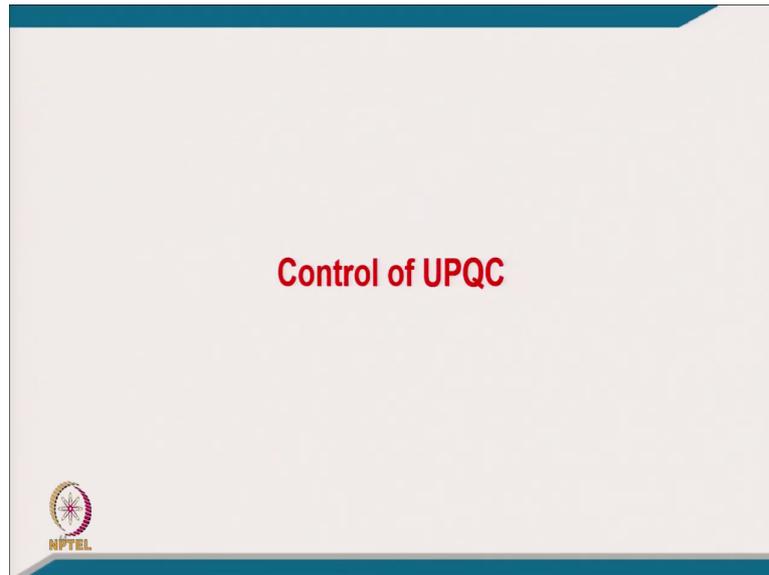


Power Quality
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Lecture - 13
Unified Power Quality Compensators (contd.)

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Welcome to the course on Power Quality and we will like to discuss today control of Unified Power Quality Compensators.

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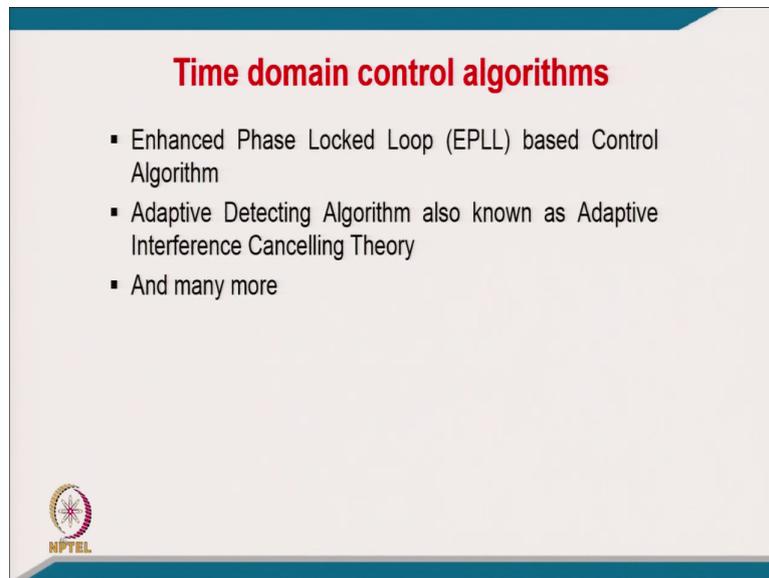
Time domain control algorithms

- Synchronous Reference Frame (SRF) Theory, also known as d-q Theory
- Unit Template Technique or PI (Proportional-Integral) Controller Based Theory
- Instantaneous Reactive Power Theory (IRPT), also known as PQ Theory or α - β Theory
- Instantaneous Symmetrical Component (ISC) Theory
- Neural Network Theory (Widrow Derived LMS based Adaline Algorithm)
- Single-Phase PQ Theory
- Single-Phase DQ Theory



Well, we have a control technique based on two classification, one is time domain control algorithms which are typically like a famous algorithm have been synchronous reference frame theory also known d-q theory, then unit template or PI control; PI controller based theory and instantaneous reactive power theory also known PQ theory or alpha-beta theory, then instantaneous symmetrical component theory, then neural network theory, widrow derived LMS algorithms and single-phase PQ theory, single-phase DQ theory.

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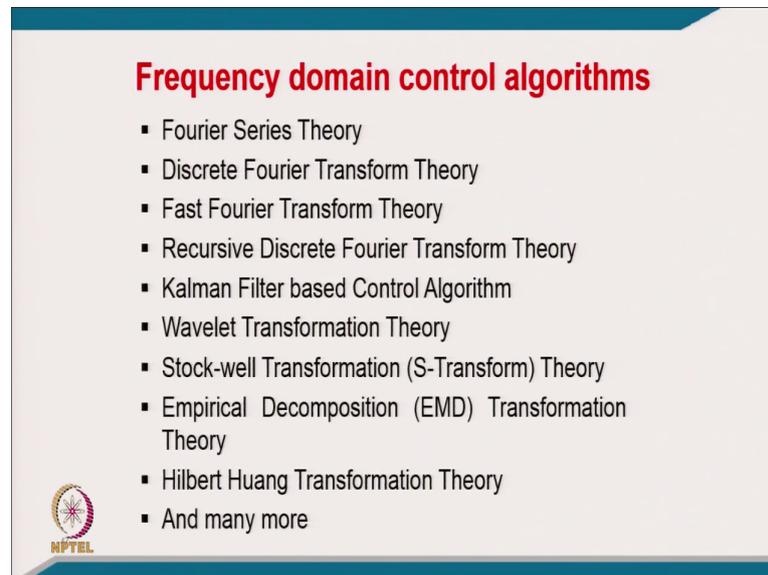
Time domain control algorithms

- Enhanced Phase Locked Loop (EPLL) based Control Algorithm
- Adaptive Detecting Algorithm also known as Adaptive Interference Cancelling Theory
- And many more

 NPTEL

Then, enhanced phase locked loop-based control algorithm, then adaptive detecting algorithm also known as a typically adaptive interference cancelling theory and many more. There are plenty of algorithm which are I mean available and are used for this typically for the control of UPQC like. These are time domain control algorithm.

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Frequency domain control algorithms

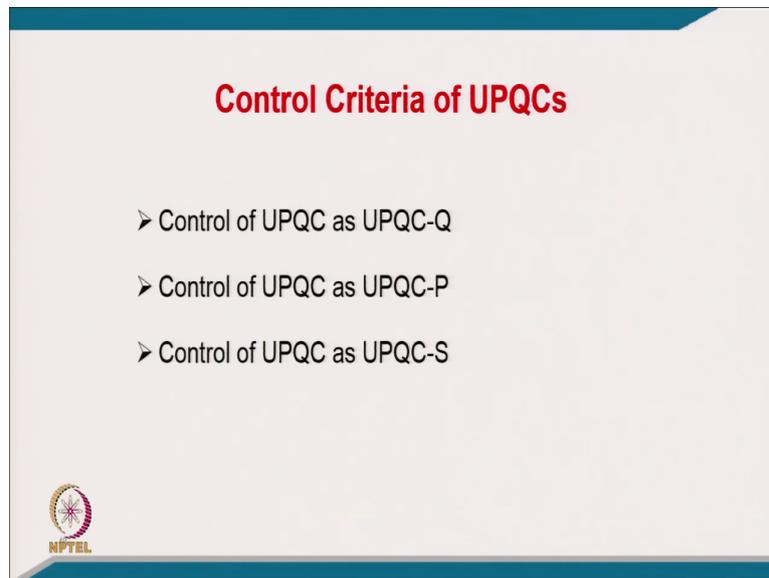
- Fourier Series Theory
- Discrete Fourier Transform Theory
- Fast Fourier Transform Theory
- Recursive Discrete Fourier Transform Theory
- Kalman Filter based Control Algorithm
- Wavelet Transformation Theory
- Stock-well Transformation (S-Transform) Theory
- Empirical Decomposition (EMD) Transformation Theory
- Hilbert Huang Transformation Theory
- And many more



There is a another set of algorithm which we call it frequency domain algorithm, they work like a Fourier series theory and discrete Fourier transform theory, then fast Fourier transform theory, recursive discrete Fourier transform theory, Kalman filter based control theory, wavelet transformation theory and stock-well transform, S-transform theory, the empirical decomposition transformation theory and Hilbert Huang transformation theory and many more like.

[FL] there are so many control algorithm which can be used for this UPQC.

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And coming to let us say control of UPQC, as a UPQC-Q control of UPQC as a UPQC-P which you discuss in previous lecture and control of UPQC-S like.

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Control of UPQC as UPQC-Q

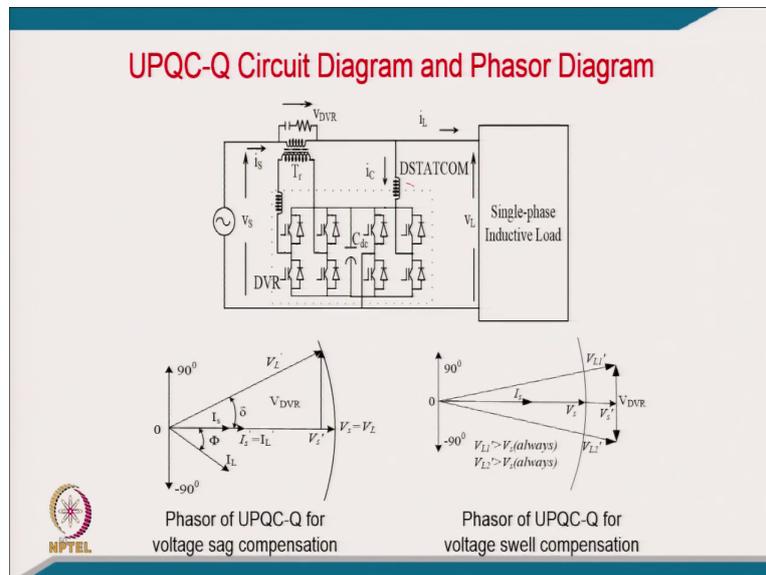
- In this mode, a DVR is used mainly for reactive power (Q) injection for fundamental voltage compensation.
- In UPQC-Q mode of operation, the DVR can not compensate for voltage swell.
- It is considered that DSTATCOM is compensating the reactive of the consumer load, of course a unity power factor is realized at the PCC and total reactive power of the system is compensated by DSTATCOM.
- Moreover, DVR is injecting a voltage at the quadrature with the ac mains current.
- In the case of voltage sag compensation also there is limitation of sag compensation depending upon the voltage rating of the DVR.



Well, coming to UPQC-Q, in this mode, a DVR is used mainly for reactive power injection for fundamental voltage compensation. In UPQC mode of operation, the DVR cannot compensate for voltage swell, and it is considered that the DSTATCOM is compensating the reactive power of the this consumer load, of course a unity power factor is realized at PCC and total reactive power of the system is compensated by the DSTATCOM.

Moreover, DVR is injecting a voltage at the quadrature with the ac mains current and in case of voltage sag compensation is there is a limitations of sag compensation depending upon the voltage rating of the DVR.

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These are typically you can think about in UPQC-Q that in a right-hand, UPQC means DSTATCOM on right-hand [FL] it can do sag compensation, but it cannot do swell compensation as you can see here, it is not cutting, it is not possible like in case of [FL] this is the limitation for this control algorithm that we cannot compensate the swell in this case like I mean or so.

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- The pu voltage sag can be expressed as,
$$X = \frac{V_{LC} - \sqrt{V_{LC}^2 - V_{DVR}^2}}{V_{LC}} \quad (1)$$
- where X is percentage of voltage sag for the compensation, V_{DVR} is the injected voltage by the DVR and V_{LC} is the load voltage after the compensation normally it is the rated load voltage or rated PCC voltage.
- The rating calculation of both DVR and DSTATCOM may be done from phasor diagram as follows.
- The injected voltage by the DVR is as,
$$V_{inj} = \sqrt{V_{LC}^2 - V_s^2} \quad (2)$$
- The VA rating of the DVR is as,
$$S_{DVR} = V_{inj} I_s = V_s I_L \cos \phi \tan \delta \quad (3)$$



And the rating as far as for voltage sag compensation, you can calculate the load voltage minus the under root this $V_{LC}^2 - V_{DVR}^2$ upon V_{LC} that is the kind of per unit voltage sag can be expressed which we can compensate depending upon the rating of the DVR and X is the percentage of voltage sag for the compensation and V_{DVR} is the injected voltage by the DVR and V_{LC} is the load voltage after the compensation normally, it is rated for load voltage or the rated PCC voltage.

[FL] rating calculation for both DVR and DSTATCOM may be done from phasor diagram as follows. [FL] the injected voltage by the DVR is now, $\sqrt{V_{LC}^2 - V_s^2}$ under root that that is the because we are injecting at the quadrature, that is the relation come for V in injected voltage and VA rating of the DVR comes is equal to $V_{inj} I_s$ that becomes $V_s I_L \cos \phi \tan \delta$ like.

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- where I_s and I_L are source and load currents. $\cos\phi$ is load power factor and δ is the angle between the load voltage and PCC voltage after the compensation.

$$\tan \delta = \frac{\sqrt{V_{LC}^2 - V_s^2}}{V_s} \quad (4)$$

- The DSTATCOM current rating is as,

$$I_{DST} = I_L \left[\frac{\sqrt{(1-X)^2 + \cos^2\phi - 2\cos\phi\cos(\phi-\delta)(1-X)}}{(1-X)} \right] \quad (5)$$

- The VA rating of DSTATCOM is as,

$$S_{DST} = V_{LC} I_{DST} = V_{LC} I_L \left[\frac{\sqrt{(1-X)^2 + \cos^2\phi - 2\cos\phi\cos(\phi-\delta)(1-X)}}{(1-X)} \right] \quad (6)$$

- Therefore, total VA rating of the UPQC is as,

$$S_{UPQC-Q} = S_{DVR} + S_{DST} \quad (7)$$


And where the I_s and I_L , the source and load current and $\cos\phi$ is the load power factor and δ is the angle between the load voltage and the PCC voltage after the compensation which we usually call like a kind of power angle or so and that can be equated under root $V_{LC}^2 - V_s^2$ under root of that divide by the V_s like I mean.

And the DSTATCOM current rating can be like $I_{DSTATCOM} = I_L$ under root $1 - X^2 + \cos^2\phi - 2\cos\phi\cos(\phi - \delta)(1 - X)$ divide by $1 - X$ so, that is the rating of typically of DSTATCOM in terms of load current rating and the VA rating of DSTATCOM with $V_{LC} I_{DSTATCOM}$ [FL], you can keep the value of $I_{DSTATCOM}$ and this is the typical rating of VA rating of the DSTATCOM and therefore, total rating will be $I; S_{UPQC}$ will be equal to $S_{DVR} + S_{DST}$ like I mean.

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Control of UPQC as UPQC-P

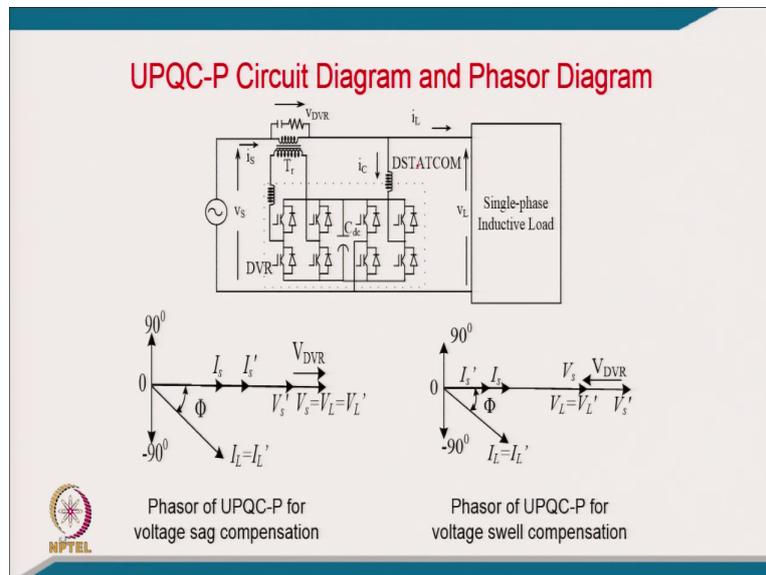
- In UPQC-P, the DVR is to inject minimum voltages for both conditions of voltage sag and swell.
- In this mode, DVR needs totally active power (P) for voltage injection of series compensation.
- In this case, the series voltage is injected in phase with the ac mains currents or PCC voltages thus requiring only active power which has to be fed or received by the DSTATCOM through dc bus.
- It increases the current and thus kVA rating of DSTATCOM. However, the kVA rating of DVR is minimal in this operating mode of UPQC as UPQC-P.
- Moreover, the DVR can compensate for voltage sag and swell in this UPQC-P mode of operation.



[FL] coming to this control of UPQC as a UPQC-P, in UPQC-P, the DVR inject the minimum voltage for the condition of voltage sag and swell and in this mode, DVR inject the total active power for the voltage injection of series compensation. In this case, the series voltage injected in phase with the ac mains current or PCC voltage thus requiring only active power which can be received by the DSTATCOM through dc bus.

It increases the current rating; current and the thus k VA rating of DSTATCOM. However, the k VA rating of DVR is minimum in this operating mode of UPQC and UPQC-Q and moreover, the DVR can compensate for voltage sag and voltage swell in this UPQC-P mode of operation.

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Well, this is the how we are going to compensate typically I mean like a voltage sag [FL], we are typically injecting the voltage by DVR in phase with the current [FL] that is and in case of swell, we are just putting the voltage opposite typically in series [FL] that virtually you can call it like a here it consume the power, it is I mean release the power I mean and which goes circulate through DSTATCOM like I mean.

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- The pu voltage sag can be expressed as,

$$X = \frac{|V_{LC} - V_S|}{V_{LC}} = \frac{|V_{inj}|}{V_{LC}} \quad (8)$$
- This UPQC-P mode of operation of UPQC requires minimum injection voltage and thus minimum VA rating of DVR but at the expense of DSTATCOM rating, which increases due to large active power flow through DSTATCOM.
- The rating calculations of both DVR and DSTATCOM may be done from phasor diagram shown in Fig. (c) as follows.
- The injected voltage by the DVR is as,

$$V_{inj} = (V_{LC} - V_S) = V_{LC} X \quad (9)$$
- The VA rating of the DVR is totally an active power and is expressed as,

$$S_{DVR} = V_{inj} I_s = |V_{LC} - V_S| I_L \cos \phi = V_{LC} X I_L \cos \phi \quad (10)$$



And the rating can be very simplified calculated as a per unit $V_{LC} - V_S$ upon V_{LC} and that is V_{inj} by V_{LC} in per unit and this UPQC-P mode of operation of UPQC require minimum injection voltage thus minimum rating of DVR but at the expense of DSTATCOM rating, which increases due to large active power flow through the DSTATCOM and the rating calculation for DVR and DSTATCOM may be done from the phase diagram and V_{inj} the injected voltage V_{LC} into V_L ; $V_{LC} X$ and the VA rating of DVR is $V_{inj} I_s$ $V_{LC} - V_S$ into $I_L \cos \phi$ [FL] its become V_{LC} into X into $I_L \cos \phi$.

