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

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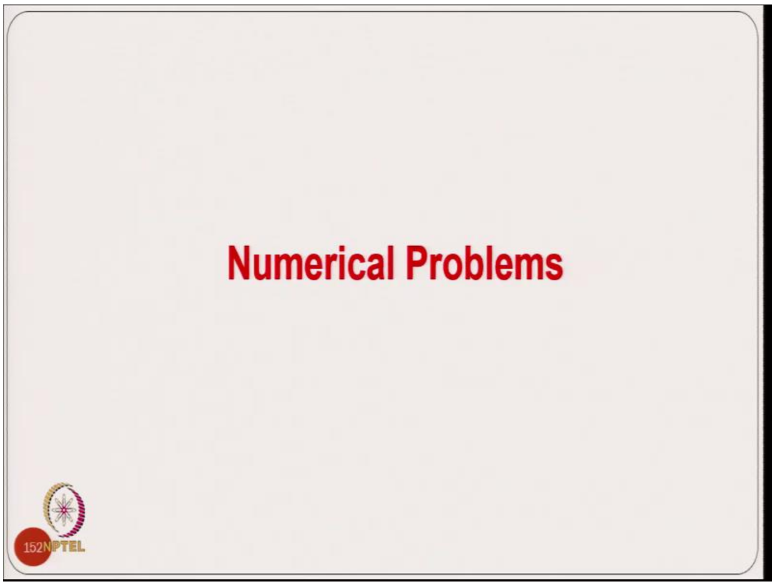

Welcome to the course on Power Quality [FL]. We are discussing the grid interface solar PV system. We will now discuss some numerical problems related to this.

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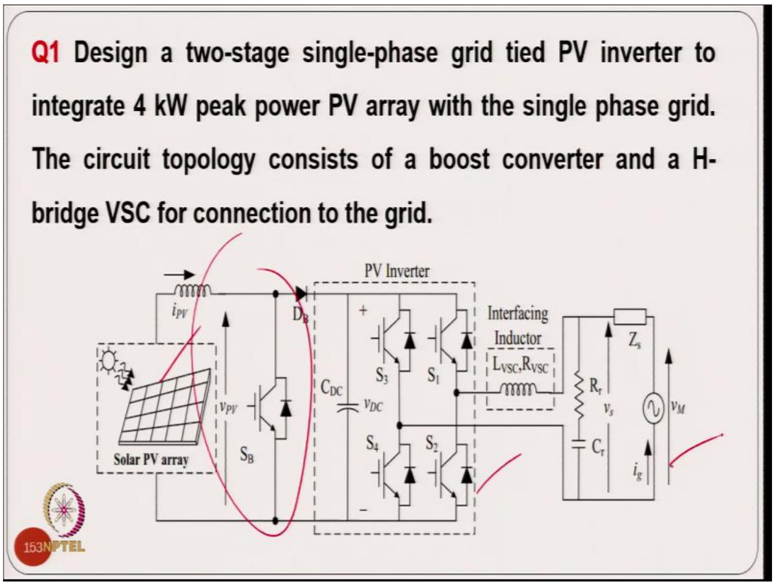

Starting with 1st example. Design a two stage single phase grid tied solar PV inverter to integrate 4 kW peak power of PV array with a single phase grid and circuit topology consist of a boost converter and H bridge voltage source converter.

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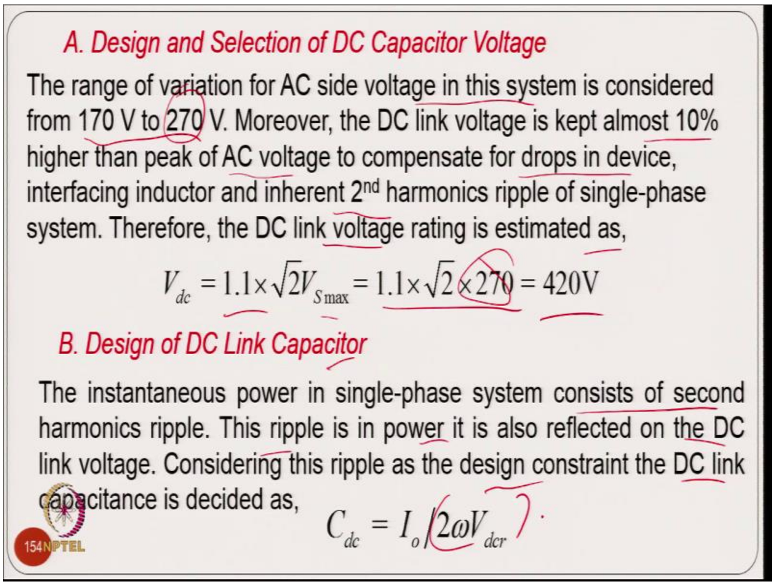

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where, I_o is the capacitor current and ω is the angular frequency and the v_{DCr} is the ripple in capacitor voltage. Considering, the ripple as 2%, v_{DCr} = 0.02*420 = 8.4 V, I_o = 4,000/420 = 9.52 A then, C_{DC} is obtained as 1804.7 μF. Therefore,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

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.

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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,

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

Maximum power, P_{maxA} = (n_s*90% of V_{oc} * n_p*90 % of I_{sc}) = 4 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.

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

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

Maximum current of the array is given as,

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

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

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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,

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

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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,

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

where Vin is the input voltage, V_{in} = 240 V, D is the duty ratio, D = 0.33, f_s is the switching frequency, f_s = 10 kHz, and ΔI_{in} is the peak to peak ripple in the boost inductor. The ΔI_{in} is considered 10% of nominal current, ΔIin = 0.2*(4000/240) = 3.34 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.

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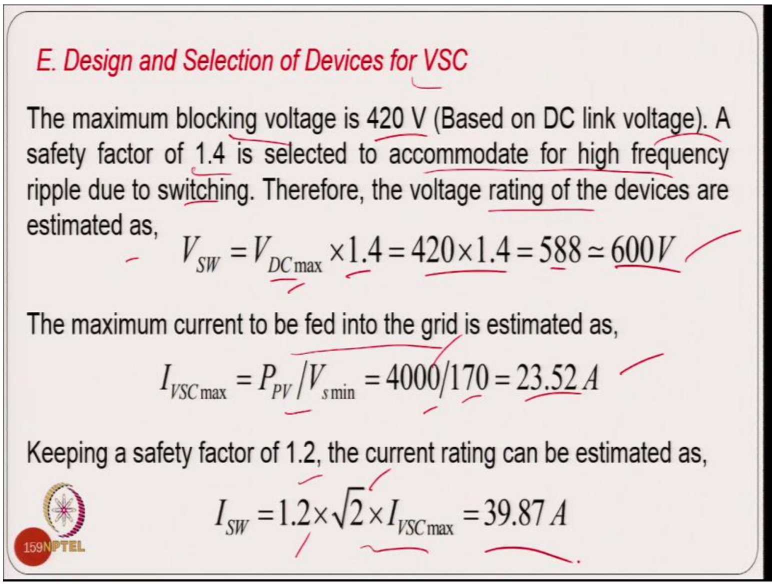

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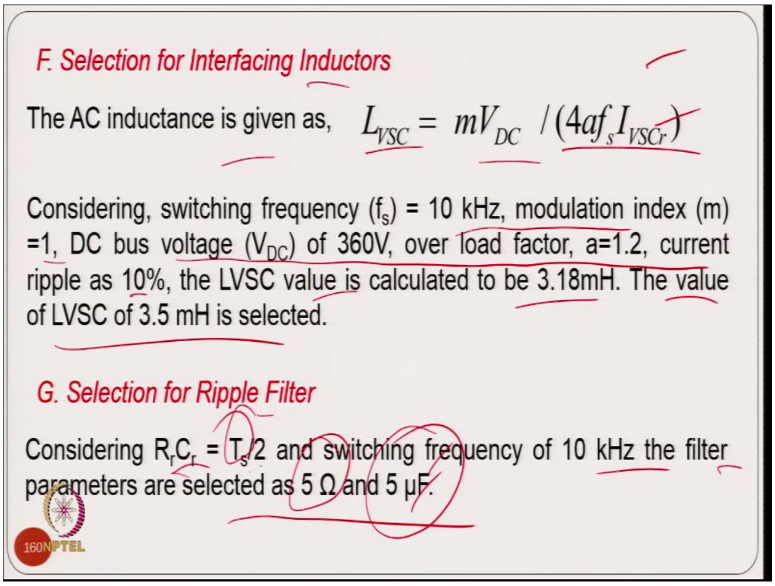

