Flexible AC Transmission Systems (FACTS) Devices
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Lecture - 33
Operation and Control of UPQC – 3

Welcome to our lectures on facts devices. We shall continue today with third lectures on the UPQC. That is we have already discussed classifications in the reference generation technique. Now, we shall considered on the rating that is very important aspects, because you know you know that that actually power electronics device is rating, increases heavily with the voltage and the current in as per on the voltage and current.

So, for this session so, rating and control these are the 2 important aspects of UPQC. And, it required to be optimally is require the rating for extract maximum benefit from the UPQC.

So, let us first talk about the control criteria, we have discussed about the reference generation technique for the DSTATCOM and the D V R and same is extended to the UPQC, there may be the number of criteria for the control of the UPQC.

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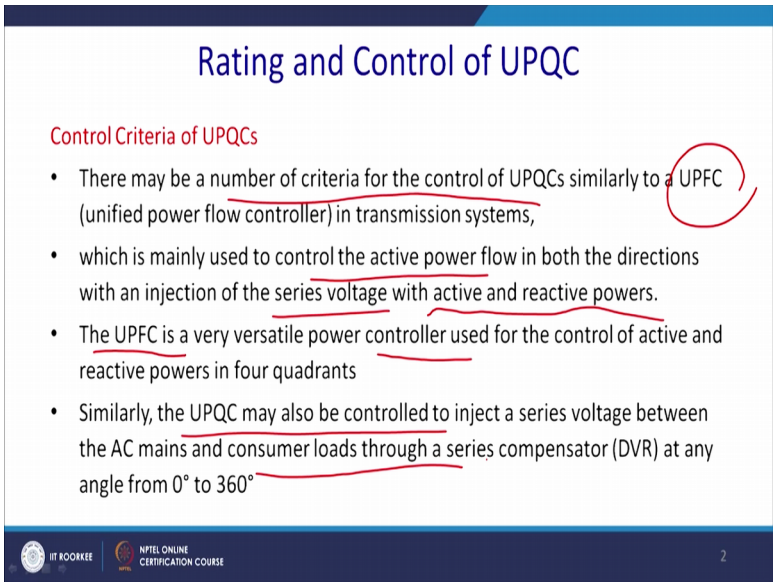

Similar to the U P F C, that is unified power flow controller, it will be you will be discussing actually U P F C after UPQC in a transmission system, which is well used to

control the active power flow in both the direction and with injections of the series voltage and the active reactive powers.

So, this will be taken up in our subsequent classes, because I wanted to discuss of the UPQC first because this is a power quality issues at the those who are approaching this facts this is the facts devices basically, and it has played a important role for the power electronics engineers.

And, the U P F C that is connected in to the transmission line is very versatile power controller, used to control active and the reactive power and it can operate in all the 4 quadrant of the V I characteristics.

So, that is actually a uniformity, same way what you have seen the STATCOM STATCOM and S V C. So, here we can have all the quadrant of operation; we shall see to it how does it implemented.

Similarly, UPQC all also control and inject a series voltage between the AC mains, and the consumer in a by the series D V R at any angle that is also can operate 360 degree operation.

Essentially, when you add that the problem of the distributions and you act to operate fast, because you know you required to operate fast because of the first changing harmonics. Then, you require and device rating required to be reduce in a distribution transformer.

So, you can use fully controlled devices, fully controlled devices in the transmission level is only GTO, but you can use IGBT in case of the UPQC. And, that is you can take faster action with the help of the faster control device, and thus it is quite important to know that actually how fast and how accurate? It can mitigate all the power quality issues.

And, power quality issue is a distribution problem and nowadays actually we have this problem a lot. And, thus UPQC is with featured even though some people says it is a power quality should be taught it is separate subject, but is the integrated with the facts devices.

So, let us consider on UPQC as UPQC-Q. So, it will inject power in voltage in quadrature. In this mode a D V R is used for mainly reactive power injection.

