

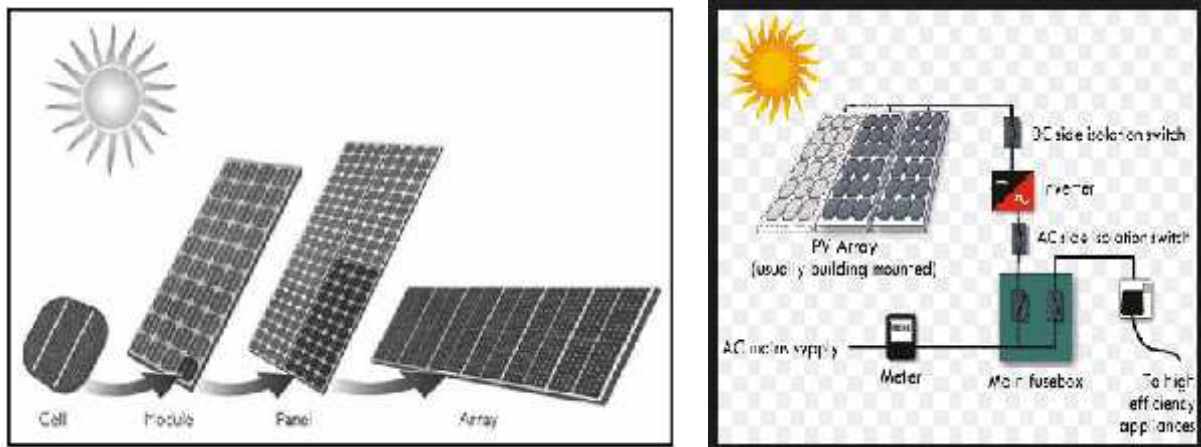
## Solar PV Module

### Purpose and Description

The purpose of this exercise is to analyze the DC and AC load flow of a solar PV module.

### Theoretical Concepts

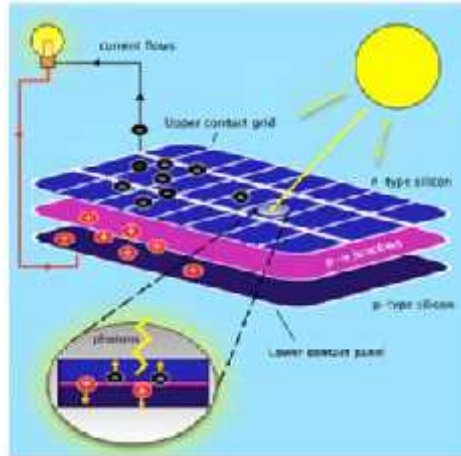
PV array is one of the important elements of renewable energy, micro-grid, smart grid, etc. It converts solar radiation energy into direct current using semiconductors and then to electric power through inverters as shown below. ETAP PV Array is used to represent individual panels connected in series and parallel combinations with a grid tied inverter and represents blocks of PV power. As shown below, a number of modules make up a typical PV panel that can be connected in a string configuration in order to achieve a desired current and voltage at the inverter input.



The physics of the PV cell is very similar to the classical p-n junction diode. When light is absorbed by the junction, the energy of the absorbed photons is transferred to the electron system of the material, resulting in the creation of charge carriers that are separated at the junction. The charge carriers may be electron-ion pairs in a liquid electrolyte or electron hole pairs in a solid semiconducting material. The charge carriers in the junction region create a potential gradient, get accelerated under the electric field and circulate as the current through an external circuit.

### Solar PV Module

The current squared times the resistance of the circuit is the power converted into electricity. The remaining power of the photon elevates the temperature of the cell.

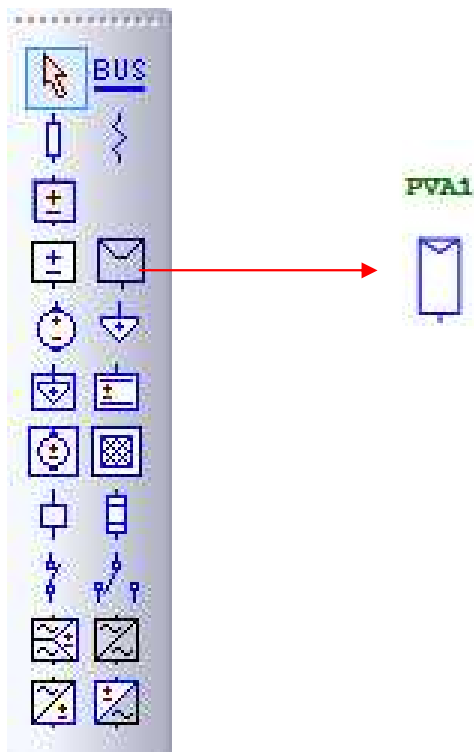


Several PV cells make a module and several modules make an array. In ETAP we define the PV panel information and specify the number of panels connected in series and parallel that make up the final PV array.

