Microgrid Sizing for Resiliency

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Sponsored by Southern California Edison

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Agenda

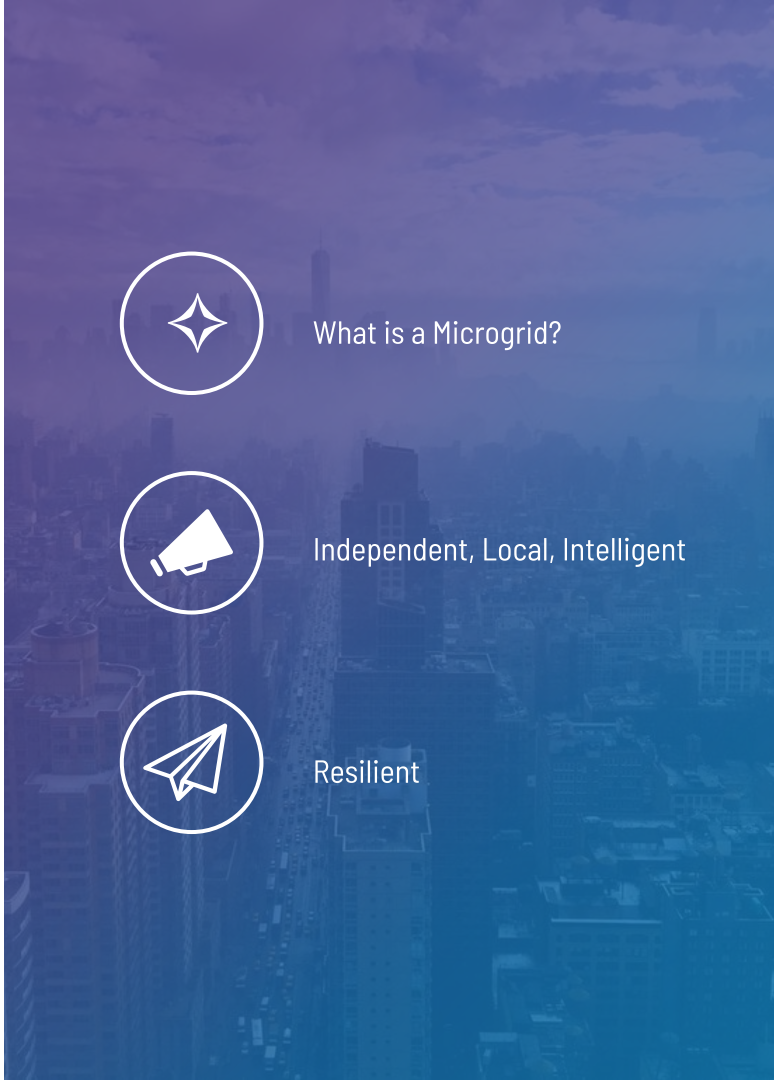
1. Problem
2. Introduction/Background
3. Project Goal
4. Project Scope
5. Project Organization
6. Schedule
7. Requirements
8. Deliverables
9. Summary

Problem

- Need to manage the burden that natural disasters like wild fire place on SCE as a utility
- Maximize the penetration of renewable-energy-based generation

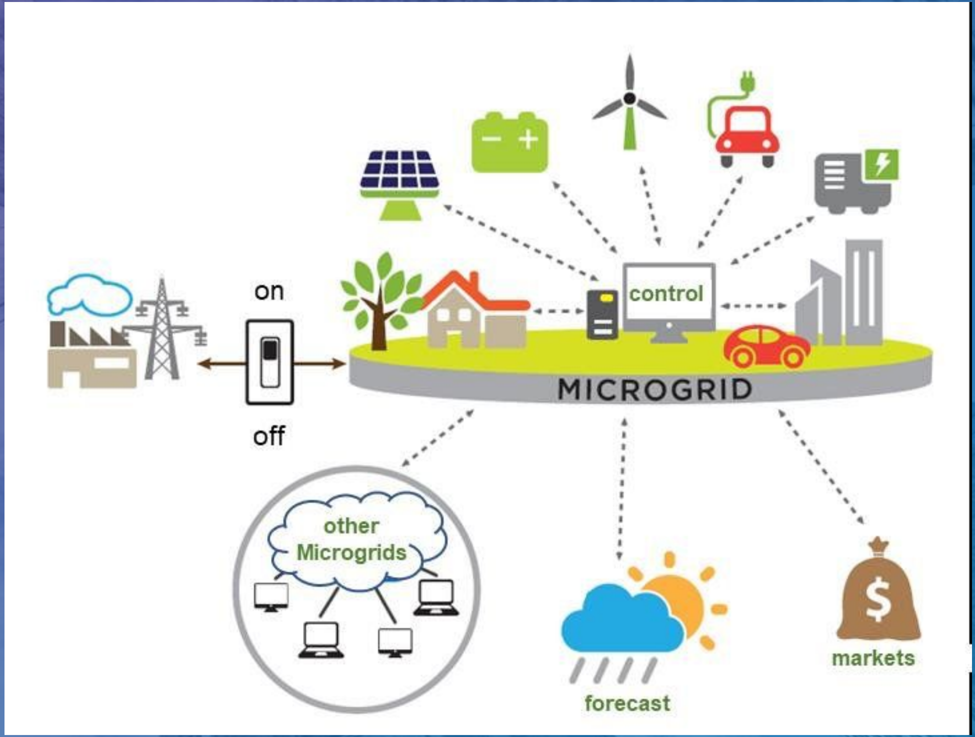
Intro: Project Background

- ❖ Resilience- the ability to adapt to changing conditions and to withstand and recover rapidly from disruption
- ❖ Microgrid- (energy source grid) The United States Department of Energy (USDOE) defines the microgrid as “a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid.
- ❖ Microgrid has 3 operational methods it can function
  - ➢ Non-operational
  - ➢ Operational in Parallel
  - ➢ Operational in Island



Microgrid

- ❖ Distributed Energy Resources (DER)- is any resource on the distribution system that produces electricity
    - ➢ Photovoltaic (PV)
    - ➢ Maximum Power Point Tracking MPPT
    - ➢ Battery Storage
    - ➢ Wind Turbines
    - ➢ Diesel Generators



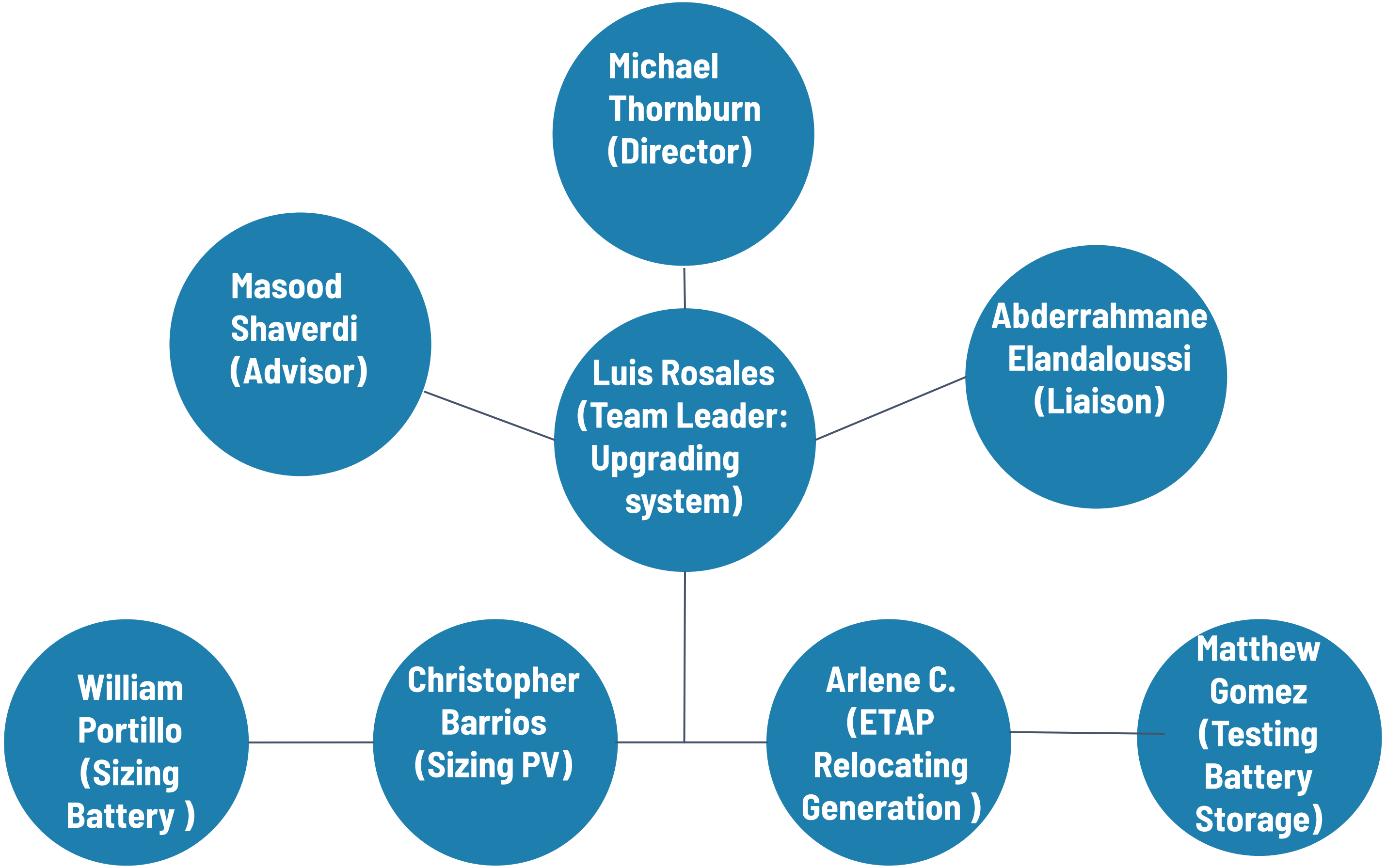
Project Goal

- Develop a microgrid system that will have the ability to operate independently of the grid in order to sustain the electrical demand in case of major grid failures that may result from natural disasters for our customer SCE.

Project Scope

- To determine the upgrades needed for the existing circuit
- Size the Distributed Energy Resources (DERs) to sustain customer load for a prolonged outages

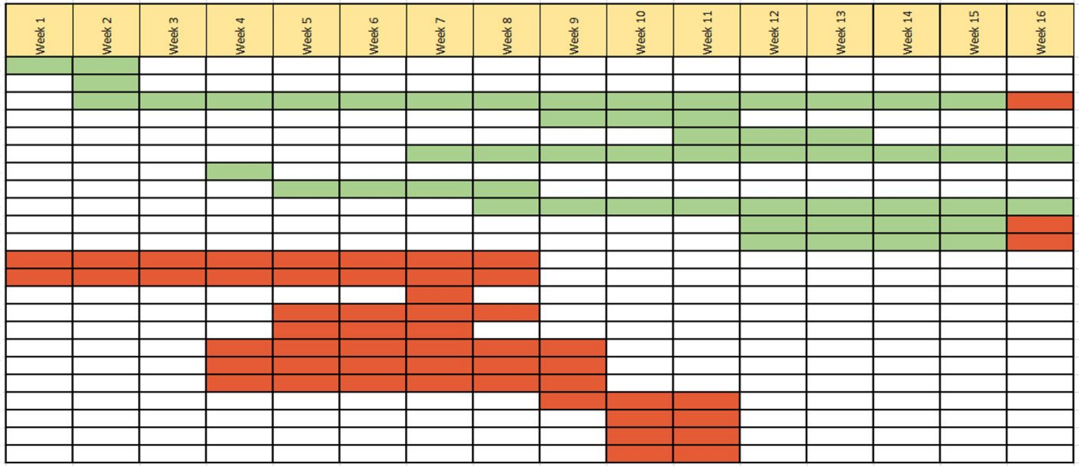
Project Organization



Schedule

Project Name	Project Duration	Project Start Date	Project End Date
13.1 Microgrid Sizing	Fall Semester	28-Aug	25-Jan
	Spring Semester	27-Jan	19-Apr

Task ID	Task Description	Task Duration	Start Date	End Date
1	Research	2	28-Aug	11-Sep
2	IEEE Feeder Model	1	11-Sep	18-Sep
2.1	Simulink 13-Bus Feeder	14	11-Sep	18-Dec
2.2	DC Source and Inverter	3	16-Oct	6-Nov
2.3	Controller	3	30-Oct	18-Nov
2.4	Photovoltatic	10	9-Oct	18-Dec
3	Bus Feeder Base-line	1	11-Sep	18-Sep
3.1	Hourly profile	4	25-Sep	14-Oct
3.2	Loads flow Analysis	9	14-Oct	18-Dec
3.3	Location of DERs	5	13-Nov	18-Dec
3.4	Minimum Power Loss	5	13-Nov	18-Dec
4	Photovoltatic part 2	7	2-Feb	22-Mar
4.1	PV modeling and upgrades	7	2-Feb	22-Mar
4.2	Photovoltatic testing	1	8-Mar	15-Mar
5	PQ control	4	15-Feb	15-Mar
5.1	PQ control upgrades	3	22-Apr	15-Mar
5	Look up table	5	15-Feb	22-Mar
5.1.1	GHI PQ	5	15-Feb	22-Mar
5.1.2	Load data PQ	5	15-Feb	22-Mar
5.2	single phase current	1	15-Mar	22-Mar
6	SAM	3	23-Mar	19-Apr
7	ETAP upgrades	2	5-Apr	19-Apr
7.1	Load arragnment	2	5-Apr	12-Apr
7.2	Generation loactions	2	5-Apr	12-Apr



Fall Semester
Spring Semester

Requirements

Functional:

- ❖ Shall utilize IEEE 13 Node Test Feeder model as a base for the microgrid system.
- ❖ Shall supply demand using a photovoltaic (PV) with battery storage system.
- ❖ Shall use peak load data in order to properly size generation.
- ❖ Microgrid system must be able to operate in “island mode”, meaning it should be able to sustain the load while isolated from the grid.