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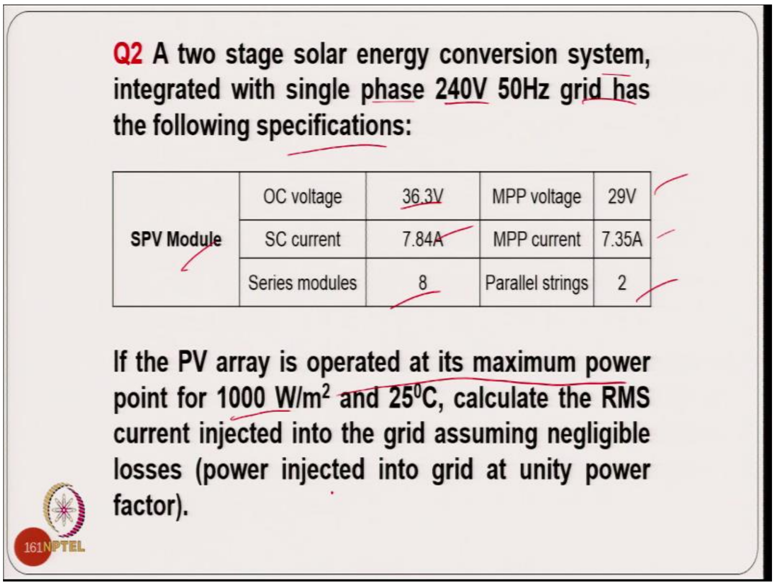

Coming to the 2nd numerical example. A two stage solar PV conversion system integrated with single phase supply of 240 V/50 Hz grid has the following specifications given in the table. If the PV array is operated at the maximum power point for 1000 W/m^2 and 25° C. Calculate the RMS current injected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

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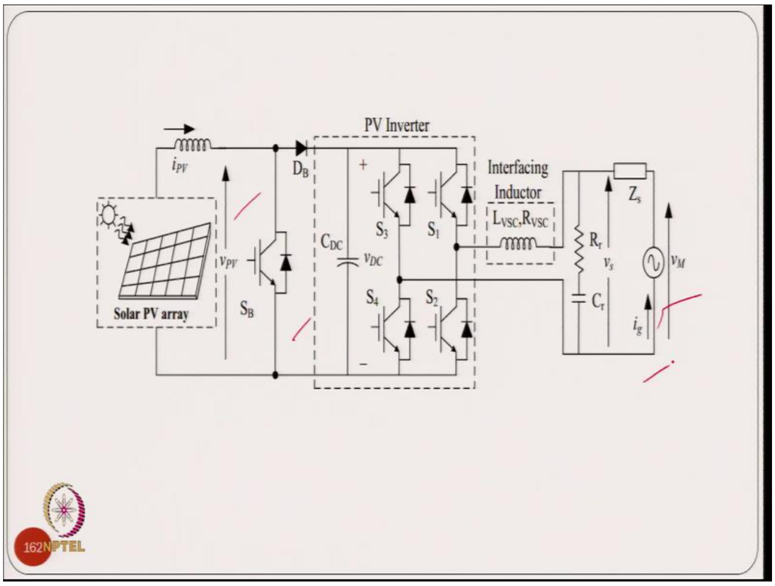

This is a typical system as mentioned in the example.

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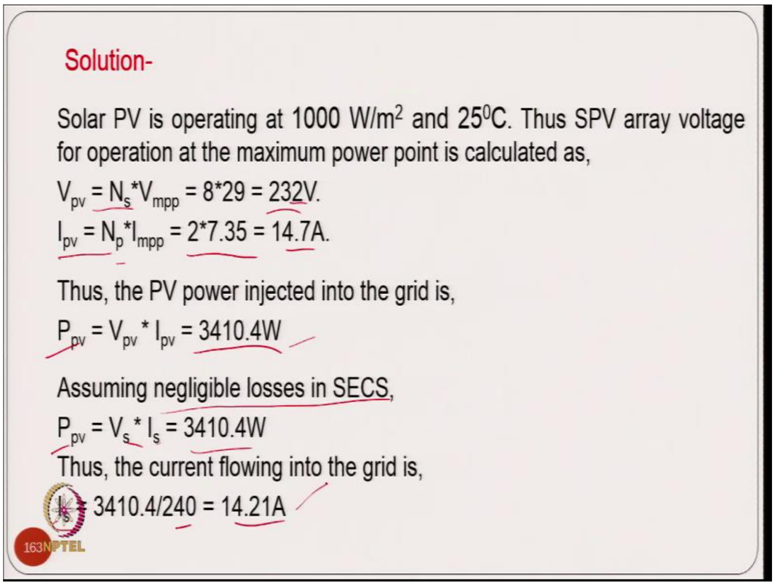

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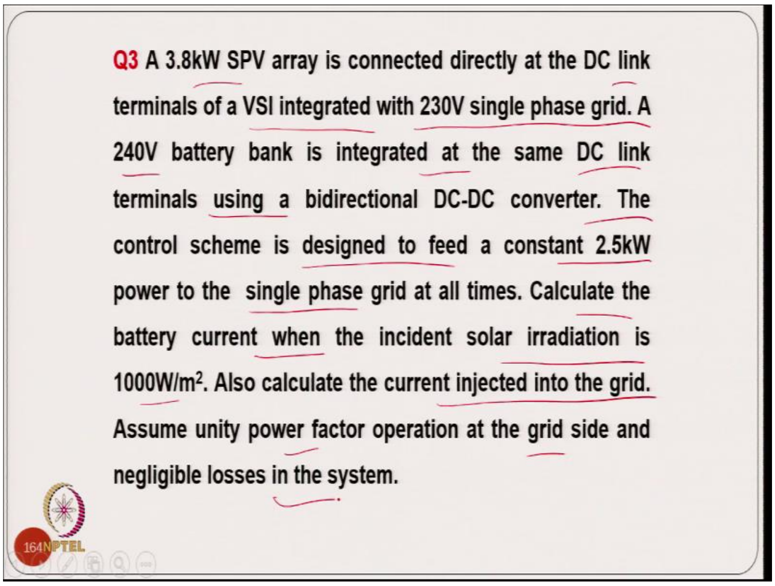

Coming to 3rd example. A 3.8 kW solar PV array is connected directly at the DC link thermals of the voltage source inverter integrated with 230 V single phase grid. A 240 V battery bank is integrated at the same DC link thermals using the bidirectional DC-DC converter. The control scheme is designed 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/m^2. Also calculate the current injected to the grid. Assuming unity power factor operation at the grid side and negligible losses in the system.

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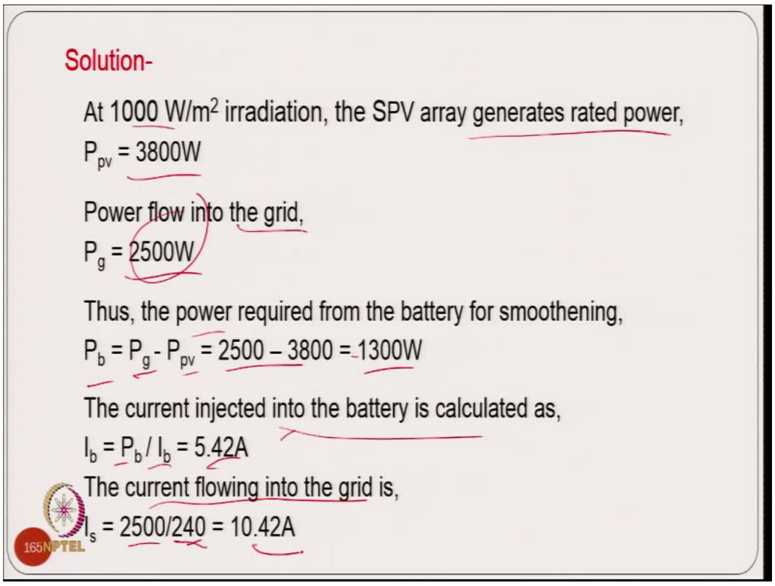

