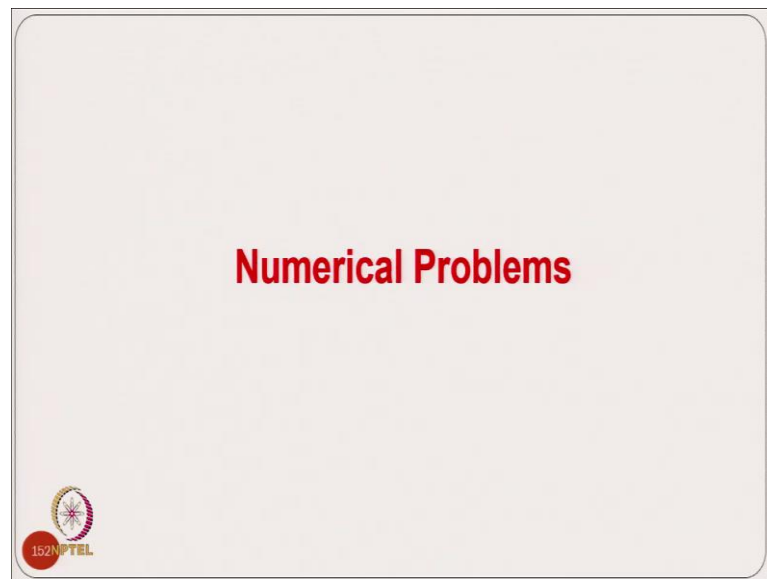


Power Quality
Prof. Bhim Singh
Department of Electrical Engineering
Indian Institute of Technology, Delhi

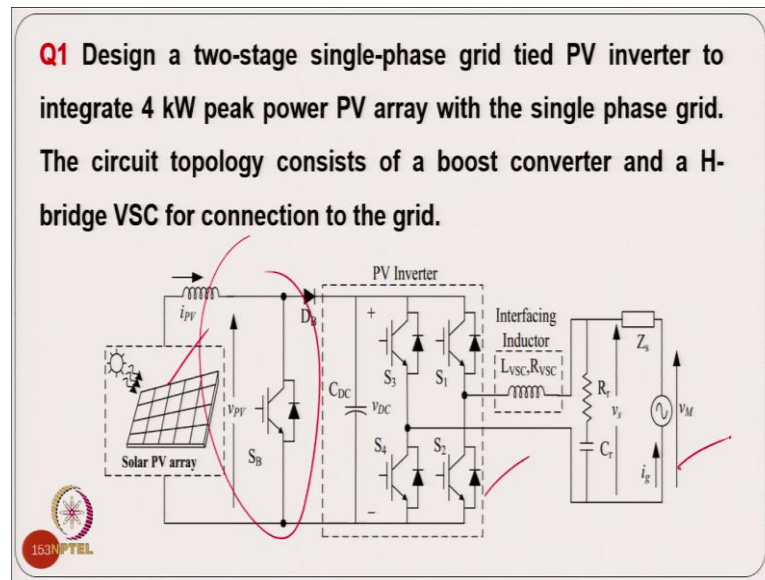
Lecture - 41
Power Quality Improvement in Solar Energy Conversion System (Contd.)
Numerical Problem

(Refer Slide Time: 00:17)



Welcome to the course on Power Quality [FL]. We are discussing the grid interface solar PV system. We will now discuss some numerical problems related to this.

(Refer Slide Time: 00:32)



Starting with 1st example. Design a two stage single phase grid tied solar PV inverter to integrate 4 kW peak power of PV array with a single phase grid and circuit topology consist of a boost converter and H bridge voltage source converter.

(Refer Slide Time: 00:52)

A. Design and Selection of DC Capacitor Voltage

The range of variation for AC side voltage in this system is considered from 170 V to 270 V. Moreover, the DC link voltage is kept almost 10% higher than peak of AC voltage to compensate for drops in device, interfacing inductor and inherent 2nd harmonics ripple of single-phase system. Therefore, the DC link voltage rating is estimated as,

$$V_{dc} = 1.1 \times \sqrt{2} V_{s \max} = 1.1 \times \sqrt{2} \times 270 = 420 \text{ V}$$

B. Design of DC Link Capacitor

The instantaneous power in single-phase system consists of second harmonics ripple. This ripple is in power it is also reflected on the DC link voltage. Considering this ripple as the design constraint the DC link capacitance is decided as,

$$C_{dc} = I_o \left(\frac{2\omega V_{dcr}}{\dots} \right)$$

A 154NPTTEL logo is present in the bottom left corner.

(Refer Slide Time: 01:45)

where, I_o is the capacitor current and ω is the angular frequency and the V_{DCr} is the ripple in capacitor voltage. Considering, the ripple as 2%, $V_{DCr} = 0.02 \times 420 = 8.4$ V, $I_o = 4,000/420 = 9.52$ A then, C_{DC} is obtained as 1804.7 μ F. Therefore, this capacitance is chosen to be 1800 μ F.

C. Design of SPV Array

The PV array is connected at the input terminals of the DC-DC boost converter. The output of the boost converter is connected at the DC link of the voltage source converter. Therefore, the PV array voltage rating is so decided that the open circuit voltage is equal to minimum DC link voltage. The Minimum DC link voltage is decided as,

$$V_{dc\ min} = 1.1 \times \sqrt{2} V_{s\ min} = 1.1 \times \sqrt{2} \times 170 = 264\text{V}$$

Taken as 270V.



(Refer Slide Time: 02:40)

A solar cell has an open circuit voltage (V_{oc}) of 0.62 V and short circuit current (I_{sc}) of 3.6 A. The active power for SPV array is given as,

$$P_{\max A} = n_s \times V_{mppC} * n_p \times I_{mppC} = 4\text{ kW}$$

Maximum power, $P_{\max A} = (n_s * 90\% \text{ of } V_{oc} * n_p * 90\% \text{ of } I_{sc}) = 4\text{ kW}$ is generally achieved under this condition thus I_{mppC} is 3.24 A and V_{mppC} is 0.558V of each cell, where n_s and n_p represent the series and parallel strings of PV cells.

$$V_{OCA} = n_s * V_{oc}, \text{ thus } n_s = V_{OCA} / V_{oc} = 270 / 0.62 = 435.48 \approx 436 \text{ cells.}$$

Considering, open circuit voltage of array (V_{OCA}) = 270 V

Maximum current of the array is given as,

$$I_{mppA} = P_{\max A} / 0.9 * V_{OCA} = 16.46\text{ A}$$

where I_{mppA} is current through PV array at peak power point.



(Refer Slide Time: 03:48)

Considering this as current for MPP, the numbers of parallel cells are calculated as 5. Thus an array of 4 kW peak power capacity is designed with 5 cells in parallel and 436 cells in series with an array of 5*436 cells.

