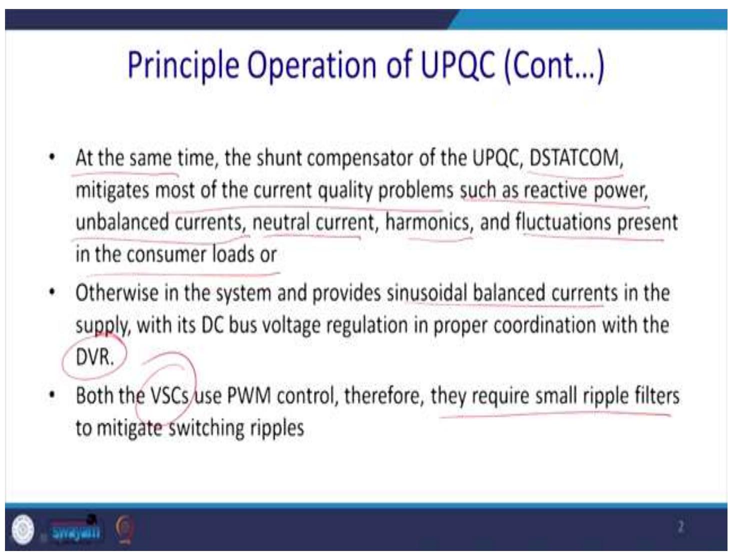
Power Quality Improvement Technique
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture - 38
Operation and Control of UPQC

Welcome to our NPTEL lectures on Power Quality Improvement Technique. Today, we are going to discuss about the Operations and Control of the UPQC. We have already discussed classification and introduction part of UPQC. Now, we shall discuss about how this UPQC will work? and its control strategies.

So, as discussed in our previous lectures it is a combination of the series and the shunt filters.

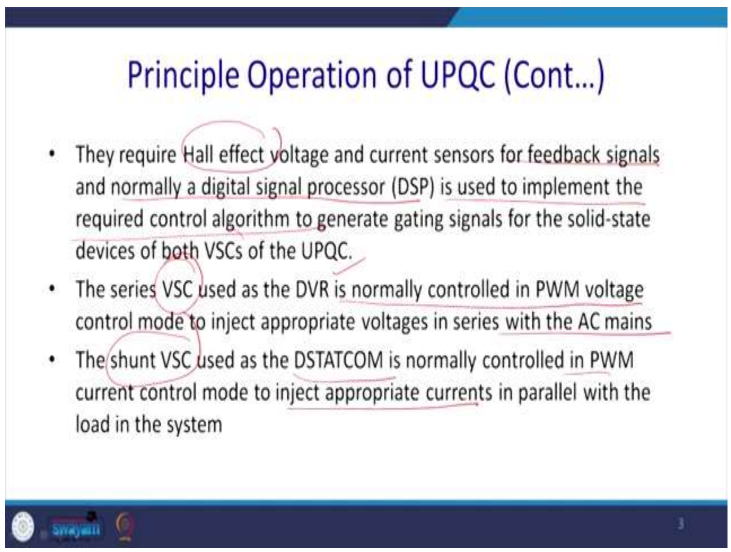
(Refer Slide Time: 00:59)



At the same time, the shunt compensator of the UPQC that is D-STATCOM or shunt active power filter may mitigate most of the current quality problems. That is its current harmonics and also the unbalanced problem of the current and also the power factor problem of the current such as reactive power. That is power factor, unbalanced current and the neutral current. This is for the three phase four wire system harmonic and if there is a fluctuating kind of load like arc welding then it is present at a consumer end, and this will mitigate this problem for this kind of loads.

Otherwise, the system will provide a sinusoidal balanced current in the supply with DC bus voltage regulation in proper coordination with DVR. This is a way that UPQC should work and both are voltage source converter and uses the PMW control. I shall discuss separately the grid connected voltage source converter control. They require small filters because switching frequency has to be around 10 kilohertz for the IGBTs. Size of the filter is going to be very less to mitigate this switching frequency ripples in voltage as well as current.

