at the Malta 230 kV and Tarryall 230 kV substations (see Figures 1 & 2 below). The solar generating facilities would be connected via a customer owned radial 230 kV line. The requested in service date was originally June 1, 2010. It is now early 2011.

The Feasibility Study for this request was issued August 7, 2009. Based on the new in service date, load flow studies were again performed as part of the System Impact Study. However, the customer indicated in the interconnection request that the PV inverters are designed to follow system voltage and frequency and have no "inertial" operating characteristics. Therefore, dynamic studies were not performed as part of this System Impact Study.

This request was studied as an Energy Resource[1] at the full 34 MW requested generation level for both the 2011 and 2016 study years. These investigations included steady-state power flow and short circuit analyses. The request was studied as a stand-alone project only, with no evaluations made of other potential new generation requests that may exist in the Large Generator Interconnection Request (LGIR) queue, other than the generation projects that are already approved and planned to be in service by June 2011 and June 2016. The main purpose of this System Impact Study was to evaluate the potential impact on the PSCo transmission infrastructure as well as that of neighboring utilities when injecting the proposed 34 MW of generation at the interconnection point at the Hartsel Substation, and delivering the additional generation to native PSCo loads. The costs to interconnect the project with the transmission system were also evaluated by PSCo Engineering.

[1] **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

Energy Resource

The results of the load flow studies for the 2011 HS case show that the Malta 230/115 kV T1 transformer is slightly overloaded in the case with the proposed generation, versus the benchmark case. This is for the contingency outage of the Dillon 230/115 kV T2 transformer. However, the overload is less than the emergency rating of the Malta transformer. Therefore, this should not present a limit to the proposed generation.

The results of the load flow studies for the 2016 HS case indicate that no facilities will be overloaded due to the proposed generation when it is operating at the full requested 34 MW level. Also, there was no adverse impact on IREA's new Hartsel-Conifer 115 kV circuit.

Based on these results, the Energy Resource analysis indicates that the customer can deliver 34 MW on a firm basis with no overload concerns due to the proposed facility Non-firm transmission capability should also be available depending upon generation dispatch levels, demand levels, import path levels (TOT 3, etc.), and the operational status of transmission facilities.

Voltage at the Point of Interconnection

The load flow studies showed that setting the PV inverters to unity power resulted in unity power factor at the POI. To maintain an acceptable voltage profile at the POI, the PV inverters should be set to maintain unity power factor at the POI.

Cost Estimates

The cost for the transmission interconnection (in 2010 dollars):

Transmission Proposal
The total estimated cost of the recommended system improvements to interconnect the project is approximately **$918,000** and includes:

- $ 0.418 million for PSCo-Owned, Customer-Funded Interconnection Facilities
- $ 0.500 million for PSCo-Owned, PSCo-Funded Network Upgrades for Interconnection
- $ 0.000 million for PSCo-Owned, PSCo-Funded Network Upgrades for Delivery to PSCo Loads

The estimated time to complete this work following receipt of authorization to proceed is **18 months**. Therefore, this work cannot be completed by the requested in service date.

The Interconnection Agreement (IA) requires that certain conditions be met, as follows:

1 The conditions of the Large Generator Interconnection Guidelines (LGIG) are met.

2 PSCO will require testing of the full range of 0 MW to 34 MW operational capability of the facility to verify that the facility can operate safely and reliably within required power factor and voltage ranges.

3 A single point of contact needs to be provided to PSCo Operations to facilitate reliable management of the transmission system.

