Flexible AC Transmission Systems (FACTS) Devices

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Lecture – 19
DSTATCOM

Welcome, to our video lectures on FACTS Devices. We shall continue today also with our shunt compensation. Today, we are going to discuss about DSTATCOM. So, DSTATCOM this will be essentially it is a distribution STATCOM. In previous lectures, we have seen the svc and the STATCOM and both were put for the shunt compensations and we find that there is a big advantage of the STATCOM over the over the SVC.

Now, those were connected mostly to the transmission line and thus it is required a high voltage, this is put into high voltage amplification and it requires step down transformer, all those things DSTATCOM is also now the part of the FACTS devices and the power quality and it is generally used for mitigation of the harmonics moreover with the compensation of the reactive power.

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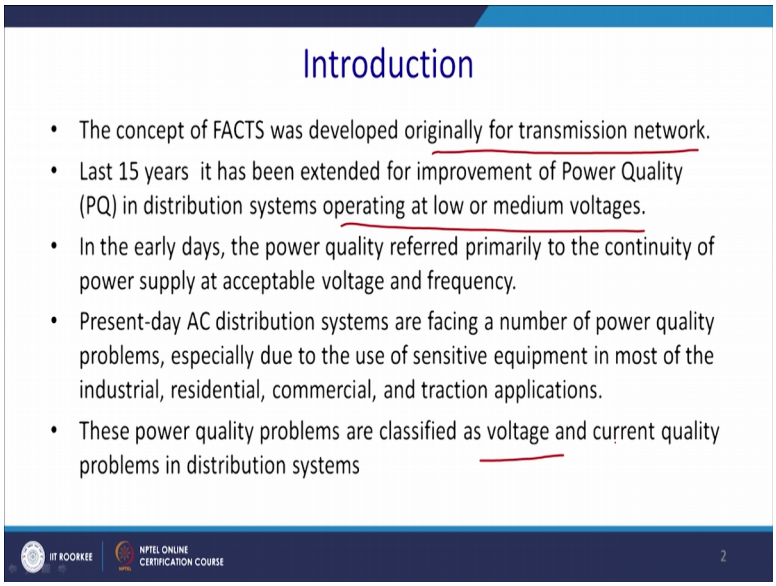

The concept of the FACTS was developed originally for transmission line network. Last 15 years it has been extended to improve the power quality. So, power quality also comes into the preview of the FACTS device nowadays in distribution system operating at low

or the medium level voltages. In the early days power quality referred to mainly the continuity of the power supply at accepter voltage and frequencies. Now, another parameter has been added to monitor the power quality. Present-day AC distribution system are facing number of power quality problem, especially due to the sensitive equipment in most of the industrial and the industrial, residential, commercial, and a trans and the tractional application. The power quality problem today are now classified as the voltage and the current quality problem in distribution system.

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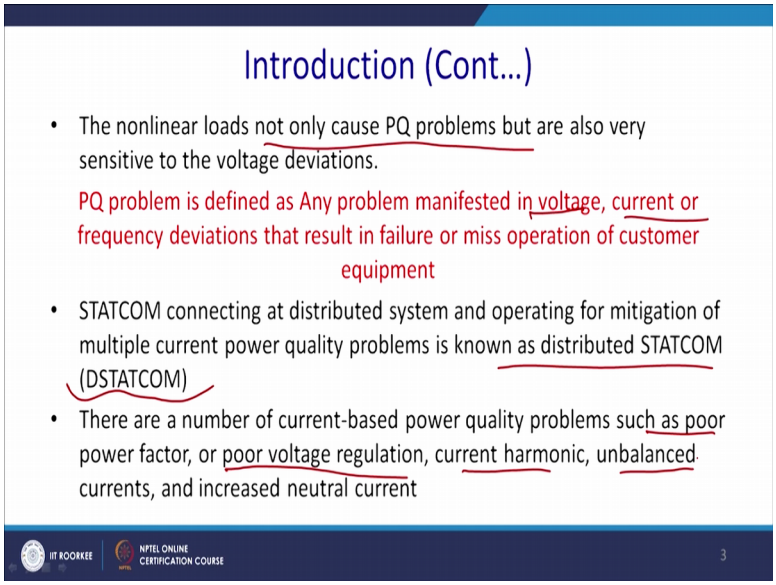

Due to advent of the power electronics we have non-linear load, load not only cause PQ problem and also very sensitive to the voltage deviation. PQ problem that is real power and the reactive power problem is defined as any problem manifested in voltage current or the frequency deviation as a result of the failure of the miss of the operation of the customer and the or the equipment.

STATCOM on the contrary, STATCOM connected and distribution system and operating for the mitigation of the multiple current and the power quality problem is known as DSTATCOM or distributed STATCOM, it is abbreviated as DSTATCOM. There are number of current based power quality problem such as poor power factor, poor voltage regulation, current harmonic, unbalanced current and the increase the neutral current, these are the problem of the poor power factor.

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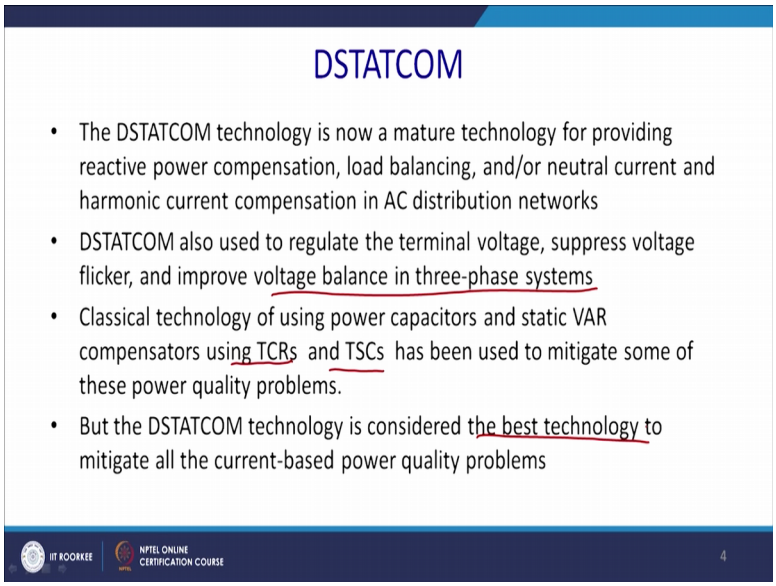

Now, DSTATCOM technology is now a mature technology for providing the reactive power compensation, load balancing and neutral and the harmonic current suppressions in the AC main networks. DSTATCOM is also used to regulate the terminal voltage, suppressed voltage flickers and improve the voltage unbalance for the three-phase system, this is the one of the utility.

Classical technology for using power capacitors and the static VAR compensator using TCR, TSCs has been used to mitigate some of this problems. But, the DSTATCOM technology is considered the best technology to mitigate this current-based power quality problem and thus it is being used frequently in FACTS devices.

