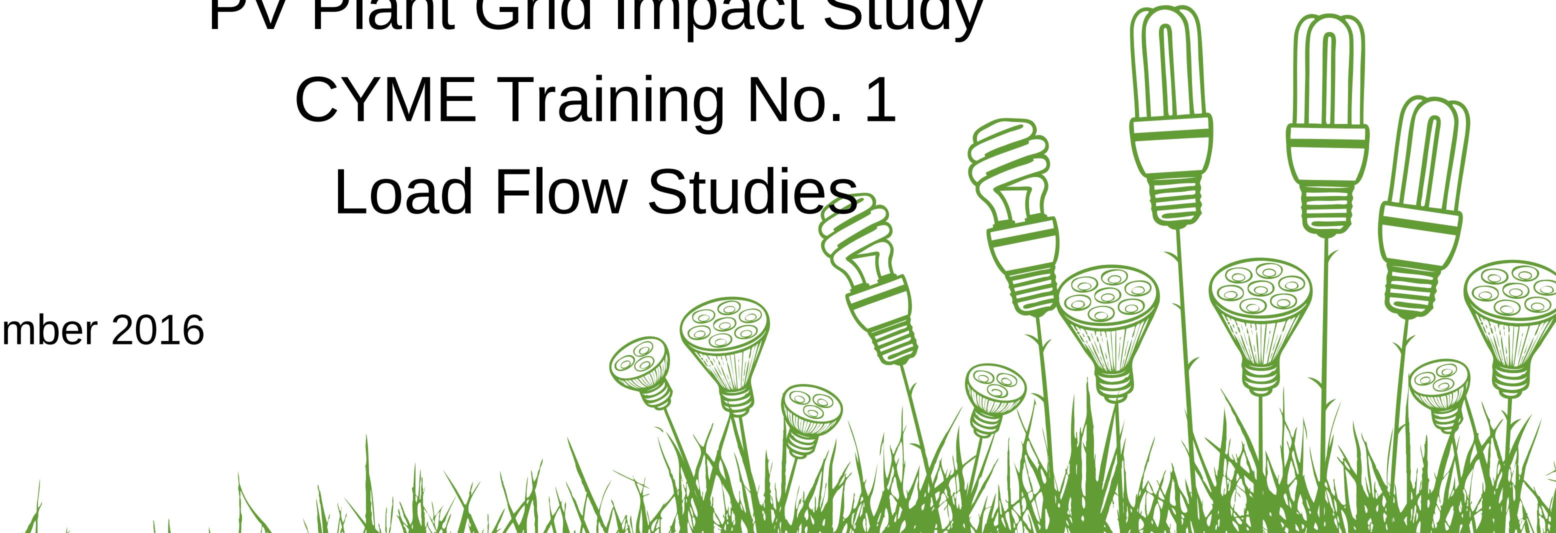
Energy Sector Capacity Building (ESCB)

PV Plant Grid Impact Study

CYME Training No. 1

Load Flow Studies



5 December 2016

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IDECO 5 MW Plant-Agenda

- Day 1:
  - Reviewing model and data
  - PV inverter/electrically coupled generator modeling
  - Steady state voltage regulation
  - Reactive power capability of inverters
  - Snapshot analysis
  - Comparing results of shadow study
- Day 2:
  - Grid code compliance
  - Long term dynamics
  - Reverse power flow

Work Flow

- Day 1:
  - Setting up the model
  - Substation Transformer Assumptions
  - Exercise 1.1: Calculating substation short circuit levels
  - Exercise 1.2: Populate PV inverter PF table
  - Discussing IRR-DCC-MV 5 Voltage Requirements
  - Load Allocation
  - Steady state snapshot analysis, Grid code compliance
- Day 2:
  - Exercise 1.3: Quasi steady state analysis-Long term dynamics
  - Exercise 1.4: Short Circuit Study
  - Comparing results of shadow study

Work Flow

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Setting up/reviewing model

- What is the current load and power factor assumed in the model?
  - Is this minimum or peak load?
- What is the source voltage?
- Are there any voltage regulating devices in the model?
- Run a load flow and generate the following results:
  - Load Flow Summary Report
  - Overloaded Lines & Cables Report
  - Overloaded Transformer Report
  - Voltage Profile at every point along the Feeder (p.u.)

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Sample report -Summary Report: Load Flow

Total Summary	kW	kvar	kVA	PF(%)
Sources (Swing)	8588.24	4303.41	9606.10	89.40
Generators	0.00	0.00	0.00	0.00
Total Generation	**8588.24**	**4303.41**	**9606.10**	**89.40**
Load read (Non-adjusted)	8192.98	4014.42	9123.62	89.80
Load used (Adjusted)	8193.00	4014.46	9123.66	89.80
Shunt capacitors (Adjusted)	0.00	-277.77	277.77	0.00
Shunt reactors (Adjusted)	0.00	0.00	0.00	0.00
Motors	0.00	0.00	0.00	0.00
Total Loads	**8193.00**	**3736.69**	**9004.90**	**90.98**
Cable Capacitance	0.00	-11.65	11.65	0.00
Line Capacitance	0.00	-305.00	305.00	0.00
Total Shunt Capacitance	**0.00**	**-316.65**	**316.65**	**0.00**
Line Losses	243.94	533.73	586.84	41.57
Cable Losses	1.16	1.39	1.80	64.00
Transformer Load Losses	82.51	348.28	357.92	23.05
Transformer No-Load Losses	67.64	0.00	67.64	100.00
Total Losses	**395.25**	**883.40**	**967.79**	**40.84**

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Setting up the Model: Reviewing 33 KV network

- Locate PV project in the model
- Model as ECG-suitable for load flow studies
- Verify size, PF of project
- 132 kV infeeder assumptions:
  - 3 ph short circuit level at 33 KV : 986 MVA
  - X/R Ratio : 25
  - 1 ph short circuit : 78 MVA
  - Resistance grounded : 15 ohms

Setting up the Model: Adding in the PV Inverter

- PV Plant Assumptions:
  - (4) Electronically Coupled Generators
    - Rated Power: 1260 kVA
    - Active Power Rating: 1260 kW
    - Rated Voltage: 0.4 kV
    - Short Circuit Current: 122.5%

Inverter type	Short-circuit surge current i_p (A)	Initial symmetrical short-circuit current I_k'' (A)	Uninterrupted short-circuit current I_k (A)		Maximal current I_{max} (A)
			Mode 1	Mode 2	
STP 5000TL-20	56.56	9.71	7.3	0	7.3
STP 6000TL-20	59.39	9.79	8.7	0	8.7
STP 7000TL-20	64.76	14.07	10.2	0	10.2
STP 8000TL-20	67.65	14.19	11.6	0	11.6
STP 9000TL-20	71.52	14.40	13.1	0	13.1
STP 10000TL-20	77.65	15.98	14.5	0	14.5
STP 12000TL-20	76.36	19.14	17.4	0	17.4
STP 10000TL-10	72.99	20.60	16.0	0	14.5
STP 12000TL-10	76.03	20.89	19.2	0	17.4
STP 15000TL-10	92.85	26.45	24.0	0	21.7
STP 17000TL-10	98.94	26.88	24.6	0	24.6
STP 15000TLEE-10	94.94	25.85	24.0	0	21.7
STP 20000TLEE-10	106.84	31.14	29	0	29
STP 20000TL-30	98.58	31.07	29	0	29
STP 25000TL-30	116.37	40.06	36.2	0	36.2
STP 12000TL-US-10	81.30	17.27	14.4	0	14.4
STP 15000TL-US-10	89.29	20.57	18	0	18
STP 20000TL-US-10	101.44	26.46	24	0	24
STP 24000TL-US-10	111.92	30.91	29	0	29
STP 30000TL-US-10	181	50.68	36.2	0	36.2
STP 60-10 / STP 60-US-10	201.2	106.6	87	0	87

Work Flow

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Substation Transformer Assumptions

- Two-Winding Transformer parameter assumptions
  - Voltage Rating 132/33 KV
  - Apparent Power Rating 100 MVA
  - Transformer Impedance 10 %
  - X/R Ratio: 25
  - Assume Off Load Tap Changer present
  - Fixed secondary taps (95% to 105%, 2.5% steps), assume 102.5% secondary tap position

