Energy Sector Capacity Building (ESCB)

AJIB PV Plant Grid Impact Study

Training No. 1

Load Flow Studies

5 December 2016

Agenda

- Introductions
- **Morning Session**
  - 9:15 – 1:00 PM: Setting up the Model
    - Review Existing Feeder Model
    - Project Background
    - Model Updates
    - Review Load/Generation Data
- **Afternoon Session**
  - 2:00 – 3:00 PM: Load Flow Analysis Part 1 – Steady State
    - Criteria Review
    - Study Cases
    - Analysis
  - 3:00 – 3:30 PM: Comparing Shadow Study Results

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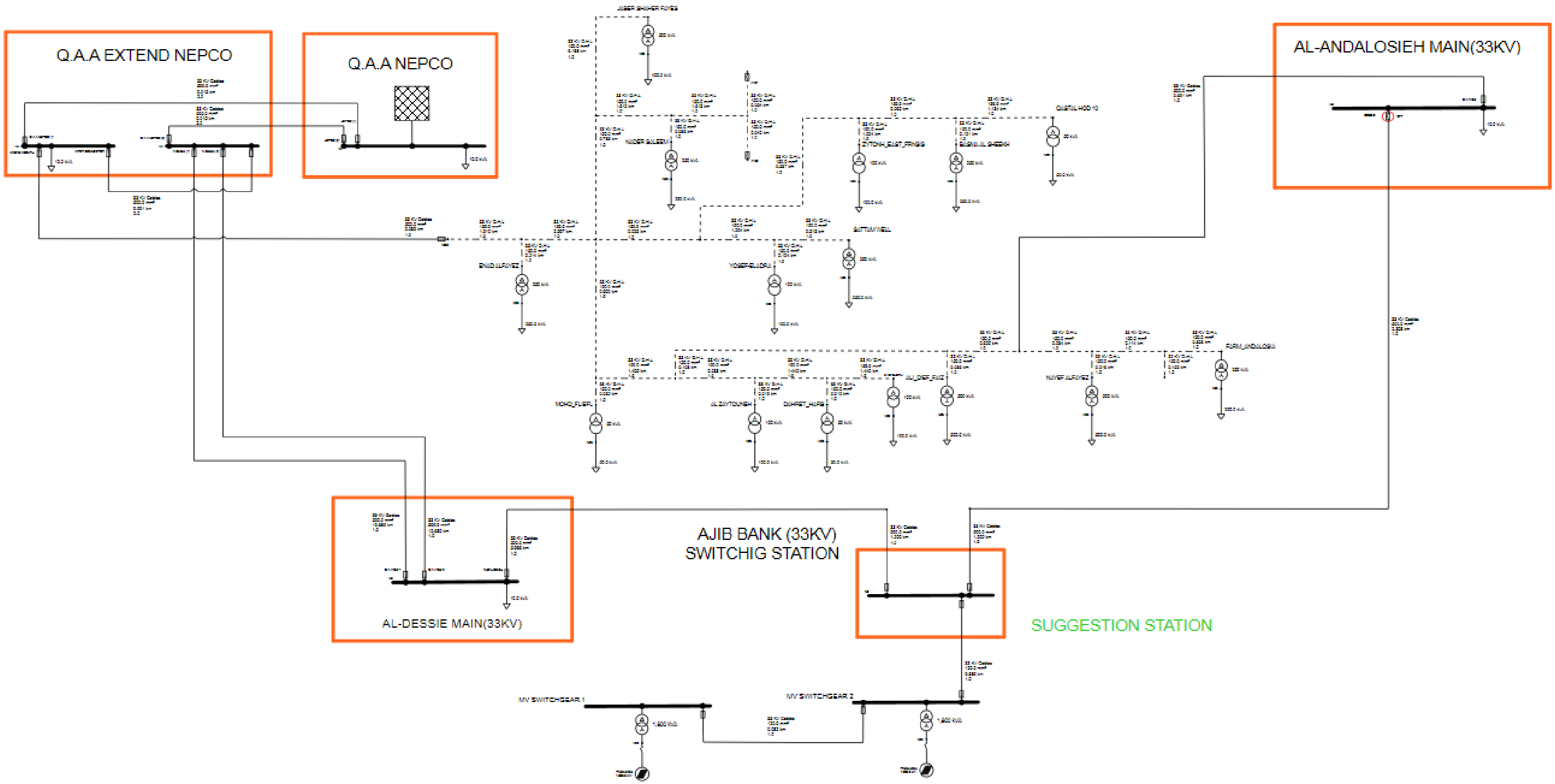
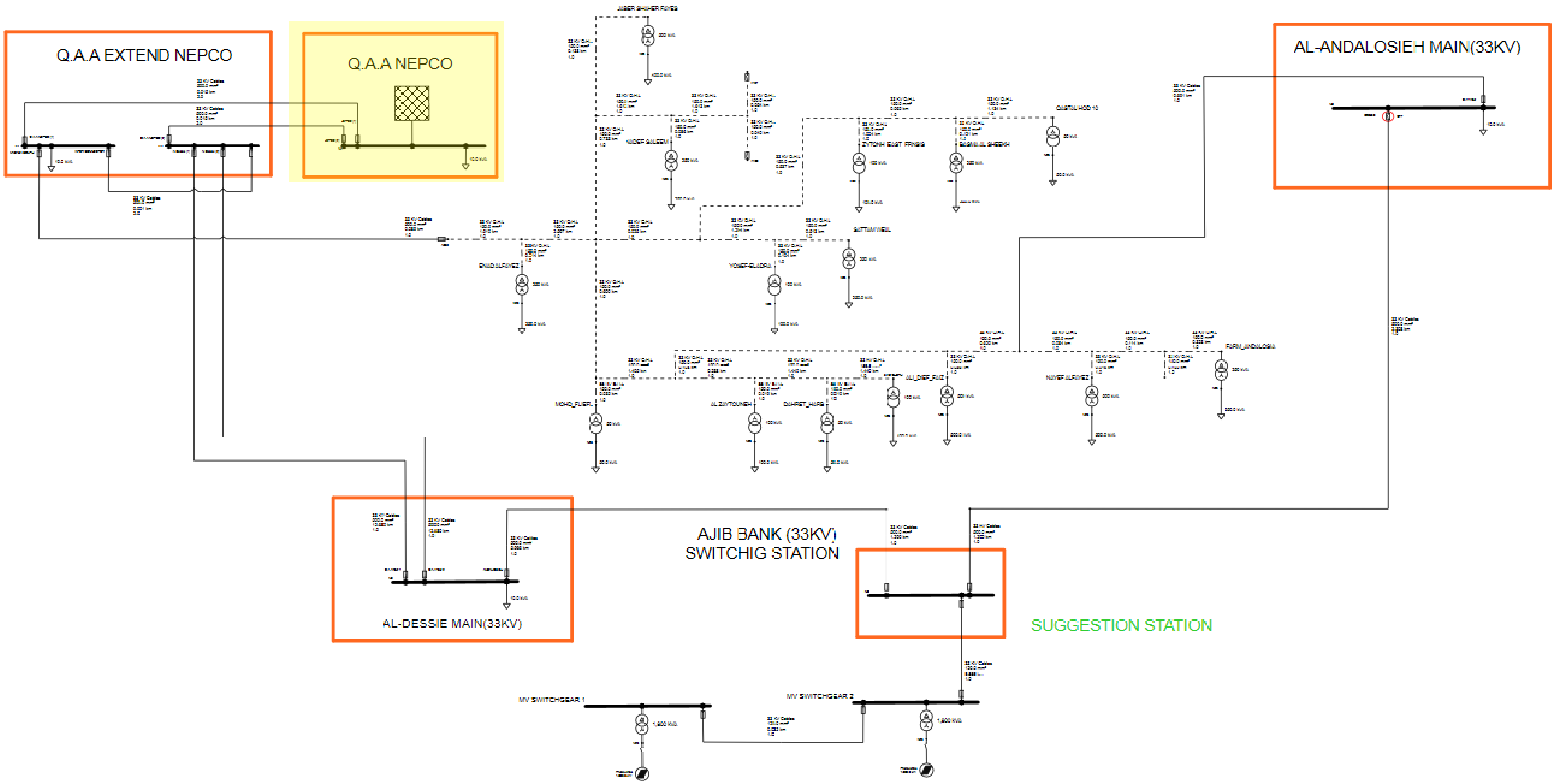
Review Existing PSS SINCAL Feeder Model



Q.A.A. NEPCO



Q.A.A EXTEND NEPCO
Q.A.A NEPCO
AL-ANDALOSIEH MAIN(33KV)
AJIB BANK (33KV)
SWITCHIG STATION
AL-DESSIE MAIN(33KV)
SUGGESTION STATION

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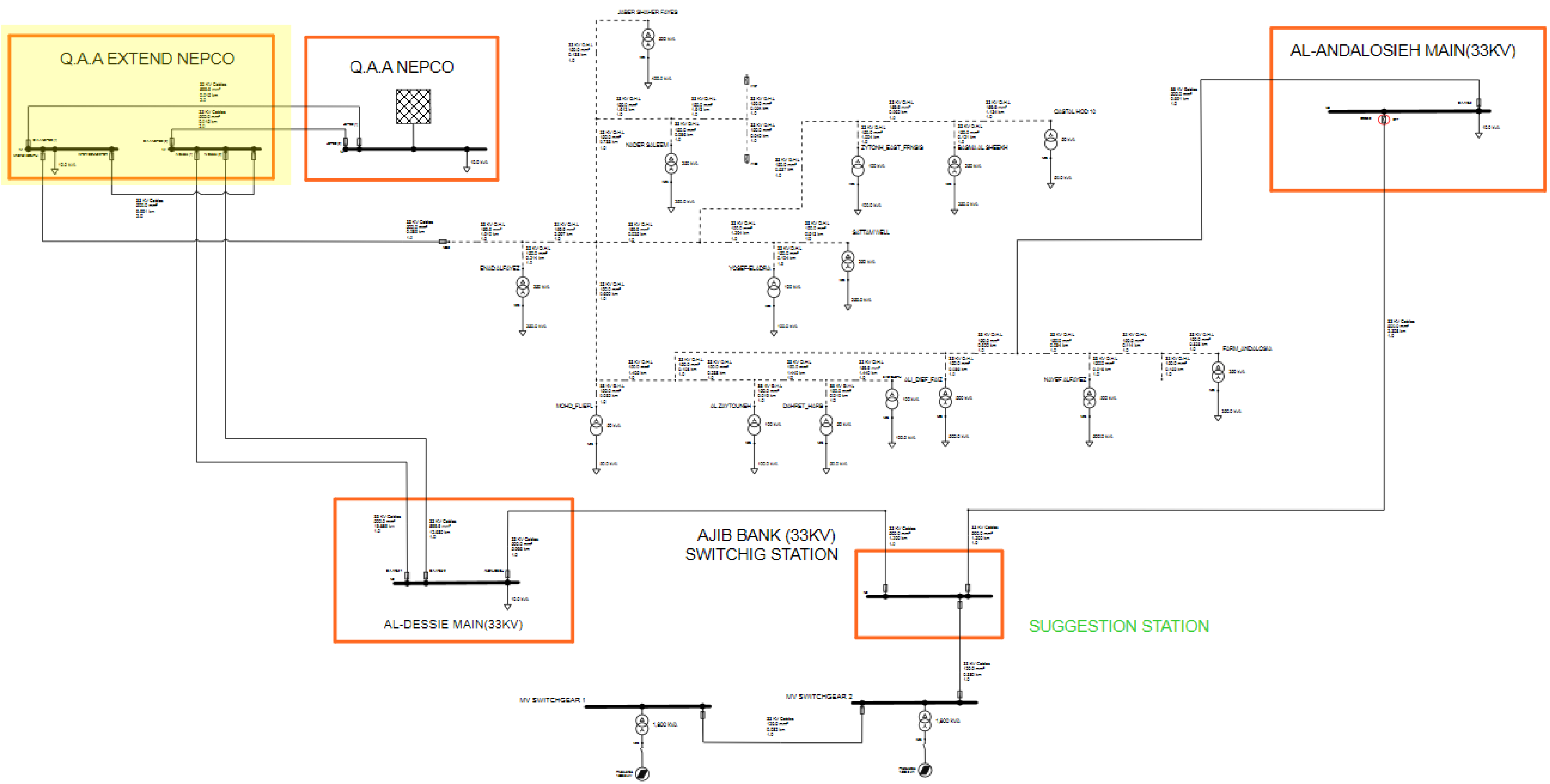
Q.A.A. EXTENDED NEPCO



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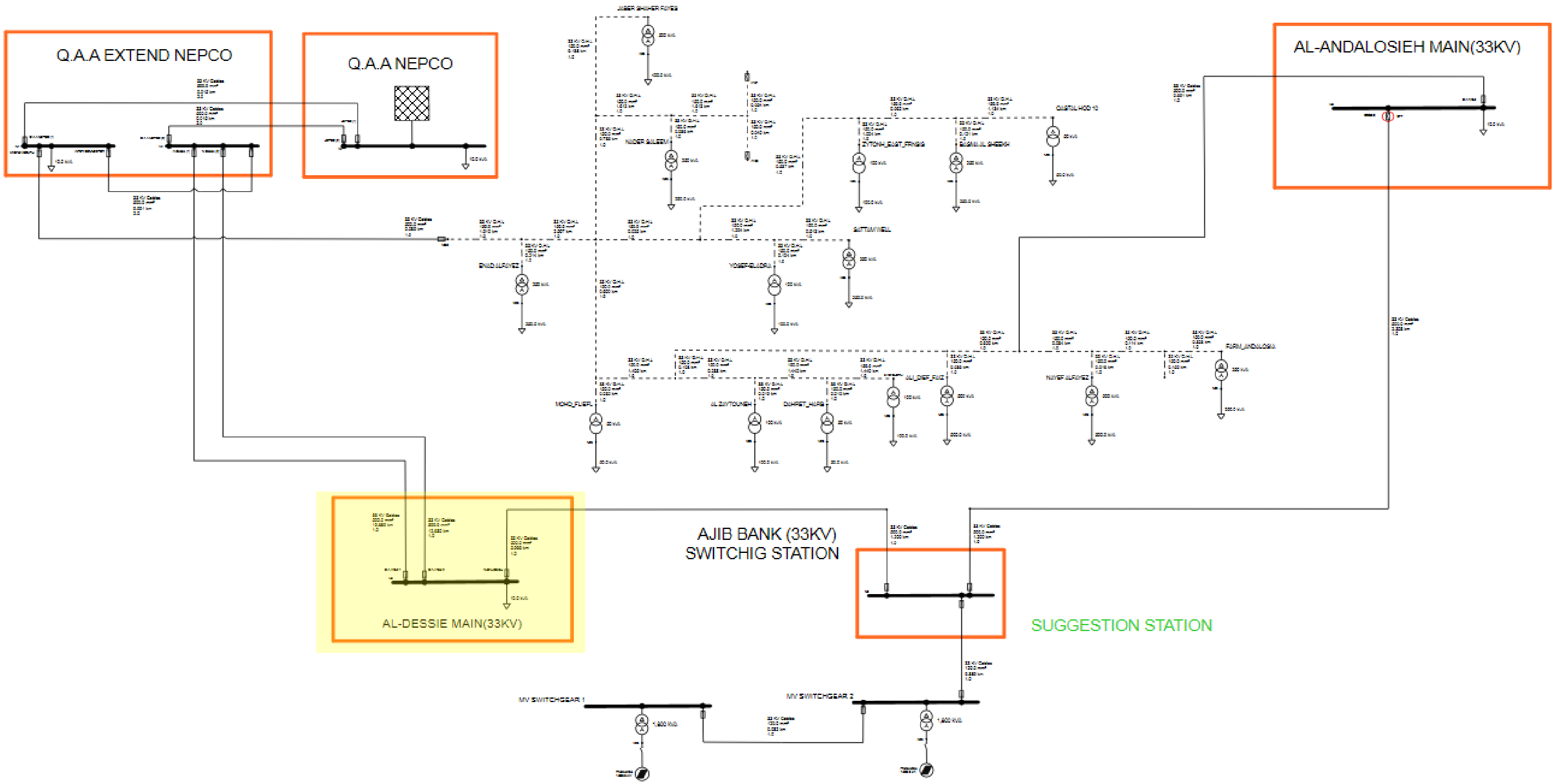
AL-DESSIE MAIN