D. Selection of Boost Inductor

The boost inductor is designed based on the allowable current ripple. The current ripple in the boost inductor is dependent on the input and output voltages of the boost converter. In this case, the boost converter is designed considering the input voltage as MPP voltage at 1000 W/m² and the output voltage as nominal DC link voltage. The nominal DC link voltage is estimated as,



$$V_{DC} = 1.1 \times \sqrt{2} V_s = 1.1 \times 1.414 \times 230 = 357.7 \approx 360 \text{ V}$$

(Refer Slide Time: 04:33)

The MPP voltage of the PV array is equal to 90 % of its open circuit voltage, which is approximately equal to 240 V. The duty ratio under this condition is estimated as,

$$D = 1 - \frac{V_{pvMPP}}{V_{DC}} = 1 - \frac{240}{360} = 0.33$$

The value of inductance (L_B) for boost converter is estimated as,

$$L_B = \frac{V_{in} D}{(\Delta I_{in} f_s)}$$

where V_{in} is the input voltage, $V_{in} = 240 \text{ V}$, D is the duty ratio, $D = 0.33$, f_s is the switching frequency, $f_s = 10 \text{ kHz}$, and ΔI_{in} is the peak to peak ripple in the boost inductor. The ΔI_{in} is considered 10% of nominal current, $\Delta I_{in} = 0.2 \times (4000/240) = 3.34 \text{ A}$. Using these values for calculation, the estimated value of an inductor for boost converter is 2.37 mH. An inductance value of 3 mH of inductor is selected for this system.



(Refer Slide Time: 05:21)

E. Design and Selection of Devices for VSC


The maximum blocking voltage is 420 V (Based on DC link voltage). A safety factor of 1.4 is selected to accommodate for high frequency ripple due to switching. Therefore, the voltage rating of the devices are estimated as,

$$V_{SW} = V_{DC\max} \times 1.4 = 420 \times 1.4 = 588 \approx 600V$$

The maximum current to be fed into the grid is estimated as,

$$I_{VSC\max} = P_{PV} / V_{s\min} = 4000 / 170 = 23.52 A$$

Keeping a safety factor of 1.2, the current rating can be estimated as,

$$I_{SW} = 1.2 \times \sqrt{2} \times I_{VSC\max} = 39.87 A$$


(Refer Slide Time: 05:53)


F. Selection for Interfacing Inductors

The AC inductance is given as, $L_{VSC} = mV_{DC} / (4af_s I_{VSCr})$

Considering, switching frequency (f_s) = 10 kHz, modulation index (m) = 1, DC bus voltage (V_{DC}) of 360V, over load factor, $a=1.2$, current ripple as 10%, the LVSC value is calculated to be 3.18mH. The value of LVSC of 3.5 mH is selected.

G. Selection for Ripple Filter

Considering $R_s = T_s/2$ and switching frequency of 10 kHz the filter parameters are selected as 5 Ω and 5 μF .




The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 06:48)

Q2 A two stage solar energy conversion system, integrated with single phase 240V 50Hz grid has the following specifications:

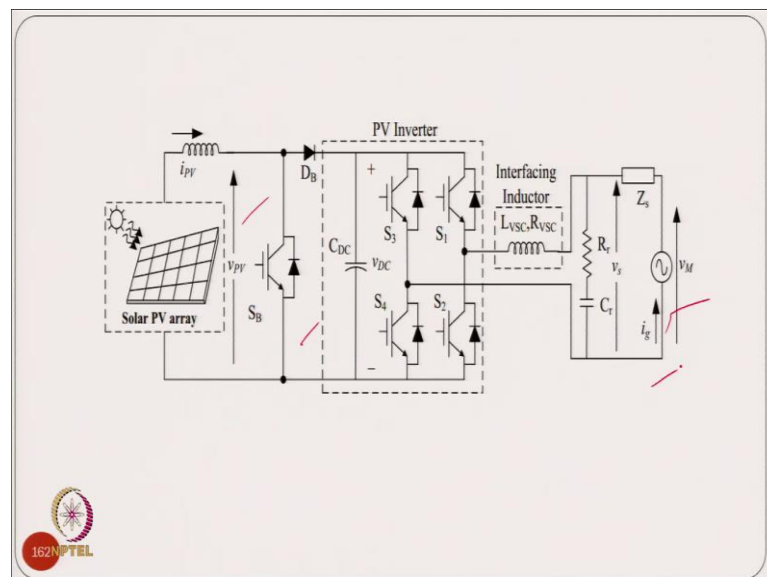
SPV Module	OC voltage	36.3V	MPP voltage	29V
	SC current	7.84A	MPP current	7.35A
	Series modules	8	Parallel strings	2

If the PV array is operated at its maximum power point for 1000 W/m² and 25°C, calculate the RMS current injected into the grid assuming negligible losses (power injected into grid at unity power factor).



Coming to the 2nd numerical example. A two stage solar PV conversion system integrated with single phase supply of 240 V/50 Hz grid has the following specifications given in the table. If the PV array is operated at the maximum power point for 1000 W/m² and 25° C. Calculate the RMS current injected into a grid assuming negligible losses (power injected in the grid at unity power factor).

(Refer Slide Time: 07:28)



This is a typical system as mentioned in the example.

(Refer Slide Time: 07:33)

Solution-

Solar PV is operating at 1000 W/m^2 and 25°C . Thus SPV array voltage for operation at the maximum power point is calculated as,

$$V_{pv} = N_s * V_{mpp} = 8 * 29 = 232\text{V.}$$
$$I_{pv} = N_p * I_{mpp} = 2 * 7.35 = 14.7\text{A.}$$


Thus, the PV power injected into the grid is,

$$P_{pv} = V_{pv} * I_{pv} = 3410.4\text{W}$$

Assuming negligible losses in SECS,

$$P_{pv} = V_s * I_s = 3410.4\text{W}$$


Thus, the current flowing into the grid is,

$$I_s = 3410.4 / 240 = 14.21\text{A}$$


The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 08:07)

Q3 A 3.8kW SPV array is connected directly at the DC link terminals of a VSI integrated with 230V single phase grid. A 240V battery bank is integrated at the same DC link terminals using a bidirectional DC-DC converter. The control scheme is designed to feed a constant 2.5kW power to the single phase grid at all times. Calculate the battery current when the incident solar irradiation is 1000W/m^2 . Also calculate the current injected into the grid. Assume unity power factor operation at the grid side and negligible losses in the system.



Coming to 3rd example. A 3.8 kW solar PV array is connected directly at the DC link thermals of the voltage source inverter integrated with 230 V single phase grid. A 240 V battery bank is integrated at the same DC link thermals using the bidirectional DC-DC converter. The control scheme is designed to feed a constant 2.5 kW power to single phase grid at all time. Calculate the battery current when the incident solar irradiation is

1000 W/m². Also calculate the current injected to the grid. Assuming unity power factor operation at the grid side and negligible losses in the system.

