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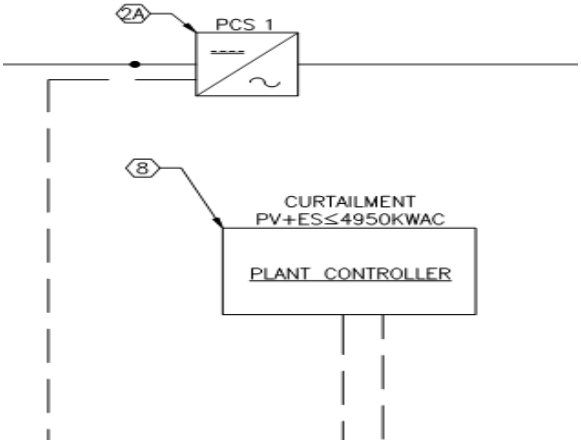
Single-Meter Solar + Storage Export Limit Scheme - Operational Narrative

Controls Layer

The first layer of protection under this scheme is an active curtailment function deployed by a plant-level controller. The plant controller will continuously monitor both the PV system kW output and the ES system kW out. If the cumulative kW output of both systems approaches the designated export limit (within a specified bandwidth), the plant controller will curtail the energy storage system. This operation will be performed autonomously and continuously throughout the discharge cycle of the ESS.

For example:

PV AC nameplate: 4950kW
ES AC nameplate: 3300kW
Export limit: 4950kW
If at t=1, the PV kW output is 4000kW, the ESS output will be limited to 950kW (minus a specified buffer).
If at t=2, the PV kW output is 4500kW, the ESS output will be limited to 450kW (minus a specified buffer).
If at t=3, the PV kW output is 1000kW, the ESS output will be limited to 3950kW (i.e. the ES will not be limited).



PLANT CONTROLLER SETTINGS			
FUNCTION	SETPOINT	TIME DELAY	DESCRIPTION
KW CURTAILMENT	4950KW	4 SEC	CURTAIL KW OUTPUT OF PCS-1 IF AGGREGATE POWER OF PV & ESS APPROACH 4950KW

Utility-Grade Relay and Revenue Grade Meter- Layer

In addition to the plant-level controls, the energy storage system will include a second layer of export limitation, enforced by a trip function within a SEL-651R installed with the G&W Viper recloser. The recloser will be tripped if the plant controller fails to effectively curtail the energy storage system, such that the designated export limit is enforced. The SEL-735 (labelled 'A' in the drawings below) will take current and voltage readings from current transformers and voltage transformers on the customer primary metering pole. The measurement points for both the current and voltage readings are upstream of the combined output of the ESS and PV system, therefore, the SEL-735 will register the combined kW output of both systems. Refer to the meter/control section for the excellent accuracies of the device and instrument transformers.

If the measured kW output exceeds the designated export limit, a digital signal will be sent to the SEL-651R via optic cable. Given a pre-defined time delay– the recloser (common to both PV and Storage) will be