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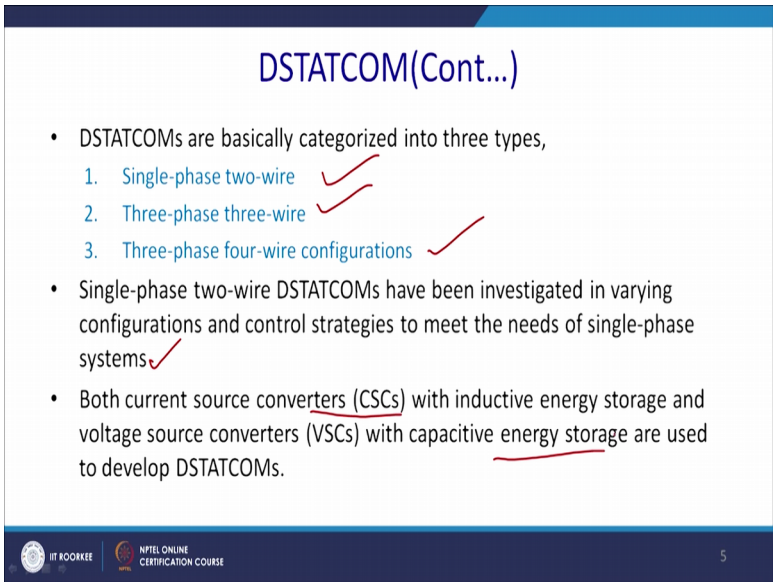

DSTATCOM can be categorized into the three types. It can be single-phase; single-phase two-wire type and in case it may be actually three-phase three-wire system; that means, three-phase three-wire type DSTATCOM can be three-phase three-wire type and three-phase four-wire type configuration is also put into the perspective. So, this is two-phased two-wires STATCOM has been investigated and varying configuration and the control study need to meet the need of the single phase and this is generally for the low voltage application and this does not find much application nowadays because distribution system are mostly three-phase four-wire or three-wire.

In this configuration both current source converter that is CSC with inductive energy storage and the voltage source converter it is VSC with capacitive energy storage are used to develop the STATCOM.

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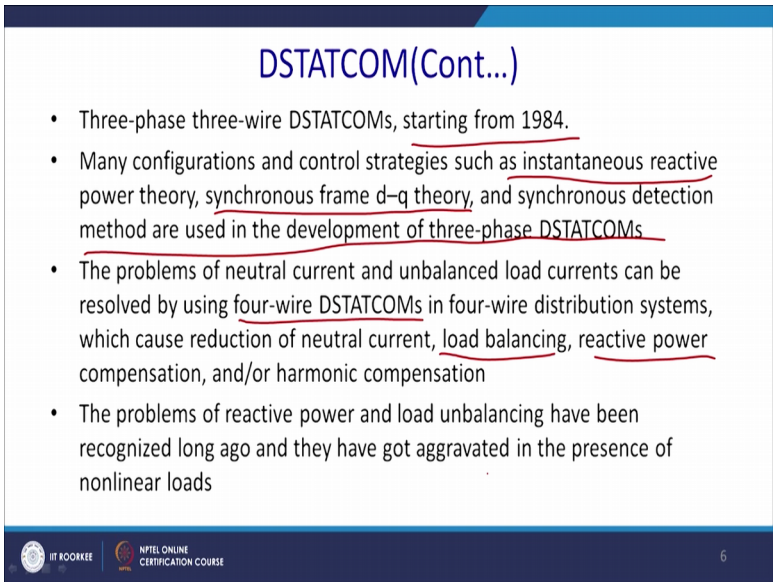

The three-phase three-wire STATCOM where actually reported in 1984 by (Refer Time: 06:02). So, that was a historic configuration that has been reported. Many configuration and the control strategy such as instantaneous reactive power theory this is also proposed by Akagi synchronous frame d-q theory synchronous detections of methods are used, but in development of the three-phase DSTATCOM.

The problem of the neutral current and the unbalanced load can be resolved by using actually four-wire system in case of the three-phase four-wire system or four-wire DSTATCOM in four-wire distribution system, which causes reduction of the neutral current load balancing reactive power compensation and harmonic compensation. The problem of reactive power and the load balancing have been recognized long ago and they have got aggravated in presence of the non-linear loads.

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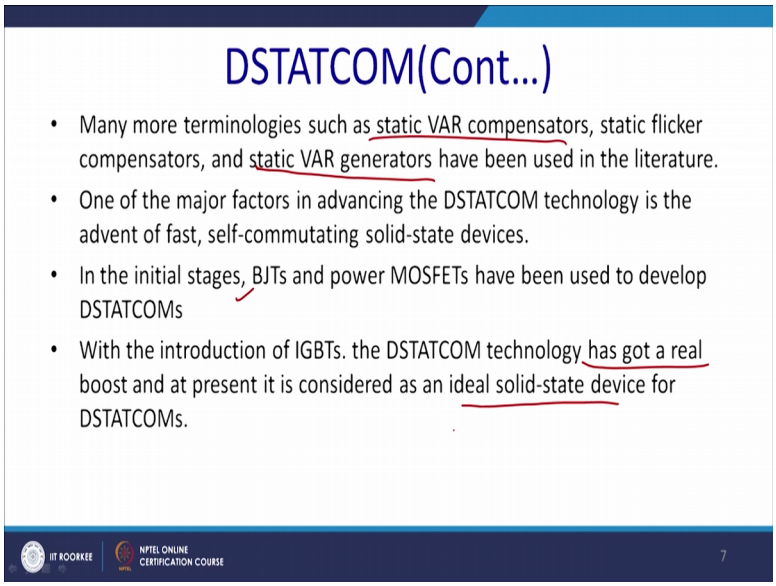

Many more terminologies such as static VAR compensator, static flicker compensator, static VAR generator can be used for the same configuration or the literature. One of the major factor of advancing the DSTATCOM technology is the advents of the fast self computing solid state region because IGBT, mostly IGBT are used in this configuration.

IGBT's are find huge amplification in this configuration. In the initial stages BJT and the power MOSFET has been used to develop the DSTATCOM and with the introduction of IGBT, nowadays IGCT the DSTATCOM technology has been has got a real boost at present and it is considered as a ideal solid state device for the DSTATCOM.