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- The DSTATCOM current rating is as,
$$I_{DST} = \sqrt{[(I_L^2 - I_S^2) + (X_L \cos \phi)^2]} \quad (11)$$
- The VA rating of DSTATCOM is as,
$$S_{DST} = V_{LC} I_{DST} = V_{LC} \sqrt{[(I_L^2 - I_S^2) + (X_L \cos \phi)^2]} \quad (12)$$
- Therefore, total VA rating of the UPQC is as,
$$S_{UPQC-Q} = S_{DVR} + S_{DST} \quad (13)$$



And the DSTATCOM rating because you just put the active power here, [FL] that is the reason it goes to $I_L^2 - I_S^2$ under root plus $X_L \cos \phi$ square like and the VA rating of DSTATCOM with $V_{LC} I_{DST}$; DST [FL] you can keep the value of DST [FL] that give the rating of DSTATCOM and the total rating of UPQC comes like $S_{UPQC-Q} = S_{DVR} + S_{DST}$.

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Control of UPQC as UPQC-S

- This control approach of UPQC-S has been featured as most generalized one with a number of objectives such as
 - a) The overall minimum VA of both DSTATCOM and DVR.
 - b) Full utilization of DVR rating with reduced burden on DSTATCOM.
 - c) Optimum sharing of rating between DVR and DSTATCOM etc.
- In UPQC-S, the DVR may inject voltages for both conditions of voltage sag and swell compensation.
- In this UPQC-S mode of operation of UPQC, the DSTATCOM is **normally used** for all current based compensation other than full reactive power of the system.

[FL] coming to as a control of UPQC as a UPQC-S, the control approach of UPQC-S has been featured as most generalized one with number of objective, the overall VA rating of both DSTATCOM and DVR, overall minimum rating I mean which consist the rating of DVR and DSTATCOM full utilization of DVR rating with reduced burden on DSTATCOM, on a optimum sharing operating between the DVR and DSTATCOM.

[FL] in UPQC, the DVR may inject the voltage both in both the condition of voltage sag and swell and in the in this UPQC-S mode of operation of UPQC, the DSTATCOM is normally used for all current based compensation other than full reactive power of the system.

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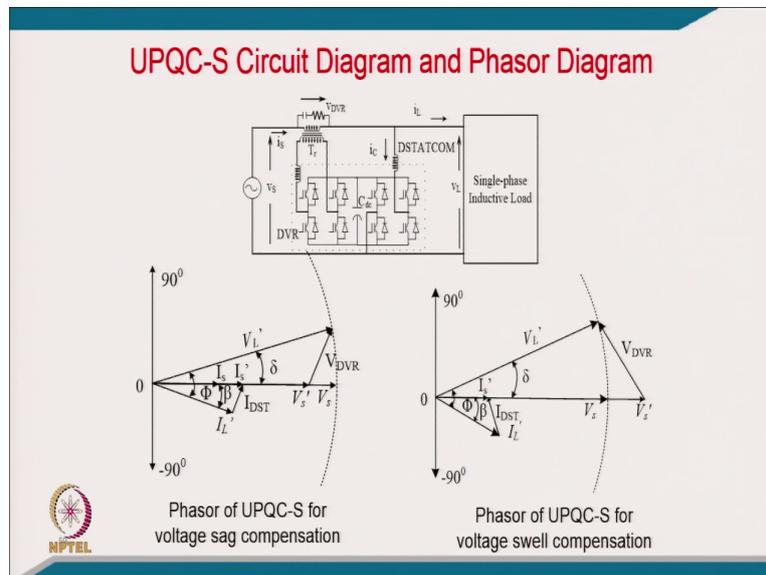
Control of UPQC as UPQC-S

- In this case, the DVR injects a voltage in series between ac mains and the load end at a predetermined phase angle with the PCC voltage.
- The DVR needs both active power (P) and reactive power (Q) through the DVR.
- This concept of UPQC-S with the phase angle control (PAC) of the series voltage injection of DVR has been perceived very recently for different objectives.



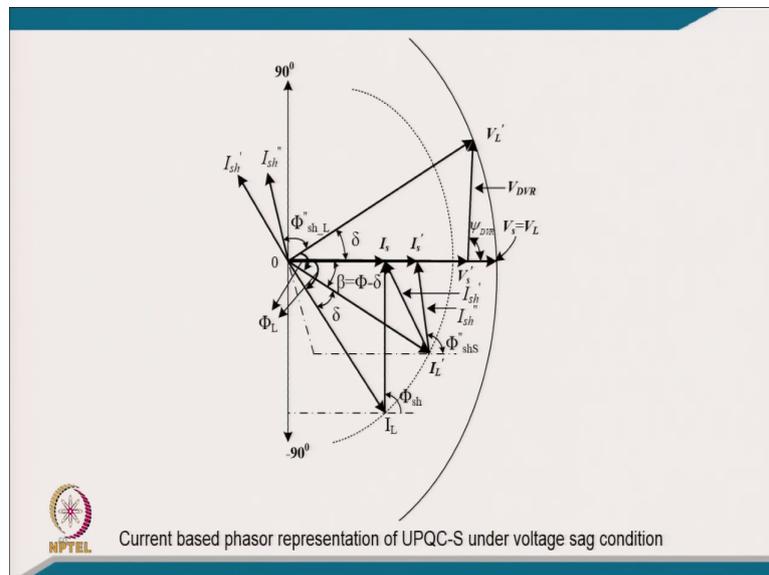
And in this case, DVR inject a voltage in series between ac main and the load end at predetermined phase angle with the PCC voltage and DVR needs both active power and reactive power through DVR. [FL] this concept of UPQC-S with phase angle control of series voltage injection of DVR has been perceived very recently in different; for different objective.

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And this is the typical I mean phasor diagram for UPQC-S. [FL] here, you can see it is a voltage sag, [FL] we are injecting the voltage of course, which is not in either phase with the current or quadrature in the current, [FL] you might be injecting the active as well as reactive power and this is for the voltage swell, again we are injecting the voltage I mean to reduce the swell at the point of common coupling that voltage is also injected neither then phase with the current nor typically at the quadrature of the current [FL] that is typically [FL] part of the reactive power it can be transfer to the DVR in this case like.

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And this is the typically phase current based representation of voltage sag compensation. [FL], you can just see earlier it is the let say voltage, but one sag come, you inject the voltage here by DVR and that is the new voltage which across the load.

And of course, when you really have this voltage goes up in a sense in that case, you will find I mean the with respect to the load voltage, the source current becomes in phase with the source voltage because you want to have a DSTATCOM [FL], even the partly the rating of the d; even the DSTATCOM is also reduced in that case and that flow is virtually transferred partly by the for the DVR like.

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- The voltage injected by DVR is its rated voltage as, $V_{DVR}=V_R$ and the angle, ψ_{DVR} at which it is to be injected w.r.t PCC voltage.

$$\psi_{DVR} = [\pi_c - \cos^{-1}\{(V_s^2 + V_{DVR}^2 - V_{LC}^2)/(2V_s V_{DVR})\}] \quad (14)$$

[FL], the voltage injected by the DVR is rated at voltage V_{DR} equal to V_R and the angle ψ_{DVR} at which the voltage injected can be calculated ψ_{DVR} as a π_c minus \cos inverse $V_s^2 + V_{DVR}^2 - V_{LC}^2$ divided by $2 V_s$. [FL], we calculate this angle virtually this of at which we are injecting, [FL], these are angle at which we are injecting and from this, typically from this triangle we calculate this relation like for calculation of this angle like or so.

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- The active power of the DVR are as,
$$P_{DVR} = V_{DVR} I_s \cos \psi_{DVR} \quad (15)$$
- The reactive power of the DVR are as,
$$Q_{DVR} = V_{DVR} I_s \sin \psi_{DVR} \quad (16)$$
- This condition of DVR is considered for the compensation by DVR with minimum active power and maximum reactive power with full utilization of its rating as $V_{DVR} = V_R$.
- The VA rating of DVR is as,
$$S_{DVR} = V_{DVR} I_s \quad (17)$$
- Let δ is the angle between the load voltage, V_L and PCC voltage V_s after the compensation. It can be calculated as,
$$\delta = \sin^{-1}\{(V_{DVR} \sin \psi_{DVR})/V_L\} \quad (18)$$



And the active power of the DVR we can calculate $V_{DVR} I_{VR}$ and this angle between the two which ψ_{DVR} , we just calculate in the reactive power of the DVR can be your $Q_{DVR} / V_{DVR} I_{DVR}$ and ψ_{DVR} like.

[FL], this condition of DVR is considered for the compensation by the DVR with minimum active power and maximum reactive power full utilization of its rating as V_{DVR} equal to V_R and the VA rating of DVR is S_{DVR} equal to $V_{DVR} I_s$ like and let the delta be the angle between the load voltage V_L and PCC voltage V_s after the compensation. It can be calculated as delta equal to $\sin^{-1}\{V_s / V_{DVR} \sin \psi_{DVR} / V_L\}$ because that is the angle between the typically V_{DVR} and V_L .

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- The angle, β between PCC voltage and the consumer load current after the compensation is as,

$$\beta = \phi - \delta \quad (19)$$
- The DSTATCOM current rating is as,

$$I_{DST} = \sqrt{\{I_L \sin \beta\}^2 + \{I_L \{(\cos \beta) - (\cos \phi)\} / (1-X)\}^2} \quad (20)$$
- The angle ψ_{DST} between DSTATCOM current and PCC voltage is as,

$$\psi_{DST} = (\pi/2) + \tan^{-1} \{ \{(\cos \beta) - (\cos \phi)\} / (1-X)\} / \sin \beta \quad (21)$$
- The active power of the DSTATCOM are as,

$$P_{DST} = V_L I_{DST} \cos \psi_{DST} \quad (22)$$
- The reactive power of the DSTATCOM are as,

$$Q_{DST} = V_L I_{DST} \sin \psi_{DST} \quad (23)$$



And the angle beta between the PCC voltage and the consumer load current after the compensation comes beta equal to phi minus delta. [FL], you can consider that compare to phi now, this angle is reduced and it makes the part of reactive power is compensated by the typically of DVR and DSTATCOM rating can be calculated now, $I_{DST} = \sqrt{I_L \sin \beta^2 + I_L \cos \beta - \cos \phi / (1-X)}$ plus $I_L \cos \beta - \cos \phi$.

And typically, divide by $1 - X$ like I mean and the angle phi DST between the DSTATCOM current and PCC voltage can be calculated from this $\pi/2 + \tan^{-1} \{ \{(\cos \beta) - (\cos \phi)\} / (1-X)\} / \sin \beta$. And the active power of the DSTATCOM are as $P_{DST} = V_L I_{DST} \cos \psi_{DST}$ like and the reactive power of the DSTATCOM can $Q_{DST} = V_L I_{DST} \sin \psi_{DST}$.

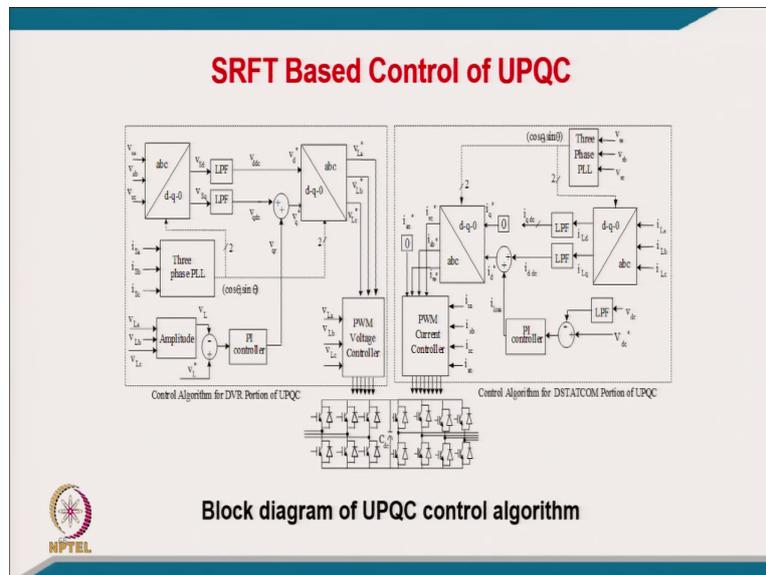
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- The VA rating of DSTATCOM is as,
$$S_{DST} = V_L I_{DST} \quad (24)$$
- Therefore, total VA rating of the UPQC is as,
$$S_{UPQC-S} = S_{DVR} + S_{DST} \quad (25)$$
- This condition of UPQC-S reduces the burden on DSTATCOM rating as some part of reactive power of the load is supplied by DVR.



And the $S_D V_L$ into I_{DST} and therefore, the total VA rating of UPQC is the sum of S_{DVR} plus S_{DST} like. [FL], this condition of UPQC-S reduces the burden on DSTATCOM rating as some part of the reactive power of the load is supplied by the DVR as the angle is shifted like.

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Well, this is a typical control algorithm I mean for using you can call it synchronous reference frame theory. [FL], typically this is the control of DVR part. [FL], we are sensing the voltage and converting with the and sensing the current from which we are getting $\cos \theta$, $\sin \theta$ [FL], we use for synchronous reference frame theory [FL], we may get even because of voltage unbalance or so repel here [FL], we have to pass on [FL] you can call it like typically through low pass filter to get dc component.

And similarly, we have a here again the voltage regulation [FL] that give us about typically about the a voltage component corresponding to the reactive power for voltage regulation or control and V_d , V_q with the again with the $\cos \theta$, $\sin \theta$ we convert to the load voltage I mean that is regulator voltage and we have a feedback voltage [FL] that give the gating

signal for the your series compensator or the DVR devices I mean which are in a part of the inverter.

And coming to DSTATCOM control, I mean here we are taking again load current and putting a again d-q transformation and then, using low pass filter, we take a here the component corresponding to which active component and we take typically of you can call it dc link voltage control because you have to regulate the DC voltage similar to like a DSTATCOM.

[FL], that you add it and then, with this with $\cos \theta$, $\sin \theta$ which are obtained from PLL of voltage [FL], you have a typically like a reference current grid current calculation you have a sense grid current and 0 sequence neutral current, you keep the 0 you keep the gating signal for four devices, here for this.

[FL], this is four leg DSTATCOM part and this is your, but the more important part here the angle is calculated from the voltage PCC voltage and here, your angle is calculated from the current [FL], this is the basic difference for that and this is typical you can call it voltage control which we discussed earlier and here, it is typically the current control. [FL] DSTATCOM operates in current control and your typically the DVR operates in voltage control mode like that is about the typically of control of.

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Control of DSTATCOM of UPQC

- The objective of the DSTATCOM is to enhance the power quality of the supply current as well as to support the common DC bus of DSTATCOM and DVR by absorbing active power by the DSTATCOM.
- The load currents in the three phases are converted into the d-q-0 frame using the Park's transformation

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos \theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin \theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$


[FL], objective of DSTATCOM is to enhance the power quality of the supply current as well as to support the common DC bus voltage of DSTATCOM and DVR is absorbing active power by the DSTATCOM and coming to these equations of this algorithm, the load current in the three phases are converted to typically into d-q reference frame.

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Control of DSTATCOM of UPQC

- Here, θ is the grid voltage phase angle.
- The d-axis and q-axis currents consist of dc (fundamental) and ripple (negative sequence and harmonics) components.

$$i_{Ld} = i_{Ld,dc} + i_{Ld,ac}, i_{Lq} = i_{Lq,dc} + i_{Lq,ac}$$

- These d-q current components of load current are then passed through low pass filters (LPF) to extract the dc components of i_{Ld} and i_{Lq} .
- **DC link voltage control**
- The DC link voltage (V_{dc}) is controlled to its reference voltage (V_{dc}^*) using a PI controller and the output of the PI controller is considered as the loss component of the current to be injected by the DSTATCOM.



Then, where the theta is the angle which calculated from the current and d-q axis of course, we have consist of dc and ac component. [FL], by using low pass filter we take only dc component part of it and that we call it like a we extract i_{Ld} , i_{Lq} that is corresponding to fundamental current like and DC link voltage control, it look like a reference voltage and we use the PI controller I mean to regulate the voltage and which we consider the loss component as in case of the DSTATCOM.

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Control of DSTATCOM of UPQC

$$v_{dce}(n) = V_{dc}^*(n) - V_{dc}(n)$$
$$I_{LOSS}(n+1) = I_{LOSS}(n) + K_{pd} \{v_{dce}(n+1) - v_{dce}(n)\} + K_{id} (v_{dce}(n+1))$$

- The amplitude direct axis (i_d^*) and quadrature axis (i_q^*) components of reference supply current

$$i_d^* = I_{LOSS} + i_{Lddc}, i_q^* = 0, i_0^* = 0$$

- For the unity power factor operation, The reference supply current must be in phase with the voltage at the PCC but with no zero-sequence component.
- Therefore, i_q^* and i_0^* are kept zero.



And this is typically the error and this is the typically the PI control equation for calculating the loss component for regulating the DC link voltage of the typically of DVR and the amplitude of that fluctuation quadrature axis you can call it that fluctuation I LOSS plus this load active component of current and quadrature, we keep 0 because you want to have a unity power factor and the 0 sequence we keep it 0.

Because you do not have a zero-sequence current flowing into the grid like I mean. [FL] for unity, power factor operation, the reference current must be in phase with the voltage at the PCC with no zero-sequence current. Therefore, i_q and i_0 are kept 0.

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Control of DSTATCOM of UPQC

➤ Estimation of reference supply currents

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

➤ Note: Inverse Park's Transformation matrix for an a-phase to d-axis alignment



And this is typically you can call it after getting i_d , i_q , you can transform to reference grid current I mean typically balance three from this the inverse Park transformation.

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Control of DVR of UPQC

- The PCC voltages are converted to the rotating reference frame using the Park's transformation.

$$\begin{bmatrix} V_{sd} \\ V_{sq} \\ V_{s0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix}$$

- The unit vectors $(\sin\theta, \cos\theta)$ derived from the supply currents using a PLL (phase locked loop) block.



And similarly, you can have a four control of DVR that we sense typically the grid voltages [FL], we convert t q voltage by this again Park transformation.