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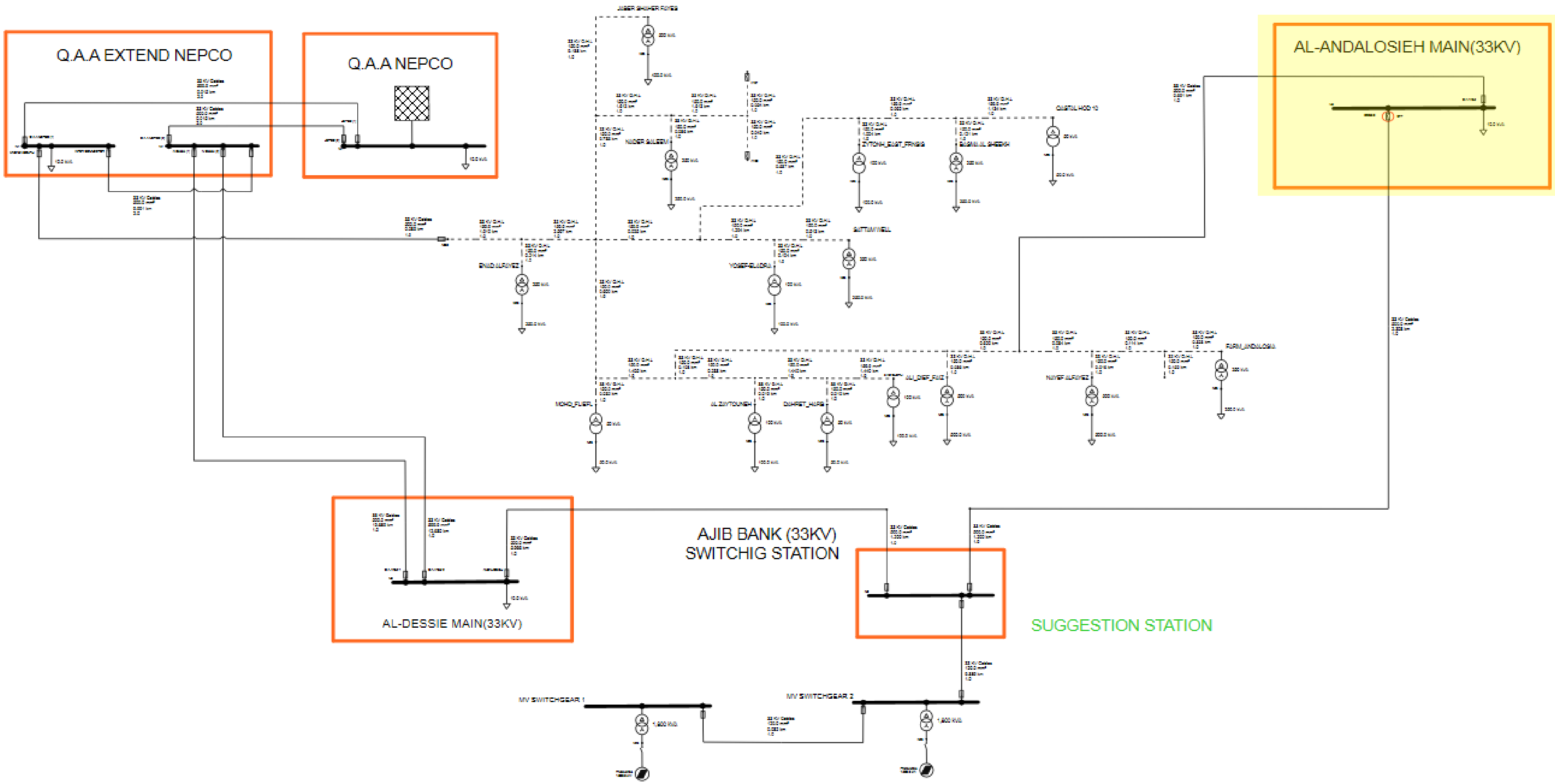
AL-ANDALOSIEH MAIN



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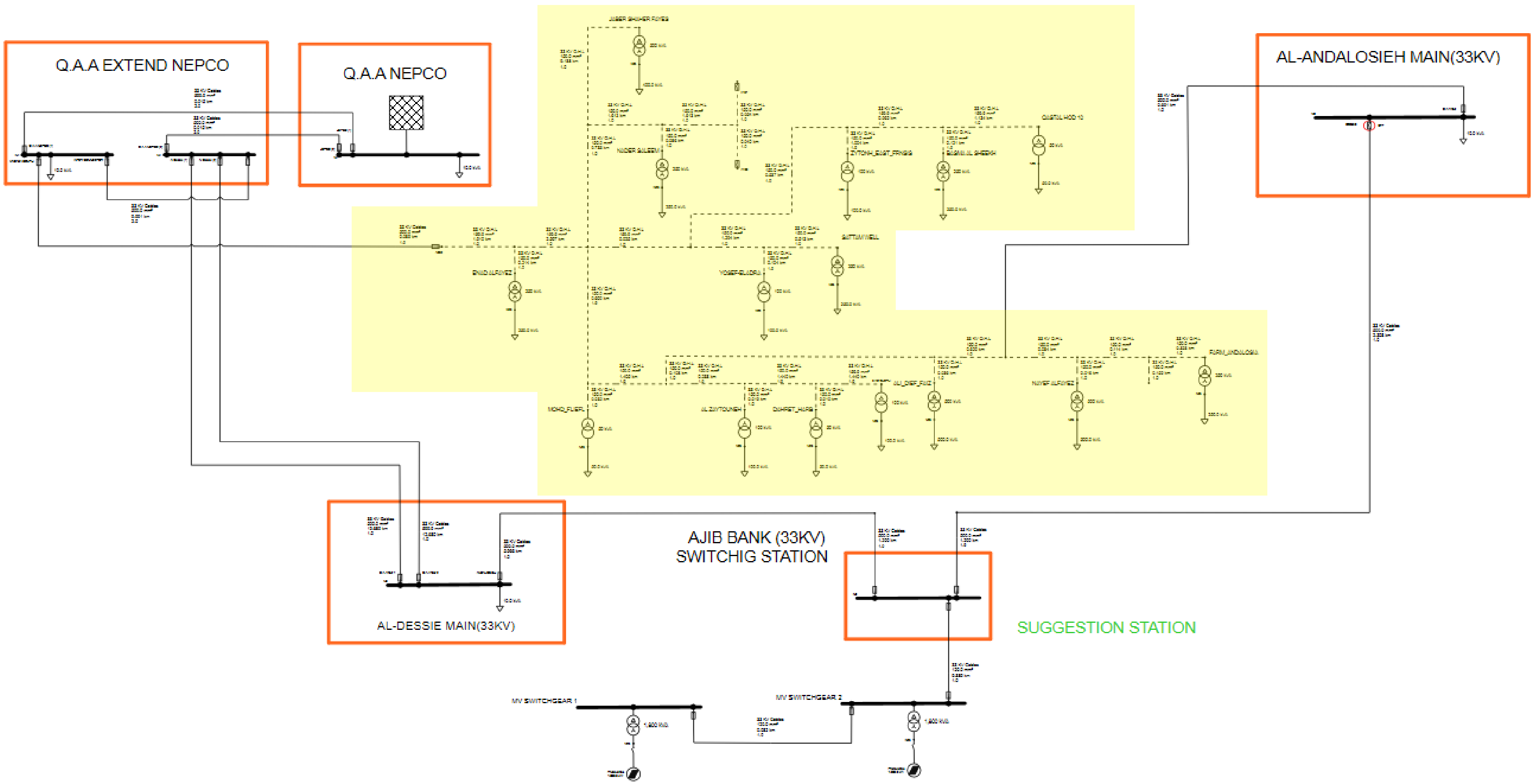
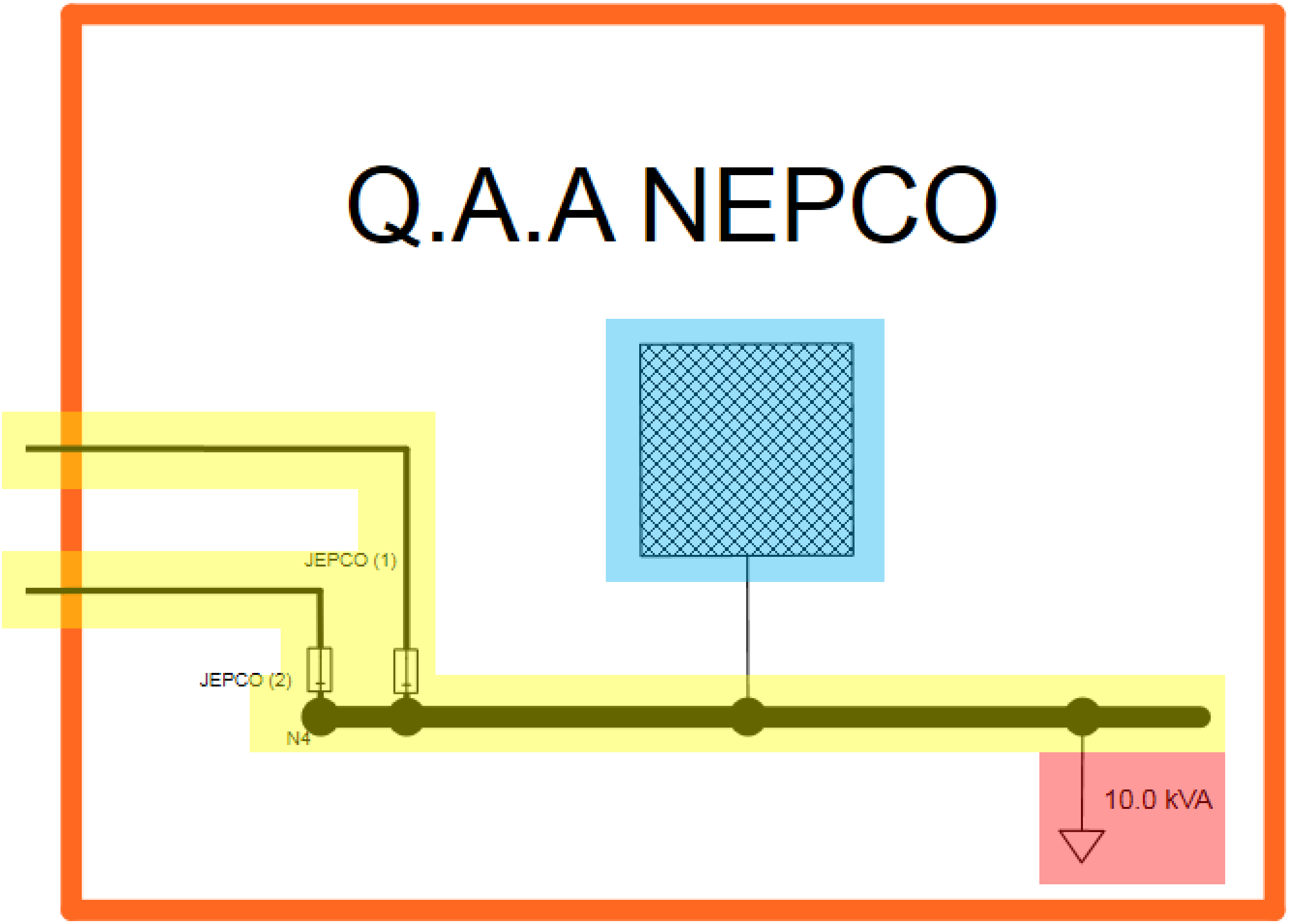
MADABA SOUTH



Q.A.A. NEPCO



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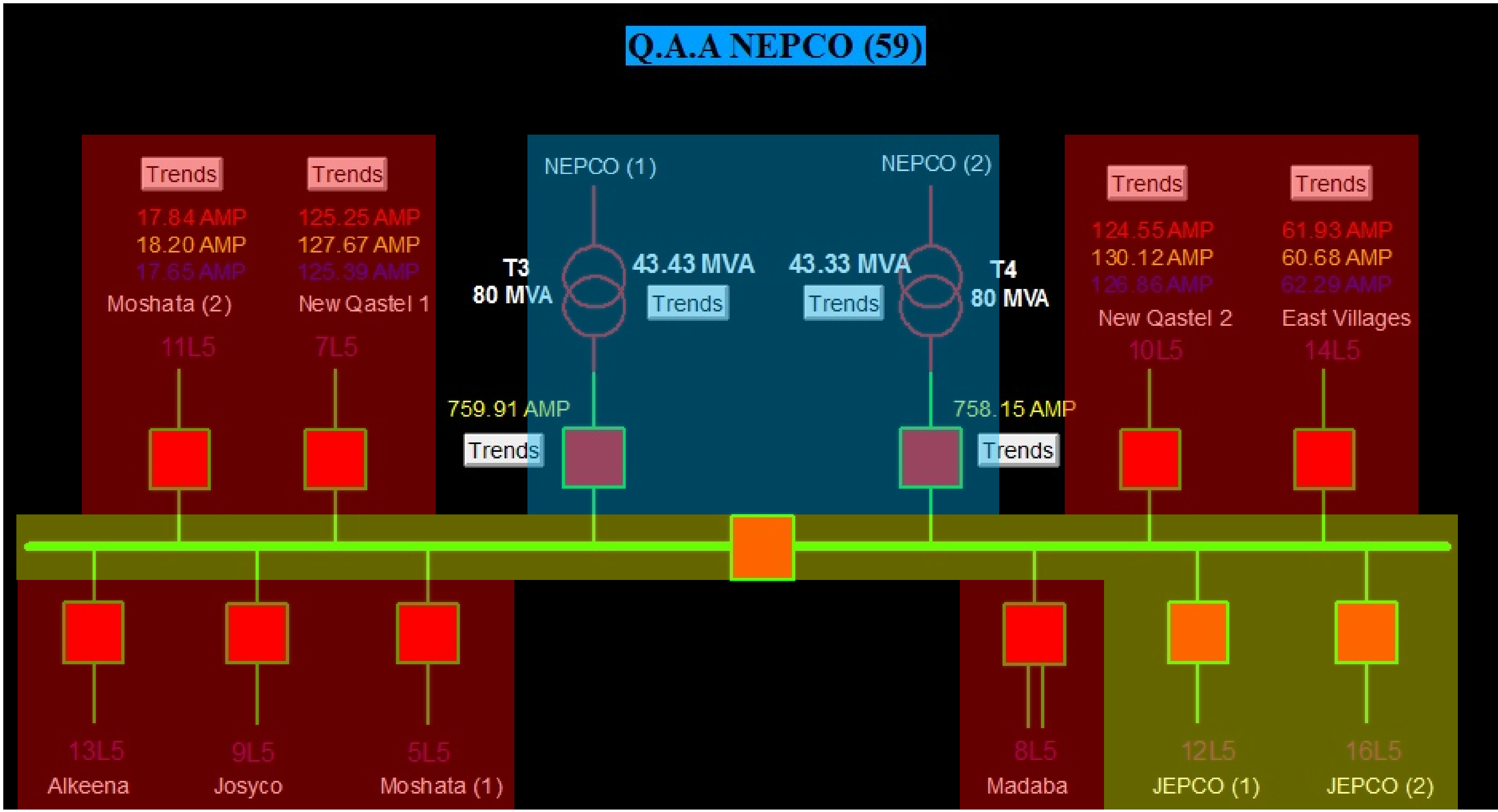
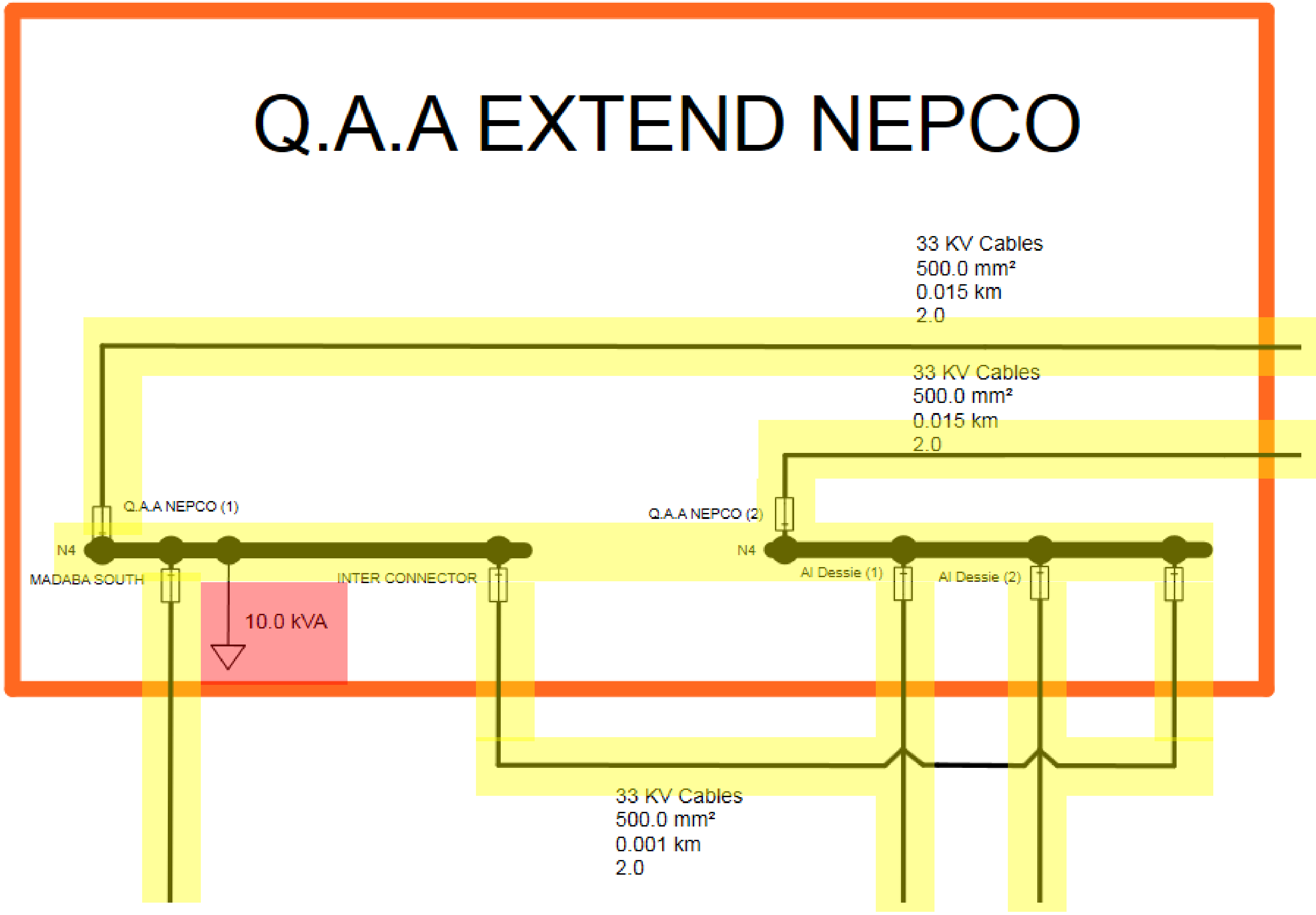
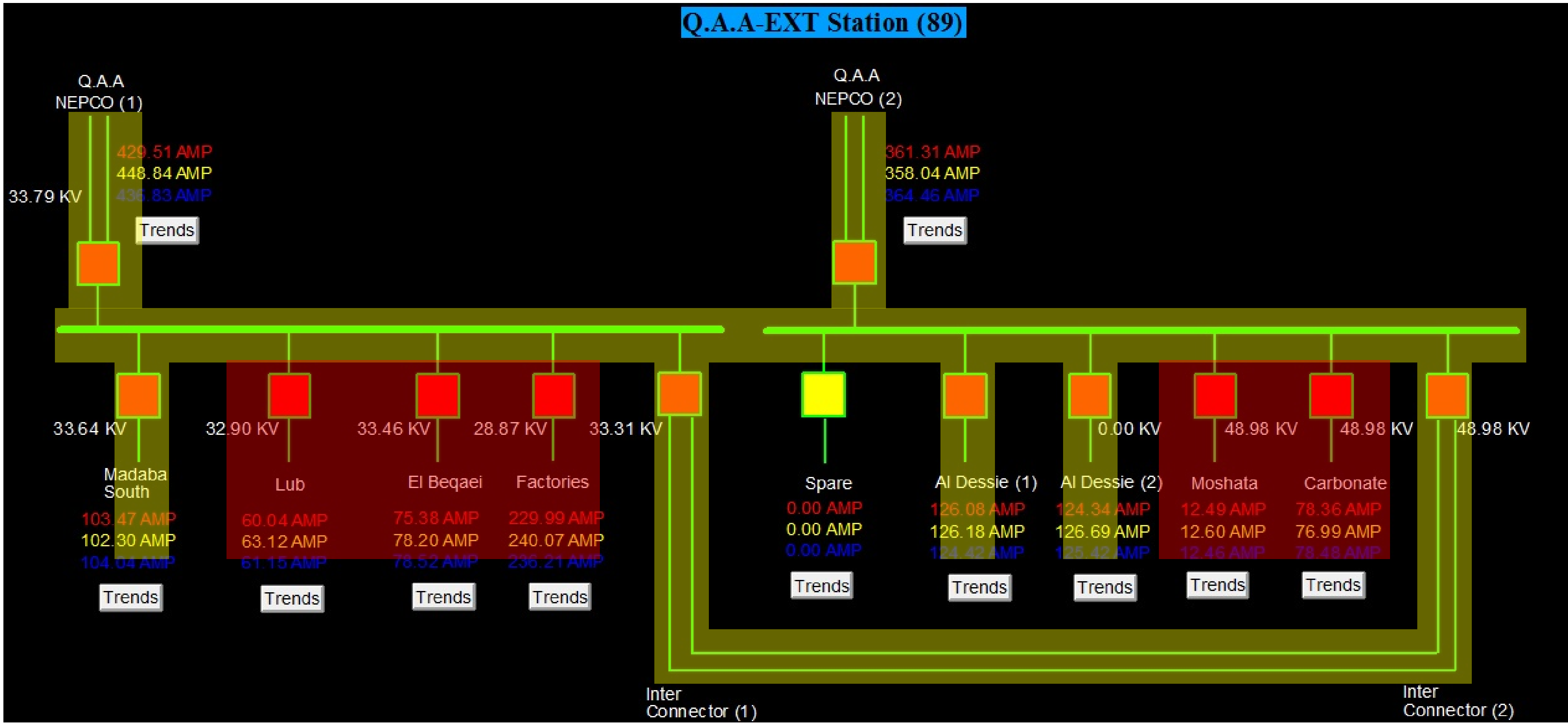