Figure 1 Network Diagram with Proposed POI at Hartsel

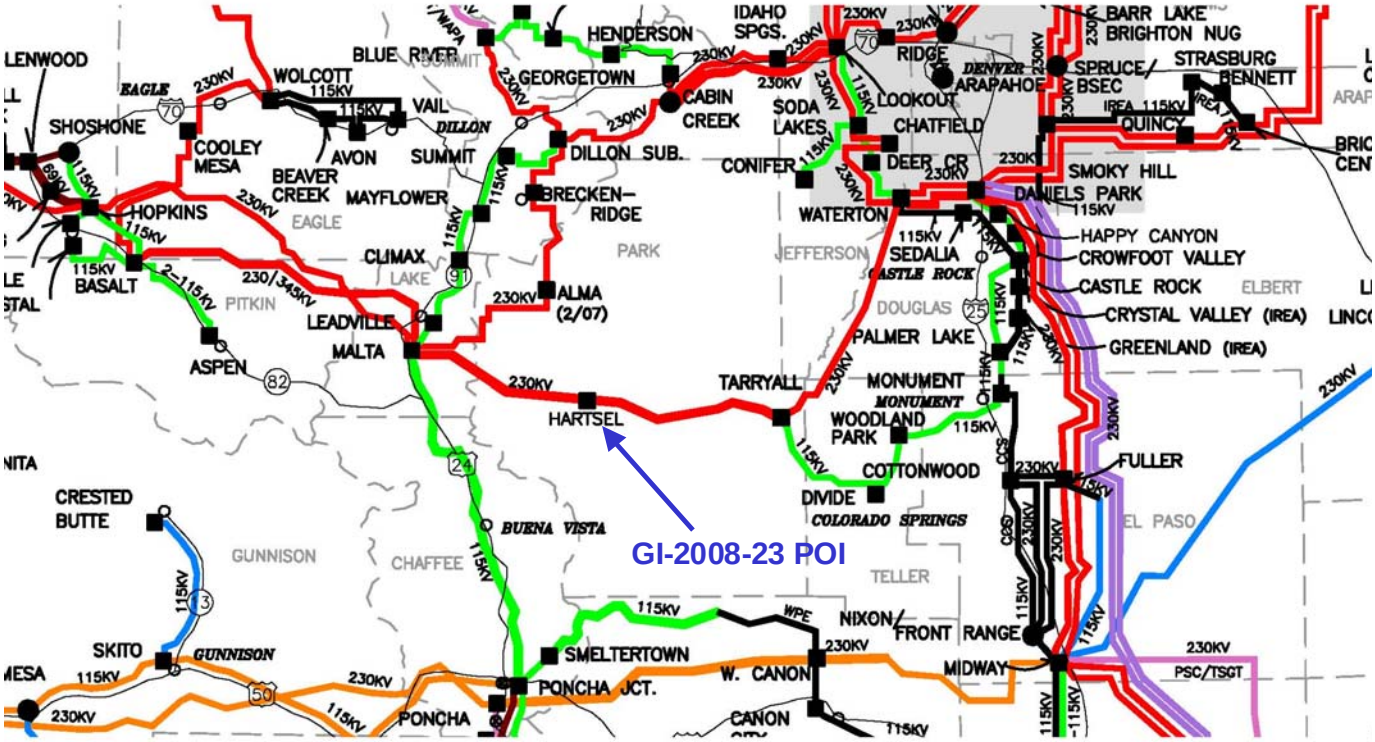
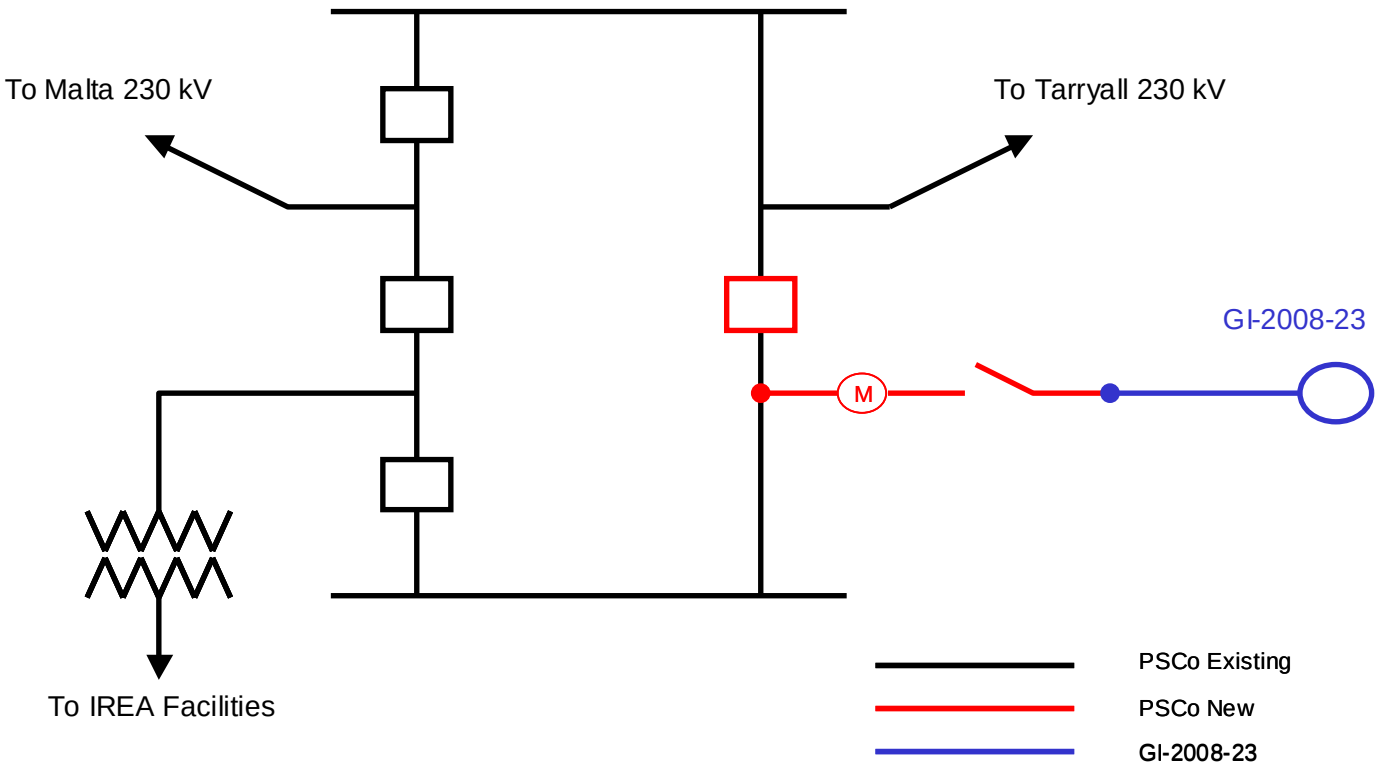