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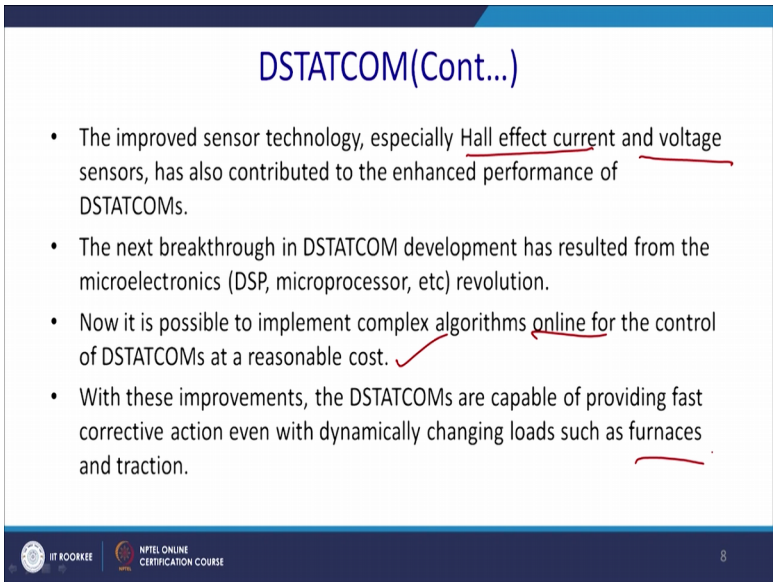

Now, moreover improved sensor technology, especially the Hall effects sensors and the voltage sensors also contributed to the enhance performance of the DSTATCOM. The next breakthrough in the DSTATCOM development has resulted from the microelectronics.

The processor capability has increased drastically, so, DSP microprocessor etcetera and its computing capability; Nowadays a possible to implement the compressed algorithm online for the control of the DSTATCOM at a reasonable cost. With these improvements, the DSTATCOMs are capable of providing corrective action even with dynamically changing loads such as furning or traction, furnaces arc furnaces or the tractions.

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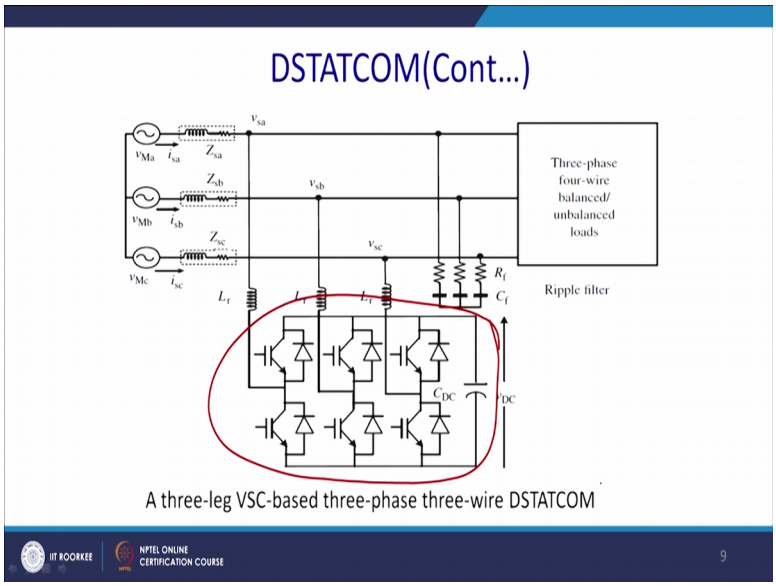

Now, this is the overall configurations of the DSTATCOM. You have three-phase four-wire balanced or unbalanced load and you may be actually fitting with the highly inductive diode based rectifier and this is the your DSTATCOM. So, it is a voltage source current control inverter, this is a three-leg VSC based three-wire DSTATCOM.

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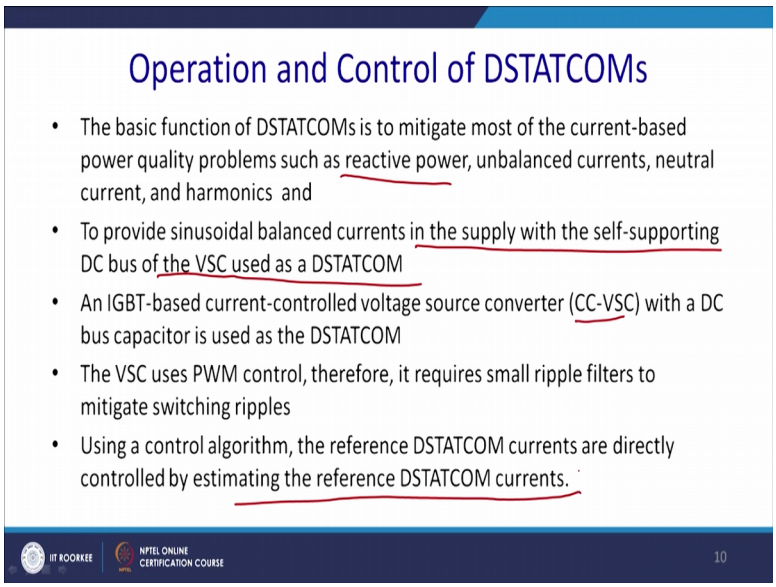

The function of the DSTATCOM is to mitigate the most of the current-based power quality problems such as reactive power, unbalanced power, zero sequent current or the

neutral current and the harmonics. To provide sinusoidal balanced current in the supply with the self supporting DC bus of the VSC used for the DSTATCOM.

An IGBT-based current control voltage source converter CC-VSC with a DC bus capacitor used for the DSTATCOM. The VSC uses PWM control therefore, it requires small ripple filters to mitigate the high frequency switching ripples. Using a control algorithm the reference of the DSTATCOM current are directly controlled and by estimated by the reference of DSTATCOM currents, we shall see that how does it work.

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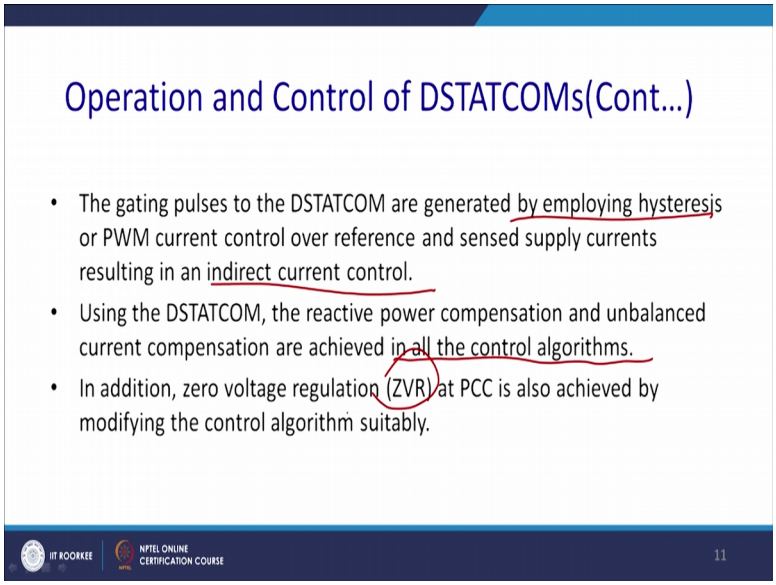

So, the gating pulses of the DSTATCOM are generated by employing the hysteresis or the PWM control over reference and sensed supply current resulting in a indirect current control. Using the DSTATCOM, the reactive power compensation and unbalanced current compensation are achieved in all the control algorithm. In addition, zero voltage regulation ZVR at PCC is also achieved by modifying the control suitably.