(Refer Slide Time: 02:44)



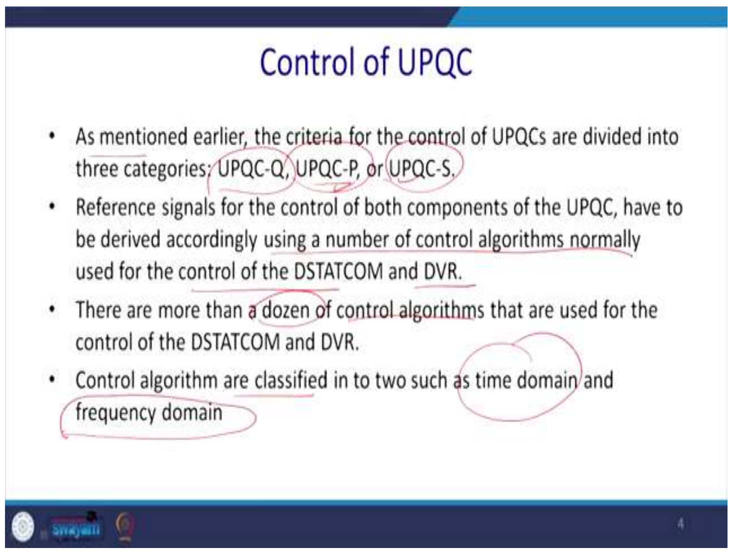
Generally, to sense the current, we have a Hall effect voltage and the current sensors. LEM kind of entities for feedback signals and nowadays we implement in the digital domain. So, it required to be fed in to the ADC s. From ADC it will go into your DSP or FPGA system to generate your control pulses.

Normally a digital signal processor DSP or maybe FPGA is used to implement the required control algorithm that, we have discussed already. The different kind of control algorithm that is mainly Agaki's method. Instantaneous reactive power theory or the SRF theory is used to implement the require control algorithm to generate the gating signals for the solid-state devices for both the UPQCs. For both this voltages converter of this UPQC.

The series part of it used as a DVR as mentioned in previous lectures also. It is normally controlled in PWM voltage control mode to inject the appropriate voltage in series with the AC mains to boost up the voltage and it can inject in quadrature with the current or in the phase of the current depending on the control strategy of the UPQC.

On the other hand, the shunt portion of this voltage source converter acts as D-STATCOM and is normally controlled in PWM controlled. It is a current control voltage source inverter essentially. Controlling PWM: PWM current control mode is implemented to inject appropriate current in parallel to the load of the system. So, this is called shunt.

(Refer Slide Time: 04:56)



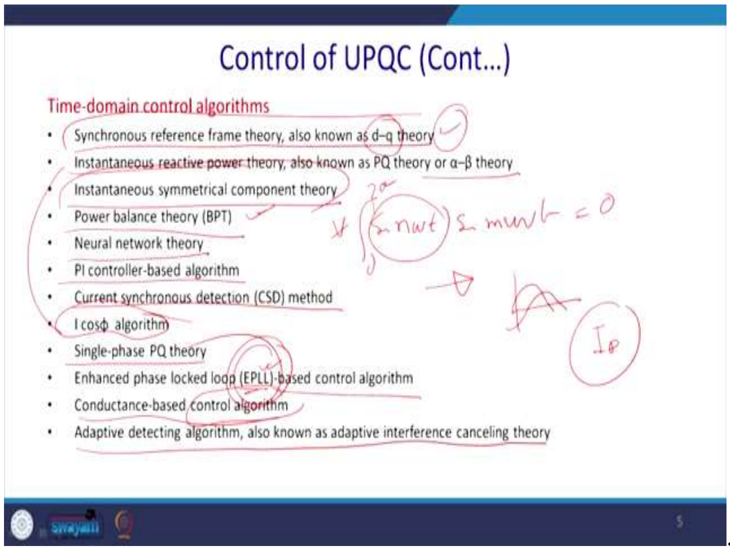
So, we have already discussed that there are different kind of UPQC. That is UPQC-Q. It injects the voltage in quadrature with the current. It injects the voltage. UPQC-P inject the voltage in phase with current and 'UPQC-S' can inject the voltage in appropriate angle or the optimal angle to compensate. So, we have already discussed this method as mentioned earlier the criteria can be UPQC-Q, UPQC-P and UPQC-S.

So, reference signal for the control for both the components of the UPQC have to be derived accordingly using the number of the control algorithm and it is normally used to control the D-STATCOM and DVR.