Q.A.A. Extended NEPCO




Q.A.A-EXT Station (89)
Q.A.A
NEPCO (1)
429.51 AMP
448.84 AMP
436.83 AMP
33.79 KV
Trends
Q.A.A
NEPCO (2)
361.31 AMP
358.04 AMP
364.46 AMP
Trends
33.64 KV
32.90 KV
33.46 KV
28.87 KV
33.31 KV
0.00 KV
48.98 KV
48.98 KV
48.98 KV
Madaba
South
103.47 AMP
102.30 AMP
104.04 AMP
Trends
Lub
60.04 AMP
63.12 AMP
61.15 AMP
Trends
El Beqaei
75.38 AMP
78.20 AMP
78.52 AMP
Trends
Factories
229.99 AMP
240.07 AMP
236.21 AMP
Trends
Spare
0.00 AMP
0.00 AMP
0.00 AMP
Trends
Al Dessie (1)
126.08 AMP
126.18 AMP
124.42 AMP
Trends
Al Dessie (2)
124.34 AMP
126.69 AMP
125.42 AMP
Trends
Moshata
12.49 AMP
12.60 AMP
12.46 AMP
Trends
Carbonate
78.36 AMP
76.99 AMP
78.48 AMP
Trends
Inter
Connector (1)
Inter
Connector (2)

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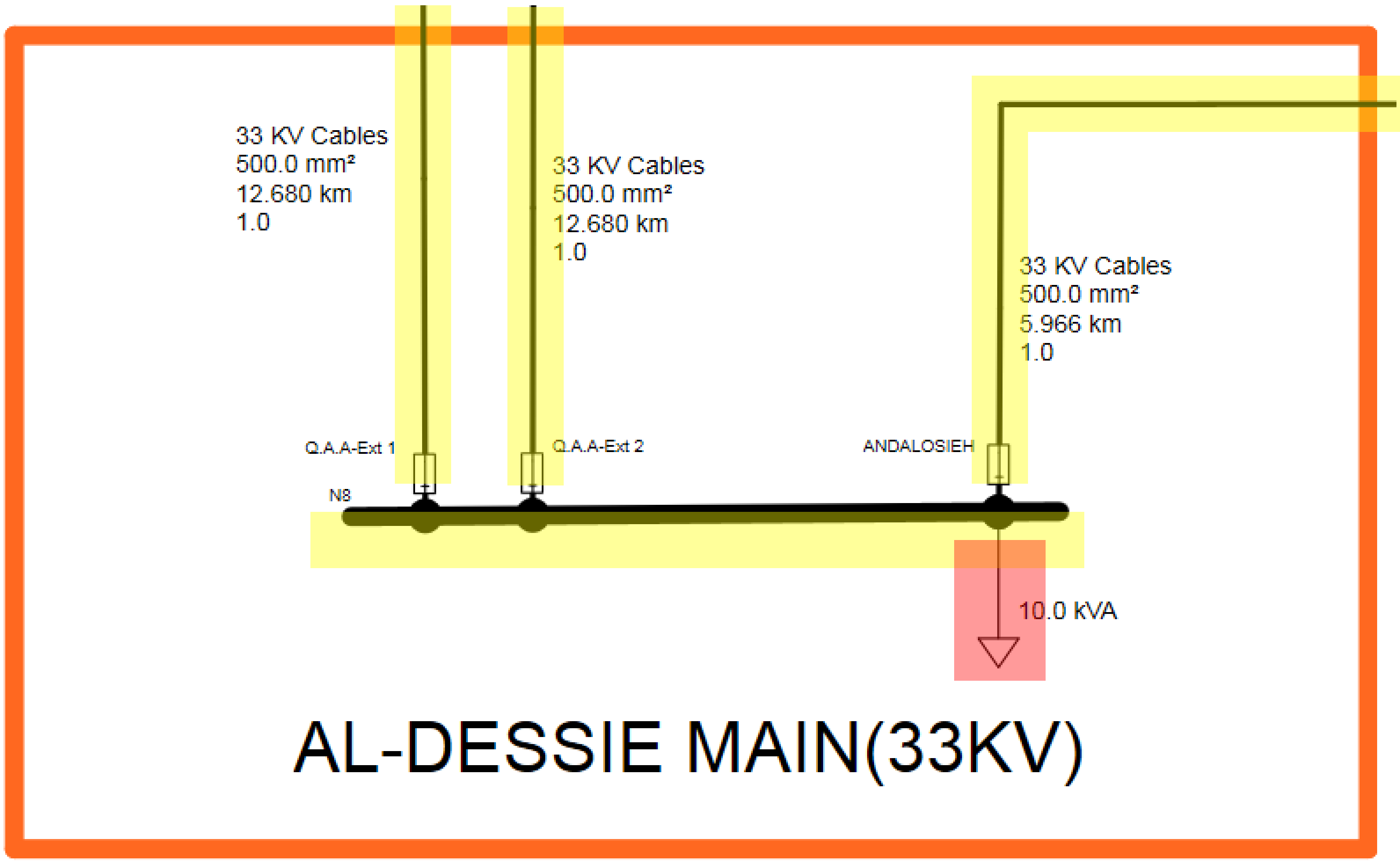
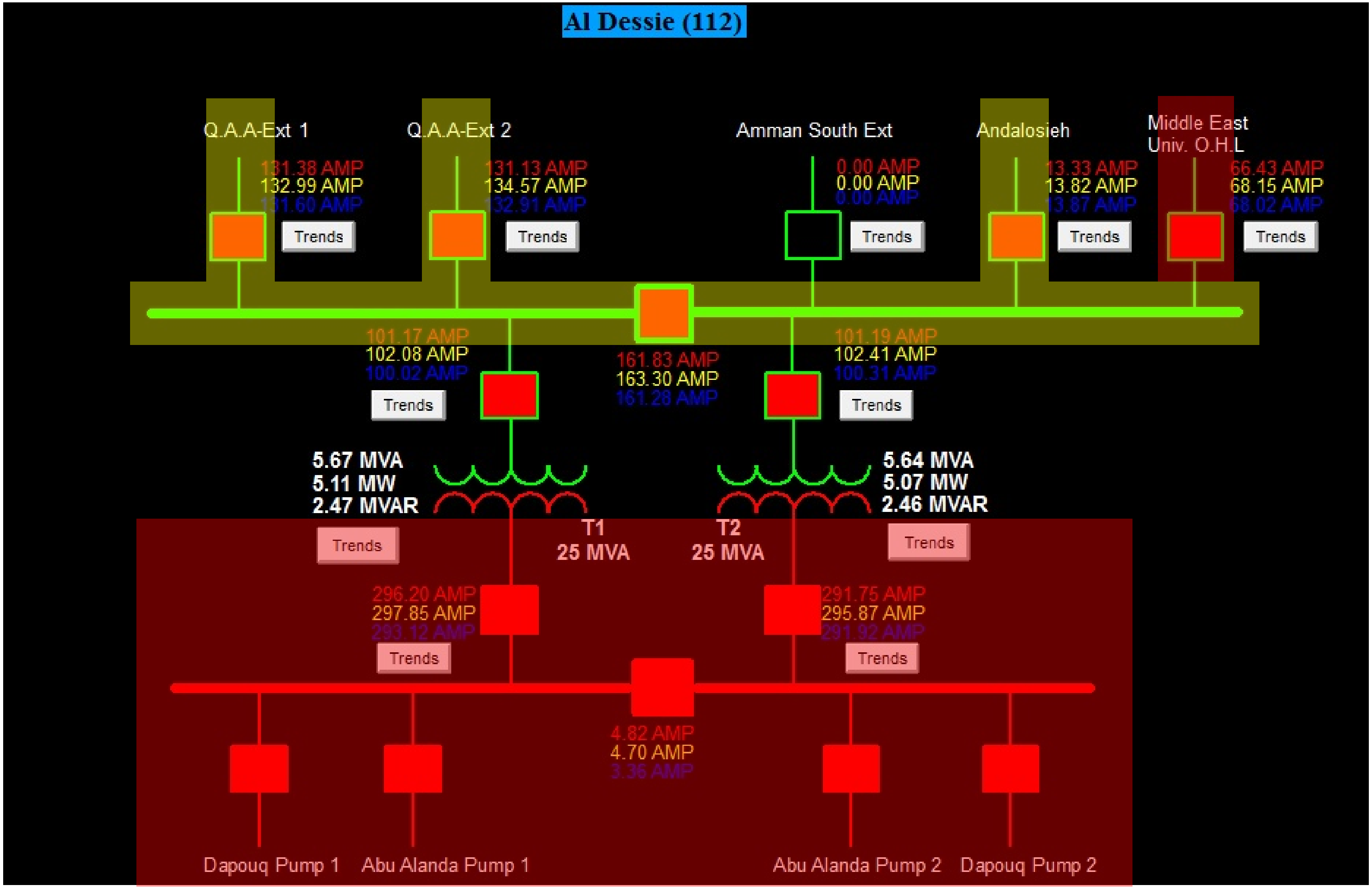
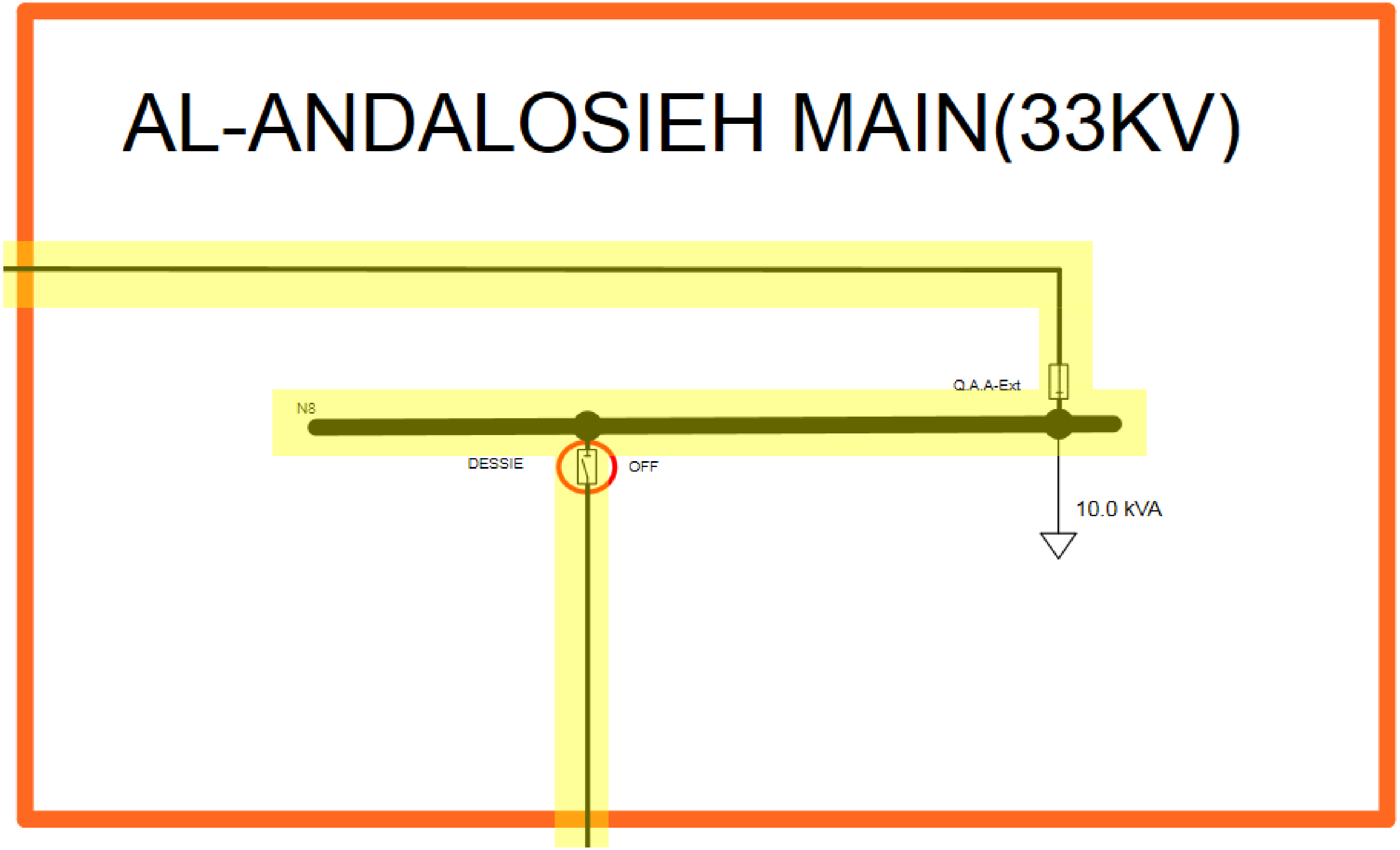
AL DESSIE MAIN




Al Dessie (112)
Q.A.A-Ext 1
131.38 AMP
132.99 AMP
131.60 AMP
Trends
Q.A.A-Ext 2
131.13 AMP
134.57 AMP
132.91 AMP
Trends
Amman South Ext
0.00 AMP
0.00 AMP
0.00 AMP
Trends
Andalosieh
13.33 AMP
13.82 AMP
13.87 AMP
Trends
Middle East
Univ. O.H.L
66.43 AMP
68.15 AMP
68.02 AMP
Trends
101.17 AMP
102.08 AMP
100.02 AMP
Trends
161.83 AMP
163.30 AMP
161.28 AMP
101.19 AMP
102.41 AMP
100.31 AMP
Trends
5.67 MVA
5.11 MW
2.47 MVAR
5.64 MVA
5.07 MW
2.46 MVAR
Trends
T1
25 MVA
T2
25 MVA
Trends
296.20 AMP
297.85 AMP
293.12 AMP
Trends
291.75 AMP
295.87 AMP
291.92 AMP
Trends
4.82 AMP
4.70 AMP
3.36 AMP
Dapouq Pump 1
Abu Alanda Pump 1
Abu Alanda Pump 2
Dapouq Pump 2