## Solar PV Module

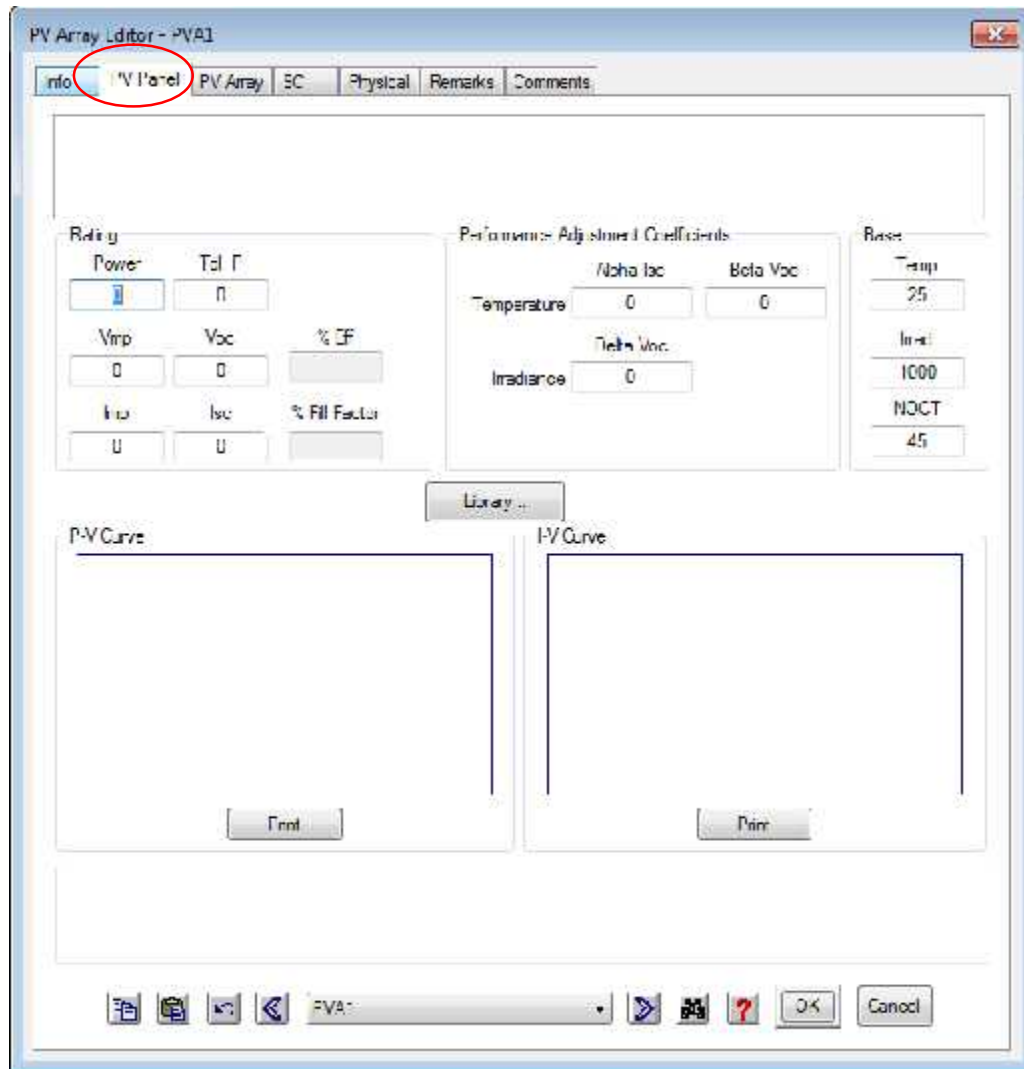
### Procedure

1. Open Solar\_PV example OTI file from Solar PV Array folder.
2. Drag and drop a PV Array on OLV from DC Editor Toolbar



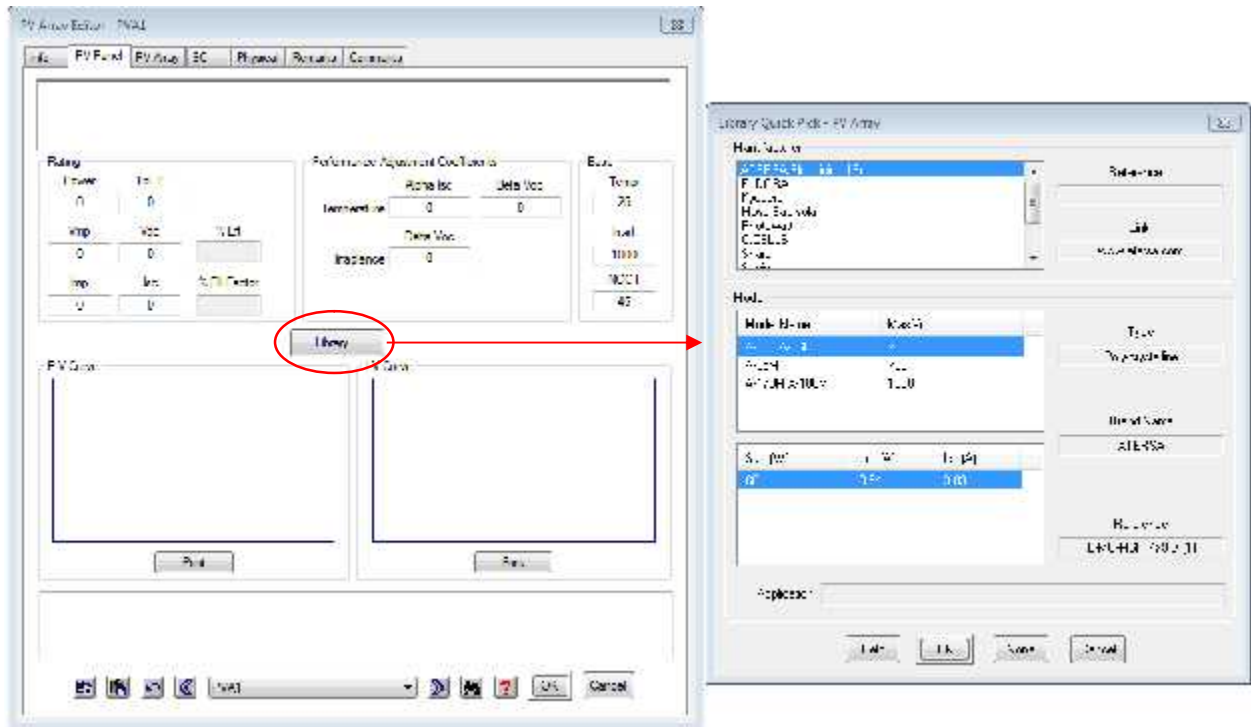
## Solar PV Module

3. Double click on PV Array (PVA1) and go to PV Panel tab as shown below.

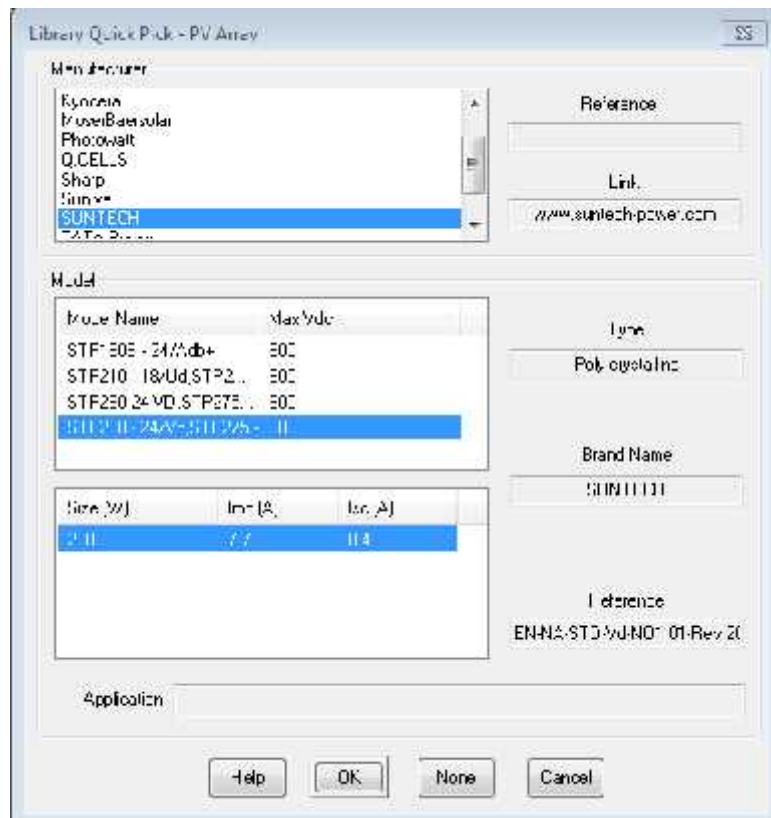


## Solar PV Module

- Click on the Library to select a PV module.

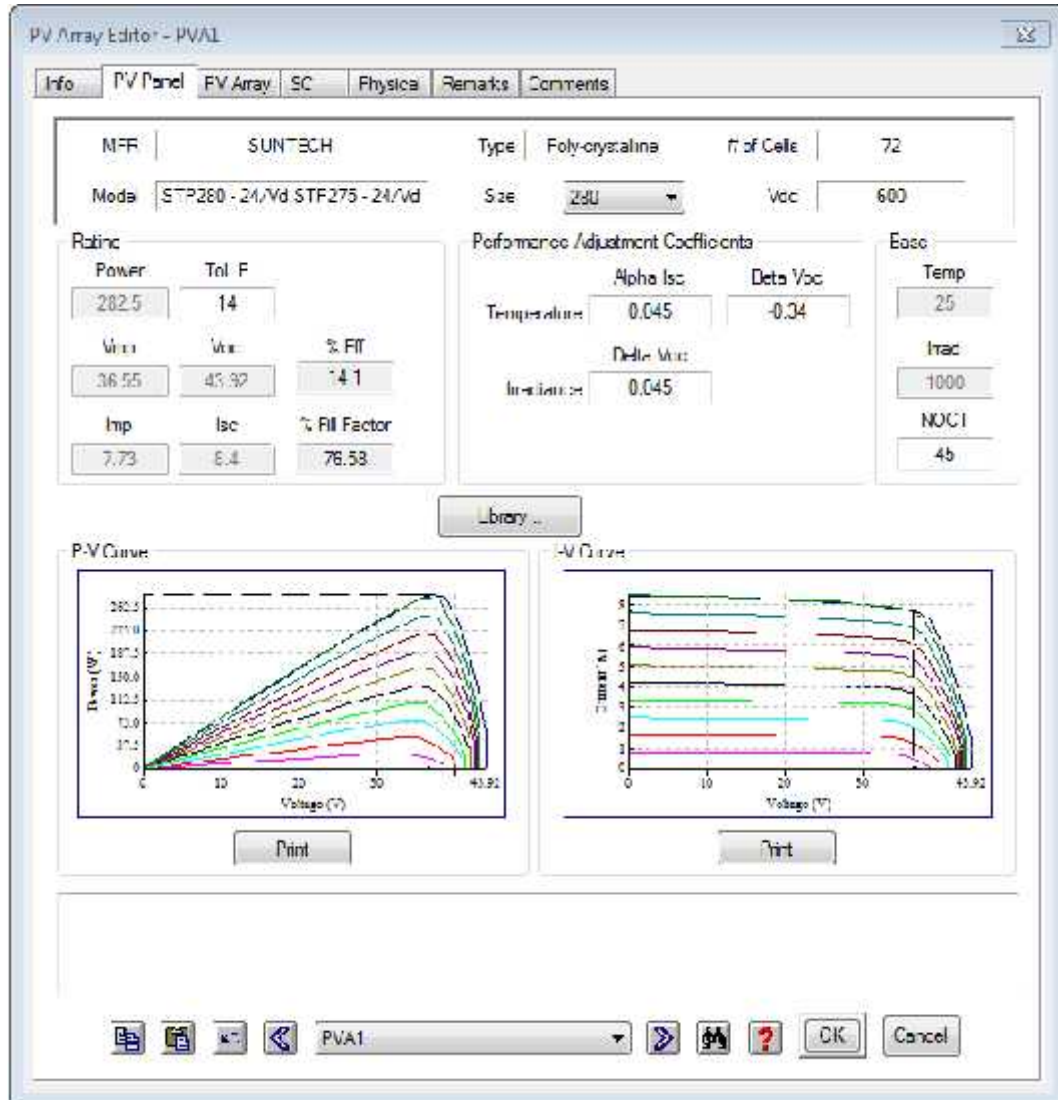


- Select Manufacturer and Model as shown below and click on OK.