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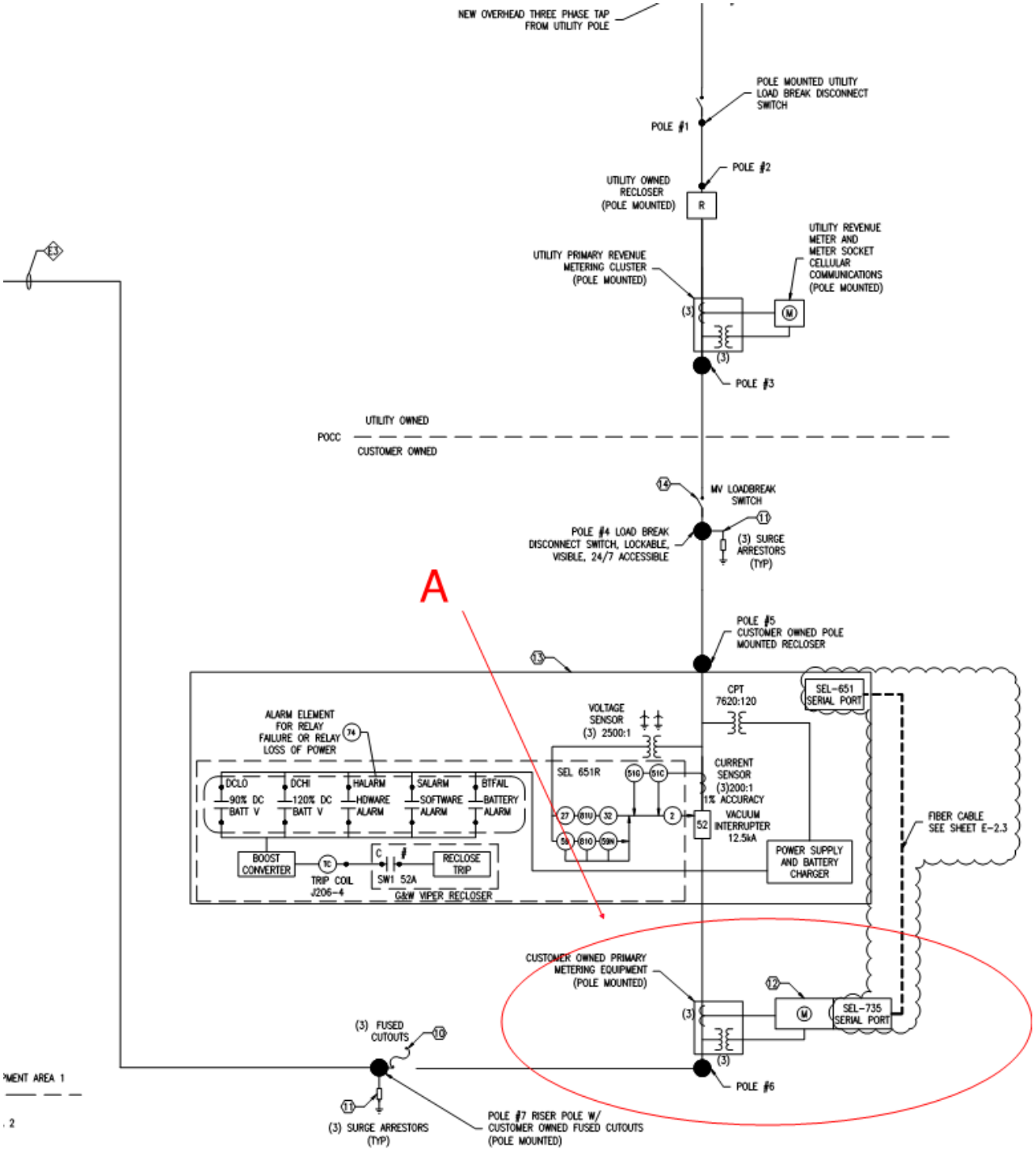
tripped, disconnecting both the ES and PV systems. The digital signal will be transmitted within 4ms by mirrored bits protocol.



Metering/Control Accuracies:

Please see following pages for SEL-735 metering and control accuracies per datasheet 20180208.

Per the datasheet, accuracy for power elements, the voltage, current, and power accuracy is +/-0.06% at unity power factor. If a system is curtailed for export at a limit of 4950kW, the accuracy in power export curtailment is

Please see the following pages for the accuracy of the meter CT and PT below.

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Per the CT datasheet (custom made for Borrego), the accuracy for current measurement is 0.15%.

Per the PT datasheet (shown below), the accuracy for voltage measurement is 0.3%.

