

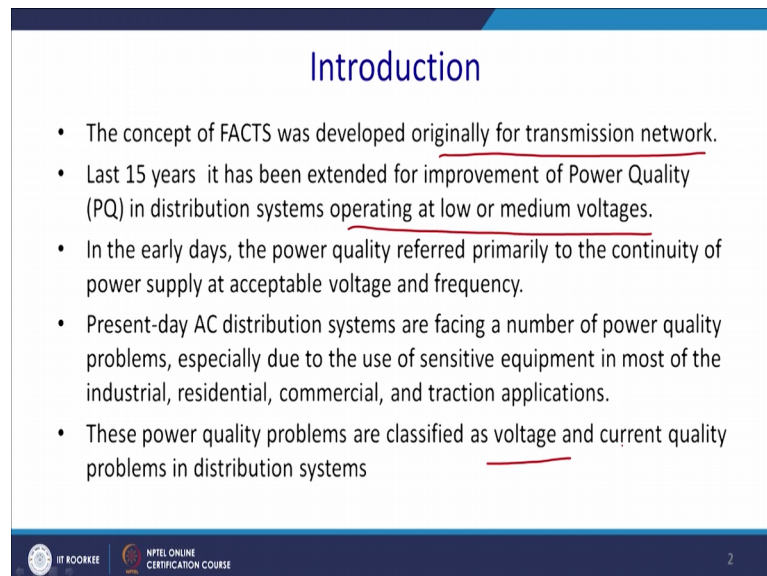
Flexible AC Transmission Systems (FACTS) Devices
Dr. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

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.

(Refer Slide Time: 01:30)



Introduction

- The concept of FACTS was developed originally for transmission network.
- Last 15 years it has been extended for improvement of Power Quality (PQ) in distribution systems operating at low or medium voltages.
- In the early days, the power quality referred primarily to the continuity of power supply at acceptable voltage and frequency.
- Present-day AC distribution systems are facing a number of power quality problems, especially due to the use of sensitive equipment in most of the industrial, residential, commercial, and traction applications.
- These power quality problems are classified as voltage and current quality problems in distribution systems

IIT ROORKEE NPTEL ONLINE CERTIFICATION COURSE 2

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 acceptor 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.

(Refer Slide Time: 02:33)

The slide is titled "Introduction (Cont...)" and contains the following content:

- The nonlinear loads not only cause PQ problems but are also very sensitive to the voltage deviations.
PQ problem is defined as Any problem manifested in voltage, current or frequency deviations that result in failure or miss operation of customer equipment
- STATCOM connecting at distributed system and operating for mitigation of multiple current power quality problems is known as distributed STATCOM (DSTATCOM)
- There are a number of current-based power quality problems such as poor power factor, or poor voltage regulation, current harmonic, unbalanced currents, and increased neutral current

At the bottom of the slide, there are logos for IIT ROORKEE and NPTEL ONLINE CERTIFICATION COURSE, and the number 3 in the bottom right corner.

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.

(Refer Slide Time: 03:49)

DSTATCOM

- The DSTATCOM technology is now a mature technology for providing reactive power compensation, load balancing, and/or neutral current and harmonic current compensation in AC distribution networks
- DSTATCOM also used to regulate the terminal voltage, suppress voltage flicker, and improve voltage balance in three-phase systems
- Classical technology of using power capacitors and static VAR compensators using TCRs and TSCs has been used to mitigate some of these power quality problems.
- But the DSTATCOM technology is considered the best technology to mitigate all the current-based power quality problems

IIT ROORKEE | NPTEL ONLINE CERTIFICATION COURSE | 4

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.

(Refer Slide Time: 04:58)

DSTATCOM(Cont...)

- DSTATCOMs are basically categorized into three types,
 1. Single-phase two-wire ✓
 2. Three-phase three-wire ✓
 3. Three-phase four-wire configurations ✓
- Single-phase two-wire DSTATCOMs have been investigated in varying configurations and control strategies to meet the needs of single-phase systems ✓
- Both current source converters (CSCs) with inductive energy storage and voltage source converters (VSCs) with capacitive energy storage are used to develop DSTATCOMs.

IIT ROORKEE NPTEL ONLINE CERTIFICATION COURSE 5

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.

(Refer Slide Time: 05:56)

DSTATCOM(Cont...)