## Solar PV Module

- The electrical characteristics of PV module will be reflected as shown below.



## Solar PV Module

- Go to PV Array, select the desired no of series modules and no of parallel modules as shown below and click in OK.

PV Array Editor - PVA1

Info PV Panel PV Array SC Physical Parameters Comments

MFR: SUNTECH Type: Poly-crystalline # of Cells: 72  
 Model: ST120U-24/vd ST120S-24/vd Size: 230 Vdc: 600

PV Panel PV Array (Total)

Watt / Panel: 202.5 # of Panels: 200  
 # in Series: 20 Volts<sub>dc</sub>: 720  
 # of Parallel: 10 kW<sub>pk</sub>: 14130  
 /m<sup>2</sup><sub>pk</sub><sub>dc</sub>: 173

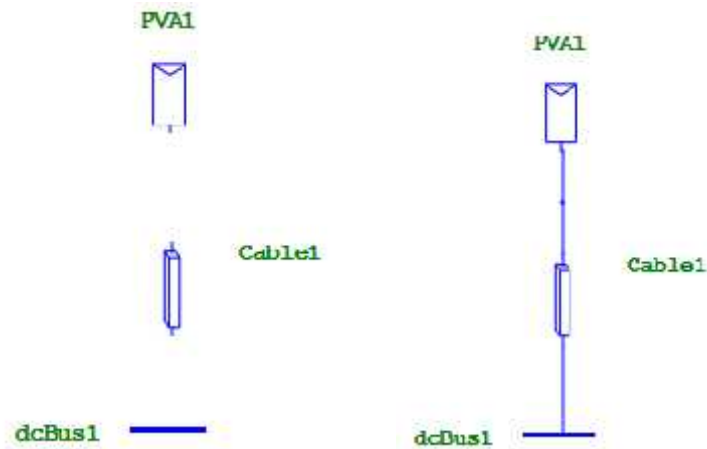
Irradiance Data

	Generation Category	Irradiance	Ta	Tc	NPR kW
1	Design	1000	30	51.3	55.67
2	Normal	900	30	58.1	49.86
3	Shutdown	800	30	55	44.08
4	Emergency	700	30	57.9	38.33
5	Standby	600	30	48.8	32.62
6	Startup	500	30	45.6	26.95
7	Accident	400	30	42.5	21.03
8	Summer Load	300	30	39.4	15.78

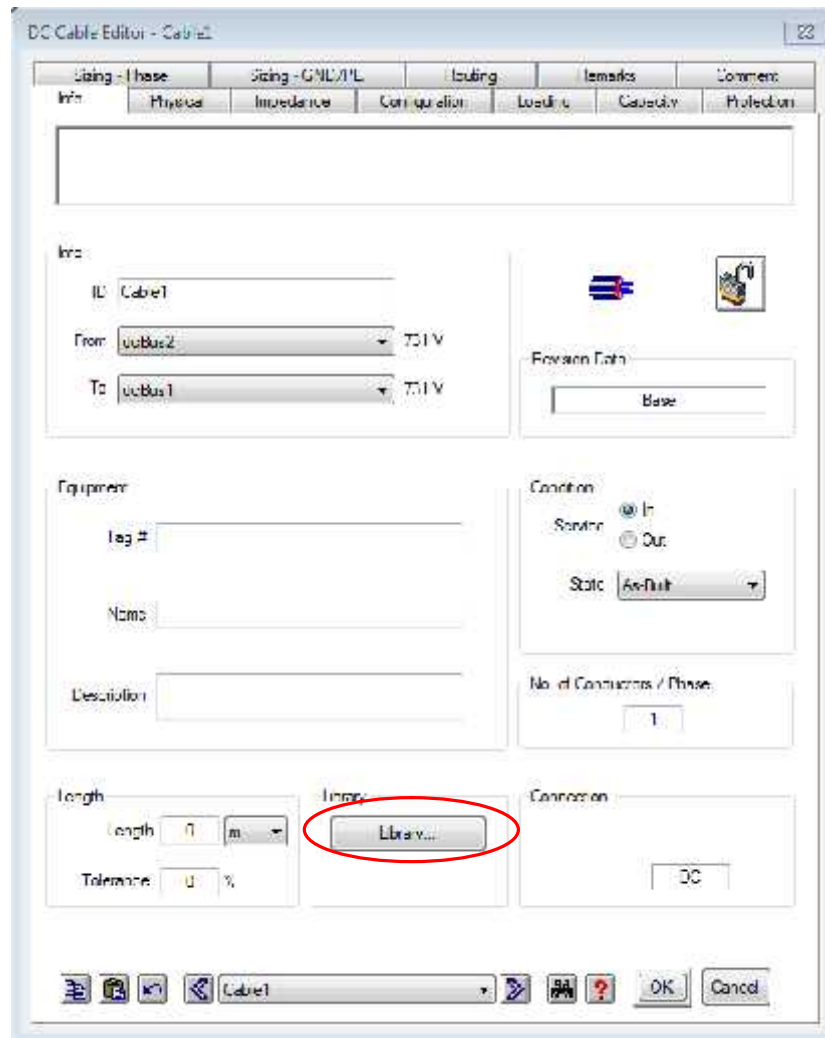
OK Cancel

## Solar PV Module

8. Drag and drop a DC bus, DC cable from DC Editor Toolbar and connect them as shown below.



9. Double click on Cable1, go to Info page and click on Library.



DC Cable Editor - Cable1

Using - Phase	Using - GND/V/L	Routing	Remarks	Comment		
Info	Physical	Impedance	Configuration	Location	Capacity	Protection

Info

ID: Cable1

From: dcBus2 751 V

To: dcBus1 751 V

Equipment

Tag #:

Name:

Description:

Condition

Source: ☒ In ☐ Out

State: As-built

No. of Conductors / Phase: 1

Length

Length: 1 m

Tolerance: 1 %

Library: **Library...**

Connection: DC

OK Cancel



## Solar PV Module

10. Select the cable from Library as shown below and click on OK.

Library Quick Pick - Cable

	Unit	Freq	Type	kV	% Class	#/C	Inaul	Source	Install
487	Metric	50	CU	0.7	100	1/C	PF	BS7211	Non-Mag.
488	Metric	50	CU	1.0	100	1/C	XLPE	BS5467	Non-Mag.
489	Metric	50	CU	1.0	100	1/C	XLPE	BS5467	Non-Mag.
490	Metric	50	CU	1.0	100	2/C	XLPE	BS5467	Non-Mag.
491	Metric	50	CU	1.0	100	2/C	XLPE	BS5467	Non-Mag.
492	Metric	50	CU	1.0	100	3/C	XLPE	BS5467	Non-Mag.
493	Metric	50	CU	1.0	100	3/C	XLPE	BS5467	Non-Mag.
494	Metric	50	CU	1.0	100	4/C	XLPE	BS5467	Non-Mag.
495	Metric	50	CU	1.0	100	4/C	XLPE	BS5467	Non-Mag.
496	Metric	50	CU	1.0	100	1/C	XLPE	BS6724	Non-Mag.
497	Metric	50	CU	1.0	100	2/C	XLPE	BS6724	Non-Mag.

U/G Ampacity			A/G Ampacity			Unit	Ref Base
Ia	Ic	HHU	Ia	Ic		Length	Temp.
15	50	120	25	30		1000 m	90