Figure 2 Proposed Interconnection Station One-Line Diagram



Introduction

Public Service Company of Colorado received an interconnection request (GI-2008-23) to install a 34 MW solar photovoltaic generation facility at Hartsel, Colorado. The project will be comprised of a 34 MW interconnected subtransmission grid of 1 MW photovoltaic modules. The proposed interconnection point is the Hartsel 230 kV substation. This substation is connected to lines terminating at the Malta 230 kV and Tarryall 230 kV substations (see Figures 1 & 2). The solar generating facilities would be connected via a customer owned radial 230 kV line. The in service date was originally June 1, 2010. However, the in service date was changed to early 2011.

The Feasibility Study for this request was issued August 7, 2009. Because of the new in service date, load flow studies were again performed as part of the System Impact Study. However, the customer indicated in the interconnection request that the PV inverters are designed to follow system voltage and frequency and have no "inertial" operating characteristics. Therefore, dynamic studies were not performed as part of this System Impact Study.

Load flow studies were performed for 2011 summer to examine system conditions corresponding to the in service date of the proposed generation. Load flow studies were also performed to examine the effect of the proposed generation on the system with the Intermountain Rural Electric Association's planned Hartsel-Conifer 115 kV line included. This line is planned to be in service in 2016.

This study examined the system reinforcements and associated costs required to facilitate the addition of the new generating plant to the transmission system as an Energy Resource. The reinforcements include the direct connection of the generation facility to the system and any network upgrades required to maintain the reliability of the transmission system.

Study Scope and Analysis

This System Impact Study evaluated the transmission impacts associated with the proposed generating station. It consisted of power flow and short circuit analyses only. The power flow analysis identified any thermal or voltage limit violations resulting from the interconnection and an identification of any network upgrades required to deliver the proposed generation to PSCo loads. The short circuit analysis identified short circuit levels and any circuit breakers that might exceed their fault interruption capability due to addition of the new generation.

PSCo adheres to NERC and WECC Reliability Criteria, as well as internal Company criteria for planning studies. During system intact conditions, criteria are to maintain transmission system bus voltages between 0.95 and 1.05 per unit of nominal, and steady-state power flows below the thermal ratings of all facilities. Per the Rocky

Mountain Area Voltage Coordination Guidelines[2], PSCo tries to maintain a transmission system voltage profile ranging from 1.01 – 1.03 per unit at regulating buses and 1.00 – 1.03 per unit at non-regulating buses. Following a single contingency, transmission system steady state bus voltages must remain within 0.90 per unit to 1.10 per unit, and power flows within 100% of the facilities' continuous thermal ratings.