- Three-phase three-wire DSTATCOMs, starting from 1984.
- Many configurations and control strategies such as instantaneous reactive power theory, synchronous frame d-q theory, and synchronous detection method are used in the development of three-phase DSTATCOMs.
- The problems of neutral current and unbalanced load currents can be resolved by using four-wire DSTATCOMs in four-wire distribution systems, which cause reduction of neutral current, load balancing, reactive power compensation, and/or harmonic compensation.
- The problems of reactive power and load unbalancing have been recognized long ago and they have got aggravated in the presence of nonlinear loads.

IIT ROORKEE | NIEL ONLINE CERTIFICATION COURSE | 6

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.

(Refer Slide Time: 07:06)

DSTATCOM(Cont...)

- Many more terminologies such as static VAR compensators, static flicker compensators, and static VAR generators have been used in the literature.
- One of the major factors in advancing the DSTATCOM technology is the advent of fast, self-commutating solid-state devices.
- In the initial stages, BJTs and power MOSFETs have been used to develop DSTATCOMs
- With the introduction of IGBTs, the DSTATCOM technology has got a real boost and at present it is considered as an ideal solid-state device for DSTATCOMs.

IIT ROORKEE NPTEL ONLINE CERTIFICATION COURSE 7

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.

(Refer Slide Time: 08:05)

DSTATCOM(Cont...)

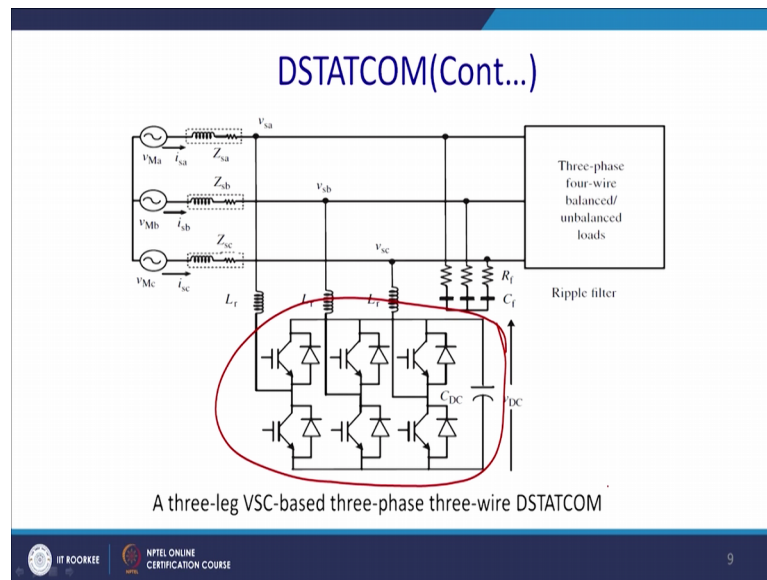
- The improved sensor technology, especially Hall effect current and voltage sensors, has also contributed to the enhanced performance of DSTATCOMs.
- The next breakthrough in DSTATCOM development has resulted from the microelectronics (DSP, microprocessor, etc) revolution.
- Now it is possible to implement complex algorithms online for the control of DSTATCOMs at a reasonable cost.
- With these improvements, the DSTATCOMs are capable of providing fast corrective action even with dynamically changing loads such as furnaces and traction.

IIT ROORKEE | NPTEL ONLINE CERTIFICATION COURSE 8

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.

(Refer Slide Time: 09:04)



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.

(Refer Slide Time: 09:47)

Operation and Control of DSTATCOMs

- The basic function of DSTATCOMs is to mitigate most of the current-based power quality problems such as reactive power, unbalanced currents, neutral current, and harmonics and
- To provide sinusoidal balanced currents in the supply with the self-supporting DC bus of the VSC used as a DSTATCOM
- An IGBT-based current-controlled voltage source converter (CC-VSC) with a DC bus capacitor is used as the DSTATCOM
- The VSC uses PWM control, therefore, it requires small ripple filters to mitigate switching ripples
- Using a control algorithm, the reference DSTATCOM currents are directly controlled by estimating the reference DSTATCOM currents.

IIT ROORKEE NPTEL ONLINE CERTIFICATION COURSE 10

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.

(Refer Slide Time: 10:50)

Operation and Control of DSTATCOMs(Cont...)

- The gating pulses to the DSTATCOM are generated by employing hysteresis or PWM current control over reference and sensed supply currents resulting in an indirect current control.
- Using the DSTATCOM, the reactive power compensation and unbalanced current compensation are achieved in all the control algorithms.
- In addition, zero voltage regulation (ZVR) at PCC is also achieved by modifying the control algorithm suitably.