Performance:

- ❖ Bus voltages must not deviate by more than 2.5% from their nominal value.
- ❖ Conductors must not be overloaded beyond 100 percent of their maximum current limit.
- ❖ System shall have a resiliency of 4 hours
- ❖ Bus frequencies shall not deviate by more than 5% of the nominal value (60 Hz)

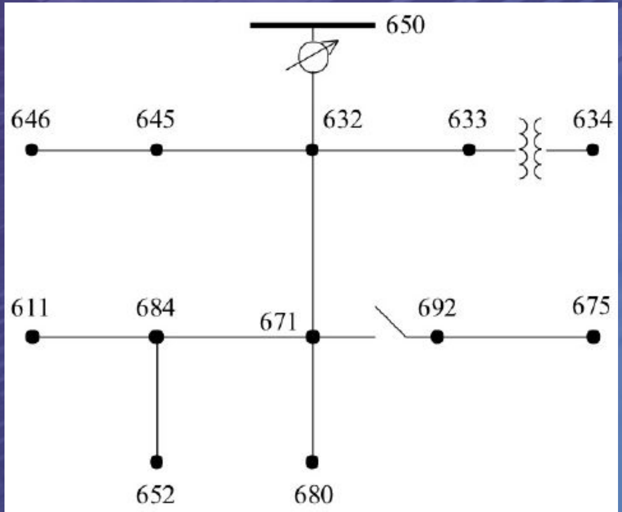
Deliverables

- 13 Bus Test Feeder Model
  - Peak load forecast
- Simulink Models
  - Inverter
  - PV standalone
  - Boost converter standalone
  - PV with MPPT
  - Lookup tables
- ETAP
  - Relocate PV source
  - Loadscaling
  - Battery storage testing

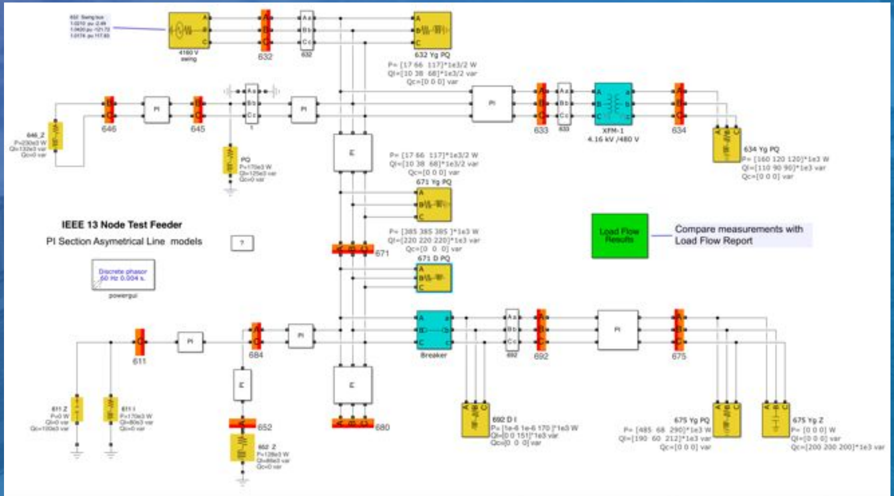
13-Bus Feeder Model

- ❖ Operates at 4.16KV, highly loaded, voltage regulator, transformer, underground & overhead lines, and shunt capacitors

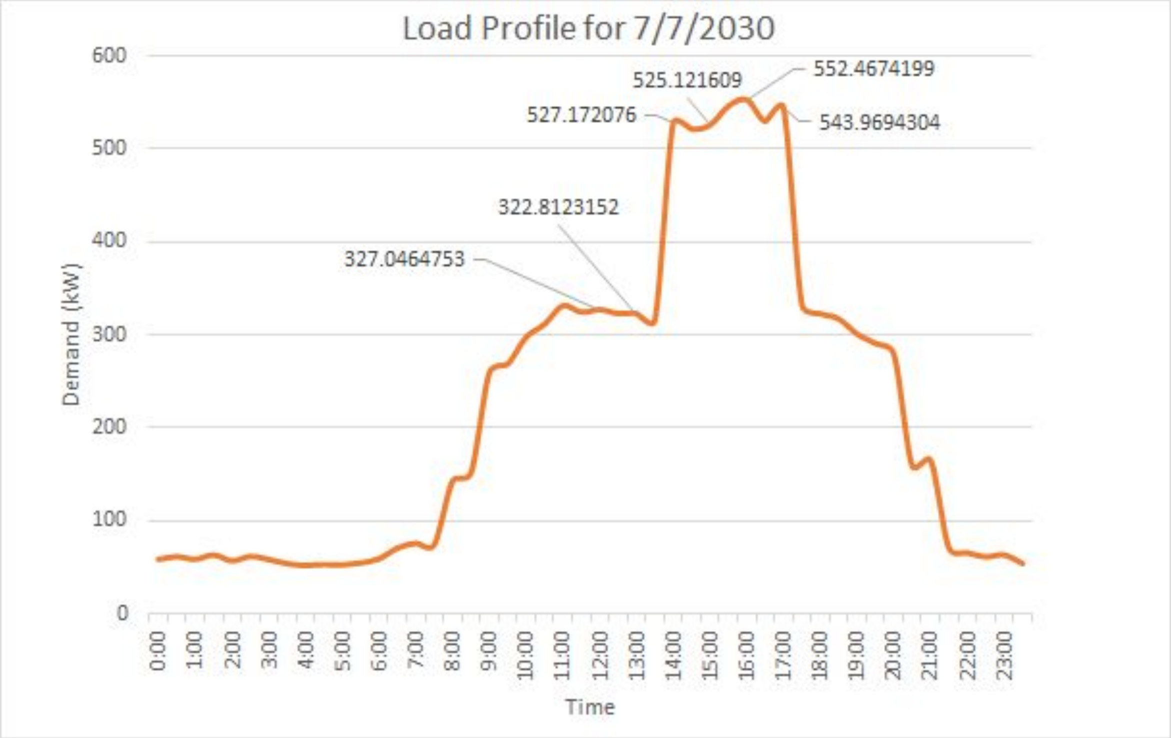
Line Diagram



Simulink Model



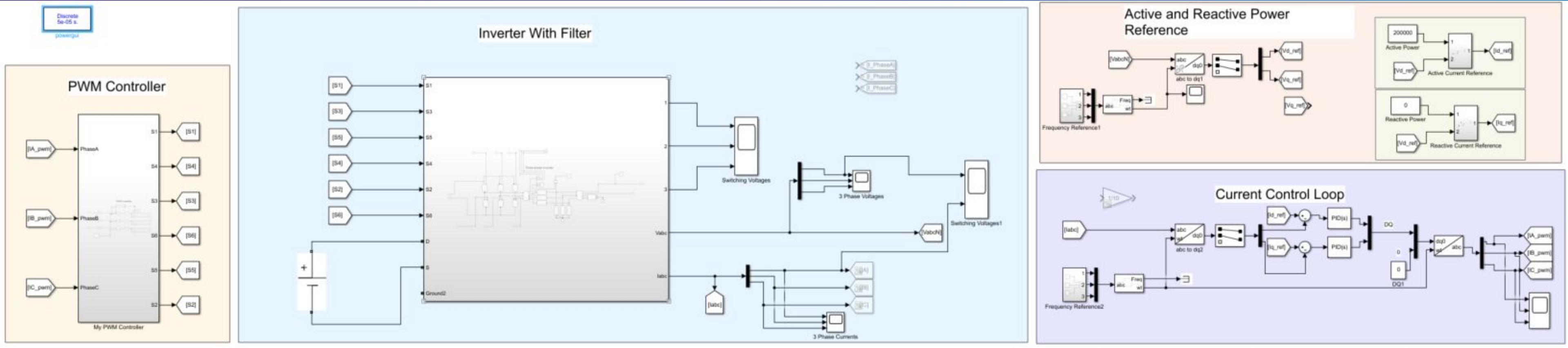
Peak Load Forecast



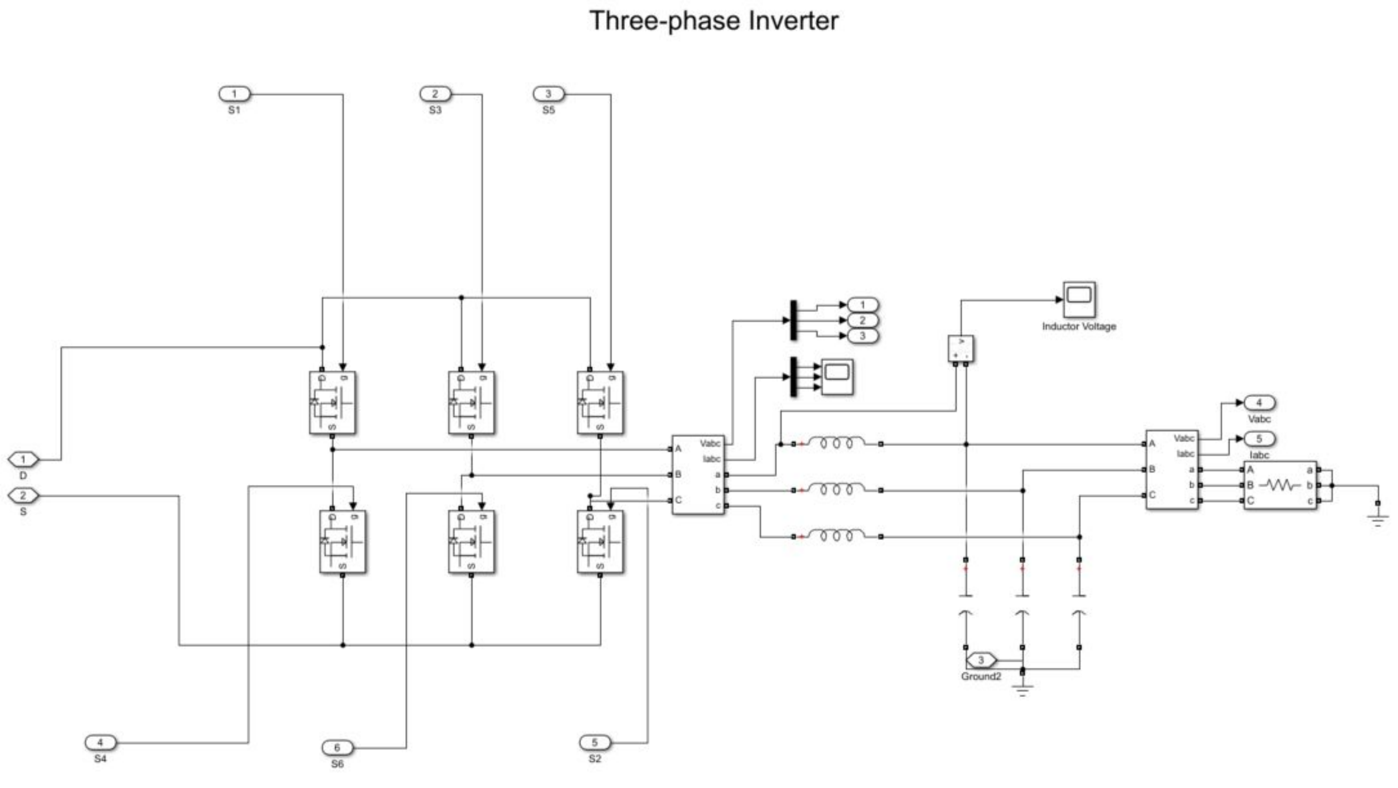
- Projected load data for 2030
- Peak demand is on July 7, 2030 and will occur at about 4:00 p.m. (Approx. 552 kW)
- Assume an initial PV sizing of 650 kW.

Simulink

Inverter With DC Source

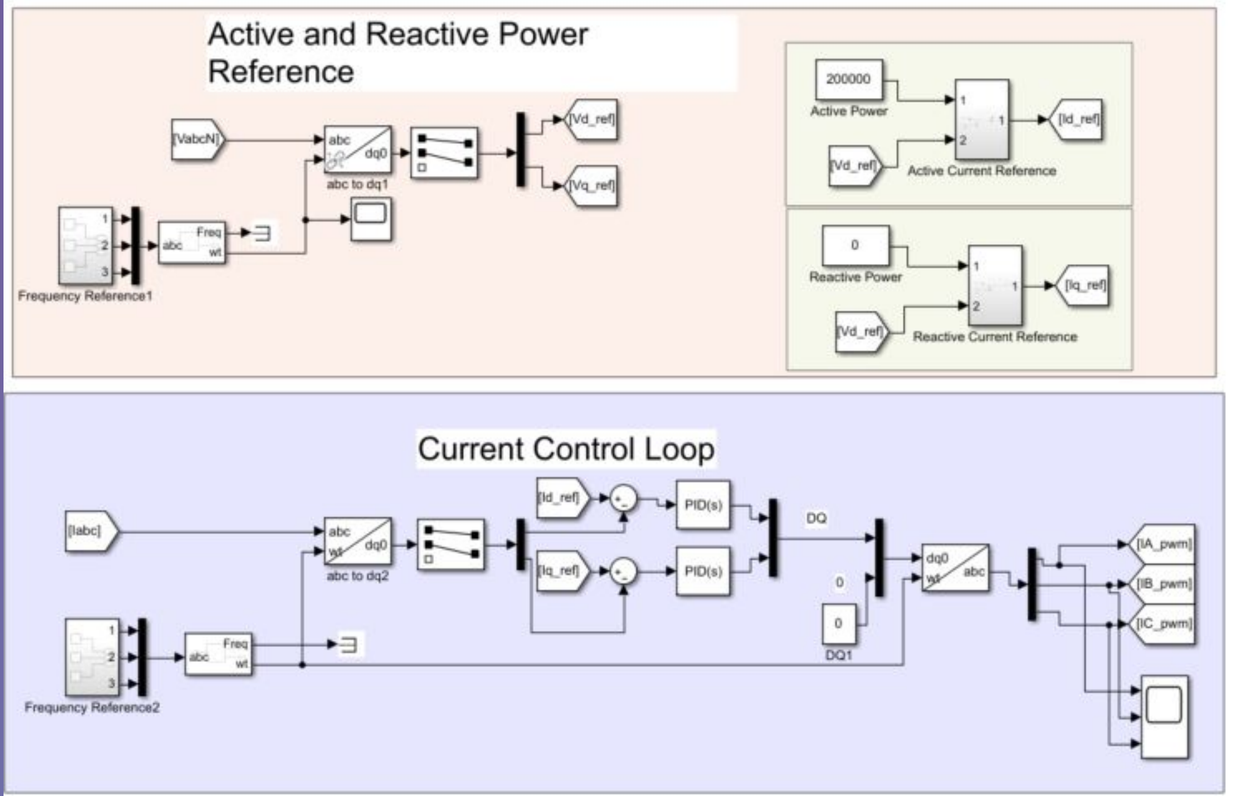


Detailed Inverter Model



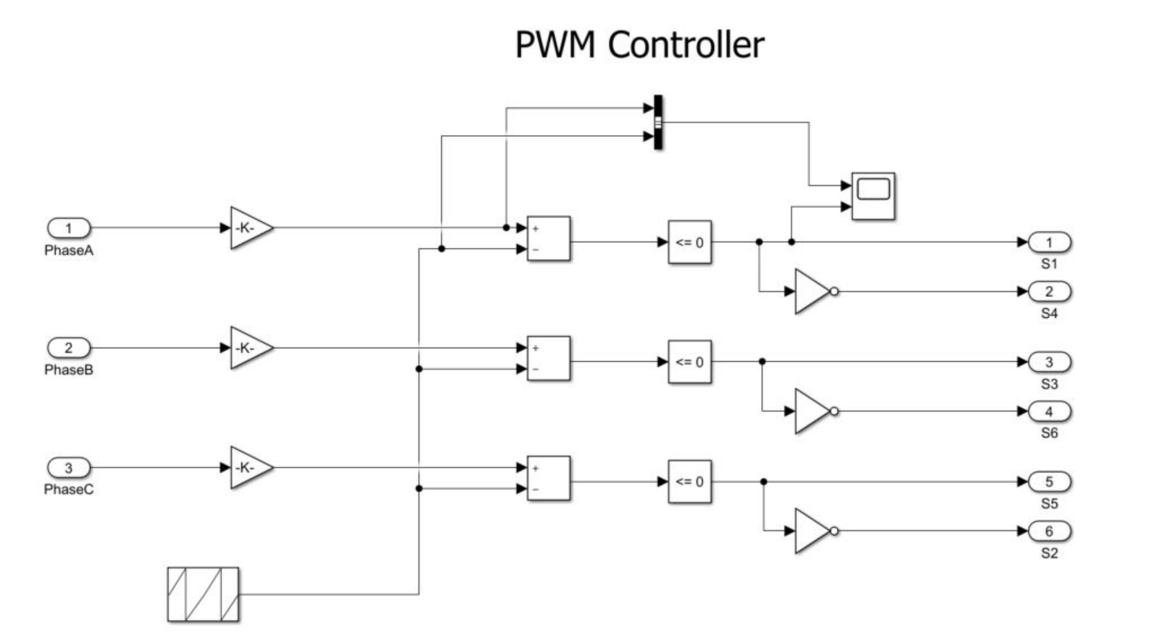
- Two-stage, three-phase inverter
- Six IGBTs are used as switches.
- Each IGBT has a switching signal which turns the IGBT off or on.
- LC low-pass filter filters out high frequencies of switching voltages.

Active and Reactive Power Controller



- Active and reactive power reference
- Voltage reference is created from phase voltages
- Current reference is calculated and passed through current control loop.