AL ANDALOSIEH MAIN



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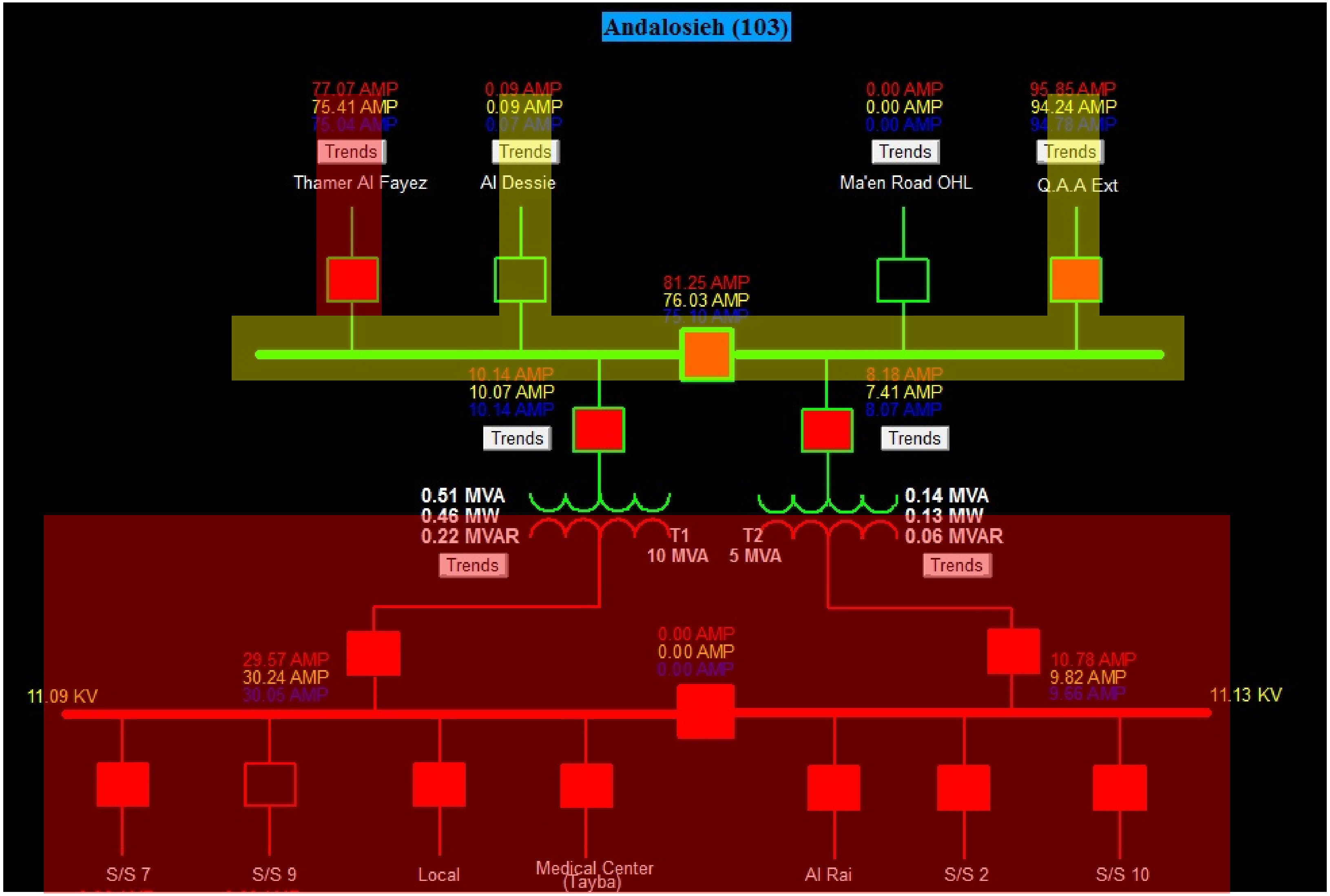

Review Existing PSS SINCAL Feeder Model

- Open “AJIB BANK STUDY-SINCAL MODEL.sin”

- Questions:
  1. What is the source voltage in percentage of nominal?
  2. What is the system short circuit MVA?
  3. What is the load power factor?
  4. What load condition does this model represent?
  5. How is voltage regulation achieved?

- Perform a load flow simulation

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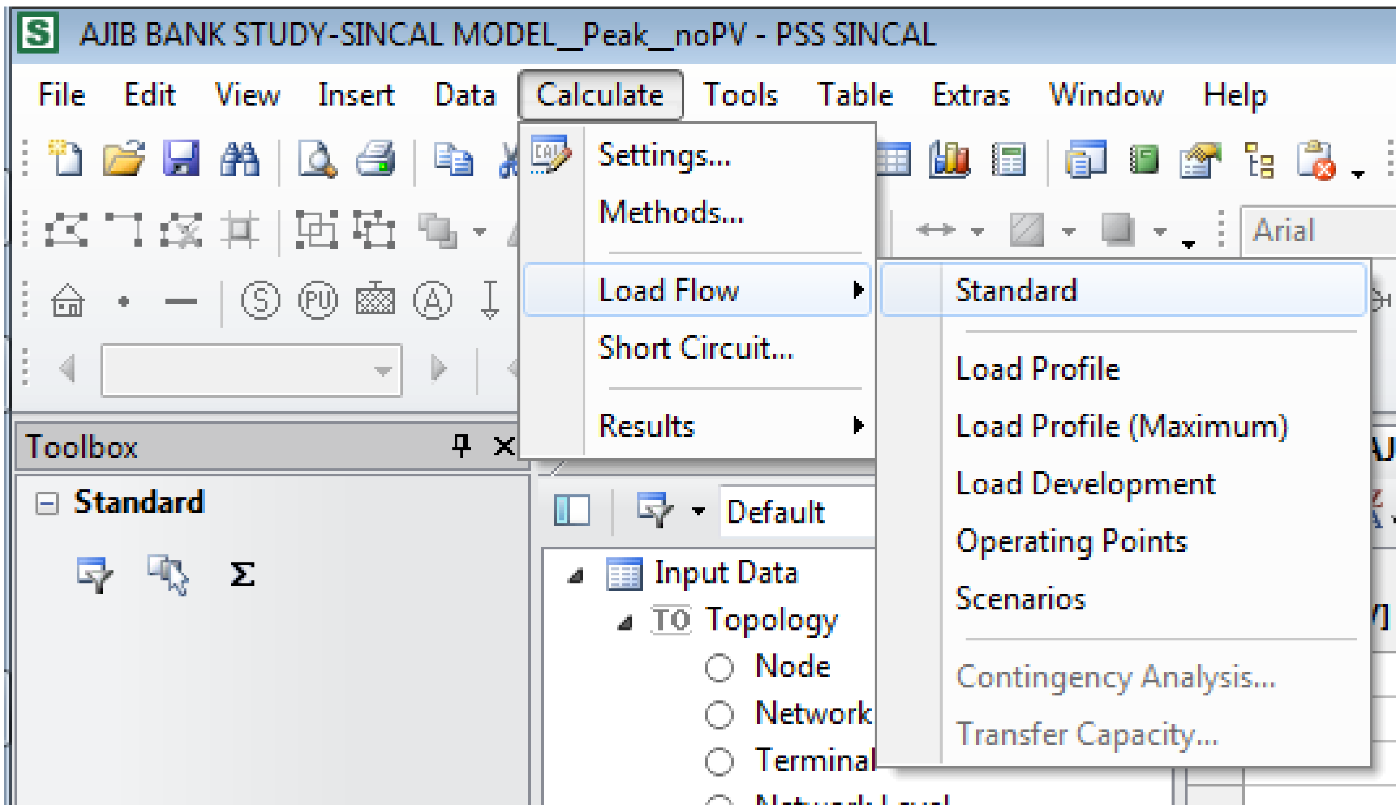
Perform Load Flow Simulation



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Project Background

- The Arab Investment Bank of Jordan (AJIB) is developing 3600 kVA PV plant in south Amman
- Seeking “Power Wheeling” mechanism in Jordan’s distribution network
- Project designed to not exceed AJIB load

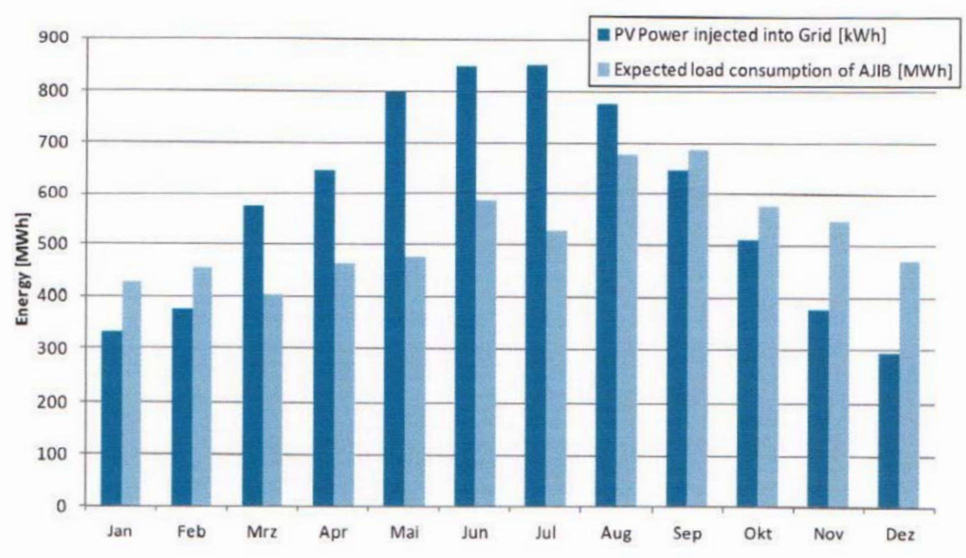

Figure 4-1: Expected PV Power and Consumption of AJIB

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Project Background

- Project Details:
  - New 33 kV switching station between Madaba and Amman
  - 6 km from the Al-Dessie Main 33 kV switching station
  - 3.5 km from the Al-Andalosieh Main 33 kV switching station (Al-Andalosieh Main end normally opened)

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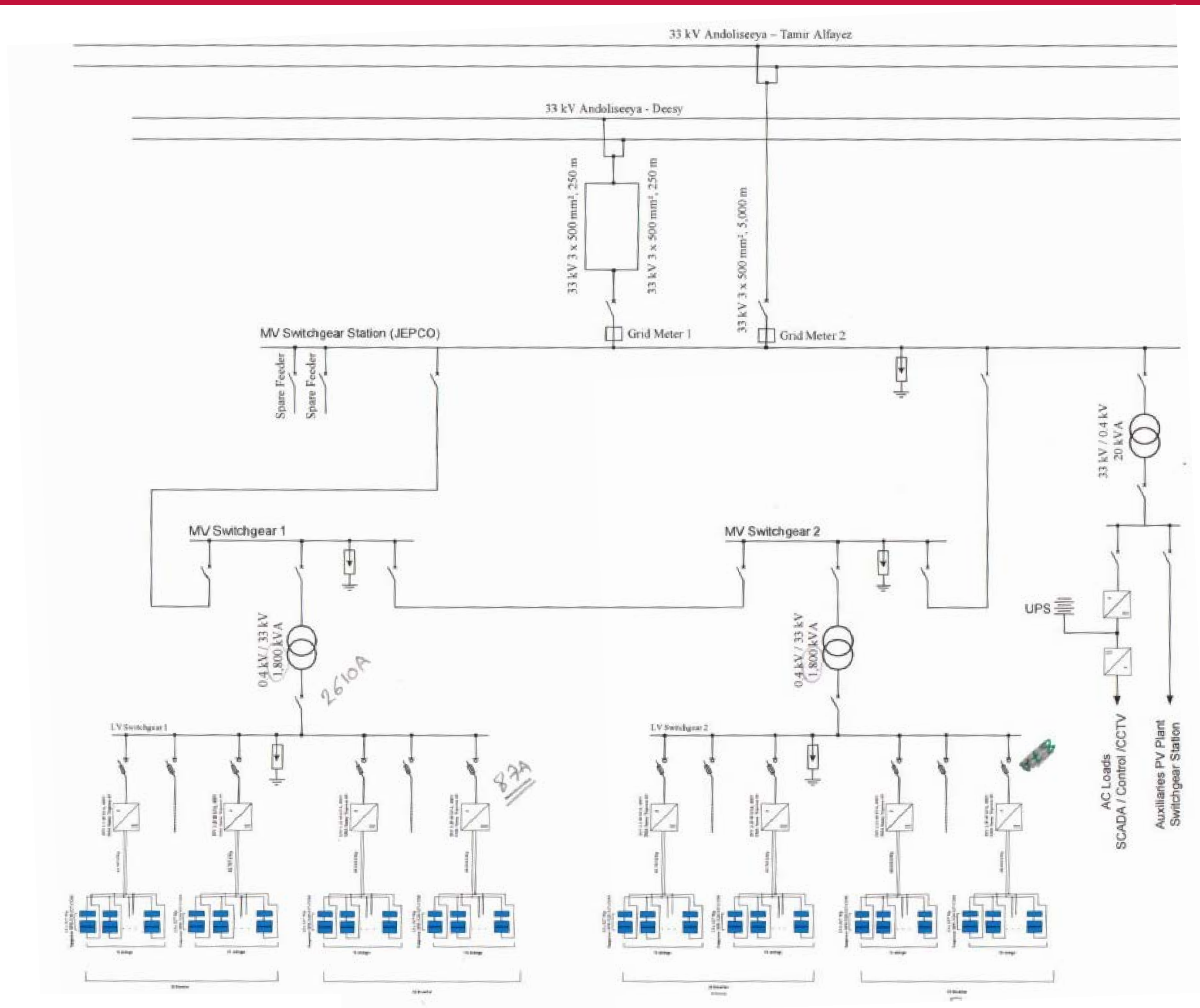
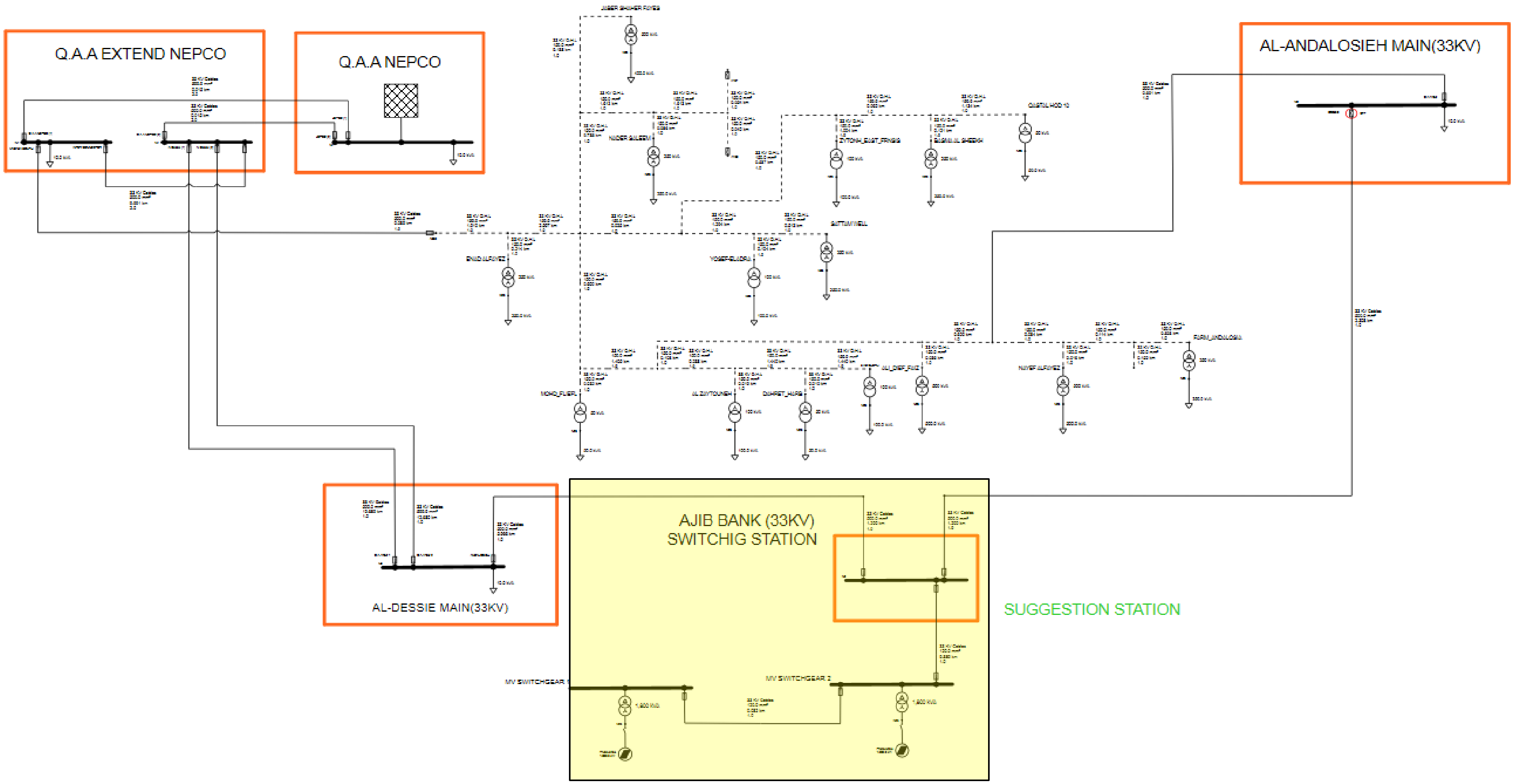