(Refer Slide Time: 08:42)

Solution-


At 1000 W/m² irradiation, the SPV array generates rated power,
 $P_{pv} = 3800W$

Power flow into the grid,
 $P_g = 2500W$

Thus, the power required from the battery for smoothening,
 $P_b = P_g - P_{pv} = 2500 - 3800 = -1300W$

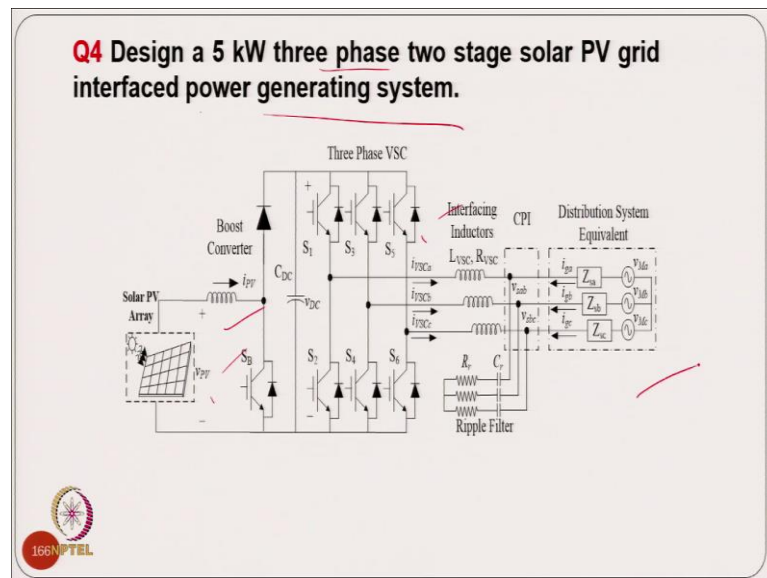
The current injected into the battery is calculated as,
 $I_b = P_b / V_b = 5.42A$

The current flowing into the grid is,
 $I_s = 2500/240 = 10.42A$



The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 09:17)



Now, coming to 4th example. Design a 5 kW 3 phase 2 stage solar PV grid interface system. So, we have a 2 state system solar PV generation, as shown in figure.

(Refer Slide Time: 09:29)

A.Design of Solar PV Array

The proposed system is designed for the peak power capacity of 5kW rated at 415 V AC grid. A solar PV module has short circuit module current (I_{sc}) of 3.8 A and open circuit module voltage (V_{ocn}) of 21 V.

The maximum power for SPV array is given as,


$$P_{mp} = (n_s * V_{mp}) * (n_p * I_{mp}) = 5 \text{ kW} \quad (1)$$

where n_s and n_p represent series and parallel strings of PV module, V_{mp} is the voltage of a module at MPPT, I_{mp} is the current of a module at MPPT and P_{mp} is the nominal power of a module at MPPT.

The P_{mp} is generally achieved under the condition given as,

$$P_{mp} = (n_s * 85\% \text{ of } V_{ocn} * n_p * 85\% \text{ of } I_{sc}) = 5 \text{ kW} \quad (2)$$

Thus, I_{mp} is 3.3 A and V_{mp} is 17.85 V of each module.



(Refer Slide Time: 10:08)

Ideally, open circuit of PV array (V_{OCT}) should be approximately equal to DC link voltage of the VSC. However due to rating constraint of PV array simulator (V_{OCT}) of 600 V is used.

The PV modules connected in series string are estimated as,

$$V_{OCT} = n_s * V_{ocn}, \text{ thus } n_s = 600/21 \approx 28 \text{ Modules} \quad (3)$$


Maximum current of the PV array is given as,

$$I_{mp} = P_{mp} / (0.85 * V_{OCT}) = 9.8 \text{ A}$$

The PV modules connected in parallel string are estimated as,

$$I_{mp} = n_p * I_{sc}, \text{ thus } n_p \approx 3 \text{ Modules} \quad (4)$$

Thus the array of 5 kW peak power capacity is designed with 3 modules in parallel and 28 modules in series with an PV array of 3*28 modules.





(Refer Slide Time: 10:50)

B. Design of DC-DC Boost Converter

The ripple current for inductor at $D = 0.2$ is given as,

$$L_b = \frac{V_{MPP} D}{\Delta I_1 f_{sw}} = \frac{510 * 0.2}{(1.68 * 10000)} = 6.07 \text{ mH} \quad (5)$$

where ΔI_1 is input current ripple, and it is considered as 20 % of DC-DC boost converter inductor current $I_1 = (P_{MPP} / V_{MPP}) = 8.4 \text{ A}$. Thus a calculated value of ΔI_1 is 1.68 A. Thus the inductance (L_b) value is selected as 6 mH.



(Refer Slide Time: 11:18)

C. Design and Selection of DC Capacitor Voltage

The design of DC link voltage V_{dc} is given as,

$$V_{dc} = \frac{(2\sqrt{2}V_{LL})}{\sqrt{3}m} = \frac{(2\sqrt{2} * 415)}{\sqrt{3} * 0.95} = 713.27 \approx 700 \text{ V} \quad (6)$$



where V_{LL} is the VSC AC line voltage, m is modulation index.

D. Selection of AC Interfacing Inductor

The AC inductor (L_f) value is calculated on the basis that current ripple Δi , switching frequency f_s , V_{dc} and is as,

$$L_f = \frac{\sqrt{3}m * V_{dc}}{12hf_s \Delta i} = \frac{\sqrt{3} * 0.95 * 700}{12 * 1.2 * 10^4 * (0.20 * 7.142)} \approx 5.5 \text{ mH} \quad (7)$$

where Δi , = 20% of input current, $f_s = 10 \text{ kHz}$, h is overloading factor and is taken as 1.2. Thus L_f is selected as 5.5 mH.



(Refer Slide Time: 11:59)


E. Design of DC Link Capacitor

The DC link capacitor value is estimated as,

$$\frac{1}{2}C_{dc} [V_{dc}^2 - V_{dc1}^2] = 3\alpha VI t \quad (8)$$
$$\frac{1}{2}C_{dc} [700^2 - 680^2] = 3 \times 1.2 \times 239.6 \times 7.14 \times 0.005$$

$C_{dc} = 2231.4 \mu\text{F}$

where V_{dc} is the reference DC bus voltage of VSC, α is the overloading factor, V_{dc1} is minimum DC link voltage and t is the time by which the DC link voltage is to be changed. The capacitor value is selected as 2200 μF .