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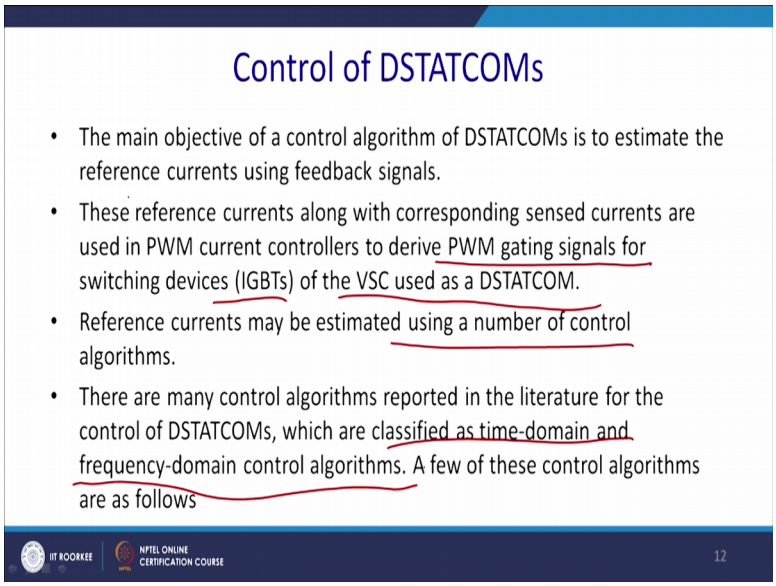

The main objective of the control algorithm of the DSTATCOM is to estimate the reference signal using feedback signals. This reference current along with corresponding sensed currents are used in PWM current control to derive the PWM generating signals for switching device of IGBT of the VSC used in DSTATCOM. The reference current may be estimated by using the number of control algorithm.

There are many control algorithm reported in the literatures for the DSTATCOM, which are classified as time domain and the frequency domain control algorithms. So, we shall see that what kind of actually reference generation technique is available. The few of this control algorithm are as follows. So, we have reported 13, do not consider it as unlucky. So, there are many. So, these are all time domain algorithm.

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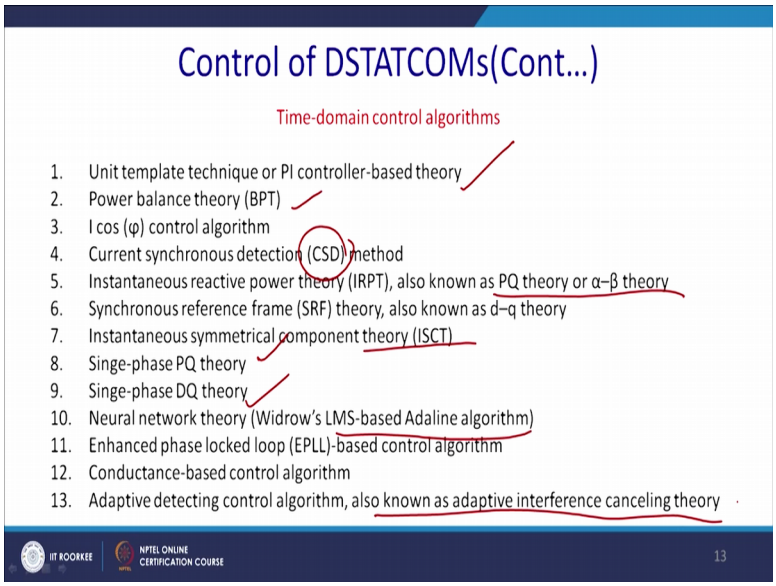

Unit template technique or the PI controlled based theory this is a very simple technique that are power balance theory, that are I cos phi control, current synchronous detections or CSD method instantaneous reactive power theory. This is very important and it is proposed by the legend of this by Akagi, IRPT and is known as the PQ theory of alpha beta theory. Synchronous reference SRF theory known as DQ theory this application first done by Subhasis Bhattacharya I tell for eh investigating shunt active power filter and instantaneous symmetrical component theory ISCT, single phase PQ theory you can extend this three-phase logic to the single phase.

Then it will be a single phase PQ theory, same way you can have a DQ model in single phase and then they are quadrature phase shifted by the quadrature, then you can have a single phase DQ theory neutral net network theory. So, it is an optimization of the weight by the NN. So, Widrow LMS based Adaline algorithm where it can tune online, enhanced phase lock loop based control algorithm.

So, here EPLL actually does the reference generation, conductance based control algorithm; so, we have to actually maximize the conductance, adaptive detection of the control algorithm known as the adaptive reference of the cancelling theory. These are the few technique that are used in the current loop and there are many, but generally we are restricted to actually first six techniques or the three-phase three-wire or four-wire system.

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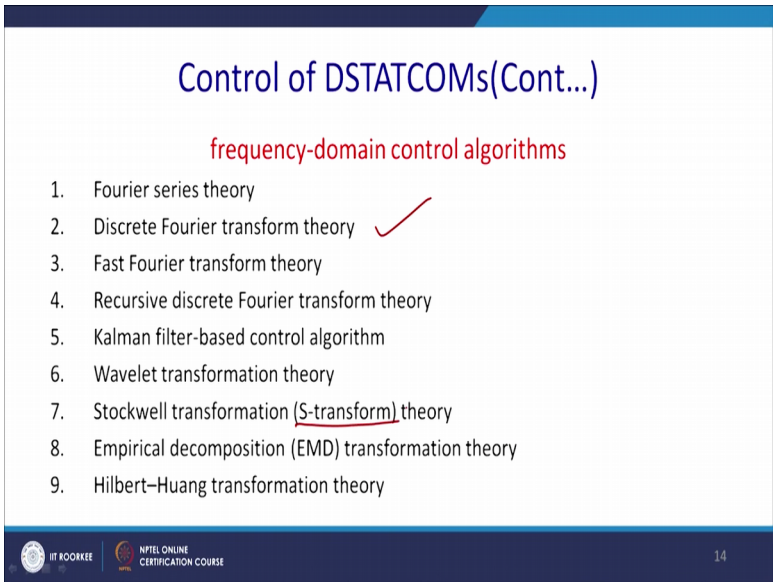

Now, we have frequency domain algorithm. These are Fourier series theory you can actually take a sample and do the FFT and find it out. So, discrete Fourier transform theory DFT. Fast Fourier transform it can compute very fast the components of the fundamentals and you can achieve discrete Fourier transform theory it can actually it can employ the sliding way and thus compute this actually the harmonic components and the other components very fast.