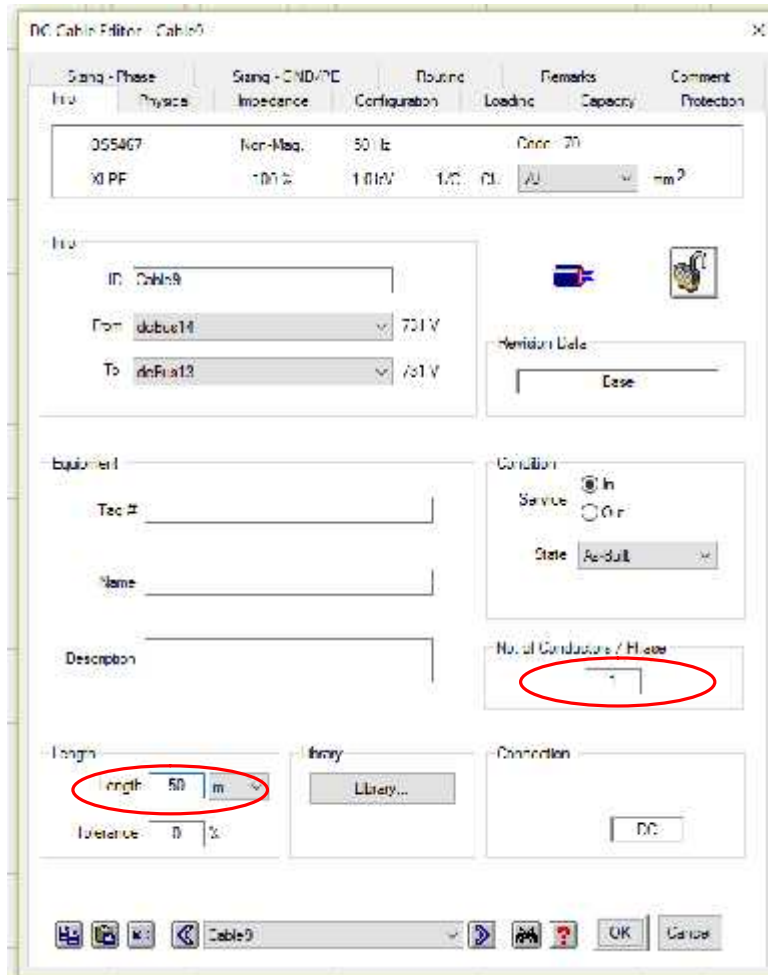
Size  
Phase PF  
20  
95  
120  
150  
185  
240

☒ Avail. Sizes  
☐ All Sizes

Help OK None Cancel

## Solar PV Module

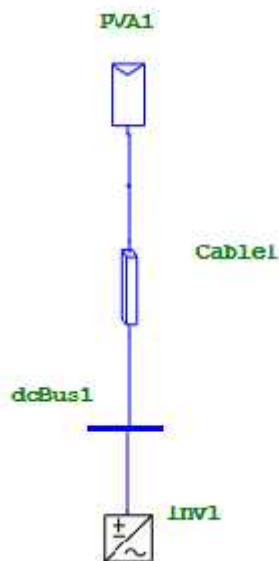
11. Enter the Length of cable and no. of conductors/phase in Info page as shown below.



String - Phase	String - COND/PC	Routing	Remarks	Comment
055467	Non-Mag.	50 Hz	Cable: 20	
XI PF	100%	1.00V	1.00	mm <sup>2</sup>

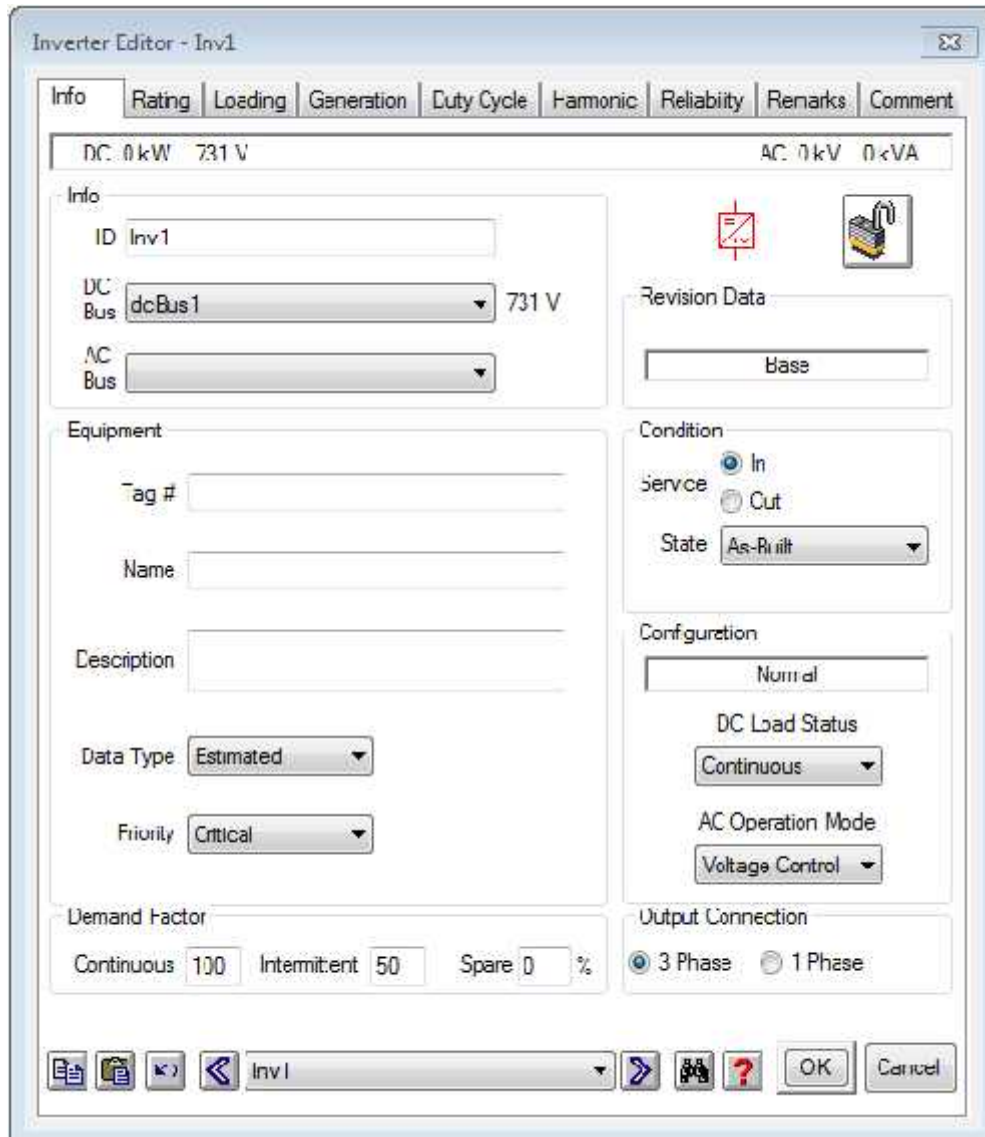
**Info**  
 ID: Cable0  
 From: dcBus14 701 V  
 To: dcFeat13 701 V  
 Condition: ☒ In ☐ Service ☐ Off  
 State: As-built  
 No. of Conductors / Phase: 1  
 Length: 50 m  
 Tolerance: 0 %  
 Library: Library...  
 Connection: DC

12. Drag and drop Inverter and connect it to dcBus1 as shown below.



## Solar PV Module

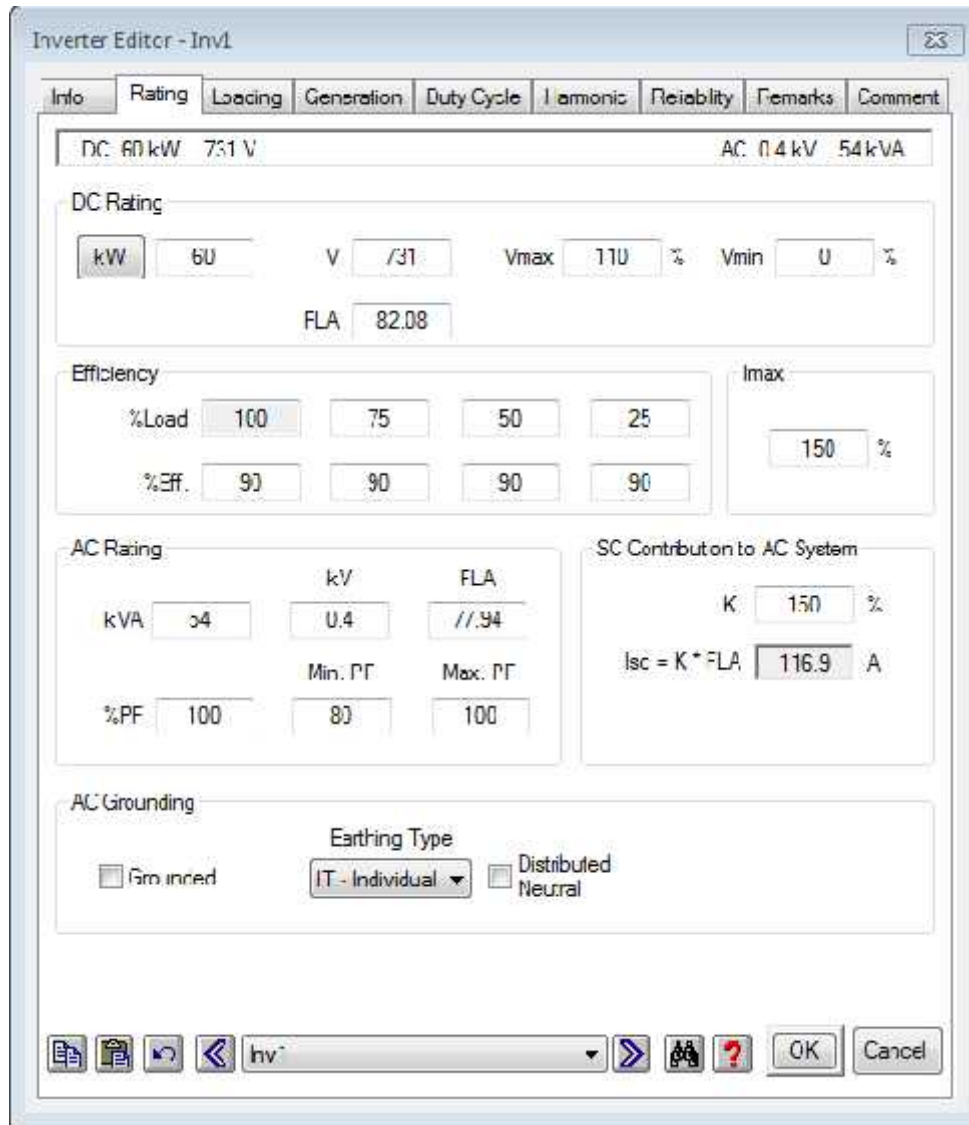
13. Double click on Inverter and the below window pops up.