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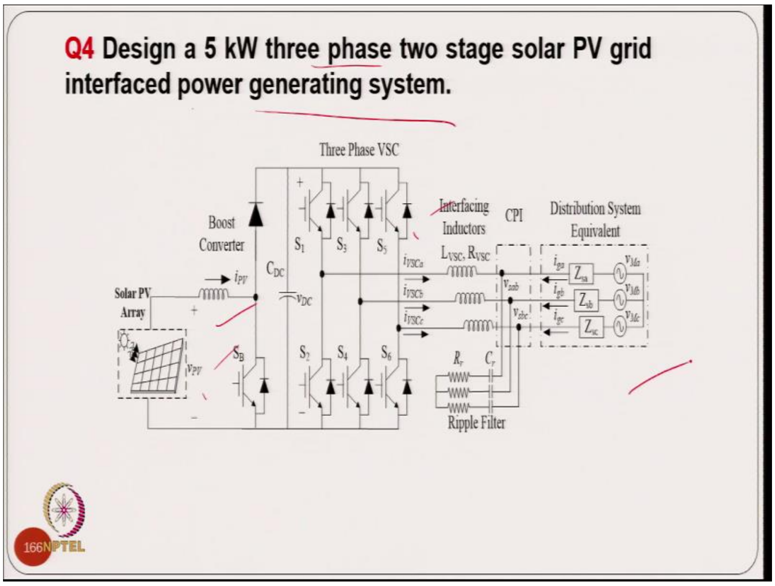

Now, coming to 4th example. Design a 5 kW 3 phase 2 stage solar PV grid interface system. So, we have a 2 state system solar PV generation, as shown in figure.

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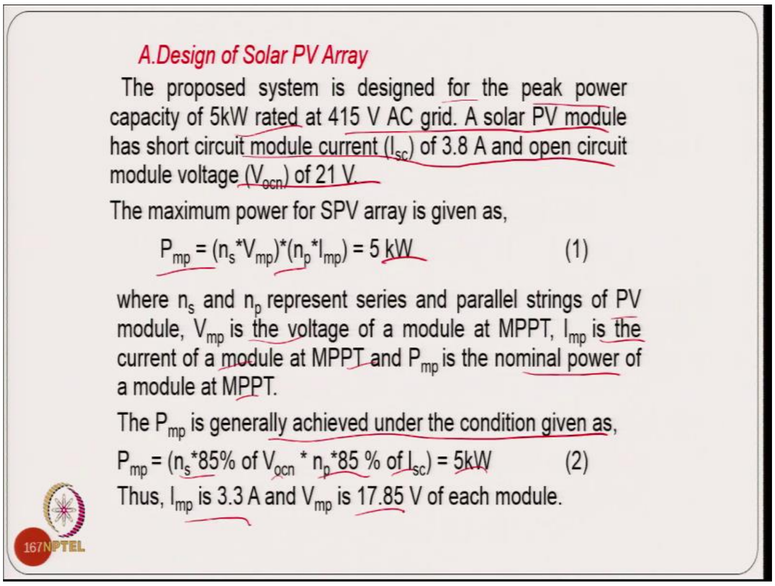

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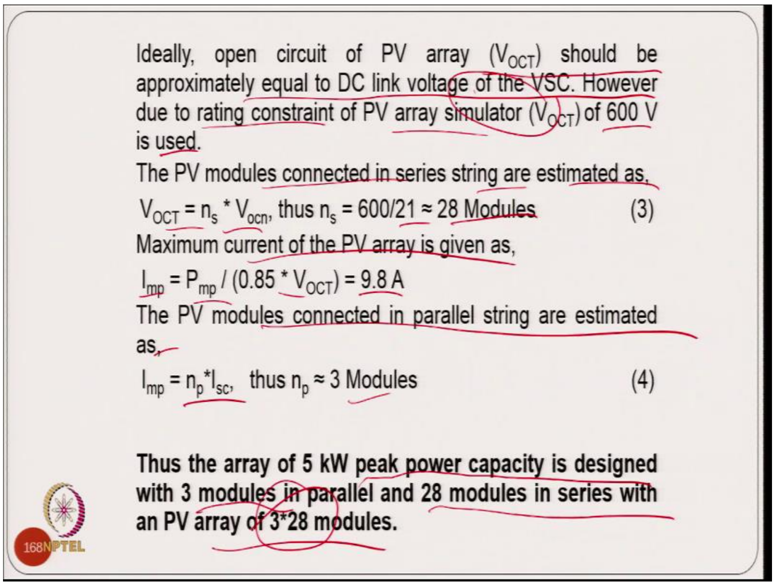

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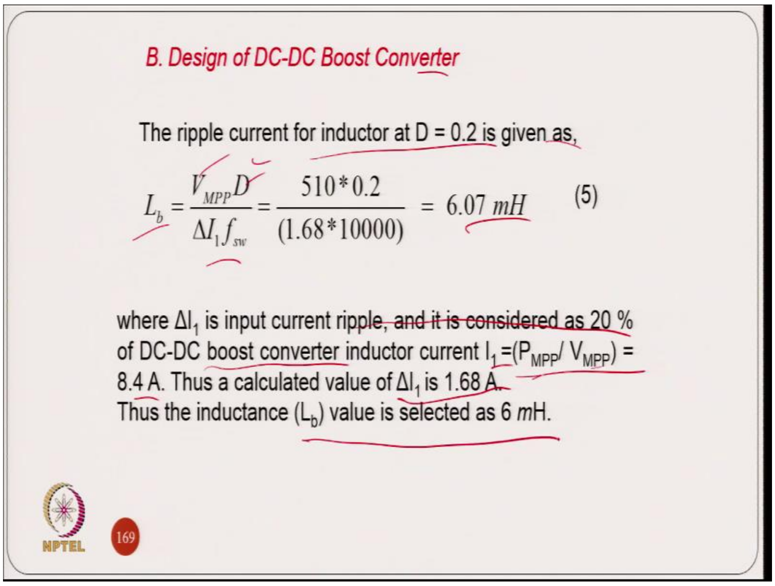

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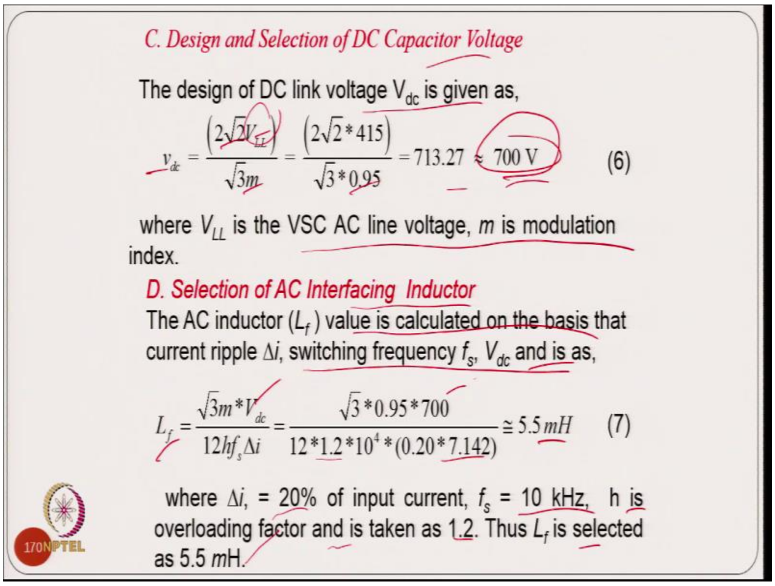

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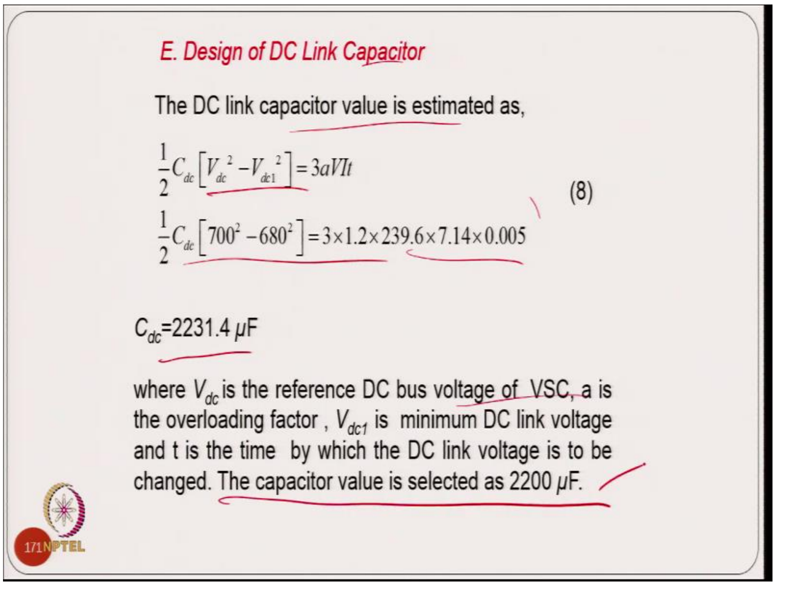