Work Flow

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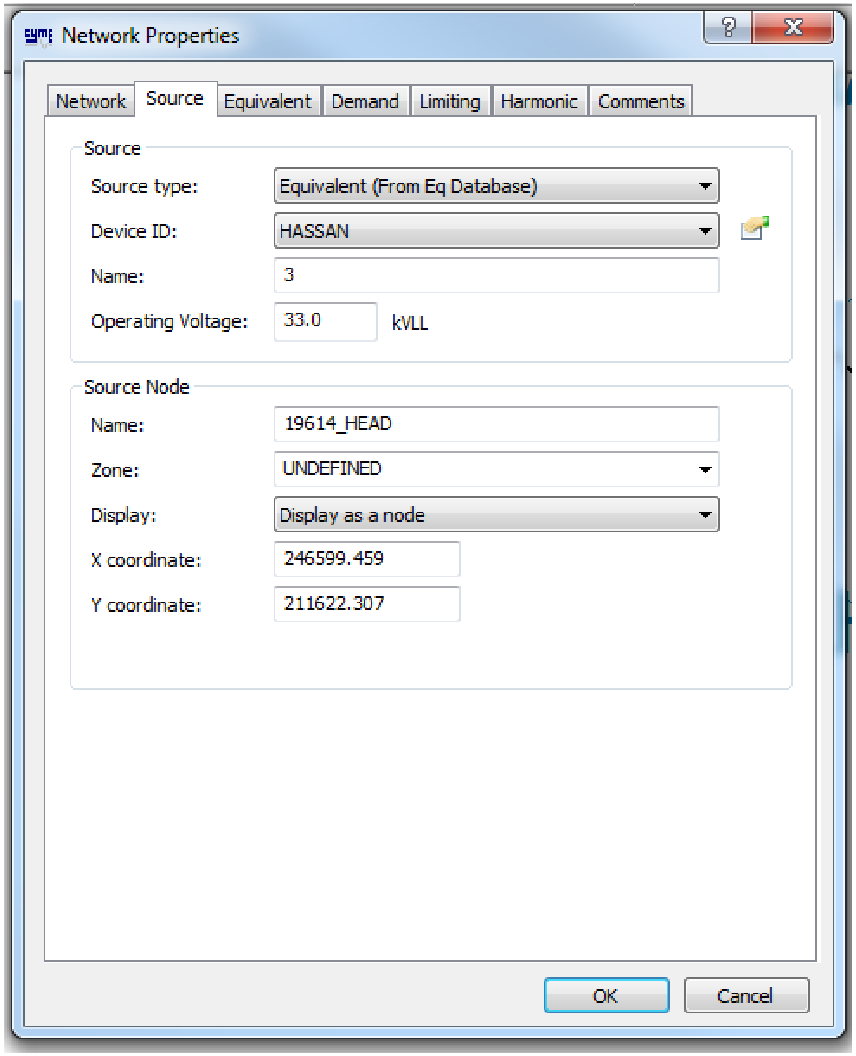
Substation short circuit calculations-IDECO model



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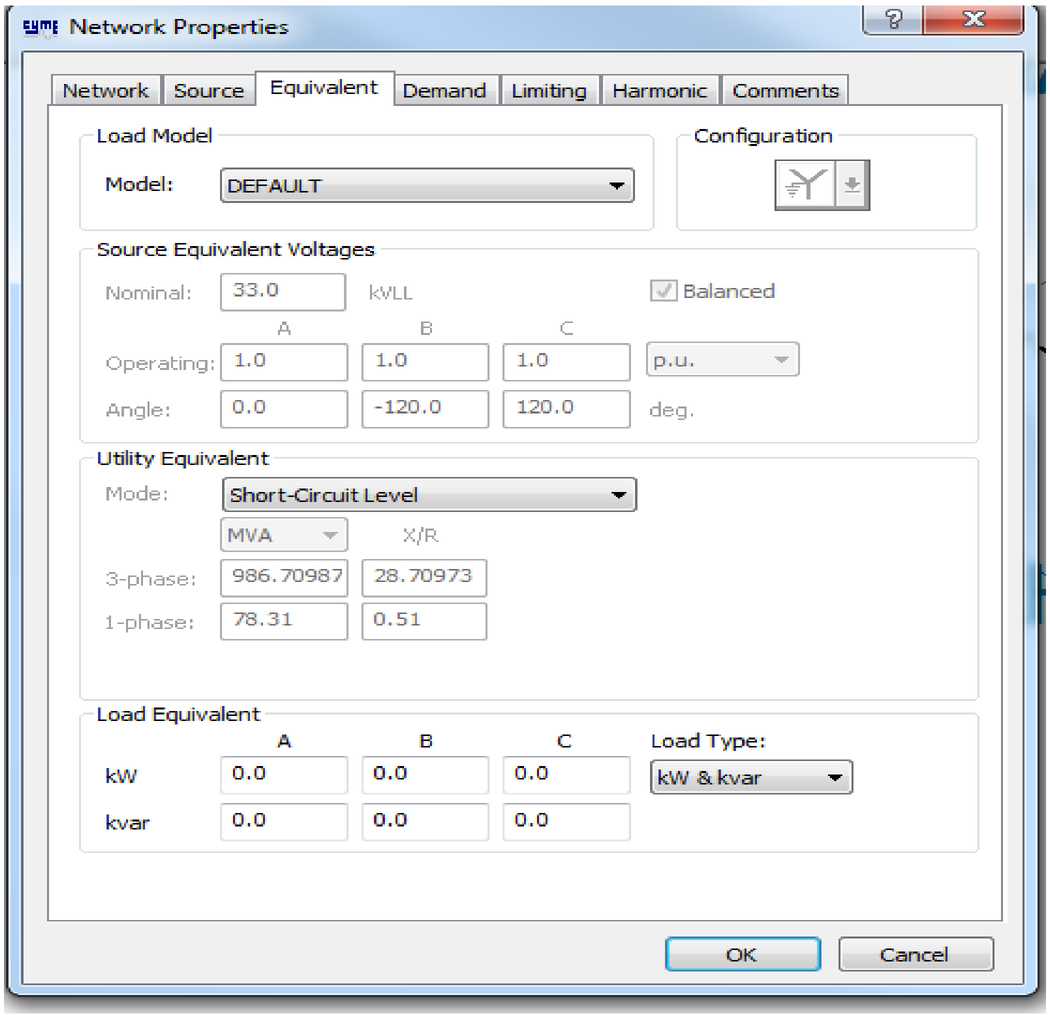
Substation short circuit calculations-IDECO model



Substation short circuit calculations-IDECO model

Exercise: Calculate short circuit MVA to model 132 KV source

- Model 132 KV source.
- Perform fault calculations using available SC MVA.
- Model substation transformer
- Simulate fault with transformer
- Compare fault levels if 132 KV and 33KV network
- Now, assume 2.5 % secondary tap position for load flow studies

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Save Base Case

- Save your model as:

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Work Flow

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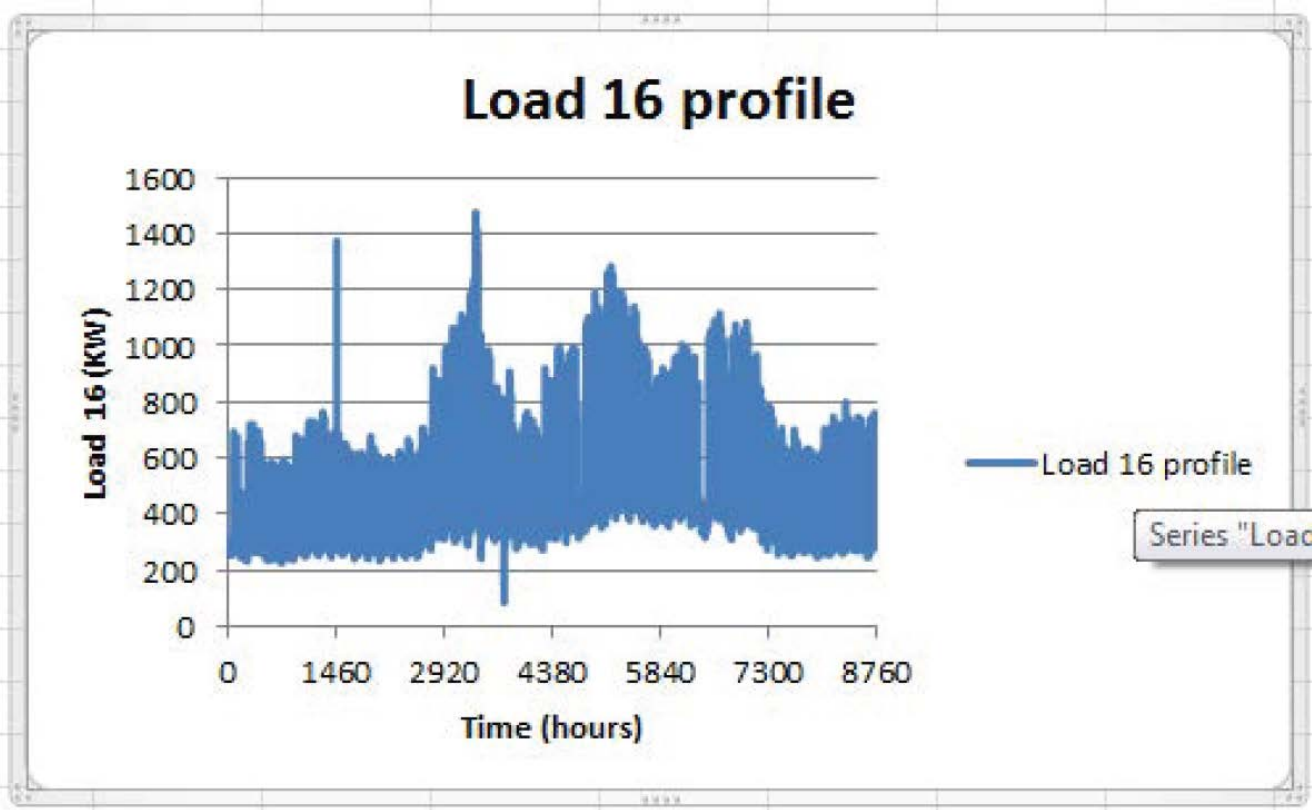
Load profile