The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 12:22)

Q5 A solar photovoltaic array, integrated with three phase 415V 50Hz grid through a DC-DC boost converter and a voltage source inverter (VSI), has the following specifications:

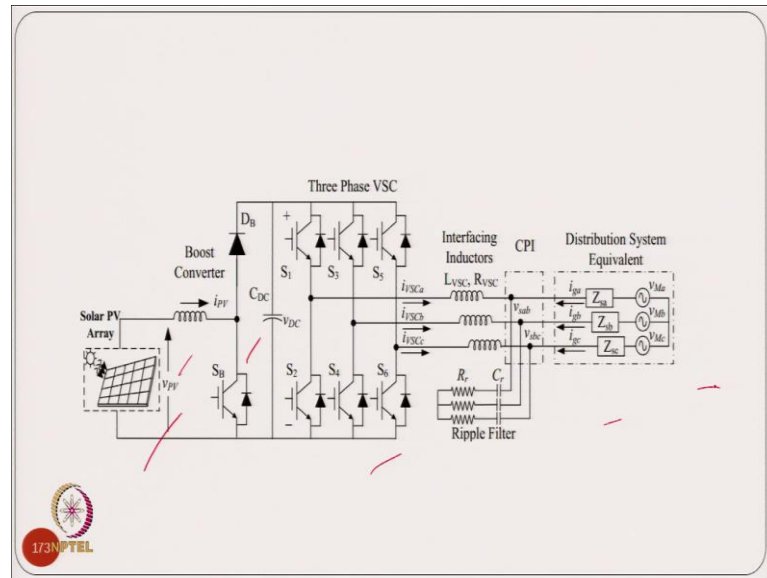
SPV Module	OC voltage	36.3V	MPP voltage	29V
	SC current	7.84A	MPP current	7.35A
	Series modules	14	Parallel strings	8

If the DC link voltage of the VSI is maintained at 700V, calculate the duty ratio of the boost converter required to operate the PV at its maximum power point for 1000 W/m² and 25°C.



Coming to 5th example. A solar photovoltaic array, integrated with 3 phase 415 V/50 Hz grid through a DC-DC boost converter and a voltage source inverter has the following specification, as shown in table. If the DC link voltage of the VSI is maintained at 700 V, calculate the duty ratio of boost converter required to operate the PV array at its maximum power point for 1000 W/m² and 25° C.

(Refer Slide Time: 13:07)



This is the typical configuration for the 5th example.

(Refer Slide Time: 13:15)

Solution-

Solar PV is operating at 1000 W/m^2 and 25°C . Thus SPV array voltage for operation at the maximum power point is calculated as,

$$V_{pv} = N_s \cdot V_{mpp} = 14 \cdot 29 = 406\text{V.}$$

Thus based on the duty cycle expression for boost converter,

$$\frac{V_{dc}}{V_{pv}} = \frac{1}{1-D}$$


Thus, $D = \frac{V_{dc} - V_{pv}}{V_{dc}} = \frac{700 - 406}{700} = 0.42$

The diagram includes a logo for IITM TEL in the bottom left corner.

The solution of this problem is given in the abovemention slides.

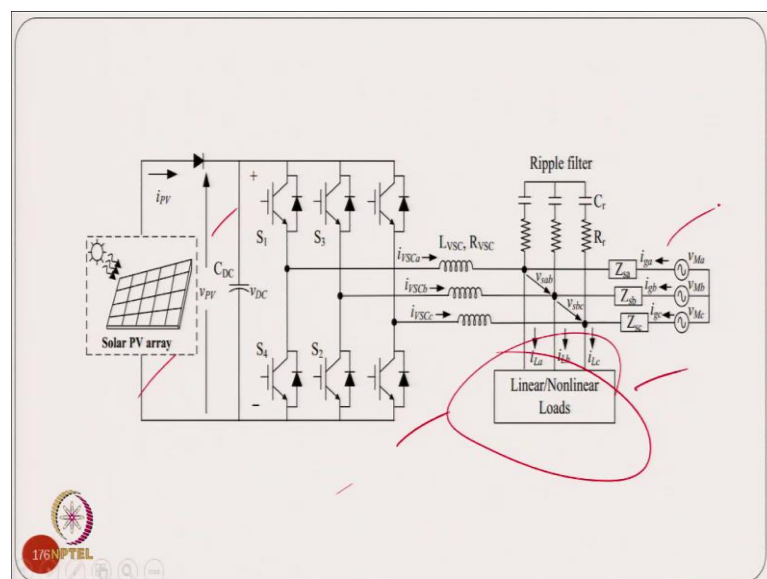
(Refer Slide Time: 13:49)

Q6 A multifunctional 30kW single stage rooftop SPV system is integrated with 415V 50Hz three phase grid using a voltage source inverter (VSI). The complete SECS is connected with a linear load. It is drawing 15 kW power at a power factor of 0.8. Calculate the voltage, current and kVA rating of the VSI of the SECS to provide reactive power compensation.



Coming to the 6th example. A multi functional 30 kW single stage rooftop solar PV photovoltaic system is integrated with the 415 V/50 Hz three phase grid using a voltage source inverter. The complete solar energy conversion system (SECS) is connected with a linear load. It is drawing 15 kW power at power factor of 0.8. Calculate the voltage current and KVA rating of the inverter of the solar energy conversion to provide reactive power compensation.

(Refer Slide Time: 14:20)



This is the mentioned system configuration.

(Refer Slide Time: 14:33)


Solution-

Given that, $V_s = 415/\sqrt{3} = 239.6$ V, $f = 50$ Hz, Active power, $P = 15$ kW
Reactive power drawn by the load,
 $Q_l = P \tan \phi = 11.25$ kVAR

As the VSI is used for reactive power compensation. Reactive power flow through the VSI is, $Q_{vsi} = 11.25$ kW

Assuming negligible losses, the active power flowing through the VSI under rated condition is, $P_{vsi} = 30$ kW


Thus, the VA rating of VSI is,

$$S_{vsi} = \sqrt{(Q_{vsi}^2 + P_{vsi}^2)} = 32.04 \text{ kVA}$$


(Refer Slide Time: 15:17)

Voltage rating of the VSI is, $V_{vsi} = 239.6$ V

Current rating of the VSI is, $I_{vsi} = 32040 / (\sqrt{3} * 239.6) = 44.57$ A




The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 15:36)

Q7. A single stage Grid connected Three Phase SPV system is supplying a linear load of 2kW and 0.5 kVAR. The grid is operating at 415V (line-line) and 50 Hz. The SPV operating point is observed to be 750V and 10A at its maximum power point at 1000 W/m². The MPPT algorithm efficiency of PV is observed to reduce according to the equation,

