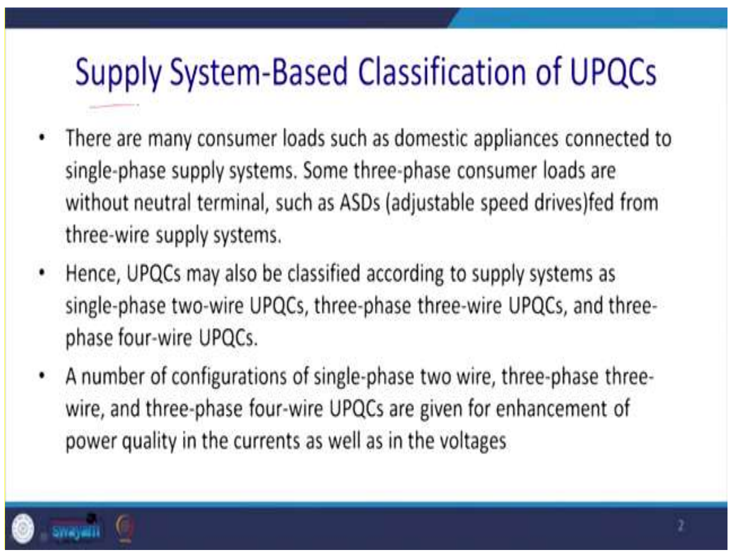
**Power Quality Improvement Technique**
**Prof. Avik Bhattacharya**
**Department of Electrical Engineering**
**Indian Institute of Technology, Roorkee**

**Lecture - 37**
**UPQC Classification**

Welcome to our NPTEL lectures on Power Quality Improvement Technique. We shall discuss on the UPQC Classifications. We have seen the classifications in our previous class.

(Refer Slide Time: 00:41)

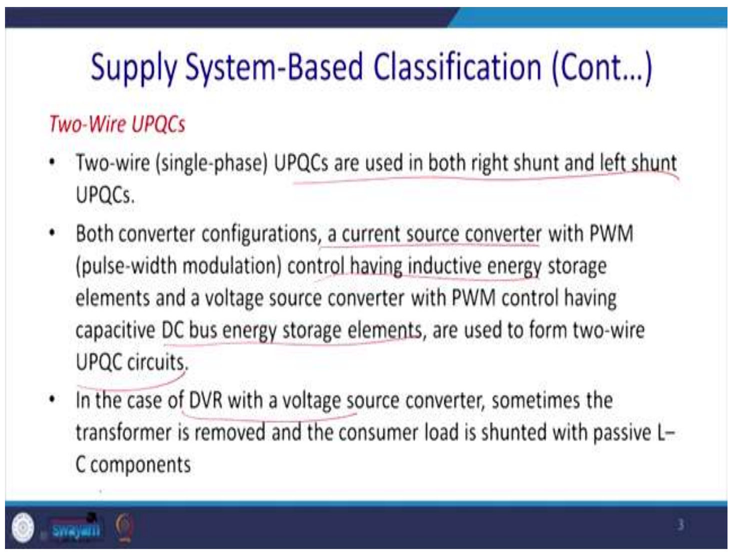



Today we shall talk about the System-Based Classification of the UPQC and there are many consumer loads such as domestic appliances connected to the single-phase systems. Some three-phase consumer loads are without neutral terminal such as adjustable speed drive from the three-phase three-wire systems. These are the source of the harmonics.

Hence, UPQC may also be classified according to that. Because we required to put the UPQC, where most problem arises. You have to put at the point of the bleeding. That is called banded method. According to the supply this is the issues. For this reason, the classifies according to the supply system are single-phase two-wire, we have discussed in the chart in detail in our previous class, three-phase three-wire UPQC and the three-phase four-wire UPQC. The number of configurations we will discuss now in detail.

Of single-phase two-wire, three-phase three-wire and three-phase four-wire system UPQC are given for the enhancement of the power quality in the current as well as the voltages. That is something we require to ensure. We require to find it out what is a source of the harmonics or the disturbance or anything? If it is due to the adjustable speed drive in a three-phase three-wire system, we should choose UPQC very close to that polluted load and ultimately, you have to keep their problem localize and does not allow to propagate this problem to other part of the power system. Thus, we have a two-wire UPQC. It is a single-phase UPQC.