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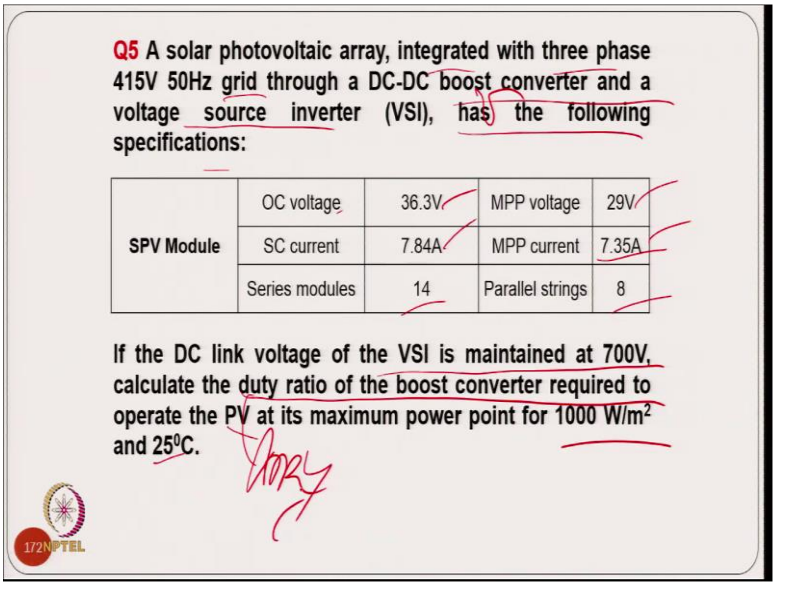

Coming to 5th example. A solar photovoltaic array, integrated with 3 phase 415 V/50 Hz grid through a DC-DC boost converter and a voltage source inverter has the following specification, as shown in table. If the DC link voltage of the VSI is maintained at 700 V, calculate the duty ratio of boost converter required to operate the PV array at its maximum power point for 1000 W/m^2 and 25° C.

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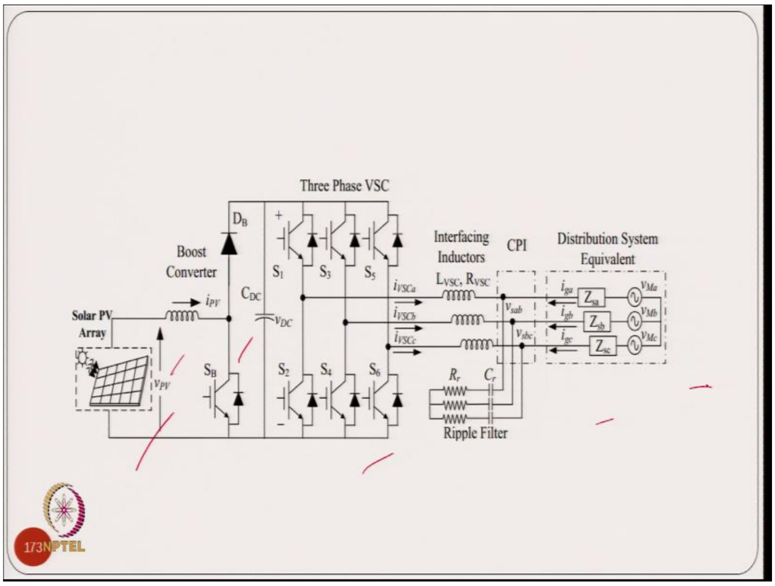

This is the typical configuration for the 5th example.

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Solution-

Solar PV is operating at 1000 W/m^2 and 25^{0}C. Thus SPV array voltage for operation at the maximum power point is calculated as,

$V_{pv} = N_s * V_{mpp} = 14*29 = 406V.$

Thus based on the duty cycle expression for boost converter,

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

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

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

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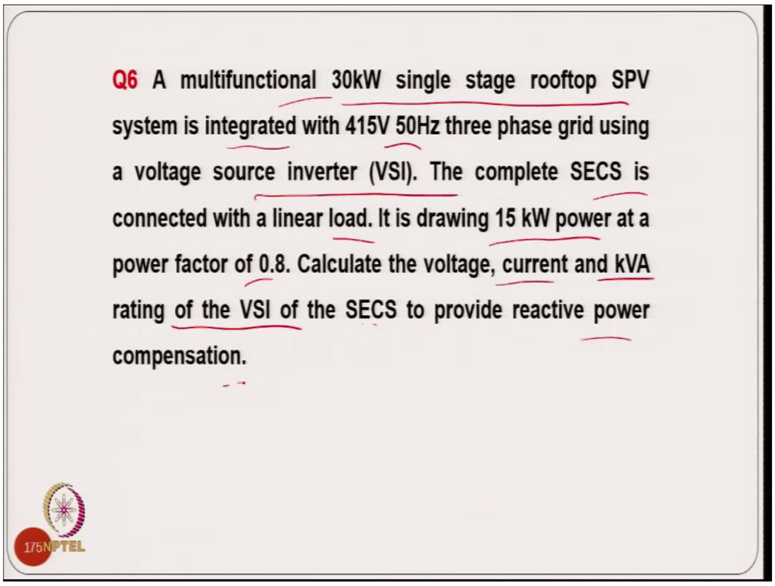

Coming to the 6[th] example. A multi functional 30 kW single stage rooftop solar PV photovoltaic system is integrated with the 415 V/50 Hz three phase grid using a voltage source inverter. The complete solar energy conversion system (SECS) is connected with a linear load. It is drawing 15 kW power at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

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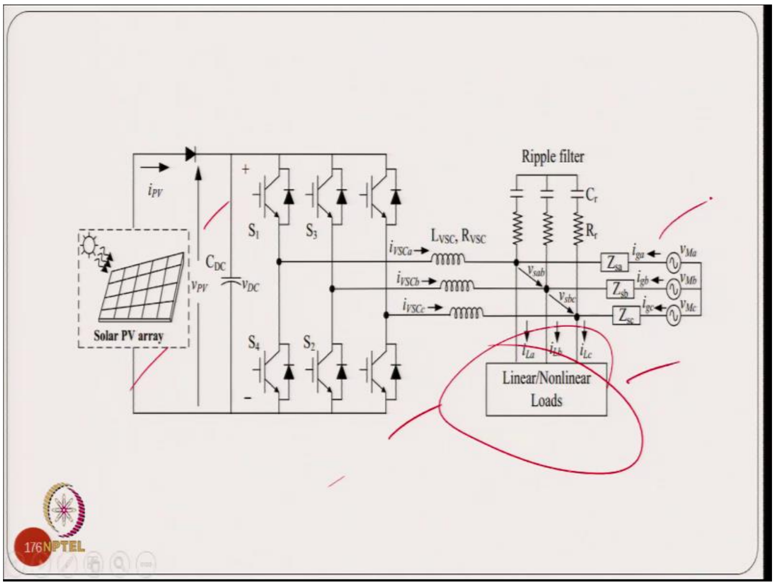

This is the mentioned system configuration.