Kalman filter-based control algorithm that is also used in practice and wavelet transformation theory that is well stated now a days, but constant is there and you have to design the mother wavelet very properly then only we can detect the time as well as the ha harmonic content in the wavelet. Stockwell transformation or S-transform theory and empirical decompositions EMD transformation theory, Hillbert-Huang transformation theory these are the few techniques may be used for estimating the reference.

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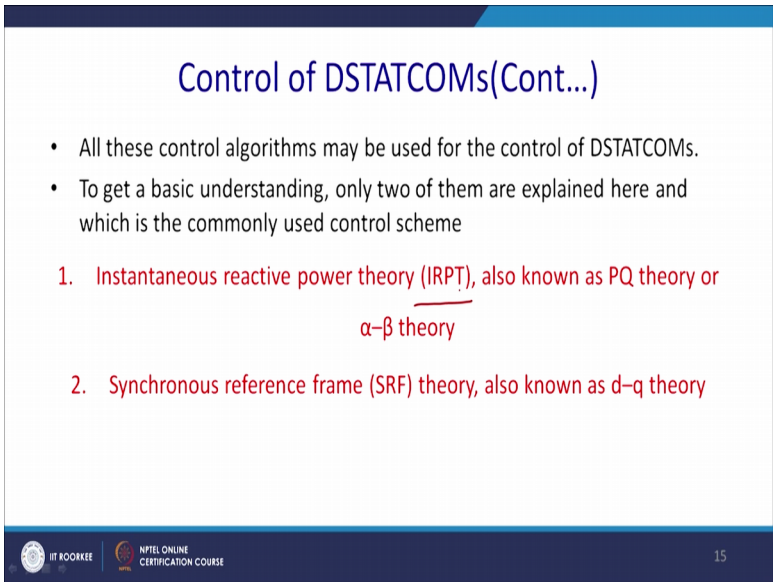

All this control algorithm may be used for the DSTATCOM. So, that is categorical statement to get the basic understanding. Here for the time constant here we shall discuss few important control technique or reference generation technique. Only two of them is explained here which has commonly called instantaneous reactive power or theory or known as PQ theory, it is proposed by Akagi another is another very common theory instantaneous reference from SRS theory known as d-q theory both the theories both these things apply for three-phase three-wire system.

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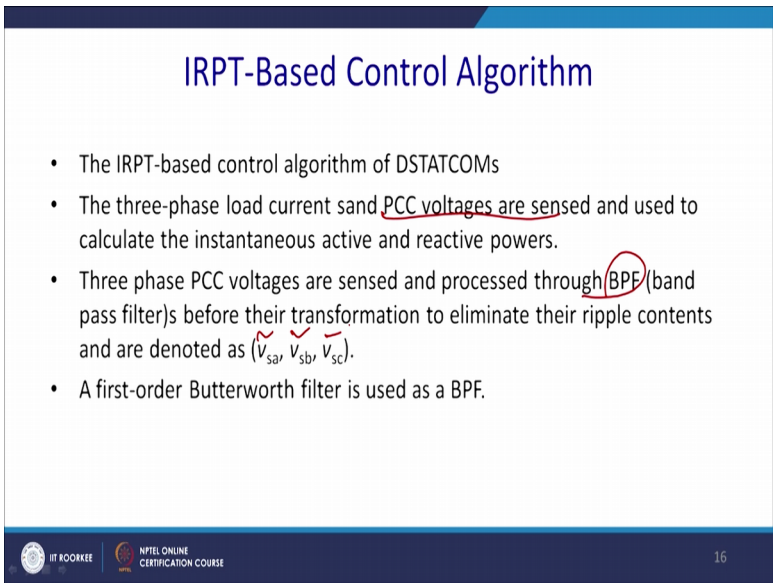

The IRPT based control algorithm of the STATCOM is been designed. The three-phase load currents sent to the sensed PCC at the common problem voltage and used to calculate the instantaneous active and the reactive power. The three-phase PCC voltages sensed are processed through the BPF that is band pass filter generally it is a low pass filter and before their transformation to eliminate their ripple content such as such as denoted by this generally we can use a first order Butterworth filter for BPF.

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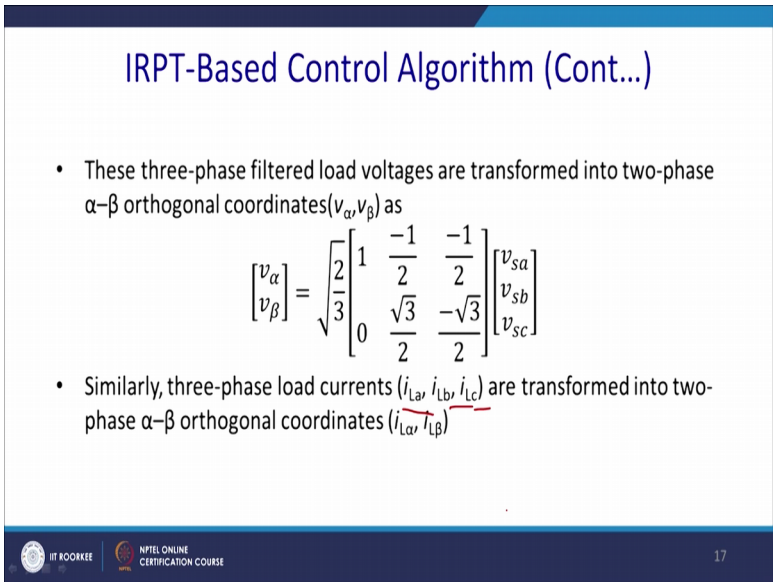

So, we can write down the matrices this three-phase filter load voltage transform into the two-phase alpha beta orthogonal coordinates. So, alpha beta you will you equal to root 2 by 3 and this is the matrix transformation matrix and this is v a, v b, v c. Similarly, we can transform the current this three load current i L, i B and all those things are transformed into the alpha beta pane in i alpha and i beta.