We will see it later. Shunt part maintains the DC link voltage and DVR injects the voltage. If it is a 'Q' control mode than swell control does not arises. Only this mode and this mode UPQC can takeout power if there is an extra voltage and then it will take out power and inject it to the DC link voltage and from the shunt path that power will go to the system.

There are more than dozens you know, although I may be wrong you know. It may be as long as 20-30 of the control algorithms that are used to control the D-STATCOM and DVR. The control algorithms are classified mostly in the two domains. One is in time domain. Another is in frequency domain.

(Refer Slide Time: 06:59)



These are the number of dominating features of the time domain algorithm. One is synchronous reference frame theory also known as the ‘dq’ theory. It is quite popular and we will discuss this strategy in tandem with the grid connected voltage source converter. There we shall discuss how these features has been incorporated not only in UPQC. Now, generally UPQC may be connected with the distributed generations. It has a capability to inject the real power as well as to improve power quality. This is a new feature which is an add on. Also, there we shall see that a grid connected converter and how this theory will work in detail?

Thereafter this instantaneous reactive power theory proposed by Agaki in 1984 and it is also known as the PQ theory or the ‘αβ’ theory. So, these are theory can be extended to the single-phase system.

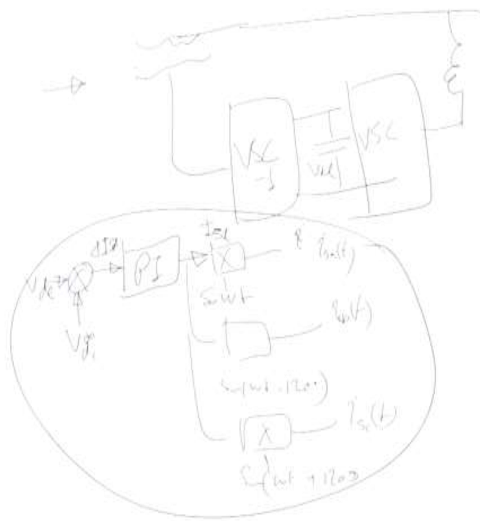
Instantaneous symmetrical component theory: we can split this unbalanced current into the positive and negative sequence and the zero sequence. Positive and negative sequence for the three phase three wire system. Positive negative and the zero sequence for three phase four wire system. Where we can find something else? Ultimately this source has to supply the positive zero sequence component. This UPQC will ensure that this negative sequence which incorporate all the unbalanced part of it and the ripple portion of it, will be the harmonic part and will be injected by the shunt portion of the current and the series portion of the voltage. Thus, other remaining portion that is the balanced positive sequence component that will be fed through this supply only. Thus, it will seem to be a resistive load connected into the system.

There is a power balanced theory also. That is called balance of power theory rather. In this while we will say not power balanced theory, we generally say BPT. So, here we require to balance with the average power. Because you know that, $\int_0^{2\pi} \sin n\omega t \sin m\omega t \, d(wt) = 0$. But these are ultimately only this 'cos' component, only this dot component will survive. Multiplication of the fundamental voltage and current will be surviving. Other term if you integrate, it will vanish. This term, if you can subtract from the instantaneous power that will be the ripple portion of the power and that required to be fed in the form of voltage and current from this UPQC. So, this is the task of it.

Now, with the advent of the soft computing technique, neural-network based theory also been proposed. So, we can generate a transfer function and you can train them to minimize a current THD as well as a voltage THD. You get it is and thus control technique can be achieved by ANN.

Similarly, there is a PI based control algorithm, where you know DC link voltage. I am going back to this white board. What happens here?

(Refer Slide Time: 11:18)



Generally, you have 2 VSC. VSC-1 and VSC-2. This is generally the shunt part and this one is generally the series part. Here this shunt path what happens? You have the V_{dc}. So, V_{dc} and you have actual V_{dc} and from there you will subtract the reference V_{dc}.

From there you essentially get an error. Positive or the negative error that you will feed to the PI. That PI essentially will give you a value ‘I’ say I_{SD}. Then this block will be multiplied to the unit voltage template or 120-degree phase shifted. That is $\sin \omega t$ and thereafter it can be multiply with the $\sin(\omega t - 120^o)$ and $\sin(\omega t + 120^o)$. So, you get reference $i_{sa}(t)$, $i_{sb}(t)$ and $i_{sc}(t)$ and you will subtract this from i_L and you try to inject it. This is also called the indirect method and this has been used for controlling this STATCOM indirectly. This is the PI controller-based algorithm.