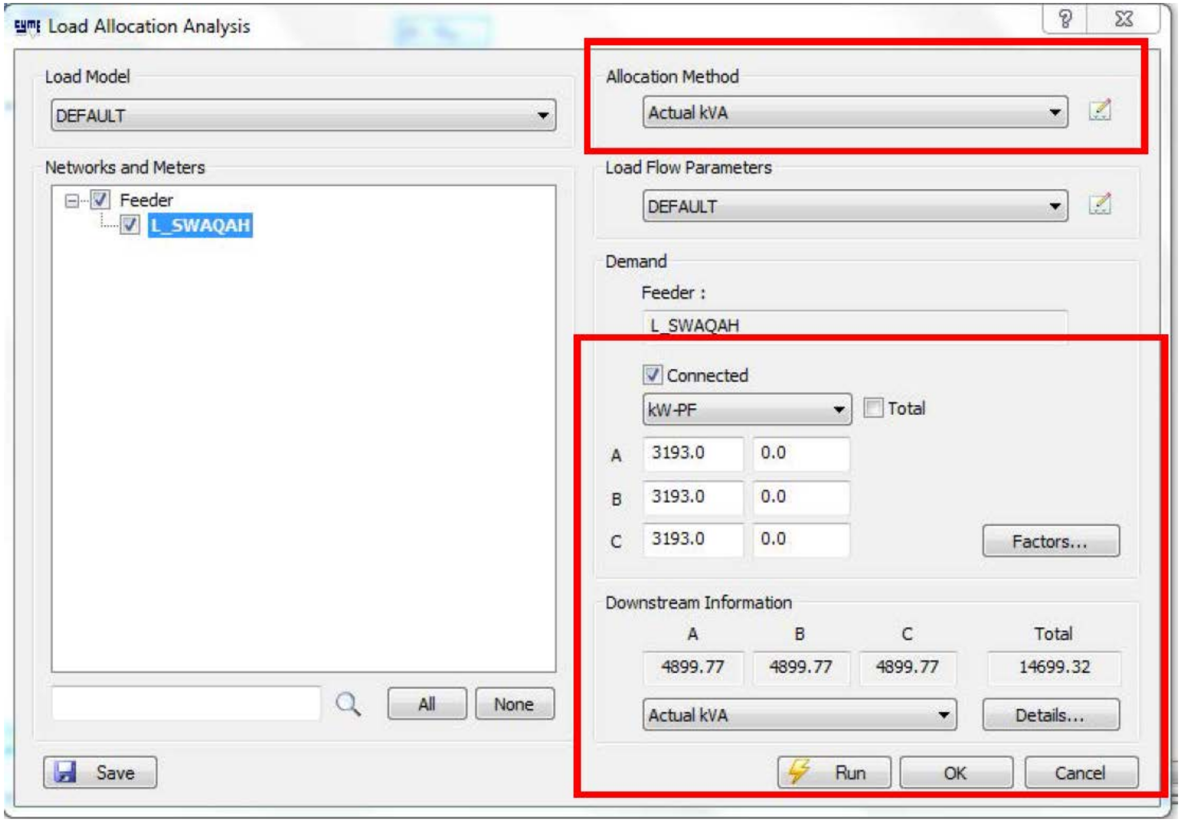
Load Allocation

- Allocate the load in the circuit to match the meter demand
- Balanced/Unbalanced phase demand ?
- What format is the load data available in ?
- Loads can be classified according to customer type if necessary-to assign different load factor.
- Analyze the circuit in peak and day minimum load conditions for planning purposes.

Load Allocation

- What load data/ demand type is available ?
  - Substation load data ? (EDCO)
  - AMI data ? (IDECO)
  - Data resolution?
- Other requirements
  - Load power factor
  - Transformer taps
  - Shunt capacitors
- Specify demand at the substation (P,PF),(Amps,PF)
- Fix load power factor and allow source to swing

Load Allocation



Load Allocation

Load Flow Box

Transformer - 7

	kVLL	kVLN	i (A)	kVA	kW	kVAR	V(pu)	PF
A	33.3	19.2	48.9	3714.1	3170.8	1934.1	1.009	85.37
B	33.3	19.2	48.9	3714.1	3170.8	1934.1	1.009	85.37
C	33.3	19.2	48.9	3714.1	3170.8	1934.1	1.009	85.37
			Total:	11142	9512	5802		

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Work Flow

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Reactive power capability

Exercise : Populate PF table

Work Flow

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  - ***Discussing IRR-DCC-MV 5 Voltage Requirements***
  - Steady state snapshot analysis, Grid code compliance

Intermittent Renewable Resources-Distribution Connection Grid Code at medium voltage (IRR-DCC-MV)

- IRR-DCC-MV 5 Voltage Requirements:
  - Voltage step limit following sudden loss or start of IRR shall not exceed 3% measured at the PCC
  - Voltage Control at the PCC required
  - Power Factor Control at the PCC required (+/- 0.88 pf)
    - Full lagging capability required from 100% to 95% nominal voltage
    - Full leading capability required from 100% to 105% nominal voltage
  - OLTC required for transformers ?

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  - ***Steady state snapshot analysis, Grid code compliance***

BEGIN MODELING

Load Flow Analysis Part 1 – Steady State Analysis

- (4) Study Cases Created:
  - Case 1: Peak Load, No PV
  - Case 2: Peak Load, Max PV
  - Case 3: Min Load, No PV
  - Case 4: Min Load, Max PV
- Power Factor Capability Analysis:
  - (3) Scenarios per Study Case
    - PV operating at 0.88 leading pf
    - PV operating at 1.0 pf
    - PV operating at 0.88 lagging pf

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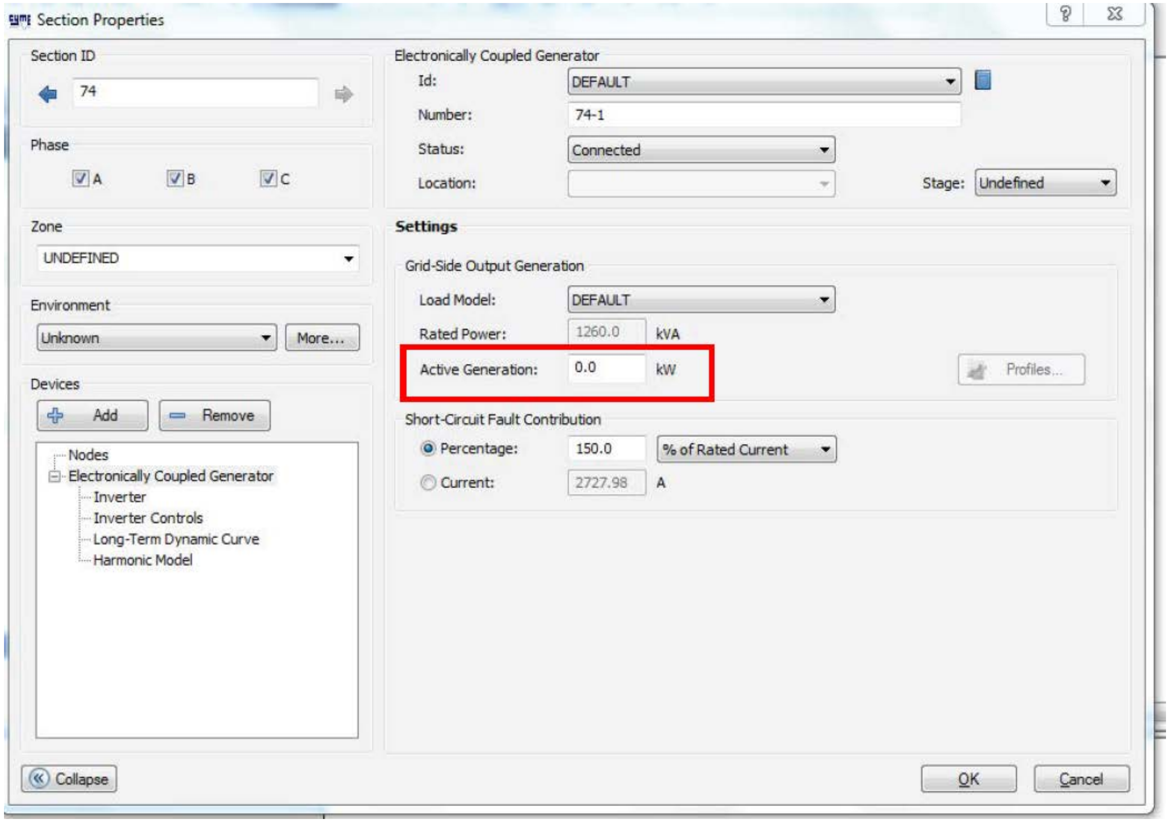
Load Flow Analysis Part 1 – Steady State Analysis

- Power Factor Capability/Control Analysis:
  - Voltage Step Limit Requirement:
    - Calculate step change in voltage between Case 1 and 2, and Case 3 and 4 for all scenarios, PCC most important, but do for all nodes
  - Losses:
    - Calculate losses for each of the runs, compare with and without PV
  - Reverse Power Flow:
    - Monitor power flow at the distribution substation for each case
  - Thermal Overloads:
    - Check overhead lines, cables , transformers against their current ratings (Rate A)