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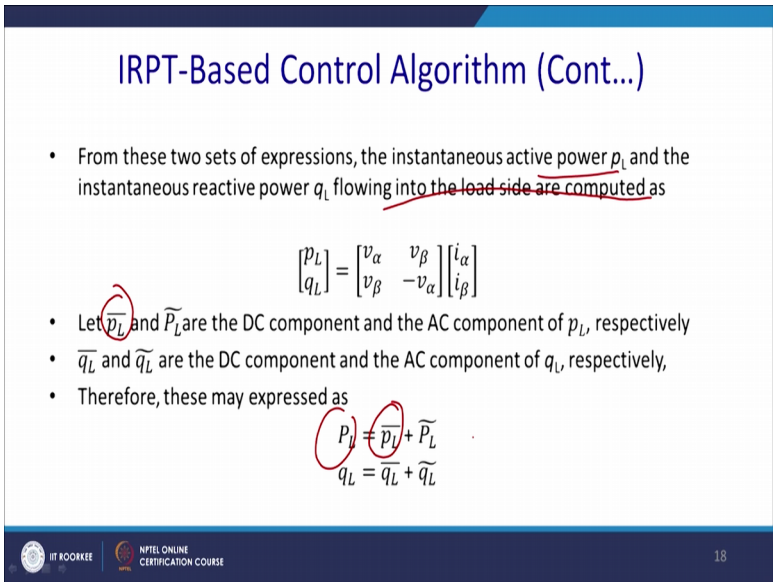

So, thus the i p L and i p q L can be written in this way from this two sets of expression the instantaneous active power p L and the instantaneous reactive power q L flowing into the loads are computed as p L and q L equal to v alpha, v beta and v beta minus v alpha equal to i into i alpha into i beta and this bar stands for the DC value.

If i p L and i P L delta are the DC component and the harmonic component of the p L respectively or the average value or the harmonic component and similarly, q L and the q L delta are the DC component of the of the DC component of the AC component of the reactive power respectively. If then you can write P L equal to that DC value plus the harmonic value of the power real power, similarly q L equal to q L plus q L delta.

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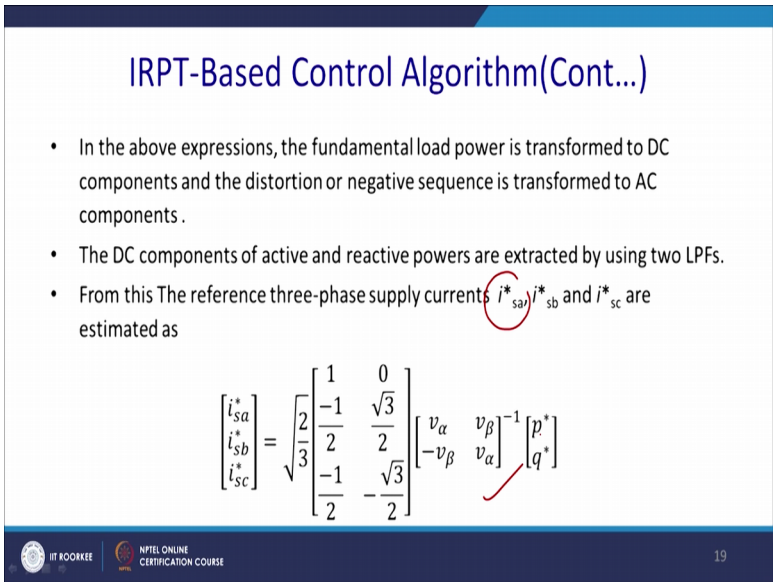

In the above expression the fundamental load power is transformed to the DC component or the negative sequence transformation eh negative sequence is transformed to AC component. The DC component of the active and the reactive power are extracted by LPFs. From this reference three-phase supply current i sa, i sb and i sc are computed. So, i sa, i sb, i sc equal to root 3 by 2 and this is the value of the i p star and the i q star.

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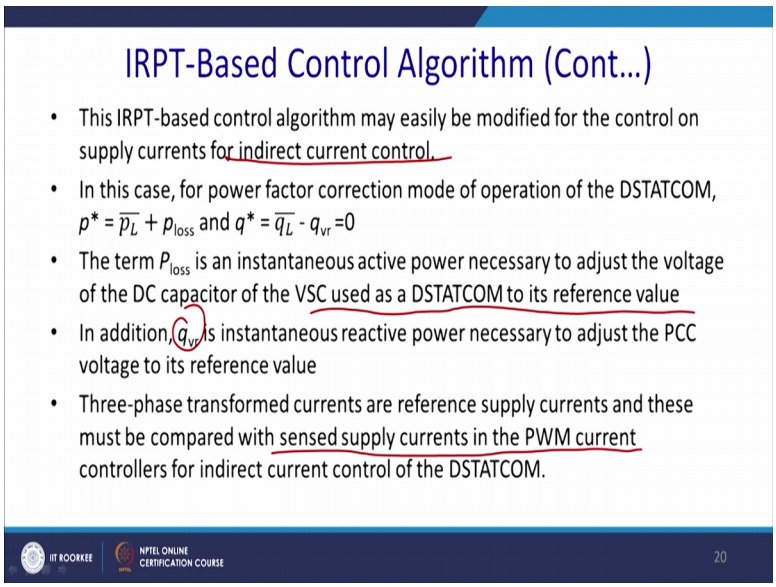

So, what they said IPRF said? This IPRF based control algorithm may be modified for the control on the supply current for indirect current control PI, PI controller based shunt

active power filter or the DSTATCOM has said to be the direct current control. In this case the power factor correction mode of operation of the DSTATCOM is p star equal to p L plus p loss similarly q star equal to q L minus q vr. In terms of the p loss the instantaneous reactive power is essential to adjust the voltage of the DC capacitor of the svc as DSTATCOM to the reference value. In addition q vr is a instantaneous reactive power necessary to adjust the PCC voltage for it is reference value. The phase transform current are reference supply current and this must be compared with the sensed supply current in the PWM current controller for indirect current control of the DSTATCOM.

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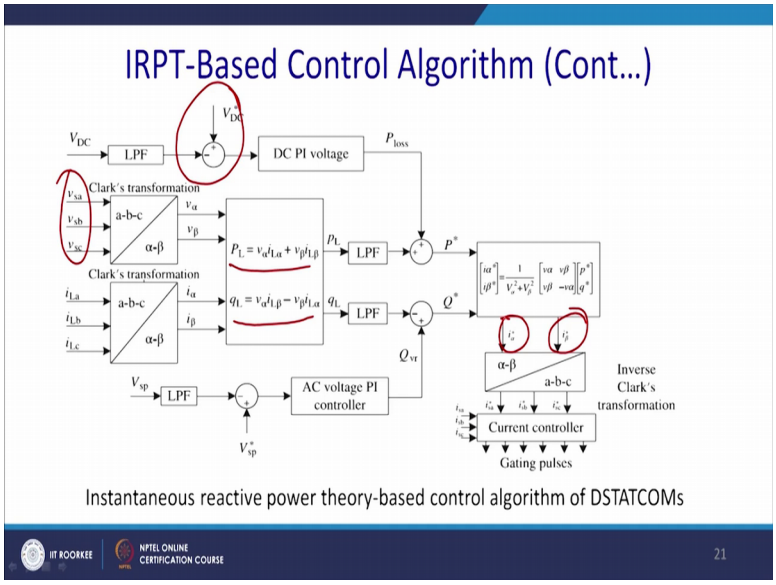

Now, this is the model so, V DC LPF. So, V DC minus so, there is a PI controller that will maintain the DC bus voltage and from there the P loss term will be calculated and you have a current sensors and the voltage sensor appear of the voltage sensors, that will estimate the that will actually sense the voltage and current and that is fit to the Clark's transformer block that is been computed by the microcontroller or DSP based processor online. So, thus v alpha, v beta, i alpha, i beta is been computed from there actually P L and q L is been computed.