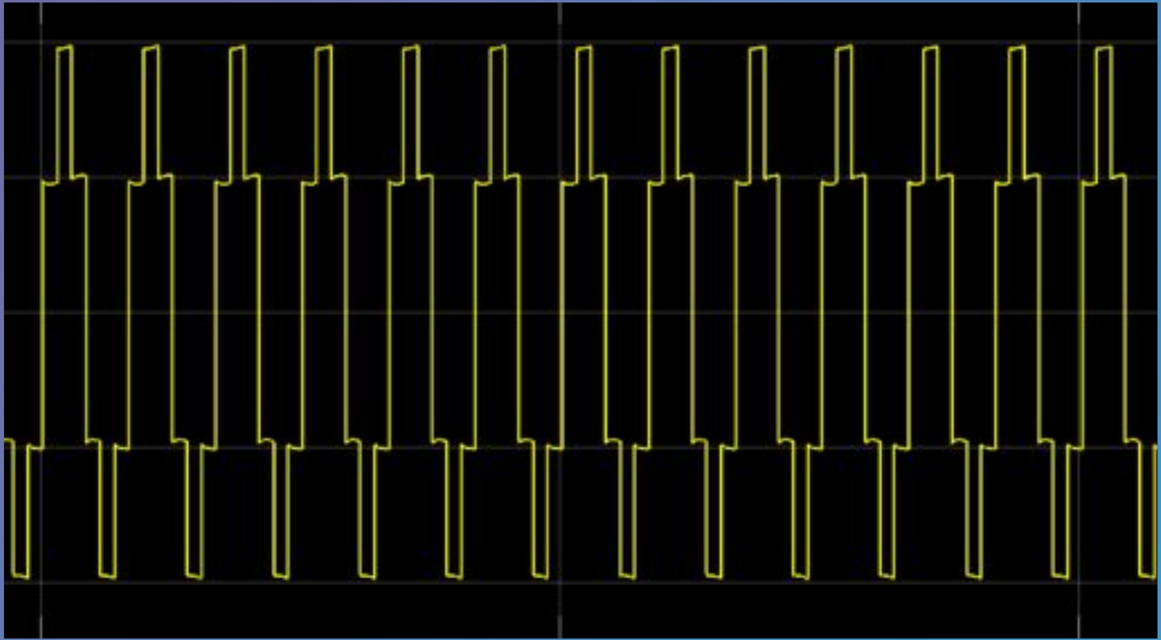
PWM Controller



- Takes output current references from control loop.
- Compares with a sawtooth signal. Whenever current is greater than the amplitude of the sawtooth wave, output of comparator will be 1, or high and vice versa.

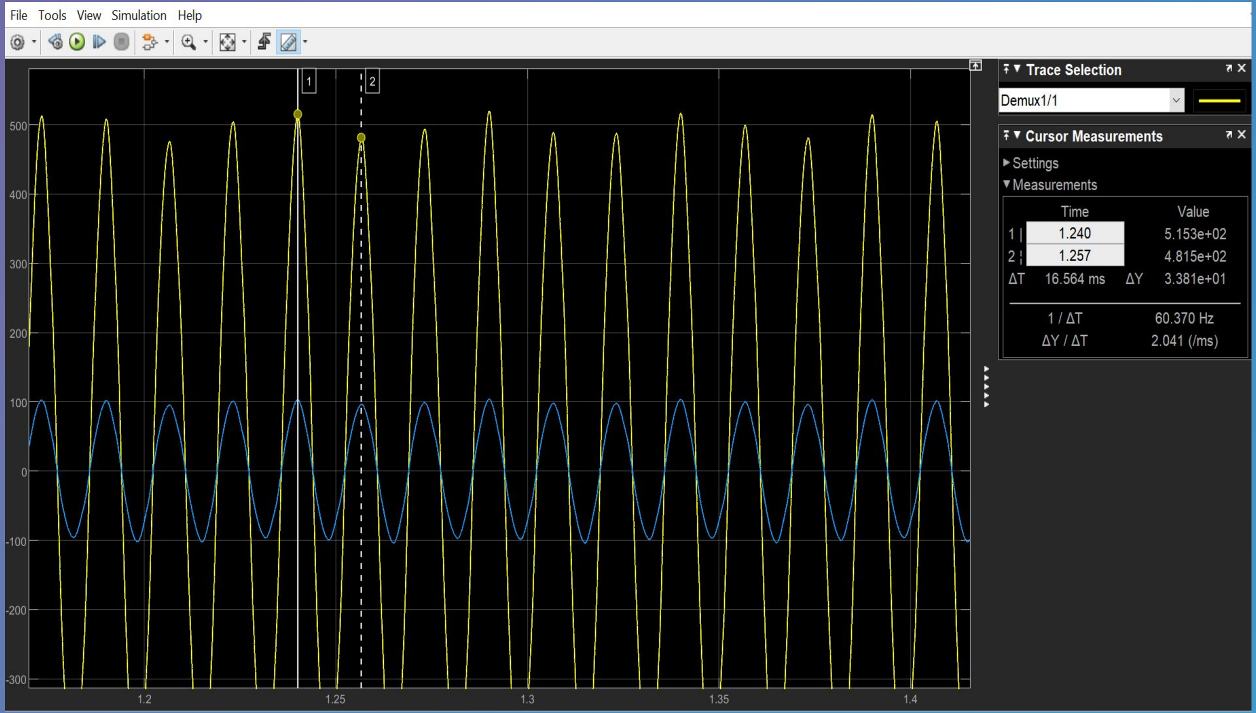
Unfiltered Output Voltage

- Modified square wave
- High frequency harmonics/distortion
- Could lead to equipment damage. Filtering is needed to reduce distortion



Filtered Inverter Output (Phase A)

- Low-pass filter blocks high frequencies and passes the low frequency voltage and current waveforms.
- Output frequency is 60 Hz, so phase-locked loop is functioning properly.



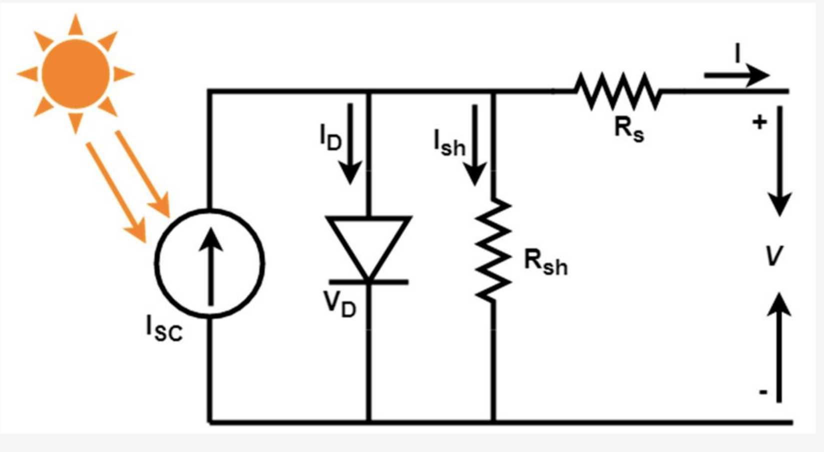
PV Diagram

- Single diode model
- Output of PV factors: solar irradiance, temperature, shadow, and dirt
- To calculate current (I)

$$I = I_{sc} - I_o \left[exp\left(\frac{V + R_S I}{V_t a} \right) - 1 \right] - \left(\frac{V + R_S I}{R_{sh}} \right)$$

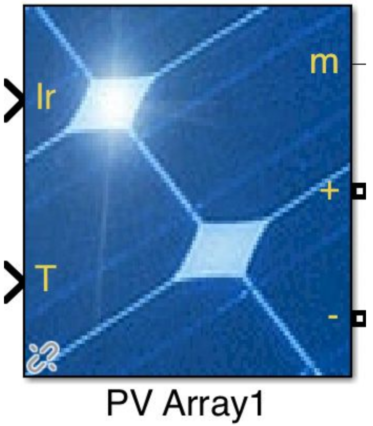
- Isc: short circuit current, Io: saturation current, ą: the diode ideality, Vt: thermal voltage of array, Rs & Rsh are series and shunt resistors of array, Ns: series connected cell, T: temperature of PN junction, K is Boltzman constant, q is charge of electron

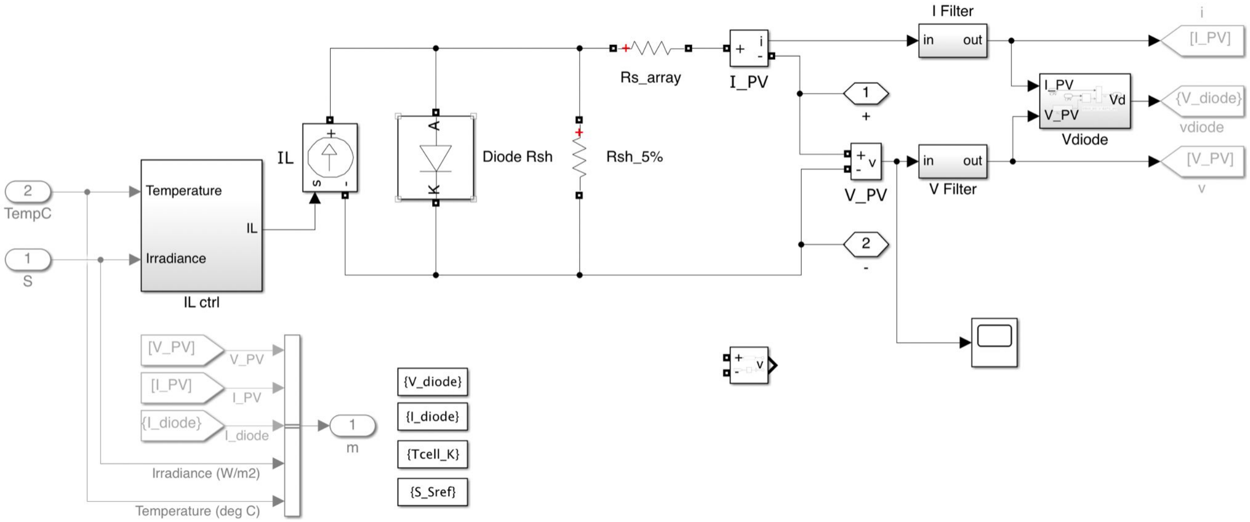
$$V_t = \frac{N_s KT}{q}$$



Simulink: PV Source

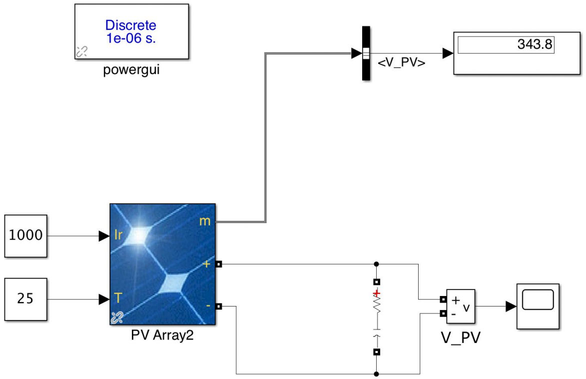
- PV block
- Under the mask
- Observe voltage & current output

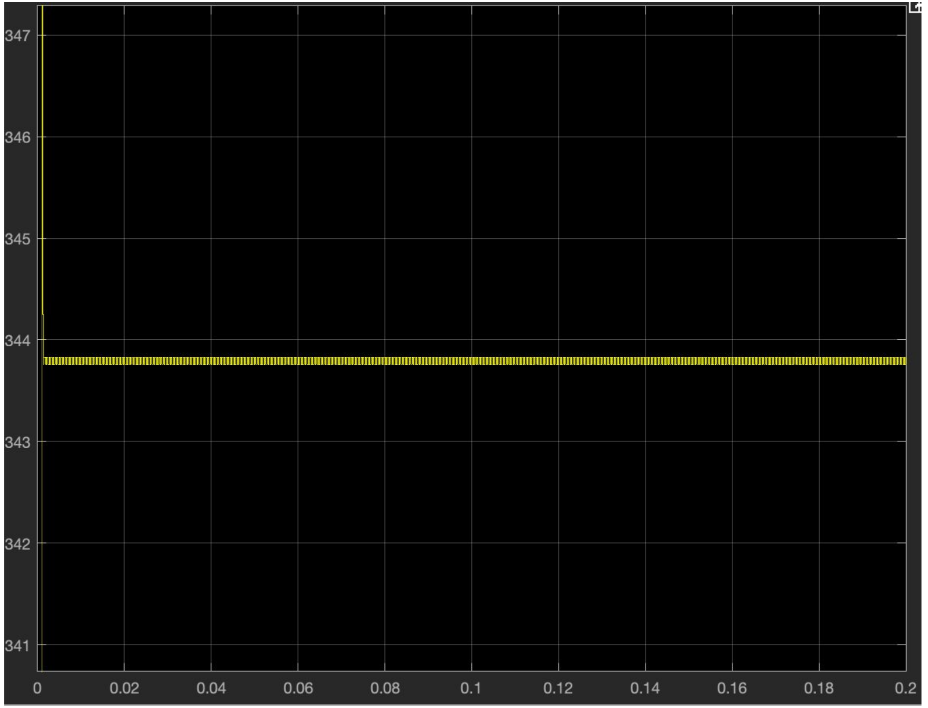




Simulink: PV Standalone

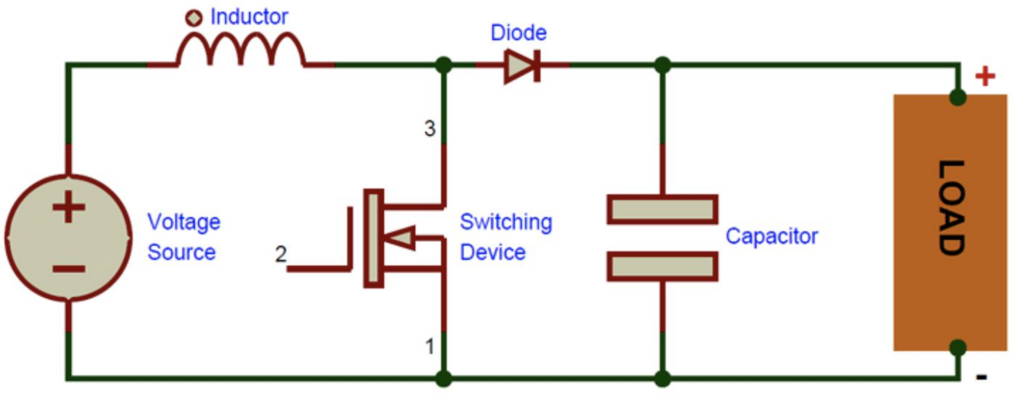
- ❖ Inputs- irradiance:1000 & Temperature: 25
- ❖ Output voltage 343.8 V





Boost Converter Diagram

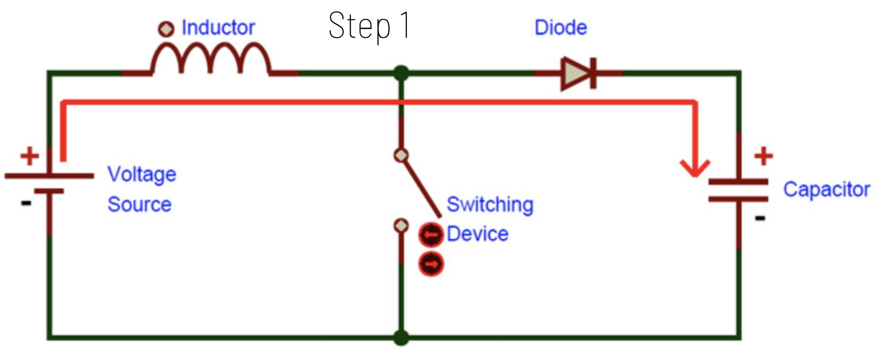
- Takes an input voltage and increases it
- Contains an Inductor, semiconductor switch, diode, capacitor