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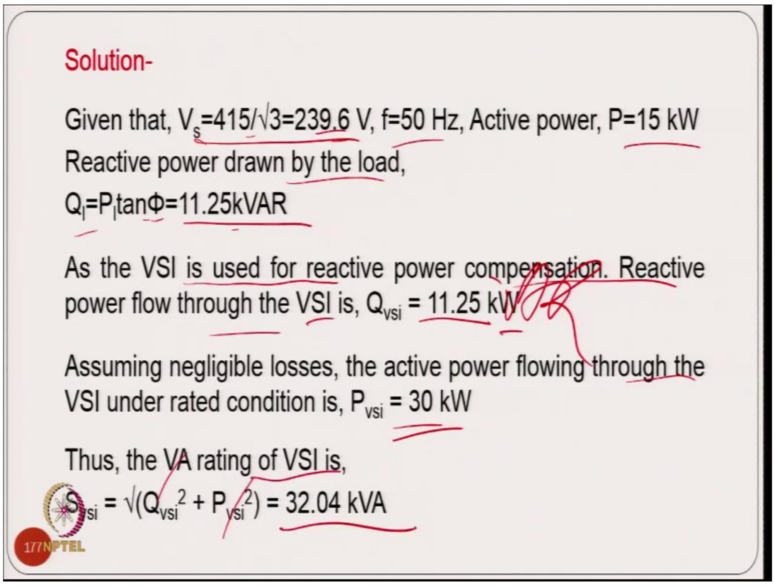

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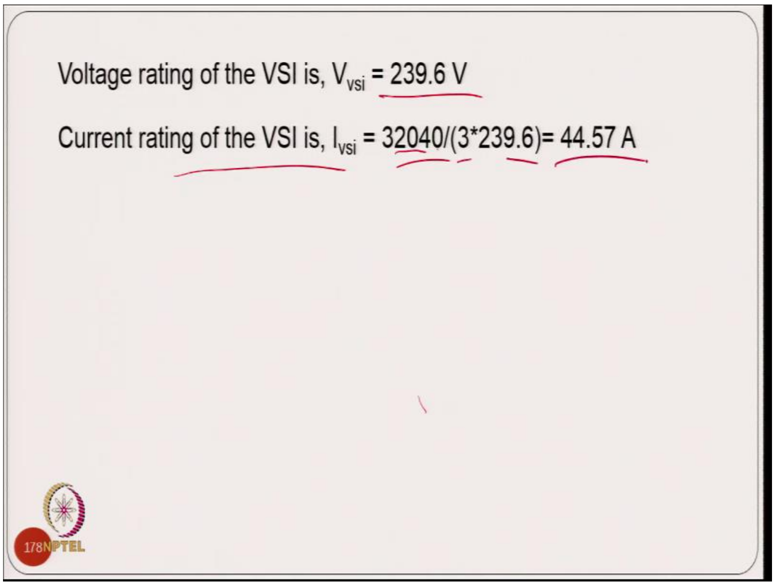

The solution of this problem is given in the abovemention slides.

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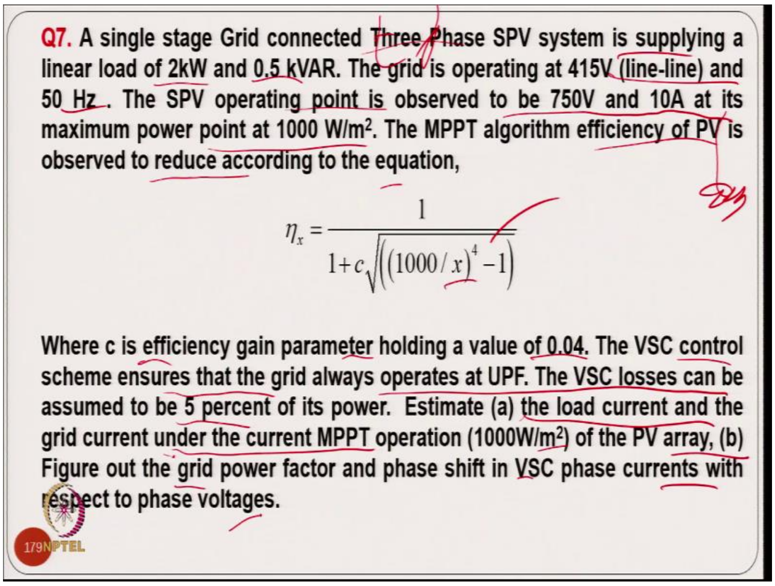

Coming to 7th example. A single stage grid connected three phase solar photovoltaic system is supplying a linear load of 2 kW and 0.5 kVAR. The grid is operating 415 V/50 Hz. The solar PV operating is 750 V at 10 A at its maximum power taking of 1000 W/m^2. The MPPT efficiency of PV array is observed 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/m^2 of PV array. Figure out the grid power factor and the phase shift in the VSC phase current with phase voltage.

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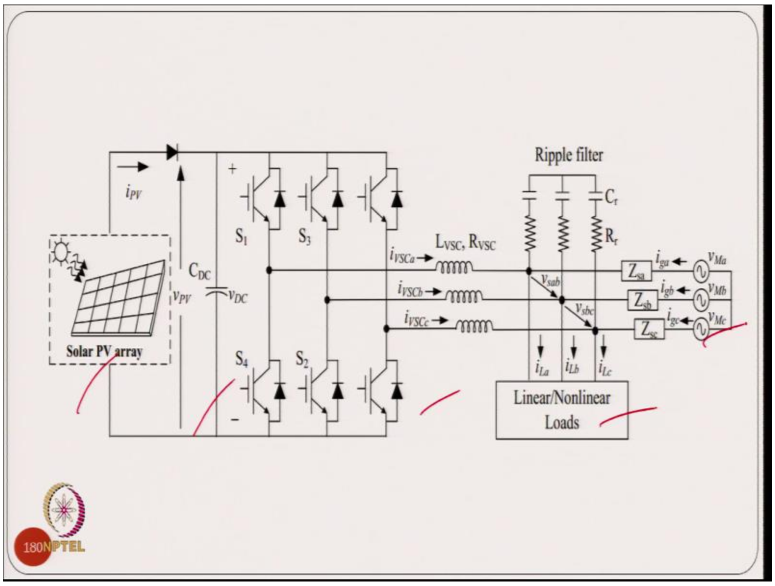

This is the system configuration for the abovementioned problem.

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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*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,

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

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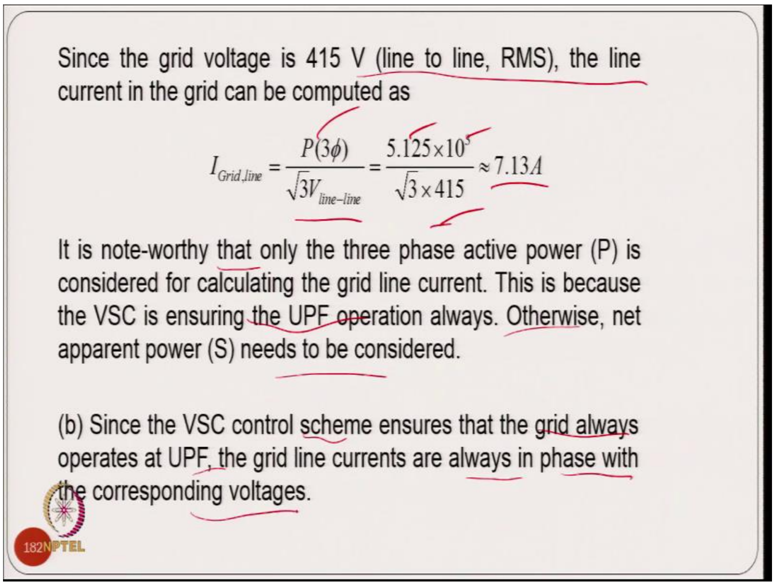

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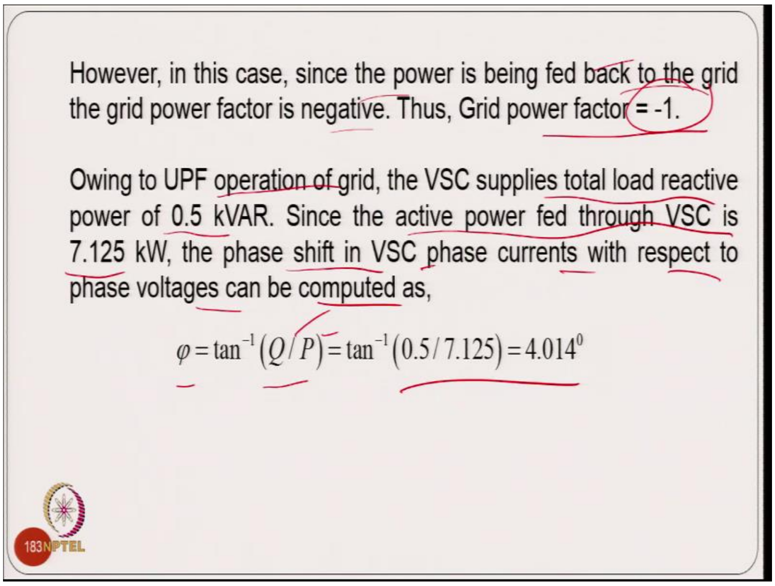