(Refer Slide Time: 02:50)

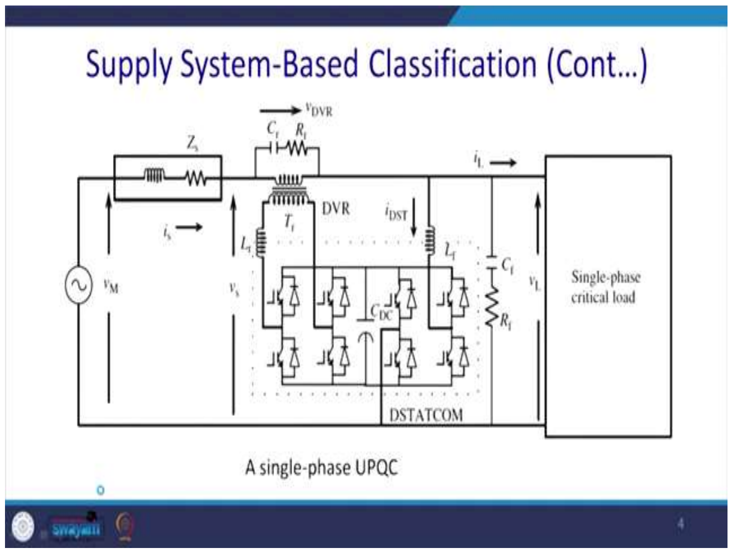



So, UPQC are used for both right shunt and the left shunt. Since voltage rating does not vary much because it is a single-phase system. For this reason, we do not have much complexity. We can use as per the rating is concerned. We can use right shunt as well as the left shunt.

Both converter configurations are current source inverter with the PWM modulation technique having inductive energy storage elements and the voltage source converter with a PWM control having capacity of DC bus energy storing element, are used to form the two-wire circuits. Generally, the shunt is the inductor and generally, you got a series injection. That generally sink through this little power from the shunt path and you send this power from this DC link voltage.

In case of the DVR with the voltage source converter, sometime the transformer is removed, because it may be a very small rating, which is removed with the consumer load shunted L and C component. That is also a configuration.

(Refer Slide Time: 04:07)



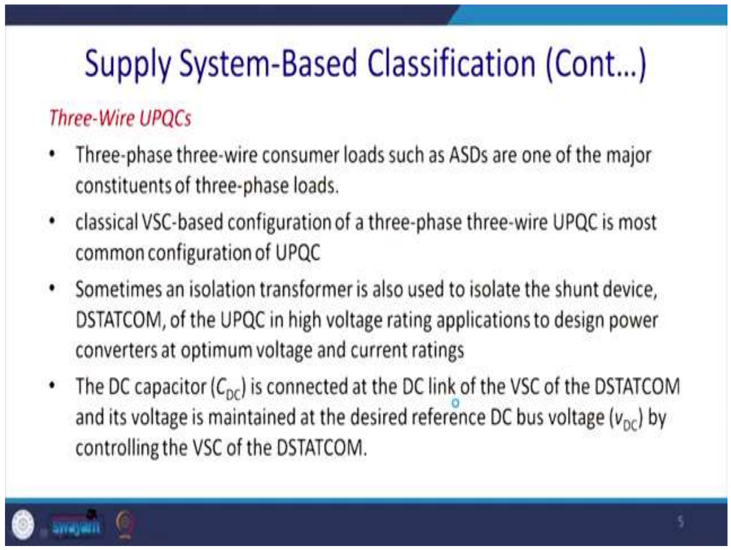

So, see that. This is a configuration. Ultimately you got a D-STATCOM. So, here mainly this capacitor is charged through this path and if there is a sag, then it requires to inject the voltage and this voltage has been injected. So, power will generally flow from this side if there is a swell. It will take out the power and this capacitor voltage will swell. Ultimately, this power has to go back to the system from the shunt path.

If it cannot do that, then we require to provide a bigger resistor to switch on this resistance and ultimately, reduce the rating of the capacitor and you have a critical load. This is a single-phase UPQC solutions. Mostly it comes with the single-phase adjustable application. For example, you may have a lifts or small lifts because nowadays, we want that the movability of the disabled everywhere.

We want a lift and maybe in an old building which does not have a proper grounding. You have fitted different kind of one man, two man lift and that rating can be up to the maybe 3 Kilowatt. But those may be adjustable speed drive and it happens. It happened to my institute itself.

We have an old building around 70 years old and we have put the lift for the mobility of the disabled and though and there we have adjustable speed drive also. These are the source of harmonics and we require to mitigate that by this single-phase UPQC.

(Refer Slide Time: 06:20)




These are the discussion that has to be followed. Now, we talk about more common UPQC that is been placed because loads are around 10 KVA to 100 KVA and thus rating of the UPQC will be in that range. The three-phase three wires consumer load such as adjustable speed, for example, malls and all you have multiple lifts operating or maybe a big building such as ASD's are one of the major constituents of the three-phase loads.