So, from there essentially you know you sense the L actually the V at the point of common coupling and v sc star and from there will sense the reactive power. And thus you get a V qr from this matrices basically the reference i alpha and i beta is can computed and you can go back to the three-phase system and alpha beta to a-b-c frame,

the reverse Clark's transformation and you can operate the current control voltage source inverter and by the gating pulses. This is the principle operation of IRPT based control signals.

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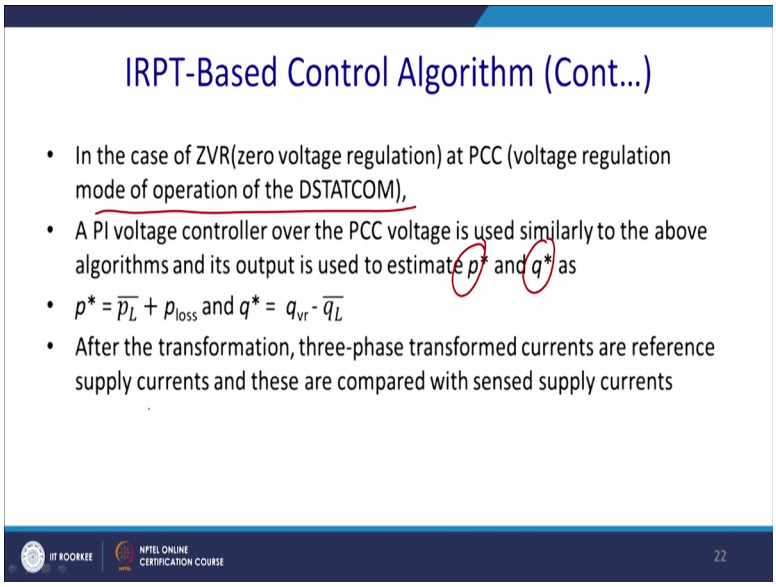

Now, in this case of the ZVR or the zero voltage regulation at PCC, the voltage regulation, mode of operation of the DSTATCOM; A PI voltage controller over the PCC voltage is used similarly to the above algorithm and it is output voltage is used to estimate p star and q star; as p star equal to p L plus p loss and q star equal to q vr minus p L. After transformation this three-phase transform current are the reference supply current and this compare with the sensed supply current.

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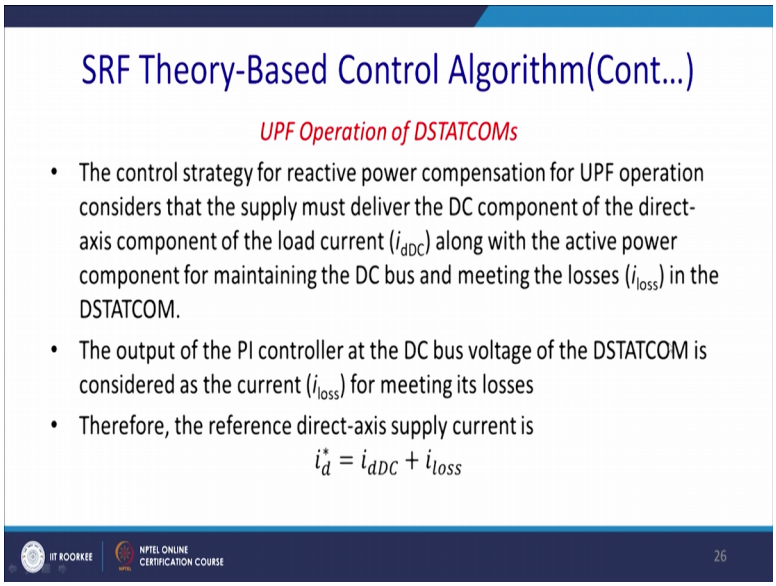

So, SRF theory based control algorithm and we shall discuss now the actually first the unity power factor of operation. In this control strategy the reactive power compensation of the UPF gen operation considered as the supply must be delivered the DC component of the direct access component to the load current i dDc along with the acting component maintaining the DC bus voltage and meeting the losses of the DSTATCOM. The output of the PI controller at the DC bus voltage of the DSTATCOM is considered as the current i loss for meeting the losses. Therefore, the reference current what we have shown previous slide.

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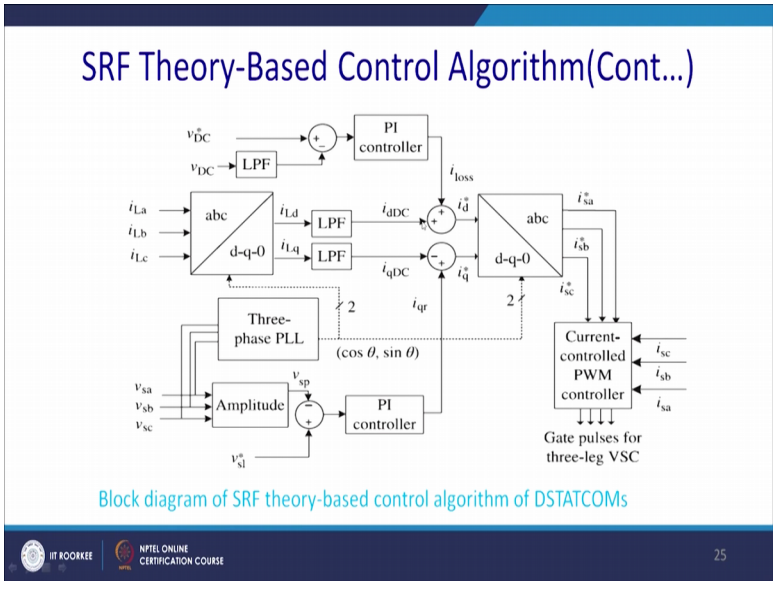

This one is basically I dDc plus the i loss. So, this is the i loss.