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Control of DVR of UPQC

- The components of the PCC voltages in d-axis and q-axis
$$V_{Sd} = V_{d dc} + V_{d ac}, \quad V_{Sq} = V_{q dc} + V_{q ac}$$
- The harmonics and the oscillatory components (v_{dac} , v_{qac}) are eliminated using low pass filters (LPF)
- The amplitude of ac load terminal voltage (V_L) is controlled to its reference voltage (V_L^*) using a PI controller and the output of the PI controller is considered as the voltage (v_{qr}) to be injected by the DVR
$$v_{qr(n)} = v_{qr(n-1)} + K_{p2}(V_{te(n)} - V_{te(n-1)}) + K_{i2}V_{te(n)}$$
$$V_{te(n)} = V_L^* - V_{L(n)}$$



And typically, again by this we have a dc component, ac component. Dc component is corresponding to fundamental voltage and ac component is corresponding to like a negative sequence or harmonics or so.

Harmonics and oscillate component are these ac and are eliminated by low pass filter and the amplitude of your ac load voltage is a control with the reference of V_L using a PI controller at the output and it is a injected voltage corresponding to we calculate corresponding to this voltage controller where this is the error is a reference load voltage and this is the feedback estimated voltage.

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Control of DVR of UPQC

➤ The direct axis (v_d^*) and quadrature axis (v_q^*) component of the reference load voltage

$$V_d^* = V_{ddc}, \quad V_q^* = V_{qdc} + V_{qr}, \quad V_0^* = 0$$

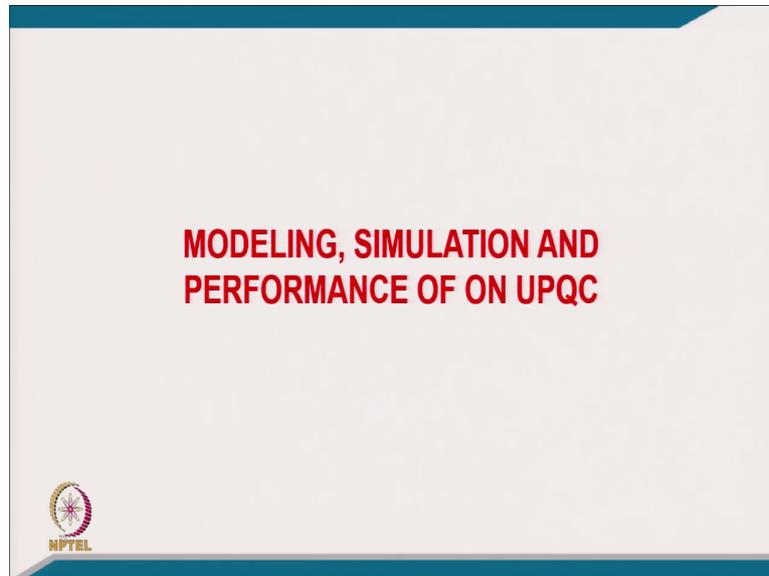
➤ The reference load voltages (v_{La}^* , v_{Lb}^* , v_{Lc}^*) in a-b-c frame

$$\begin{bmatrix} V_{La}^* \\ V_{Lb}^* \\ V_{Lc}^* \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} V_d^* \\ V_q^* \\ V_0^* \end{bmatrix}$$


And the direct axis component we can calculate, it is a dc component and the quadrature typically the corresponding to the pi controller as well as those supply voltage and that is 0 sequence is 0 and once we get V_d, V_q , we apply the inverse current transformation where theta is calculated from the PLL from the current [FL], we get the load voltage and this load voltage with the sense load voltage we put the PLL.

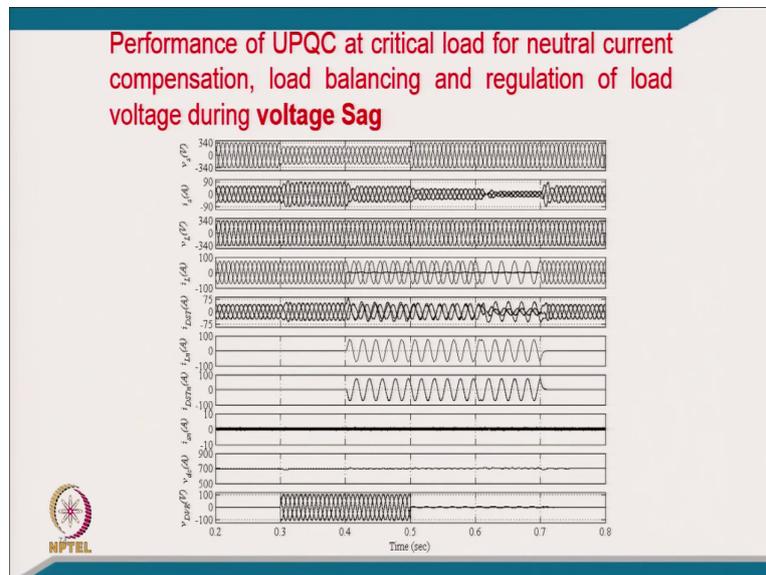
[FL], that is complete the one kind of control, the simplest control of your SRF theory for the typically for this UPQC like.

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Coming to modeling, simulation, and performance of UPQC.

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[FL], this is a typical case performance of UPQC at critical load for neutral current compensation, load balancing and regulation of load during the voltage sag compensation. [FL], you can see clearly here it is supply voltage, here it is a voltage sag and corresponding to voltage sag, certainly for same power which load is drawing because load power remain constant.

[FL], you will find the current is increase, the supply current increasing, but it is balance and sinusoidal I mean here and here part of the one phase load is reduced that is the reason current is reduced and here, you can call it another typically the voltage comes normal [FL], current reduces and here, again another phase load is reduced, then you get the current in the supply further lower and then, it comes to a normal condition from where it started.

And you can clearly this is the load voltage it remain regulated, sinusoidal and balance across the load, but the load current you can call it is a lagging power factor load, here it was two phase load and single phase load. [FL], load unbalancing, neutral current compensation, all are taken care and these are of course, DSTATCOM current.

And this is the load neutral current and this is the DSTATCOM fourth leg neutral current, this is the source neutral current which is regulated 0 and the dc link voltage regulated well and this is the DVR voltage when voltage sag is there, it is injected that is why the load voltage is maintained regulated.

[FL], this providing the compensation, keeping a load voltage, sinusoidal balance and the grid current balance, but the grid current magnitude will change at because it is a in the supply side for deriving the constant power to the Load like I mean.

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Performance of UPQC at critical load for neutral current compensation, load balancing and regulation of load voltage during voltage Sag

- At 0.3s, a sag in supply voltage (0.3 pu) is created for 10 cycles.
- It is observed that the load voltage is regulated to constant amplitude under voltage sag and nominal operating conditions.
- It is observed that only during sag, a voltage is injected by DVR portion of UPQC to regulate the load voltage.
- Due to sag in supply voltage, an increment in supply current is observed.
- At 0.4 s, the load is changed to two-phase load and to single-phase load at 0.6 s. These loads are applied again at 0.7s.



[FL], performance of UPQC at critical load and neutral compensation, load balancing and regulation, we have already discussed about this what the typically the voltage sag have been, then load voltage regulated constant and you observed that only voltage sag, voltage injected by DVR to regulate the load voltage and due to sag in supply, the increment in supply current is observed and the load is changed from 2 phase and single phase [FL], these are applied again back to.

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Performance of UPQC at critical load for neutral current compensation, load balancing and regulation of load voltage during **voltage Sag**

- It is observed that supply currents are balanced and are in phase with supply voltage even under unbalanced load at supply.
- The load neutral current is supplied by fourth-leg of DSTATCOM.
- Hence the supply neutral current is approximately zero under all operating conditions.



[FL], it is observed that supply current are balanced and are in phase with the supply voltage even unbalanced load supply and the load neutral current is supplied by fourth-leg of DSTATCOM. Hence, the supply neutral current is approximately zero with all operating condition.

This is the another case when we have a voltage swell I mean like the UPQC perform. [FL], you can see here, from here to a there is a voltage swell. For nominal, it is going to little higher and because of same power that is why current is going to down, but here one phase load is reduced so current reduces further and here, the voltage comes normal, but current have to increased typically slightly.

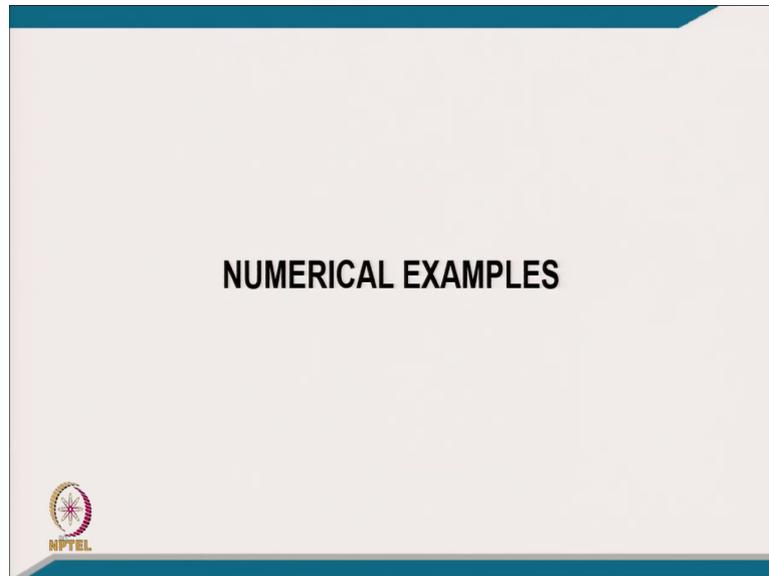
And here, another phase load is reduced [FL], current further reduces on supply, but supply current are balance and sinusoidal and load voltage regulator across the load and that is why load current are not affected even the voltage swell here.

But here two-phase load, single-phase load and again back to and here, DSTATCOM current, this is a load neutral current which is compensated by fourth-leg of the DSTATCOM, this is the source neutral maintained 0 and dc link voltage regulated to constant and this is the DVR voltage which are injected to compensate the voltage typically the voltage swell here so that load voltage is regulated like.

[FL], this is a compensation for voltage swell like. [FL], these are the observation that a voltage swell is applied of 0.3 per unit for 10 cycle and you observe that load voltage regulated at a constant amplitude under the voltage swell and nominal operating condition. It can be observed that only during swell, a voltage is injected by DVR portion of UPQC to regulate that load voltage and due to swell in supply voltage, a decrease in supply current is observed.

And the load is changed at this time to two-phase and then, single-phase and these load are applied again back and it can be observed the supply current are balanced are in phase with the supply voltage even under unbalanced load and load term and neutral current is supplied by the fourth leg of DSTATCOM. Hence, the supply neutral current is approximately zero under all operating conditions.

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[FL], with this, we cover typically the case study. Now, we will like to discuss the numerical examples of this UPQC like.

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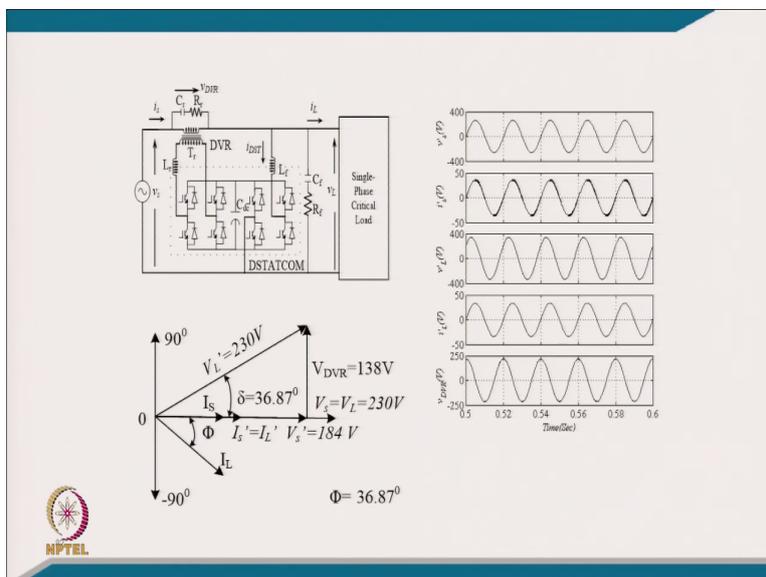
Q.1 A single-phase unified power quality compensator (UPQC consisting of DSTATCOM and DVR using two VSCs with common DC bus capacitor) is to be designed for a load of 230 V, 50 Hz, 25A, 0.8 lagging power factor as a **Right Hand UPQC-Q** (shown in Fig). There is a **voltage sag of -20%** in supply system with base value of 230 V. Calculate (a) the voltage rating of DVR of UPQC-Q, (b) the current rating DVR of UPQC-Q, (c) the VA rating of DVR of UPQC-Q, (d) the voltage rating of DSTATCOM of UPQC-Q, (e) the current rating of DSTATCOM of UPQC-Q, (f) the VA rating of DSTATCOM of UPQC-Q, and (g) total VA rating of UPQC-Q to provide reactive power compensation of the load for unity power factor at AC mains with a constant regulated voltage of 230 V at 50 Hz across the load.



[FL], coming to the first numerical example, a single-phase UPQC, unified power quality compensator consisting of DSTATCOM and DVR using two voltage source currents with common DC bus capacitor is to be designed for a load of 230 volt, 50 hertz, 25 ampere, 0.8 lagging power factor as a right hand UPQC-Q and there is a voltage sag of minus 20 percent in the supply system with base voltage of 230 volt.

Calculate the voltage rating of the DVR of UPQC-Q, the current rating of UPQC-Q, the VA rating of DVR of UPQC-Q, the voltage rating of DSTATCOM of UPQC-Q and the current rating of DSTATCOM of UPQC-Q, the VA rating of DSTATCOM of UPQC-Q and the total VA rating of the UPQC-Q to provide reactive power compensation of load for unity power factor at AC mains constant regulated voltage of 230, 50 hertz across the load.

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[FL], this is the typically, the condition where voltage sag is apply because it is a UPQC-Q [FL], there was a voltage sag, the voltage is reduced from 230 volt to 184 I mean typically for that much voltage we have to inject like a V DVR equal to after and this is the new voltage typically in this. [FL], that is the concept of UPQC-Q, there is no reactive power at round phase [FL], this complete model is developed.

And then, these are the typically the performance result after the simulation. [FL], you can say supply voltage, supply current, which is at unity power factor, these are load to voltage which regulated across the load current, and this is the injected voltage by the typically to for the sag I mean typically to compensate voltage sag from the supply to the load voltage.

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Solution: Given that, $V_s = 230$ V, $f=50$ Hz, a load of 230 V, 50 Hz, 25A, 0.8 lagging power factor. There is a voltage sag -20% in supply system with base value of 230 V.
The active power of the load is, $P_L = V_L \cdot I_L \cdot \text{pf} = 230 \cdot 25 \cdot 0.8 = 4600$ W.
The supply current during nominal operating condition is as,
 $I_{sN} = P_L / V_s = 4600 / 230 = 20$ A.
During nominal grid operation,
 $V_{DSTN} = 230$ V
 $I_{DSTN} = I_L \sin \phi = 25 \cdot \sqrt{1 - 0.8^2} = 15$ A,
 $S_{DSTN} = V_{DSTN} \cdot I_{DSTN} = 230 \cdot 15 = 3450$ VA.
During nominal grid operation $V_{DVRN} = 0$. Hence during nominal grid operation $S_{DVRN} = 0$.
Voltage Sag Compensation by Right Hand UPQC-Q
(a) The voltage rating of DVR of UPQC-Q is computed as.
There is voltage sag of -20% in the supply system with base value of 230 V.



[FL], coming to numerical part of this, given that V S equal to 230-volt, f equal to 50 hertz, a load of 230-volt, 50 hertz, 25 ampere, 0.8 lagging power factor and there is a voltage sag of minus 20 percent in supply system with the base of 230 volt. The active power of the load is P L equal to V L I L pf [FL], this comes around 4600 watt and the supply current during normal condition is your P L upon V S [FL], it comes 20 ampere.

And during nominal grid condition, the typically the voltage is 230 volt and I DSTATCOM is I L sin phi that is 25 under root 1 minus 0.8 square so, it is a 15 ampere and the DSTATCOM rating is 230 and 15 that become 3450 VA. During normal grid operation, the V DVR is 0.

Hence, during the this is 0, but volt during the voltage sag compensation, I mean during normal condition DSTATCOM is suppose true, but DVR not suppose true because there is no voltage sag, but when voltage sag is there, the DVR comes into action [FL], voltage rating of

UPQC is computed as there is a voltage sag of minus 20 percent in supply system with base of 230 volt.

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Supply voltage reduces to $V_s' = 230 * (1 - 0.20) = 184$ V. and $X = 0.2$.
 The supply current during voltage sag compensation is as,
 $I_s' = P_L / V_s' = 4600 / 184 = 25$ A.
 The voltage rating of DVR, $V_{DVR} = \sqrt{(V_L'^2 - V_s'^2)} = \sqrt{(230^2 - 184^2)} = 138$ V.
 (b) The current rating DVR of UPQC must be same as supply current after shunt compensation as.
 $I_{DVR} = I_s' =$ The fundamental active component of load current,
 $I_s' = P_L / V_s' = 4600 / 184 = 25$ A.
 (c) The VA rating of series element of UPQC-Q is as,
 $Q_{DVR} = V_{DVR} * I_{DVR} = (138 * 25)$ VA = 3450 VAR.
 $P_{DVR} = 0.0$ as the voltage of DVR is injected at the quadrature with its current.
 $S_{DVR} = \sqrt{(P_{DVR}^2 + Q_{DVR}^2)} = Q_{DVR} = 138 * 25$ VA = 3450 VA.
 (d) The voltage rating of DSTATCOM of UPQC-Q is equal to AC load voltage of $V_{sh} = 230$ V, since it is connected across the load of 230 V sine waveform.

And supply voltage reduces to 230 typically of with 20 percent sag 184 and X is 0.2. [FL], we can calculate the. Now, typically the so, supply current because power is same 4600 divide by 184 [FL], current on the supply it becomes 25 ampere and the voltage rating of the DVR you can calculate is $V_L^2 - V_S^2$ because UPQC-Q we are injecting at the quadrature with the current [FL], that comes to 138.

And current rating of UPQC is the same as the supply current that is 25 ampere and the VA rating of UPQC is $V_{DVR} I_{DVR}$ [FL], we get voltage injected there which we calculate here multiplied the current [FL], it become 3450 VA r and P_{DVR} is 0 because we are not taking

any active power injection for the we are injecting the voltage at the quadrature with the current [FL], S DVR will be $P_{DVR} Q^2 [FL]$ that is $138^2 / 25 [FL]$ this is 3450.