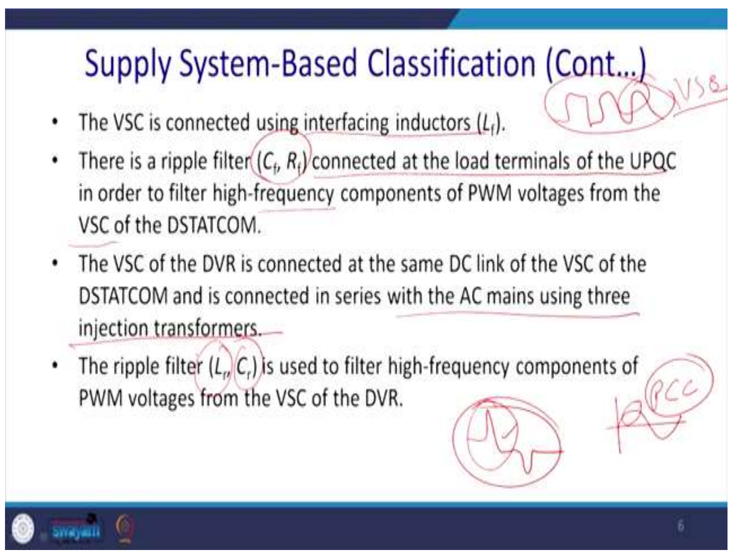
Classical VSC-based configuration of three-phase three-wire UPQC is most common configuration of the UPQC. Sometime an isolation transformer is also used to isolate the shunt device, D-STATCOM of UPQC in high voltage rating application to design power converter at optimum voltage and current rating. This is something what we have seen. We can design that different way. We have sometime a constraint of the power quality.

We require a power quality and no one will say that in a money is available. You required to have an optimization to it. It may have a rating optimization and thus the component cost optimizations, warm optimization or sometime. We may go for the rating optimization in this. This is a different kind of constraint that can be put by the supply in India, accordingly engineers have to design it.

The DC capacitors is connected in the DC link of the VSC of the D-STATCOM and its voltage is maintained at the desired level by the controller. Desired reference of the DC bus voltage, $V_{DC}$ by controlling the voltage source controller of the D-STATCOM. Generally, capacitor required to be maintained at little higher. I just go back to this. It is same for the single-phase system. This capacitor voltage required to be maintained a little higher.

So, that the power can sink through it. Ultimately what happened? You know. We required to inject current to this point. For this reason, we required to inject power if there is a leading power factor.

(Refer Slide Time: 09:12)




The VSC is connected using an interfacing inductor. It is very simple because generally, this VSC is generating the PWM pulses. You got this kind of pulses of variable width and maybe you are compensating current of this nature. Also, the point of common coupling, where it is connected, this shunt part, it is something like this. For this reason, what we required to do? We have an instantaneous voltage difference between these two and current required to be this maybe.

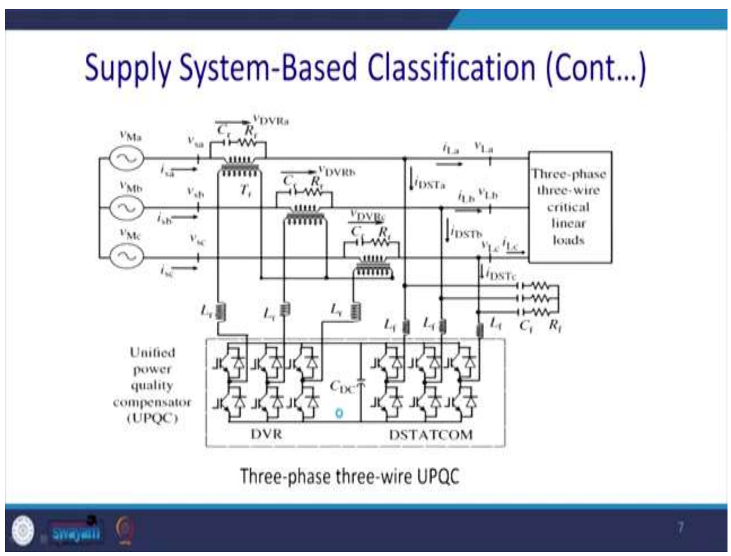
Thus, we require an interfacing inductor, which will act as a buffer between the VCC & VSC. That is voltage source converter and this is the voltage at the point of common coupling for the shunt part because I assume that already voltage has been injected by the

DVR and thus, it got a pure sinusoidal current. It may be compensating, maybe the harmonics and current require to be injected, by the shunt part is this.

There is a ripple filter $C_f$ and $R_f$ connected at the load terminals of the UPQC. In order to filter the high frequency components of PWM voltages from the VSC to the STATCOM. The VSC of the DVR is connected at the same DC link of the VSC of the D-STATCOM and it is connected in series with the AC mains using the AC injections. This is the way of operation of the D-STATCOM.

Moreover, the ripple filter $L_r$ and $C_r$ is used for switching. Generally, it is switch, maybe IGBT. That is switching may be at 10 kilohertz. Those switching ripple require to go out. Ultimately this is not a big challenge because your power system is a low pass filter, which is used to filter out the high frequency component of the PWM voltage from the VSC of the DVR.