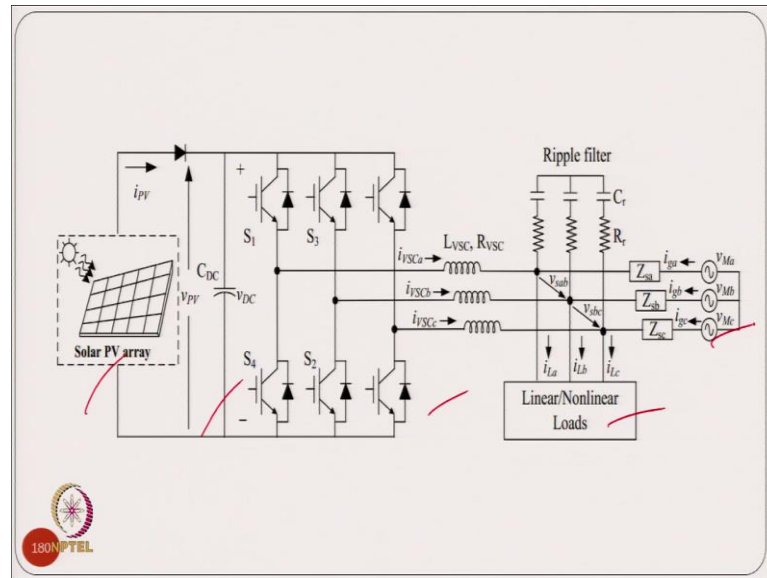
$$\eta_x = \frac{1}{1 + c \sqrt{\left(\left(\frac{1000}{x}\right)^4 - 1\right)}}$$

Where c is efficiency gain parameter holding a value of 0.04. The VSC control scheme ensures that the grid always operates at UPF. The VSC losses can be assumed to be 5 percent of its power. Estimate (a) the load current and the grid current under the current MPPT operation (1000W/m²) of the PV array, (b) Figure out the grid power factor and phase shift in VSC phase currents with respect to phase voltages.



Coming to 7th example. A single stage grid connected three phase solar photovoltaic system is supplying a linear load of 2 kW and 0.5 kVAR. The grid is operating 415 V/50 Hz. The solar PV operating is 750 V at 10 A at its maximum power taking of 1000 W/m². The MPPT efficiency of PV array is observed to reduce the according to typically this equation. Where, c is efficiency gain parameter holding a value of 0.04. The voltage source converter control scheme ensures the grid always operate at unity power factor. The voltage source converter losses can be also assumed for 5 % of its power. Estimate, the load current and the grid current under the current MPPT operation 1000 W/m² of PV array. Figure out the grid power factor and the phase shift in the VSC phase current with phase voltage.

(Refer Slide Time: 16:39)



This is the system configuration for the abovementioned problem.

(Refer Slide Time: 16:44)

Solution-

(a) Solar PV is operating at 750V and 10A. Thus the net power supplied by the PV is 7500 or 7.5 kW.

Considering the inverter losses as 5%, Net inverter active power supplied = $0.95 \times 7.5 = 7.125$ kW.

The Load active power = 2kW.

Thus, the net power fed to the grid = 5.125 kW.

Since the grid voltage is 415 V (line to line, RMS), the line current flowing in the load can be computed as,

$$I_{Load, line} = \frac{S(3\phi)}{\sqrt{3}V_{line-line}} = \frac{\sqrt{2^2 + 0.5^2} \times 10^3}{\sqrt{3} \times 415} \approx 2.87 A$$

A 180° TEL logo is in the bottom left corner.


(Refer Slide Time: 17:37)

Since the grid voltage is 415 V (line to line, RMS), the line current in the grid can be computed as

$$I_{Grid, line} = \frac{P(3\phi)}{\sqrt{3}V_{line-line}} = \frac{5.125 \times 10^4}{\sqrt{3} \times 415} \approx 7.13A$$

It is note-worthy that only the three phase active power (P) is considered for calculating the grid line current. This is because the VSC is ensuring the UPF operation always. Otherwise, net apparent power (S) needs to be considered.


(b) Since the VSC control scheme ensures that the grid always operates at UPF, the grid line currents are always in phase with the corresponding voltages.



(Refer Slide Time: 18:07)

However, in this case, since the power is being fed back to the grid the grid power factor is negative. Thus, Grid power factor = -1.

Owing to UPF operation of grid, the VSC supplies total load reactive power of 0.5 kVAR. Since the active power fed through VSC is 7.125 kW, the phase shift in VSC phase currents with respect to phase voltages can be computed as,

$$\phi = \tan^{-1}(Q/P) = \tan^{-1}(0.5/7.125) = 4.014^\circ$$



The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 18:39)

Q8. Compute the load current and the grid current in Question-7, for the solar insolation dip to 600 W/m^2 and load increase by 2.5 kW and 1 kVAR . The MPPT algorithm efficiency of PV is observed to reduce with insolation increase according to the equation,

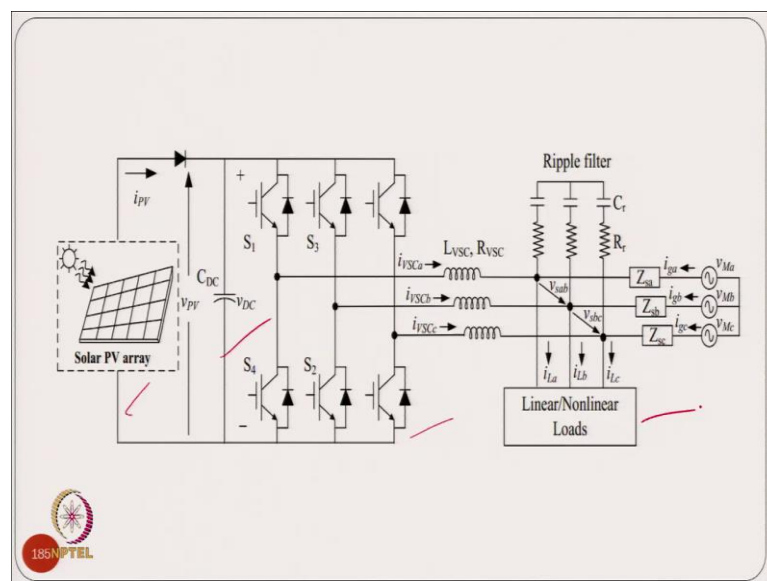
$$\eta_x = \frac{1}{1 + c \sqrt{\left(\left(\frac{1000}{x}\right)^4 - 1\right)}}$$

Where c is efficiency gain parameter holding a value of 0.03 . After change in insolation, estimate grid power factor and phase shift in VSC phase currents with respect to phase voltages. The PV array is operating at 750 V with solar insolation of 600 W/m^2 .



Coming to the 8th example. Compute the load current and a grid current in previous question, for solar PV insolation dip to 600 W/m^2 and load increases by 2.5 kW and 1 kVAR . The MPPT algorithm efficiency of PV array is observed to reduce with insolation increase according to the equation given in the slide. Where, c is the efficiency gain parameter holding a value of 0.03 . After change in insolation, estimate the grid power factor and phase in shift in the VSC phase current with respect to the phase voltage. The PV array is operating at 750 V with the solar PV in insolation of 600 W/m^2 .