[FL], voltage rating of DSTATCOM is equal to 230 volt and its connected across the load of 230 volt sine wave.

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(e) The current rating of DSTATCOM of UPQC-Q is computed as follows.

The DSTATCOM of UPQC-Q is to correct the power factor of the supply to unity, hence the required reactive power by DSTATCOM is now lower than the load reactive power as the angle between supply voltage and load current is reduced to $\beta = \phi - \delta$.

Where $\cos\phi$ is load power factor and δ is the angle between the load voltage and PCC voltage after the compensation. This angle δ is computed as follows.

$\tan \delta = \sqrt{(V_{LC}^2 - V_s^2)} / V_s = 138/184 = 0.75$, $\delta = 36.87^\circ$, and power factor angle is as $\phi = \cos^{-1}(0.8) = 36.87^\circ$.

The DSTATCOM current rating is as,

$$I_{DST} = I_L \left[\sqrt{\{(1-X)^2 + \cos^2\phi - 2\cos\phi\cos(\phi-\delta)(1-X)\}} / (1-X) \right]$$

$$= 25 \left[\sqrt{\{0.8^2 + 0.8^2 - 2*0.8*\cos(36.87^\circ - 36.87^\circ)*0.8\}} / 0.8 \right] = 0A$$

(f) The VA rating of DSTATCOM is as, $S_{DST} = V_{DST} I_{DST}$
 $= 230*0 = 0 VA$.



[FL], current rating of UPQC computed typically to correct the power factor unity hence the required reactive power of DSTATCOM is now lower than the reactive power of the angle between the voltage and current [FL], that is $\phi - \delta$ and $\cos\phi$ is the load power factor and δ is the angle between the load voltage, PCC voltage after the compensation.

[FL], that $\tan \delta$ equal to $V_{LC}^2 - V_s^2$ divide by V_s [FL], it comes 0.75, δ is 36.5 and power factor angle is also 36.5. [FL], DSTATCOM current rating if

you put the value, it comes 0 ampere [FL], DSTATCOM because whatever the reactive power required by the load, it is already compensated by the DVR. [FL], VA rating of the DSTATCOM will be 0.

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Hence the VA rating of UPQCQ under voltage sag is as,
 $S_{UPQCQ(\text{under sag})} = S_{DST} + S_{DVR} = 0 + 3450 = 3450 \text{ VA}$.
Hence considering the overall ratings (both normal and under voltage sag), the ratings of both the compensators is as,
 $V_{DST} = 230 \text{ V}$, $I_{DST} = 15 \text{ A}$, $S_{DST} = 230 * 15 = 3450 \text{ VA}$.
 $V_{DVR} = 138 \text{ V}$, $I_{DVR} = 25 \text{ A}$, $S_{DVR} = 3450 \text{ VA}$.
(g) The VA rating of UPQC,
 $S_{UPQCQ} = S_{DST} + S_{DVR} = 3450 + 3450 = 6900 \text{ VA}$.



And typically, the VA rating of the this total UPQC will be DSTATCOM plus DVR. [FL], DSTATCOM DV DSTATCOM is 0 [FL], DVR takes this much 3450. Hence, considering the overall rating both normal and under the rating of the both compensator is typically of DSTATCOM 230 and the nominal condition is 15 [FL], this is the typical rating of DSTATCOM and DVR rating is typically 3450. [FL], total VA rating will be sum of both that comes 6900 volt ampere like.

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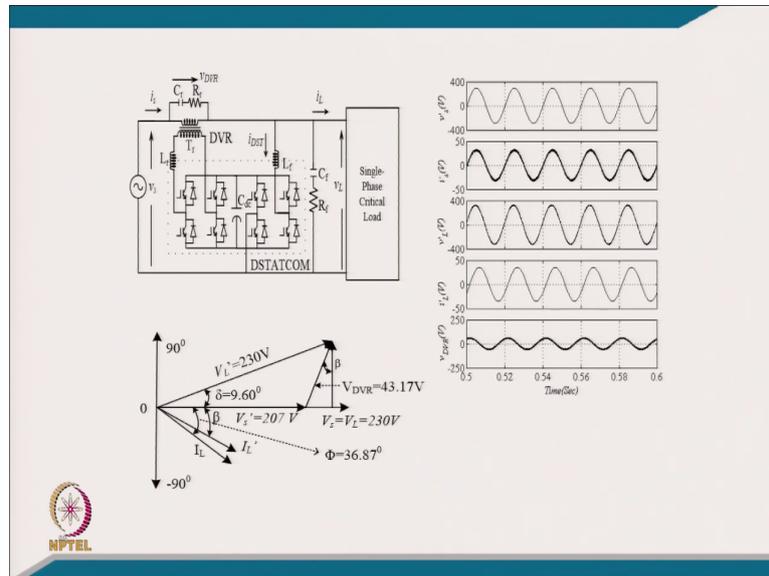
Q.2 A single-phase unified power quality compensator (UPQC consisting of DSTATCOM and DVR using two VSCs with common DC bus capacitor) is to be designed for a load of 230 V, 50 Hz, 25A, 0.8 lagging power factor as a **Left Hand UPQC-Q** (shown in Fig.). There is a **voltage sag of -10%** in supply system with base value of 230 V. Calculate (a) the voltage rating of DVR of UPQC-Q, (b) the current rating DVR of UPQC-Q, (c) the VA rating of DVR of UPQC-Q, (d) the voltage rating of DSTATCOM of UPQC-Q, (e) the current rating of DSTATCOM of UPQC-Q, (f) the VA rating of DSTATCOM of UPQC-Q, and (g) total VA rating of UPQC-Q to provide reactive power compensation of the load for unity power factor at AC mains with a constant regulated voltage of 230 V at 50 Hz across the load.



[FL], coming to numerical example 2nd, a single-phase UPQC I mean consisting of DSTATCOM and DVR using two VSCs with common DC bus capacitor is designed for a load of 230-volt, 50 hertz, 25 ampere, 0.8 lagging power factor as the left hand UPQC and there is a voltage sag of 10 percent in the supply system with the base supply voltage of 230 volt.

Calculate the voltage rating of DVR of UPQC-Q, current rating of UPQC-Q, VA rating of UPQC-Q, the voltage rating of UPQC-Q and current rating of UPQC-Q and VA rating of DSTATCOM UPQC-Q and total VA rating of UPQC-Q for reactive power compensation of the load for unity power factor at AC mains and with a constant regulated voltage of 230 across the load.

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[FL], this is typically the you can call it how we are doing the compensation. [FL], here we have a typically the voltage sag and we are injecting the voltage virtually of this one to compensate, but now, you can say it is a typically I mean like and then, these are the wave form.

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Solution: Given that, $V_s = 230$ V, $f = 50$ Hz, a load of 230 V, 50 Hz, 25A, 0.8 lagging power factor. There is a voltage sag -10% in supply system with base value of 230 V.

It means after the voltage supply voltage reduces to $V_s' = 230 \times (1 - 0.10) = 207$ V, and $X = 0.1$.

The active power of the load is, $P_L = V_L \times I_L \times \text{pf} = 230 \times 25 \times 0.8 = 4600$ W.

The supply current during the voltage sag compensation is as follows, $I_s' = P_L / V_s' = 4600 / 207 = 22.22$ A.

During nominal grid operation,

$V_{DSTN} = 230$ V

$I_{DSTN} = I_L \sin \phi = 25 \times \sqrt{1 - 0.8^2} = 15$ A.

$S_{DSTN} = V_{DSTN} \times I_{DSTN} = 230 \times 15 = 3450$ VA.

Since $V_{DVRN} = 0$, so $S_{DVRN} = 0$.

Voltage Sag Compensation by Left Hand UPQC-Q

(a) The voltage rating of DVR of UPQC-Q is computed as.

There is voltage sag of -10% in the supply system with base value of 230 V. Therefore, the DVR of Left Hand UPQC-Q must inject at



[FL], given 230-volt, 50 hertz, say load of 230, 0.8 lagging power factor. There is a voltage sag of minus 10 percent with a 230 volt. It means the voltage is reduces to typically 207 point, X become 0.1 and the load power factor load power is typically 230 into 4600 and the your current become 22.22 and voltage rating of DSTATCOM 230 and current rating will be corresponding to reactive power of 15.

[FL], DSTATCOM rating is typically 3450 and D; your DVR rating is 0 under normal condition. Now, voltage sag compensation by left hand UPQC, the voltage rating of u DVR of UPQC is compulsory, there is a voltage sag of minus 10 percent in supply system with base value of 230.

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quadrature of the load current to provide the required voltage at the load end.

$$V_L \cos \phi = V_s \cos \beta, \cos \beta = V_L \cos \phi / V_s = 230 \times 0.8 / (230 \times 0.9) = 8/9,$$
$$\beta = 27.27^\circ, \delta = \phi - \beta = 36.87^\circ - 27.27^\circ = 9.60^\circ.$$
$$V_L \sin \delta = V_{DVR} \sin(90^\circ - \beta), V_{DVR} = V_L \sin \delta / \sin(90^\circ - \beta) = 43.17 \text{ V.}$$

The voltage rating of DVR, $V_{DVR} = V_L \sin \delta / \sin(90^\circ - \beta) = 43.17 \text{ V.}$

(b) The current rating of DVR of UPQC must be same as load current as,

$$I_{DVR} = I_L = 25 \text{ A.}$$

(c) The VA rating of DVR of UPQC-Q is as,

$$Q_{DVR} = V_{DVR} \times I_{DVR} = 43.17 \times 25 \text{ VA} = 1079.25 \text{ VAR.}$$

$P_{DVR} = 0.0$ as the voltage of DVR is injected at the quadrature with its current.

$$S_{DVR} = \sqrt{P_{DVR}^2 + Q_{DVR}^2} = Q_{DVR} = 1079.25 \text{ VA} = 1079.25 \text{ VA.}$$

(d) The voltage rating of DSTATCOM of UPQC-Q is equal to ac supply voltage of $V_{DST} = 207 \text{ V}$, since it is connected across the PCC of 207 V sine waveform.



And therefore, DVR left must inject the voltage at quadrature with provide the load [FL], $V_L \cos \phi$ equal to V_n and $\cos \phi$. From this relation, we are able to get typically beta equal to 27.27 and delta equal to 5 minus beta that come 36 [FL], angle comes 9.6 degree and from this, we can calculate putting the value of beta here [FL], we can find out the rating of V DVR 43.17.

And the current rating of DVR same as the load rating because it is connected on the typically of series compensator on the load side and VA rating of UPQC is typically your voltage rating into current [FL], this come that much DVR and P 0 because it is a UPQC-Q [FL], you do not inject the any active power and the S DVR will be P DVR that is equal to 1079.29 [FL], that is the VA rating and the voltage rating of DSTATCOM of UPQC equal to the ac

voltage that is 207 because it is connected on the grid side [FL], it is; it connected across PPC so, it is a 207 sine waveform

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(e) The current rating of DSTATCOM of UPQC-Q is computed as follows.
 The DSTATCOM of UPQC-Q is to correct the power factor of the source to unity, hence the required reactive power by DSTATCOM is now lower than the load reactive power as the angle between supply voltage and load current is reduced to $\beta = \phi - \delta$.
 The DSTATCOM current rating is as,
 $I_{DST} = I_L' \sin \beta = 25 \sin 27.27^\circ = 11.45 \text{ A}$.
 $Q_{DST} = V_s' I_L' \sin \beta = 207 * 11.45 = 2370.15 \text{ VA}$.
 $P_{DST} = 0.0$, as there no active power consumed by either DSTATCOM or DVR.

(f) The VA rating of DSTATCOM is as,
 $S_{DST(\text{under sag})} = \sqrt{P_{DST}^2 + Q_{DST}^2} = Q_{DST} = V_s' I_{DST} = V_s' I_L' \sin \beta = 207 * 11.45 = 2370.15 \text{ VA}$.
 Hence the VA rating of UPQCQ under voltage sag is as,
 $S_{UPQCQ(\text{under sag})} = S_{DST} + S_{DVR} = 2370.15 + 1079.25 = 3449.4 \text{ VA}$.



And the current rating of UPQC is computed typically as follows. The UPQC is correct to correct the power factor of the source to unity, hence the required reactive power of DSTATCOM is now lower than the your load reactive power as angle of load current that is a beta equal to phi minus delta, [FL], you can just calculate the DSTATCOM rating from $I \sin \phi$ [FL], it is a 11.45 and Q_{DST} will be here $V_L I_L \sin \beta$ [FL], it comes like a 20; 2370.18 after multiplication of this and P_{DST} is 0 because it is not circulating any active power because DSTATCOM need active power like I mean.

[FL], VA rating of DSTATCOM will be directly Q DST and that is typically 2370 and total rating of this during sag will have to DSTATCOM rating and the DVR rating typically it come 3449.4 VA like.

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However, during nominal grid condition, DSTATCOM has to supply all reactive power of the load, hence its rating is to be 3450VA.

$$S_{DST} = 3450 \text{ VA.}$$

Hence considering an overall rating, (both normal and under voltage sag), the ratings of both the compensators are as,

$$V_{DST} = 230 \text{ V, } I_{DST} = 15 \text{ A.}$$

$$S_{DST} = V_{DST} * I_{DST} = 230 * 15 = 3450 \text{ VA.}$$

$$V_{DVR} = 43.17 \text{ V, } I_{DVR} = 25 \text{ A.}$$

$$S_{DVR} = V_{DVR} * I_{DVR} = 1079.25 \text{ VA.}$$

(g) The VA rating of UPQC, $S_{UPQC} = S_{DST} + S_{DVR} = 3450 + 1079.25$

$$S_{UPQC} = 4529.25 \text{ VA.}$$


However, during normal condition, DSTATCOM has to supply the all reactive power of the load, hence its rating have to be like a 3450 and hence, the considering overall rating both normal and the rating of the typically DSTATCOM is 230, 15 [FL], it come the DSTATCOM rating and DVR rating voltage is this and current rating is this. [FL], it is a d DVR rating and total rating will be the sum of both which is sum of these two [FL], it comes 4529.25 VA.

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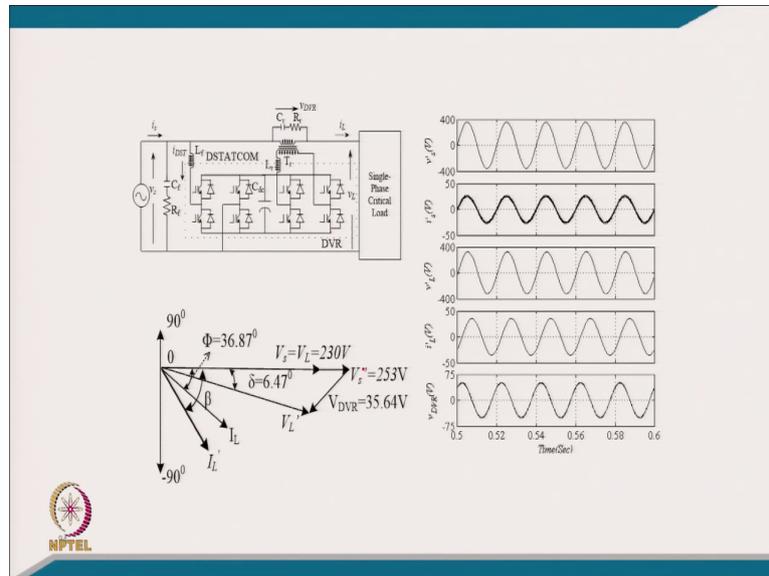
Q.3 A single-phase unified power quality compensator (UPQC consisting of DSTATCOM and DVR using two VSCs with common DC bus capacitor) is to be designed for a load of 230 V, 50 Hz, 25A, 0.8 lagging power factor as a **Left Hand UPQC-Q** (shown in Fig.). There is a **voltage swell of +10%** in supply system with base value of 230 V. Calculate (a) the voltage rating of DVR of UPQC-Q, (b) the current rating DVR of UPQC-Q, (c) the VA rating of DVR of UPQC-Q, (d) the voltage rating of DSTATCOM of UPQC-Q, (e) the current rating of DSTATCOM of UPQC-Q, (f) the VA rating of DSTATCOM of UPQC-Q, and (g) total VA rating of UPQC-Q to provide reactive power compensation of the load for unity power factor at AC mains with a constant regulated voltage of 230 V at 50 Hz across the load.



[FL], coming to a numerical example 3, a single-phase UPQC I mean consisting of DSTATCOM and DVR using two VSCs with common DC link capacitor is to be designed for a load of 230 volt, 50 hertz, 25 ampere, 0.8 lagging power factor at the left hand UPQC.

And there is a voltage swell of 10 percent in the supply system with the typically if you calculate the voltage rating of the UPQC, current rating of UPQC and VA rating of the UPQC of DVR and then, the current rating of DSTATCOM of UPQC, voltage rating of DSTATCOM VA rating and the total VA rating of UPQC to provide reactive power compensation of load and unity power factor at AC mains regulated.

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[FL], you can see here, it is a DSTATCOM which put on left side and DVR on right side and accordingly, how the voltage injection is taking place. [FL], after making the model, it is coming typically the waveform.

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Solution: Given that, $V_s = 230$ V, $f=50$ Hz, a load of 230 V, 50 Hz, 25A, 0.8 lagging power factor.

During nominal grid operation,

$$V_{DSTN} = 230 \text{ V}$$
$$I_{DSTN} = I_L \sin\theta = 25 \times \sqrt{1-0.8^2} = 15 \text{ A,}$$
$$S_{DSTN} = V_{DSTN} \times I_{DSTN} = 230 \times 15 = 3450 \text{ VA.}$$

The rating of the DVR is as, $V_{DVRN} = 0$, hence $S_{DVRN} = 0$.

The active power of the load is, $P_L = V_L \times I_L \times \text{pf} = 230 \times 25 \times 0.8 = 4600 \text{ W.}$

Voltage Swell Compensation by Left Hand UPQC-Q

There is a voltage swell +10% in supply system with base value of 230 V. It means during the voltage swell, the supply voltage increases to $V_s = 230 \times (1+0.10) = 253 \text{ V.}$

The supply current during voltage swell compensation is as follows.

$$I_s' = P_L / V_s' = 4600 / 253 = 18.18 \text{ A.}$$

(a) The voltage rating of DVR of UPQC-Q is computed as.