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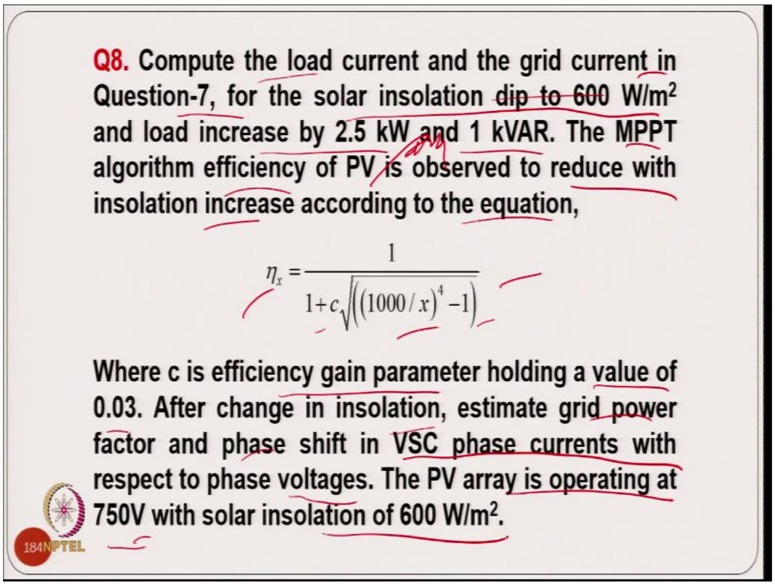

Coming to the 8th example. Compute the load current and a grid current in previous question, for solar PV insolation dip to 600 W/m^2 and load increases by 2.5 kW and 1 kVAR. The MPPT algorithm efficiency of PV array is observed to reduce with insolation increase according to the equation given in the 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.

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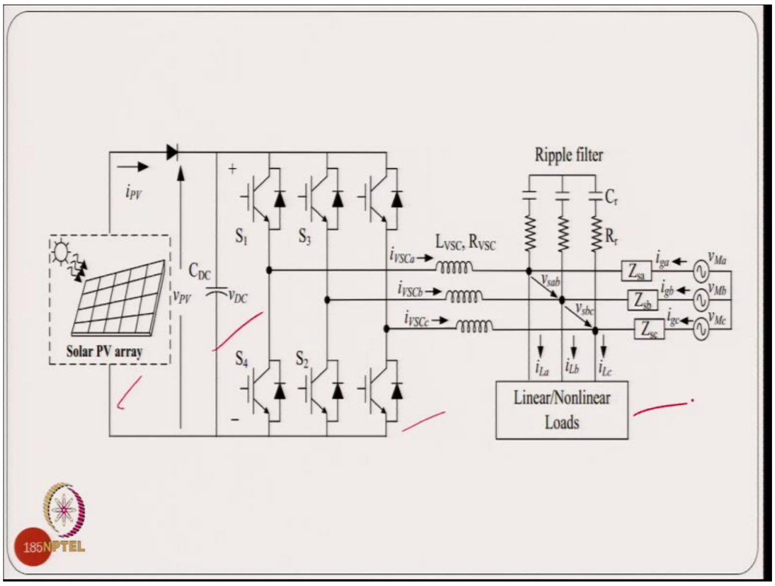

This is the system configuration for this problem.

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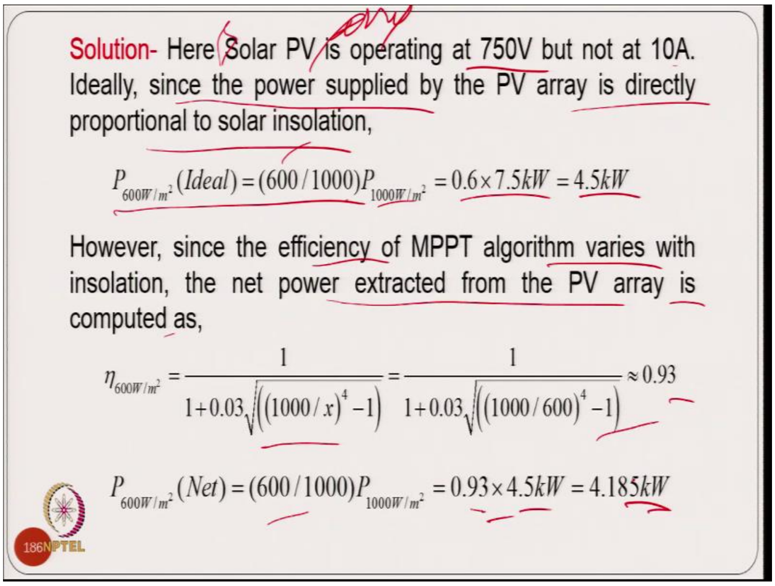

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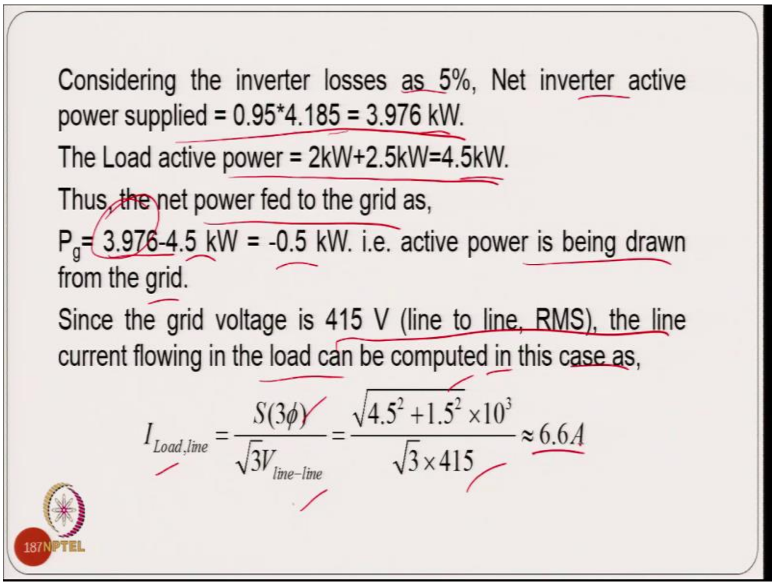

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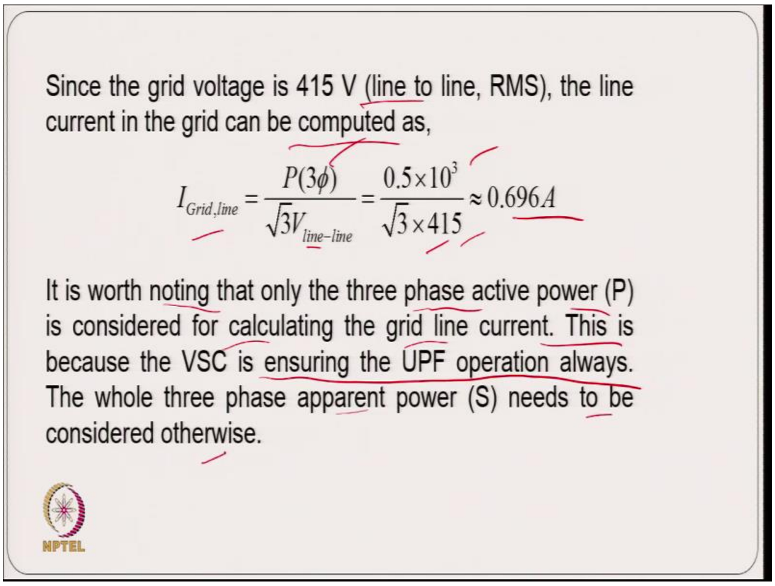

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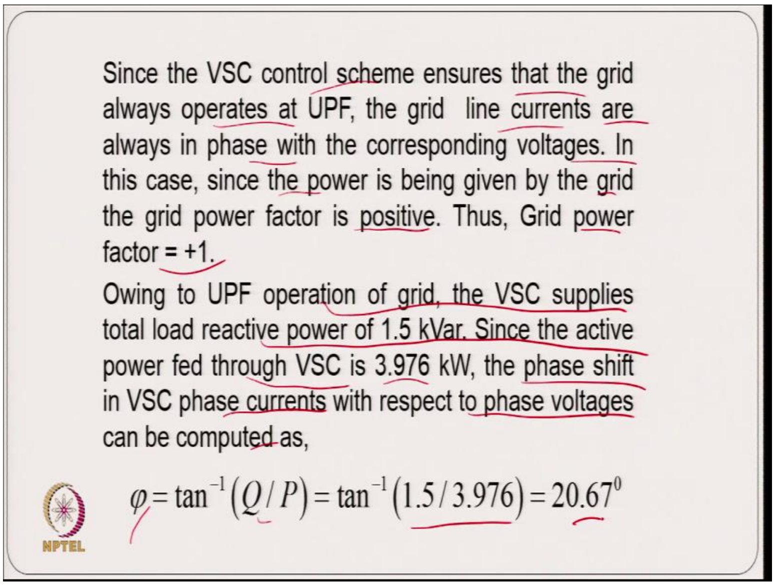