How a Boost Converter Works

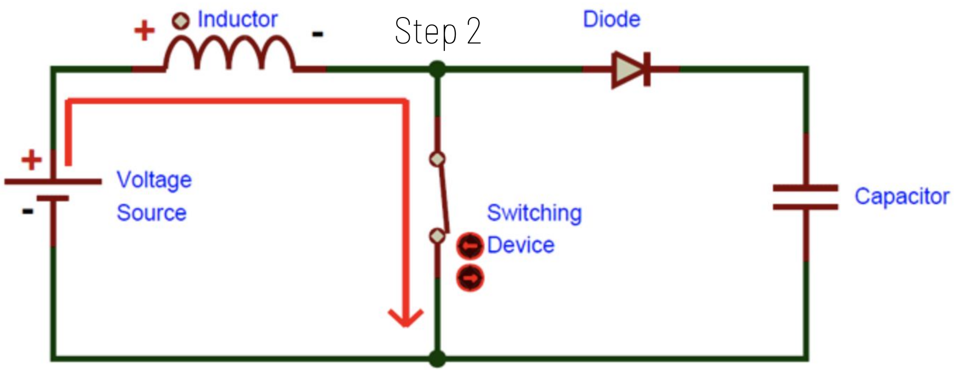
Step 1:

- ❖ Nothing occurs capacitor is charges by Input voltage minus the diode drop



Step 2:

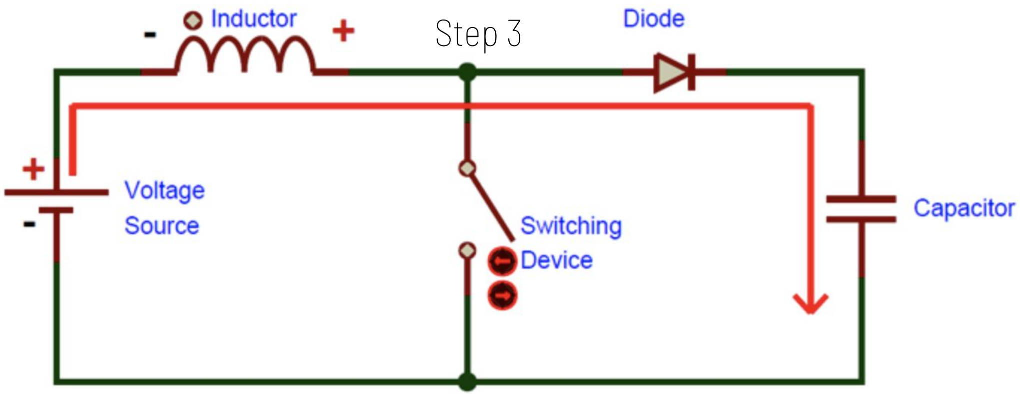
- ❖ Switch on. Current diverted through IGBT through inductor.
- ❖ Output capacitor stays charge
- ❖ Magnetic field builds up around inductor.
- ❖ Inductor has a polarity voltage charge



How a Boost Converter Works

Step 3:

- IGBT is turn off. Inductor current stops.
- Inductor generates a large voltage with opposite polarity of the voltage
- Inductor acts as a voltage source which is in series with the supply voltage source
- Capacitor is charge is larger voltage now



Simulink: Boost Converter Standalone

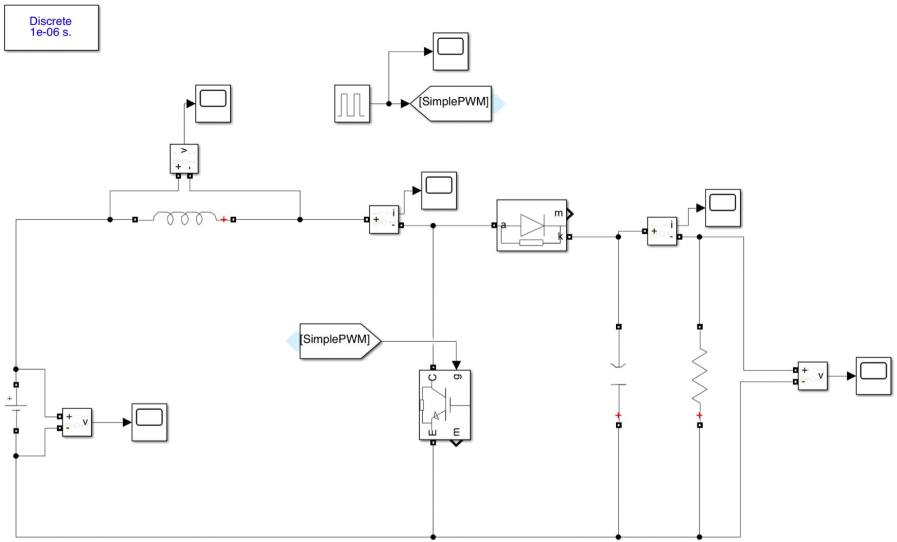
Formulas:

- ❖ Output voltage Vo=(vin)(1/(1-D))
- ❖ Duty ratio D=(W/T)
- ❖ Capacitor

$$C_{OUT(min)} = \frac{I_{OUT(max)} \times D}{f_S \times \Delta V_{OUT}}$$

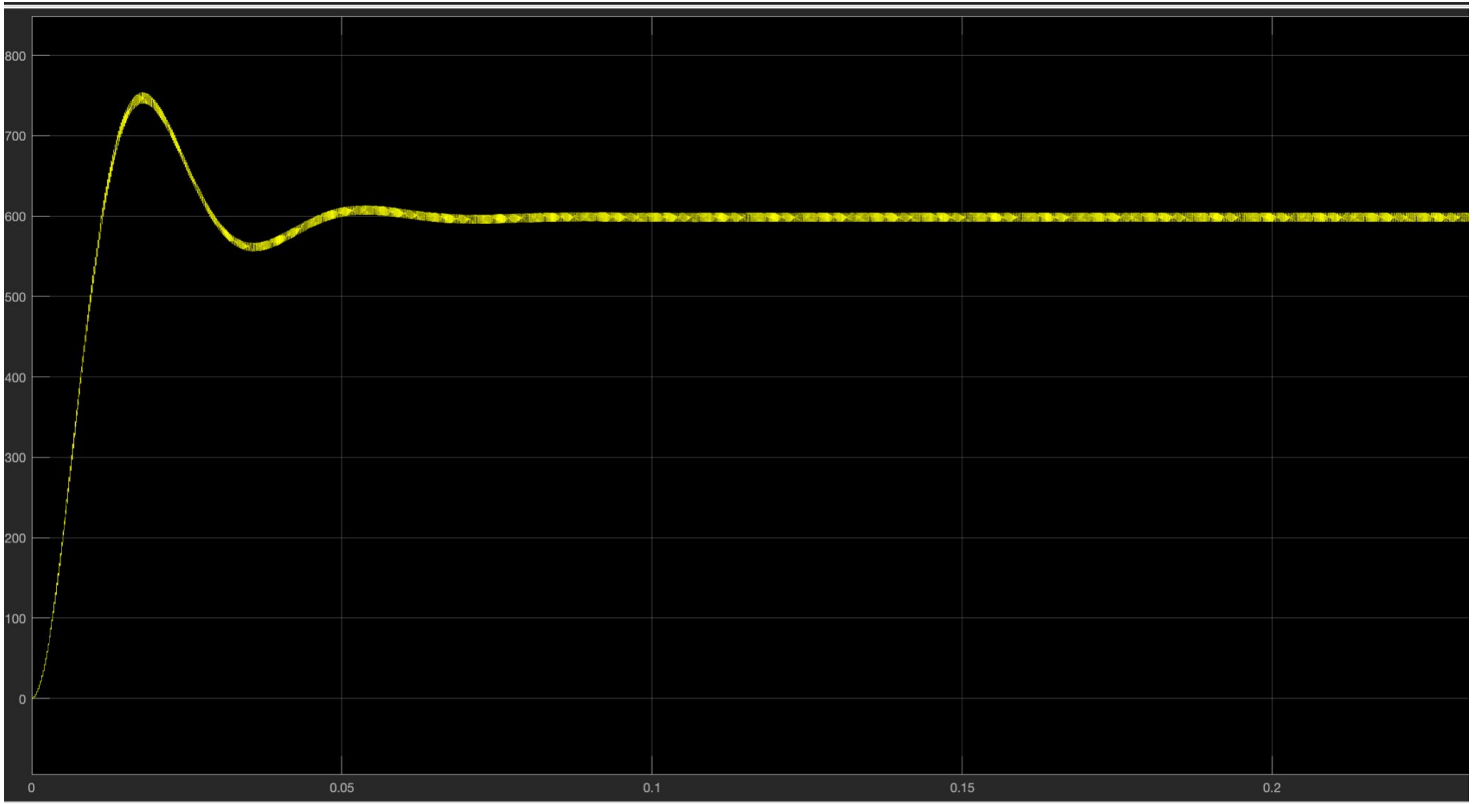
- ❖ Inductor

$$L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f_S \times V_{OUT}}$$



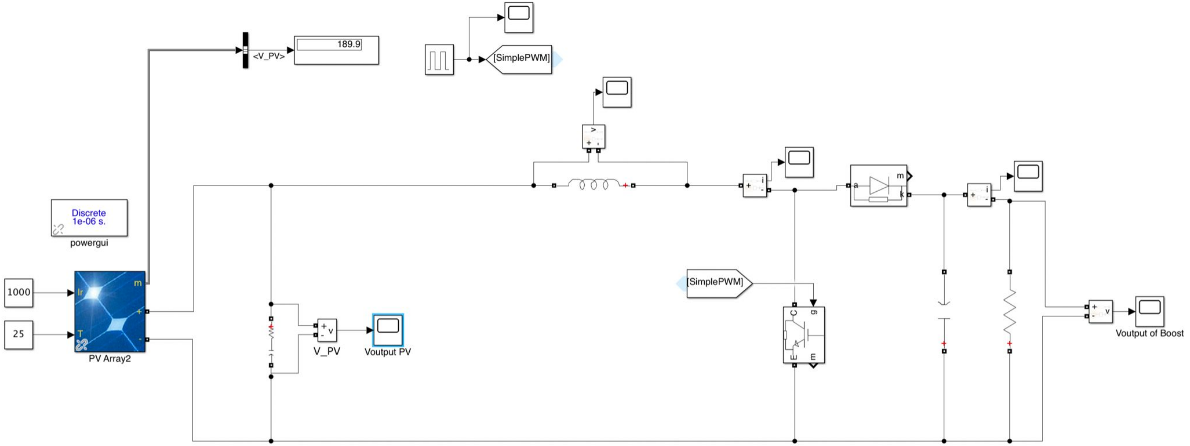
Period (secs)	Durty Ratio (%)	Inductor (H)	Capacitor (F)	Load (ohms)	DC Source: Input voltage	Boost Converter: Output voltage
0.0002	58.3	1.45E-03	3.23E-03	2	250 V	599V