There is voltage swell of +10% in the supply system with base value of 230 V. Therefore, the DVR of Left Hand UPQC-Q must inject at



[FL], coming to numerical part of this, given that V_s equal to 230 volt, a 50 hertz, a load of 230 volt, 50 hertz, 25 ampere and 0.8 lagging power factor and during nominal grid condition, the voltage is 230 and DSTATCOM supplying reactive power [FL], that comes your at 0.8 power factor of 25 ampere, it comes 15 ampere. [FL], DSTATCOM computing it 230 into 15 [FL], it become 3450 VA and the rating of DVR we say is 0 volt and the VA rating of DVR in the normal condition and active power load, you can find out typically 4600. [FL], that is under normal condition.

Now, coming to voltage swell compensation by left hand UPQC, there is a voltage swell of 10 percent in the supply with the voltage of 230 it means during voltage swell, the supply voltage increases typically of 253 and supply current during the voltage swell compensation is typically the current on supply will be your active power force of the load 4600 divided by

253 [FL], current becomes 18.18 and the voltage rating of the DVR from we can calculate from the voltage swell 10 percent, [FL], we can calculate the value of 230 volt.

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the quadrature of the load current to provide the required voltage at the load end.

$$V_L \cos\theta = V_s \cos\beta, \cos\beta = V_L \cos\theta / V_s = 230 * 0.8 / (230 * 1.1) = 0.8 / 1.1,$$

$$\beta = 43.34^\circ$$

$$\delta = \beta - \theta = 43.34^\circ - 36.87^\circ = 6.47^\circ$$

$$V_L \sin\delta = V_{DVR} \sin(90^\circ - \beta), V_{DVR} = V_L \sin\delta / \sin(90^\circ - \beta) = 35.64V$$

The voltage rating of DVR, $V_{DVR} = V_L \sin\delta / \sin(90^\circ - \beta) = 35.64V$.

(b) The current rating DVR of UPQC must be same as load current as.

$$I_{DVR} = I_L = 25A$$

(c) The VA rating of DVR of UPQC-Q is as

$$Q_{DVR} = V_{DVR} * I_{DVR} = 35.64 * 25 VA = 891.15VAR.$$

$$P_{DVR} = 0.0,$$

$$S_{DVR(\text{during swell})} = \sqrt{(P_{DVR}^2 + Q_{DVR}^2)} = Q_{DVR} = 891.15VA = 891.15VA.$$

(d) The voltage rating of DSTATCOM of UPQC-Q is equal to ac source voltage of $V_{DST} = V_s = 253V$, since it is connected across the PCC of 253 V sine waveform.



[FL], since it is a DVR put on left side must inject the voltage in quadrature with the current of the load I mean like and we can find out V_L equal to V_L [FL] to form this calculation, we will get beta equal to 43.34 and from this delta, we can calculate the delta beta minus 5.

[FL], it comes like a 6.47 and from this relation of $V_L \sin\delta$, $V_{DVR} \sin$ minus beta [FL], we can calculate the value of V_{DVR} 35.64 and the voltage rating of the DVR same as this value and current rating of DVR is the same as the load current that is 25 ampere [FL], VA rating of DVR will be your voltage rating multiplied by current rating [FL], it becomes 891.15 VAR.

And power rate of course, the power is active power is 0 [FL], the total rating of your DVR will P square plus Q square [FL], it comes only Q because P is 0 [FL], it comes 89.15 VA. [FL], voltage rating of DSTATCOM of UPQC is equal to the ac voltage that is V DSTATCOM equal to V S 253 volt, since it is putting on the left side across the grid and since its connected across the PCC of 253 voltage sine wave.

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(e) The current rating of DSTATCOM of UPQC-Q is computed as follows.
 The DSTATCOM of UPQC-Q is to correct the power factor of the source to unity, hence the required reactive power by DSTATCOM is now higher than the load reactive power as the angle between supply voltage and load current is increased to $\beta = \phi + \delta$.
 The DSTATCOM current rating is as,
 $I_{DST} = I_L \sin \beta = 25 \sin 43.34^\circ = 17.16 \text{ A}$.
 $Q_{DST} = V_s I_L \sin \beta = 253 * 17.16 = 4341.01 \text{ VAR}$.
 $P_{DST} = 0.0$.

(f) The VA rating of DSTATCOM is as,
 $S_{DST} = \sqrt{P_{DST}^2 + Q_{DST}^2} = Q_{DST}$
 $= V_s I_{DST} = V_s I_L \sin \beta = 253 * 17.16 = 4341.01 \text{ VA}$.
 Hence the VA rating of UPQCQ under voltage swell is as,
 $S_{UPQCQ(\text{under swell})} = S_{DST} + S_{DVR} = 4341.01 + 891.15 = 5233.13 \text{ VA}$.



And current rating of the DSTATCOM of UPQC is computed as all. The DSTATCOM UPQC to correct the power factor of the source to unity, hence the required reactive power by the DSTATCOM is now higher than the load reactive power as angle between the supply voltage and load current is increased.

[FL], that is beta plus delta and DSTATCOM current rating now is a I L sin beta equal to typically 17.16 and Q of this will be voltage that is PCC voltage multiply current [FL] it

become 4341.01 VAR and power active power is 0 because UPQC-P [FL], there is no active power required for DVR that is why DSTATCOM also do not have a to circulate any active power.

[FL], VA rating of DSTATCOM will be $P \sin \phi$ [FL], it is $Q \sin \phi$ and that is your $V \sin \phi$ into $I \sin \phi$ [FL], this become 253 into 17.16 [FL], it become 4314 VA. Hence, the total VA rating of UPQC will be your S DVT; S DST plus S DVR DSTATCOM rating and plus DVR rating that is typically sum of these two [FL], it become 53; 5233.13 VA like.

(Refer Slide Time: 33:28)

Hence considering an overall rating (both normal and under voltage swell), ratings of both compensators are as,
 $V_{DST}=253 \text{ V}$, $I_{DST}=17.16 \text{ A}$, $S_{DST}=V_{DST} \cdot I_{DST} =253 \cdot 17.16=4341 \text{ VA}$.
 $V_{DVR}= 35.64 \text{ V}$, $I_{DVR}=25 \text{ A}$, $S_{DVR}=V_{DVR} \cdot I_{DVR} =891.15 \text{ VA}$.
 $S_{DST}=4341 \text{ VA}$ and $S_{DVR}=891.15 \text{ VA}$.

(g) The VA rating of UPQC,
 $S_{UPQCQ} = S_{DST} + S_{DVR} = 4341.01 + 891.15 = 5233.13 \text{ VA}$.



[FL], hence considering the overall rating both normal and voltage swell, the rating of both compensator I mean we can call it voltage of DSTATCOM 253, current 17.16 [FL], the S DST becomes like typically 4314 and V DVR is 35.64, voltage rating I DVR 25 ampere [FL],

it becomes like a 891 15 and [FL], your DSTATCOM rating is $\sqrt{3}$ and DVR rating is 91 [FL], total rating of UPQC is a sum of both [FL], it become 5233.13 VA like.

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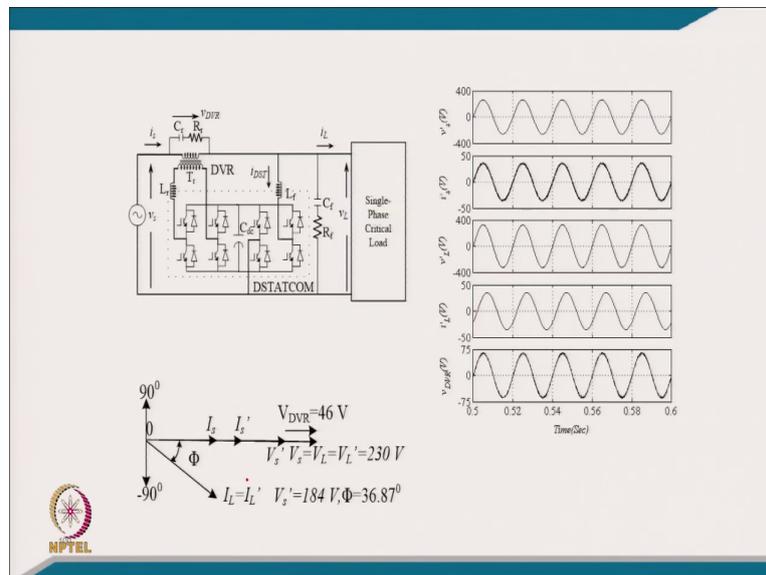


Q.4 A single-phase unified power quality compensator (UPQC consisting of DSTATCOM and DVR using two VSCs with common DC bus capacitor) is to be designed for a load of 230 V, 50 Hz, 25 A, 0.8 lagging power factor as a **Right Hand UPQC-P** (shown in Fig.). There is a **voltage sag of -20%** in supply system with base value of 230 V. Calculate (a) the voltage rating of DSTATCOM of UPQC-P, (b) the current rating of DSTATCOM of UPQC-P, (c) the VA rating of DSTATCOM of UPQC-P, (d) the voltage rating of DVR of UPQC-P, (e) the current rating DVR of UPQC-P, (f) the VA rating of DVR of UPQC-P, (g) total VA rating of UPQC-P to provide reactive power compensation for unity power factor at AC mains with a constant regulated voltage of 230 V at 50 Hz across the load.

[FL], coming to numerical example 4, a single-phase UPQC consisting of DSTATCOM and DVR with a two VSCs common is to be designed for a load of 230-volt, 50 hertz, 25, 0.8 lagging power factor as a right hand UPQC and there is a voltage sag of 20 percent in the supply system with base impedance of 230 volt.

Calculate the voltage rating of DSTATCOM, the current rating of DSTATCOM, VA rating of DSTATCOM and the voltage rating of DVR, the current rating of DVR and the VA rating of DVR, the total VA rating of UPQC to provide the reactive power compensation for unity power factor ac mains with constant regulated voltage of 230-volt, 50 hertz across the load.

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[FL], here typically we can call it a (Refer Time: 34:44), typically UPQC P with the right hand normally. [FL], we are injecting the voltage in phase with the current like you can see so that active power injected here. [FL], this active power when we are injecting, we are taking active power from DSTATCOM. [FL], under sag condition, we will take active power and inject here the voltage and for swell condition, we will take power and feed the voltage to this. [FL], these are typically waveform.

Once the load voltage is regulated where there is a I mean sag in this [FL], this is the typically the injected voltage in addition to these that become load voltage and source current accordingly adjusted, but the load and typically the load current and typically load voltage are not affected and that is the typical how we are injecting from under sag, this voltage in phase

with the current I mean because power factor unity because it is already making unity this current [FL], current and voltage both are in phases as far as supply side is concerned.

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Solution: Given that, $V_s = 230$ V, $f = 50$ Hz, a load of 230 V, 50 Hz, 25A, 0.8 lagging power factor. There is a voltage sag -20% ($X = 0.2$ pu) in supply system with base value of 230 V.

The active power of the load is, $P_L = V_L \cdot I_L \cdot \text{pf} = 230 \cdot 25 \cdot 0.8 = 4600$ W.

During nominal grid operation,

$$V_{\text{DSTN}} = 230 \text{ V}$$

$$I_{\text{DSTN}} = I_L \sin \theta = 25 \cdot \sqrt{1 - 0.8^2} = 15 \text{ A,}$$

$$S_{\text{DSTN}} = V_{\text{DSTN}} \cdot I_{\text{DSTN}} = 230 \cdot 15 = 3450 \text{ VA.}$$

The rating of DVR is as, $V_{\text{DVRN}} = 0$, hence, $S_{\text{DVRN}} = 0$.

Voltage Sag Compensation by Right Hand UPQC-P

It means that during the voltage sag, the supply voltage reduces to $V_s' = V_s \cdot (1 - X) = 230 \cdot (1 - 0.20) = 184$ V.

The supply current during voltage sag compensation is as,

$$I_s' = P_L / V_s' = 4600 / 184 = 25 \text{ A.}$$

(a) The voltage rating of DSTATCOM of UPQC is equal to AC load voltage of $V_{\text{DST}} = 230$ V, since it is connected across the load of 230V sine waveform.



[FL], coming to numerical part of it, typically given that the V S equal 230-volt, 50 hertz, a load of 50; 230-volt, 50 hertz, 25 point ampere point 5, 0.8 lagging power factor. [FL], there is a voltage sag of minus 20 percent, X equal to 0.2 in the supply system with the base value of 230 volt and active power of the load is your typically 230, 25 into 0.8 4600 watt and during normal condition, the V DSTATCOM is 230 volt and I DSTATCOM will be corresponding to 15 ampere.

[FL], DSTATCOM rating is your voltage multiply current so, its become 3450 VA. [FL], rating of the DVR voltage is 0, current VR rating is also, then DSTATCOM rating is DVR

rating is 0 because of nominal condition, we are not injecting any voltage and [FL], there is no action of the DVR, but DSTATCOM have to still correct the power factor to unity.

Now, coming to the voltage sag compensation by right hand UPQC, it means that the voltage during sag the supply voltage reduces by 20 percent [FL], this is the typical voltage for the Ps, your grid voltage or PCC voltage and the current of the grid can be then power divide by this voltage [FL], it become 25 ampere and the DSTATCOM rating is equal to the your 230 volt, since connected across the load directly.

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(b) The current rating of DSTATCOM of UPQC is computed as. The DSTATCOM of UPQC is to correct the power factor load to unity, hence the required reactive power of the load it must supply, therefore, $I_{DSTR} = \text{reactive current of the load} = I_L \sqrt{1 - PF^2} = 25 * 0.6 = 15 \text{ A}$.

Active power component of the DSTATCOM current,
 $I_{DSTA} = (V_s * X) * I_s / V_s = (46 * 25) / 230 = 5 \text{ A}$.

Total current of DSTATCOM, $I_{DST} = \sqrt{I_{DSTA}^2 + I_{DSTR}^2} = 15.81 \text{ A}$.

(c) The VA rating of VSC of DSTATCOM of UPQC,
 $S_{DST} = V_{DST} * I_{DST} = (230 * 15.81) \text{ VA} = 3636.62 \text{ VA}$.

(d) The voltage rating of DVR of UPQC is computed as,
 The voltage rating of DVR, $V_{DVR} = V_s * X = 230 * 0.20 = 46 \text{ V}$.

(e) The current rating DVR of UPQC is same as the supply current after shunt compensation as.
 $I_{DVR} = I_s'$ = the fundamental active component of load current,
 $I_s' = P_L / V_s' = 4600 / 184 = 25 \text{ A}$.



[FL], the rating of the, current rating of DSTATCOM UPQC is computed as all as that the DSTATCOM UPQC is to correct the power factor of the load to unity, hence the required reactive power of the load must be supply from the DSTATCOM and that comes like a 25 into 0.6 into 15 ampere and the active power of the DSTATCOM will be corresponding to the

active power required by the your DVR that is the power of DVR divide by 230 [FL], it is a 5 ampere.

[FL], total current of the DSTATCOM will be the reactive current plus active current [FL], that comes like a typically your 15.81 from 5 ampere and 15 ampere, it become 15.81 and VA rating of the DSTATCOM will be the voltage multiply the current [FL], it comes 3636.62 and voltage rating of DVR of UPQC is calculated directly from V S into X [FL], that is a 46 volt and the current rating of the DVR of UPQC same as the supply after the compensation. [FL], I DVR equal to I S, the fundamental active component of load current is 4600 divide by 184 that is a 25 ampere.

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(f) The VA rating of DVR of UPQC-P,
 $S_{DVR} = V_{DVR} * I_{DVR} = 46 * 25 \text{ VA} = 1150 \text{ VA}$.
 The VA rating of UPQCP during voltage sag is as,
 $S_{UPQCP(\text{under sag})} = S_{DST} + S_{DVR} = 3636.62 + 1150 = 4786.62 \text{ VA}$.
 Hence considering an overall rating (both normal and under voltage sag), ratings of both compensators are as,
 $V_{DST} = 230 \text{ V}$, $I_{DST} = 15.81 \text{ A}$,
 $S_{DST} = V_{DST} * I_{DST} = 230 * 15.81 = 3636.62 \text{ VA}$.
 $V_{DVR} = 46 \text{ V}$, $I_{DVR} = 25 \text{ A}$, $S_{DVR} = V_{DVR} * I_{DVR} = 1150 \text{ VA}$.
 $S_{DST} = 3636.62 \text{ VA}$ and $S_{DVR} = 1150 \text{ VA}$.
 (g) The overall VA rating of UPQC-P is as,
 $S_{UPQCP} = S_{DST} + S_{DVR} = 3636.62 + 1150 = 4786.62 \text{ VA}$.



And the VA rating of DVR will be your V DVR into I DVR [FL], 46 into 25 ampere that becomes your 1150 VA and the VA rating of the UPQC during the voltage sag is your S DST plus S DVR [FL], it comes your typically 3636.62 divide plus 1150 [FL], it become 4786.62.

Hence, considering the overall rating both normal and under voltage sag rating of both compensator [FL], DSTATCOM 230 volt with 15.81 ampere [FL], that is the rating of the typically of DSTATCOM 3636.62 and DVR is compensating 46 volt with a current of 25 ampere [FL], it is a DVR rating is 1150 and the overall rating of the VA of either DV DST plus DVR [FL], that is 6 point; 3636.62 plus 1150 [FL], it become 4786.62 VA.

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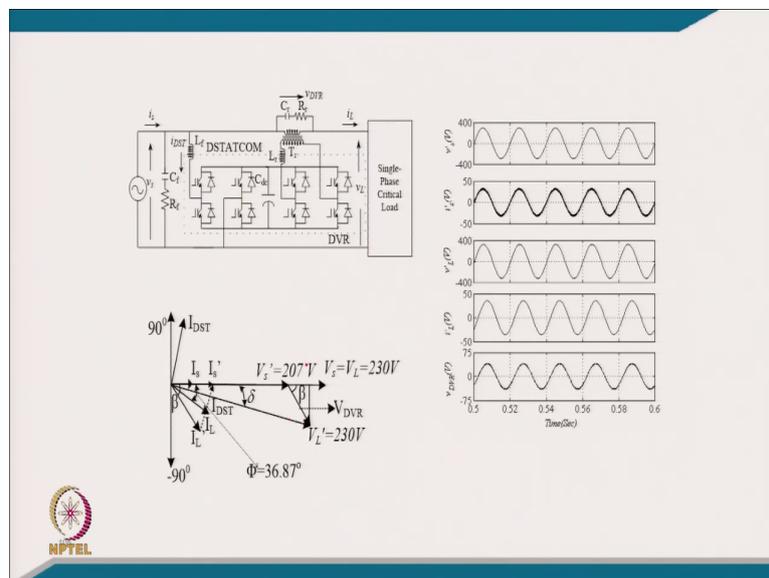
Q.5 A single-phase unified power quality compensator (UPQC consisting of DSTATCOM and DVR using two VSCs with common DC bus capacitor) is to be designed for compensation of a load of 230 V, 50 Hz, 25 A, 0.8 lagging power factor as a **Left Hand UPQC-P** (shown in Fig.). There is a **voltage sag of -10%** in supply system with base value of 230 V. Calculate (a) the voltage rating of DVR of UPQC-P, (b) the current rating DVR of UPQC-P, (c) the VA rating of DVR of UPQC-P, (d) the voltage rating of DSTATCOM of UPQC-P, (e) the current rating of DSTATCOM of UPQC-P, (f) the VA rating of DSTATCOM of UPQC-P, and (g) total VA rating of UPQC to provide reactive power compensation for unity power factor at AC mains with a constant regulated voltage of 230 V at 50 Hz across the load.