System One-Line Diagram in PSS SINCAL



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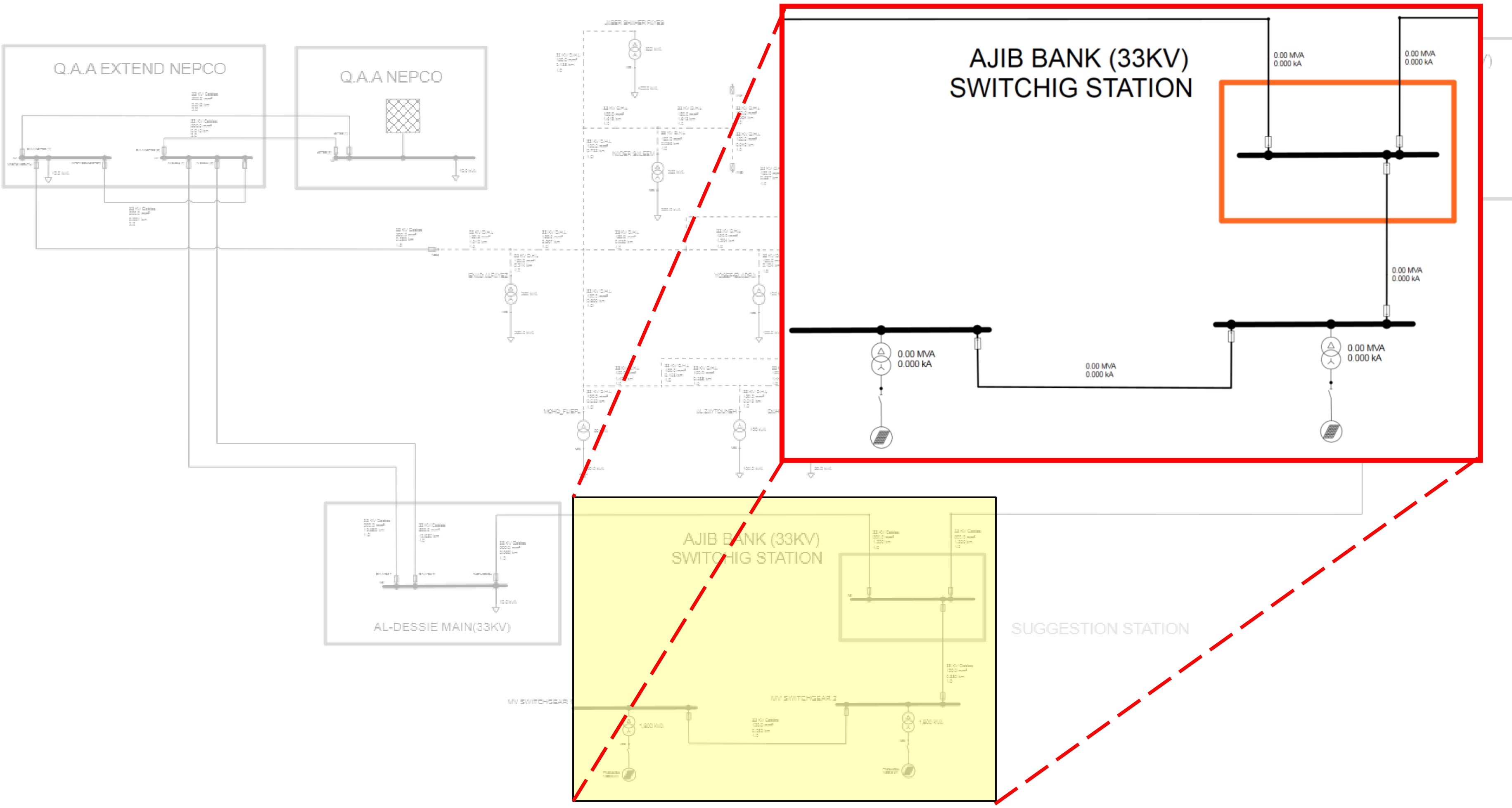
System One-Line Diagram in PSS SINCAL



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Equipment Details

- AJIB Plant Data
- PV Modules
- Inverter Data
- Inverter SC Data

AJIB PV Power Plant	Data
Installed capacity (DC peak power)	3,910.92 kWp
Total power (AC) nom. inverter output	3,600 kVA AC
Number of strings	920
PV Modules	
Manufacturer	Sunpower
Module type	SPR-X20-327-COM
Nominal power at STC	327 Wp
Technology	Monocrystalline
Number of modules	11,960
Number of modules per string	13
Mounting Structure	
Manufacturer	-
Orientation	East/West (Azimuth 88.4°, -91.6°)
Installation type	Fixed
Inclination	10°
Row distance	3 m
Inverters	
Inverter manufacturer	SMA
Inverter type	Sunny Tripower 60
Nominal output power	60 kVA
Number of inverters	60
Number of strings per inverter	15 x 40 / 16 x 20
Voltage	400 V (3 phase)
Frequency	50 Hz
Cabling	
DC ohmic losses	0.5% (STC)
AC losses	1.5% (STC)
Transformer	
Transformer manufacturer	Siemens
Transformer type	0.4 kV / 33 kV
Nominal power	1,800 kVA

Review Load Data

- Load and generation profiles required to perform steady state analysis
- Identify the peak and minimum load date and time
- 8760 branch flows provided by JEPCO
  - 1/11/2015 – 1/11/2016
- Peak/Minimum load date and time identified in “MODEL LOADS.txt”
- Composite load profiles will be created and discussed during the Long-Term Dynamics training

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Review Load Data

- AL DESSIE 33KV LOAD PROFILE
- ANDALOSIEH 33KV LOAD PROFILE
- Q.A.A Ext. NEPCO 33KV LOAD PROFILE
- Q.A.A NEPCO 33KV LOAD PROFILE
- MODEL LOADS

Generator Profile

- Solar data was not available at the time of the study
- Black & Veatch utilized the PV profiles from the IDECO project
- The IDECO profiles were per-unitized so they can be applied to this project
- <u>Generator Profile</u>

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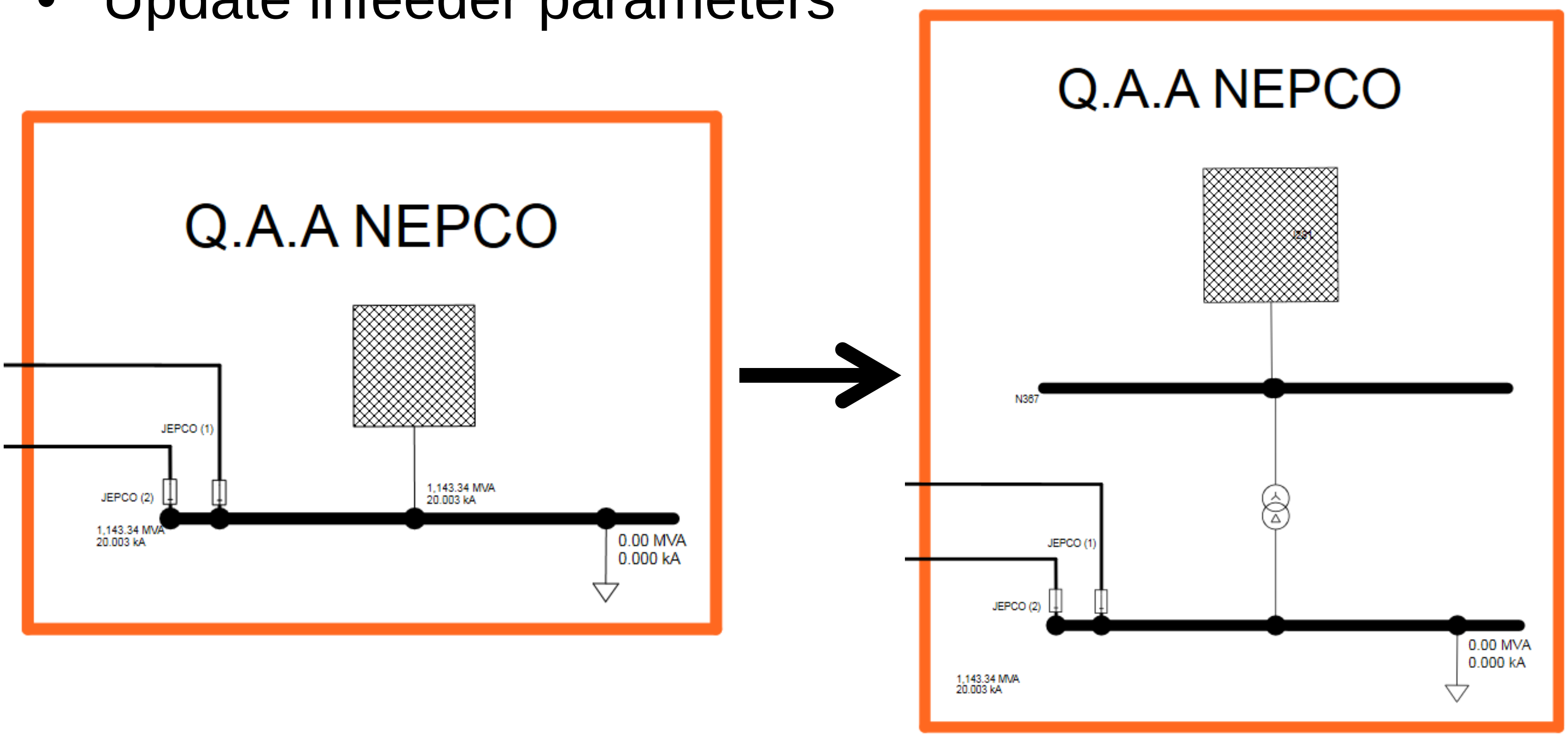
Model Updates

- Include 132/33 kV transformer
- Update infeeder parameters



Setting up the Model: 132/33 kV Transformer

- Two-Winding Transformer parameter assumptions:
  - Apparent Power Rating: 100 MVA
  - Impedance Voltage at Rated Current: 6%
  - R/X Ratio: 4%
  - Vector Group: DNY11
  - Assume $Z_1 = Z_0$
  - Fixed secondary taps (95% to 105%, 2.5% steps)
  - Adjust secondary tap position to maintain approximately nominal voltage at the 33 kV bus

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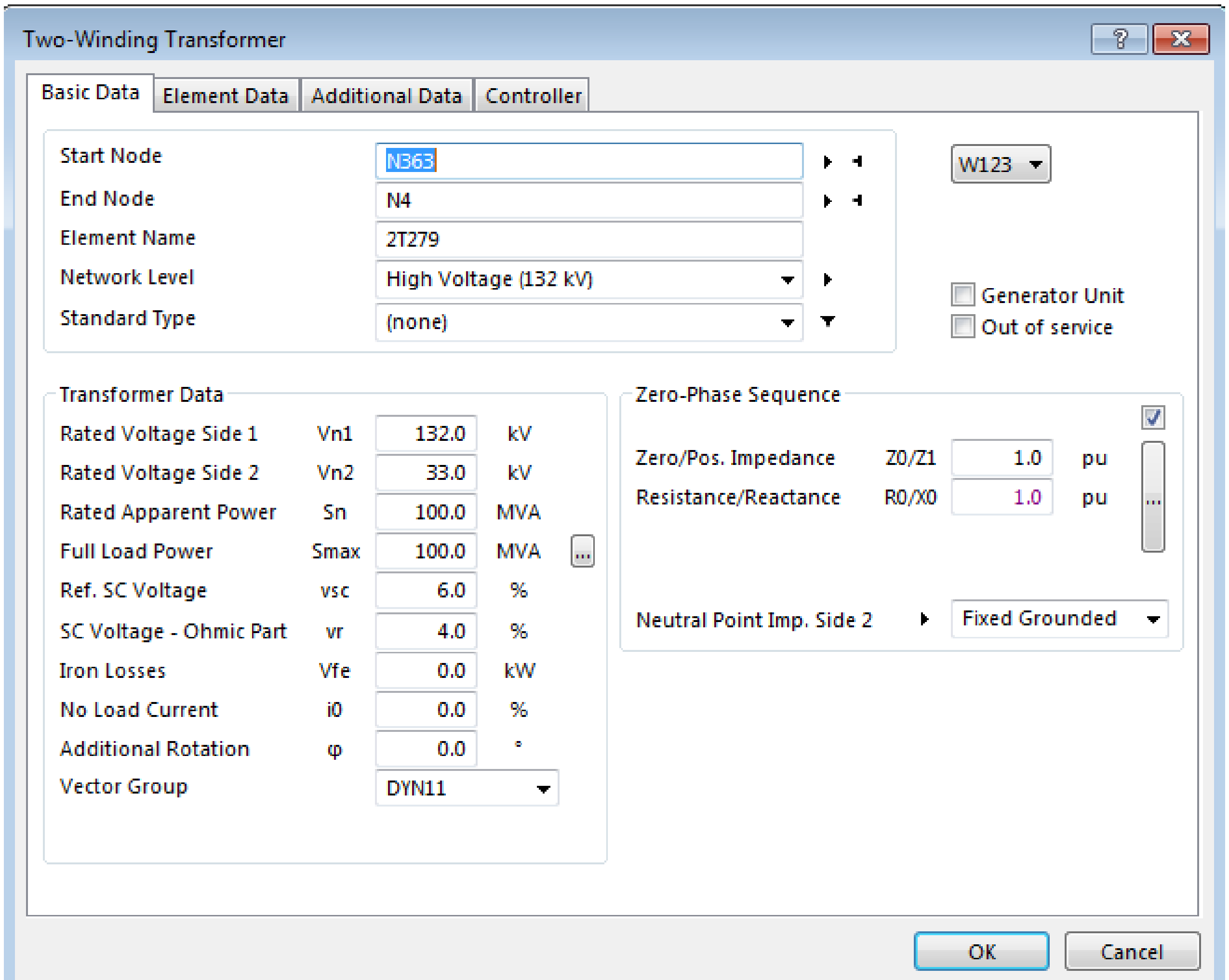
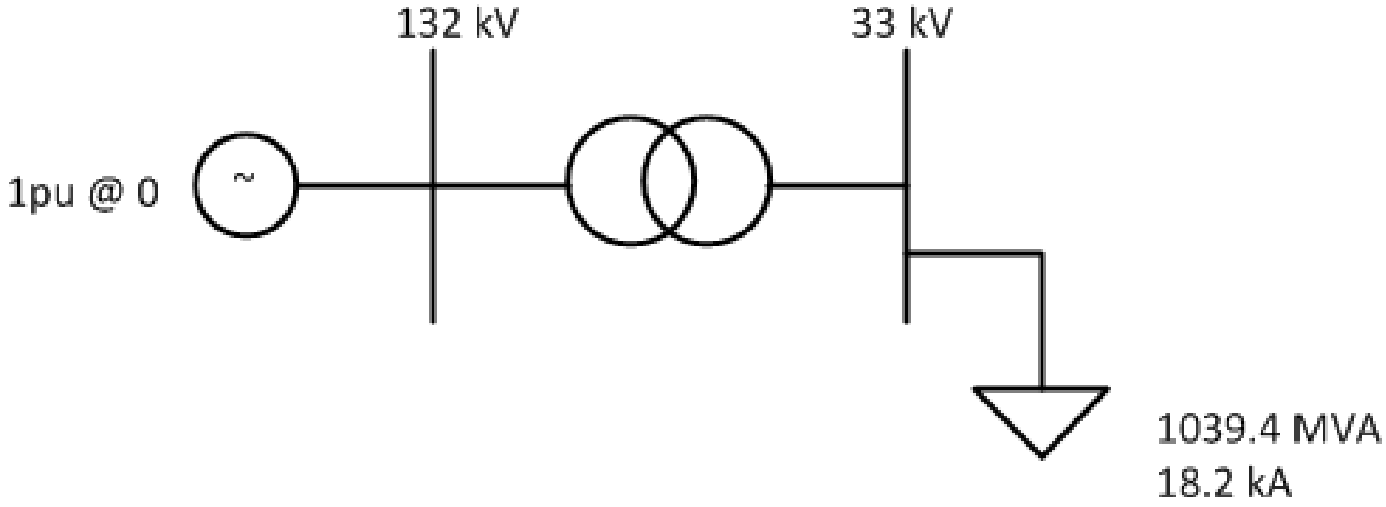
Setting up the Model: 132/33 kV Transformer



Update Infeeder Parameters

- $SC_{MVA} = 1039.4\ MVA\ at\ 33\ kV$



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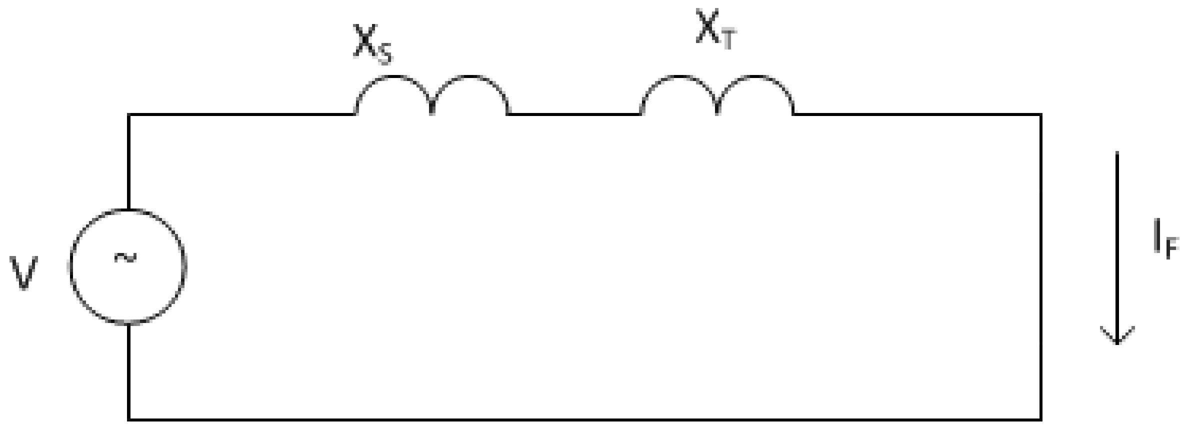
Update Infeeder Parameters

- $S_{BASE} = 100\ MVA$
- $I_{BASE} = \dfrac{100\ MVA}{\sqrt{3}\ 33\ kV} = 1749.5\ A$
- $I_{F,pu} = \dfrac{18.2\ kA}{1.75\ kA} = 10.39\ pu$