For this project, potential affected parties include the Intermountain Rural Electric Association (IREA), Tri-State Generation & Transmission (TSG&T), and Western Area Power Administration (WAPA).

Power Flow Study Models

The power flow studies for 2011 summer were based on the WECC approved 10HS3SBP load flow base case. Load levels were adjusted to reflect 2011 heavy summer peak system conditions. The case was modified to include new facilities that are planned to be in service by the summer of 2011. The load at Hartsel was also updated based on the latest load forecast from IREA. Updates were received and included from Black Hills Energy, Colorado Springs Utilities, Platte River Power Authority, Tri-State Generation and Transmission, and Western Area Power Administration.

The power flow studies for 2016 summer were based on PSCo's 2015 heavy summer budget load flow base case, which was based on the WECC approved 2015HS2 base case. Load levels were adjusted to reflect 2016 heavy summer peak system conditions. The case was modified to include new facilities that are planned to be in service by the summer of 2016. These facilities included completion of the IREA Hartsel-Conifer 115 kV loop. The load served from the Hartsel-Conifer 115 kV circuit was updated based on the latest load forecast from IREA. Updates were received and included from Black Hills Energy, Colorado Springs Utilities, Platte River Power Authority, Tri-State Generation and Transmission, and Western Area Power Administration.

The Project's solar photovoltaic/inverter generation units were modeled as illustrated in the one-line diagram provided by the Customer. This included 39 PV inverters and generator step-up transformers arranged in four 34.5 kV collector system loops. Each PV inverter was dispatched to 872 kW. The reactive capability was set to unity power factor at each PV inverter unit. The 230 kV side of the main step-up transformer was connected to the point of interconnection at Hartsel via a 230 kV line whose impedance was provided by the Customer.

For each study year, two main power flow generation dispatch scenarios were evaluated. One was created as a benchmark case and the other was created with the

[2] The Voltage Coordination Guidelines Subcommittee of the Colorado Coordinated Planning Group developed these guidelines. The subcommittee consisted of representatives from major Colorado utilities including Colorado Springs Utilities, Platte River Power Authority, Tri-State Generation and Transmission, Public Service Company of Colorado, and Western Area Power Administration-Rocky Mountain Region. Other major utilities outside of Colorado were involved in the development of these guidelines.

new generation. To evaluate the capabilities of the existing transmission system and the potential reinforcements that would be required, the power flow models were modified to simulate a higher flow bias through the TOT 5 transfer path. The TOT 5 transfer level gives an indication of the level of flows from western Colorado to the east. In the 2011 HS case, TOT 5 was stressed by scaling western Colorado generation (Zones 790 & 791) to its maximum and offsetting that with PSCo generation in the eastern Denver metro area. The TOT 5 flows in the 2011 HS benchmark and proposed generation cases were 499 MW and 495 MW, respectively. In the 2016 HS case, the western Colorado generation was already dispatched to its maximum in the starting case. Therefore, there was no need to further stress the case. The TOT 5 flows in the 2016 HS benchmark and proposed generation cases were 436 MW and 434 MW, respectively.

PSCo control area (Area 70) wind generation facilities were dispatched to approximately 12% of facility ratings, consistent with other similar planning study models.

Power Flow Study Process

Automated contingency power flow studies were completed on the reference model and the model with the proposed generation using PTI-Siemens' PSSE program, ACCC Activity, switching out single branches one at a time for all of the transmission facilities (lines and transformers) in control areas 70 (PSCo) and 73 (WAPA RM). Results from the two cases were compared and new overloads or overloads that increased by greater than 5% in the new generator case were noted.

Power Flow Results

The results of the load flow studies for the 2011 HS case showed one new overload. The Malta 230/115 kV T1 transformer was overloaded at 100.1% of its 100 MVA normal rating in the case with the proposed generation, versus 98.8% in the benchmark case. This is for the contingency outage of the Dillon 230/115 kV T2 transformer. However, the emergency rating of the Malta transformer is 115 MVA. Therefore, transmission operations personnel should be able to implement changes on the system to reduce loading on the Malta transformer to below its normal rating. Therefore, this should not present a limit to the proposed generation.