Similarly, current synchronous detection technique is another method. All require an explanation and thereafter there is an algorithm to find it out $I \cos \phi$ component. That is essentially in phase component. You have a voltage and current maybe phase shifted by an angle and ultimately you require to get the I_P. I_P essentially is $I \cos \phi$. This you require to estimate and thus you subtract from the load current and rest of the current will be fed through the shunt active power filter for the current. You will calculate the same thing from the voltage as well.

Single phase PQ theory: his is an extension of this. You know ‘αβ’ transformation for ‘abc’ to ‘αβ’ frame or the PQ. Here you have to split it into the 90 degree out of phase from a single-phase system and you try to compensate the reactive power.

Similarly, you may have an enhanced phase lock loop control-based algorithm. We shall discuss about the PLL in next class because PLL is a very important entity and it is quite important in the d-q methods and other method also. So, enhanced PLL theory, because we require to be talking about the drawbacks of the d-q theory. d-q theory is very much sensitive on the estimation of the, this ‘ϴ’.

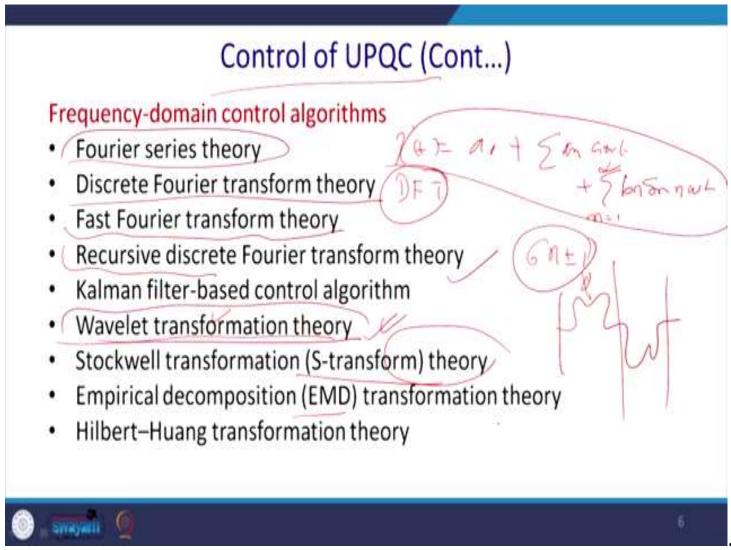
If there is an error in estimation of the ‘ϴ’, this synchronous reference generation technique will fail and thus to enhance the capability and mostly it fails when voltage is dirty. If voltage is clean then there is no problem. If voltage is dirty then there is a problem and mostly there is a problem of the unbalanced voltage. For this reason, we employ the EPLL. There it can be an enhanced PLL. While discussing PLL, we shall takeout this issue in detail.

Then conductance-based algorithm: please understand this, when UPQC has been connected, this circuit to behave totally resistive. Thus, impedance will be minimum and the conductance will be maximum. Ultimately, we require to do something. We require to reduce the current into the system. So, algorithm is based on that and we try to reduce it, since voltage is maintained constant. That is the task of the utility if utility does not provide, then you should provide the constant voltage by the DVR and then algorithm will ensure that you take minimum current from the source. This is the conductance-based algorithm and thus of course, you mitigate the other losses.

Adaptive detection technique known as the adaptive reference and the cancelling theory. Mostly this is the wavelet-based theory, when there is a load change it has been detected. Based on that we may have some kind of analysis and we can try to evolve maybe the control loop. That is maybe the MRAQ or other method because you try to estimate the two quantity from the two methods, one is adjustable method and another is adaptable method and try to get the actual value of the ‘ϴ’. Mostly MRAQ has been used to estimate this PLL and then it is been applied here. This is generally the technique most of the researchers follows.

Now, same way we have seen the complexity on the time domain. There is a big challenge. Your computation burden is quite more. To get rid of that computation burden, we wanted to have a control reference generation technique in frequency domain.