[FL], coming to 5th numerical example, a typically a single-phase UPQC I mean consisting of DSTATCOM and DVR using two VSCs with common DC bus is to be designed for compensation of load of 230-volt, 50 hertz, 25 ampere, 0.8 lagging power factor as a left hand

UPQC and there is a voltage sag of minus 10 percent in the supply system with base value of 230 volt.

Calculate the voltage rating of DVR UPQC, current rating of DVR, volt VA rating of DVR, voltage rating of DSTATCOM, current rating of the DSTATCOM and VA rating of DSTATCOM and total VA rating of UPQC to provide reactive power compensation for unity power factor at AC mains constant regulated voltage of 230-volt, 50 hertz across the load.

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[FL], this is typically because we are putting left hand DSTATCOM and it is a DVR on series on the load side [FL], that is typically the phasor diagram that ok, this is typically how we are injecting the voltage here and these are the typical waveform.

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Solution: Given that, $V_s = 230$ V, $f=50$ Hz, a load of 230 V, 50 Hz, 25 A, 0.8 lagging power factor. There is a voltage sag -10% ($X=0.1$ pu) in supply system with base value of 230 V.

During nominal grid operation,

$$V_{DSTN} = 230 \text{ V}$$
$$I_{DSTN} = I_L \sin \phi = 25 * \sqrt{1 - 0.8^2} = 15 \text{ A,}$$
$$S_{DSTN} = V_{DSTN} * I_{DSTN} = 230 * 15 = 3450 \text{ VA.}$$

The rating of DVR is as, $V_{DVRN} = 0$, and $S_{DVRN} = 0$.

Voltage Sag Compensation by Left Hand UPQC-P.

It means that during the voltage sag, the supply voltage reduces to $V_s' = V_s * (1 - X) = 230 * (1 - 0.10) = 207$ V.

The active power of the load is, $P_L = V_L * I_L * \text{pf} = 230 * 25 * 0.8 = 4600$ W.

The supply current during the voltage sag compensation is as follows. $I_s' = P_L / V_s' = 4600 / 207 = 22.22$ A.

(a) The voltage rating of DVR of UPQC-P is computed as.

There is voltage sag of -10% in the supply system with base value of 230 V. Therefore, the DVR of Left Hand UPQC-P must inject a



[FL], coming to numerical portion of it that the V S equal to 230-volt, 50 hertz, a load of 230-volt, 50 hertz, 25 ampere, 0.8 lagging power factor. There is a voltage sag of minus 10 percent and in the supply system with base value of 230 volt. [FL], during normal grid condition, the V DSTATCOM is 230 volt and current rating is for reactive power of the load [FL] that is corresponding to 15 ampere and the rating of the DSTATCOM is your 230 into 15, 3450 VA and the rating of DVR is typically 0 because we are not injecting any voltage and that is the real and VA rating is also there, but for the voltage sag compensation by left hand UPQC.

Now, DVR have two function for voltage injection [FL], it means that during voltage sag, the supply voltage reduces to V S equal to let say V S minus 1 X [FL], 230 into 1 minus 0.1 [FL],

it become the voltage typically of 207 volt in place of 230 and the active power of the load now is $V_L I_L$ [FL], that is 230 into 25 into 0.8, 4600 watt.

[FL], supply current during the voltage sag compensation is as a P L upon V S [FL], it becomes 22.22 because there is a voltage sag here. [FL], voltage rating of that your DVR of UPQC, the voltage sag 10 percent [FL], typically for nominal voltage of 230 volt.

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voltage in phase of the load current to provide the required voltage at the load end.

From phasor diagram (Fig.),

$$V_s' \sin \delta = V_{DVR} \sin \phi \text{ and } (V_s' \cos \delta + V_{DVR} \cos \phi) = V_L'$$

Substituting values, $V_s' = 0.9 \times 230$ V, $V_L' = 230$ V, $\cos \phi = 0.8$ and $\sin \phi = 0.6$, and solving these above equations, one gets, $V_{DVR} = 29.71$ V and $\delta = 4.94^\circ$ and $\beta = \delta + \phi = 41.83^\circ$.

The voltage rating of DVR, $V_{DVR} = 29.71$ V.

(a) The current rating DVR of UPQC-P must be same as load current as, $I_{DVR} = I_L' = 25$ A.

(b) The VA rating of DVR of UPQC-P is as,

$$Q_{DVR} = 0.0 \text{ VAR,}$$

$$P_{DVR} = V_{DVR} \cdot I_{DVR} = (29.71 \times 25) \text{ VA} = 742.75 \text{ W.}$$

$$S_{DVR} = \sqrt{P_{DVR}^2 + Q_{DVR}^2} = P_{DVR} = 742.75 \text{ VA.}$$

(c) The voltage rating of DSTATCOM of UPQC-P is equal to maximum voltage across it, $V_{DST} = V_s = 230$ V.



Therefore, left hand must inject the voltage in phase with the load current to provide the required voltage. [FL], the from phasor diagram $V_s \sin \delta$ equal to typical putting the value here [FL], if you put value here, the all the [FL], we get the DVR equal to 29.71 and delta is 4.94 and beta comes 41 point typically 83.

[FL], VA rating of the DVR will be 29.7 volt and current rating of this will be same as the load current rating because it is connected on the load side 25 ampere and the VA rating typically of the your DVR UPQC is your 0 because we are only putting active power not the reactive power [FL], DVR will be same as here [FL], we put the this voltage and current [FL], 742.75 watt and S DVR will be the same as P DVR [FL] that is 742.75 and voltage rating of DSTATCOM of UPQC equal to the your 230 volt.

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(d) The current rating of DSTATCOM of UPQC-P is computed as follows.
 The DSTATCOM of UPQC-P is to correct the power factor of the AC mains to unity, hence the required reactive power by DSTATCOM is now higher than the load reactive power as the angle between supply voltage and the load current is changed to $\beta = \phi + \delta$.
 The DSTATCOM current rating is as,
 $Q_{DST} = V_s' I_L' \sin \beta = 207 * 25 * \sin 41.83^\circ = 3450 \text{ VAR}$
 $P_{DST} = - P_{DVR} = V_{DVR} I_{DVR} = (29.71 * 25) \text{ VA} = - 742.75 \text{ W}$

(e) The VA rating of DSTATCOM is as,
 $S_{DST} = \sqrt{(P_{DST}^2 + Q_{DST}^2)} = 3529.1 \text{ VA}$
 $I_{DST} = S_{DST} / V_{DST} = 3529.1 / 207 = 17.04 \text{ A}$
 The VA rating of UPQCP during sag compensation is as,
 $S_{UPQCP(\text{under sag})} = S_{DST} + S_{DVR} = 3529 + 742.75 = 4271.75 \text{ VA}$



And the current rating of DSTATCOM is computed as follows. [FL], DSTATCOM UPQC is to correct the power factor of AC mains to unity, hence the required reactive power by DSTATCOM now higher than the load reactive power as the angle between the supply voltage and load current is changed beta equal to phi plus delta and DSTATCOM rating is as

your Q equal to $V_L I_L \sin \beta$ [FL], that comes 3450 VAR and P DST equal to your typically your voltage and current [FL], it become minus 74; 42.75.

And the VA rating of typically of now DST; DSTATCOM will be $P^2 + Q^2$ [FL], it become 3.3529 which we calculated here and your I DST will be your; S DST will be your typically your VA divide by voltage [FL], it is 17.04 and voltage rating of UPQC during sag will be S DVR and plus S DST [FL], it become 3529 plus 742.275 [FL], it is a 4271.75 VA like.

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Hence considering overall rating (both normal and under voltage sag), ratings of both compensators are as,

$$V_{DST} = 230 \text{ V,}$$

$$I_{DST} = 17.04 \text{ A,}$$

$$S_{DST} = V_{DST} \cdot I_{DST} = 230 \cdot 17.04 = 3921.2 \text{ VA.}$$

$$V_{DVR} = 29.71 \text{ V, } I_{DVR} = 25 \text{ A, } S_{DVR} = V_{DVR} \cdot I_{DVR} = 742.75 \text{ VA.}$$

(f) The VA rating of UPQC-P is as,

$$S_{UPQCP} = S_{DST} + S_{DVR} = 3921.2 + 742.75 = 4663.95 \text{ VA.}$$


Hence, considering the overall rating for normal and under voltage sag, the rating of both compensator are DSTATCOM 230 volt and current rating 17.04 and the DSTATCOM rating is 230 into 17 [FL], it become 3921 point VA and DVR voltage rating is 29.71 and current is 25

ampere [FL], its rating come 742.75 and total rating will be S D DSTATCOM, S DVR [FL], adding these two, it become 4663.95 VA.

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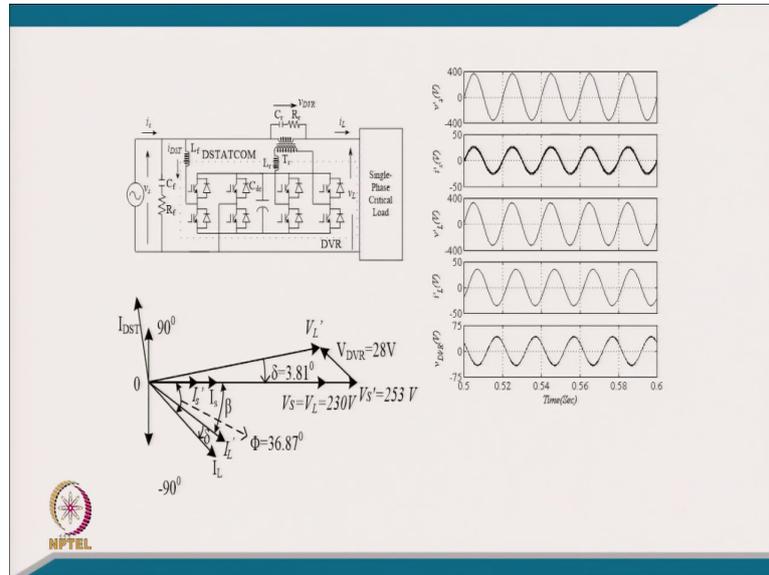
Q.6 A single-phase unified power quality compensator (UPQC consisting of DSTATCOM and DVR using two VSCs with common DC bus capacitor) is to be designed for the compensation of a load of 230 V, 50 Hz, 25 A, 0.8 lagging power factor as a **Left Hand UPQC-P** (shown in Fig.). There is a **voltage swell of +10%** in supply system with base value of 230 V. Calculate (a) the voltage rating of DVR of UPQC-P, (b) the current rating DVR of UPQC-P, (c) the VA rating of DVR of UPQC-P, (d) the voltage rating of DSTATCOM of UPQC-P, (e) the current rating of DSTATCOM of UPQC-P, (f) the VA rating of DSTATCOM of UPQC-P, (g) total VA rating of UPQC-P to provide reactive power compensation for unity power factor at AC mains with constant regulated voltage of 230 V at 50 Hz across the load.

[FL], coming to 6th numerical example, a single-phase UPQC consisting of DSTATCOM and DVR using two; V two VSC with the common DC bus capacitor is to be designed for compensation of load of 230-volt, 50 hertz, 25 ampere, 0.8 lagging power factor as a left hand UPQC and there is a voltage swell of 10 percent in the supply system with the base value of 230-volt.

[FL], calculate the voltage rating of DVR, current rating of DVR, VA rating of the DVR and voltage rating of DSTATCOM, current rating of DSTATCOM and VA rating of DSTATCOM and total VA rating of UPQC-P to provide reactive power compensation for

unity power factor at AC mains with constant regulated voltage of 230-volt, 50 hertz across the load.

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[FL], this is you can again see that it is a left hand UPQC yeah, it is a left hand UPQC so, DSTATCOM put on the grid side and your DVR is put on the load side and this is the typically the phasor diagram performing to this condition and this is the typically the waveform after getting the grid model and solving that.

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Solution: Given that, $V_s = 230$ V, $f=50$ Hz, a load of 230 V, 50 Hz, 25 A, 0.8 lagging power factor. There is a voltage swell +10% in supply system with base value of 230 V.

The active power of the load is, $P_L = V_L \cdot I_L \cdot \text{pf} = 230 \cdot 25 \cdot 0.8 = 4600$ W.

Grid current under nominal operating condition is,

$$I_s = P_L / V_s = 4600 / 230 = 20 \text{ A.}$$

During nominal grid condition injected voltage by DVR should be zero hence $V_{\text{DVRN}} = 0$, $I_{\text{DVRN}} = I_L = 25 \text{ A}$.

During nominal grid condition, $I_{\text{DSTN}} = I_L \sin \theta = 15 \text{ A}$.

Voltage Swell Compensation by Left Hand UPQC-P

It means that after the voltage swell voltage increases to

$$V_s' = 230 \cdot (1 + 0.10) = 253 \text{ V.}$$

The supply current after the voltage swell compensation is as,

$$I_s' = P_L / V_s' = 4600 / 253 = 18.18 \text{ A.}$$

(a) The voltage rating of DVR of UPQC-P is computed as.

There is voltage swell of +10% in the supply system with base value of 230 V. Therefore, the DVR of Left Hand UPQC-P must



[FL], coming to the numerical portion of it, given that V S equal to 230-volt, 50 hertz, a load voltage of 230-volt, 50 hertz of 25 ampere, 0.8 lagging power factor. There is voltage swell of 10 percent in the supply system with the base value of 230-volt and the active power of the load is $V_L I_L$, power factor [FL], it comes like a 4600 watt and grid current under normal operating condition is P_L upon V_S .

[FL], it is a typically 20 ampere and during normal grid condition, the injected voltage by DVR should be equal to 0 and typically, the DVR current is 25 ampere and normal grid condition the DSTATCOM current is reactive power of reactive current of the load and voltage typically [FL], is the same at 230 [FL], you have a your DSTATCOM rating 230 into 15 I mean like.

[FL], now coming to voltage swell condition by left hand UPQC means that after the voltage swell, voltage increases so, it is a 230 into 1.101 [FL], it become 253-volt and supply current after the voltage compensation is your power divide by V S [FL], it is your current become 18.18 because the voltage increases because of voltage swell across the PCC. [FL], the voltage rating of DVR for UPQC computed as since there is a voltage swell of 10 percent in the supply system with base voltage of 230-volt.

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Inject a voltage in out of phase of the load current to provide the required voltage at the load end.
 From phasor diagram (Fig.),
 $V_s' \sin \delta = V_{DVR} \sin \phi$ and $V_s' \cos \delta = V_L + V_{DVR} \cos \phi$
 Substituting values, $V_s' = 1.1 * 230$ V, $V_L = 230$ V, $\cos \phi = 0.8$ and $\sin \phi = 0.6$, and solving these above equations, one gets,
 $V_{DVR} = 28.05$ V and $\delta = 3.81^\circ$ and $\beta = \phi - \delta = 33^\circ$
 The voltage rating of DVR, $V_{DVR} = 28.05$ V.
 (b) The current rating DVR of UPQC must be same as load current as.
 $I_{DVR} = I_L = 25$ A.
 (c) The VA rating of DVR of UPQC-P is as,
 $Q_{DVR} = 0.0$ VAR,
 $P_{DVR} = V_{DVR} * I_{DVR} = 28.05 * 25$ VA = 701 W.
 $S_{DVR} = \sqrt{P_{DVR}^2 + Q_{DVR}^2} = P_{DVR} = 701$ VA.
 (d) The voltage rating of DSTATCOM of UPQC-P is equal to ac source voltage of $V_{DST} = V_s = 253$ V, since it is connected across the PCC of 253 V sine waveform.



Therefore, the DVR of left hand UPQC must inject the voltage in out of the phase of load current to provide the required voltage at load end and from the phasor diagram, we can calculate the typically the voltage $V \sin \delta$ equal to $V_{DVR} \sin \phi$ [FL], from which we can calculate putting the value here, we can find out the typically the V_{DVR} equal to 28.05 and the angle β come 33 I mean that $\phi - \delta$, δ already we calculated.

[FL], VA rating of the DSTATCOM DVR is 28.05 and current rating of DVR is same as the load one that is typically 25 ampere and the reactive power is 0 because it is only injecting the active power the your DVR and the power is now voltage multiply the current [FL], 28.05 into 25 [FL], that is 701 watt and S DVR will be the same as P DVR [FL], that is 701 VA. The voltage rating of DSTATCOM UPQC-P is equal to the AC voltage of V DSTATCOM 253 since it is connected across the PCC of 253 sine wave.

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(e) The current rating of DSTATCOM of UPQC-P is computed as follows.

The DSTATCOM of UPQC-P is to correct the power factor of the source to unity, hence the required reactive power by DSTATCOM is now lower than the load reactive power as the angle between supply voltage and load current is reduced to $\beta = \phi - \delta$.

The DSTATCOM current rating is as,

$$Q_{DST} = V_s \cdot I_L \cdot \sin \beta = 253 \cdot 25 \cdot \sin(33) = 3450 \text{ VAR.}$$

$$P_{DST} = P_{DVR} = V_{DVR} \cdot I_{DVR} = 701 \text{ W.}$$

(f) The VA rating of DSTATCOM is as,

$$S_{DST} = \sqrt{P_{DST}^2 + Q_{DST}^2} = 3520.5 \text{ VA}$$

Current through DSTATCOM during voltage swell is

$$I_{DST} = S_{DST} / V_s = 3520.5 / 253 = 13.91 \text{ A}$$

The VA rating of UPQCP during voltage swell is as,

$$S_{UPQCP(\text{under swell})} = S_{DST} + S_{DVR} = 3520.5 + 701 = 4221.5 \text{ VA}$$


[FL], current rating of DSTATCOM P is connected as follows. The DSTATCOM of UPQC is to correct the power factor of the source to unity, hence the required reactive power by DSTATCOM is now lower than the load reactive power as the angle between supply voltage and load current is reduced to beta which is phi minus delta. [FL], DSTATCOM current

rating reduces to your V_L , V_S into $I_L \sin \beta$ [FL], it is a 253 into 25 into angle of β 33 degree [FL], it come 3450 VAR.