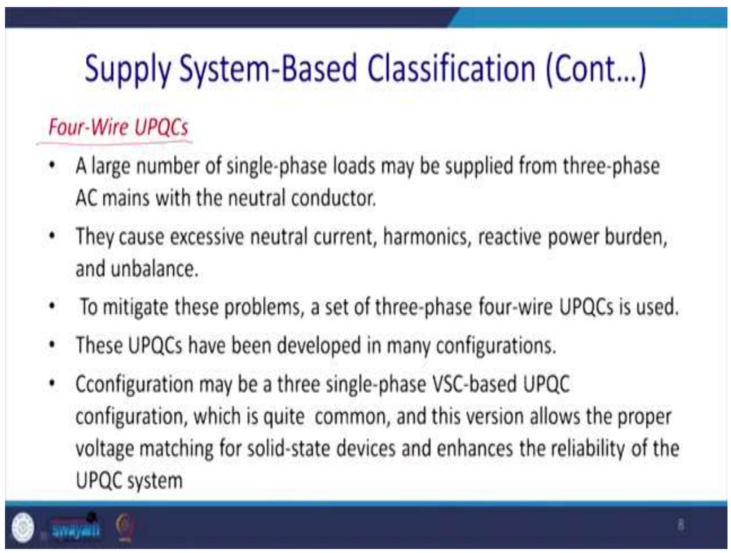
(Refer Slide Time: 11:57)




This is the overall structures of the three-phase three-wire UPQC. These are DVR. As I told you these are the $L_f$ because you got an instantaneous difference and ultimately, you have to mitigate the switching ripples. For this reason, you have a small capacitance and $L_f$. Those will damp out those frequencies. Ultimately this L and this C will have a resonance frequency at a very close to your switching frequency. It is passively damped by the resistor $R_f$ also or the it may be the physical resistance which is not connected. It may be due to this series resistance of the inductors and the capacitor is been put into the lump parameter as $R_f$.

Similarly, you know we have this series injections for the $L_r$ and we have a DVR and $C_r$ and there is a leakage reactance that will mitigate your switching frequency, ripples and that will be sank or mitigated actively by the $R_r$ resistances. This is the principle of operations of the three-phase three-wire two level UPQC. Similarly, we have a problem of the neutral current and thus we have a problem of the unbalanced. We wanted to compensate instead of putting the three single-phase unit in each phases.

(Refer Slide Time: 13:50)




We will require to combine and we will put it to a three-phase four-wire system. Thus, what happens? A large number of single-phase loads maybe supplied by the three-phase main with the neutral conductor and all are maybe polluting. Maybe you have an inductive load, maybe you have many adjustable speed drives and also you have a problem of the unbalanced current. That is the neutral current.

The cause of excessive neutral current is what I am saying harmonics. This maybe a source of the harmonic, reactive power burden as well as unbalanced current. If there is an unbalance due to the voltage, it is very difficult to clean up by this shunt path. We assume that it is not there. DVR already compensated. But anyway, in that case as since DVR is the integral part of this system in case of the UPQC so, it has been cleared up.

To mitigate this problem a set of the three-phase four-wire UPQC is used. So, bundle of the problem.

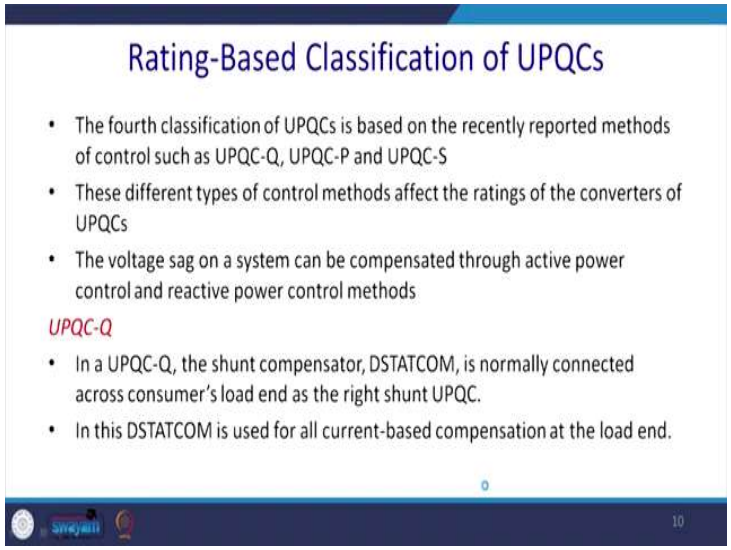
You just put one single solution. This is the way and for this reason we generally do this way. We have studied load flow equations there is a harmonic load flow. You require to do for the fifth harmonic. We have to do the for the seventh harmonic and thus, what you do in a load flow? You find it the maximum sag point.

Same way here you require to find it out which bus has maximum power quality problem in case of the harmonic from many buses, and thus, you have to put it through its saddle point. This UPQC. That itself is a topic of researcher. To mitigate the problem a set of three-phase four-wire system UPQC is been used. The UPQC have been developed in many configurations. Configuration maybe there, maybe there single-phase VSC based UPQC, which is quite common. In this version it allows the proper voltage match for the solid-state devices and enhances the reliability of the UPQC.