In the below calculation, we showing the total possible inaccuracy (the worst case) of the SEL-735 in series with the instrument transformers:

Given:
Max Export= 4,950,000 W
Expected Voltage (@ Max Export)= 13,800 v
Expected Current (@ Max Export)= 358.7 A
PT Ratio= 63.5:1
CT Ratio= 400:5 = 80:1

$$\frac{\text{Primary Set Point (Watts)}}{\text{PT Ratio}*\text{CT Ratio}} = \text{Secondary Set Point (Watts)}$$

$$\frac{4{,}950{,}000\ \text{W}}{63.5*80} = 974.41\ \text{W}$$

If we perform the calculation with 'worst case' CT and PT inaccuracies, read by SEL-735 (inaccuracy of 0.06%):

Expected Secondary Voltage
$\frac{13{,}800\text{v}}{63.5} = 217.32\text{v}$

Secondary Voltage with 0.3% error
217.32v * 1.003 = 217.97v

Worst Case Secondary Voltage (read by SEL-735)
217.97 v * 1.0006 = 218.1v

Expected Secondary Current
$\frac{358.7\ \text{A}}{80} = 4.484\ \text{A}$

Secondary Current with 0.15% error
4.484 *1.0015 = 4.49 A

Worst Case Secondary Current (read by SEL-735):
4.49 * 1.0015 = 4.493 A

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Actual Power (in worst scenario):
4.493 A * 218.1 v = 979.85 w

Power Calculation by SEL-735 (in the worst case scenario):
974.41 W

As shown in the line above, the system could possibly be exporting 979.85W (secondary) while the meter is still only reading 974.41W. This 979.85 W, on the primary side would be:

979.85 * 63.5 * 80 = 4,977,671.3 W

$$\frac{(4{,}977{,}671.3\ \text{W} - 4{,}950{,}000\ \text{W})}{4{,}950{,}000\ \text{W}} * 100 =$$ 0.56% Inaccuracy

To be safe the set point in our SEL-735 should reflect this possible error and will be set at:

4,922,483.32 W

Therefore, a worst case 0.56% inaccuracy would produce a 4,950,000 W export.

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Dimensions

Refer to *Dimensions and Mounting on page 16* for meter dimensions.

Routine Dielectric Test

Current Inputs:	2.75 kVac for 1 s
Voltage Inputs:	2.2 kVac for 1 s
Inputs and Outputs:	2.2 kVac for 1 s
Power Supply:	3.11 kVdc for 1 s
EIA-485 Port:	1.5 kVdc for 1 s
IEC 60255-5:2000 Dielectric tests performed on all units with the CE mark:	2200 Vdc for 1 s on EIA-485 communications port 2000 Vac for 1 s on contact inputs, contact outputs, and analog inputs

Terminal Connections

Rear Screw-Terminal Tightening Torque

Current Input Terminal Block (ring terminals are recommended)

Minimum:	0.9 Nm (8 in-lb)
Maximum:	1.4 Nm (12 in-lb)

Connectorized®

Minimum:	0.5 Nm (4.4 in-lb)
Maximum:	1.0 Nm (8.8 in-lb)

Compression Plug Mounting Ear

Minimum:	0.18 Nm (1.6 in-lb)
Maximum:	0.25 Nm (2.2 in-lb)

Connectorized terminals accept wire size 12–24 AWG.

User terminals or stranded copper wire should be at a minimum temperature rating of 105°C (221°F).

Synchrophasor Measurements

Compliance	P Class Synchrophasor data compliant with IEEE C37.118.1-2011 as amended by IEEE C37.118.1a-2014.
Data Transfer:	IEEE C37.118.2-2011 (Backward compatible with IEEE C37.118-2005)
Message Rates:	60 Hz: 1,2,4,5,10,12,15,20,30,60 messages per second 50 Hz: 1,2,5,10,25,50 messages per second

Nominal Voltage:

120V when VBASE < 180

240V when 180 < VBASE < 250

250V when VBASE ≥ 250

Voltage Range:

80%–120% of Nominal Voltage

Nominal Current:

5A with CL2/10/20 current card

10A with CL10/20 current card

Current Range:

10% to 200% of Nominal current with CL2/10/20 current card

25% to 200% of Nominal current with CL10/20 current card

Processing Specifications

AC Voltage and Current Inputs

512 samples per power system cycle.