Output Voltage of Boost Converter

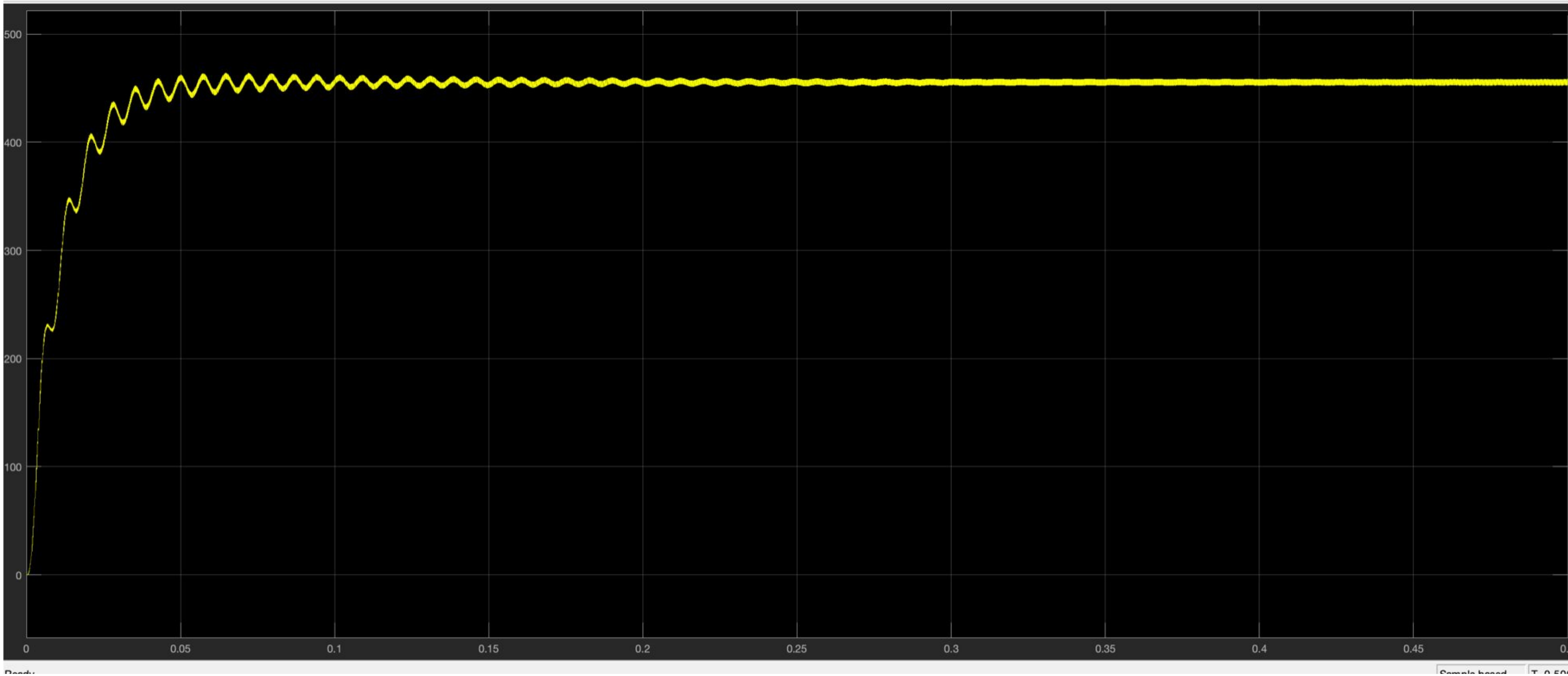


PV and Boost connected

- ❖ Input Voltage: 198V
- ❖ Output Input: 453.23V



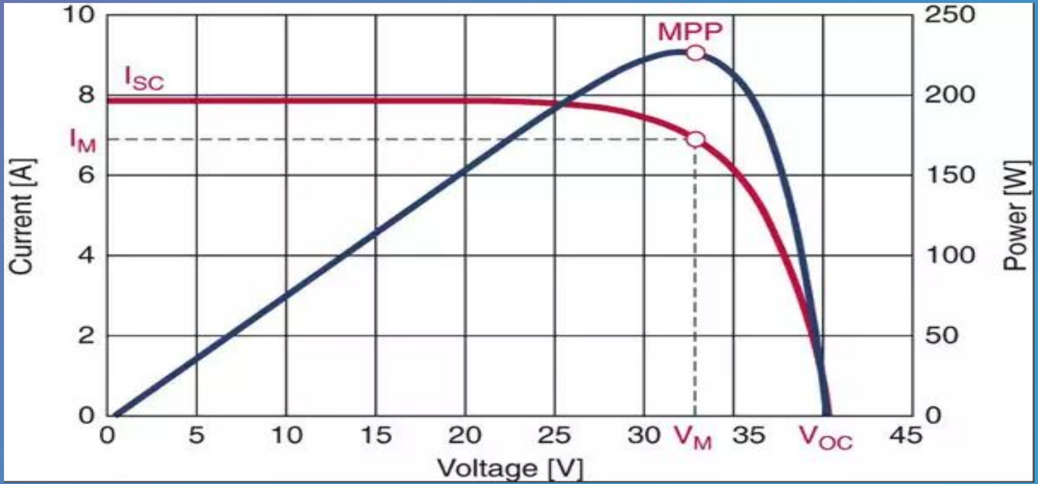
Output Voltage of Boost Converter



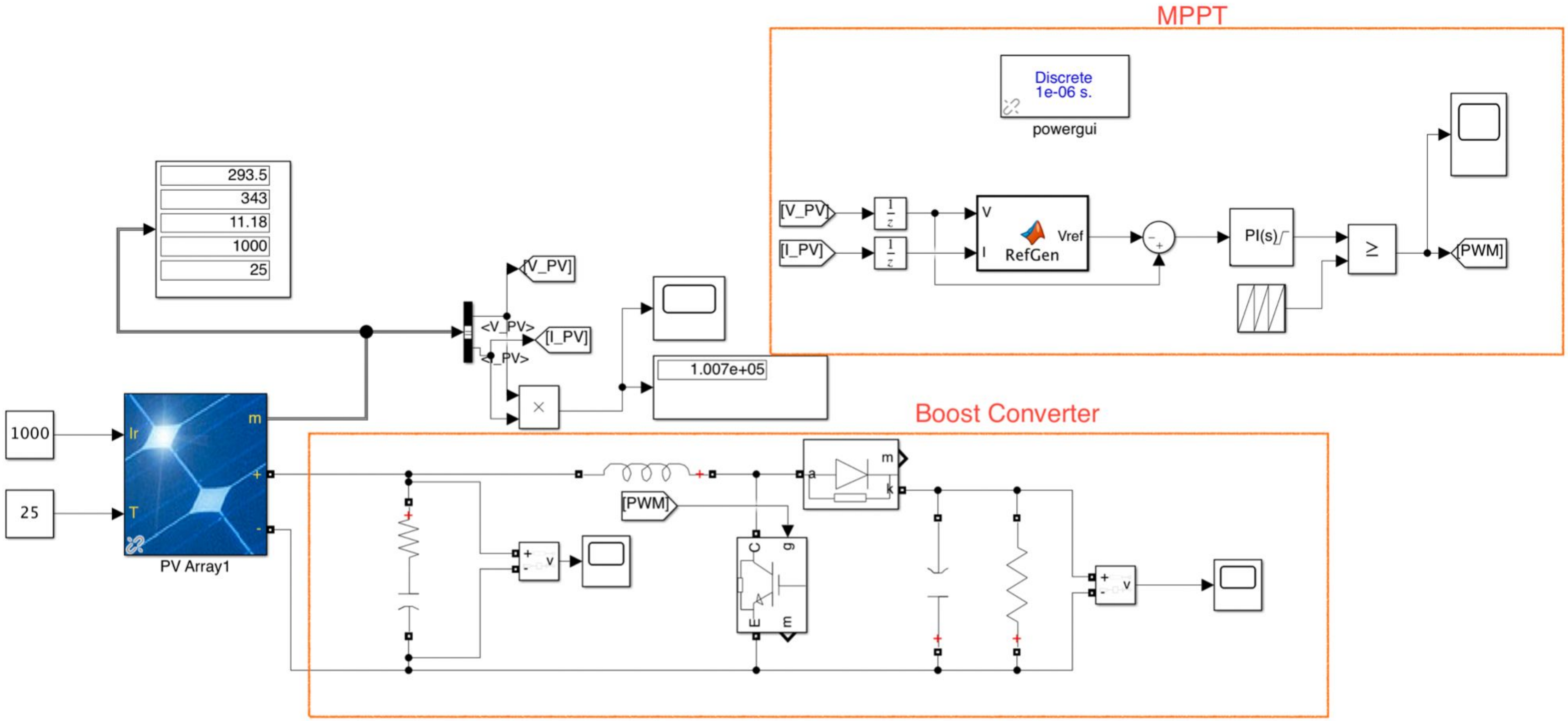
MPPT Code & Graph

```
function Vref = RefGen(V, I)

Vrefmax = 363;
Vrefmin = 0;
 Vrefinit = 300;
 deltaVref = 1;
 persistent Vold Pold Vrefold;

 dataType = 'double';

 if isempty(Vold)
     Vold = 0;
     Pold = 0;
     Vrefold = Vrefinit;
 end

 P = V*I;
 dV = V-Vold; %change in voltage
 dP = P-Pold; %change in power

 if dP ~= 0 %change in delta P
     if dP<0 %decrease in output power
         if dV<0
             Vref = Vrefold + deltaVref; %Vref is increased if output voltage drops
         else
             Vref = Vrefold - deltaVref; %Vref is decreased if output voltage increases
         end
     else %increase in output power
         if dV<0
             Vref = Vrefold - deltaVref; %Vref is decreased if output voltage drops
         else
             Vref = Vrefold + deltaVref; %Vref is increased if output voltage increases
         end
     end
 else Vref= Vrefold; %Vref is uncahnged if no change in output power
 end

 if Vref >= Vrefmax | Vref <= Vrefmin
     Vref = Vrefold; %Resets Vref to initial value if not within limits
 end

 Vrefold = Vref; %update reference voltage
 Vold = V; %update output voltage
 Pold = P; %update output power
```

- MPPT are used to increase or maximize the output power in a Photovoltaic system.
- MPPT is an algorithm implemented in PV inverters to continuously adjust the impedance seen by the solar array to keep the PV system operating at the peak power of the PV panel.
- The algorithm helps control the voltage to ensure that the system operates at “maximum power point” on the power voltage curve.

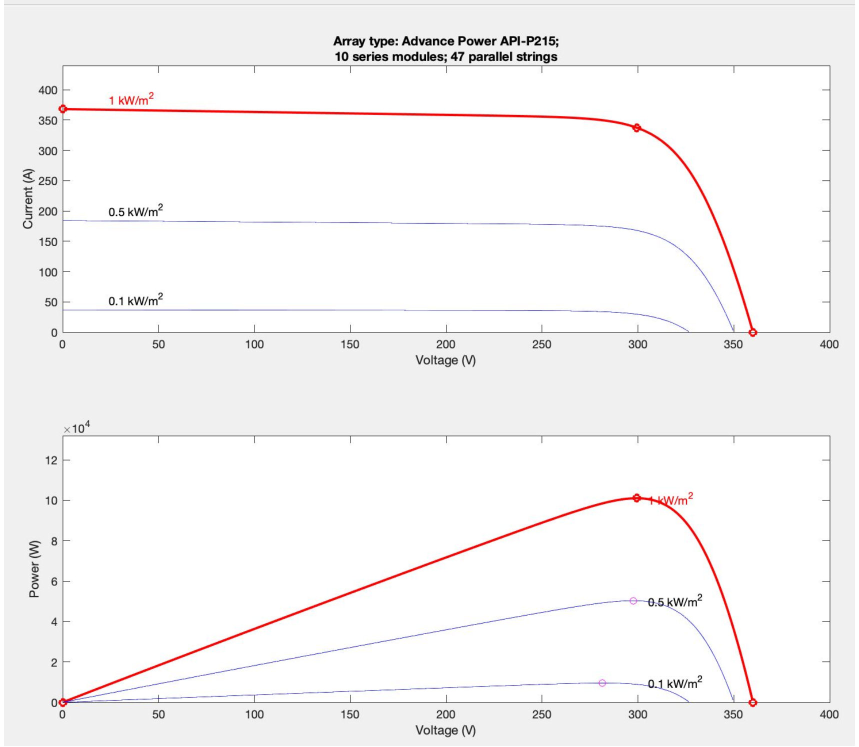


Simulink: PV System with MPPT



I-V Curves & P-V Curves

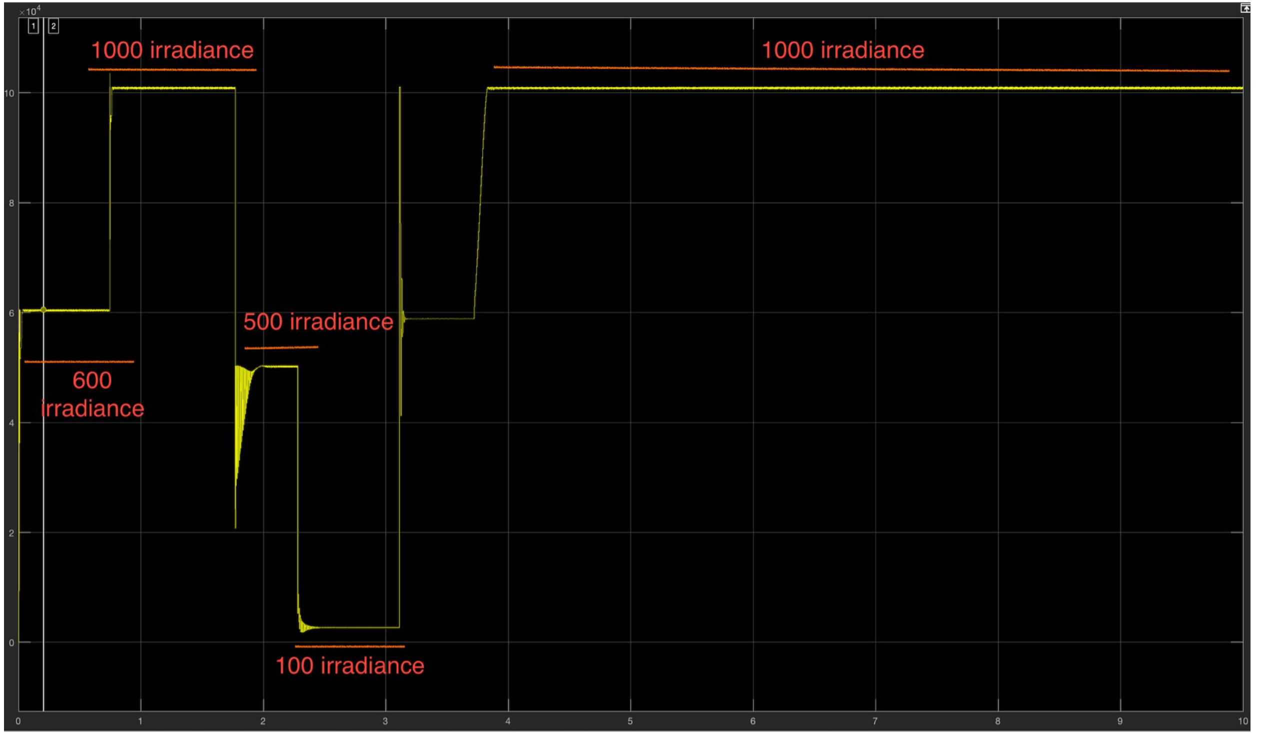
- Top Curve- irradiance: 1000 & power: 101kW
- Middle Curve- irradiance: 500 & power: 50kW
- Bottom Curve- irradiance:100 & power: 9.5KW



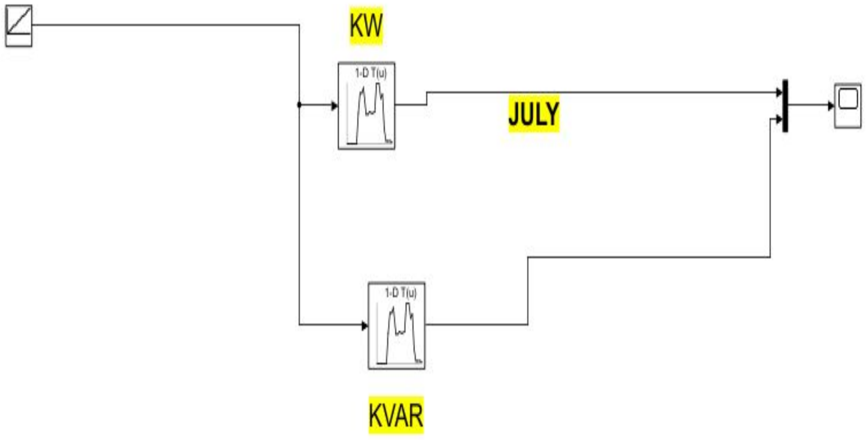
Simulation of MPPT

Input of irradiance:

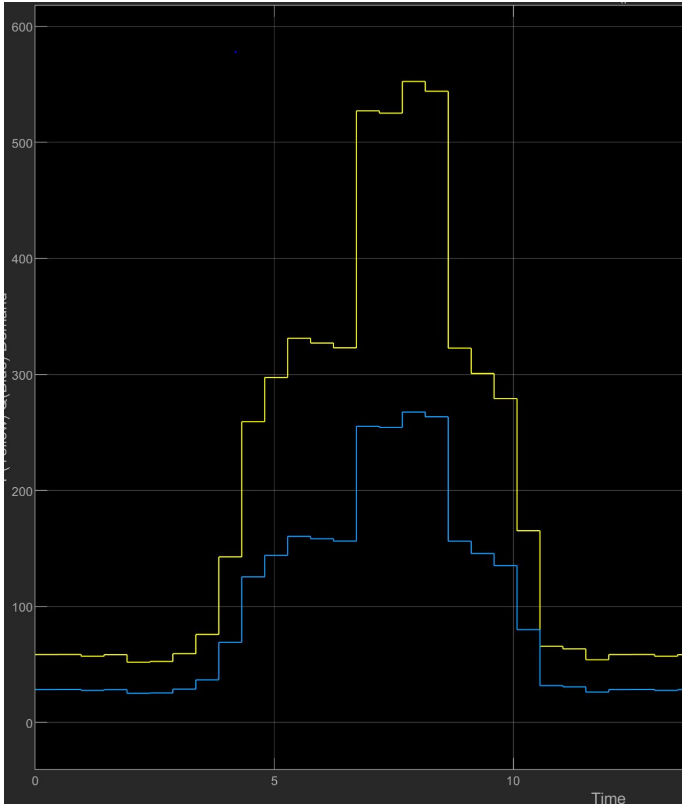
- ❖ Sec: 0-1, P:60kW
- ❖ Sec:1-2, P: 101kW
- ❖ Sec:1.8-2.2, P:50kW
- ❖ Sec:2.2-3.1, P:9.5kW
- ❖ Sec:4-10, P: 101kW



Load Lookup Table

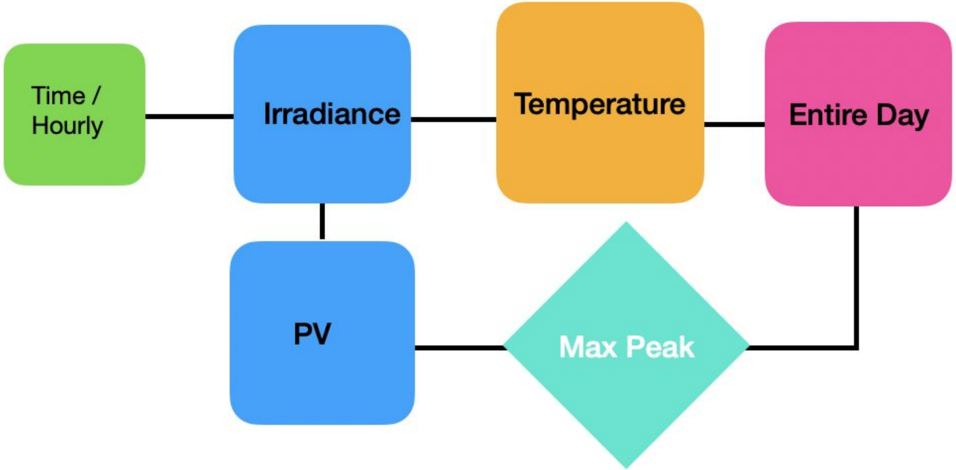


Yellow : Active Power (P)
Blue: Reactive Power (Q)