(Refer Slide Time: 17:58)



So, simplest form is that the Fourier series theory. You can express your i_L in terms of 'a_0' if DC component is present. Generally, it is not present. $i_L(t) = a_0 + \sum_{n=1}^{\infty} \cos n\omega t + \sum_{n=1}^{\infty} \sin n\omega t$. From there by trial and error or maybe by training ANN, you try to take out the roots. Because you know that what kind of load it is. If you have a 6-pulse non-linear load, then your harmonic constraint will be $6n \pm 1$. So, you estimate that.

Apart from that if you are from the symmetry of the data then you can calculate. So, this is the data. You have an odd-wave symmetry and from there you know that this will be the harmonic constraint and you try to map this harmonic constraint accordingly.

Thereafter, there can be another method. That is discrete Fourier transform theory. That is DFT. So, you get a data. All the data has been collected from the Hall sensors and that is been fed to this ADC. From this ADC the data goes to the MATLAB or any programming language domain. Thereafter taking data of the two cycles or you may reconstruct if there is a steady state available. From the quarter of the cycle you can construct the full cycle. You require two cycle data mainly and you can do it. It is called the DFT. You can have the DFT and find out the frequency component accordingly.

Same way you can do the FFT. FFT is quite popular method. So, there we can find out the FFT. Since load is stationary, you need not have to find the FFT. When load change is detected, then you can go for a change in the data and thus you can go for the recursive Fourier transform or sliding window Fourier transform. So, it gives you the better results. Same way, we can use in a digital domain that Kalman filter based algorithm to estimate the voltage and the current component of the frequency.

Another is the wavelet transformation theory, that I was discussing. It is gaining popularity quite recently in a power system domain. If there is a load change or the fault occurs then based on the mother-load change, there will be change in pattern that can be detected easily. From there we can estimate the magnitude as well as the phase of the current changes and from there we can estimate. Ultimately, we generally do FFT after that to re-verify the actual data.

One of the advantages is that, wavelet can detect the moment load has changed and also it can give you the amount of the load change and what is the component required to be injected. But sometime, it does not give very good data depending on how well you have designed the mother wavelet and that is the challenge. This is something those who are working with the wavelet they can appreciate it better.

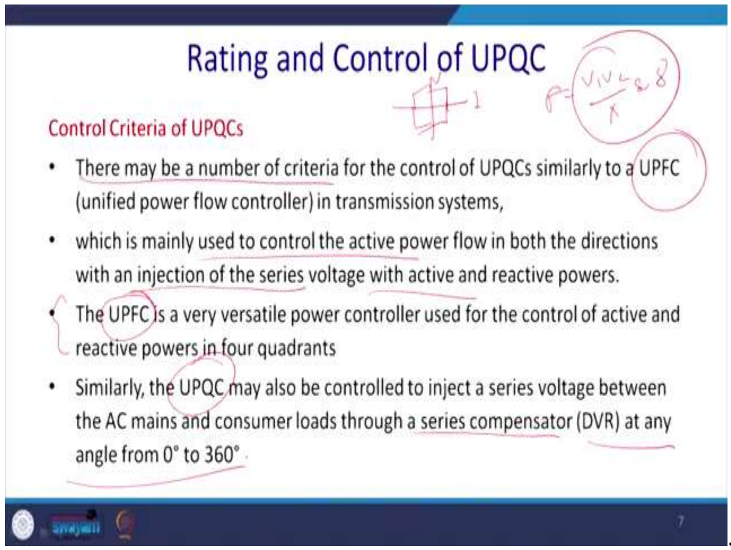
How well you have designed the wavelet based on its reference generation? If you have wrongly calculated the compensating voltage and current then of course, you do not get the desired THD. Another is that if you want to compensate more voltage or current, there will be a sag or swell in the system and the capacitor voltage either will collapse in long term or it will try to swell up.

Same way Stockwell transformations or the S-transformation theory are nowadays used. This is a mathematical calculation. So, this is based on that. We can also estimate the different parameters of the Fourier series.

Same way the empirical decompositions of the transformation theory, this also gives you the load current component in the Fourier domain and also this is quite familiar. It has been used in a communication engineering and their technique can be very well be useful here. That is called Hilbert-Huang transformation theory and this is also can be applicable to estimate the voltage to be injected and also current to be calculated.