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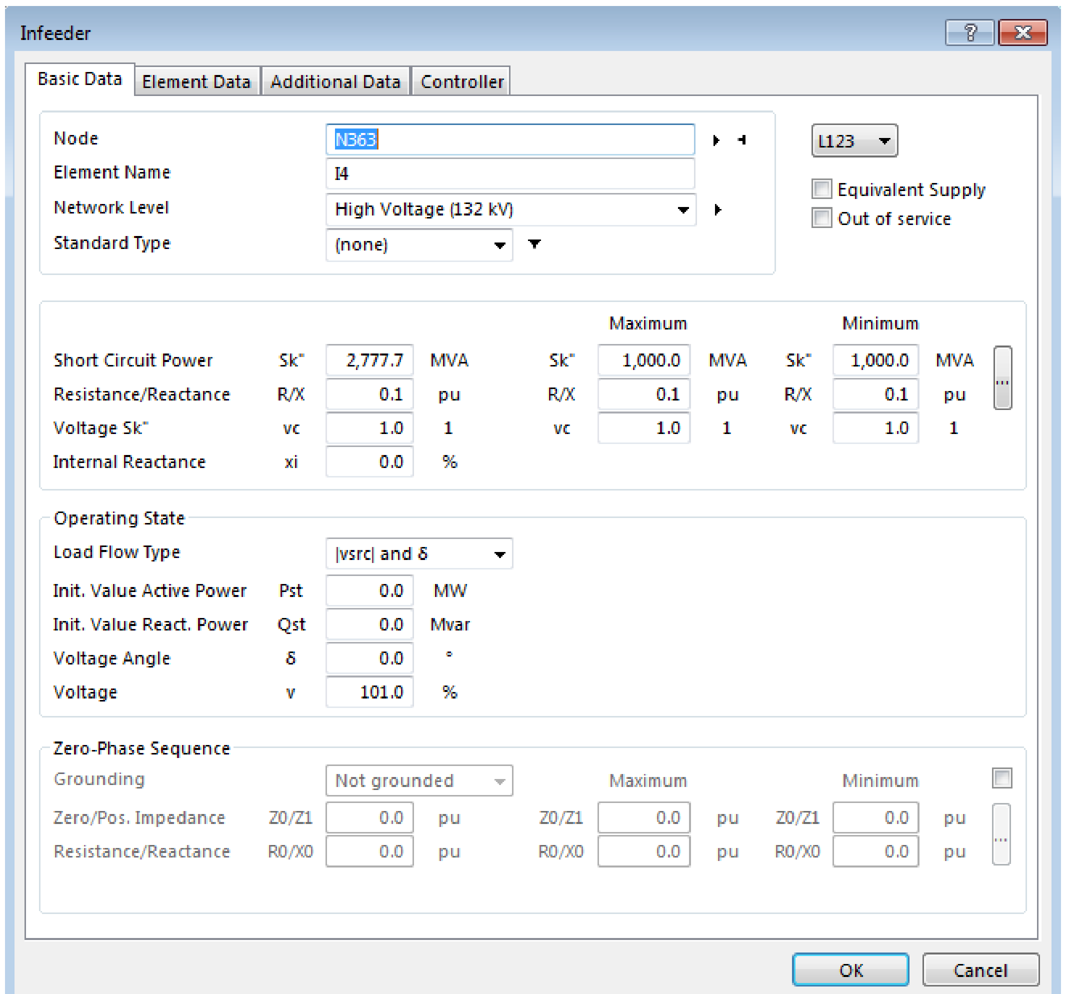
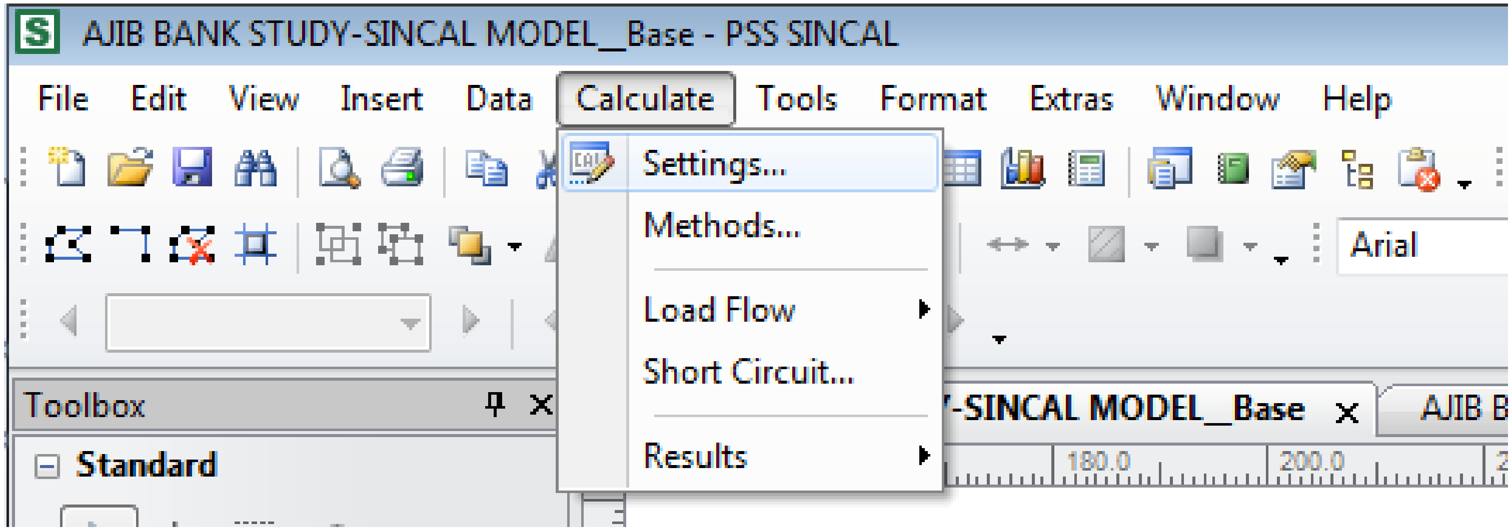
Update Infeeder Parameters

- $I_F = \frac{V}{X_S+X_T} = 10.39\ pu = \frac{1}{X_S+X_T}$
- $X_S + X_T = 0.096\ pu$
- Assume $X_T = 0.06$
- $SC_{MVA,new} = \frac{V}{X_S} = \frac{1}{0.036} = 27.7\ pu = 2777.7\ MVA$

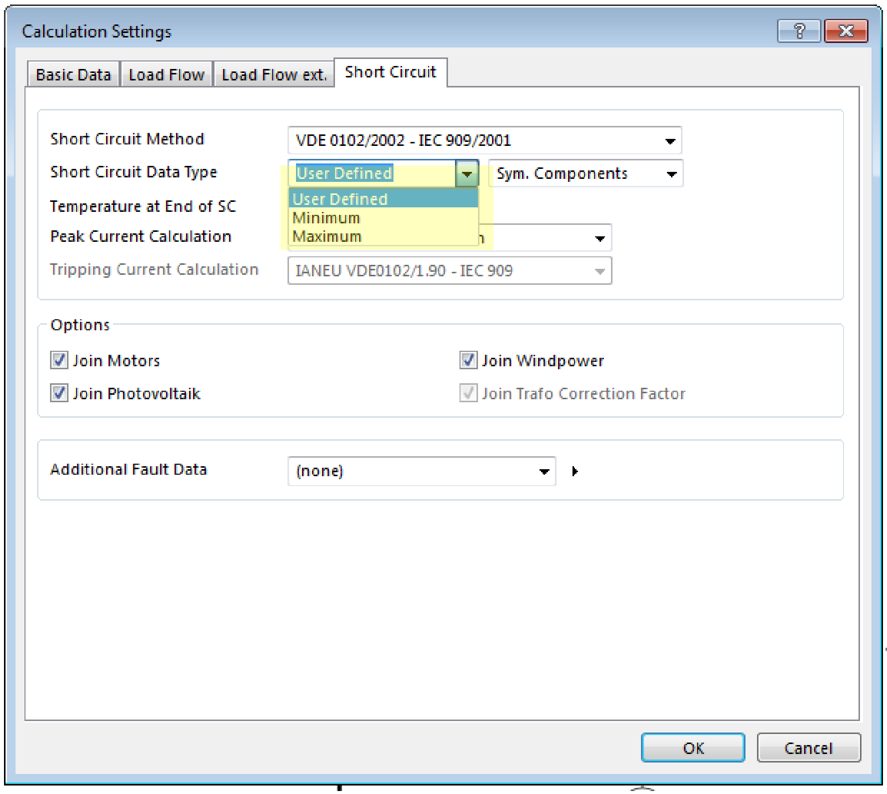
Update Infeeder Parameters

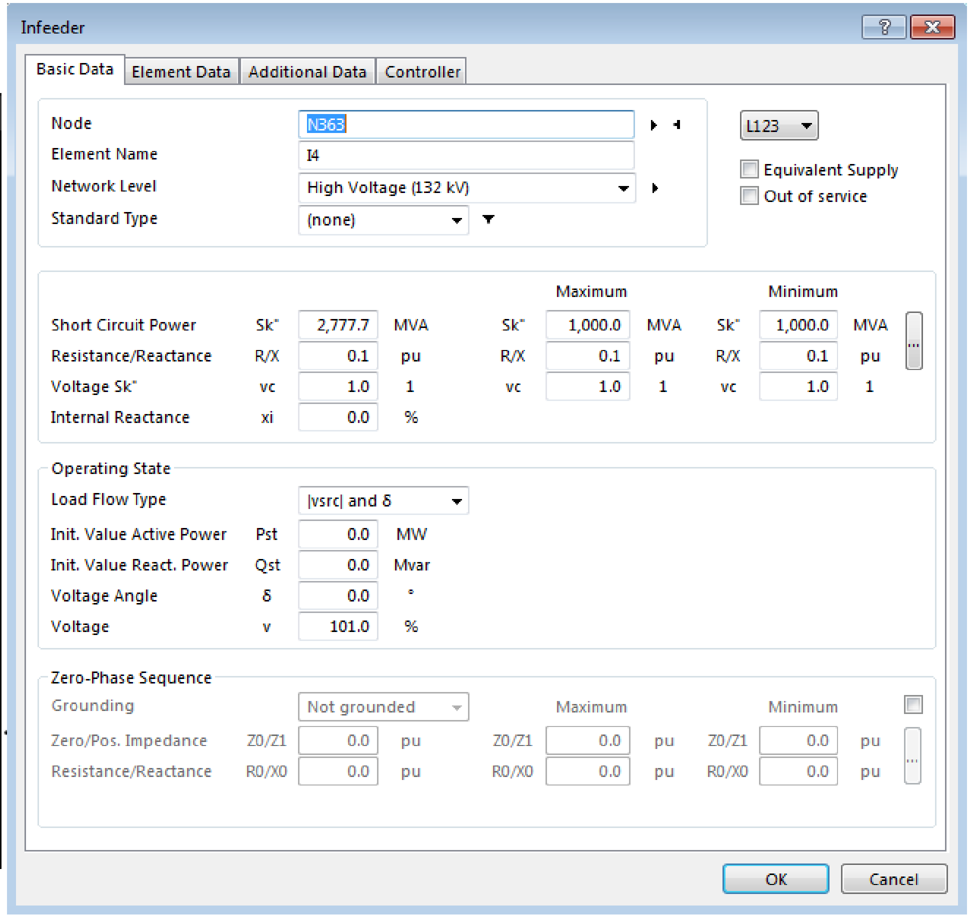


Check Short Circuit Calculation Settings



Check Short Circuit Calculation Settings

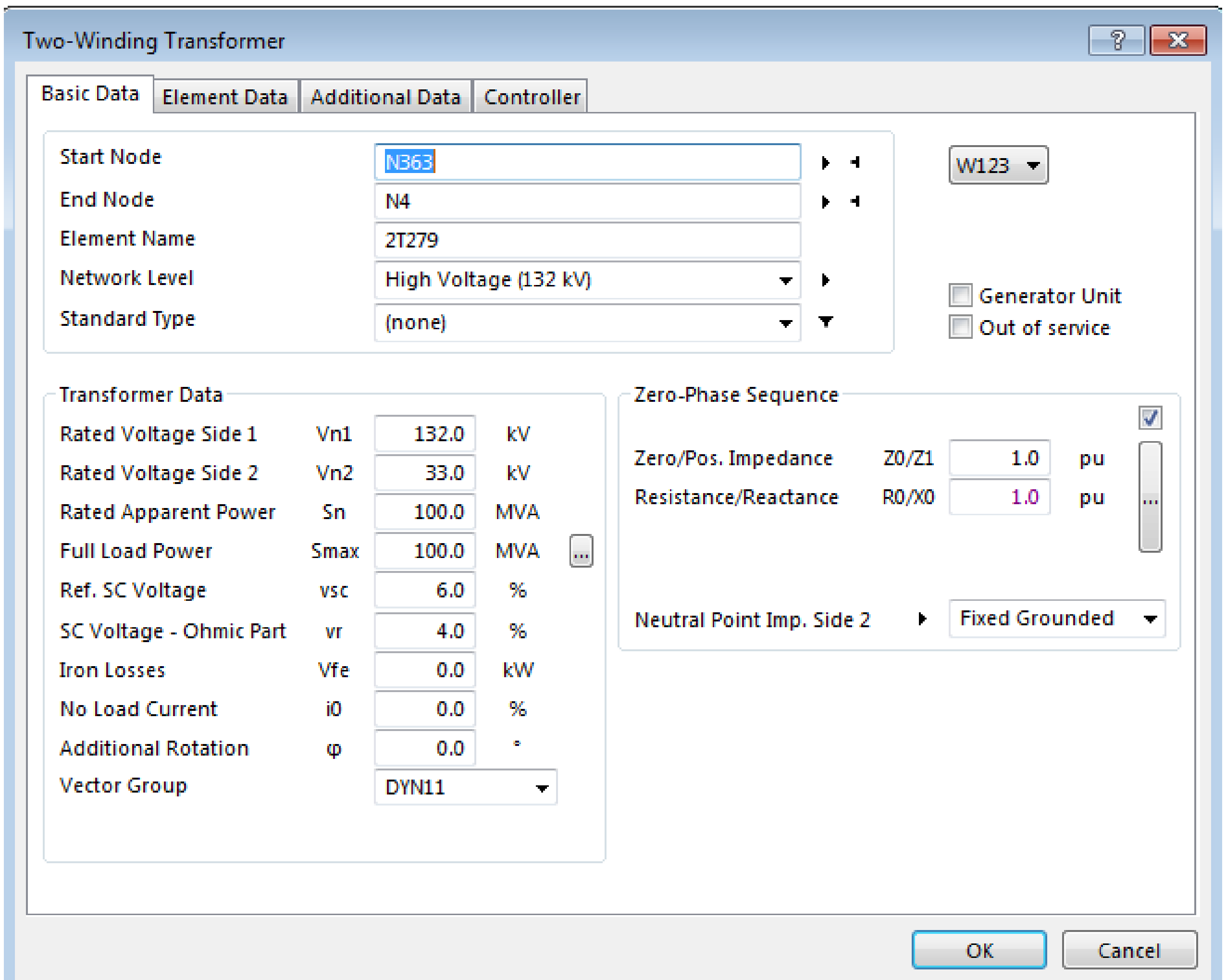




Model Updates

- Run Load Flow simulation
  - Check voltage at Q.A.A. NEPCO 33 kV bus
  - Check 132/33 kV transformer tap settings
  - Compare with original case

Model Updates



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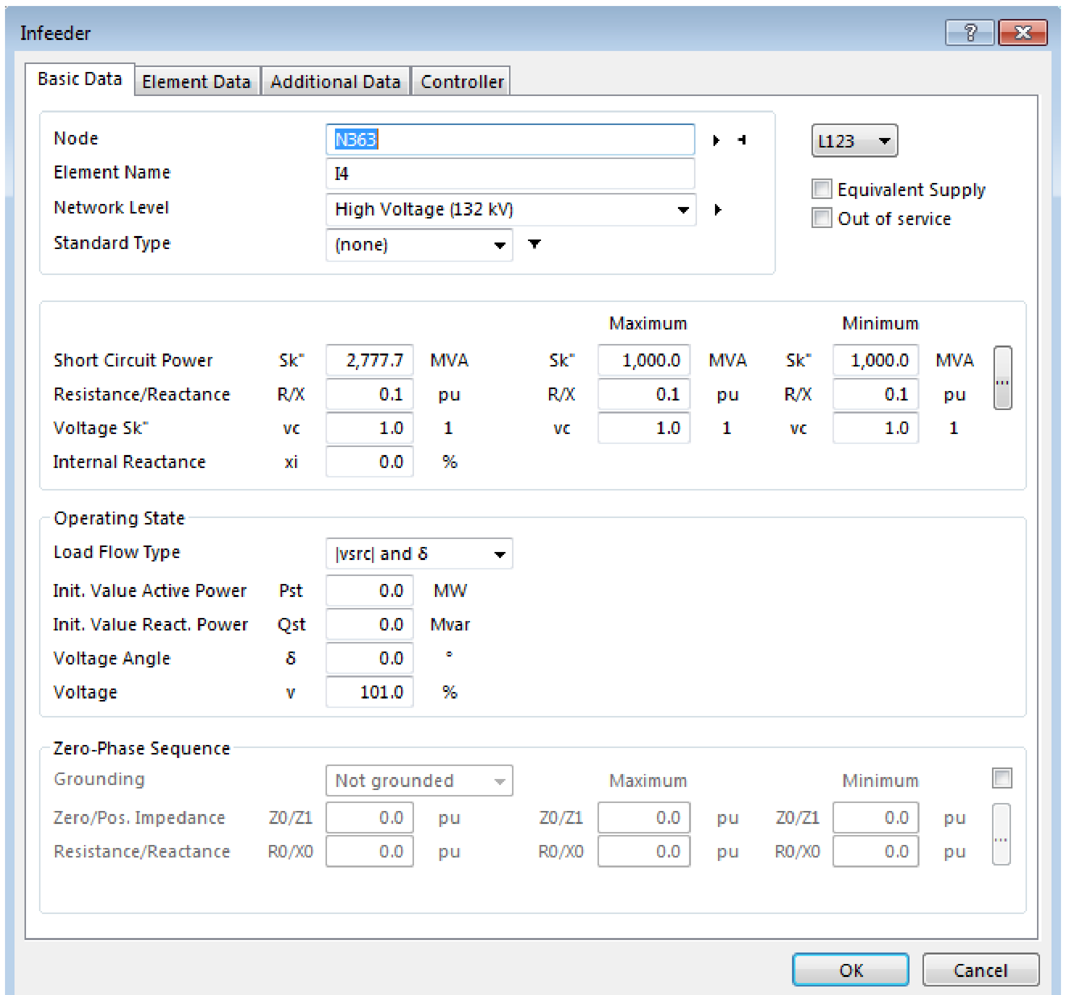
Model Updates