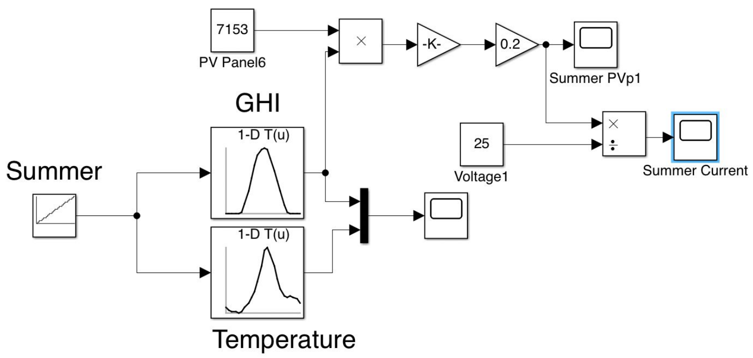


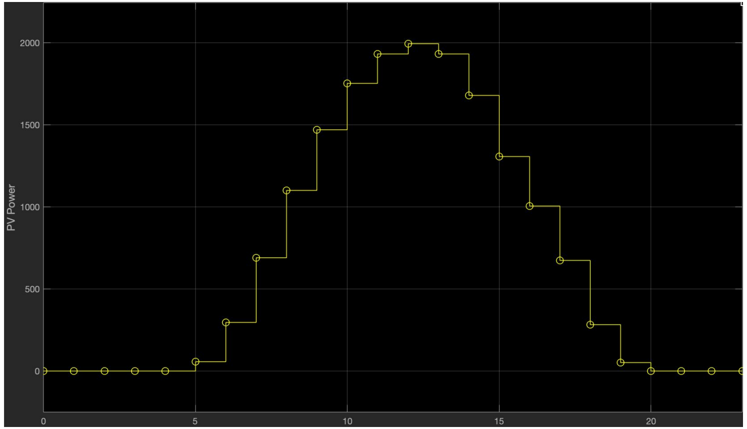
GHI Look up table

- Yearly GHI lookup table data
  - GHI & Temp
  - Calculate PV peak to gain power
  - Peak varies on hour of the day

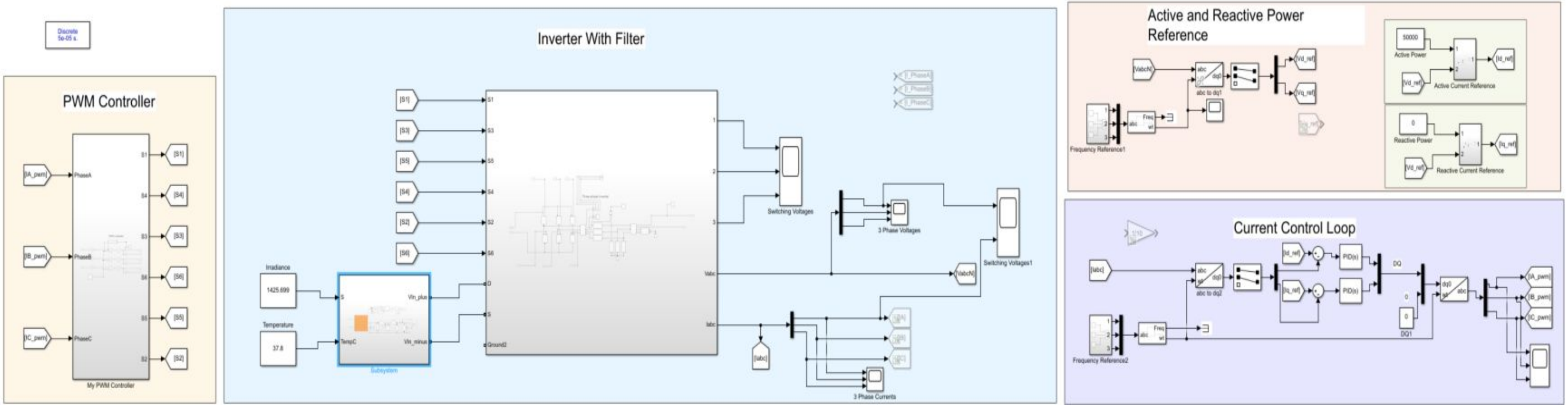


PV Peak in the Summer for 1 Day





PV With Inverter System



Projected PV Output 7/7/2030

Time (p.m.)	Temperature	GHI	Total Output (Aggregate) (kw)	Total Demand (kw)
12:00	37.8	1425.699	600	327.0465
13:00	37.1	1379.201	588	322.8123
14:00	36.3	1249.006	564	527.1721
15:00	35.3	1046.561	428.4	525.1216
16:00	34.2	787.6037	294	552.4674
17:00	32.8	467.1255	105.84	543.9694
18:00	31.1	188.1378	17.34	322.6168
19:00	28.9	44.35189	0.96	300.8024
20:00	27.4	0	0	279.0661
21:00	26.8	0	0	165.2476
22:00	26.6	0	0	65.71137
23:00	26.9	0	0	63.43246
0:00	27.2	0	0	41.616

Electric Load Percentages

- Electric Load Pattern: Residential, Commercial, Industrial, Other Demand by NREL

Hour	Total Demand (kW)	Percent Residential (%)	Residential Demand (kW)	Percentage Commercial (%)	Commercial Demand (kW)	Percentage Industrial (%)	Industrial Demand (kW)	Percentage Other (%)	Other Demand (kW)
12pm	327.05	26.09	85.33	43.48	142.20	19.57	64.00	13.04	42.65
1pm	322.81	25.00	80.70	50.00	161.41	18.75	60.53	12.50	40.35
2pm	527.17	27.27	143.76	50.50	266.22	18.18	95.84	12.12	63.89
3pm	525.12	29.00	152.29	48.00	252.06	18.00	94.52	12.00	63.01
4pm	552.47	31.00	171.26	46.00	254.14	17.00	93.92	12.00	66.30
5pm	543.97	34.00	184.95	40.00	217.59	16.00	87.04	10.00	54.40
6pm	322.62	37.37	120.56	35.35	114.05	15.15	48.88	10.10	32.58
7pm	300.80	38.93	117.10	32.97	99.17	15.95	47.98	10.63	31.98
8pm	279.07	40.44	112.85	32.58	90.92	16.85	47.02	11.23	31.34
9pm	165.25	41.66	68.84	29.76	49.18	17.85	29.50	13.09	21.63
10pm	65.71	39.50	25.96	27.16	17.85	18.51	12.16	12.34	8.11
11pm	63.43	37.14	23.56	28.00	17.76	21.42	13.59	14.28	9.06
12am	41.62	32.35	13.46	27.35	11.38	22.05	9.18	14.70	6.12

SAM

Monthly Load Summary

	Energy (kWh)	Peak (kW)
Jan	133,070.92	477.81
Feb	119,848.54	501.01
Mar	134,633.73	479.82
Apr	135,879.94	490.27
May	135,406.02	521.14
Jun	135,242.91	497.79
Jul	151,910.03	552.47
Aug	155,233.72	545.48
Sep	141,929.73	544.14
Oct	139,827.58	511.98
Nov	133,826.56	517.05
Dec	134,714.95	520.68
Annual	1,651,524.62	552.47

System Advisor Model (SAM)

SAM can simulate theoretical situation to determine the best sizing, peaks, energy, etc., throughout the year

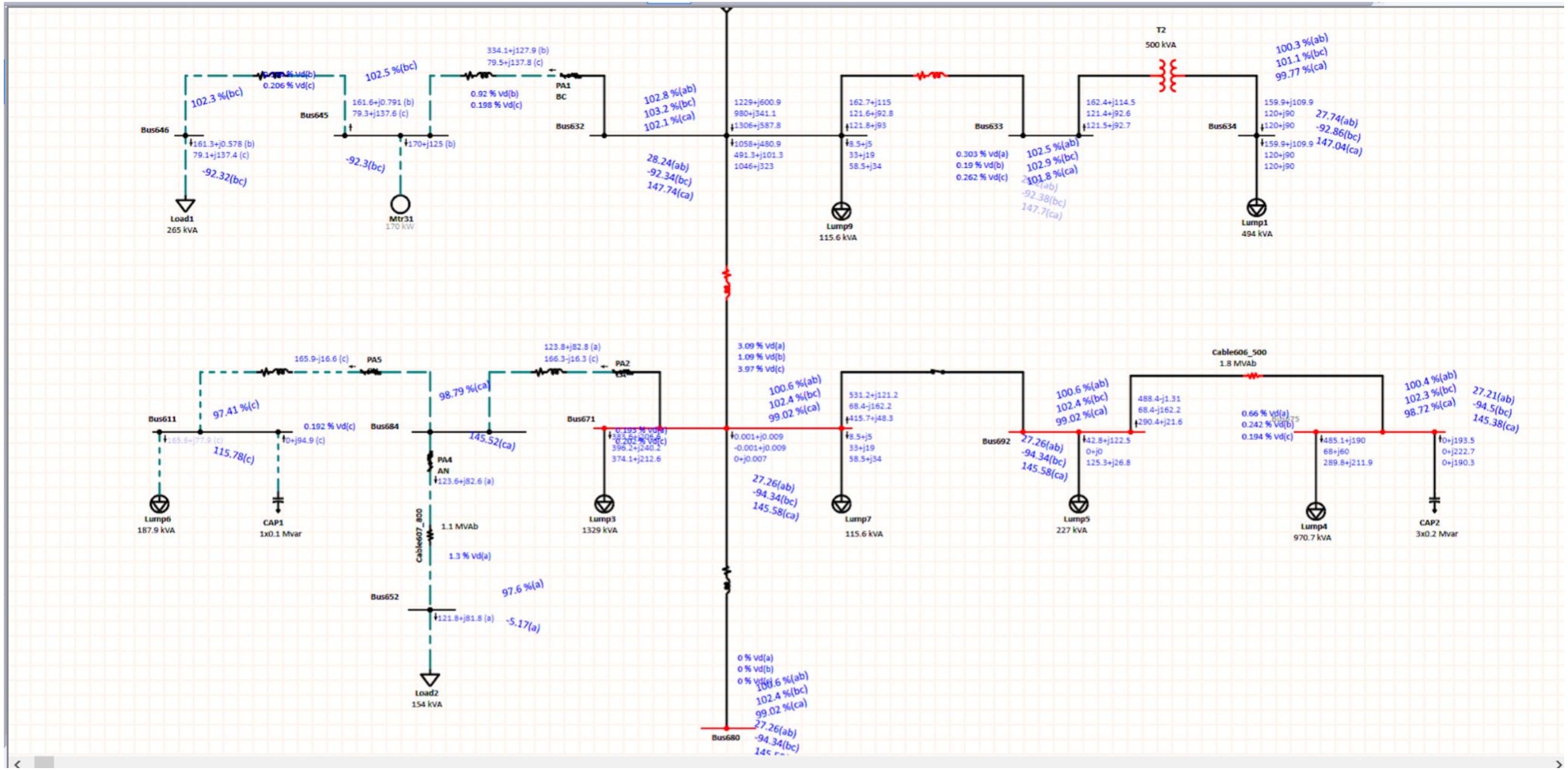
SAM

After running the software we have the choice to send it to EXCEL and sort it.

Battery BankSize (KWH)	Battery Bank Power (KW)	Desire Size (KW) DC	Net Present Value
600	600	600	326,051

ETAP

IEEE 13 Bus Feeder



IEEE 13 Bus Feeder Alert View

Unbalanced Load Flow Analysis Alert View - Output Report: origna_IEEEI_13bus

Study Case: ULF
Configuration: Normal

Data Revision: Base
Date: 04-18-2021

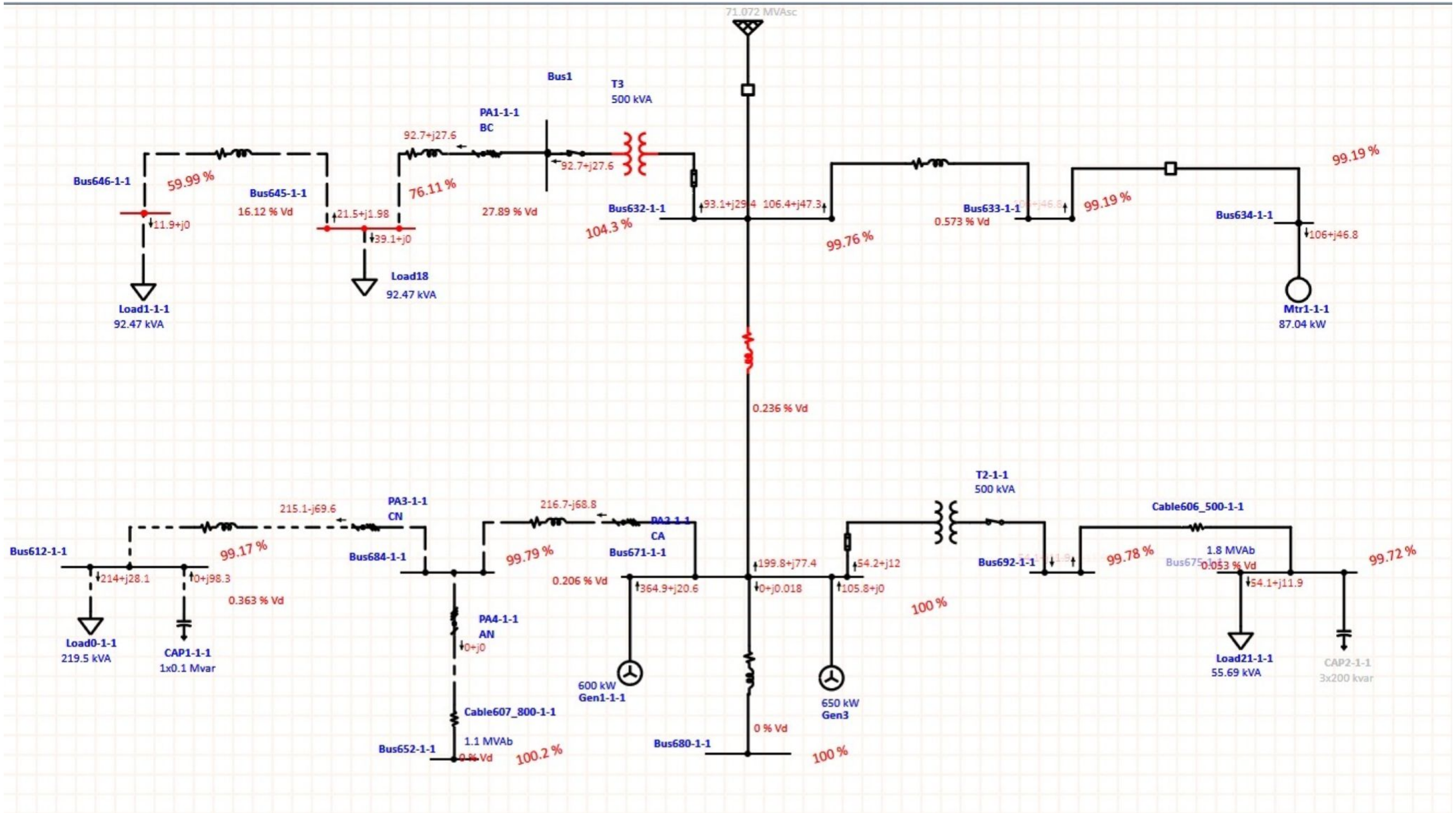
Filter

☐ Zone ☐ Area ☐ Region

Critical

Device ID	Type	Condition	Rating / Limit	Operating A	Operating B	Operating C	%Op. A	%Op. B	%Op. C
Bus671	Bus	Over Voltage	4.16 kV	2.38 kV	2.53 kV	2.35 kV	99	105.3	97.7
Bus671	Bus	VUF 0 (Zero Seq.)	2.418 kV	0.08 kV	0 kV	0 kV	3.4	0	0
Bus675	Bus	Over Voltage	4.16 kV	2.36 kV	2.53 kV	2.34 kV	98.4	105.5	97.5
Bus675	Bus	VUF 0 (Zero Seq.)	2.413 kV	0.09 kV	0 kV	0 kV	3.6	0	0
Bus680	Bus	Over Voltage	4.16 kV	2.38 kV	2.53 kV	2.35 kV	99	105.3	97.7
Bus680	Bus	VUF 0 (Zero Seq.)	2.418 kV	0.08 kV	0 kV	0 kV	3.4	0	0
Bus692	Bus	Over Voltage	4.16 kV	2.38 kV	2.53 kV	2.35 kV	99	105.3	97.7
Bus692	Bus	VUF 0 (Zero Seq.)	2.418 kV	0.08 kV	0 kV	0 kV	3.4	0	0
Cable606_500	Impedance	LIUR (Pos. Seq.)	132.999 Amp	72.35 Amp	63.41 Amp	8.94 Amp	54.4	47.7	6.7
Cable606_500	Impedance	IUF 2 (Neg. Seq.)	119.311 Amp	45 Amp	45 Amp	45 Amp	37.7	37.7	37.7
Cable606_500	Impedance	IUF 0 (Zero Seq.)	119.311 Amp	67.38 Amp	67.38 Amp	67.38 Amp	56.5	56.5	56.5
Line601_22	Line	LIUR (Pos. Seq.)	374.124 Amp	99.57 Amp	173.68 Amp	74.11 Amp	26.6	46.4	19.8
Line601_22	Line	IUF 2 (Neg. Seq.)	372.634 Amp	105.22 Amp	105.22 Amp	105.22 Amp	28.2	28.2	28.2
Line601_22	Line	IUF 0 (Zero Seq.)	372.634 Amp	72.33 Amp	72.33 Amp	72.33 Amp	19.4	19.4	19.4
Line602	Line	LIUR (Pos. Seq.)	68.366 Amp	12.88 Amp	7.24 Amp	5.64 Amp	18.8	10.6	8.2
Line602	Line	IUF 2 (Neg. Seq.)	68.36 Amp	6.3 Amp	6.3 Amp	6.3 Amp	9.2	9.2	9.2
Line602	Line	IUF 0 (Zero Seq.)	68.36 Amp	6.68 Amp	6.68 Amp	6.68 Amp	9.8	9.8	9.8
T2	2W XFMR	LIUR (Pos. Seq.)	592.515 Amp	111.64 Amp	62.78 Amp	48.86 Amp	18.8	10.6	8.2
T2	2W XFMR	IUF 2 (Neg. Seq.)	68.361 Amp	6.3 Amp	6.3 Amp	6.3 Amp	9.2	9.2	9.2
T2	2W XFMR	IUF 0 (Zero Seq.)	68.361 Amp	6.68 Amp	6.68 Amp	6.68 Amp	9.8	9.8	9.8