The results of the load flow studies for the 2016 HS case indicate that no facilities will be overloaded due to the proposed generation when it is operating at the full requested 34 MW level. Also, there was no adverse impact on IREA's new Hartsel-Conifer 115 kV circuit.

Based on these results, there are no network upgrades required for delivery of the proposed generation to PSCo load centers. Therefore, 34 MW of Energy Resource capability is available on a firm basis. Non-firm transmission capability should also be

available depending upon generation dispatch levels, demand levels, import path levels (TOT 5, etc.), and the operational status of transmission facilities.

Voltage at the Point of Interconnection

To ensure reliable operation, the voltage should be maintained within the limits specified in the Rocky Mountain Area Voltage Coordination Guidelines for the Northwest Colorado Region 1; per the guidelines, PSCo tries to maintain an ideal transmission system voltage profile ranging from 1.01 – 1.03 per unit at regulating buses and 1.00 – 1.03 per unit at non-regulating buses. In the 2011 HS load flow case, the voltage at the POI was 1.010 pu and the power factor was unity. In the 2016 HS case, the voltage at the POI was 1.023 pu and the power factor was also unity. In both cases all of the PV inverters were set to unity power factor. However, the customer stated that the power factor of the PV inverters was adjustable. Therefore, to maintain an acceptable voltage profile at the POI and avoid adverse system impacts, the PV inverters should be set to maintain unity power factor at the interconnection point.

Short Circuit Study Results

The Customer indicates that the short circuit current from the proposed solar ranch will be less than 125% of full load current. Therefore, since the three phase fault current is presently less than 15% of the breaker fault duty, no new circuit breakers are expected to exceed their capabilities following installation of the new generation. The calculated short circuit parameters for the point of interconnection at Hartsel are shown in Table 1 below.

Table 1 Short Circuit Parameters at the POI

System Condition	Three-Phase Fault Level (Amps)	Single-Line-to-Ground Fault Level (Amps)	Thevenin System Equivalent Impedance (R +j X) (ohms)
All Facilities in Service	5655.38	5033.86	Z1(pos)= 2.67457 +j 23.3276 Z2(neg)= 2.68520 +j 23.3243 Z0(zero)= 5.06577 +j 31.7967

Costs Estimates and Assumptions

GI-2008-23 (System Impact Study Report)

The estimated total cost for the required upgrades is **$918,000.**

Table 2 PSCo Owned; Customer Funded Interconnection Facilities

Element	Description	Cost Est. (Millions)
Hartsel 230 kV Substation	Interconnect customer to the 230 kV ring bus at Hartsel Substation • 230 kV bidirectional metering • Three 230 kV combination CT/PT instrument transformers • One 230 kV, 3000 A, Gang Operated Switch • Associated foundations and structures • Associated line relaying and testing • Deadend structure to terminate customer's line	**$0.395**
	Customer Load Frequency and Generator Witness Testing. (Customer generation telemetry equipment, and witnessing the Customer generator commissioning testing).	**$0.013**
	Customer Generator Communication to Lookout.	**$0.010**
	Total Cost Estimate for PSCo-Owned, Customer-Funded Interconnection Facilities	**$0.418**

Table 3 PSCo Owned; PSCo Funded Interconnection Facilities

Element	Description	Cost Estimate (Millions)
Hartsel 230 kV Substation	Additional breaker position in the 230 kV ring bus at Hartsel Substation • One 230 kV, 40 kA, Circuit Breaker • Two 230 kV, 3000 A, Gang Operated Switches • Associated Structures and Foundations	**$0.500**
	Total Cost Estimate for PSCo-Owned, PSCo-Funded Interconnection Facilities	**$0.500**