IIT ROORKEE NPTEL ONLINE CERTIFICATION COURSE 11

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.

(Refer Slide Time: 11:37)

Control of DSTATCOMs

- The main objective of a control algorithm of DSTATCOMs is to estimate the reference currents using feedback signals.
- These reference currents along with corresponding sensed currents are used in PWM current controllers to derive PWM gating signals for switching devices (IGBTs) of the VSC used as a DSTATCOM.
- Reference currents may be estimated using a number of control algorithms.
- There are many control algorithms reported in the literature for the control of DSTATCOMs, which are classified as time-domain and frequency-domain control algorithms. A few of these control algorithms are as follows

IIT ROORKEE NIEL ONLINE CERTIFICATION COURSE 12

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.

(Refer Slide Time: 12:49)

Control of DSTATCOMs(Cont..)

Time-domain control algorithms

1. Unit template technique or PI controller-based theory ✓
2. Power balance theory (BPT) ✓
3. $I \cos(\varphi)$ control algorithm
4. Current synchronous detection (CSD) method
5. Instantaneous reactive power theory (IRPT), also known as PQ theory or α - β theory
6. Synchronous reference frame (SRF) theory, also known as d-q theory
7. Instantaneous symmetrical component theory (ISCT)
8. Single-phase PQ theory ✓
9. Single-phase DQ theory ✓
10. Neural network theory (Widrow's LMS-based Adaline algorithm)
11. Enhanced phase locked loop (EPLL)-based control algorithm
12. Conductance-based control algorithm
13. Adaptive detecting control algorithm, also known as adaptive interference canceling theory

IIT ROORKEE | NIEL ONLINE CERTIFICATION COURSE | 13

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.

(Refer Slide Time: 15:07)

The slide is titled "Control of DSTATCOMs(Cont...)" in blue text. Below the title, the subtitle "frequency-domain control algorithms" is written in red. A list of nine items follows, with a red checkmark next to the second item. The items are: 1. Fourier series theory, 2. Discrete Fourier transform theory ✓, 3. Fast Fourier transform theory, 4. Recursive discrete Fourier transform theory, 5. Kalman filter-based control algorithm, 6. Wavelet transformation theory, 7. Stockwell transformation (S-transform) theory, 8. Empirical decomposition (EMD) transformation theory, and 9. Hilbert–Huang transformation theory. At the bottom left, there are logos for IIT ROORKEE and NPTEL ONLINE CERTIFICATION COURSE. The number 14 is in the bottom right corner.

Control of DSTATCOMs(Cont...)

frequency-domain control algorithms

1. Fourier series theory
2. Discrete Fourier transform theory ✓
3. Fast Fourier transform theory
4. Recursive discrete Fourier transform theory
5. Kalman filter-based control algorithm
6. Wavelet transformation theory
7. Stockwell transformation (S-transform) theory
8. Empirical decomposition (EMD) transformation theory
9. Hilbert–Huang transformation theory

IIT ROORKEE NPTEL ONLINE CERTIFICATION COURSE 14

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 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.

(Refer Slide Time: 16:30)

Control of DSTATCOMs(Cont...)

- All these control algorithms may be used for the control of DSTATCOMs.
- To get a basic understanding, only two of them are explained here and which is the commonly used control scheme

1. Instantaneous reactive power theory (IRPT), also known as PQ theory or α - β theory
2. Synchronous reference frame (SRF) theory, also known as d-q theory

IIT ROORKEE | NPTEL ONLINE CERTIFICATION COURSE 15

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.

(Refer Slide Time: 17:20)

IRPT-Based Control Algorithm

- The IRPT-based control algorithm of DSTATCOMs
- The three-phase load current and PCC voltages are sensed and used to calculate the instantaneous active and reactive powers.
- Three phase PCC voltages are sensed and processed through BPF (band pass filter)s before their transformation to eliminate their ripple contents and are denoted as $(\vec{v}_{sa}, \vec{v}_{sb}, \vec{v}_{sc})$.
- A first-order Butterworth filter is used as a BPF.

IIT ROORKEE | NPTEL ONLINE CERTIFICATION COURSE 16



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.

(Refer Slide Time: 18:03)

IRPT-Based Control Algorithm (Cont...)