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Model Updates

- Save your model as:
  - AJIB BANK STUDY-SINCAL MODEL__Base.sin

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Review of MRR-DCC-MV Criteria

- IRR must be able to operate in reactive power control mode and follow operating point within 0.88 lag power factor to 0.88 lead power factor at the PCC
- Full 0.88 lagging reactive capability shall be available at 100% to 95% of nominal voltage
- Full leading reactive capability of 0.95 power factor shall be made available at 100% to 105% of nominal voltage
- The reactive power support must be dynamic up to the plant's rated capacity
- Maximum step voltage change at PCC limited to 3%

Review of MRR-DCC-MV Criteria
Required PQ Capability

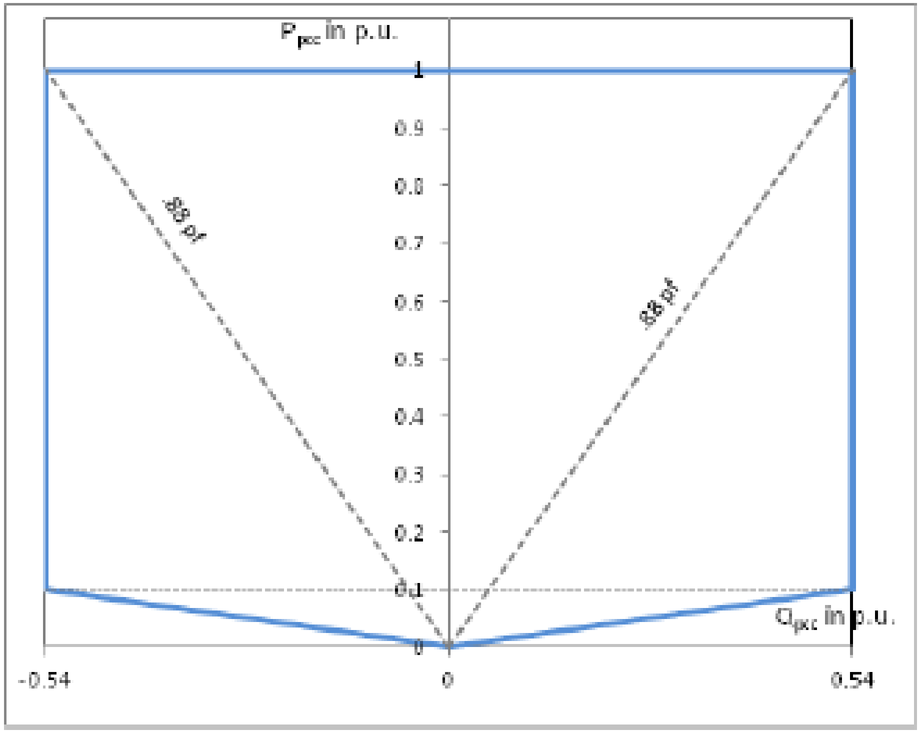

Figure 5-3 - Minimum PQ Diagram to be Fulfilled by IRR plant

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Review of MRR-DCC-MV Criteria
Voltage Tolerance at PCC

Table 5-1 –IRR Plant Voltage Protection Setting Requirements at the PCC

Voltage Range (% $V_{nominal}$)	Delay to Trip
V= 119%	0.5s
V= 114%	1s
$90 \leq V \leq 110$	Continuous Operation
V = 87%	2.5s
V = 81%	0.5s

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Load Flow Analysis Part 1 – Steady State Analysis

- Steady State analysis is a static analysis:
  - Load flow calculations performed at fixed load and generation values…snapshot in time
- (4) Study Cases:
  - Case 1: minimum load, AJIB offline
  - Case 2: minimum load, AJIB at nameplate output
  - Case 3: peak load, AJIB offline
  - Case 4: peak load, AJIB at nameplate output
- Assess system performance with and without the AJIB PV plant

Load Flow Analysis Part 1 – Steady State Analysis

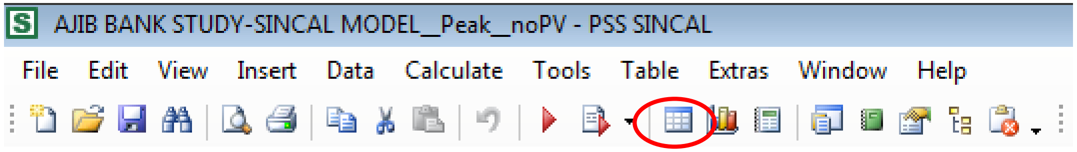
- (3) Scenarios per Study Case, (8) runs total
  - PV operating at 0.88 leading pf
  - PV operating at 1.0 pf
  - PV operating at 0.88 lagging pf
- Voltage Step Limit Requirement: Calculate step change in PCC voltage between Case 1 and 2, and Case 3 and 4 for all scenarios
- Calculate losses for each of the cases
- Monitor for reverse power flow at the distribution substation for each case
- Monitor all lines, cables, and transformers for thermal overloads for each case

Create Study Cases

- Open the model:
  - AJIB BANK STUDY-SINCAL MODEL__Base.sin
- Create the following cases:
  - AJIB BANK STUDY-SINCAL MODEL__Peak__noPV
  - AJIB BANK STUDY-SINCAL MODEL__Peak__MaxPV__100
  - AJIB BANK STUDY-SINCAL MODEL__Peak__MaxPV__88lag
  - AJIB BANK STUDY-SINCAL MODEL__Peak__MaxPV__88lead
  - AJIB BANK STUDY-SINCAL MODEL__Min__noPV
  - AJIB BANK STUDY-SINCAL MODEL__Min__MaxPV__100
  - AJIB BANK STUDY-SINCAL MODEL__Min__MaxPV__88lag
  - AJIB BANK STUDY-SINCAL MODEL__Min__MaxPV__88lead
- Load data available in MODEL LOADS.txt

Update Load Data in PSS SINCAL

- Check the Tabular View (F9) to see the load levels



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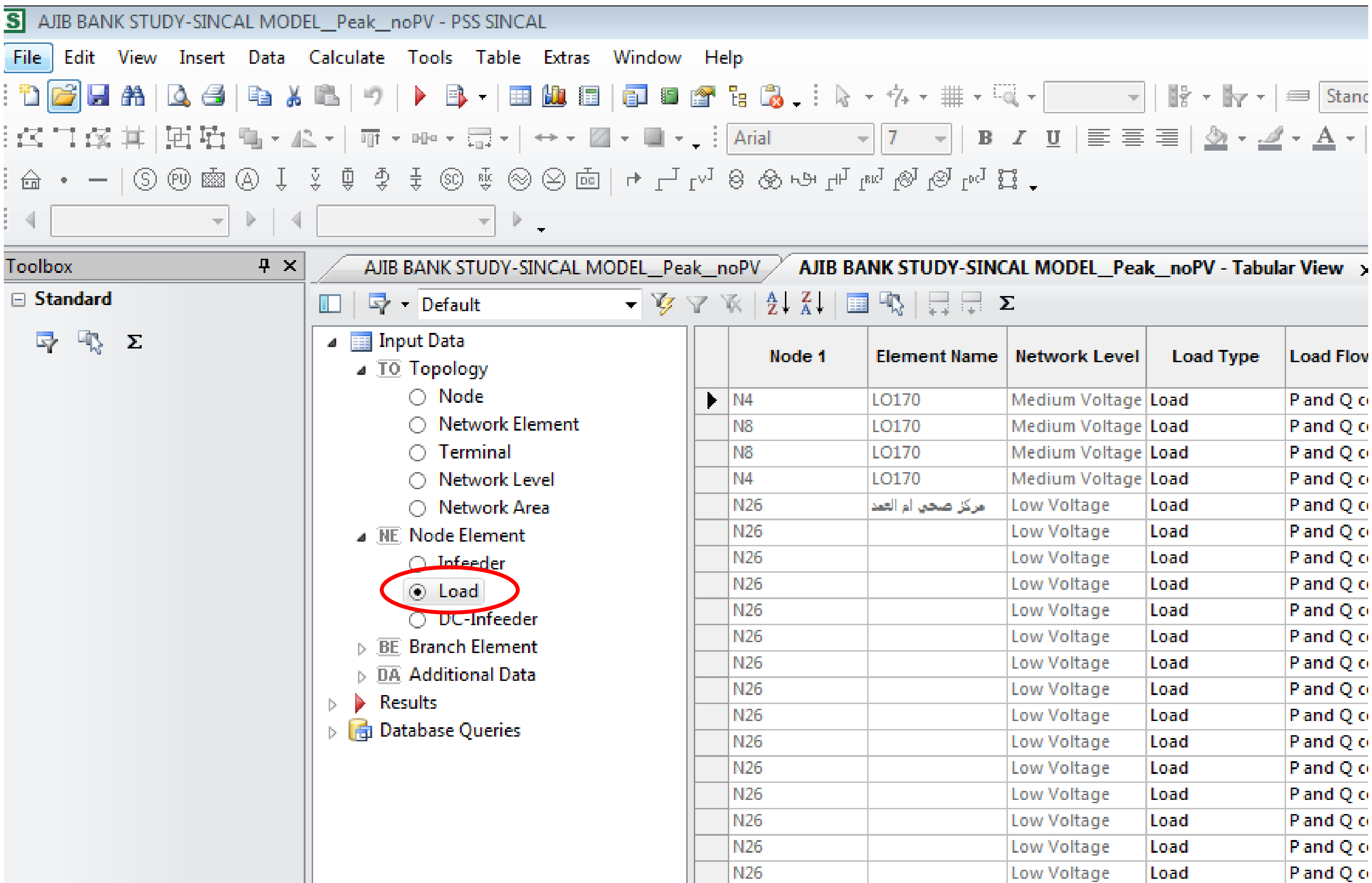
Update Loads in PSS SINCAL



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Update Loads in PSS SINCAL

- 33 kV loads specified as current, power factor, and voltage (I, cos(θ), and V)
  - 33 kV loads assumed to have 0.92 power factor
  - Current levels specified in MODEL LOADS.txt
- 0.415 kV loads specified as a factor of total connected kVA
  - 0.415 kV loads assumed to have 0.90 power factor
  - fS = 0.16 for peak load conditions
  - fS = 0.11 for minimum load conditions
  - Based on observance of current flows from:
    - Q.A.A. Extended NEPCO
    - AL ANDALOSIEH MAIN

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Update Loads in PSS SINCAL

- Updating 33 kV loads

	Node 1	Element Name	Network Level	Load Type	Load Flow Type	Load Input	P [kW]	Q [Mvar]	v [%]	V [kV]	S [MVA]	cosφ	I [kA]
▶	N4	LO170	Medium Voltage	Load	P and Q const	I, cosφ and V				33.00		0.92	0.853
	N8	LO170	Medium Voltage	Load	P and Q const	I, cosφ and V				33.00		0.92	0.087
	N8	LO170	Medium Voltage	Load	P and Q const	I, cosφ and v			100.0			0.92	0.261
	N4	LO170	Medium Voltage	Load	P and Q const	I, cosφ and V				33.00		0.92	0.577
	N26	مركز صحي ام العمد	Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.250	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.400	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.250	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.100	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.250	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.100	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.250	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.050	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.050	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.100	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.050	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.100	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.500	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.500	0.90	
	N26		Low Voltage	Load	P and Q const	S, cosφ and V				0.41	0.250	0.90	

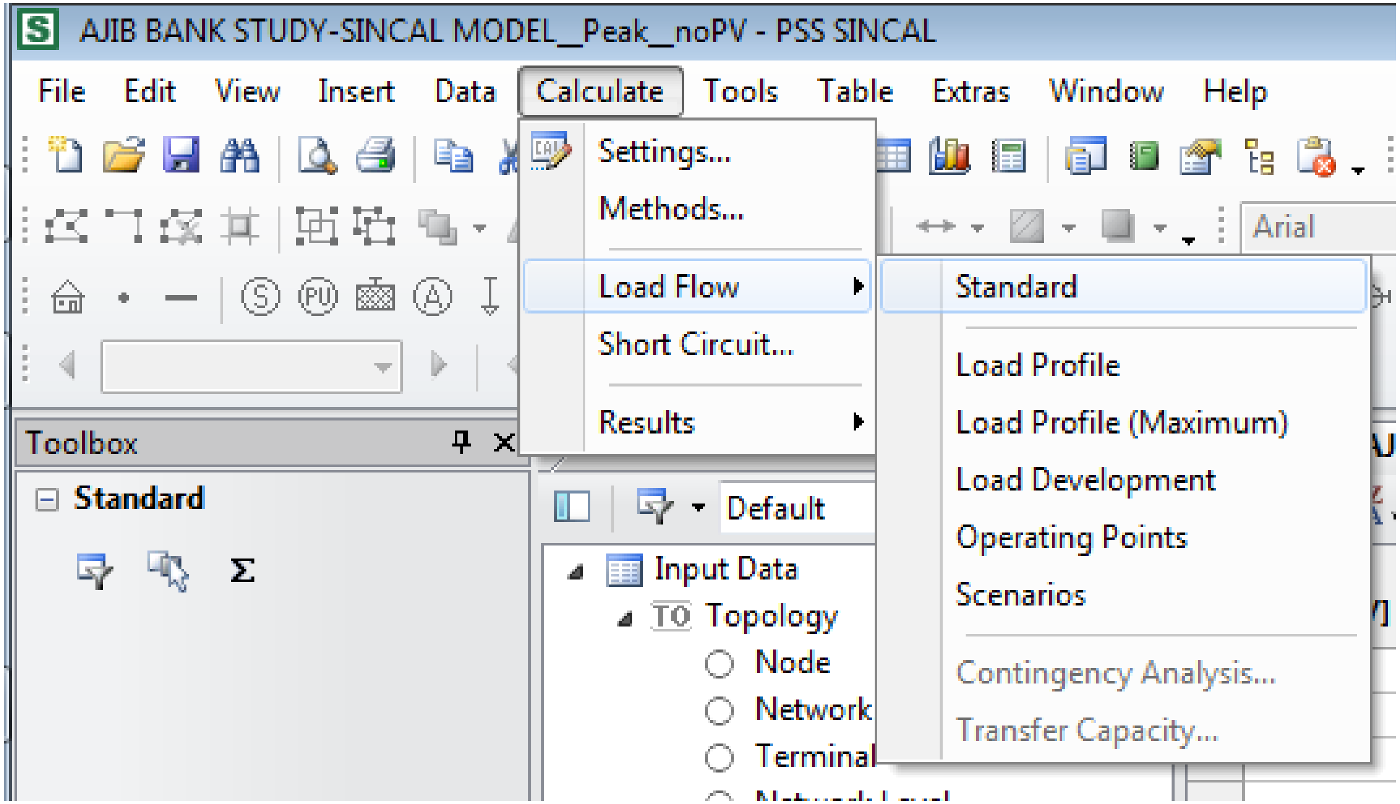
Update Loads in PSS SINCAL

- Updating 0.415 kV loads:

I [kA]	E [MWh]	t [s]	EP [kWh]	EQ [kvarh]	Pi [kW]	Qi [kvar]	fP	fQ	fS
0.853									
0.087									
0.261									
0.577									
									0.16
									0.16
									0.16
									0.16
									0.16
									0.16
									0.16
									0.16
									0.16
									0.16
									0.16
									0.16
									0.16
									0.16
									0.16

Solve Load Flow and Confirm Load Levels

- Run Load Flow simulation



Run Load Flow Studies on Study Cases

- Objective is to populate this table of results:

Control Mode	Inverter PF	Inverter (MW)	Inverter (MVA)	PCC PF	PCC Voltage	PCC Voltage Step Change (%)	Feeder Load (Peak/Min)	Feeder Losses (MW)	Thermal Overloads (Y/N)	Reverse Power Flow (Y/N)	Acceptable (Y/N)	Notes
N/A	N/A	0.00										
Power Factor	1.00	3.60										
Power Factor	0.88	3.60										
Power Factor	-0.88	3.60										
N/A	N/A	0.00										
Power Factor	1.00	3.60										
Power Factor	0.88	3.60										
Power Factor	-0.88	3.60										