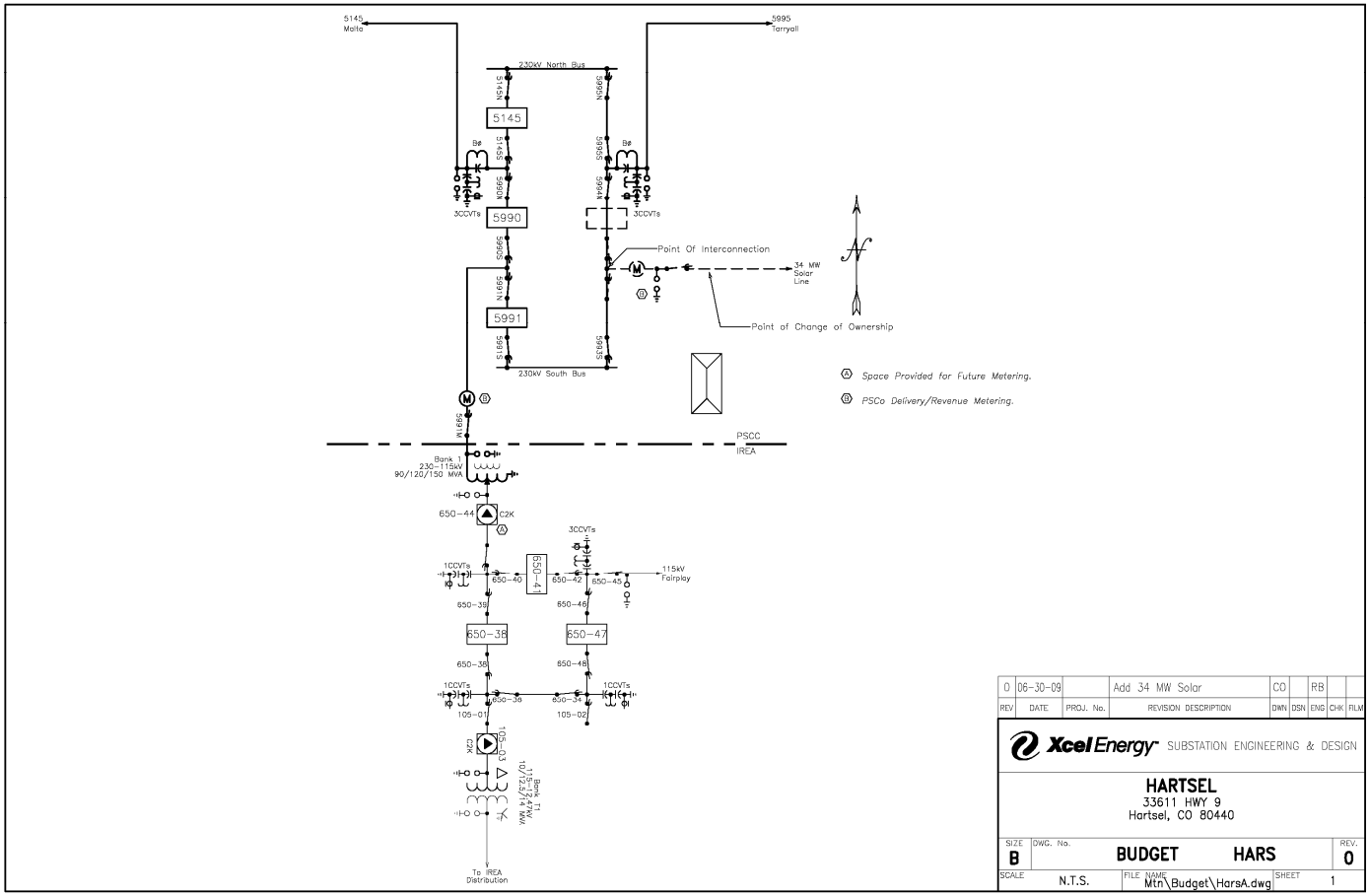
Assumptions for Alternatives

- The cost estimates provided are "scoping estimates" with an accuracy of +/- 30%.
- Estimates are based on 2010 dollars (no escalation applied).
- There is no contingency or AFUDC included in the estimates.

- Labor is estimated for straight time only – no overtime included.
- Lead times for materials were considered for the schedule.
- PSCo (or it's Contractor) crews will perform all construction and wiring associated with PSCo owned and maintained facilities.
- The estimated time for PSCo to site, engineer, procure and construction the scope of work identified in Tables 3 is **18 months** after authorization to proceed has be obtained. This is completely independent of other queued projects and their respective in-service dates.

Appendix

A. Proposed Interconnection Station One-line



B. Project Schedule