And power of course, DVR equal to DST because whatever power DSTAT DVR needs it had to supply through DSTATCOM [FL], it come same as 701 watt. [FL], VA rating of the DSTATCOM will be $P^2 + Q^2$ [FL], it come 3520.5 VA and current rating through DSTATCOM in voltage swell condition is that typically VA rating divide by the voltage.

[FL], it say current now DSTATCOM is 13.91 ampere and the VA rating of UPQC will be your VA rating of DSTATCOM plus VA rating of the DVR [FL], it comes totally adding two, it become 4221.5 VA.

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Hence considering an overall rating (both normal and under voltage swell), ratings of both compensators are as,

$$V_{DST} = 253 \text{ V,}$$
$$I_{DST} = 15 \text{ A,}$$
$$S_{DST} = V_{DST} * I_{DST} = 253 * 15 = 3795 \text{ VA.}$$
$$V_{DVR} = 28.05 \text{ V,}$$
$$I_{DVR} = I_L = 25 \text{ A,}$$
$$S_{DVR} = V_{DVR} * I_{DVR} = 701 \text{ VA.}$$

(g) The overall VA rating of UPQC-P is as,

$$S_{UPQC-Q} = S_{DST} + S_{DVR} = 3795 + 701 = 4496 \text{ VA.}$$


Hence, the considering the overall rating both normal and under voltage, the rating of compensator as V DSTATCOM 253 volt and I DST 15 ampere and S DSTATCOM is multiplication of those 3795 VA and V DVR equal to 28 volt, I DVR 25 ampere [FL], VA rating of the DVR is 701 VA and a overall VA rating of UPQC is your DSTATCOM rating plus your DVR rating so, it become 4496 VA.

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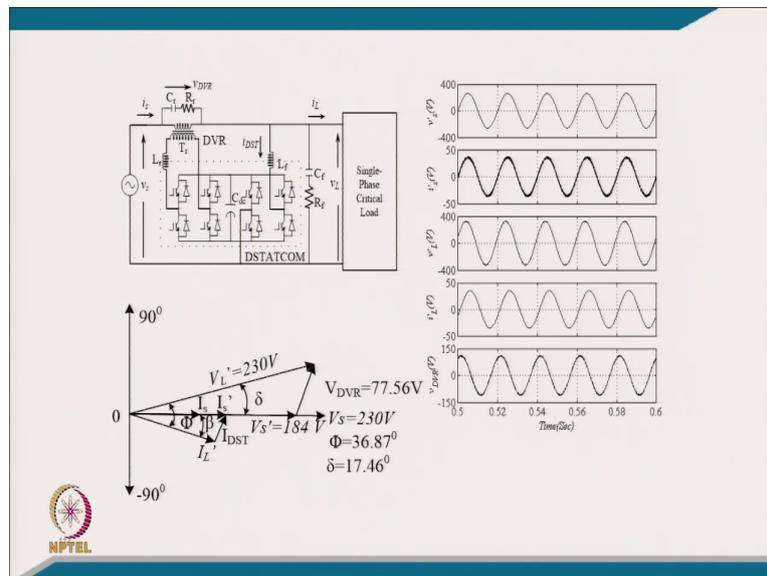


Q.7 A single-phase unified power quality compensator (UPQC consisting of DSTATCOM and DVR using two VSCs with common DC bus capacitor) is to be designed for a load compensation of 230 V, 50 Hz, 25 A, 0.8 lagging power factor as a **Right Hand UPQC-S** (shown in Fig.). There is a **voltage sag of -20%** in the supply system with base value of 230 V. Calculate (a) the voltage rating of DVR of UPQC-S, (b) the current rating DVR of UPQC-S, (c) the VA rating of DVR of UPQC-S, (d) the voltage rating of DSTATCOM of UPQC-S, (e) the current rating of DSTATCOM of UPQC-S, (f) the VA rating of DSTATCOM of UPQC-S, (g) total VA rating of UPQC-S to provide reactive power compensation for unity power factor at PCC with constant regulated voltage of 230 V at 50 Hz across the load. Consider same rating of the both VSCs.

[FL], coming to the 7th numerical example, a single phase UPQC consisting of DSTATCOM, DVR using 2 VSC with common DC bus capacitor is to be designed for a load compensation of 230-volt, 50 hertz, 25 ampere, 0.8 lagging power factor as a right hand UPQC and there is a voltage sag of 20 percent in the supply voltage with the base value of 230-volt.

Calculate the voltage rating of DVR, current rating of DVR, VA rating of DVR, voltage rating of DSTATCOM, current rating of DSTATCOM, VA rating of DSTATCOM and total rating of the UPQC as to provide the reactive power compensation for unity power factor at PCC with constant regulated voltage of 230-volt, 50 hertz across the load consider the same VA rating of both VSCs. [FL], this is a interesting, you can call it the assumption like.

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And why it is this? Because normally the inventory of both, I mean inverter is same. [FL], we can load keeping the losses also same [FL], it is a right hand UPQC [FL], DSTATCOM on right side closer to the load and the DVR is in series with the line which is right configuration, we already discussed earlier now, only the method of control is different here.

[FL], you have a supply voltage, supply current for going to the power and this is the load voltage, load current and this is the DVR injected voltage so that the load voltage regulated compared to the there is a voltage sag on the typically.

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Solution: Given that, $V_s = 230$ V, $f=50$ Hz, a load of 230 V, 50 Hz, 25 A, 0.8 lagging power factor. There is voltage sag of -20% in the supply system with base value of 230 V. Both VSCs are of same ratings.

Under Steady State Condition for Unity Power Factor at ac Mains without Voltage Sag

The active power of the load is, $P_L = V_L \cdot I_L \cdot \text{pf} = 230 \cdot 25 \cdot 0.8 = 4600$ W.

The reactive power of the load is, $Q_L = V_L \cdot I_L \cdot \sqrt{1 - \text{pf}^2} = 230 \cdot 25 \cdot 0.6 = 3450$ VAR.

The supply current is as, $I_s = P_L / V_s = 4600 / 230 = 20$ A.

Each VSC has reactive power rating equal to half of the reactive power of the load, which is equal to $Q_{DST} = Q_{DVR} = Q_L / 2 = 3450 / 2 = 1725$ VAR.

From the following relation of reactive power of DVR, the power angle can be computed as.

$Q_{DVR} = V_L I_s \sin \delta = 1725$, therefore, $\delta = 22.02^\circ$ and $P_{DVR} = -V_L I_s (1 - \cos \delta) = -339.69$ W.

[FL], coming to the numerical portion, given that V S equal to 230-volt, 50 hertz, a load of 30; 230-volt, 50 hertz, 25 ampere, 0.8 lagging power factor. There is a voltage sag of 20 percent in the supply system with the base value of 230-volt and both voltage source converter are the same rating [FL], this is interesting case like because you are having a equal loading of both.

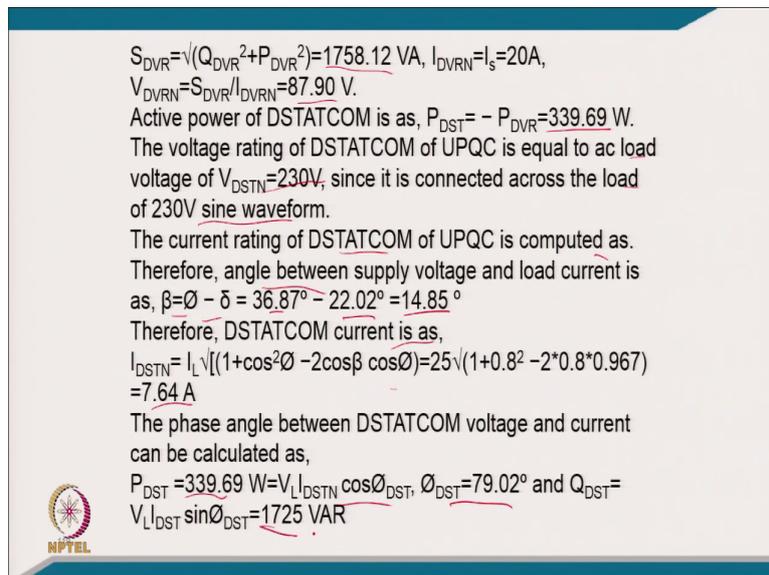
[FL], under a steady state condition for unity power factor without voltage sag the active power of the load is typically $V_L I_L \cos \phi$ [FL], it becomes like your 230 into 25.8 [FL],

4600 watt and reactive power of the load is your Q L equal to your typically 230, 25 into 0.6 [FL], it is a 3450 VAR.

Now, the supply current typically will be your active power divide by 230 that is 20 ampere. [FL], each VSC reactive power rating have to be half of the reactive power of the load [FL], which is equal to your Q DST equal to Q DVR equal to Q L by 2 [FL], it is a 3450 by 2 [FL], each I mean you can call it compensator have a VA rating 7, 1725 VAR.

[FL], from the following relation of reactive power of DVR, the power angle can be calculated [FL], we know the Q DVR V L I sin delta [FL], it is the 1725 so, there delta we can calculate and from this P DVR will be from this relation, we can find out will be your 339.69.

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$S_{DVR} = \sqrt{(Q_{DVR})^2 + P_{DVR}^2} = 1758.12 \text{ VA}$, $I_{DVRN} = I_s = 20\text{A}$,
 $V_{DVRN} = S_{DVR} / I_{DVRN} = 87.90 \text{ V}$.
 Active power of DSTATCOM is as, $P_{DST} = -P_{DVR} = 339.69 \text{ W}$.
 The voltage rating of DSTATCOM of UPQC is equal to ac load voltage of $V_{DSTN} = 230\text{V}$, since it is connected across the load of 230V sine waveform.
 The current rating of DSTATCOM of UPQC is computed as.
 Therefore, angle between supply voltage and load current is as, $\beta = \theta - \delta = 36.87^\circ - 22.02^\circ = 14.85^\circ$
 Therefore, DSTATCOM current is as,
 $I_{DSTN} = I_L \sqrt{(1 + \cos^2 \theta - 2 \cos \beta \cos \theta)} = 25 \sqrt{(1 + 0.8^2 - 2 * 0.8 * 0.967)} = 7.64 \text{ A}$
 The phase angle between DSTATCOM voltage and current can be calculated as,
 $P_{DST} = 339.69 \text{ W} = V_L I_{DSTN} \cos \theta_{DST}$, $\theta_{DST} = 79.02^\circ$ and $Q_{DST} = V_L I_{DST} \sin \theta_{DST} = 1725 \text{ VAR}$



Now, the S DVR will be Q DVR plus P DVR [FL], that is typical this VR and I DVR equal to 20 ampere and V DVR equal to now, this much voltage. Once you know VA rating and current rating, we can find out the voltage rating.

The active power of DSTATCOM is equal to same as the typically of power of DVR that is 339.69 which we calculate earlier and the voltage rating of the DSTATCOM of UPQC equal to the AC load 230-volt and it is a across the load of this. [FL], current rating of DSTATCOM is computed from the angle calculation of beta equal to phi and that is $36.87 - 22$ [FL], 14.85.

Therefore, DSTATCOM current rating will be $I_L I_{mean} \sqrt{1 + \cos^2 \theta}$ that is the angle between the typical [FL], it comes typically of 7.64 ampere and the phase angle between the DSTATCOM and current you can call it θ_{DST} 339 which is DSTATCOM need this; DVR need this power [FL], DSTATCOM have to supply 339.69 watt and this can be equated to $V_L I_{DSTN} \cos \theta_{DST}$ [FL], you get the angle for phi DSTATCOM 79.02 and Q DSTATCOM, we can calculate is 1725 VAR.

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Voltage Sag Compensation by Right Hand UPQC-S

Each VSC has reactive power rating equal to half of the reactive power of the load, which is equal to $Q_{DST} = Q_{DVR} = Q_L/2 = 3450/2 = 1725 \text{ VAR}$.

From the relation of reactive power of DVR (see Phasor Diagram of Fig.), power angle is computed as.

It means that after the voltage supply voltage reduces to $V_s' = 230*(1 - 0.20) = 184 \text{ V}$, and $X=0.2$.

$Q_{DVR} = V_L' I_s' \sin \delta = 1725 \text{ VAR}$, therefore, $\delta = 17.46^\circ$. (As $I_s' = P_L / V_s' = 4600/184 = 25 \text{ A}$ and $V_L' = 230 \text{ V}$).

(a) The voltage rating of DVR of UPQC-S is as,

(b) $V_{DVR} = \sqrt{(V_L')^2 + V_s'^2 - 2*V_L'*V_s'*\cos \delta} = 77.56 \text{ V}$.

The current rating DVR of UPQC-S is as, It is connected in series with the supply, therefore, $I_{DVR} = I_s' = 25 \text{ A}$.

(c) The VA rating of DVR of UPQC-S is as,

$S_{DVR} = V_{DVR} * I_{DVR} = 77.56*25 = 1939.02 \text{ VA}$.



[FL], for after coming the voltage compensation, typically by right hand UPQC [FL], each VSC have a reactive power equal to half of the reactive power load which is equal to like a Q L Q DST equal to Q VR Q L by 2 that is 1725 VAR. From the relation of reactive power of DVR, the power angle is computed as typically from this relation [FL], your V supply voltage reduces to 184 and with the sag of 20 percent, then Q DVR will be a typically I S equal to that same as the DVR of the already we have given.

[FL], we can calculate delta from here and then, once we know delta, we can find out typically the given a current in the D; you can call it current in the supply and the voltage rating of the you can call it of DVR can be calculated from the phase this phasor [FL], it come 77.56 and current rating DVR is same as the connected in series with the supply. Therefore, it

is a I DVR equal to I S 25. [FL], VA rating of the DVR can be calculated, this 77.56 into 25 [FL], it become 1939.02 VA.

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And the active power flowing through DVR is as,
 $P_{DVR} = -\sqrt{(S_{DVR}^2 - Q_{DVR}^2)} = -885 \text{ W}$.
 This -sign denotes that DVR absorbing this active power which is fed to dc bus and therefore, active power of DSTATCOM is as, $P_{DST} = -P_{DVR} = 885 \text{ W}$.
 The voltage rating of DSTATCOM of UPQC-S is equal to AC load voltage of $V_{DST} = 230 \text{ V}$, since it is connected across the load of 230 V sine waveform.
 The current rating of DSTATCOM of UPQC-S is computed as. Therefore, an angle between the supply voltage and the load current is as, $\beta = \phi - \delta = 36.87^\circ - 17.46^\circ = 19.41^\circ$.
 Therefore, DSTATCOM current is as,
 Or $I_{DST} = S_{DST} / V_{DST} = S_{DVR} / V_{DST} = 1939.02 / 230 = 8.43 \text{ A}$.
 The phase angle between DSTATCOM voltage and current can be calculated as,
 $P_{DST} = 885 \text{ W} = V_L I_{DST} \cos \phi_{DST}$, $\phi_{DST} = 62.86^\circ$ and
 $Q_{DST} = V_L I_{DST} \sin \phi_{DST} = 1725 \text{ VAR}$.

And the active power flow through DVR will be corresponding to your S square plus minus Q square [FL], it is a 885 watt and the minus sign denotes the DVR absorbing the active power which is fed from DC bus therefore, active power of the DSTATCOM is minus DVR that is 885 and voltage rating of DSTATCOM is same as 230-volt, then it is connected across the load and current rating of the DSTATCOM UPQC computed. [FL], therefore, angle between of supply voltage will be beta equal to phi minus delta [FL], it comes for 19.41.

And DSTATCOM current will be then I DST, S DST by typically this. [FL], we know S DVR because both rating are equal divide by 230 [FL], we get the current of 8.43. [FL], phase angle between DSTATCOM voltage and current will be now P you know, from P we can find

out the angle of DSTATCOM, 62.86 and Q DST can be calculated that is already 7; 1725 there is equal reactive power.

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(f) The VA rating of DSTATCOM of UPQC-S is as.
 $S_{DST} = S_{DVR} = \sqrt{P_{DST}^2 + Q_{DST}^2} = 1939.02 \text{ VA}$, which conforms the solution.

The VA rating of UPQCS during voltage sag is as,
 $S_{UPQCS(\text{under sag})} = S_{DST} + S_{DVR} = 1939.02 + 1939.02 = 3878.04 \text{ VA}$.

Hence considering an overall ratings (both normal and under voltage sag), ratings of both compensators are as,
 $V_{DVR} = V_{DVRN} = 87.90 \text{ V}$, $I_{DVR} = 25 \text{ A}$,
 $S_{DVR} = V_{DVRN} * I_{DVRN} = 87.90 * 25 = 2197.5 \text{ VA}$.
 $V_{DST} = 230 \text{ V}$, $I_{DST} = 8.43 \text{ A}$, $S_{DST} = V_{DST} * I_{DST} = 230 * 8.43 = 1939 \text{ VA}$.

The VA rating of UPQC-S, $S_{UPQC-S} = S_{DST} + S_{DVR} = 1939 + 2197.5 = 4136.5 \text{ VA}$.

Alternatively, If both the VSC of same VA are considered for same inventory then, $S_{DST} = S_{DVR} = 2197.5 \text{ VA}$.

The overall VA rating of UPQC-S is as,
 $S_{UPQC-S} = S_{DST} + S_{DVR} = 2197.5 + 2197.5 = 4395 \text{ VA}$.



[FL], VA rating of DSTATCOM will be P square Q square that comes 1939.2 VA which conforms the solution and VA rating during the voltage sag is your S DST that is both equal and that come 3878.07. Hence considering a overall rating both normal and under rating of both compensator is 89 into 25 that is 2197.5 and DSTATCOM to 238 point that is comes 1939 [FL], total rating of this is 4136.5. [FL], actually both VSC are of same VA rating, then the inventory is same [FL], S D are equal to 2197 VA and overall rating will be of sum of both [FL], that is 439 5 VA like.