(Refer Slide Time: 19:27)



This is the system configuration for this problem.


(Refer Slide Time: 19:32)

Solution- Here Solar PV is operating at 750V but not at 10A. Ideally, since the power supplied by the PV array is directly proportional to solar insolation,

$$P_{600W/m^2} (Ideal) = (600/1000)P_{1000W/m^2} = 0.6 \times 7.5kW = 4.5kW$$

However, since the efficiency of MPPT algorithm varies with insolation, the net power extracted from the PV array is computed as,

$$\eta_{600W/m^2} = \frac{1}{1+0.03\sqrt{\left(\left(\frac{1000}{x}\right)^4 - 1\right)}} = \frac{1}{1+0.03\sqrt{\left(\left(\frac{1000}{600}\right)^4 - 1\right)}} \approx 0.93$$

$$P_{600W/m^2} (Net) = (600/1000)P_{1000W/m^2} = 0.93 \times 4.5kW = 4.185kW$$


(Refer Slide Time: 20:11)


Considering the inverter losses as 5%, Net inverter active power supplied = $0.95 \times 4.185 = 3.976$ kW.

The Load active power = $2kW + 2.5kW = 4.5kW$.

Thus, the net power fed to the grid as,

$$P_g = 3.976 - 4.5 \text{ kW} = -0.5 \text{ kW. i.e. active power is being drawn from the grid.}$$

Since the grid voltage is 415 V (line to line, RMS), the line current flowing in the load can be computed in this case as,

$$I_{Load, line} = \frac{S(3\phi)}{\sqrt{3}V_{line-line}} = \frac{\sqrt{4.5^2 + 1.5^2} \times 10^3}{\sqrt{3} \times 415} \approx 6.6A$$


(Refer Slide Time: 20:50)

Since the grid voltage is 415 V (line to line, RMS), the line current in the grid can be computed as,

$$I_{Grid, line} = \frac{P(3\phi)}{\sqrt{3}V_{line-line}} = \frac{0.5 \times 10^3}{\sqrt{3} \times 415} \approx 0.696 A$$

It is worth noting that only the three phase active power (P) is considered for calculating the grid line current. This is because the VSC is ensuring the UPF operation always. The whole three phase apparent power (S) needs to be considered otherwise.



(Refer Slide Time: 21:23)

Since the VSC control scheme ensures that the grid always operates at UPF, the grid line currents are always in phase with the corresponding voltages. In this case, since the power is being given by the grid the grid power factor is positive. Thus, Grid power factor = +1.

Owing to UPF operation of grid, the VSC supplies total load reactive power of 1.5 kVar. Since the active power fed through VSC is 3.976 kW, the phase shift in VSC phase currents with respect to phase voltages can be computed as,




$$\phi = \tan^{-1}(Q/P) = \tan^{-1}(1.5/3.976) = 20.67^\circ$$

The solution of this problem is given in the abovemention slides.

(Refer Slide Time: 22:02)

Summary

- Classification and design of various VSC based single-phase and three-phase configurations for SECSs have been investigated for feeding solar PV power into the grid, wherein the SECSs include conventional PV inverter as well as multifunctional PV VSCs which simultaneously help in power quality improvement.
- The performance of various single-stage and two-stage system configurations is implemented and evaluated.




With this we would like to summarize. The classification and design of various voltage source converter single phase and three phase configurations for solar energy conversion system have been investigated for feeding the solar PV power into the grid. Wherein, the solar energy conversion systems include the conventional PV inverter as well as the multifunctional voltage PV voltage source converter which simultaneously help in power quality improvement. The performance of various single stage and two-stage configurations are evaluated.

(Refer Slide Time: 22:33)

Summary

- The control and implementation of single-phase two-stage grid tied SECS have been achieved. A boost converter is used for MPPT and a single-phase bridge VSC is used as grid interfacing power converter. A simple control and implementation of a two-stage PV inverter and multifunctional SECS are carried out under nominal and non-ideal grid conditions.
- The control and implementation of single-phase single-stage grid tied SECS for single power conversion stage based PV inverter and multifunctional SECS are carried out under nominal and non-ideal grid conditions.




The control and implementation of single-phase two-stage grid tied solar PV system have been achieved. A boost converter is used for maximum power tracking and a single phase bridge voltage source converter is used for grid interfacing power converter. A simple control and implementation of two-stage PV inverter and multi-functional SECS are carried out under nominal and non-ideal grid condition. The control and implementation of single-phase single-stage tied system conversion single phase PV inverter and multifunctional SECS are carried out under the nominal and non ideal and grid voltage condition.

(Refer Slide Time: 23:05)

Summary

- The control and implementation of two-stage three-phase three-wire grid tied SECS are made. A boost converter is used for MPPT and a three-phase bridge VSC is used as grid interfacing power converter. The novel control and implementation for three-phase three-wire grid tied PV inverter and multifunctional SECS are carried out under nominal and non-ideal grid conditions.
- The control and implementation of single-stage three-phase three-wire grid tied SECS for single-stage three-phase PV inverter and a three-leg VSC based SECS with load compensation are carried out.




The control and implementation of two-stage three-phase three-wired system are made. So, boost converter is used for MPPT of three-phase voltage source converter, and a three phase VSC used as a grid interfacing power converter and novel control and implementation of three phase PV inverter and multifunctional SECS are carried out under nominal and non-ideal condition. The control and implementation of single-phase three-phase for the single-phase inverter and three phase three leg voltage with load compensation are carried out.

(Refer Slide Time: 23:33)

Summary

- The control and implementation of two-stage three-phase four-wire grid tied SECS are realized. A boost converter is used for MPPT and a four-leg VSC is used as grid interfacing power converter. The proposed system not only feeds solar power into the grid but also helps in power quality improvement of four-wire distribution system.
- The control and implementation of single-stage three-phase four-wire grid tied SECS using a four-leg VSC based system configurations are carried out wherein the VSC not only serves for MPPT but also helps in power quality improvement of four-wire distribution system.




The control and implementation of two-stage three-phase four-wire grid tied system are realized. A boost converter is used for a maximum power tracking and four-leg VSC is used for grid interfacing power converter. This system not only feeds the solar power into the grid, but also helps in power quality improvement of four-wire distribution system.

The control implementation of single-stage three-phase four-wire grid tied solar energy conversion system using a four-leg voltage source converter based system configuration are carried out, but the VSC not only serves the for the MPPT, but also help in power quality improvement of four-wire distribution system.

(Refer Slide Time: 24:07)

Summary

- The control and implementation of power quality improvement techniques for SPV system operating under both grid connected and standalone with seamless transition capabilities are carried out.