The screenshot shows the 'Inverter Editor - Inv1' dialog box. It has a tabbed interface with 'Info' selected. The top bar shows 'DC: 0 kW 731 V' and 'AC: 0 kV 0 <VA'. The 'Info' tab contains several sections: 'Info' with fields for ID (Inv1), DC Bus (dcBus1), and AC Bus; 'Equipment' with fields for Tag #, Name, and Description, and dropdowns for Data Type (Estimated) and Priority (Critical); 'Demand Factor' with input fields for Continuous (100), Intermittent (50), and Spare (0) percentages; 'Revision Data' with a 'Base' field; 'Condition' with radio buttons for In (selected) and Out, and a 'State' dropdown (As-Built); 'Configuration' with a 'Normal' dropdown; 'DC Load Status' with a 'Continuous' dropdown; 'AC Operation Mode' with a 'Voltage Control' dropdown; and 'Output Connection' with radio buttons for 3 Phase (selected) and 1 Phase. The bottom of the dialog has a toolbar with icons for file operations and a list box showing 'Inv 1'.

## Solar PV Module

14. Go to Rating Page and enter the below parameters as shown and click on OK.



**Inverter Editor - Inv1**

Info Rating Loading Generation Duty Cycle Harmonic Reliability Remarks Comment

DC: 60 kW 751 V AC: 0.4 kV 54 kVA

**DC Rating**

kW: 60 V: 751 Vmax: 110 % Vmin: 0 %

FLA: 82.08

**Efficiency**

%Load: 100 75 50 25

%Eff.: 90 90 90 90

**Imax:** 150 %

**AC Rating**

kVA: 54 kV: 0.4 FLA: 116.9

%PF: 100 Min. PF: 80 Max. PF: 100

**SC Contribution to AC System**

K: 150 %

Isc = K \* FLA 116.9 A

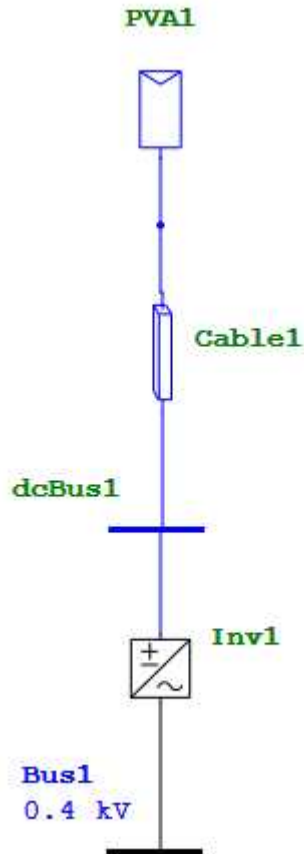
**AC Grounding**

Earthing Type: IT - Individual Distributed Neutral

Buttons: [File] [Print] [Undo] [Redo] [Inverter] [Help] [OK] [Cancel]