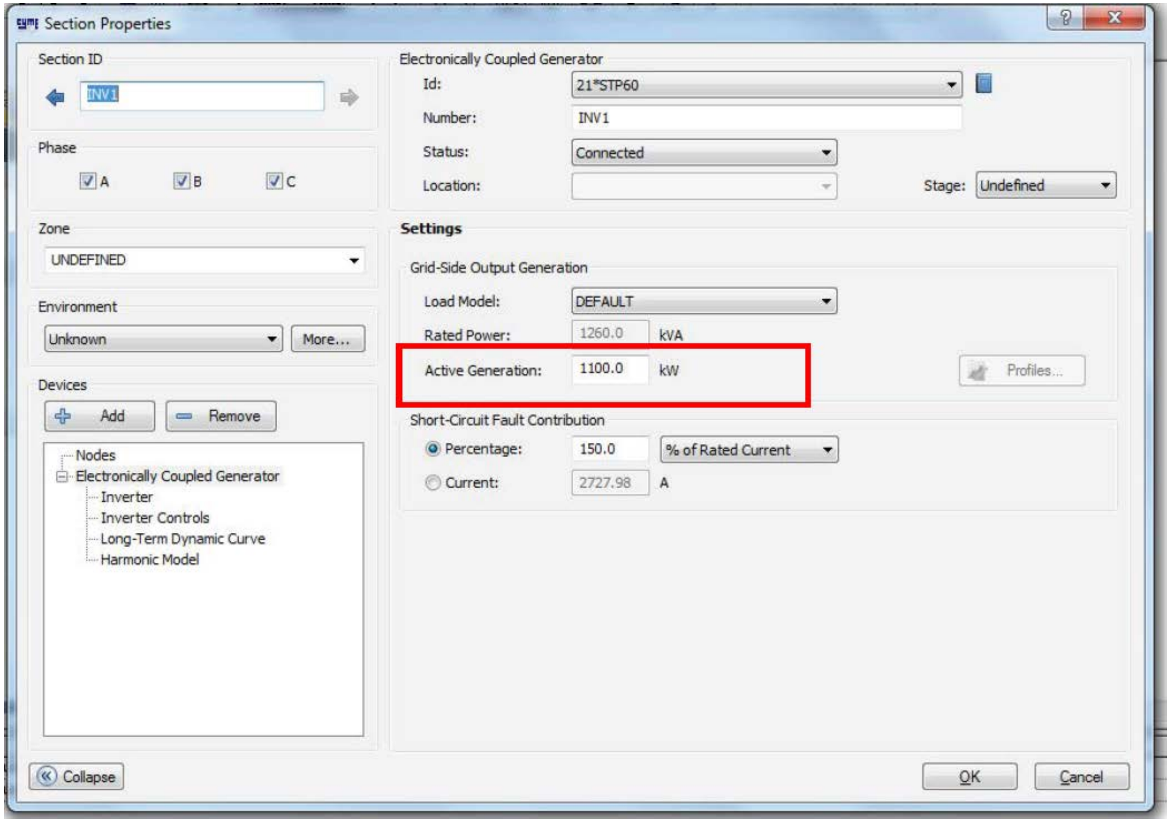
Load Flow Analysis Part 1 – Steady State Analysis

- Voltage Control Capability:
  - Study all (4) cases with the PVs operating in voltage control mode, determine whether voltage can be controlled to within 0.90 and 1.10 per-unit
  - Voltage Step Limit Requirement:
    - Calculate step change in voltage between Case 1 and 2, and Case 3 and 4 for all scenarios, PCC most important, but do for all nodes
  - Losses:
    - Calculate losses for each of the (12) runs, compare with and without PV
  - Reverse Power Flow:
    - Monitor power flow at the distribution substation for each case
  - Thermal Overloads:
    - Monitor power flow at the distribution substation for each case
  - PV Inverter Documentation Review:
    - Confirm PV inverters can supply full 0.88 leading reactive capability for voltages between 100% to 105%
    - Confirm PV inverters can supply full 0.88 lagging reactive capability for voltages between 100% to 95%

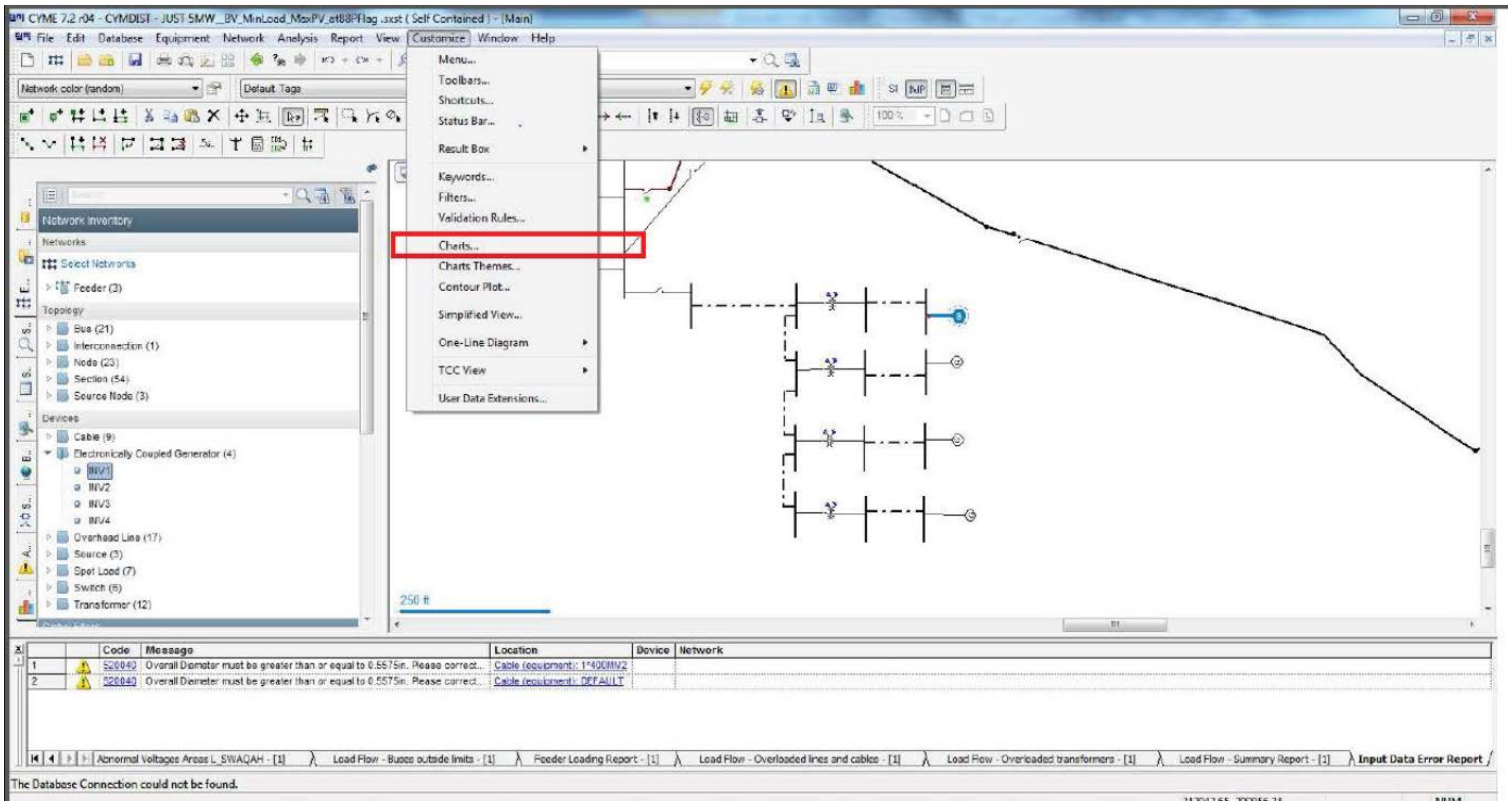
Snapshot Analysis -No PV (Basecase)