This is where you will apply the three-phase four-wire system and mostly, its rating is little less because voltage is four-wire system is 440 Volt and current cannot be very huge and for this reason, it is limited to around 100 Kilowatt. Now, this part was common for the three-phase three-wire system with a three-phase four-wire system. You got an extra leg, in case of the three-phase four-wire system and this is for the neutral wire compensation.

You require to have another entity extra. Otherwise there is another topology that can be used. You can split this DC link and you can put this fourth wire on the middle of the DC link. But there is a problem that, it is not controllable. Current will flow as it is, and also the performance of this unbalance cannot be checked also. For actively controlling the neutral current, we require to have a fourth leg.

(Refer Slide Time: 18:02)

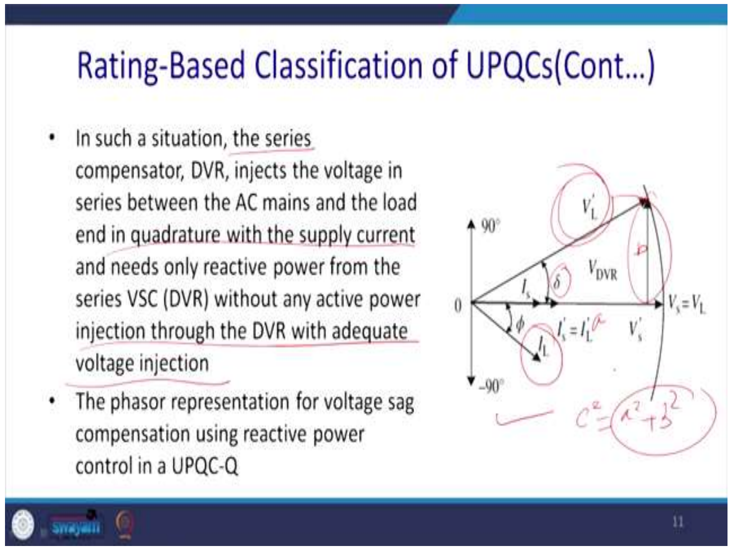



Thereafter, this a Rating-Based Classification of the UPQC. The fourth classifications of UPQC is based on recently reported method. It is not very recently reported rather 20 years ago that is the UPQC-Q. It mainly compensates the reactive power and UPQC-P. It mainly compensates the real power and UPQC-S, its KVA rating is constant. If you have a flexibility use either P or Q. These different types of control methods affect rating of the converter of the UPQC's.

The voltage sag on the system can be compensated through the reactive power control and the reactive power control methods. Because you may have made it a capacity compensation. What has been done by the over excited synchronous generator? Same thing you can achieve by the sag control. What happens then? You have a voltage. You inject the voltage by 90 degree. You got this voltage, but problem lies as, your current has to be compensated accordingly. That is a part of the shunt path.

In case of the UPQC-Q. We will show you the next slides. Total discussions of it. The shunt compensator D-STATCOM is normally connected across the consumer end or load end and the right shunt of the UPQC. This D-STATCOM is used for all current based compensation at the load end.

(Refer Slide Time: 19:46)

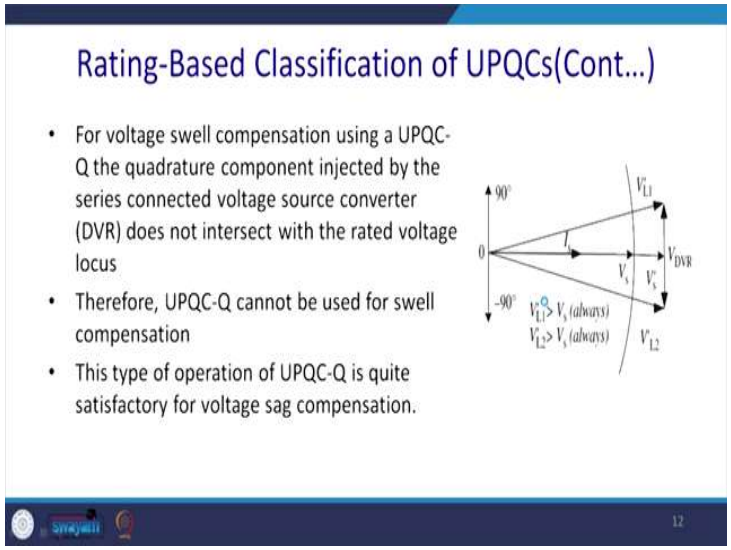



This is the case. Now, this is a voltage and you inject the voltage at quadrature and thus, you got a new voltage here and ultimately, you have got a compensation where it will make this $I_S' = I_L'$ and you got a new angle. It was initially phi now it will be delta. So, let us explain it.

In this Q, in such a situation, the series compensated DVR inject voltage in series between the AC mains and the load in quadrature with the supply current and needs only the reactive power from the DVR which generally, is generated by switching, without any active power injection through the DVR with the accurate or adequate injection.