ETAP Case: 5pm



ETAP Case: 5pm Alert View

Unbalanced Load Flow Analysis Alert View - Output Report: Load_scaling_1

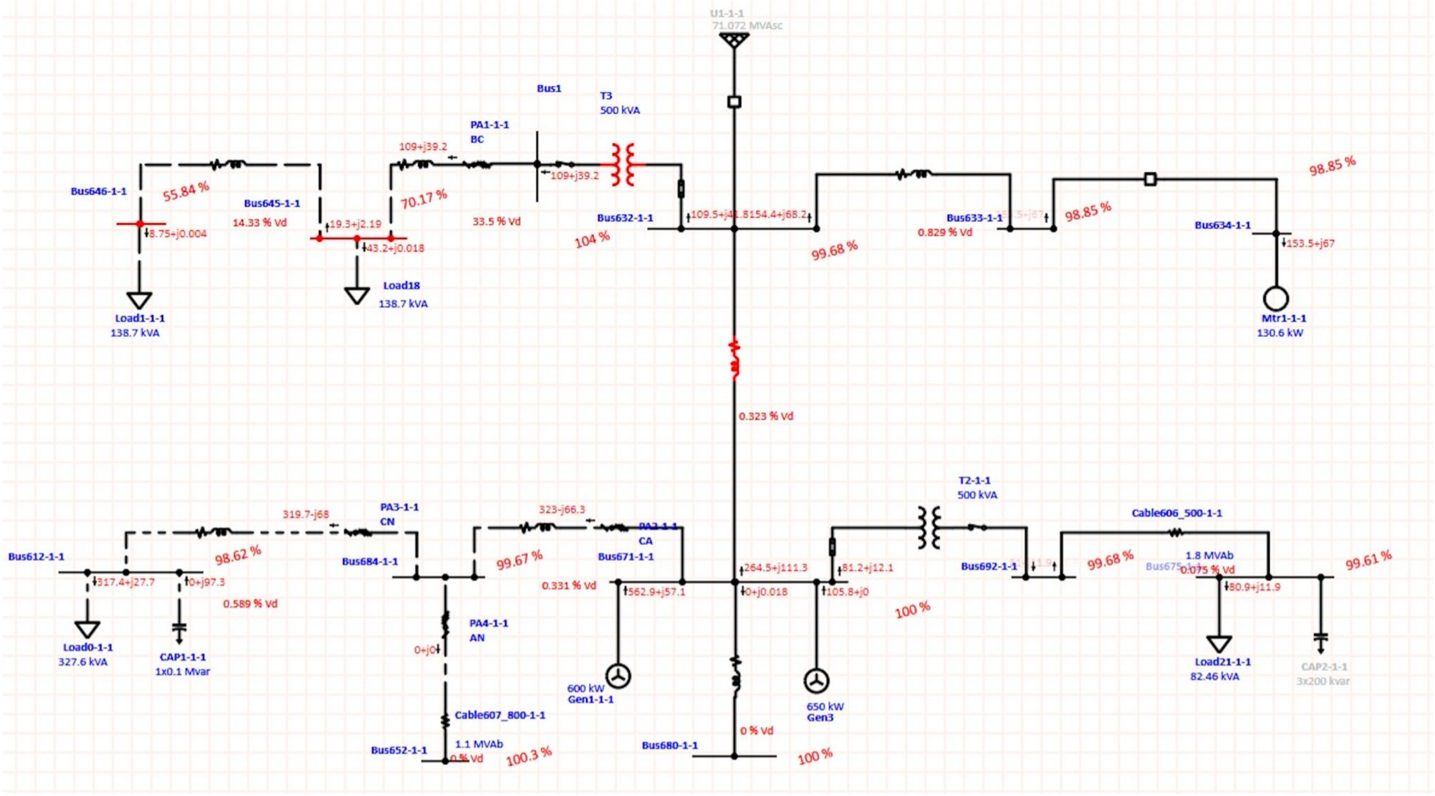
Study Case: ULF　　Data Revision: Base
Configuration: Normal　　Date: 04-17-2021

Filter
☐ Zone　☐ Area　☐ Region

Critical

Device ID	Type	Condition	Rating / Limit	Operating A	Operating B	Operating C	%Op. A	%Op. B	%Op. C
Bus645-1-1	Bus	Under Voltage	0.24 kV	0 kV	0.12 kV	0.09 kV	0	86.6	65.6
Bus646-1-1	Bus	Under Voltage	0.24 kV	0 kV	0.1 kV	0.07 kV	0	69.7	50.3
Line601_22-1-1	Line	LIUR (Pos. Seq.)	31.585 Amp	6.58 Amp	11.57 Amp	4.99 Amp	20.8	36.6	15.8
Line601_22-1-1	Line	IUF 2 (Neg. Seq.)	29.741 Amp	13.43 Amp	13.43 Amp	13.43 Amp	45.2	45.2	45.2
T3	2W XFMR	LIUR (Pos. Seq.)	258.906 Amp	258.91 Amp	129.45 Amp	129.45 Amp	100	50	50
T3	2W XFMR	IUF 2 (Neg. Seq.)	13.582 Amp	13.58 Amp	13.58 Amp	13.58 Amp	100	100	100

ETAP Case: 5 P.M. Load Scaling by 1.5



ETAP Case: 5 P.M. Alert View Load Scaling by 1.5

Unbalanced Load Flow Analysis Alert View - Output Report: 5pm_loadflow_x1.5

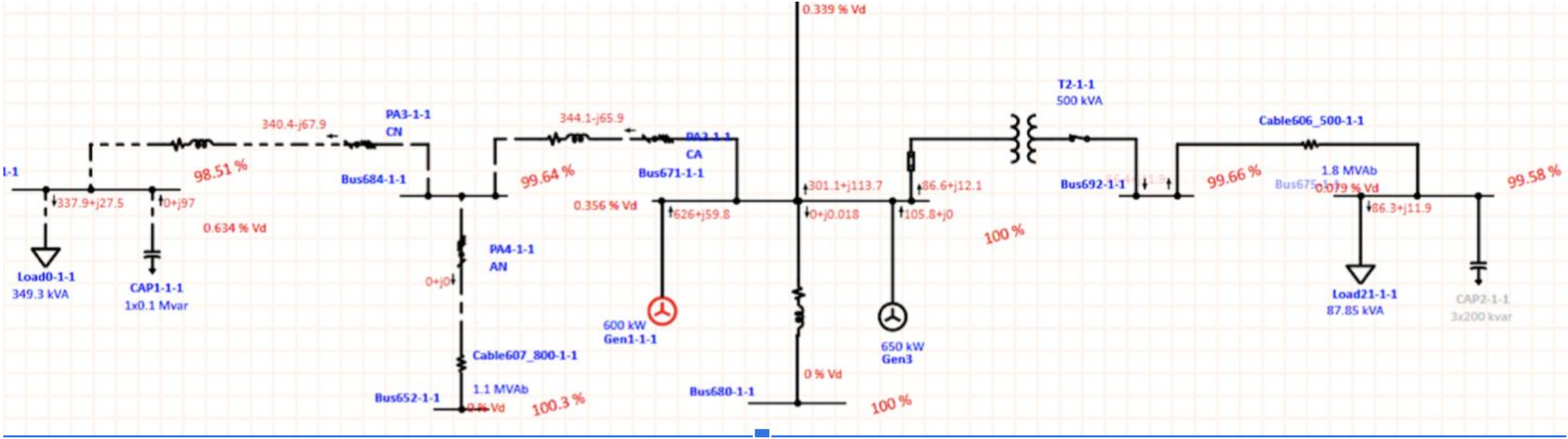
Study Case: ULF
Configuration: Normal
Data Revision: Base
Date: 04-17-2021

Filter
☐ Zone ☐ Area

Critical

Device ID	Type	Condition	Rating / Limit	Operating A	Operating B	Operating C	%Op. A	%Op. B	%Op. C
Bus645-1-1	Bus	Under Volt...	0.24 kV	0 kV	0.11 kV	0.08 kV	0	81.9	58.5
Bus646-1-1	Bus	Under Volt...	0.24 kV	0 kV	0.09 kV	0.07 kV	0	64.6	47.1
Line601_22-...	Line	LIUR (Pos....	41.773 Amp	7.49 Amp	14.13 Amp	6.64 Amp	17.9	33.8	15.9
Line601_22-...	Line	IUF 2 (Neg...	39.832 Amp	16.07 Amp	16.07 Amp	16.07 Amp	40.4	40.4	40.4
T3	2W XFMR	LIUR (Pos....	311.434 Amp	311.43 Amp	155.72 Amp	155.72 Amp	100	50	50
T3	2W XFMR	IUF 2 (Neg...	16.338 Amp	16.34 Amp	16.34 Amp	16.34 Amp	100	100	100

ETAP Case: 5pm Load Scale by 1.6



ETAP: 5pm Load Scaling by 1.6

Unbalanced Load Flow Analysis Alert View - Output Report: loadscaling_X1.6

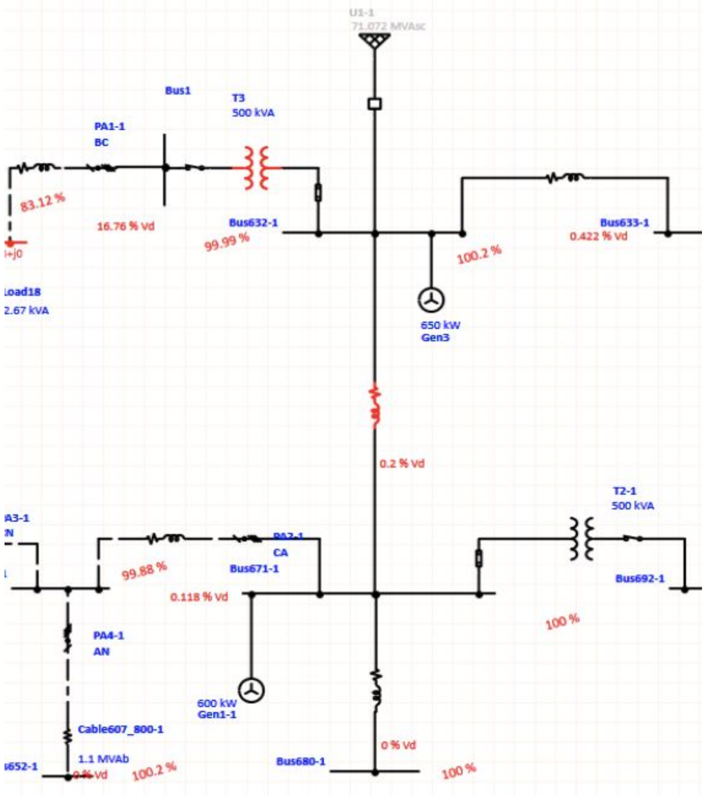
Study Case: ULF | Data Revision: Base
Configuration: Normal | Date: 04-17-2021