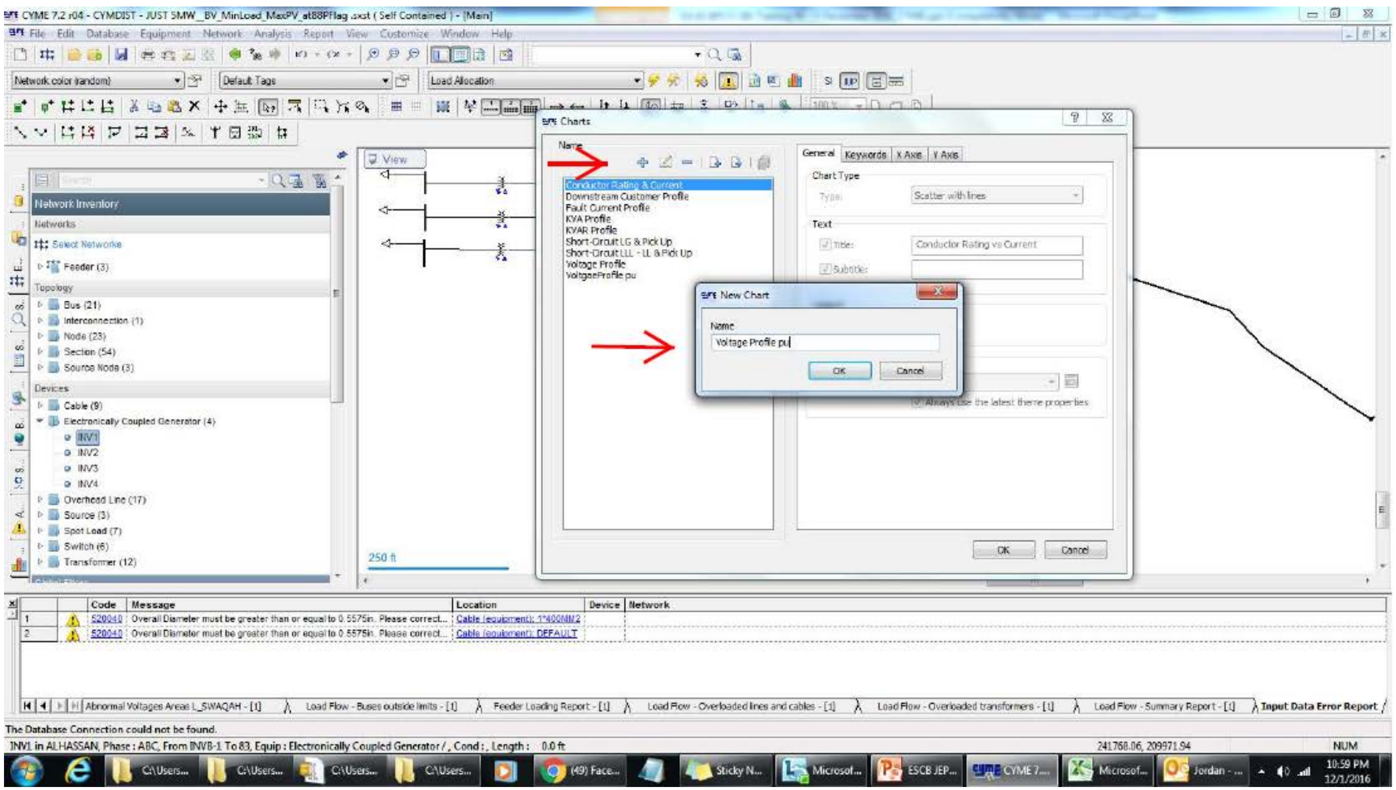
Snapshot Analysis-Max PV



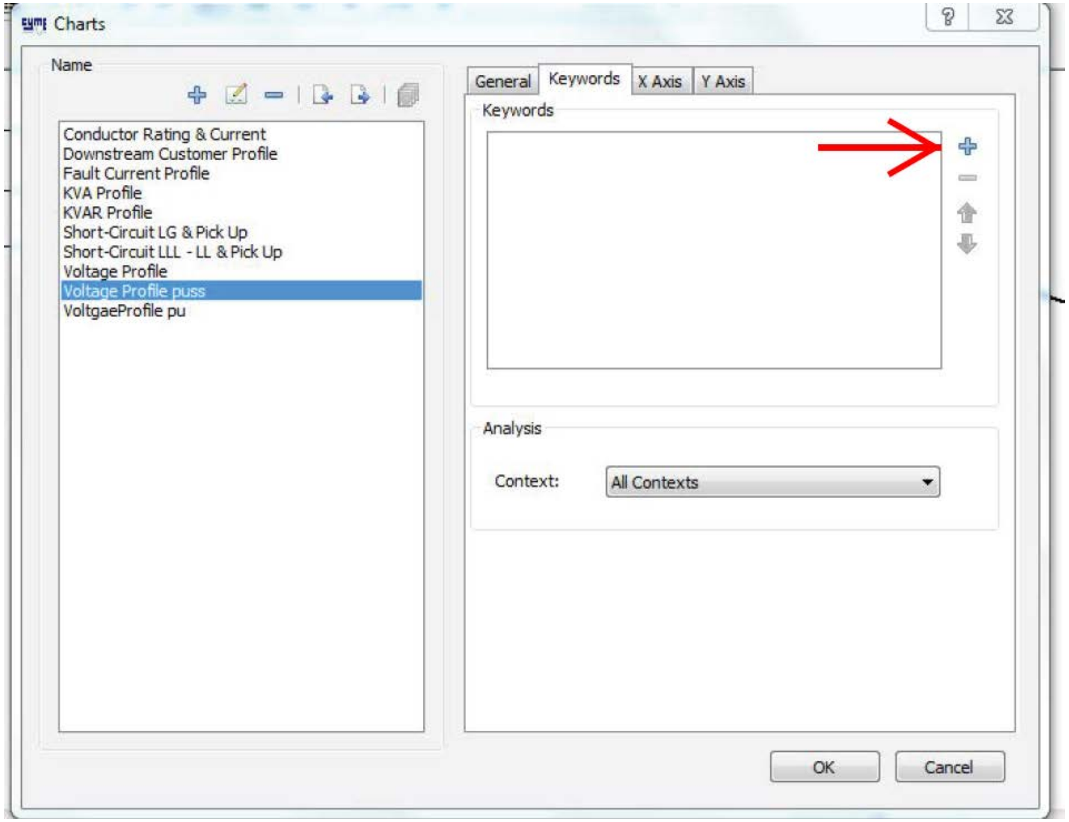
Snapshot Analysis- Voltage Profile



Snapshot Analysis- Voltage Profile



Snapshot Analysis- Voltage Profile



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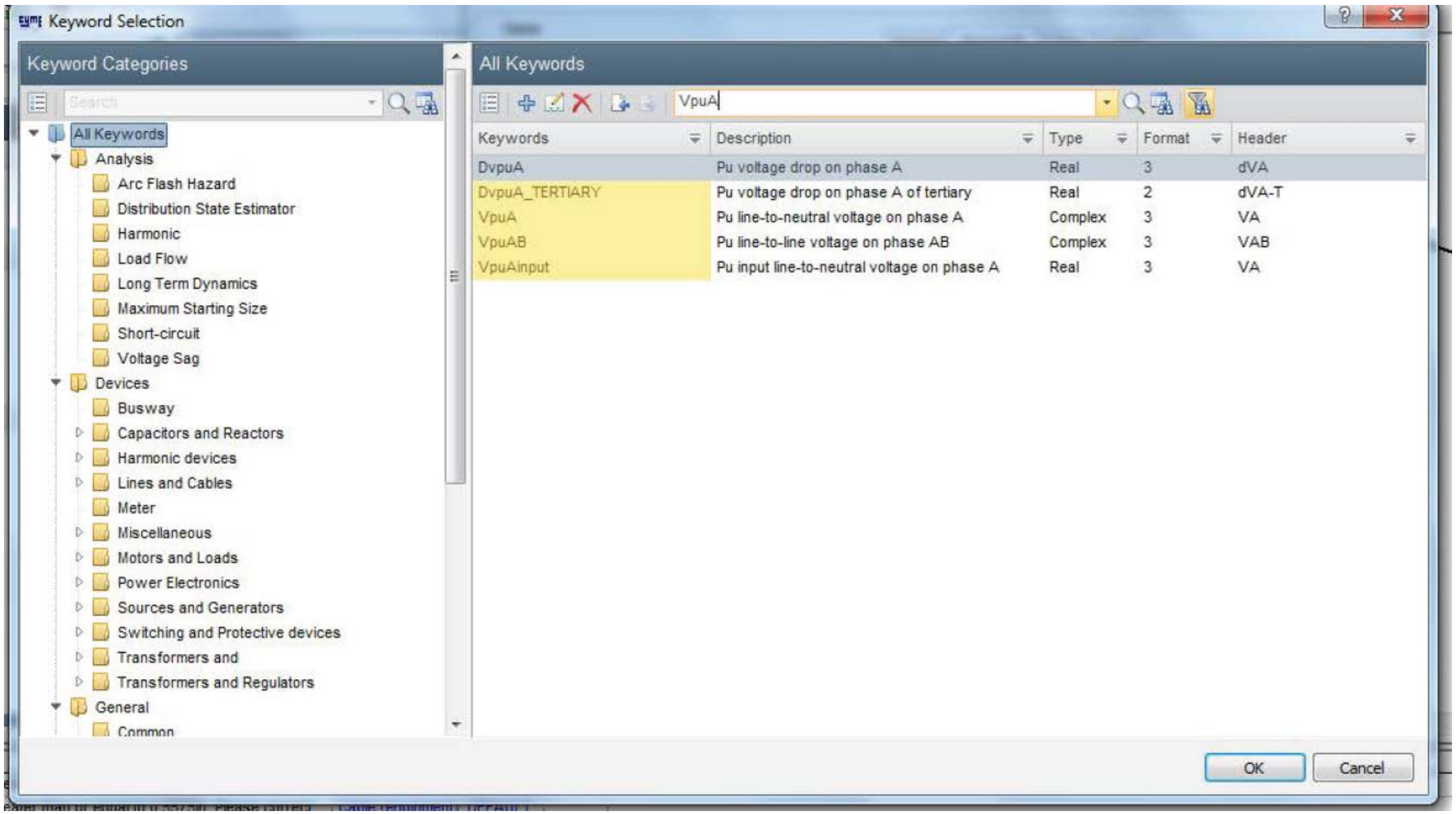
Snapshot Analysis- Voltage Profile