The phasor representation of the voltage sag compensation of the reactive power is shown in this figure. Ultimately you had initially $V_S$ and this was a $V_L$. You inject the voltage 90 degree to it. This is a DVR voltage and new voltage will be this and by compensations by current, it will try to make it sinusoidal and also there is a harmonic component that also require to be mitigated, not only the power factor.

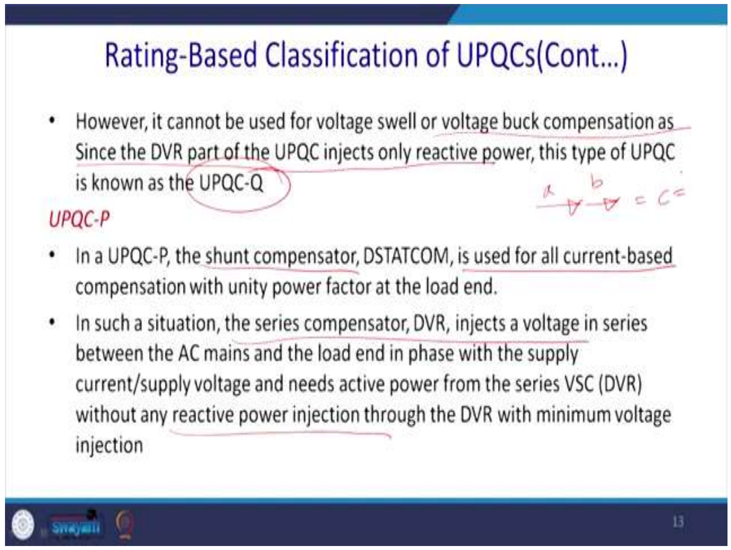
(Refer Slide Time: 21:29)




Now, UPQC based on P. You will have a voltage DVR. Now, what you will inject? In phase with the current. Thus, real power required to be pumped and thus what happens? You get a little higher voltage or less voltage depending on the compensation. For voltage swell compensation using UPQC-Q, the quadrature component injected by the series connected voltage source converter DVR does not intersect with the voltage locus. You can see that. Therefore, Q cannot be used for the swell compensation.

This is a one of the biggest differences that you know. Of course, you know this is 'a' and this is 'b.' You know $c^2 = a^2 + b^2$. So, you never get $c < a$. So, sag compensation is not possible in case of the Q compensation. But here you can inject in series or at 180 degrees of the series and thus, you can change the directions of the voltage and thus, you can also compensate the sag. This type of operation of the UPQC is quite satisfactory for the voltage sag compensation, where swell does not come into the picture.

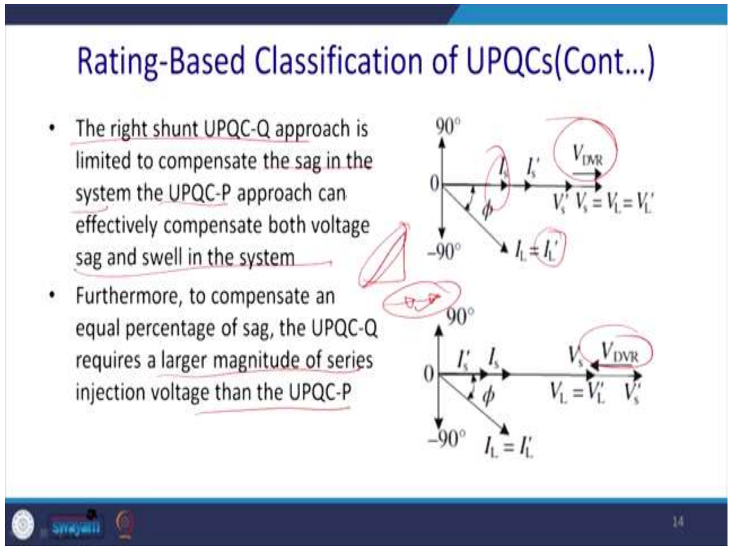
(Refer Slide Time: 23:10)




However, it cannot be used for the voltage swell or the voltage buck compensation and since DVR is part of the UPQC it injects only the reactive power and this type of UPQC is also known as the UPQC-Q and the figure of the UPQC is P has been shown in the previous page. In UPQC-P, the shunt compensator of D-STATCOM used for all current based compensations at the unity power factor at the load end. So, this is the case.

In such a situation, the series compensator DVR inject in series between the AC mains and the load end in the phase supply current and supply voltage and needs active power from the series for VSC or the DVR. Generally, it is DVR. Without any reactive power injection through the DVR with minimum injection. Ultimately if you inject in phase generally ‘a’ plus ‘b’, ‘c’ is maximum when it is in phase. For this reason, it is more effective vectorially. But it require to flow the real power. That is the challenge. Thus, the rating required to be higher. Device rating require to be higher in case of the ‘P’ type of UPQC.