The control and implementation of power quality improvement techniques for solar power photovoltaic system operating under both grid connected and standalone system similar transition capability also carried out.

(Refer Slide Time: 24:20)


REFERENCES

- [1] Bhim Singh, Ambrish Chandra and Kamal Al-Haddad, Power Quality: Problems and Mitigation Techniques, John Wiley & Sons Ltd., U.K, 2015
- [2] B. Singh, Chinmay Jain and Sagar Goel, "ILST Control of Single-Stage Dual Purpose Grid Connected Solar PV System," *IEEE Transactions on Power Electronics*, vol.29, no.10, pp.5347-5357, 2014.
- [3] Chinmay Jain and Bhim Singh, "A Single-Phase Single-Stage Multifunctional Grid Interfaced Solar PV System under Abnormal Grid Conditions," *IET Generation, Transmission and Distribution*, vol.9, no. 10, pp.886-894, 2015.
- [4] S. Deo, C. Jain and B. Singh, "A PLL-Less Scheme for Single-Phase Grid Interfaced Load Compensating Solar PV Generation System," *IEEE Transactions on Industrial Informatics*, vol.11, no.3, pp.692-699, 2015.
- [5] Chinmay Jain and Bhim Singh, "A Three-Phase Grid Tied SPV System with Adaptive DC Link voltage for CPI Voltage Variations," *IEEE Transactions on Sustainable Energy*, vol.7, no.1, pp.337-344, Jan. 2016.
- [6] Bhim Singh and Chinmay Jain, "An Assessment of SPSS Grid Interfaced SPV System under Abnormal Grid Conditions," *IETE Journal of Research*, vol. 61, no. 6, pp. 581-589, 2015.
- [7] B. Singh, D. T. Shahani and A. K. Verma, "Neutral network controlled grid interfaced solar photovoltaic power generation," *IET Power Electronics*, vol. 7, no. 3, pp. 614-626, March 2014.



(Refer Slide Time: 24:23)

8. Bhim. Singh, Shailendra Kumar and C. Jain, "Damped-SOGI-Based Control Algorithm for Solar PV Power Generating System," *IEEE Trans. Industry Applications.*, vol. 53, no. 3, pp. 1780-1788, May-June 2017.
9. Shailendra Kumar and Bhim Singh, "Implementation of High Precision Quadrature Control for Single Stage SECS," *IEEE Trans. Ind. Inform.*, Early Access, 2017.
10. Shailendra Kumar and Bhim Singh, "A Multipurpose PV System Integrated to Three-Phase Distribution System Using LWDF Based Control Approach," *IEEE Trans. Power Electron.* Early Access, 2017.



(Refer Slide Time: 24:23)

- [11] Chinmay Jain and Bhim Singh, "A Frequency Shifter Based Simple Control for Multifunctional Solar PV Grid Interfaced System," *37th National System Conference*, 2013, pp. 1-6.
- [12] Chinmay Jain and Bhim Singh, "A PEF Based Control for Single-Phase Multifunctional SECS with Adaptive DC Link Structure for PCC Voltage Variations," in *Proc. of 30th Annual IEEE Applied Power Electronics Conference & Exposition*, 2015, pp. 1722-1729.
- [13] Chinmay Jain and Bhim Singh, "A Single-Phase Two-Stage Grid Interfaced SPV System with Adjustable DC Link voltage for VSC under Non Ideal Grid Conditions," in *Proc. of IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, 2014, pp. 1-6.
- [14] Chinmay Jain and Bhim Singh, "A SOGI-FLL Based Control Algorithm for Single Phase Grid Interfaced Multifunctional SPV under Non Ideal Distribution System," in *Proc. of Annual IEEE India International Conference (INDICON)*, 2014, pp. 1-6.
- [15] B. Singh, Chinmay Jain and Sagar Goel, "A UVT Based Control for Single-Stage Grid Interfaced SPV System with Improved Power Quality," in *Proc. of 6th IEEE Power India Conference (PICON)*, 2014, pp. 1-6.
- [16] Chinmay Jain and Bhim Singh, "Luenberger Observer Based Control Algorithm for Single-Phase Two-Stage Multifunctional Grid Connected Solar Energy Conversion System," in *Proc. of 9th International Conference on Industrial and Information Systems (ICIIS)*, 2014, pp. 1-6.
- [17] Chinmay Jain and Bhim Singh, "A SOGI-Q Based Control Algorithm for Multifunctional Grid Connected SECS," in *Proc. of 6th IEEE India International Conference on Power Electronics (IICPE)*, 2014, pp. 1-6.
- [18] Chinmay Jain and Bhim Singh, "An Assessment of RAD Based Control Algorithm for Single-Stage Multitasking Grid Tied SECS," in *Proc. of Innovative Applications of Computational Intelligence on Power, Energy and Controls with their impact on Humanity (CIPECH)*, 2014, pp. 273-278.



(Refer Slide Time: 24:23)


[19] [Bhim Singh](#) and [Chinmay Jain](#), "A GNPL-EPLL Based Control Algorithm for Multitasking Solar Energy Conversion System," in *Proc. of 8th International Conference on Capacitors CAPACIT*, 2014, pp. 1-6.

[20] [Chinmay Jain](#) and [Bhim Singh](#), "A Second Order Generalized Integrator (SOGI) based Control Algorithm for Single-Phase Single-Stage Grid Interfaced Multifunction Solar Photo-Voltaic (SPV) System," in *Proc. of Emerging Trends in Electrical And Electronics Engineering, Jamia Millia Islamia, New Delhi*, 2015.

[21] [Bhim Singh](#), [Chinmay Jain](#), [Sagar Goel](#), [Ambrish Chandra](#) and [Kamal Al-Haddad](#), "A Multifunctional Grid Tied Solar Energy Conversion System with ANF Based Control Approach," in *Proc. of IEEE Energy Conversion Congress and Exposition (ECCE)*, 2015, pp. 434 - 441.

[22] [Chinmay Jain](#), [Sagar Goel](#), [Bhim Singh](#), [Ambrish Chandra](#) and [Kamal Al-Haddad](#), "A Distribution Grid Tied Multifunctional SPV System Operating with Control Approach Based on Decoupled Adaptive Neural Network," in *Proc. of IEEE IAS Annual Meeting Conference*, 2015.

[23] [Bhim Singh](#), [Chinmay Jain](#) and [Anmol Bansal](#), "An Improved Adjustable Step Adaptive Neuron Based Control Approach for Grid Supportive SPV System," in *Proc. of 12th Annual IEEE India International Conference (INDICON)*, 2015.



(Refer Slide Time: 24:24)

[23] [Bhim Singh](#), [Chinmay Jain](#) and [Anmol Bansal](#), "An Improved Adjustable Step Adaptive Neuron Based Control Approach for Grid Supportive SPV System," in *Proc. of 12th Annual IEEE India International Conference (INDICON)*, 2015.