So, let us come to the control criteria of the UPQC.

(Refer Slide Time: 23:44)



There maybe a number of criteria for the UPQC similar to the UPFC that has been mostly used in the FACTS devices and that is been put into the transmission line. Which is mainly used to control the active power flow because, we deal with the power flow in case of FACTS devices, and we are controlling the quality of the power in case of the UPQC. Mainly used for the controlling the active power flow in both the directions with injections of the series. For the reactive power can also be done.

So, there you know power flow $P = \frac{V_1 V_2 V_3}{X} \sin \delta$. So, you have to play around with these parameters, but nowadays this concept also extended in the distribution domain because of the penetration of the distribution generation. Because you know solar inverter. It is ideal in night. So, why cannot it act as a UPQC in night? Even daytime, it can act as a UPQC with the solar cell integrated and thus what happens? It can also send you the balance of power and it mitigates the power quality as well. These features are add-on. That is the integration of the power quality with the distributed generation. With the injections of the series voltage with active and the reactive power.

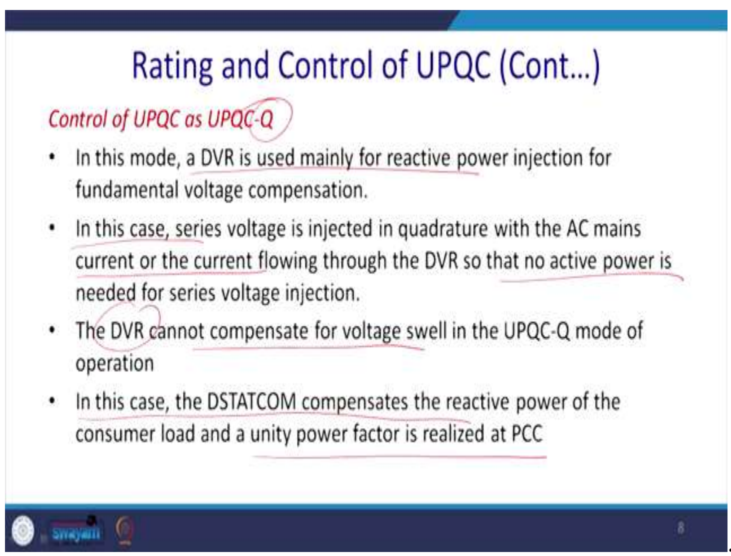
Generally, we require to know the features of the UPFC to understand the UPQC better. It is a versatile power flow controller used for the control of the active and the reactive power in all the four-quadrant. All the four-quadrant means say this is a 'I' and this is a 'V'. So, you can operate here. You can operate here. You can operate here. You can operate here. Voltage can be positive with the reference and current can be in negative directions.

For example, when a solar inverter is feeding back to the grid, you want to have whatever power has been generated to be dispatched, because grid is an infinite sink. You want the power handling capability of this grid to increase and reduce the congestions. This is being done by the UPFC for the past 30 years.

Now, we want to do the same thing here. Since nowadays, due to the distributed generations sometime load becomes also generator. Thus, we require to change the way it will operate.

Similarly, the UPQC may also be used to control the injection of the series voltage between AC mains and consumer load through a series compensator (DVR) at any angle from 0 to 360 degree. This is one of the major features of UPQC.

(Refer Slide Time: 27:35)



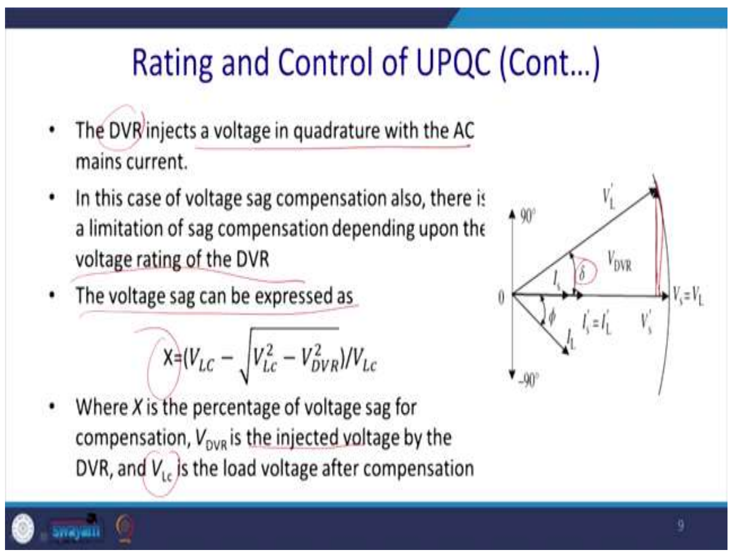
.