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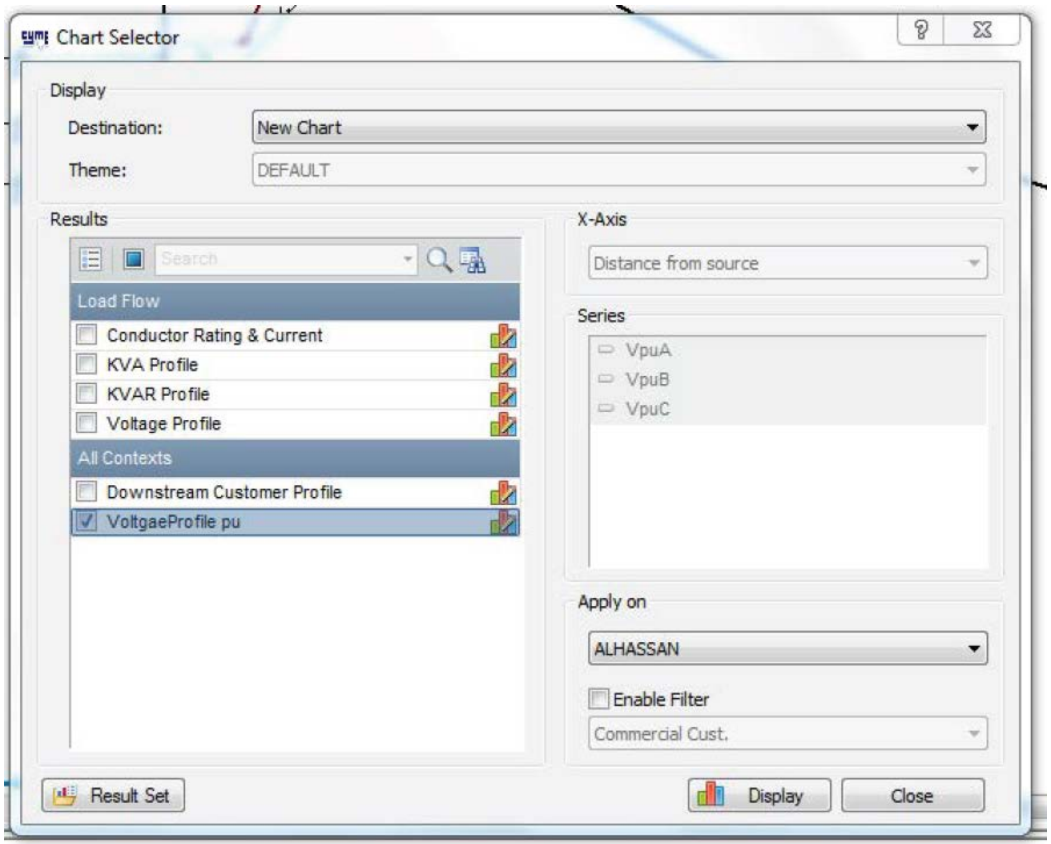
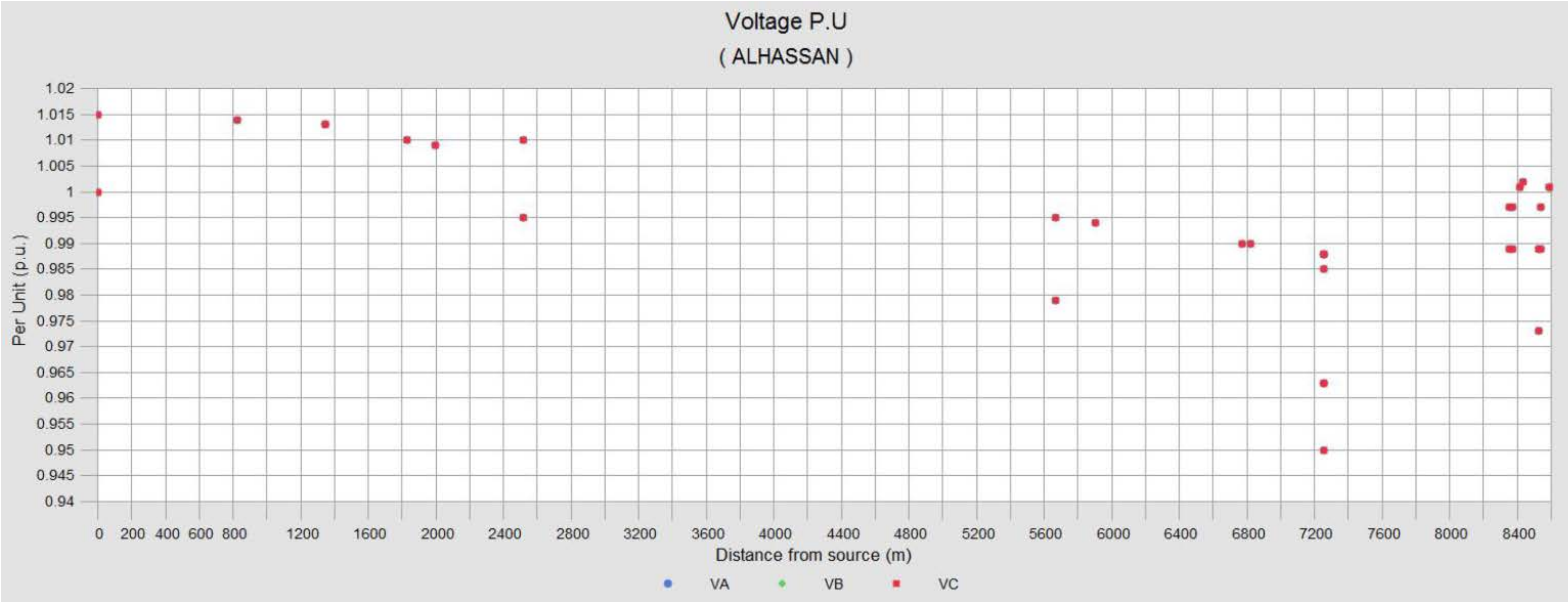
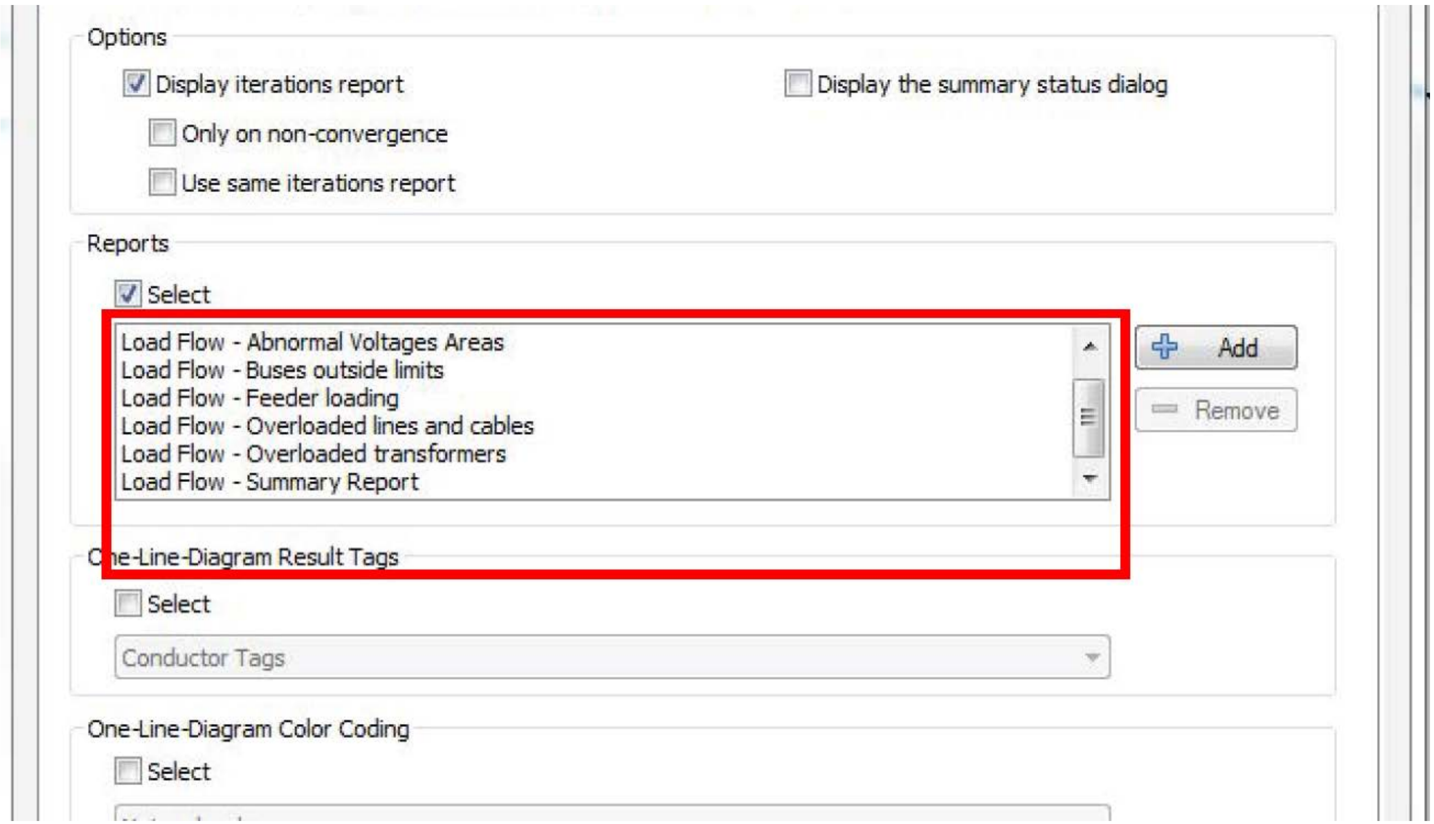


Snapshot Analysis- Voltage Profile



Snapshot Analysis- Exporting Reports



Step Voltage Requirement

- Calculate step voltage change at the PCC
- Analyze with no PV and Max PV
- Compare against IRR-DCC-MV 5 Voltage Requirements.