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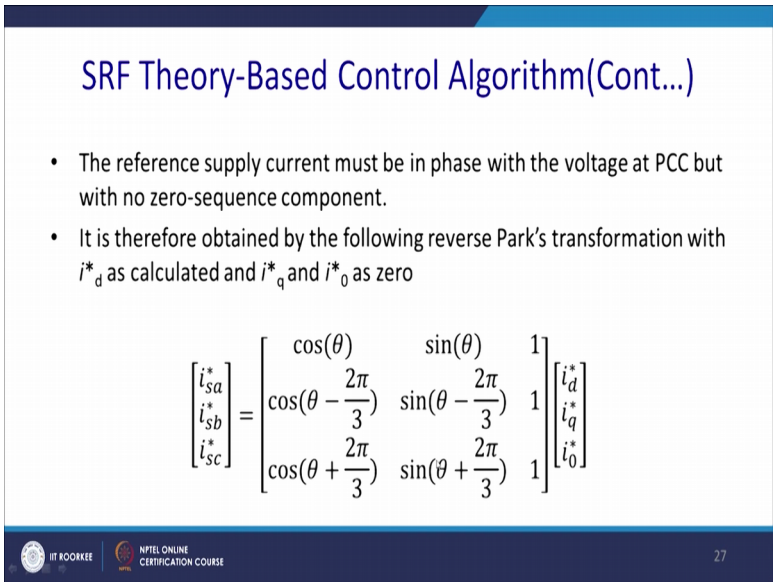

Similarly, same thing is carried out for q axis. Now, actually the reference current supplied must be in phase with the voltage at PCC with a no zero-sequence component, that is the requirement. It is there for obtained by following the reverse Park's transformations and thus we said I i d, i q and as zero. So, we can calculate this reverse Park's transformations and you make i star 0 as zero.

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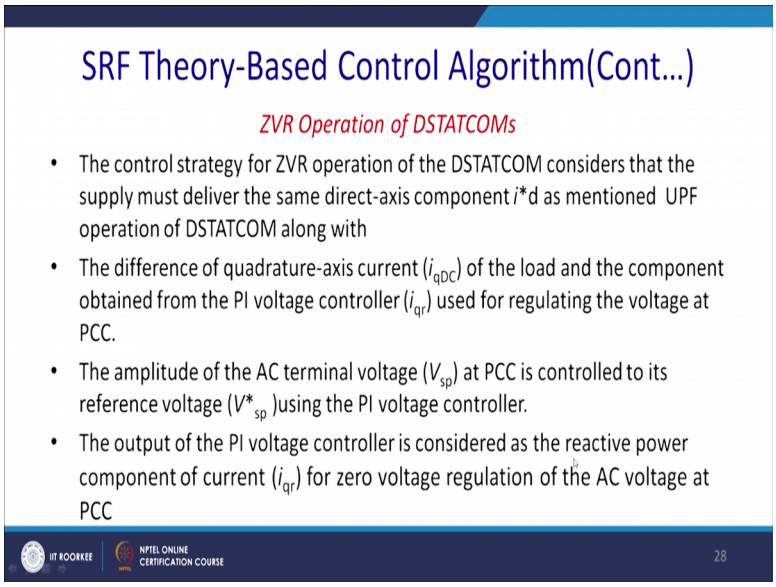

So, there is another operation that is called ZVR operation of the DSTATCOM. This control strategy the operation of the DSTATCOM is considered that the supply must deliver same direct as access component i d as mentioned by actually unity power factor operation of the DSTATCOM. Along with the difference of the quadrature axis i Dqc of the load and the component obtained from the PI controller and i qr used for regulating the voltage and common coupling PCC.

So, both require to be supplied the amplitude of the AC terminal voltage V sp at PCC is controlled to its voltage reference V sp star the PI from the PI controller. The output voltage of the PI controller is considered as a considered as a reactive power component of the co component of the current that is i qr for the zero voltage regulation the AC voltage at the PCC it has to be maintained.

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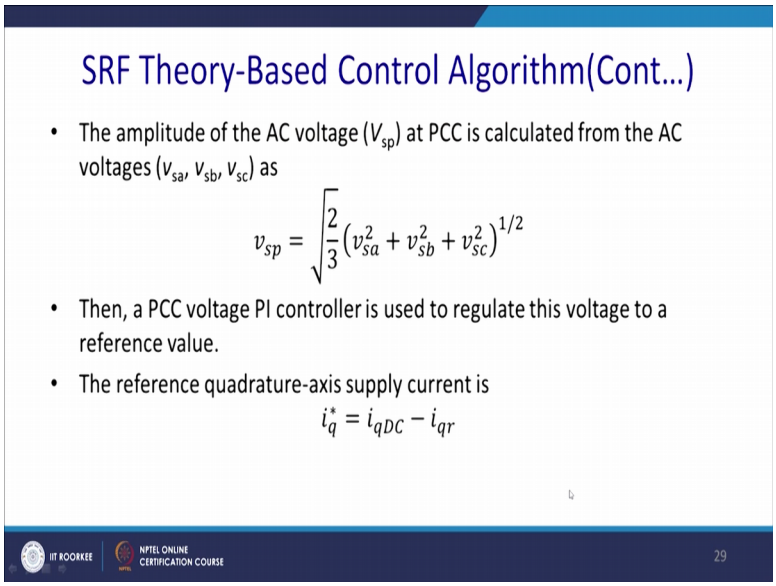

Now, so, we can find it out what should be the amplitude of it by this following equation the amplitude of the V sc at point of common coupling can be calculated in following way, then PCC voltage is controlled controller is used to regulate the voltage at the reference value and thus you can have a calculation of the i q star and i q star is calculated i qDC minus i qr.

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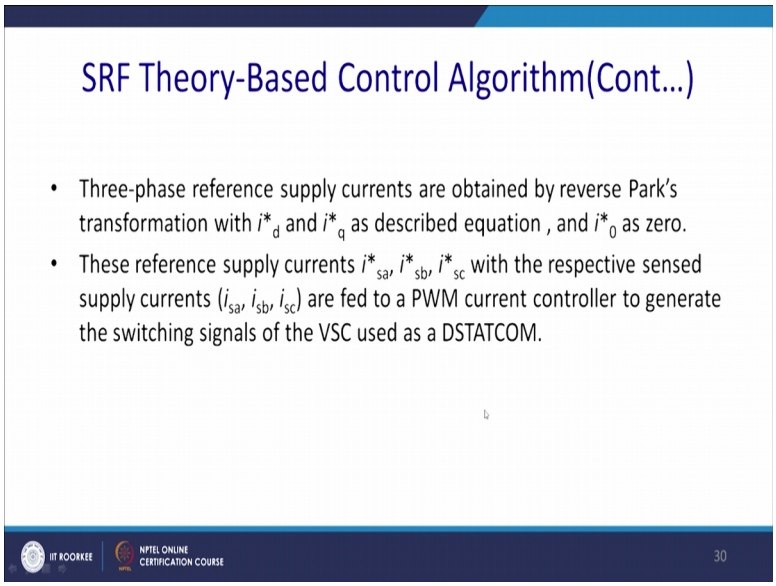

So, the three-phase reference supply current are obtained by the reverse Park's transformation is transmitted to i d star and i q star in the equation and this i q 0 is set to 0, strictly. The reference supply voltage is been calculated from the reverse Park's transformation and it is fed to the current control PWM block to generate the reference current in that way actually we get the switching signal for the current control voltage source inverter or DSTATCOM. So, we will continue with the next class.

Thank you.