Control Processing

1/2-cycle processing interval

SELOGIC Pickup and Accuracies

SELOGIC Timers:	±1/2 cycle
Analog Values:	±3%

Metering/Monitoring

Voltage, Current, and Power Accuracy

Unity Power Factor:	±0.06%
0.5 Power Factor:	±0.16%

Energy Accuracy (Form 5 and Form 9 only)

Unity Power Factor:	±0.06% guaranteed ±0.02% typical
0.5 Power Factor:	±0.16% guaranteed ±0.06% typical

ANSI C12.20-2015 Accuracy Class 0.1

IEC 62053-22:2003 Accuracy Class 0.2, three times as accurate

IEC 62053-23:2003 Accuracy Class 2, nine times as accurate

Frequency Accuracy

FREQ_PQ:	±0.001 Hz
FREQ:	±0.05 Hz

The SEL-735 meets IEC 61000-4-30 frequency accuracy requirements from 42.5 Hz–68 Hz.

Power Quality

IEC 61000-4-30:2015 Class A

Flicker

PST:	±5% over the range 0.5–25 P_{ST} (10-min interval)
PLT:	±5% over the range 0.5–25 P_{LT} (2-hour interval)

Type Tests

Electromagnetic Compatibility Immunity

Surge Withstand Capability:	IEC 60255-22-1:2007, Severity Level: 2.5 kV common mode, 1.0 kV differential mode 1.0 kV peak common mode on communications ports IEEE C37.90.1-2002 Severity Level: 2.5 kV oscillatory, 4 kV fast transient
Electrostatic Discharge Immunity:	IEC 60255-22-2:2008 Severity Level: 4 (both polarities at Levels 1, 2, 3, and 4) IEC 61000-4-2:2008 Severity Level: 4
Radiated Electromagnetic Field Immunity:	IEC 60255-22-3:2007 IEC 61000-4-3:2010, Severity Level: 10 V/m ANSI C12.20-1998, Severity Level: 15 V/m

SEL-735 Data Sheet: This is the overall accuracy of the meter's voltage, current, and power measurements

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Voltage Transformer Type: VEF 15-09

Primary Voltage (V)	Winding Ratio	Catalog Number	IEEE Accuracy Class, 60HZ	Thermal Rating (VA)
2400/4160 GY*	20:1	121531009 395000	0.3WXY	1000
4200/7280 GY*	35:1	121531009 395001	0.3WXY	1000
4800/8320 GY*	40:1	121531009 395002	0.3WXY	1000
7200/12470 GY	60:1	121531009 395003	0.3WXY	1000
7620/13200 GY	63.5:1	121531009 395004	0.3WXY	1000
7970/13800 GY	66.42:1	121531009 395005	0.3WXY	1000
8400/14400 GY	70:1	121531009 395006	0.3WXY	1000

PT datasheet: This (0.3%) is the overall accuracy of the voltage measurements

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Undervoltage (27) and Overvoltage (59)

Pickup Ranges (V Secondary)

300 V Maximum Inputs

Phase:	1.00–300.00 V, 0.01 V steps
Phase-to-Phase:	1.76–520.00 V, 0.02 V steps
Sequence:	2.00–300.00 V, 0.02 V steps

8 V LEA Maximum Inputs

Phase:	0.03–8.00 V[a]
Phase-to-Phase:	0.05–13.87 V[a]
Sequence:	0.05–8.00 V[a]

Eaton NOVA LEA Inputs (37 Vac Maximum)

Phase:	0.12–37.09 V[a]
Phase-to-Phase:	0.21–64.24 V[a]
Sequence:	0.25–37.09 V[a]

Lindsey SVMI LEA Inputs (200 Vac Maximum)

Phase:	1.00–200.00 V
Phase-to-Phase:	1.76–346.00 V
Sequence:	2.00–200.00 V

Siemens LEA Inputs (8.49 Vac Maximum)

Phase:	0.03–8.49 V[a]
Phase-to-Phase:	0.05–14.72 V[a]
Sequence:	0.05–8.00 V[a]