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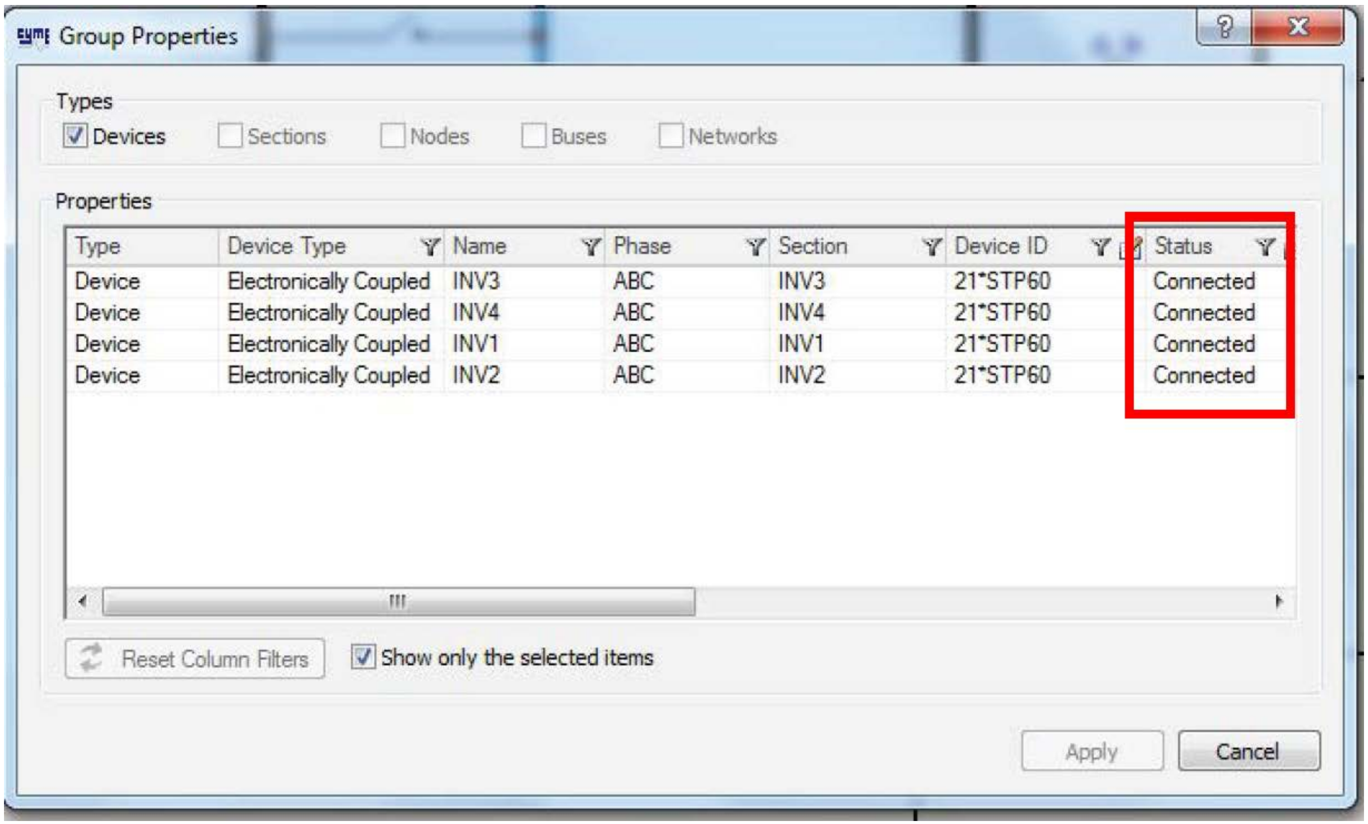
Step Voltage Requirement



Snapshot Analysis-Reverse power flow

- Plot KWTOT at the substation

Snapshot Analysis

- Repeat analysis for 0.88 PF lead and lag.
- Repeat analysis for Max Load.
- Tabulate the results and compare.

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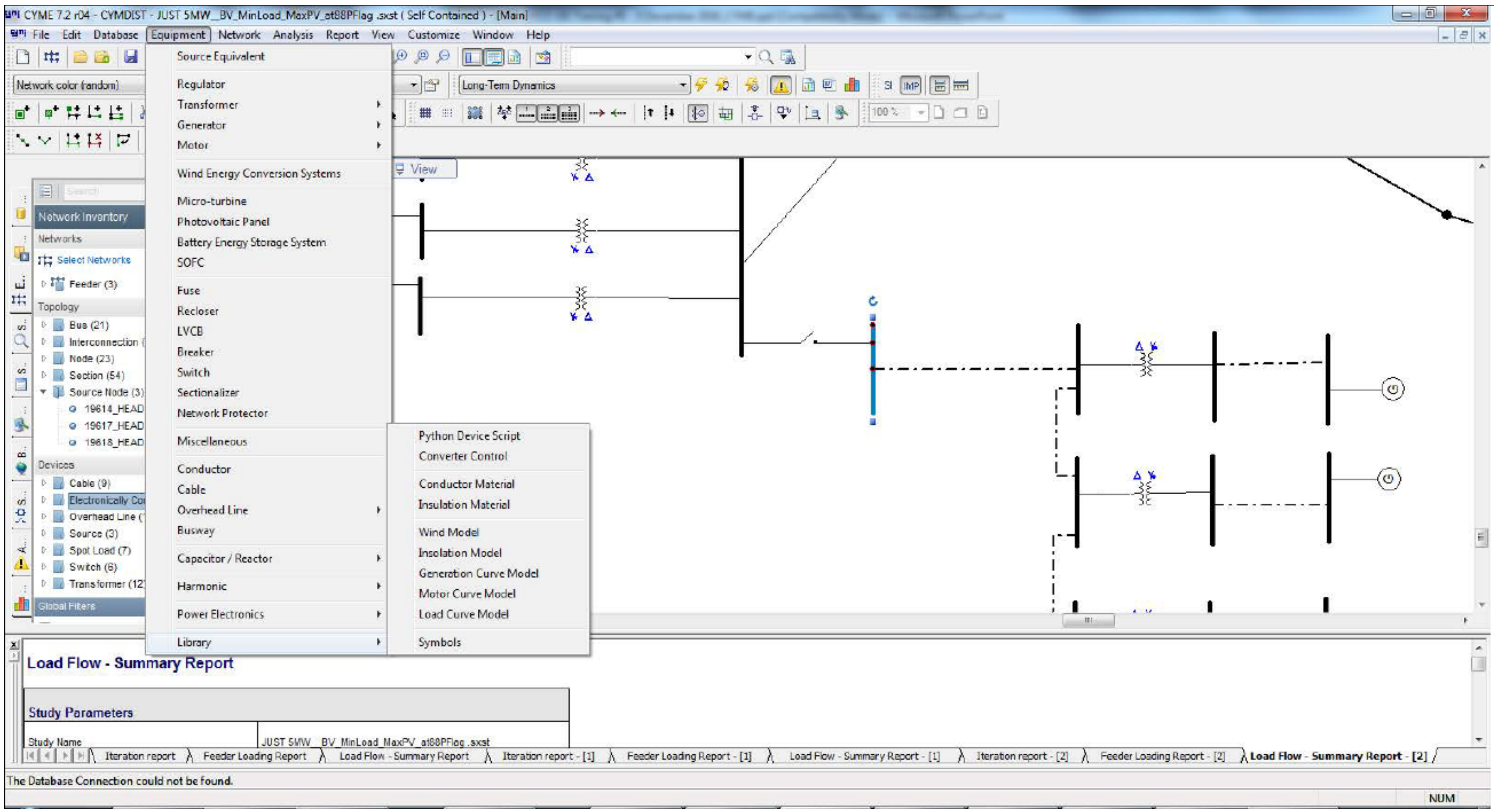
Quasi steady state analysis-Time series analysis

- Why is quasi steady state analysis needed ?
- Need to study coincident PV analysis
- Help identify the time dependent aspects of power flowing in distribution systems
- Captures interaction between changing load and PV output.
- 8760 (hourly analysis) done for this study.

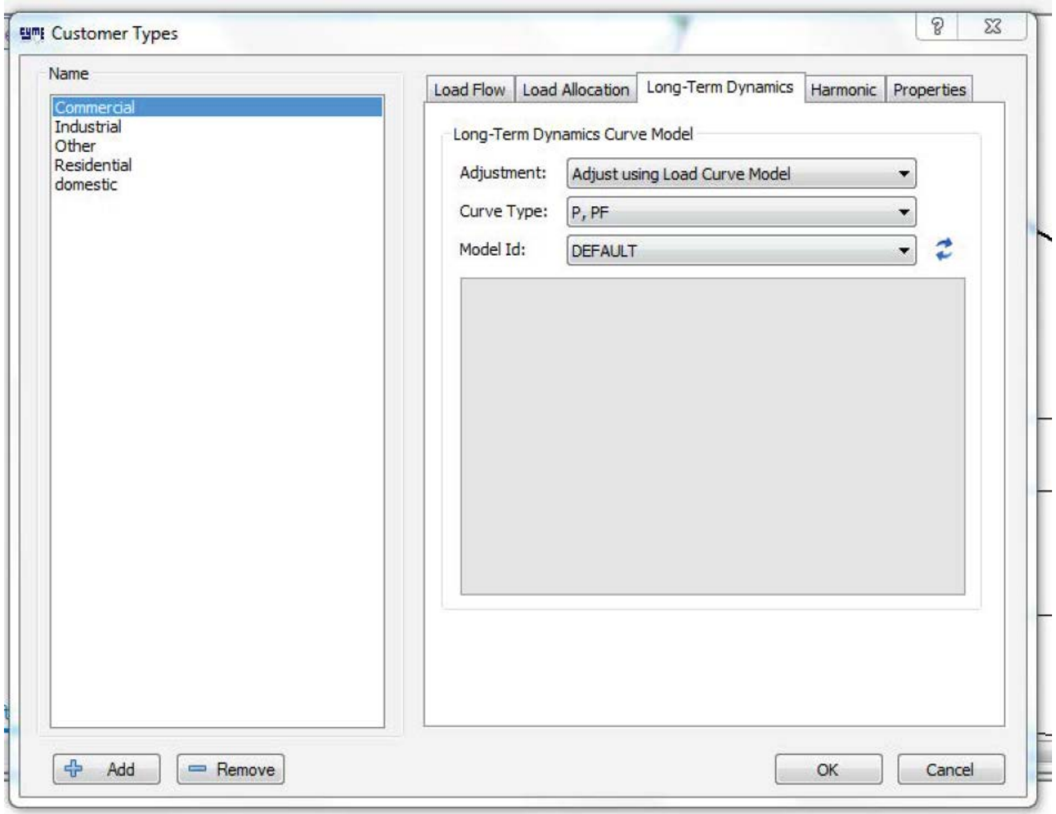
Quasi steady state analysis-Long term dynamics

- Setting up the model
- Defining load and generation curves in the library
- Assigning the curves
- Visualizing results
  - Voltage profile of the feeder
  - Power flow at the substation
  - Power factor at the substation
  - Voltage regulation and status of voltage regulating equipment ?