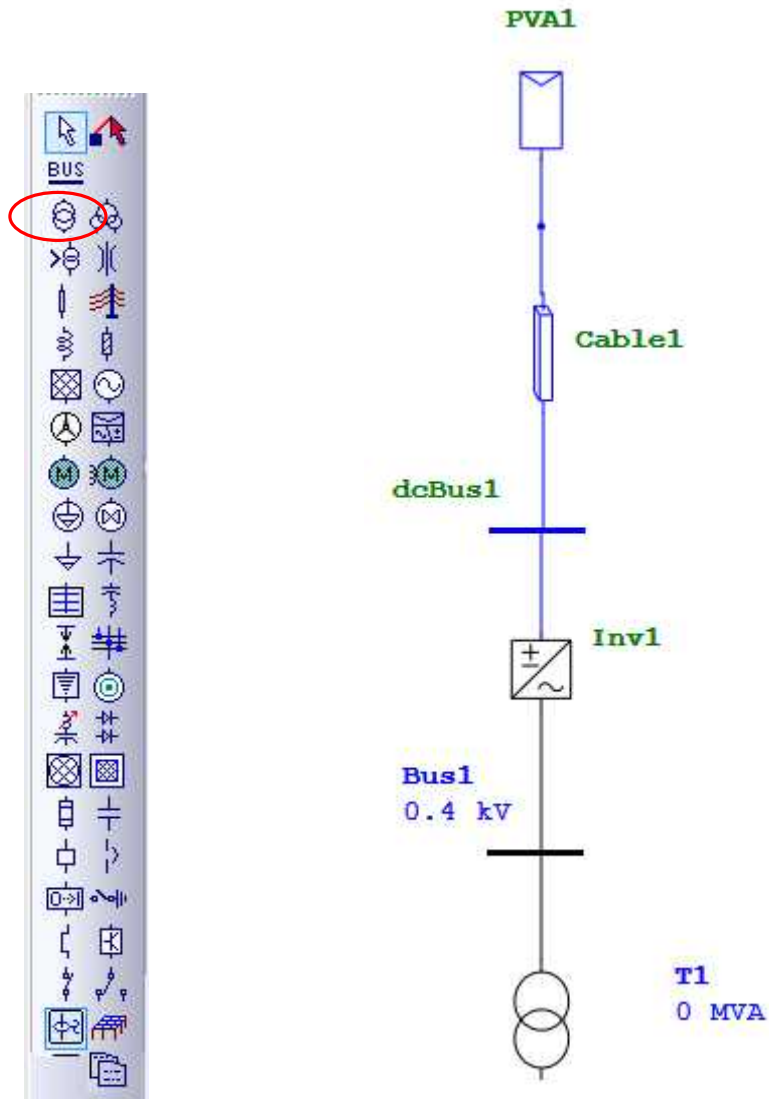
## Solar PV Module

15. Drag and drop an AC bus from AC Editor Toolbar as shown below and connect to inverter.



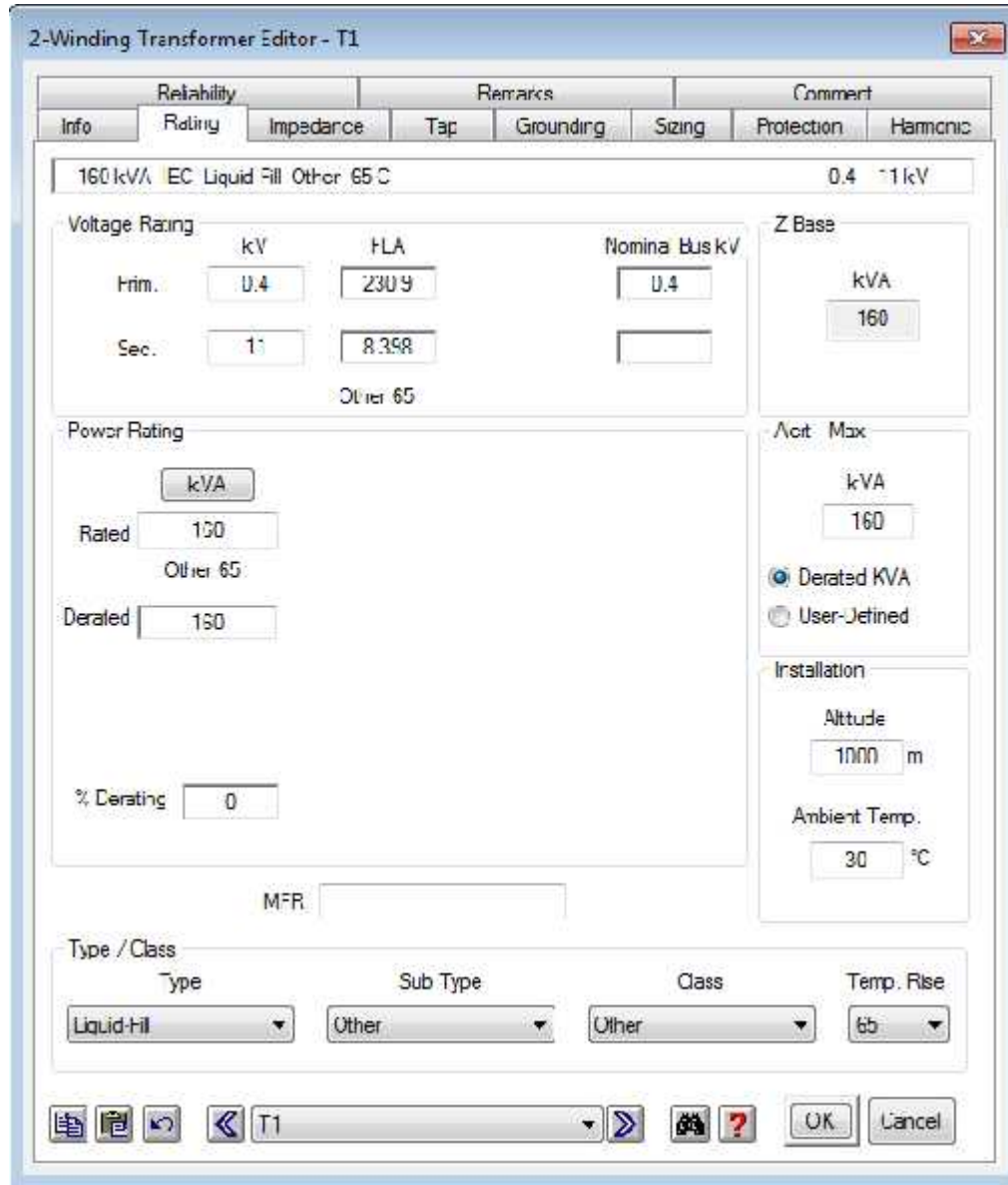
## Solar PV Module

16. Drag and drop a transformer from AC Editor Toolbar as shown below and connect to AC bus as shown below.



## Solar PV Module

17. Double click on transformer, Go to Rating Page and enter the below parameters as shown.



**2-Winding Transformer Editor - T1**

Reliability		Remarks		Comment													
Info	Rating	Impedance	Tap	Grounding	Sizing												
160 kVA EC Liquid Fill Other 65 C																	
0.4 11 kV																	
<b>Voltage Rating</b> <table border="1"> <thead> <tr> <th></th> <th>kV</th> <th>FLA</th> <th>Nominal Bus kV</th> </tr> </thead> <tbody> <tr> <td>Prim.</td> <td>0.4</td> <td>2309</td> <td>0.4</td> </tr> <tr> <td>Sec.</td> <td>11</td> <td>8358</td> <td></td> </tr> </tbody> </table>							kV	FLA	Nominal Bus kV	Prim.	0.4	2309	0.4	Sec.	11	8358	
	kV	FLA	Nominal Bus kV														
Prim.	0.4	2309	0.4														
Sec.	11	8358															
Other 65																	
<b>Power Rating</b> <table border="1"> <thead> <tr> <th></th> <th>kVA</th> </tr> </thead> <tbody> <tr> <td>Rated</td> <td>150</td> </tr> <tr> <td>Derated</td> <td>150</td> </tr> </tbody> </table>							kVA	Rated	150	Derated	150						
	kVA																
Rated	150																
Derated	150																
Other 65																	
<b>Installation</b> <table border="1"> <thead> <tr> <th></th> <th>Altitude</th> <th>Ambient Temp.</th> </tr> </thead> <tbody> <tr> <td></td> <td>1000 m</td> <td>30 °C</td> </tr> </tbody> </table>							Altitude	Ambient Temp.		1000 m	30 °C						
	Altitude	Ambient Temp.															
	1000 m	30 °C															
<b>Type / Class</b> <table border="1"> <thead> <tr> <th>Type</th> <th>Sub Type</th> <th>Class</th> <th>Temp. Rise</th> </tr> </thead> <tbody> <tr> <td>Liquid-Fill</td> <td>Other</td> <td>Other</td> <td>65</td> </tr> </tbody> </table>						Type	Sub Type	Class	Temp. Rise	Liquid-Fill	Other	Other	65				
Type	Sub Type	Class	Temp. Rise														
Liquid-Fill	Other	Other	65														
MFR: <input type="text"/>																	
<input type="button" value="OK"/> <input type="button" value="Cancel"/>																	

## Solar PV Module

18. Go to Impedance Page and enter the impedance as shown and click on OK.

2-Winding Transformer Editor - T1

Reliability: Info Rating Impedance Remarks: Tap Grounding Sizing Comment: Protection Harmonic

0 MVA IEC Liquid-Fill Other 65 C 0.4 0 kV

Impedance

	%Z	X/R	R/X	%X	%R
Positive	4	1.5	0.667	3.323	2.219
Zero	4	1.5	0.667	3.323	2.219

Typical Z & X/R Typical X/R

Z Base

MVA

0

Other 65

Z Variation

	%Z	% Z Variation
@ -5 % Tap	4	0
@ 5 % Tap	4	0

Z Tolerance

+ 0 %

No Load Test Data (Used for Unbalanced Load Flow only)