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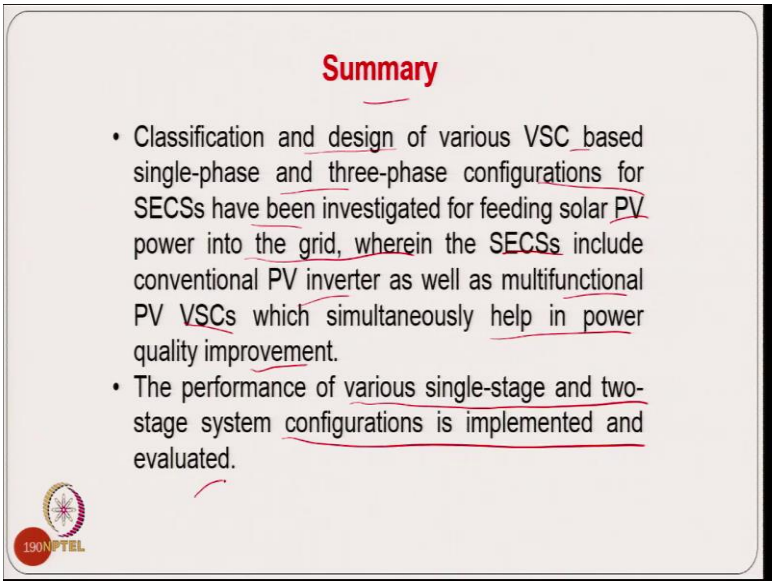

With this we would like to summarize. The classification and design of various voltage source converter single phase and three phase configurations for solar energy conversion system have been investigated for feeding the solar PV power into the grid. Wherein, the solar energy conversion systems include 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.

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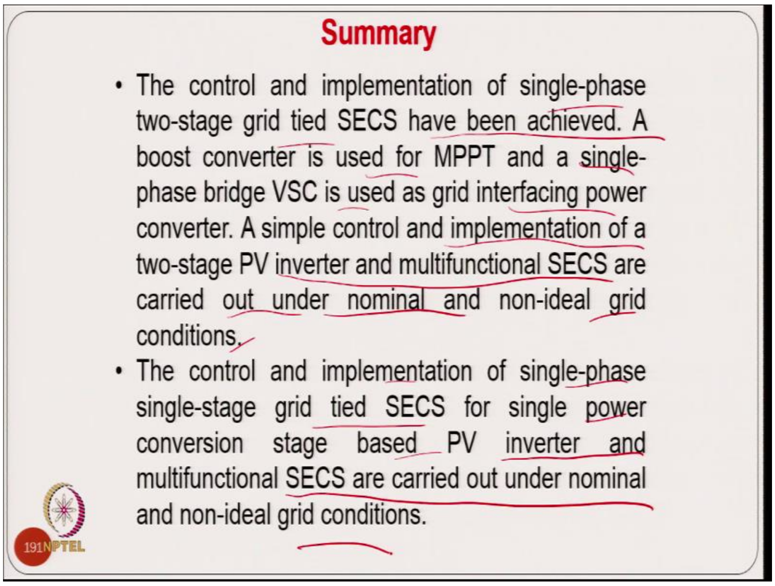

The control and implementation of single-phase two-stage grid tied solar PV system have been achieved. A boost converter is used for maximum power tracking and a single phase bridge voltage source converter is used for grid interfacing power converter. A simple control and implementation of two-stage 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.

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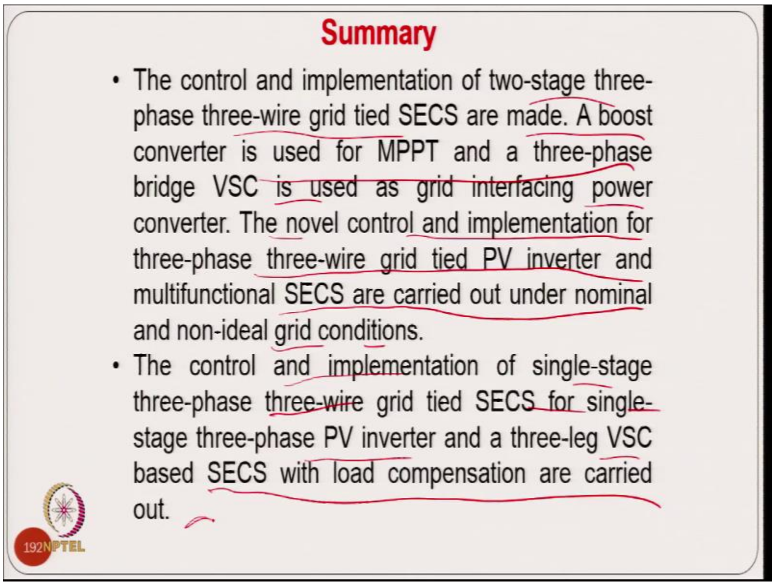

The control and implementation of two-stage three-phase three-wired system are made. So, boost converter is used for MPPT of three-phase voltage source converter, and a three phase VSC used as a grid interfacing power converter and novel control and implementation of three phase PV inverter and multifunctional 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.

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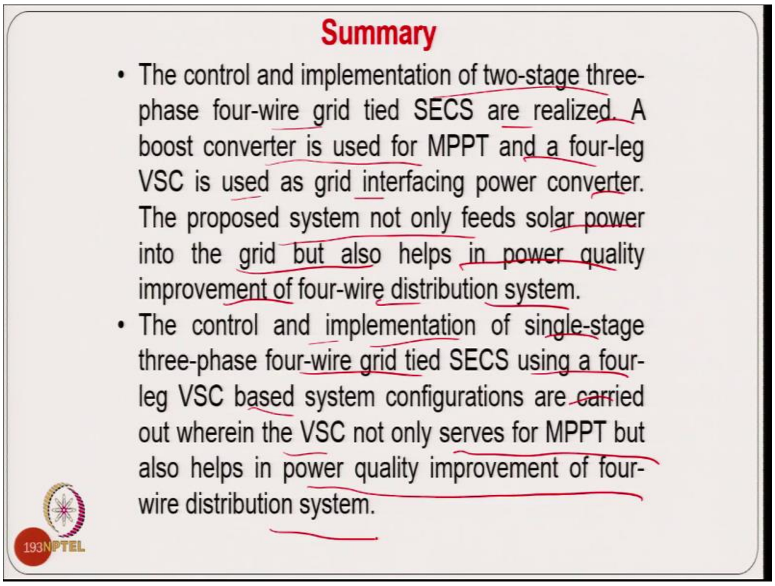

The control and implementation of two-stage three-phase four-wire grid tied system are realized. A boost converter is used for a maximum power tracking and four-leg VSC is used for grid interfacing power converter. This system not only feeds the solar power into the grid, but also helps in power quality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

The control implementation of single-stage three-phase four-wire gird 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.

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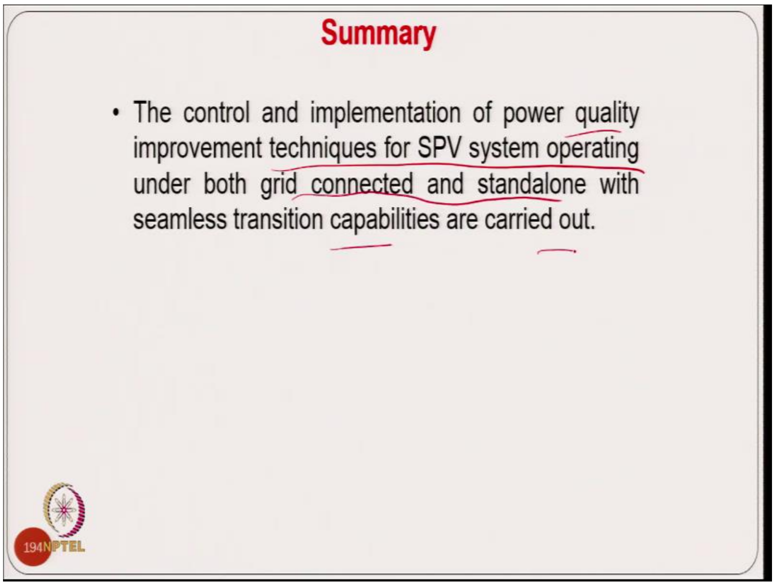

The control and implementation of power quality improvement techniques for solar power photovoltaic system operating under both grid connected and standalone system similar transition capability also carried out.