- These three-phase filtered load voltages are transformed into two-phase α - β orthogonal coordinates (v_α, v_β) as

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix}$$
- Similarly, three-phase load currents (i_{La}, i_{Lb}, i_{Lc}) are transformed into two-phase α - β orthogonal coordinates ($i_{L\alpha}, i_{L\beta}$)



17

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.

(Refer Slide Time: 18:30)

IRPT-Based Control Algorithm (Cont...)

- From these two sets of expressions, the instantaneous active power p_L and the instantaneous reactive power q_L flowing into the load side are computed as

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

- Let $\overline{p_L}$ and $\widetilde{p_L}$ are the DC component and the AC component of p_L , respectively
- $\overline{q_L}$ and $\widetilde{q_L}$ are the DC component and the AC component of q_L , respectively,
- Therefore, these may expressed as

$$\begin{aligned} p_L &= \overline{p_L} + \widetilde{p_L} \\ q_L &= \overline{q_L} + \widetilde{q_L} \end{aligned}$$

IIT ROORKEE NIEL ONLINE CERTIFICATION COURSE 18

So, thus the $i p_L$ and $i q_L$ 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_α , v_β and v_β minus v_α equal to i_α into i_β 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 $q_L \Delta$.

(Refer Slide Time: 19:46)

IRPT-Based Control Algorithm(Cont...)

- In the above expressions, the fundamental load power is transformed to DC components and the distortion or negative sequence is transformed to AC components .
- The DC components of active and reactive powers are extracted by using two LPFs.
- From this The reference three-phase supply currents i_{sa}^* , i_{sb}^* and i_{sc}^* are estimated as

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1 & \sqrt{3} \\ 2 & 2 \\ -1 & -\sqrt{3} \\ 2 & -2 \end{bmatrix} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p^* \\ q^* \end{bmatrix}$$





19

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 $\frac{\sqrt{3}}{2}$ and this is the value of the i_p star and the i_q star.

(Refer Slide Time: 20:33)

IRPT-Based Control Algorithm (Cont...)

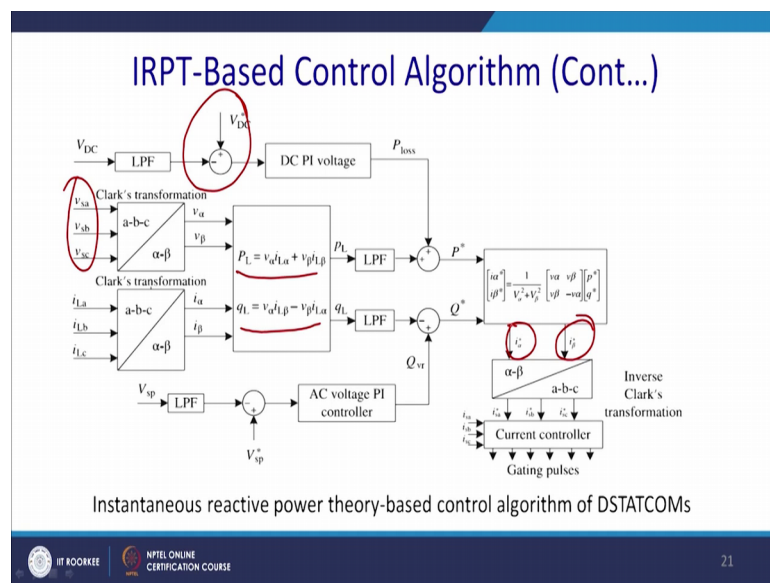
- This IRPT-based control algorithm may easily be modified for the control on supply currents for indirect current control.
- In this case, for power factor correction mode of operation of the DSTATCOM, $p^* = \overline{p}_L + p_{loss}$ and $q^* = \overline{q}_L - q_{vr} = 0$
- The term p_{loss} is an instantaneous active power necessary to adjust the voltage of the DC capacitor of the VSC used as a DSTATCOM to its reference value
- In addition, q_{vr} is instantaneous reactive power necessary to adjust the PCC voltage to its reference value
- Three-phase transformed currents are reference supply currents and these must be compared with sensed supply currents in the PWM current controllers for indirect current control of the DSTATCOM.



20

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.