	% FLA	kW	% G	% B
Positive	0	0	0	0
Zero	0	0	0	0

☐ Buried Delta Winding

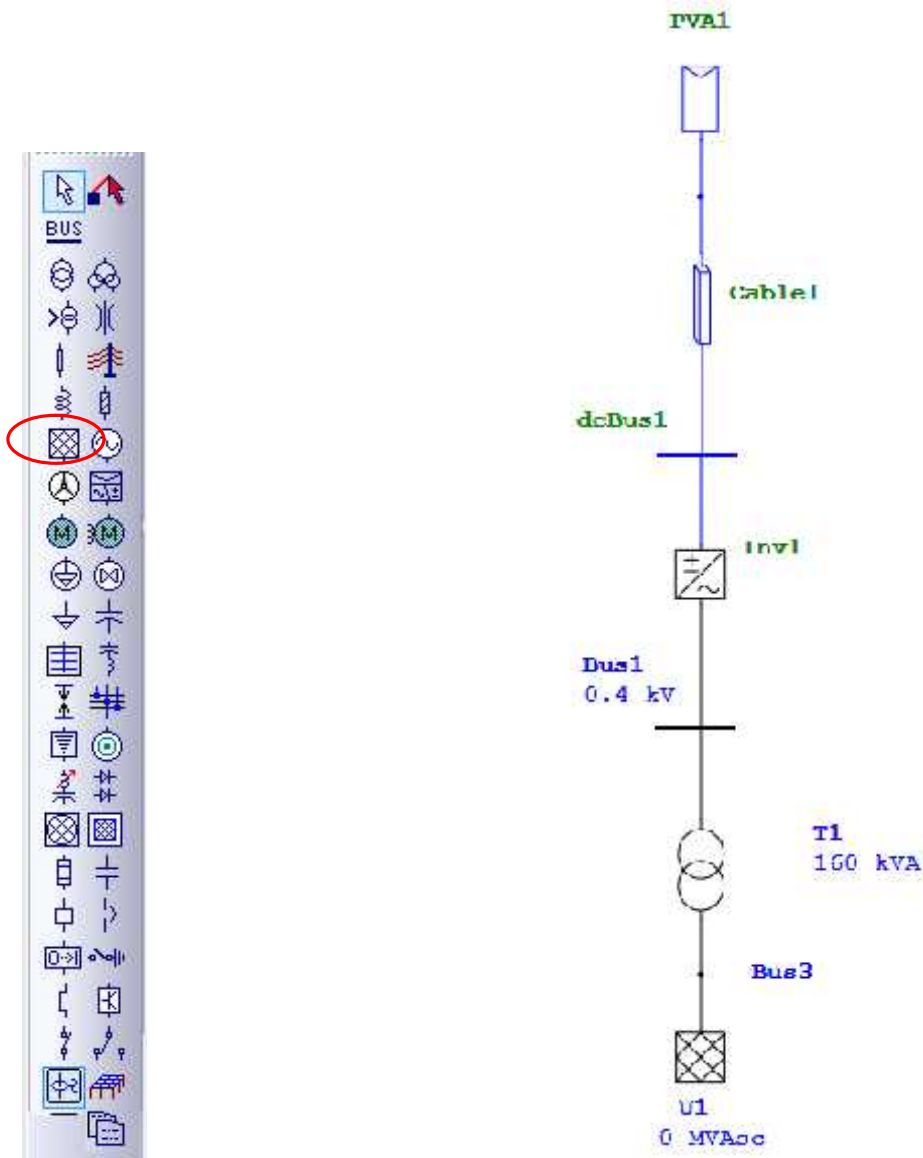
Zero Sec. Impedance Typical Value

OK Cancel



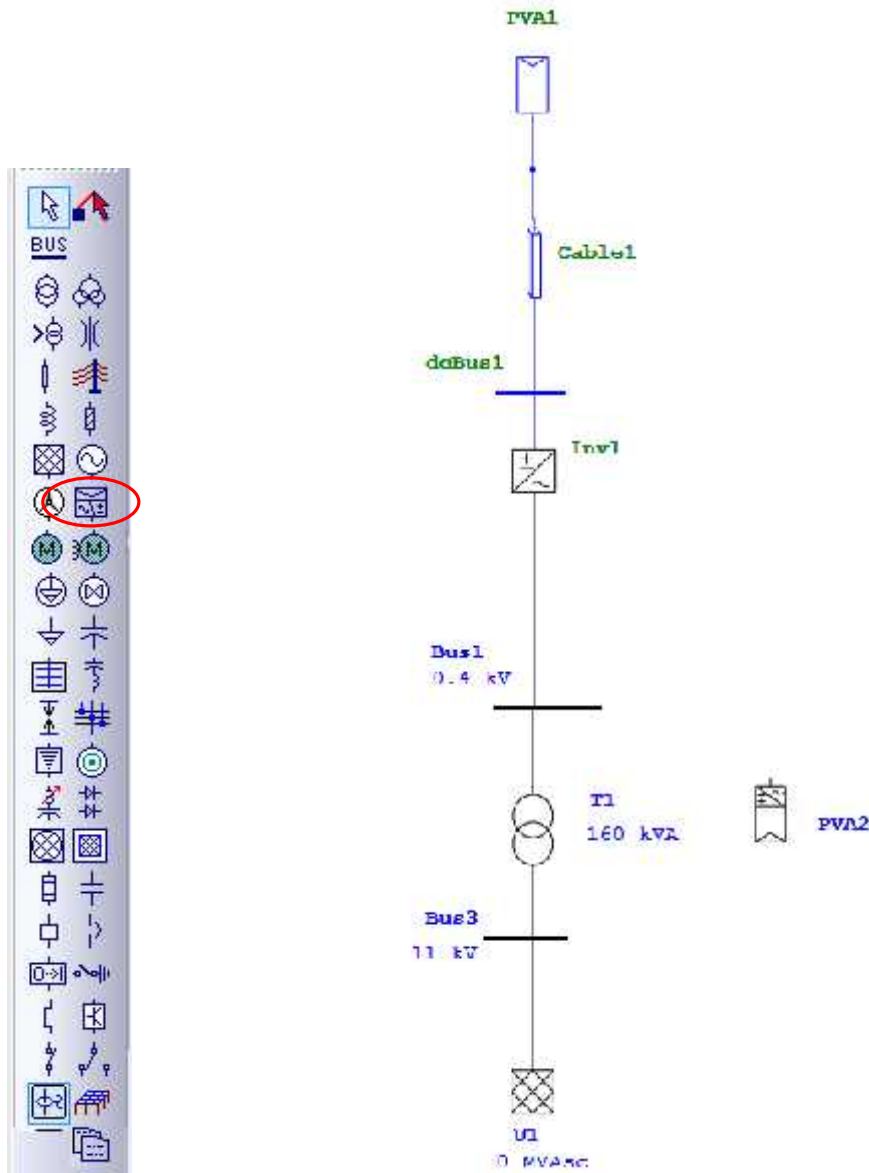
## Solar PV Module

19. Drag and drop AC Grid from AC Editor Toolbar and connect to transformer as shown below.



## Solar PV Module

20. Drag and drop PV Array from AC Editor Toolbar as shown below.



21. Double click on AC PV Array and follow steps 3 to 7 to select PV Array.

22. Go to Inverter page, click on Inverter Editor as shown below

## Solar PV Module

**PV Array Editor - PVA2**

Info | PV Panel | PV Array | **Inverter** | Physical | Time Domain | Remarks | Comments

MFR	SUNTECH	Type	Poly-crystalline	# of Cells	72
Model	STP230 - 24/Vd, STP275 - 24/Vd	Size	280	Vdc	600

**PV Array - Total Rated**

Vmts,cc: 731

kW,dc: 50.51

Amps,cc: 77.3

**Inverter**

ID: Inv3

	kW	V	FLA	%EFF
DC	0	0	0	90
	kVA	kV	FLA	%PF
AC	0	0	0	100

**Inverter Editor...**

☒ Maximum Power Point Tracker (MPPT)

**PV Array to Inverter Cable**

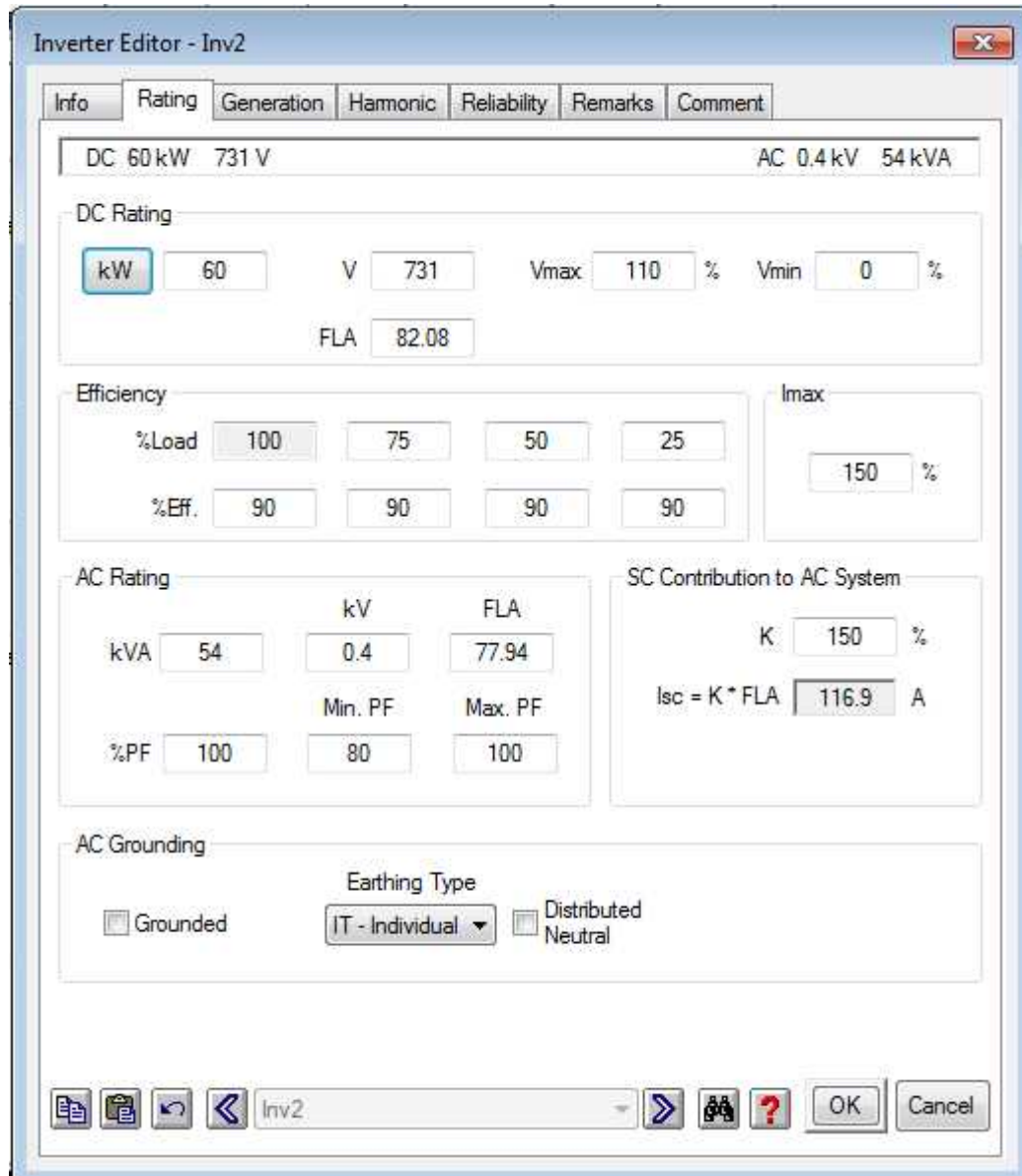
Cable Library

PVA2

OK Cancel

## Solar PV Module

23. The below window pops up. Go to Inverter page, and enter the below shown parameters.



The image shows the 'Inverter Editor - Inv2' dialog box with the 'Rating' tab selected. The parameters are as follows:

Section	Parameter	Value
DC Rating	DC Rating	60 kW
	V	731
	Vmax	110 %
	Vmin	0 %
Efficiency	%Load 100	90
	%Load 75	90
	%Load 50	90
	%Load 25	90
AC Rating	kVA	54
	kV	0.4
	FLA	77.94
	%PF	100
SC Contribution to AC System	K	150 %
	Isc = K * FLA	116.9 A
	Imax	150 %
	Min. PF	80
AC Grounding	Earthing Type	IT - Individual
	Distributed Neutral	<input type="checkbox"/>

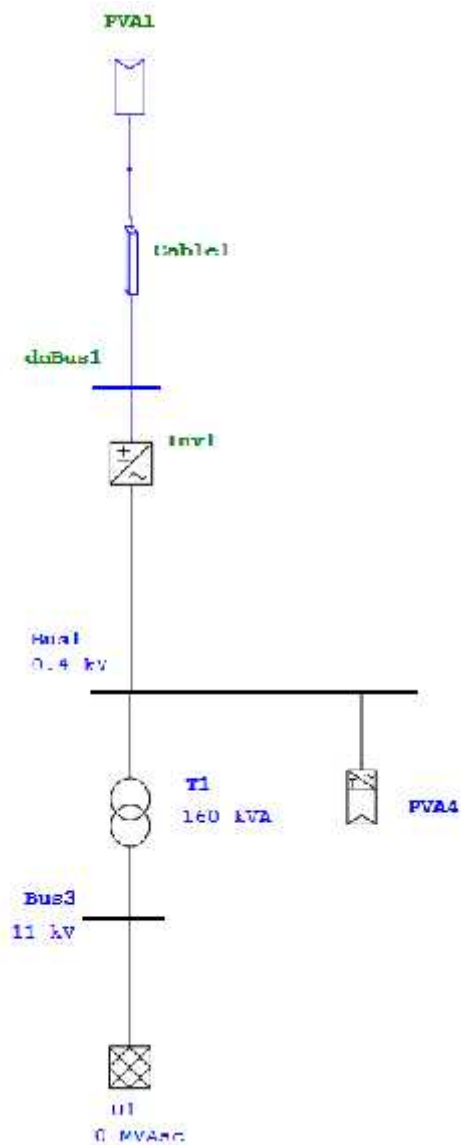
Additional parameters shown in the dialog:

- DC 60 kW 731 V
- AC 0.4 kV 54 kVA
- FLA 82.08

The dialog box includes tabs for Info, Rating, Generation, Harmonic, Reliability, Remarks, and Comment. The 'Rating' tab is currently active. The bottom of the dialog shows a toolbar with icons for file operations, a dropdown menu set to 'Inv2', and 'OK' and 'Cancel' buttons.

## Solar PV Module

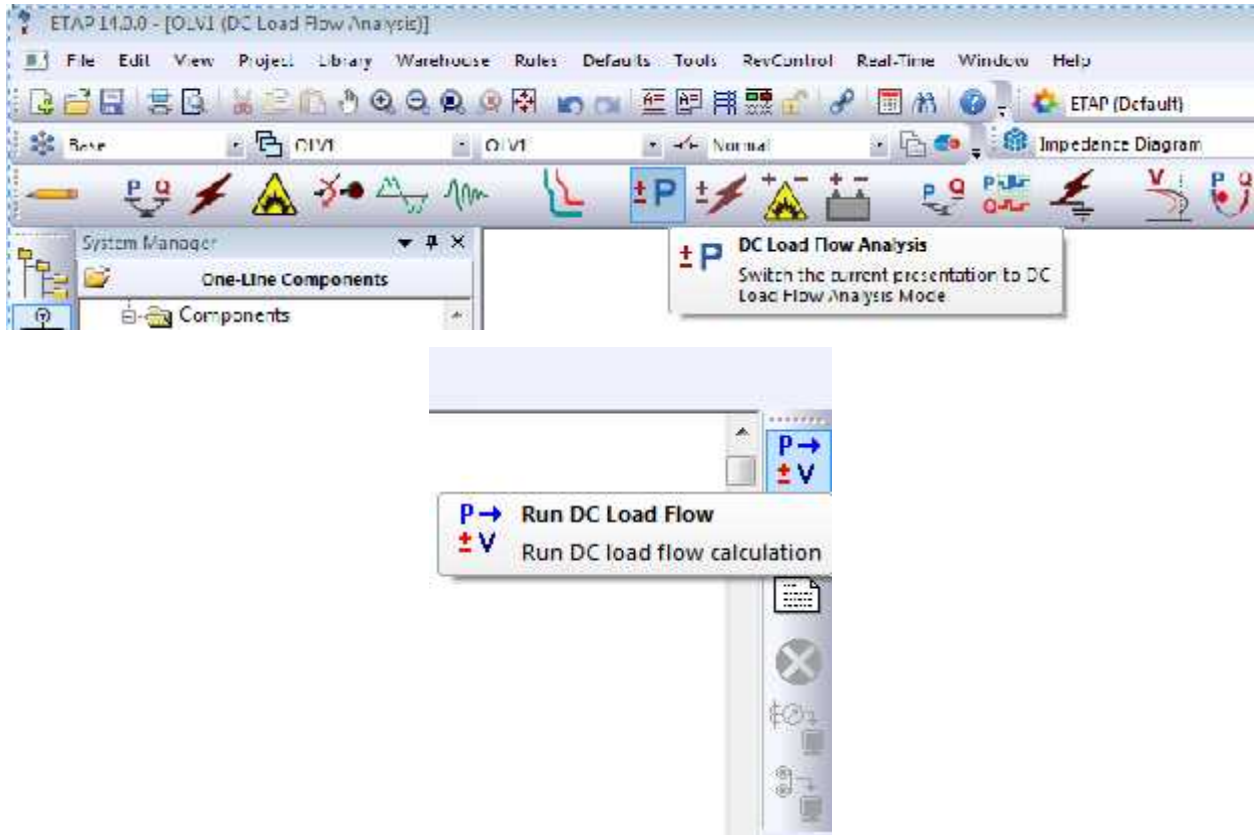
24. Connect the AC PV Array to Bus1 as shown below.





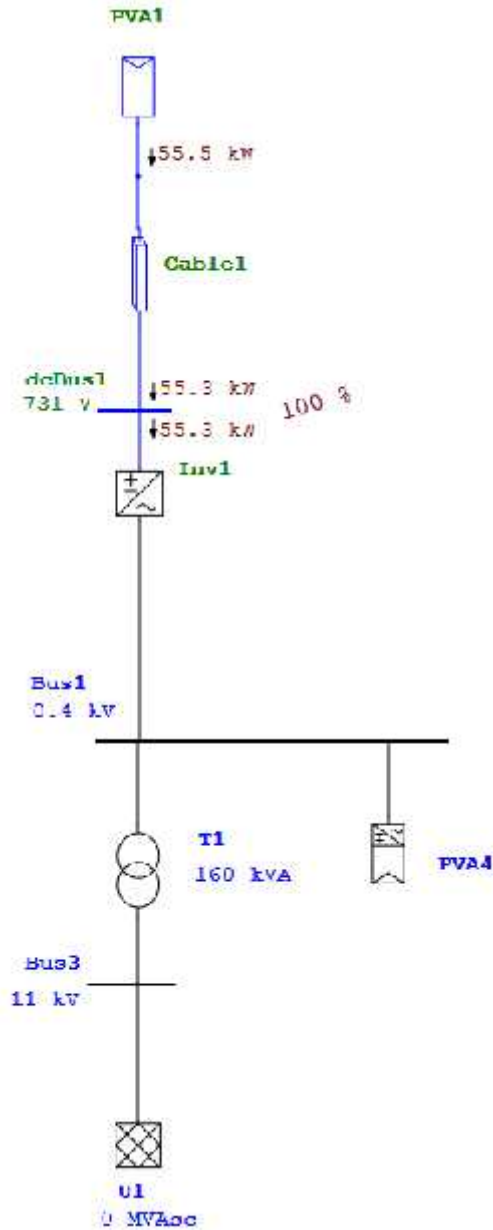
## Solar PV Module

25. Go to DC Load Flow Analysis Module and Run DC Load Flow as shown below.



## Solar PV Module

26. The DC load flow results are as shown below.



27. Go to AC Load Flow Analysis Module and Run AC Load Flow as shown below.





## Solar PV Module

28. The AC load flow results are as shown below