Long term dynamics-Adding curves to the library



Long term dynamics-Assign curves to loads and generators



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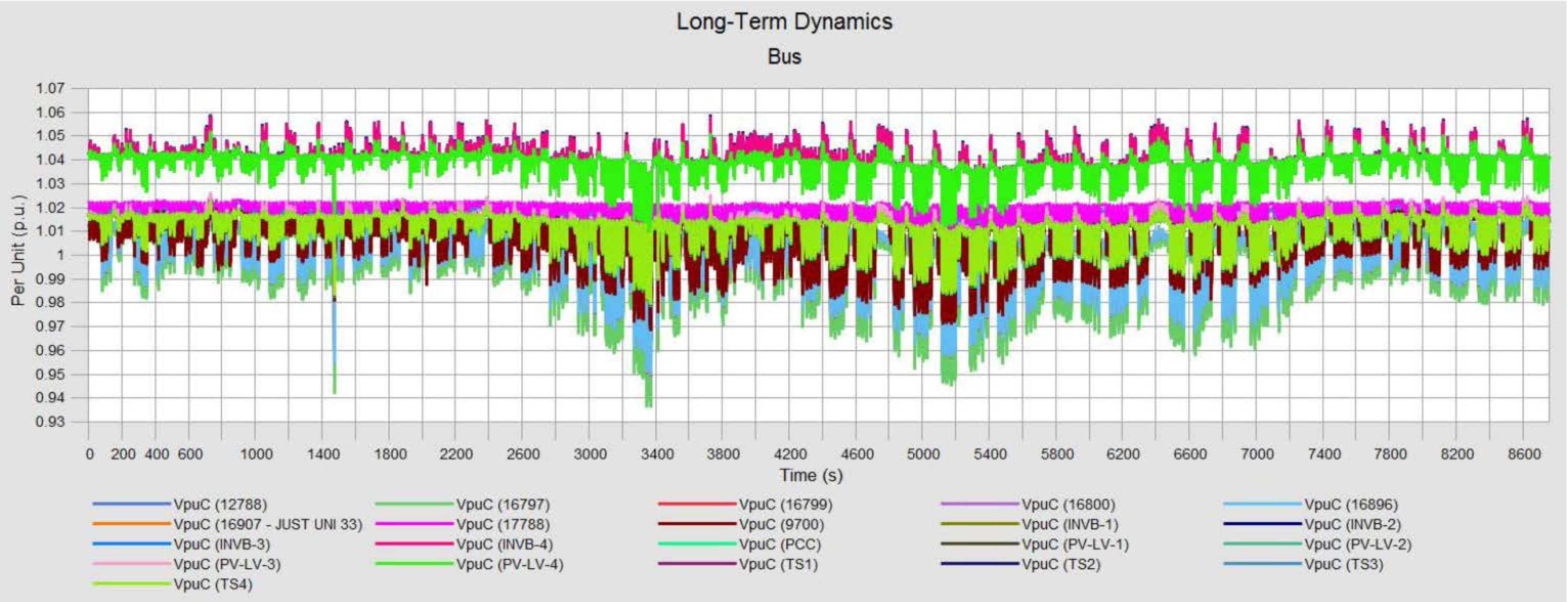
Visualizing results-Voltage Profile



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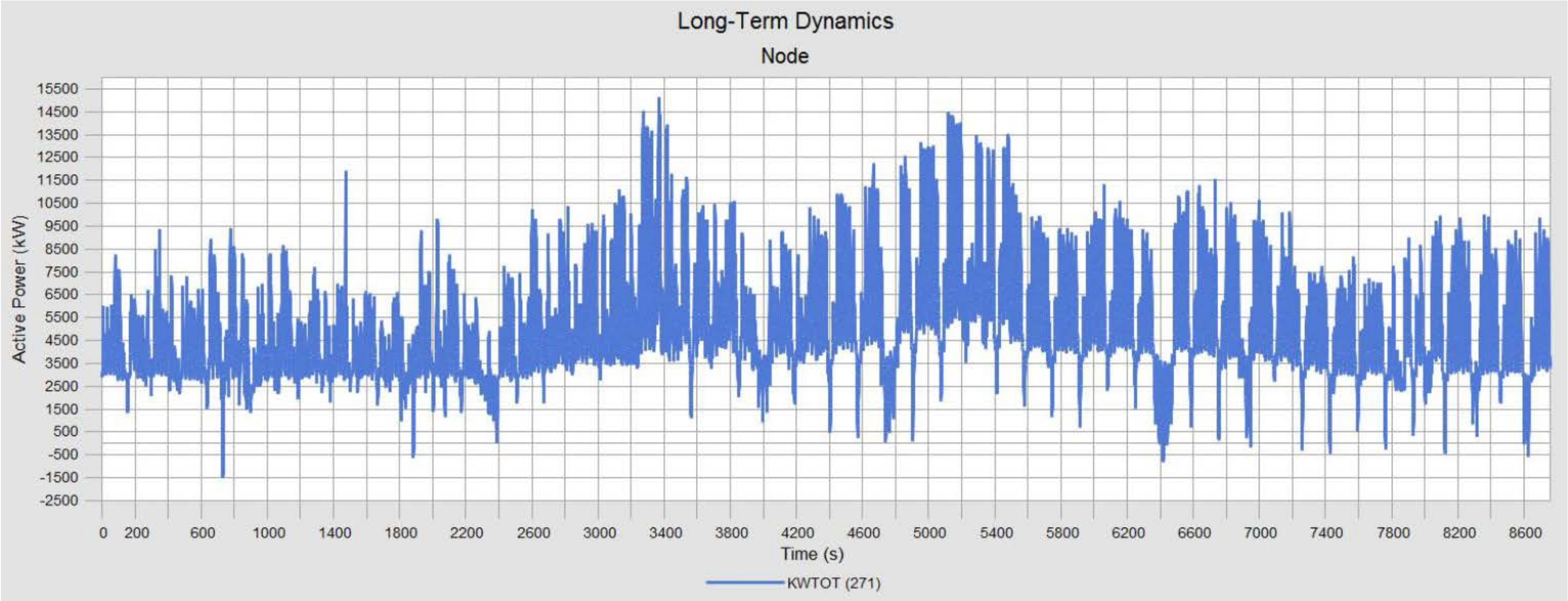
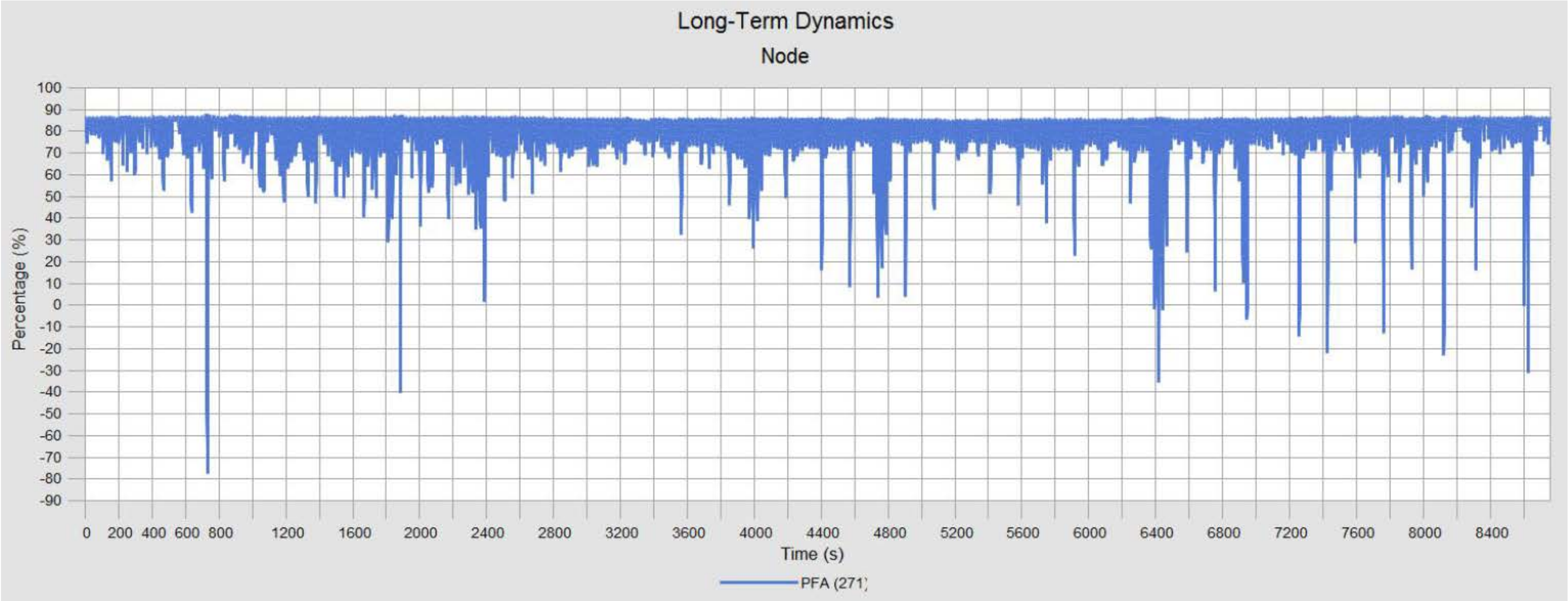
Visualizing results-Active power at the substation



Visualizing results-Power factor at the substation



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Short Circuit Study

- Compute fault current contribution from the project

Comparing Shadow Study Results