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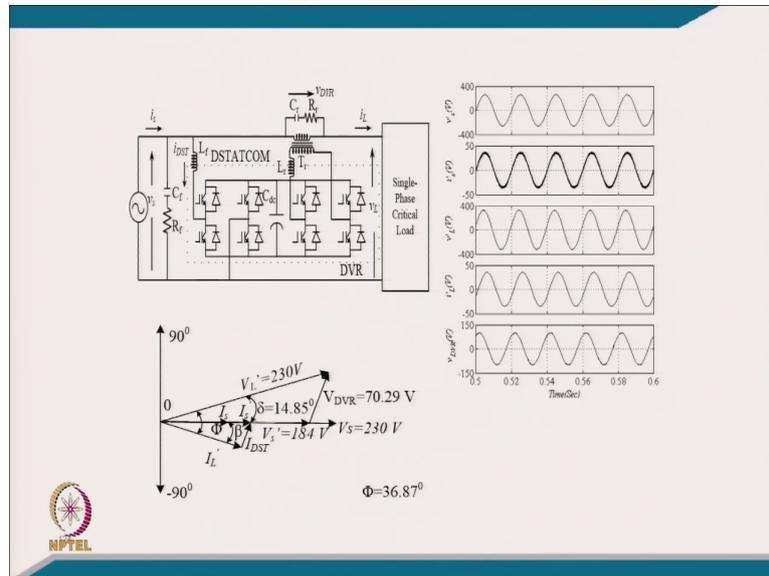
Q.8 A single-phase unified power quality compensator (UPQC consisting of DSTATCOM and DVR using two VSCs with common DC bus capacitor) is to be designed for a load compensation of 230 V, 50 Hz, 25 A, 0.8 lagging power factor as a **Left Hand UPQC-S** (shown in Fig.). There is a **voltage sag of -20%** in the supply system with base value of 230 V. Calculate (a) the voltage rating of DSTATCOM of UPQC-S, (b) the current rating of DSTATCOM of UPQC-S, (c) the VA rating of DSTATCOM of UPQC-S, (d) the voltage rating of DVR of UPQC-S, (e) the current rating of DVR of UPQC-S, (f) the VA rating of DVR of UPQC-S, (g) total VA rating of UPQC-S to provide reactive power compensation for unity power factor at PCC with constant regulated voltage of 230 V at 50 Hz across the load. Consider same rating of both VSCs.



[FL], coming to the example 8, a single-phase UPQC consisting of DSTATCOM DVR using two VSC with common DC link capacitor is designed for a load compensation of 230-volt, 50 hertz, 25 ampere, 0.8 lagging power factor to the left hand UPQCs and there is a voltage sag of 20 percent in the supply voltage the base value of 230-volt.

And calculate the voltage rating of DSTATCOM of UPQC, current rating of UPQC and VA rating of UPQC, the voltage rating of DVR, voltage rating current rating of DVR and VA rating of DVR and total VA rating of UPQC to provide reactive power compensation unity power factor with constant regulated voltage of 230-volt, 50 hertz across the load. Consider the rating of both VSCs same.

(Refer Slide Time: 55:38)



[FL], here what we are putting a DSTATCOM on the left side and DVR on right side. Why we are taking such numerical? Just to see the relative value with the different configuration for the same loading condition is same sag or swell conditions [FL], that is typically the phasor.

(Refer Slide Time: 55:52)

Solution: Given that, $V_s = 230$ V, $f=50$ Hz, a load of 230 V, 50 Hz, 25A, 0.8 lagging power factor. There is a voltage sag – 20% in the supply system with base value of 230 V. Both VSCs are of same ratings.

The UPQC-S operation under nominal grid condition is as,

The active power of the load is,
 $P_L = V_L \cdot I_L \cdot \text{pf} = 230 \cdot 25 \cdot 0.8 = 4600$ W.

The reactive power of the load is,
 $Q_L = V_L \cdot I_L \cdot \sqrt{1 - \text{pf}^2} = 230 \cdot 25 \cdot 0.6 = 3450$ VAR.

The supply current is as, $I_s = P_L / V_s = 4600 / 230 = 20$ A.

Each VSC has reactive power rating equal to half of the reactive power of the load, which is equal to
 $Q_{DST} = Q_{DVR} = Q_L / 2 = 3450 / 2 = 1725$ VAR.

From the following relation of reactive power of DSTATCOM, the power angle can be computed as.

The reactive power DSTATCOM is as, $Q_{DST} = V_s I_s \sin \beta = 1725$ VAR, $\beta = 17.46^\circ$, $\delta = \theta - \beta = 36.87^\circ - 17.46^\circ = 19.41^\circ$



[FL], coming to numerical part, given that V S equal 230-volt, 50 hertz, a load of 230-volt, 50 hertz, 25 ampere, 0.8 lagging power factor and there is a voltage sag of 20 percent in the supply system with the base value of 230-volt and both UPQC are of same rating. [FL], UPQC-S operation under nominal condition is at the active power of the load is equal to V L I into pf [FL], that is typically 4600 watt and reactive power of the load is your Q L, V L that is 3450 VAR and supply current will be now power divide by voltage that is 20 ampere.

[FL], each VSC have a reactive power equal to the half of the typically reactive power of the load which is your typically Q L upon this [FL], it comes 1725 VAR. From the following relation, the reactive power of DSTATCOM, the power angle can be calculated. [FL], we know this putting the value here of beta [FL], beta comes 17.46 degree and delta comes 30 typically of 19.41 degree which produces the rating typically corresponding to that [FL].

(Refer Slide Time: 56:51)

The active power DSTATCOM is as,

$$P_{DST} = V_s I_s - V_s I_L \cos \beta = 4600 - 5485.15 = -885.15 \text{ W.}$$

The current of DSTATCOM is as,

$$I_{DSTN} = S_{DST} / V_{DSTN} = (\sqrt{P_{DST}^2 + Q_{DST}^2}) / V_{DSTN} = 8.43 \text{ A.}$$

$$\theta_{DST} = \cos^{-1}(P_{DST} / (V_{DSTN} * I_{DSTN})) = 117.22^\circ.$$

$$S_{DST} = V_{DSTN} * I_{DSTN} = V_s * I_{DSTN} = 230 * 8.43 = 1938.90 \text{ VA.}$$

Active power of DVR is as, $P_{DVR} = -P_{DST} = 885.15 \text{ W.}$

The current rating of DVR of UPQC-S is equal to ac load current of $I_{DVR} = I_L = 25 \text{ A}$, since it is connected in series between the load.

In this case VA rating of both VSC must be the same, because of equal sharing of reactive power and same active power due to common dc bus.

The voltage rating DVR of UPQC is computed as.

$$V_{DVRN} = S_{DVR} / I_{DVRN} = 1938.90 / 25 = 77.56 \text{ V.}$$

$$Q_{DVR} = V_{DVRN} * I_{DVRN} * \sin \theta_{DVR} = 1725 \text{ VAR, } \theta_{DVR} = 62.79^\circ \text{ and}$$

$$P_{DVR} = -P_{DST} = 885.15 \text{ W.}$$

$$S_{DVR} = \sqrt{P_{DVR}^2 + Q_{DVR}^2} = 1938.95 \text{ VA.}$$


We can call it active power of DSTATCOM will be equal to typically of $V_s I_s$ minus $V_s I_L \cos \beta$ [FL], it comes 885.15 and current rating of DSTATCOM can be calculated from S, P, Q square under root divide by voltage [FL], it comes 8.43 ampere and angle of DSTATCOM comes from this power and VA rating [FL], it comes 117.22 degree and the VA rating of this becomes like a current and voltage [FL], it comes 1938.90 VA and active power of DVR is same as the DSTATCOM [FL], that is we calculate [FL], it is 885.15.

And current rating of DVR of UPQC equal to the ac load 25, since connected this, [FL], VA rating of both must be same [FL], because of equal sharing of reactive power, the same power to common bus. [FL], voltage rating of UPQC should be like your VA rating divide by current [FL], it is a 77.56 and Q_{DVR} will be voltage into different [FL], that comes typically

putting a value 1725 and the P is same 885 [FL], you can calculate VA rating of your P square plus Q square under root of that [FL], it becomes 1938.95 VA like.

(Refer Slide Time: 58:00)



First Method: Voltage Sag Compensation by Left Hand UPQC-S
 Each VSC has reactive power rating equal to half of the reactive power of the load, which is equal to
 $Q_{DST} = Q_{DVR} = Q_L / 2 = 3450 / 2 = 1725 \text{ VAR}$.
 The supply voltage under voltage sag is as,
 $V_s' = V_s * (1 - X) = V_s * (1 - 0.2) = 184 \text{ V}$.
 From following relation of reactive power of DSTATCOM, the power angle can be computed as,
 The reactive power DSTATCOM is as, $Q_{DST} = V_s' I_L' \sin \beta = 1725 \text{ VAR}$
 On solving the above equation the different angles are calculated as, $\beta = 22.02^\circ$, $\delta = 0^\circ - \beta = 36.87^\circ - 22.02^\circ = 14.85^\circ$.
 The active power DSTATCOM is as,
 $P_{DST} = V_s' I_s' - V_s' I_L' \cos \beta = V_s I_s - V_s' I_L' \cos \beta$
 $= 230 * 20 - 184 * 25 * \cos 22.02^\circ = 4600 - 4264.31 = 335.69 \text{ W}$.
 (a) The voltage rating of DSTATCOM of UPQC-S is as.
 The voltage rating of the DSTATCOM is as. $V_{DST} = 184 \text{ V}$.

[FL], coming to the there are two options [FL], you can calculate two way. [FL], coming to first method, the voltage sag compensation by left hand UPQC-S. Each VSC has a reactive power rating equal to the half of the reactive power of the load, which is equal to the Q DST equal to 3450 by 2, 1725 VAR and supply voltage under voltage sag condition is typically of 184.

[FL], from the relation of reactive power of DSTATCOM angle can be calculated [FL] that is typically 1725 VAR and solving this equation, we can calculate the beta, it comes to 22.02. [FL], we can calculate form delta from here [FL], it comes 1.14.85 degree and active power of DSTATCOM is typically calculated from there [FL], it comes typically the value of

335.69. [FL], voltage rating of DSTATCOM of UPQC it typically 184 because it is connected across the source.

(Refer Slide Time: 58:50)



(b) The current of DSTATCOM is as,
 $I_{DST} = S_{DST} / V_{DST} = (\sqrt{P_{DST}^2 + Q_{DST}^2}) / V_{DST} = 1757.36 / 184 = 9.55 \text{ A.}$

(c) The VA rating of DSTATCOM of UPQC-S is as.
 $S_{DST} = V_{DST} * I_{DST} = V_s * I_{DST} = 184 * 9.55 = 1757.36 \text{ VA.}$
 Active power of DVR is as, $P_{DVR} = - P_{DST} = - 335.69 \text{ W.}$
 The current rating of DVR of UPQC-S is equal to ac load current of $I_{DVR} = I_L = 25 \text{ A}$, since it is connected in series between the load and ac mains.

(d) The voltage rating DVR of UPQC is computed as.
 $V_{DVR} = S_{DVR} / I_{DVR} = 1757.36 / 25 = 70.29 \text{ V.}$

(e) The current rating of the DVR is same as load current as it is connected in series of the load as, $I_{DVR} = I_L = 25 \text{ A.}$
 $P_{DVR} = - P_{DST} = - 335.69 \text{ W.}$
 $Q_{DVR} = V_{DVR} * I_{DVR} * \sin \phi_{DVR} = 1725.11 \text{ VAR.}$
 $S_{DVR} = \sqrt{P_{DVR}^2 + Q_{DVR}^2} = 1757.36 \text{ VA.}$

(f) The VA rating of UPQC-S,
 $S_{UPQC-Q} = S_{DST} + S_{DVR} = 1757.36 + 1757.36 = 3514.72 \text{ VA.}$

And current rating of your VA rating know [FL], current rating you can calculate [FL], it is a P square, Q square under root that V DSTATCOM [FL], it is typically comes in 9.55 ampere and VA rating of DSTATCOM of UPQC same as your V DST, I DST so, 184 into 95 [FL], this is a 1757.36 and active power of DVR and DSTAT comes in that is 339.69.

[FL], current rating of DVR is equal to the load current that is 25 ampere. [FL], since it is connected in series with the load [FL], voltage rating of DVR and UPQC is computed as your S DVR upon I DVR and it is your typically 1757.36 by 25.

[FL], it comes 70.29 volt and current rating of DVR is the same as the load current that is 25 ampere and P DVR equal to P DST 3359 and Q DVR equal to typically 1725 point on this relation and S DVR will be like a P square, Q square under root [FL], 15; 1757.36 VA and voltage rating, VA rating of UPQC will be your DST; DSTATCOM rating, VA rating and this both are equal [FL], it come 3514.27 like.

(Refer Slide Time: 60:00)

Second Method: Voltage Sag Compensation by Left Hand UPQC-S

It means after the voltage supply voltage reduces to $V_s' = V_s(1 - X) = 230(1 - 0.20) = 184$ V, and $X=0.2$, $K_0 = V_s/V_s' = 1.25$, $n_0 = 1/K_0 = 0.8$. The supply current after the sag compensation is as, $I_s' = P_L/V_s' = 4600/184 = 25$ A.

In Left Hand UPQC-S, each VSC has reactive power rating equal to half of the reactive power of the load, which is equal to $Q_{DST} = Q_{DVR} = Q_L/2 = 3450/2 = 1725$ VAR.

(a) Since DSTATCOM is connected across the ac mains so the voltage rating of DSTATCOM is same as ac mains voltage as, $V_{DST} = V_s' = 230(1 - 0.2) = 184$ V.

Under the voltage sag, from following relation of reactive power of DSTATCOM, the power angle can be computed as.

$Q_{DST} = V_s' I_L' \sin \beta = n_0 V_s I_L' \sin \beta = 1725$ VAR, $\beta = 22.02^\circ$, $\delta = \theta$, $\beta = 36.87^\circ - 22.02^\circ = 14.85^\circ$

$P_{DST} = V_s' I_s' - V_s' I_L' \cos \beta = 4600 - 4264.31 = 335.69$ W.

$\phi_{DST} = \tan^{-1}(Q_{DST}/P_{DST}) = 78.99^\circ$



And second method for voltage sag compensation is by left hand UPQC. It means after the sag compensation reduces to typically 230.8 [FL], it became 184 and K 0 in the phasor diagram is 1.25, n 0 is 1 upon K 0 0.8 [FL], supply current after the sag compensation is typically your 4600 divide by 184, 25 ampere. In left hand has the each VSC reactive power rating equal to the half of the reactive power [FL], that is the load reactive power by 2 [FL], that comes 1725 VAR.

And since the DSTATCOM is connected across the ac main [FL], voltage rating of the DSTATCOM same as the voltage rating of the DSTATCOM [FL], it comes like 184 and under voltage sag from the following relation of reactive power, the power angle can be calculated typically from reactive power [FL], basically beta comes to 22 and delta comes typically 14.85 and P we can calculate the power of DSTATCOM. From this relation, it comes 339.69 and the angle of DSTATCOMs like a 78.99 degree.

(Refer Slide Time: 61:02)

(b) The current of DSTATCOM is computed as,

$$I_{DST} = P_{DST} / (V_{DST} * \cos \theta_{DST}) = 9.55 \text{ A.}$$

(c) The VA rating of the DSTATCOM is computed as,

$$S_{DST} = V_{DST} * I_{DST} = V_S * I_{DST} = 184 * 9.55 = 1757.36 \text{ VA.}$$

The rating of DVR is computed from the common relations of DSTATCOM and DVR as.
 Active power of DVR is as, $P_{DVR} = - P_{DST} = - 335.69 \text{ W.}$

(d) The current rating of DVR of UPQC-S is equal to ac load current of $I_{DVR} = I_L = 25 \text{ A}$, since it is connected in series between the load and ac mains.

(e) The voltage rating DVR of UPQC is computed as.

$$V_{DVR} = S_{DVR} / I_{DVR} = 1757.36 / 25 = 70.29 \text{ V.}$$

$$P_{DVR} = - P_{DST} = - 335.69 \text{ W.}$$

(f) The VA rating of DVR is computed as.

$$Q_{DVR} = V_{DVR} * I_{DVR} * \sin \theta_{DVR} = 1725 \text{ VAR.}$$

$$S_{DVR} = \sqrt{(P_{DVR}^2 + Q_{DVR}^2)} = 1757.36 \text{ VA.}$$



And the current rating of DSTATCOM is calculated from P divide by voltage in cos [FL], it comes 9.55 and VA rating of DSTATCOM is this voltage on the DSTATCOM across 184 into 9.95; 9.55 [FL], it comes 1757.36.

And rating of DVR is computed from common relation of DVR [FL], DVR rating is P equal to P DST equal to 3359 69 and current rating of DVR is equal to the ac load current of 25

ampere, a connected series with the load and voltage rating of DVR is same, the VA rating divide by current [FL], which come 70.29 and P is power; active power in both of DSTATCOM [FL], its comes 33.69 and you can calculate the S DVR, Q DVR equal to this methoding and S DVR, P square under root [FL], its come 15; 1757.36 like.

(Refer Slide Time: 61:52)

The VA rating of UPQCS during voltage sag is as,
 $S_{UPQCS(\text{under sag})} = S_{DST} + S_{DVR} = 1757.36 + 1757.36 = 3514.72 \text{ VA}$.
Hence considering an overall rating (both normal and under voltage sag), ratings of both compensators are as,
 $V_{DVR} = V_{DVRN} = 77.56 \text{ V}$, $I_{DVR} = 25 \text{ A}$,
 $S_{DVR} = V_{DVR} \cdot I_{DVR} = 77.56 \cdot 25 = 1939 \text{ VA}$.
 $V_{DST} = 230 \text{ V}$, $I_{DST} = 9.55 \text{ A}$, $S_{DST} = V_{DST} \cdot I_{DST} = 230 \cdot 9.55 = 2196 \text{ VA}$.
Hence if both the VSCs share equal VA all the time then minimum rating required is as,
(g) The VA rating of UPQC-S,
 $S_{UPQC-S} = S_{DST} + S_{DVR} = 1939 + 2196.5 = 4135.5 \text{ VA}$.
Alternately, if both the VSC of same VA are considered for same inventory then,
 $S_{DST} = S_{DVR} = 2197.5 \text{ VA}$.
The VA rating of UPQC-S,
 $S_{UPQCS} = S_{DST} + S_{DVR} = 2196.5 + 2196.5 = 4393 \text{ VA}$.



[FL], VA rating of UPQC will be your; your VA rating of the DSTATCOM and DVR [FL], it is a sum of both, both are equal to it become 3514.72. Hence considering the overall rating of normal, its rating of both compensator are typically DSTATCOM voltage during 7756 and DVR current rating 25 and the VA rating is your this multiplied by 1939 point VA and V DSTATCOM 230-volt with the 9.5 [FL], it becomes like a 2196 VA.

Hence the both VSC share the equal at the time of minimum rating [FL], you can call it S VA rating of the UPQC will be S DST, VA rating of the DSTATCOM plus DVR [FL], it

becomes your 9; 1939 and 2196.5 [FL], it become 4135.5. [FL], alternatively both VSC of the same are considered [FL], you can call it S DSTATCOM, S DVR 2197.5. [FL], total VA rating becomes sum of both that is a 4393 VA like.