[24] [Bhim Singh](#) and [Chinmay Jain](#) "A Decoupled Adaptive Noise Detection Based Control Approach for Grid Supportive SPV System" in *Proc. of IEEE IAS ICPS/PCIC Hyderabad Conference*, 2015.


[25] [Chinmay Jain](#) and [Bhim Singh](#) "An Offset Reduction Second Order Generalized Integrator based Control Algorithm for Single-Phase S-DSTATCOM," in *Proc. of National System Conference*, 2015.

[26] [Bhim Singh](#) and [Chinmay Jain](#) "A Double Frequency Tuned SOGI Based Control Approach for Roof Top S-DSTATCOM" in *Proc. of National Power Electronic Conference*, 2015.

[27] [Anubhav Jain](#), [Chinmay Jain](#) and [Bhim Singh](#) "A Dual Tangent Based Algorithm for Maximum Power Point Tracking of Solar PV Systems", in *Proc. of 41st Annual Conference of the IEEE Industrial Electronics Society (IECON)*, 2015.

[28] [Bhim Singh](#), [Ankit Singhal](#), [Chinmay Jain](#), [Sagar Goel](#) and [Ankur Garg](#) "Power Quality Enhancement of Grid Integrated Solar PV System based on Adaptive Noise Reduction Control" *IEEE PES annual meeting*, 2015.

[29] [Bhim Singh](#), [Shailendra Dwivedi](#) and [Chinmay Jain](#), "Damped-SOGI Based Control Algorithm for Solar PV Power Generating System" in *Proc. of IEEE IAS Joint Industrial and Commercial Power Systems / Petroleum and Chemical Industry Conference*, 2015.



(Refer Slide Time: 24:24)


[30] [Arun Kumar Verma](#), [Bhim Singh](#) and [D.T Shahani](#), "Grid Interfaced Solar Photovoltaic Power Generating System with Power Quality Improvement at AC Mains", The 3rd IEEE international conference on sustainable energy technologies (ICSET, 12),24-27 Sept.2012. Kathmandu, Nepal.

[31] [Arun Kumar Verma](#), [Bhim Singh](#) and [D.T Shahani](#), "Fuzzy-Logic Based MPPT Control of Grid Interfaced PV Generating System with Improved Power Quality," IEEE Fifth POWER INDIAConference, Dec.19-22, 2012, DCRUST, [Murthal](#), ([Sonapat](#)) Haryana-India.

[32] [Bhim Singh](#), [D.T Shahani](#) and [Arun Kumar Verma](#), "Power Balance Theory Based Control of Grid Interfaced Solar Photovoltaic Power Generating System with Improved Power Quality," IEEE International Conference on Power Electronics, Drives and Energy Systems 2012 (PEDES 2012)" 16-19 Dec 2012, ISC, Bangalore, India.

[33] [Bhim Singh](#), [D.T Shahani](#) and [Arun Kumar Verma](#), "IRPT Based Control of a 50 kW Grid InterfacedSolar Photovoltaic Power Generating System with Power Quality Improvement," in proc. Fourth IEEE Conference on Power Electronics for Distributed Generation Systems, July 8 – 11, Arkansas, USA.

[34] [Bhim Singh](#), [D.T Shahani](#) and [Arun Kumar Verma](#), "Simusoidal Integrator based control of a grid interfaced solar photovoltaic power generating system," Accepted in IEEE ICPS Kathmandu. 27-30 October 2013.



(Refer Slide Time: 24:24)

[35] [Arun Kumar Verma](#), [Bhim Singh](#) and [D.T Shahani](#), "Current Synchronous Detection Based Control of Grid Interfaced Solar Photovoltaic Power Generating System," IEEE INDICON, 2013, pp. 1-6


[36] [B. Singh](#), [S. Dwivedi](#), [I. Hussain](#) and [A. K. Verma](#), "Grid integration of solar PV power generating system using QPLL based control algorithm," in Proc. IEEE Power India Int. Conf. (PIICON), New Delhi, India, 5-7 Dec. 2014, pp. 1-6.

[37] [S. Kumar](#), [A. K. Verma](#), [I. Hussain](#) and [B. Singh](#), "Performance of grid interfaced solar PV system under variable solar intensity," in Proc. 6th India Int. Conf. Power Electronics (IICPE), 8-10 Dec. 2014, pp.1-6.

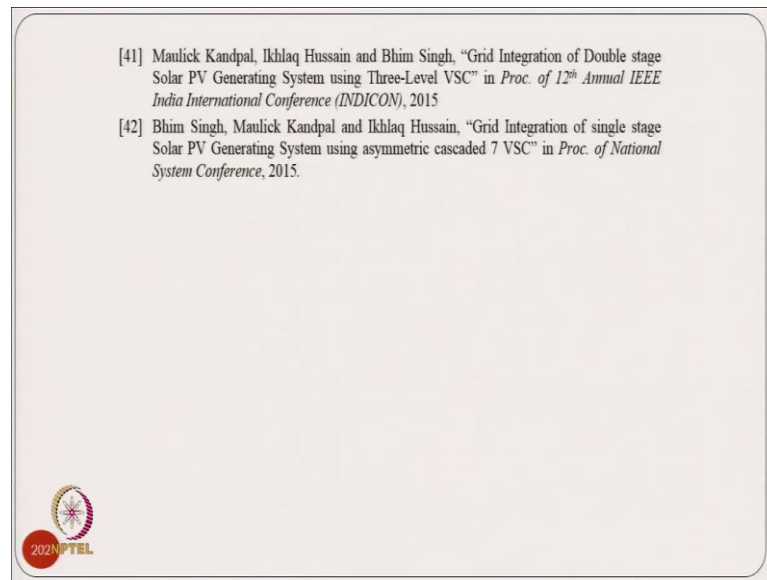
[38] [B. Singh](#) and [I. Hussain](#), "Grid integration of single stage solar PV power generating system using 12-pulse VSC," in Proc. 6th IEEE India Int. Conf. Power Electronics (IICPE), 8-10 Dec. 2014, pp. 1-6.

[39] [I. Hussain](#) and [B. Singh](#), "Grid integration of large capacity solar PV plant using multipulse VSC with robust PLL based control," in Proc. IEEE Power India Int. Conf. (PIICON), New Delhi, India, 5-7 Dec. 2014, pp. 1-6.

[40] [I. Hussain](#) and [B. Singh](#), "Investigations on solar PV grid interfaced power generating system using two-level twelve-pulse double bridge converter," in Proc. 9th IEEE Int. Conf. Industrial Information Systems (ICIIS), 15-17 Dec. 2014, pp. 1-6.



(Refer Slide Time: 24:25)



And these are the some of the references, which are used in this.

Thank you.