Filter: Zone, Area, Region

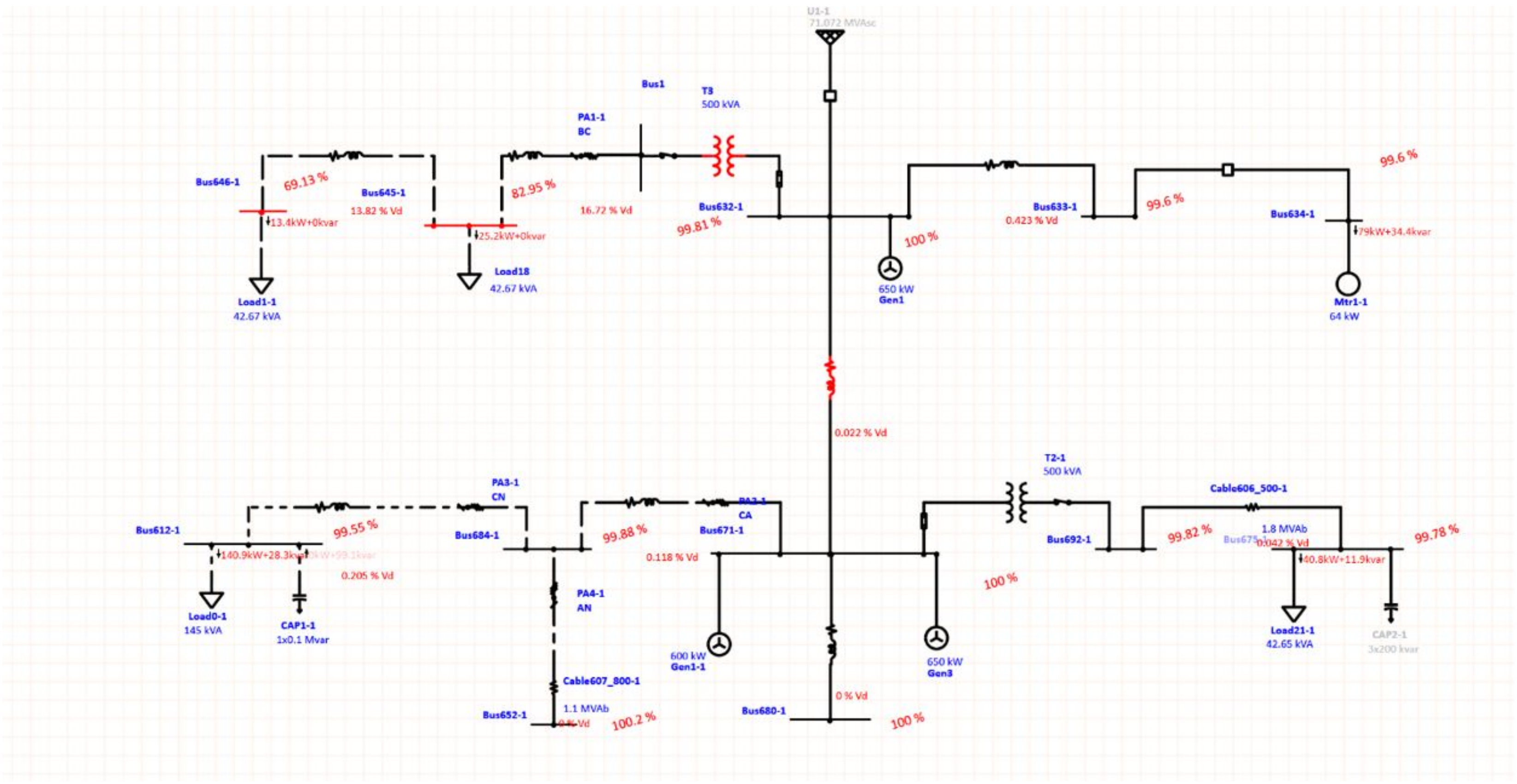
Critical

Device ID	Type	Condition	Rating / Limit	Operating A	Operating B	Operating C	%Op. A	%Op. B	%Op. C
T3	2W XFMR	LIUR (Pos. Seq.)	360.925 Amp	79.58 Amp	39.79 Amp	39.79 Amp	22	11	11
T3	2W XFMR	IUF 2 (Neg. Seq.)	324.729 Amp	138.52 Amp	138.52 Amp	138.52 Amp	42.7	42.7	42.7
T3	2W XFMR	IUF 0 (Zero Seq.)	324.729 Amp	93.78 Amp	93.78 Amp	93.78 Amp	28.9	28.9	28.9
Line601_22-1-1	Line	LIUR (Pos. Seq.)	45.08 Amp	3.57 Amp	7.8 Amp	4.23 Amp	7.9	17.3	9.4
Line601_22-1-1	Line	IUF 2 (Neg. Seq.)	44.667 Amp	8.22 Amp	8.22 Amp	8.22 Amp	18.4	18.4	18.4
Gen1-1-1	SynGen	Overload	0.6 MW	0.63 MW	0 MW	0 MW	104.3	0	0
Bus646-1-1	Bus	Under Voltage	0.24 kV	0 kV	0.1 kV	0.07 kV	0	68.7	49.5
Bus645-1-1	Bus	Under Voltage	0.24 kV	0 kV	0.12 kV	0.09 kV	0	85.8	64.4
Bus3	Bus	Under Voltage	0.2 kV	0.11 kV	0 kV	0 kV	57	0	0

ETAP: Relocate PV-12pm



ETAP: Split PV-12PM BUS 632

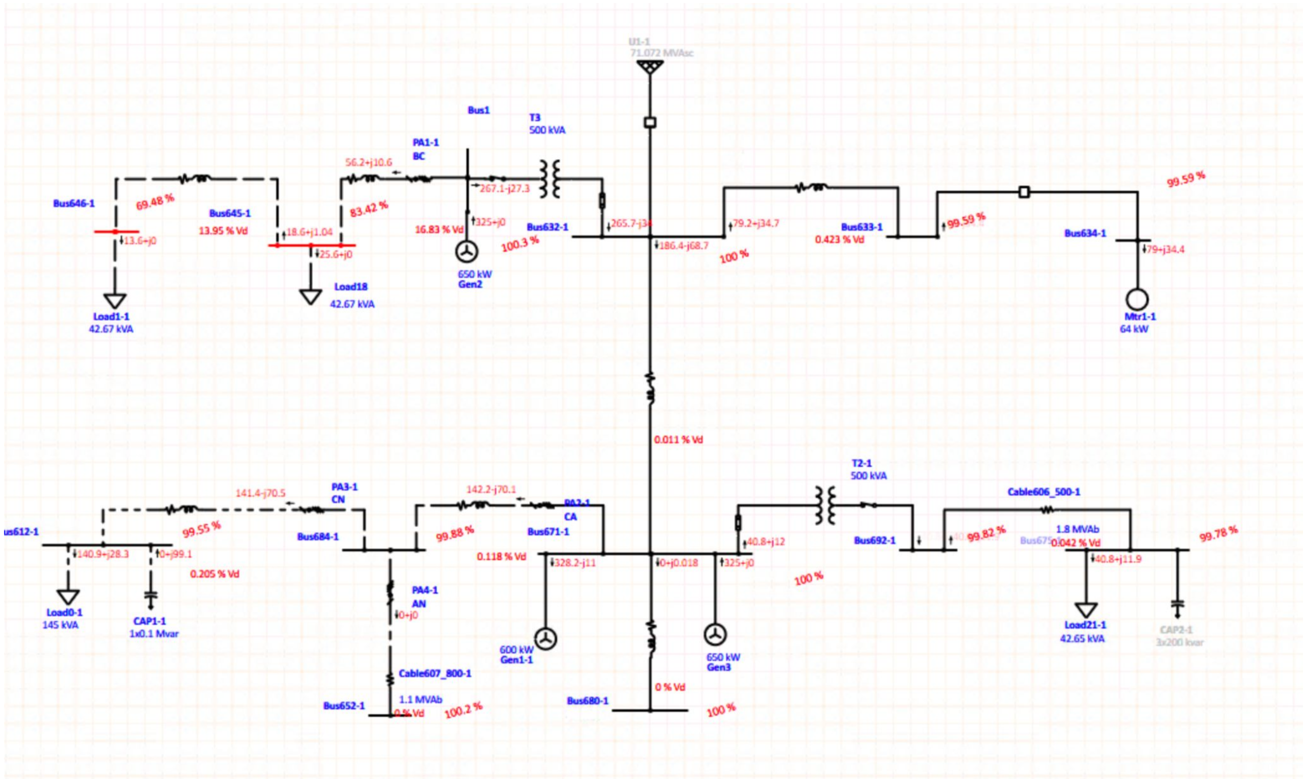


Losses: Split PV-BUS 632

Branch Losses Summary Report

CKT / Branch		From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop in Vmag	Amperes in Buried Winding
ID	Phase	MW	Mvar	MW	Mvar	kW	kvar	From	To		
Line601 22-1	A	0.061	0.001	-0.061	-0.001	0.1	0.1	100.1	100.0	0.1	
	B	0.038	-0.018	-0.038	0.018	0.0	0.1	99.9	100.0	0.1	
	C	0.067	-0.029	-0.066	0.029	0.1	0.2	100.0	100.0	0.0	
Line601 33-1	A	0.000	0.000	0.000	0.000	0.0	0.0	100.0	100.0	0.0	
	B	0.000	0.000	0.000	0.000	0.0	0.0	100.0	100.0	0.0	
	C	0.000	0.000	0.000	0.000	0.0	0.0	100.0	100.0	0.0	
Line602-1	A	0.026	0.012	-0.026	-0.012	0.1	0.1	100.1	99.7	0.4	
	B	0.026	0.011	-0.026	-0.011	0.1	0.1	99.9	99.5	0.4	
	C	0.027	0.011	-0.026	-0.011	0.1	0.1	100.0	99.5	0.5	
Line603 BC300-1	B	-0.008	0.007	0.011	-0.006	2.5	0.5	77.1	89.9	12.8	
	C	-0.005	-0.007	0.008	0.007	2.5	0.5	61.1	76.0	14.8	
Line603 BC500-1	B	-0.025	0.016	0.031	-0.011	5.9	4.7	89.9	100.2	10.3	
	C	-0.019	-0.017	0.024	0.021	5.9	4.8	76.0	99.2	23.2	
Line604 ACN300-1	A	0.000	0.000	0.000	0.000	0.0	0.0	100.1	100.0	0.1	
	C	-0.141	0.070	0.142	-0.070	0.8	0.4	99.7	100.0	0.3	
Line605 CN300-1	C	-0.141	0.071	0.141	-0.070	0.5	0.3	99.6	99.7	0.2	
Cable606 500-1	A	0.014	0.004	-0.014	-0.004	0.0	0.0	99.8	99.8	0.0	
	B	0.014	0.004	-0.014	-0.004	0.0	0.0	99.8	99.8	0.0	
	C	0.014	0.004	-0.014	-0.004	0.0	0.0	99.8	99.8	0.0	
Cable607 800-1	A	0.000	0.000	0.000	0.000	0.0	0.0	100.1	100.2	0.0	
T2-1	A	0.014	0.004	-0.014	-0.004	0.0	0.0	100.0	99.8	0.2	0
	B	0.014	0.004	-0.014	-0.004	0.0	0.0	100.0	99.8	0.2	0
	C	0.014	0.004	-0.014	-0.004	0.0	0.0	100.0	99.8	0.2	0
T3	A	0.012	-0.014	0.000	0.000	12.5	-14.2	100.1	100.1	0.0	0
	B	0.037	0.007	-0.031	0.011	6.1	18.2	99.9	100.2	0.2	0
	C	0.006	0.018	-0.024	-0.021	-18.4	-3.4	100.0	99.2	0.8	0
						18.8	12.5				

Splitting PV:650kW Bus 1 at 12 P.M.



ETAP:Splitting PV 12 P.M. Alert View Analysis

Unbalanced Load Flow Analysis Alert View - Output Report: Untitled

Study Case: ULF
Configuration: Normal

Data Revision: Base
Date: 04-25-2021

Filter
☐ Zone ☐ Area ☐ Region

Critical

Device ID	Type	Condition	Rating / Limit	Operating A	Operating B	Operating C	%Op. A	%Op. B	%Op. C
Bus645-1	Bus	Under Voltage	0.24 kV	0 kV	0.12 kV	0.11 kV	0	89.9	76.9
Bus646-1	Bus	Under Voltage	0.24 kV	0 kV	0.11 kV	0.09 kV	0	77.1	61.9

Battery Storage Sizing

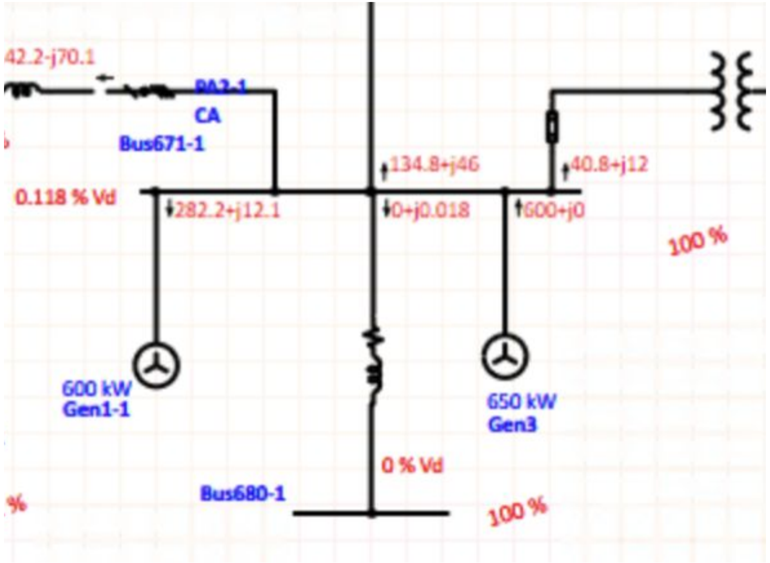
- Similar to PV sizing, except rating is in kWh instead of kW. The sizing study was performed using an initial size of 600 kWh.

- One source represents PV and models the projected generation. The other source is set to “swing” control mode and represents battery storage.

- “Battery storage” source will either absorb or inject power depending on the difference between supply and demand.

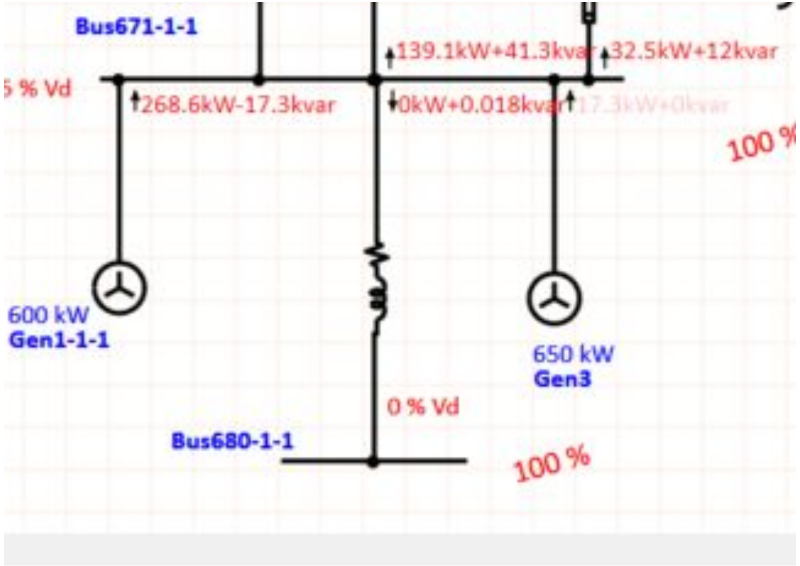
ETAP 12pm Case (Total Demand: 327.05 kW)

- High GHI, therefore high PV production.
- Relatively lower demand, so there is excess power from PV.
- Excess energy is stored in the battery to be used later.



ETAP 6pm Case

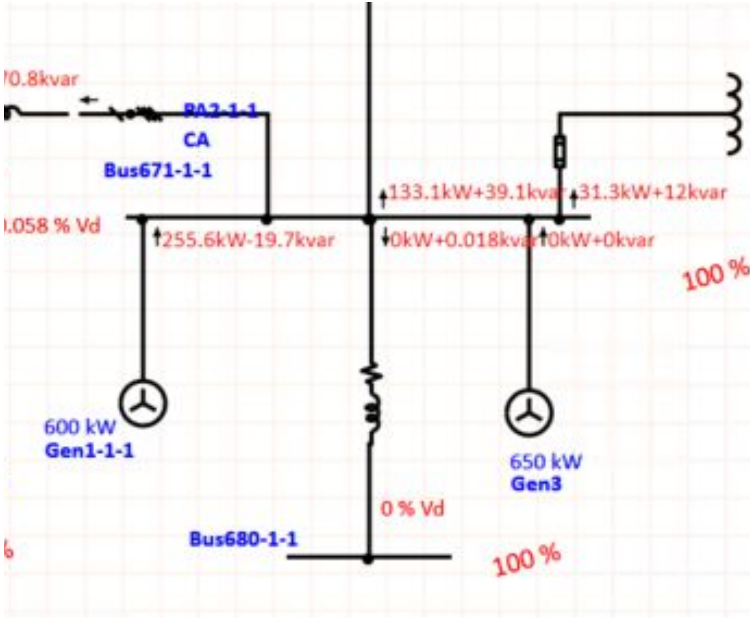
- Low output from PV
- Battery Storage is now outputting power to supply the remaining demand.



ETAP 8pm Case

- All cases ran after 6pm have zero output from PV due to lack of GHI from the sun.

- Battery is forced to supply the demand on its own.



Results of Battery Storage Testing

- For later hours, there is no PV production, but still significant demand from 6pm-9pm.
- To completely sustain demand with no PV production, we would need to double capacity of battery (600 kWh->1200 kWh).
- This would give a resiliency of about 6 hours

Time (p.m.)	Power Supplied from Battery (kw) (ETAP)
6:00	268.6
7:00	267.7
8:00	255.6
9:00	158.9
10:00	63.8
11:00	64.5
12:00	41.5
Total (kwh)	1120.6

Summary

- ❖ The following challenges have been a source of trouble for the team.
  - ➢ Software difficulties
  - ➢ Road bumps of changing routes
  - ➢ Finishing strong as a unit
- ❖ We are pleased with the results of this project that we have put together even though the challenging has put our backs against the wall. Through our analysis, we determined that a 650 kW PV source and battery storage with a capacity of 1200 kWh would completely sustain the demand for around 6 hours.