(Refer Slide Time: 21:37)

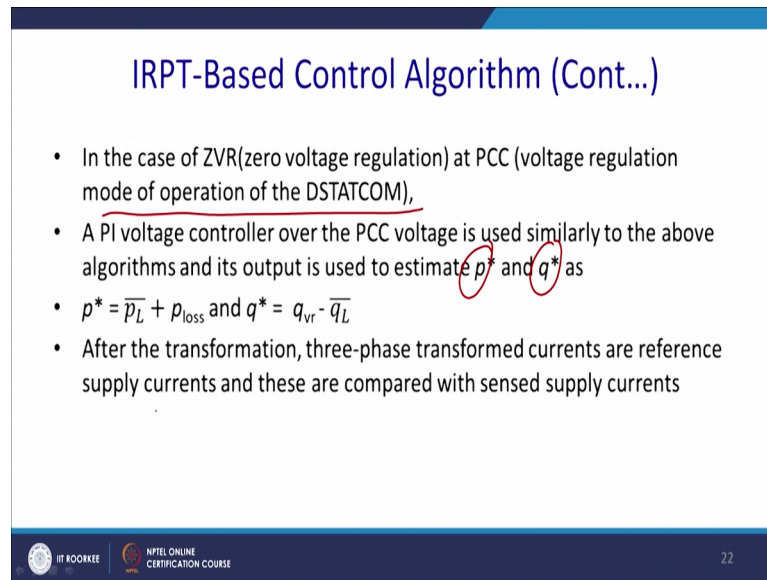


Now, this is the model so, V DC LPF. So, V DC minus so, there is a PI controller that will maintain the DC bus voltage and from there the P loss term will be calculated and you have a current sensors and the voltage sensor appear of the voltage sensors, that will estimate the that will actually sense 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.

(Refer Slide Time: 23:16)



The slide is titled "IRPT-Based Control Algorithm (Cont...)" in blue text. It contains four bullet points. The first bullet point is underlined in red. The second and third bullet points have red circles around the terms p^* and q^* . The footer contains logos for IIT Roorkee and NPTEL Online Certification Course, along with the slide number 22.

IRPT-Based Control Algorithm (Cont...)

- In the case of ZVR(zero voltage regulation) at PCC (voltage regulation mode of operation of the DSTATCOM),
- A PI voltage controller over the PCC voltage is used similarly to the above algorithms and its output is used to estimate p^* and q^* as
- $p^* = \overline{p_L} + p_{\text{loss}}$ and $q^* = q_{vr} - \overline{q_L}$
- After the transformation, three-phase transformed currents are reference supply currents and these are compared with sensed supply currents

IIT ROORKEE NPTEL ONLINE CERTIFICATION COURSE 22

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 its output voltage is used to estimate p^* and q^* ; as p^* equal to p_L plus p_{loss} and q^* 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.



(Refer Slide Time: 23:51)

SRF Theory-Based Control Algorithm(Cont...)

UPF Operation of DSTATCOMs

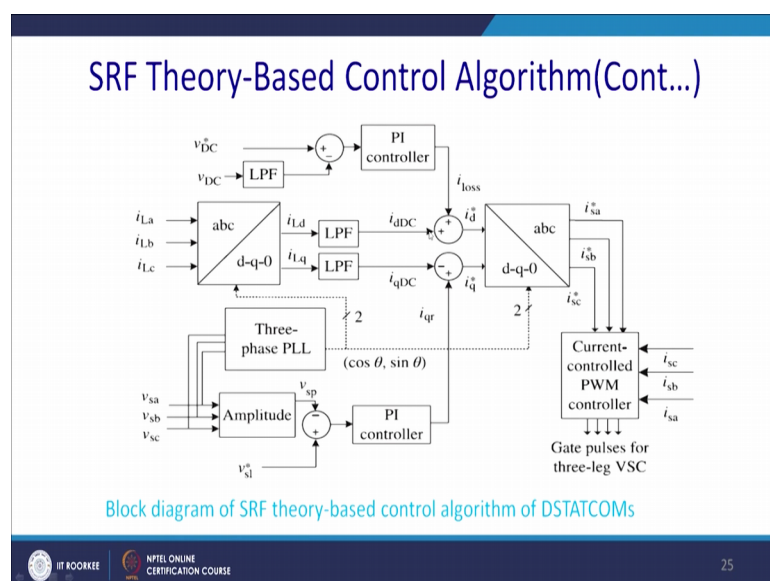
- The control strategy for reactive power compensation for UPF operation considers that the supply must deliver the DC component of the direct-axis component of the load current (i_{dDC}) along with the active power component for maintaining the DC bus and meeting the losses (i_{loss}) in the DSTATCOM.
- The output of the PI controller at the DC bus voltage of the DSTATCOM is considered as the current (i_{loss}) for meeting its losses
- Therefore, the reference direct-axis supply current is

$$i_d^* = i_{dDC} + i_{loss}$$



26

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.