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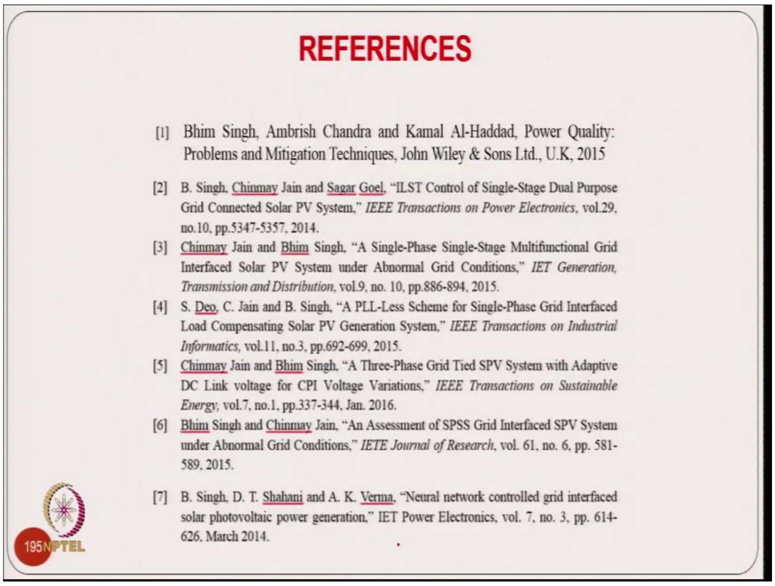

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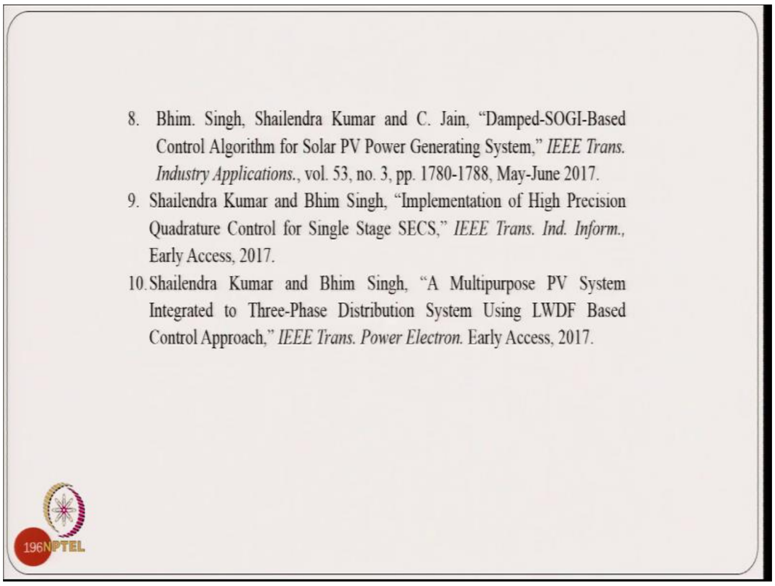

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[21] Bhim Singh, Chinmay Jain, Sagar Goel, Ambrish Chnadra and Kamal Al-Haddad, "A Multifunctional Grid Tied Solar Energy Conversion System with ANF Based Control Approach," in *Proc. of IEEE Energy Conversion Congress and Exposition (ECCE)*, 2015,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

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[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 12^{th} Annual IEEE India International Conference (INDICON)*, 2015.

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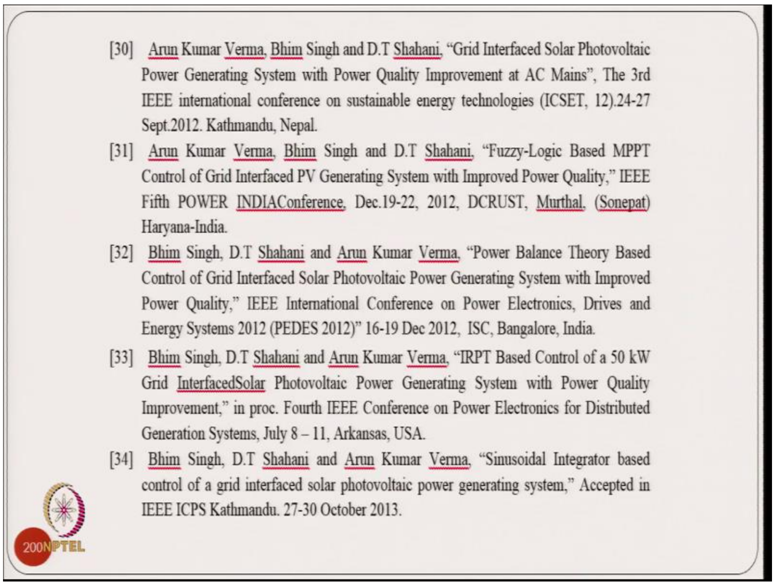

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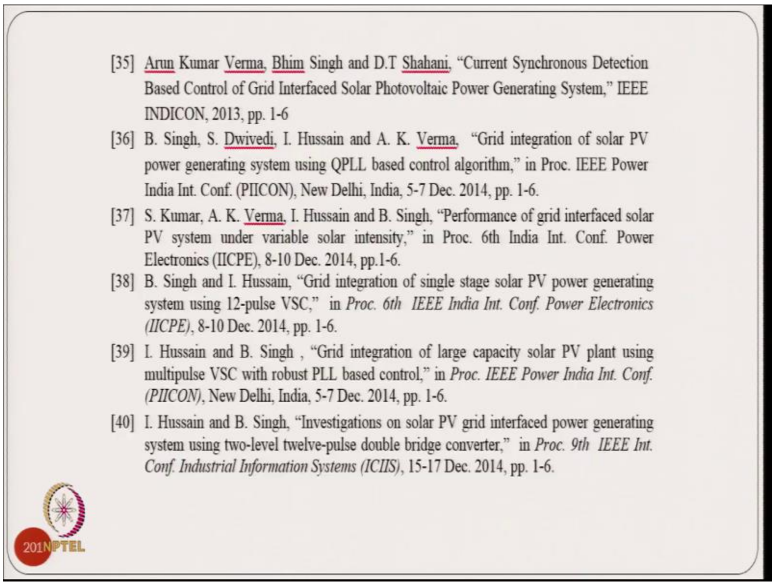

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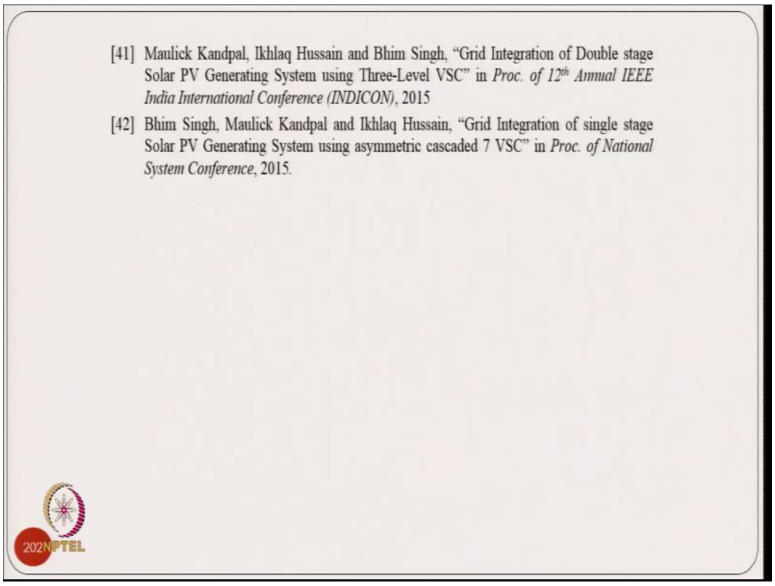

And these are the some of the references, which are used in this.

Thank you.