(Refer Slide Time: 24:41)

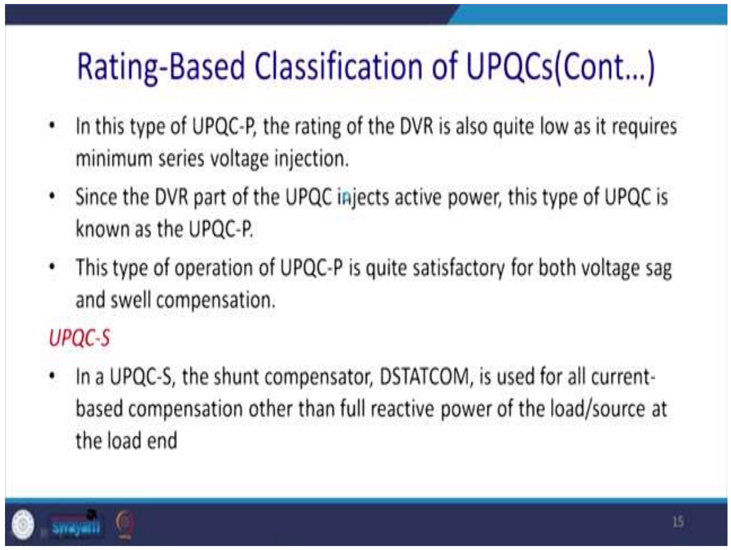



This is the current based. Previously it was a voltage based. It was 'I' and now, what happens? You inject the $V_s = V_L + V_L'$ and this is the DVR voltage in phase with the current. Ultimately, you know $I_L$ will be in a same phase because you are just increasing the magnitude of the voltages. Same way as previously, you can inject the DVR 180 is phase shifted voltage and thus it will come down, but the phase and current will remain same.

We assume that it is a right shunt compensation. All the assumption and our discussion is based on the right shunt. Left shunt, we generally do not use. The right shunt UPQC, UPQC-Q approach is limited to the compensation of the sag. Compensation of the sag in the system. The UPQC-P can effectively compensate both voltage sag as well as the voltage swell of the system.

Furthermore, to compensate an equal percentage of the sag the UPQC requires a larger magnitude of the series injection than the UPQC-P because you know this is the case. Once you have in phase, this is the magnitude. Of course, this magnitude is better than this magnitude. But challenge of 'P' is that real power required to flow from this D-STATCOM in case of the sag compensation.

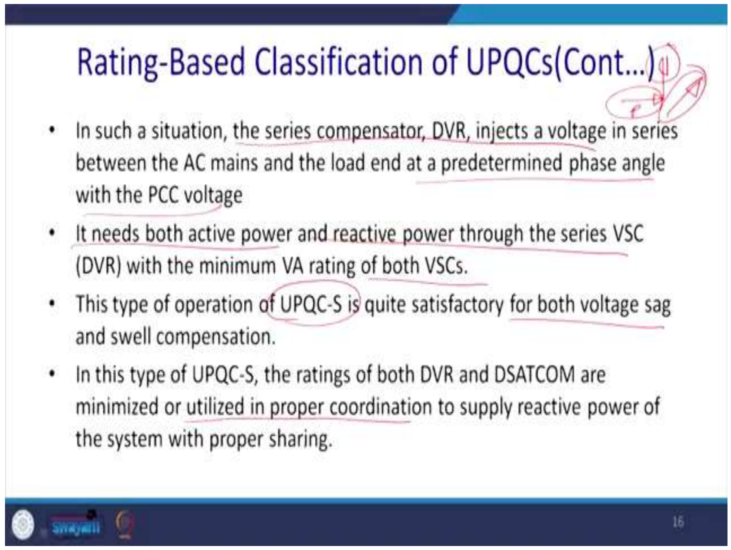
(Refer Slide Time: 26:31)




Also, the reverse. Real power has to go out in case of the swell compensation. In this type of the UPQC-P, the rating of the DVR is also quite low and requires the minimum series voltage injection. Since DVR, part of the UPQC injects active power, this type of UPQC is known as the UPQC-P and this type of compensations of UPQC-Q is quite satisfactory for both the sags and the swell compensation.

But it is poor, you have a problem related to the poor power factor. There UPQC-Q always perform better and thus, there is a middle man in the road that is the UPQC-S. That based on the KVA rating and it has a flexibility. We can inject any voltage. In case of the UPQC-S, the shunt compensator D-STATCOM is used for the all current based compensation other than full reactive power of the load or the source end.