We have discussed this UPQC as UPQC-Q. Just a recall. That in this mode generally, it injects the voltage in quadrature with the current. In this mode DVR is used for reactive power injections for fundamental voltage compensations. In this case, series voltage is injected in quadrature with AC mains. Current flow through the DVR also acts as that and no active power is required.

So, power handling capability is minimum, but effective case is also minimum because it only injects power in the quadrature. So, you require to have a huge injection of the voltage to mitigation of the sag. Thus, rating of the switches requires to be high. Power handling capability maybe low, but that is quite contradictory if rating of the switch is high, then definitely your switches have a higher capability of the handling power.

As told in a previous class also. DVR cannot compensate voltage swell because always your hypotenuse will be more than your base. For this reason this mode of operation only preferred for the sag correction and in this case D-STATCOM compensates the active power of the consumer load and the unity factor is realized at the PCC.

(Refer Slide Time: 29:12)

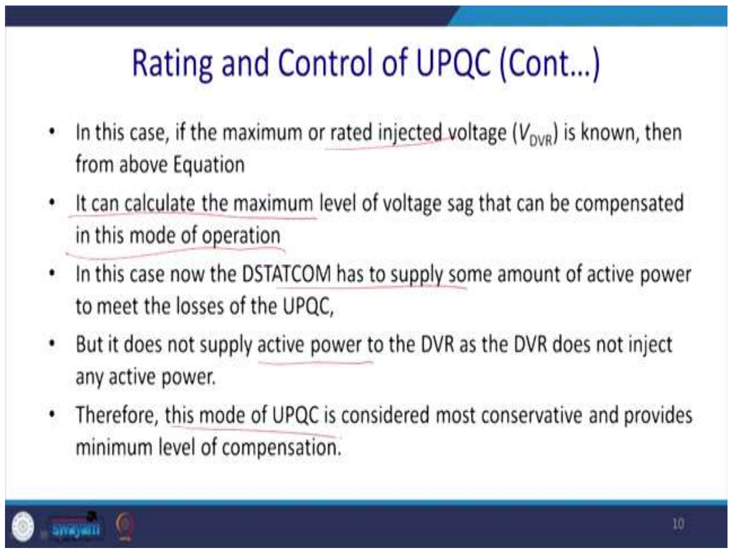


Now let us talk about that. We have discussed the classifications there. Now, let us talk about the rating of this UPQC. So, the DVR injects the voltage in quadrature in the AC mains current and this is the voltage that has been injected in quadrature with the voltage. In quadrature with the current. Pardon me. Ultimately this is the new angle δ with the current and it was a previously V_S and this was a ϕ.

Thus, what happens? In this case, there is a limitation of the sag compensation depending upon the voltage rating of the DVR. So, how much you can inject? There is a limit. It can be 0.5 per unit. This hypotenuse can be the half of this base maybe. Thus, you have a limit of the compensation of the sag.

So, voltage sag for this reason can be expressed as X that is $X = \frac{\left(V_{LC}\sqrt{V_{LC}^2 - V_{DVR}^2}\right)}{V_{LC}}$. Where X represents the percentage of the sag for the compensation, of the DVR is injected by the DVR and V_{LC} is the load voltage after compensations. So, this is the calculations for mitigation of the sag.

(Refer Slide Time: 31:04)



What we can do? In this case the rated injected voltage is known from these above equations. That is fixed because you have chosen that kind of rating. It can calculate the voltage sag and that can be compensated with this mode of operation.

In this case now the D-STATCOM, it has to supply some amount of the reactive power to meet the losses of the UPQC, but it does not supply any active power to the DVR as the DVR does not inject any real or active power. Therefore, this method of UPQC is considered most conservative and provides minimum level of compensation.

Thank you for your attention, I will be continuing to the different kind of UPQC in our next class.

Thank you.