Steady-State Pickup Accuracy

300 V Maximum

Phase:	±0.5 V plus ±1% of setting
Phase-to-Phase:	±1 V plus ±2% of setting
Sequence:	±1.5 Vac plus ±3% of setting @ 12.5–300 Vac

8 V LEA Maximum[a]

Phase:	±10 mV plus ±1% of setting
Phase-to-Phase:	±20 mV plus ±2% of setting
Sequence:	±30 mVac plus ±3% of setting @ 0.33–8.00 Vac

Eaton NOVA LEA[a]

Phase:	±60 mV plus ±1% of setting
Phase-to-Phase:	±120 mV plus ±2% of setting
Sequence:	±180 mVac plus ±3% of setting @ 1.55–37.09 Vac

Lindsey SVMI LEA[a]

Phase:	±0.5 V plus ±1% of setting
Phase-to-Phase:	±1 V plus ±2% of setting
Sequence:	±1.5 Vac plus ±3% of setting @ 12.5–200 Vac

Siemens LEA[a]

Phase:	±10 mV plus ±1% of setting
Phase-to-Phase:	±20 mV plus ±2% of setting
Sequence:	±30 mVac plus ±3% of setting @ 0.33–8.49 Vac

Transient Overreach:	±5%
Pickup/Dropout Time:	<1.25 cycles

Synchronism-Check Elements (25)

Slip Frequency Pickup Range:	0.005–0.500 Hz, 0.001 Hz steps
Slip Frequency Pickup Accuracy:	±0.003 Hz
Phase Angle Range:	0–80°, 0.01° steps
Phase Angle Accuracy:	±4°

Under- and Overfrequency Elements (81)

Frequency Range:	40.00–65.00 Hz, 0.01 Hz steps
Frequency Accuracy:	±0.01 Hz
Time Delay Range:	2.00–16,000.00 cycles, 0.25-cycle steps
Time Delay Accuracy:	±0.25 cycle plus ±0.1%
Undervoltage Frequency Element Block Range	
300 V Inputs:	12.50–300.00 V[a]

Rate-of-Change-of-Frequency Element

Pickup Range:	0.10–15.00 Hz/s, 0.01 Hz/s steps
Dropout:	95% of pickup
Pickup Accuracy:	±100 mHz/s and ±3.33% of pickup
Pickup/Dropout Time:	See *Equation 4.5* in the *SEL-651R-2 Instruction Manual*
Pickup Time Delay:	0.10–60.00 seconds, 0.01-second steps
Dropout Time Delay:	0.00–60.00 seconds, 0.01-second steps
Timer Accuracy:	±6 ms and ±0.1% of setting

Power Elements[b]

Minimum Current:	0.01 A
Minimum Voltage:	40 V
Steady-State Pickup Accuracy:	0.58 W plus ±5% of setting at unity power factor
Pickup/Dropout Time:	<3.75 cycles
Time Delay Accuracy:	±0.25 cycle plus ±0.1% of setting

Load Encroachment[b]

Minimum Current:	0.1 A
Minimum Voltage:	12.5 Vac
Forward Load Impedance:	0.5–640.0 ohms secondary
Forward Positive Load Angle:	–90° to +90°
Forward Negative Load Angle:	–90° to +90°
Negative Load Impedance:	0.50–640 ohms secondary
Negative Positive Load Angle:	+90° to +270°
Negative Negative Load Angle:	+90° to +270°
Pickup Accuracy	
Impedance:	±3%
Angle:	±2°

SELogic Control Equation Variable Timers

Pickup Ranges	
0.00–999,999.00 cycles:	0.25-cycle steps (programmable timers)
Pickup/Dropout Accuracy:	±0.25 cycle plus ±0.1% of setting

SEL-651R datasheet: This is the overall accuracy on the power export limit (32) function in the SEL-651R-2

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Relay Failsafe Protection requirements

Currently National Grid requires DC power supply and relay failure protection in the 651 relays, which has been programmed logically in the relay. Borrego's single line shows the Equivalent 74 element schematic which has been accepted by NGRID in the past. Please see the schematic below.