(Refer Slide Time: 28:00)



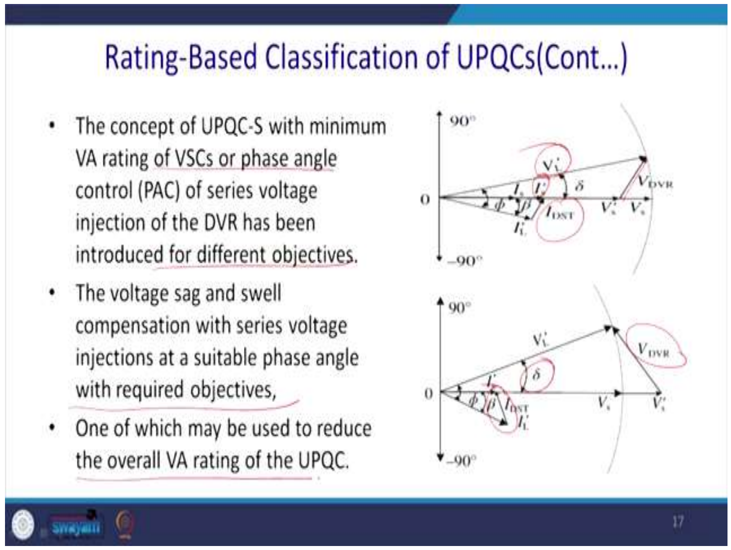

Now, what happens here? In such a situation series compensation DVR inject a voltage in series in between the AC mains and the load end phase angle at the PCC. It is pre calculated. What kind of voltage you require to inject? You will solve this problem on the assignment. What kind of angle is required to be calculated based on that. You will set the angle for the injection.

It needs both active power and the reactive power through the series VSC. So, ultimately instead of this or this you may have this because in case of the UPQC-P, you have this. In case of the UPQC-Q you have this. But accurately you require this. That is not possible. Then, we require to use the both UPQC-P and ‘Q’ together. Instead of that it is merged and optimal angle compensation can be obtained.

It needs both active and the reactive power flow through the VSC (DVR) with the minimum VA rating with both voltage source converter. This type of operation of the UPQC-S is gaining popularity and is quite satisfactorily for both sags as well as the swell compensation and if you have more sag problem, then you use it as a UPQC-Q mostly.

Moreover, this type of UPQC-S the rating of the DVR and D-STATCOM are optimized and this is the optimizations of the rating and thus, you require a minimum bomb cost. Something like that. Minimize or utilize in a proper condition to supply reactive power of the system for proper sharing of this rating of this D-STATCOM and the DVR. This flexibility is possible. So, let us see how does it operate?

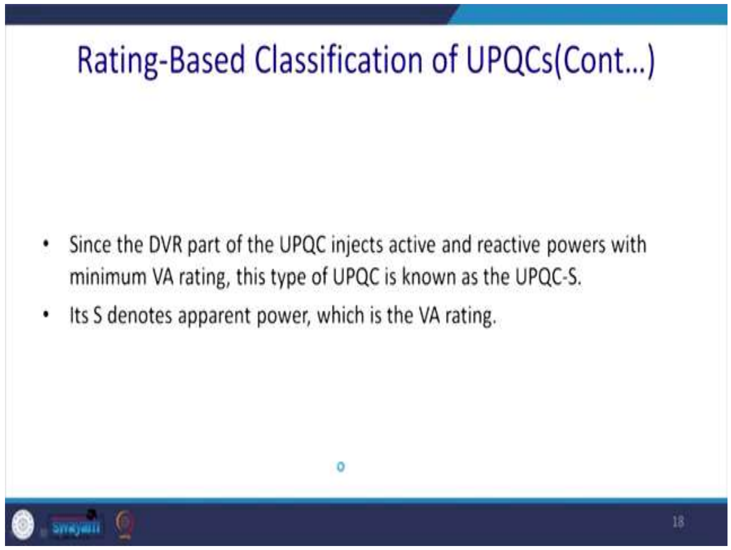
(Refer Slide Time: 30:24)




You know this was the current and ultimately, you inject in this optimal angle. Thus, the resultant load voltage become this, after compensations. You had the angle between this. In a phase this is a 'L'. Now, you become the $L'$, but you inject the DST and ultimately you come here. With respect to $V_L$ and $I_S$, you got an angle. That is 'δ' which is pre calculated based on that you will go to the injection. Same way here also. You inject the DVR voltage this too. If you want to have a sag compensation and thus, you require to inject $I_{DST}$ also and thus, you get a new 'δ' which is pre calculated.

So, what we can say here? The concept of the UPQC-S with the minimum VA rating because switch cost is major here, and like the patent cost and other thing in other industries. Rating of the VSC of the phase angle control in abbreviation this is PAC of the series voltage injection of the DVR has been introduced for different objectives. The voltage sag and voltage swell compensation with series voltage injection had a suitable phase angle with required objective has been fulfilled or can be achieved. That is what it has been shown here. One of which may be used to reduce the overall VA rating of the UPQC.

(Refer Slide Time: 32:21)




Apart from that, since the DVR part of the UPQC injects the active and the reactive power with a minimum VA rating, this type of, (there is another name of it) UPQC is known as the UPQC-S, where 'S' denotes for the apparent power which is the VA rating optimization. Optimized VA rating. That is stand for it.

Thank you. Thank you for your attentions. We shall continue our discussions of the power quality improvement technique in our next classes.