- Open Load Flow Results Summary (BLANK).xlsx

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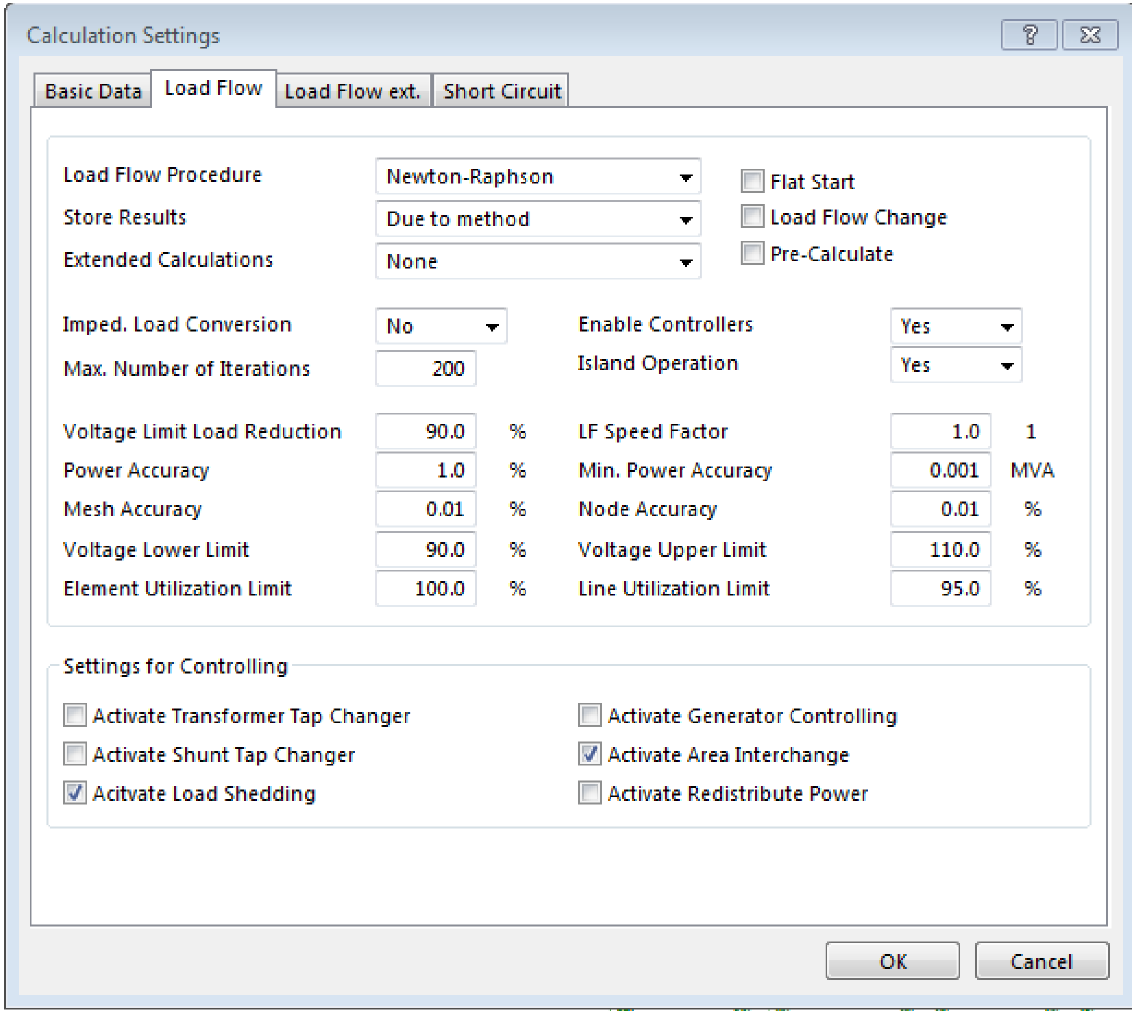
Load Flow Analysis Part 1 – Steady State
Peak Load, No PV

- This scenario constitutes the pre-project case
- Open the model:
  - AJIB BANK STUDY-SINCAL MODEL __Peak__noPV.sin
- Run Load Flow simulation
- Populate the relevant results into summary table
- Extract system results to spreadsheet

Confirm Load Flow Settings



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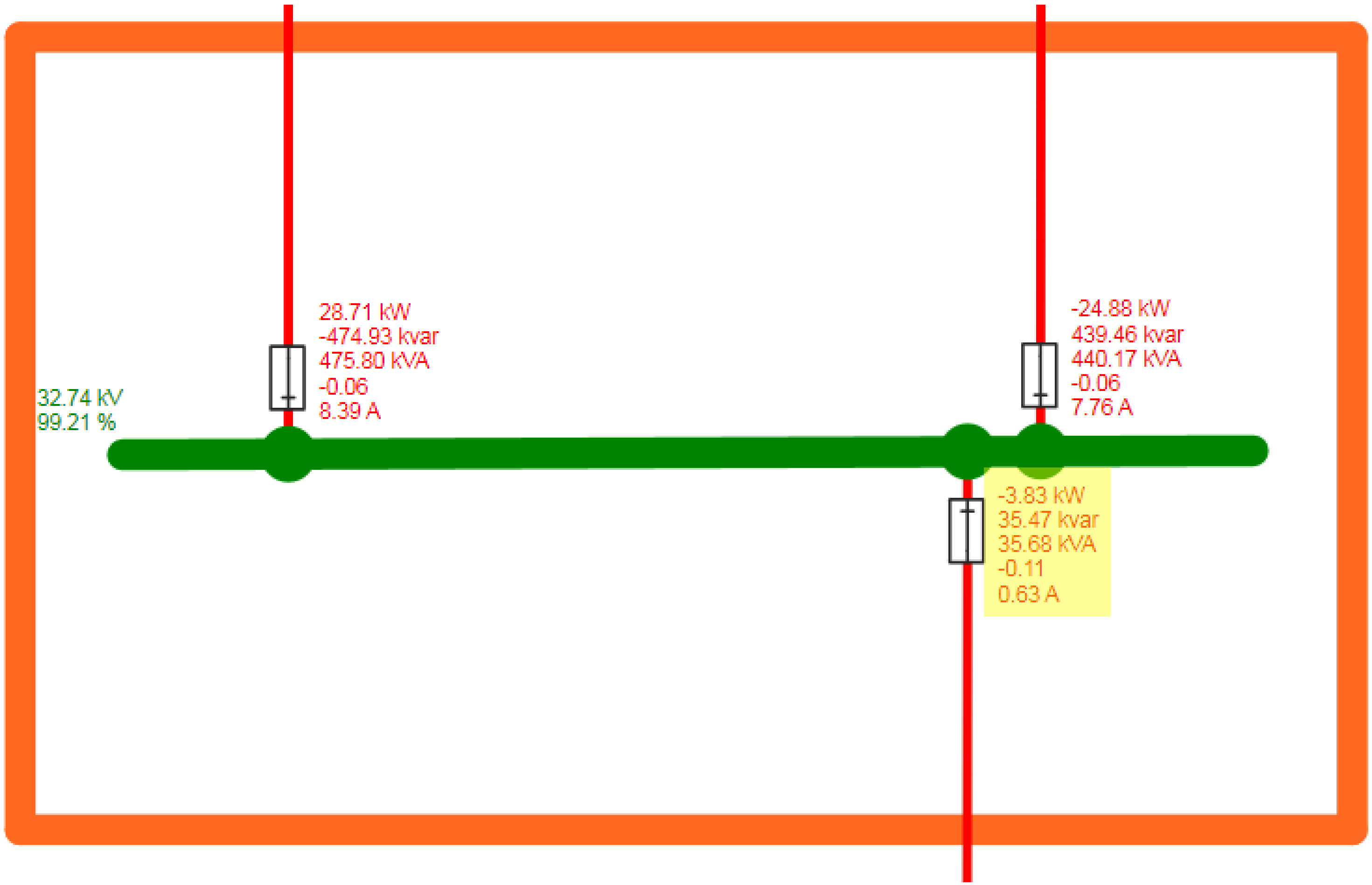
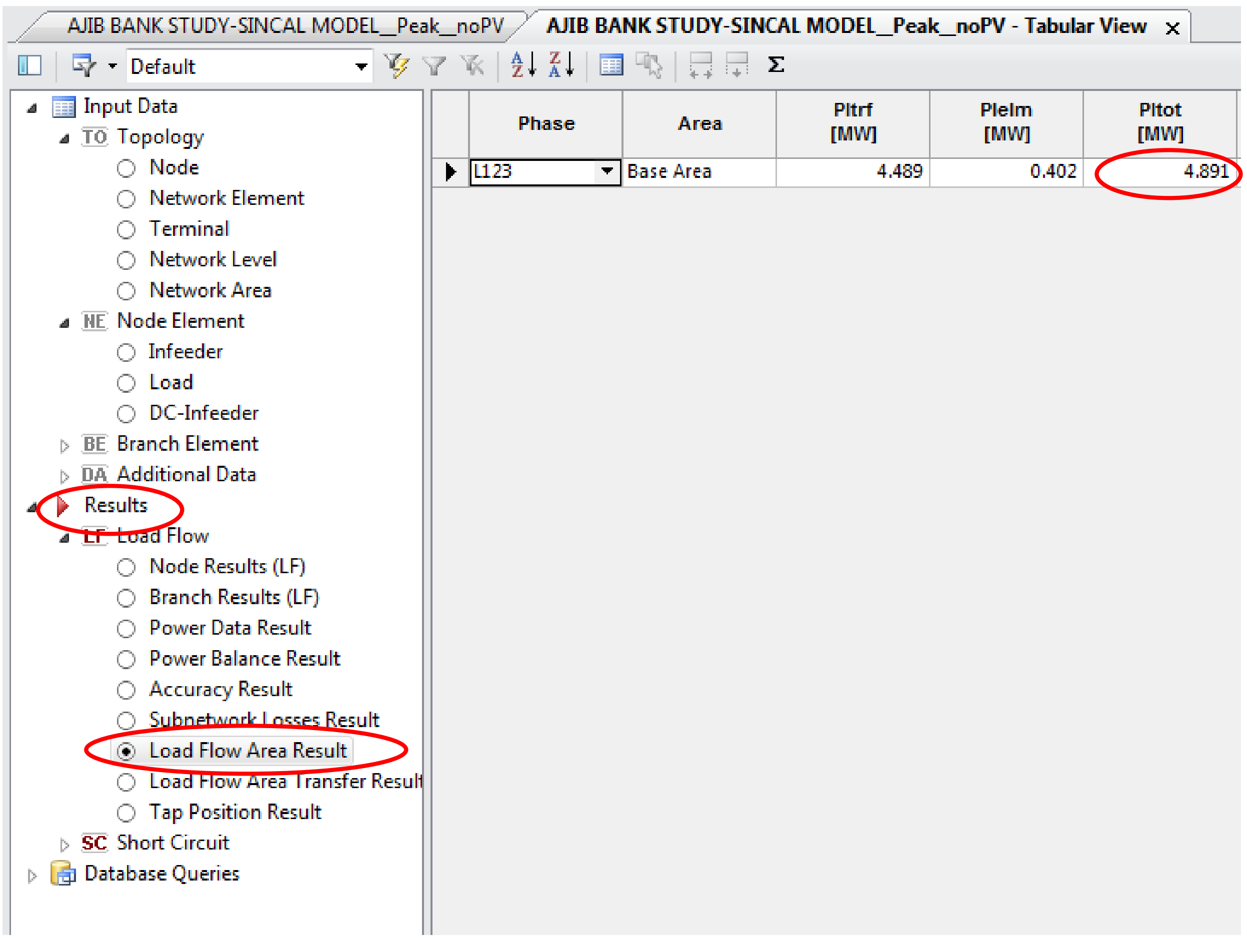
Load Flow Analysis Part 1 – Steady State Peak Load, No PV

- Perform Load Flow simulation
- What is the power factor at the PCC?
- What is the voltage in percent at the PCC?
- What are the total feeder losses?
- Are there any thermal overloads?
- Is there reverse power flow at the Q.A.A. NEPCO station?
- Does this scenario comply with the IRR-DCC-MV requirements?

Checking the Power Factor and Voltage at the PCC



Determine Total Feeder Losses



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Check for Thermal Overloads

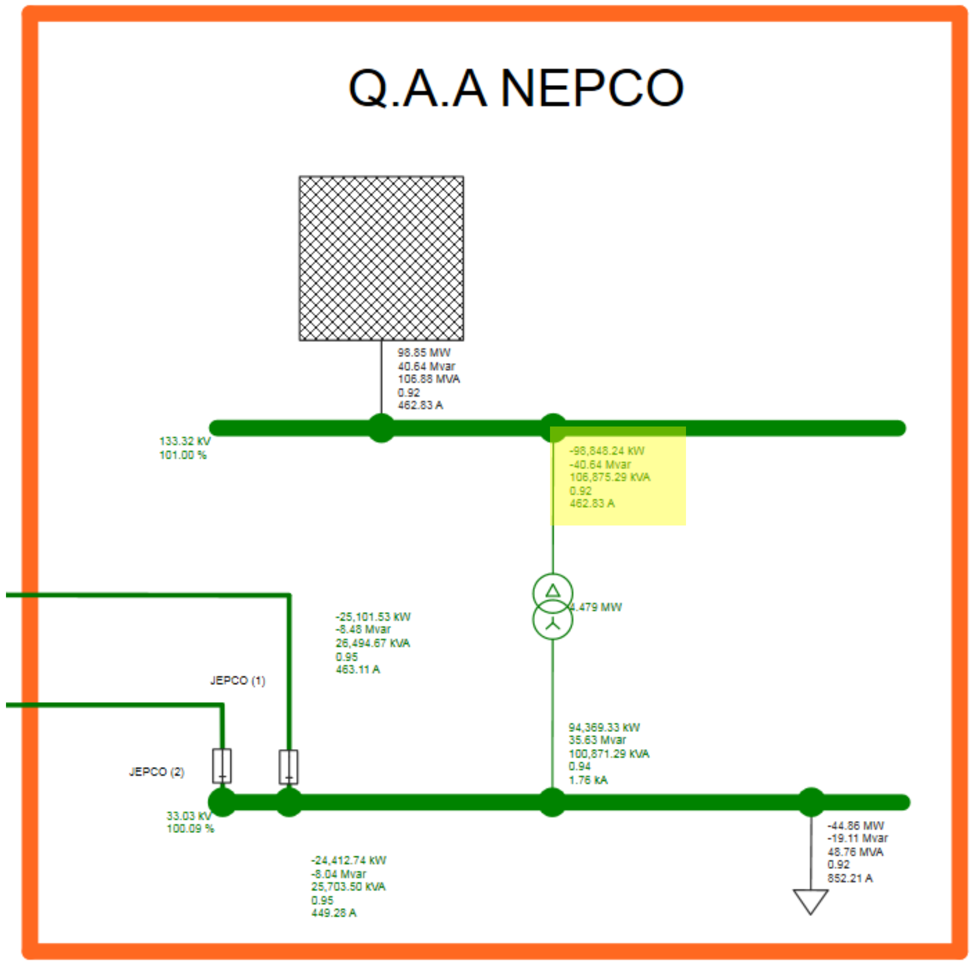
AJIB BANK STUDY-SINCAL MODEL__Peak__noPV | AJIB BANK STUDY-SINCAL MODEL__Peak__noPV - Tabular View

Default

- Input Data
  - TO Topology
    - Node
    - Network Element
    - Terminal
    - Network Level
    - Network Area
  - NE Node Element
    - Infeeder
    - Load
    - DC-Infeeder
  - BE Branch Element
  - BA Additional Data
- Results
  - LF Load Flow
    - Node Results (LF)
    - Branch Results (LF)
    - Power Data Result
    - Power Balance Result
    - Accuracy Result
    - Subnetwork Losses Result
    - Load Flow Area Result
    - Load Flow Area Transfer Result
    - Tap Position Result
  - SC Short Circuit
- Database Queries

dV [kV]	dφ [°]	I/Ib [%]	I/Ib1 [%]	I/Ib2 [%]	I/Ib3 [%]	Ibp [kA]	I/Ibp [%]	Ibs [kA]	I/Ibs [%]	Sb [MVA]	S/Sb [%]
8.381	1.664	106.875	0.000	0.000	0.000	0.437	105.817	1.750	100.778	100.000	106.875
2.200	-1.664	100.871	0.000	0.000	0.000	0.437	105.817	1.750	100.778	100.000	100.871
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.973	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	48.755	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.064	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.080	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.080	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	32.980	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	14.918	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	100.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	100.000
0.001	-0.002	46.875	0.000	0.000	0.000	0.988	46.873	0.988	46.875	56.472	46.917
0.001	0.002	46.873	0.000	0.000	0.000	0.988	46.873	0.988	46.875	56.472	46.917
0.001	-0.002	45.475	0.000	0.000	0.000	0.988	45.474	0.988	45.475	56.472	45.516
0.001	0.002	45.474	0.000	0.000	0.000	0.988	45.474	0.988	45.475	56.472	45.516
0.153	0.176	28.304	0.000	0.000	0.000	0.340	28.304	0.340	28.319	19.434	28.328
0.153	-0.176	28.319	0.000	0.000	0.000	0.340	28.304	0.340	28.319	19.434	28.245

Check for Reverse Power Flow



Extract Results to Spreadsheet

- Save the following result sets to a spreadsheet:
  - Node Results
  - Branch Results
  - Load Flow Area Result
- Copy contents of each to a separate tab in a blank spreadsheet
- Save the spreadsheet as “Peak__noPV.xlsx”

Update Load Flow Results Summary Table

Control Mode	Inverter PF	Inverter (MW)	Inverter (MVA)	PCC PF	PCC Voltage	PCC Voltage Step Change (%)	Feeder Load (Peak/Min)	Feeder Losses (MW)	Thermal Overloads (Y/N)	Reverse Power Flow (Y/N)	Acceptable (Y/N)	Notes
N/A	N/A	0.00	0.00	0.11	99.21	0.00%	Peak	4.89	N	N	Y	Pre-Project Case
Power Factor	1.00	3.60										
Power Factor	0.88	3.60										
Power Factor	-0.88	3.60										
N/A	N/A	0.00										
Power Factor	1.00	3.60										
Power Factor	0.88	3.60										
Power Factor	-0.88	3.60										

Repeat for all Study Cases

- Open the model:
  - AJIB Bank Study-SINCAL Model__Peak__maxPV__100.sin

Comparing Shadow Study Results

- Review and compare Black & Veatch results with JEPCO results
- Are they different?
- Discuss why…