(Refer Slide Time: 24:38)





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

(Refer Slide Time: 24:46)

SRF Theory-Based Control Algorithm(Cont...)

- The reference supply current must be in phase with the voltage at PCC but with no zero-sequence component.
- It is therefore obtained by the following reverse Park's transformation with i_d^* as calculated and i_q^* and i_0^* as zero

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 1 \\ \cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & 1 \\ \cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \\ i_0^* \end{bmatrix}$$



27



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.

(Refer Slide Time: 25:29)

SRF Theory-Based Control Algorithm(Cont...)

ZVR Operation of DSTATCOMs

- The control strategy for ZVR operation of the DSTATCOM considers that the supply must deliver the same direct-axis component i_d^* as mentioned UPF operation of DSTATCOM along with
- The difference of quadrature-axis current (i_{qDC}) of the load and the component obtained from the PI voltage controller (i_{qr}) used for regulating the voltage at PCC.
- The amplitude of the AC terminal voltage (V_{sp}) at PCC is controlled to its reference voltage (V_{sp}^*) using the PI voltage controller.
- The output of the PI voltage controller is considered as the reactive power component of current (i_{qr}) for zero voltage regulation of the AC voltage at PCC



28

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_{Dq} 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 q component of the current that is i_{qr} for the zero voltage regulation the AC voltage at the PCC it has to be maintained.

(Refer Slide Time: 26:36)

SRF Theory-Based Control Algorithm(Cont...)

- The amplitude of the AC voltage (V_{sp}) at PCC is calculated from the AC voltages (v_{sa} , v_{sb} , v_{sc}) as

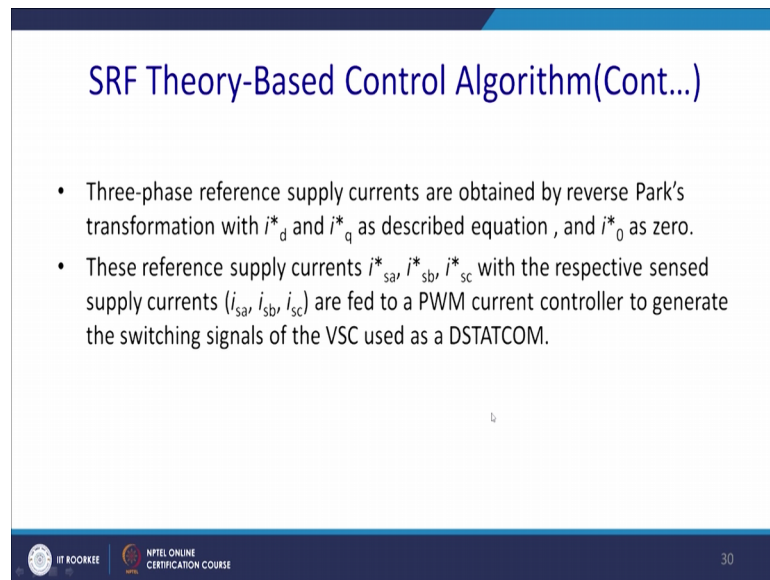
$$v_{sp} = \sqrt{\frac{2}{3}(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)^{1/2}}$$
- Then, a PCC voltage PI controller is used to regulate this voltage to a reference value.
- The reference quadrature-axis supply current is

$$i_q^* = i_{qDC} - i_{qr}$$

IIT ROORKEE | NPTEL ONLINE CERTIFICATION COURSE | 29

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 $i_{q\text{ star}}$ and $i_{q\text{ star}}$ is calculated i_{qDC} minus i_{qr} .

(Refer Slide Time: 27:06)



SRF Theory-Based Control Algorithm(Cont...)

- Three-phase reference supply currents are obtained by reverse Park's transformation with i_d^* and i_q^* as described equation, and i_0^* as zero.
- These reference supply currents i_{sa}^* , i_{sb}^* , i_{sc}^* with the respective sensed supply currents (i_{sa} , i_{sb} , i_{sc}) are fed to a PWM current controller to generate the switching signals of the VSC used as a DSTATCOM.

30

So, the three-phase reference supply current are obtained by the reverse Park's transformation is transmitted to i_d^* and i_q^* in the equation and this i_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.