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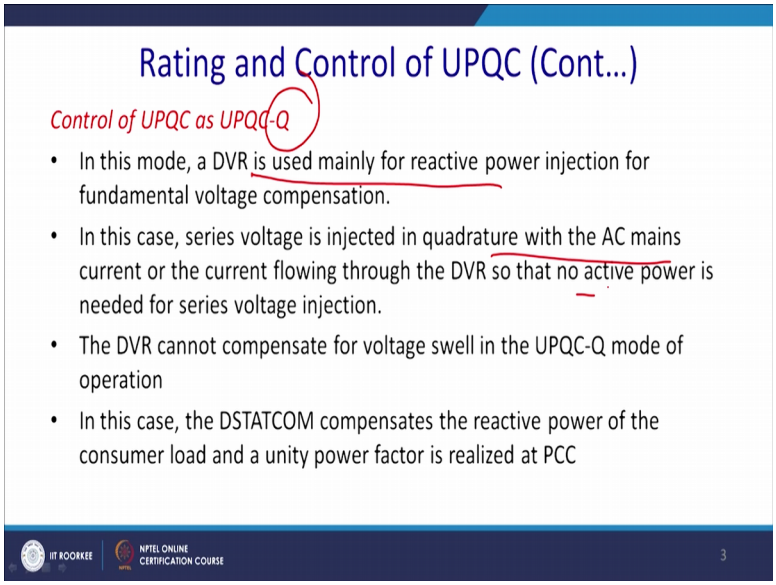

For the fundamental voltage compensation so, in this case the series voltage is injected in quadrature with the A C mains mains current or the current flowing through the D V R. So, that no active power is needed for the series injection.

So, it will not take any active power only to meet the losses of the switches, it require the active power. The D V R cannot compensate voltage swell in the UPQC-Q mode, because it cannot inject the voltage in phase yes it is in a perpendicular to it.

So, sag or swell maintenance or the voltage regulation will not be actually possible only it can actually control the flow of the reactive power. In this case DSTATCOM compensate the reactive power of the consumer load and unity power factor is realized at point of common coupling, this is a principle operation of the Q UPQC-Q.

So, it can handle the reactive power very well and it can it can basically inject voltage in quadrature, in than and also that DSTATCOM also can compensate the reactive power. Sag and swell composition cannot be achieved. And, more over if the current in DSTATCOM is apart from the reactive point it may be one balance kind of thing. So, then also it cannot compensated. So, D V R inject let us see that how does it work?.

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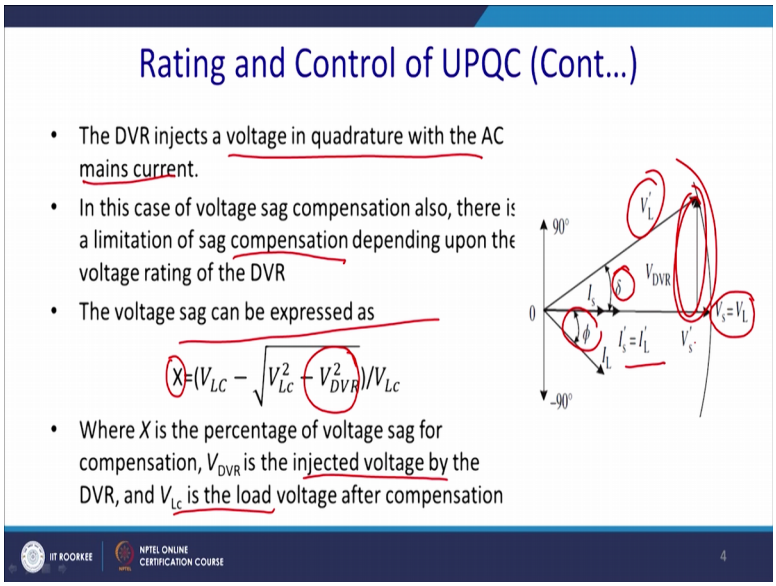

D V R inject voltage in quadrature with the A C mains line, they in this case the voltage sag compensatable there is also a limitation of the sag compensation depending upon the voltage rating of the D V R. Of course, these are the switches. So, switches as a voltage setting capability.

So, voltage sags can be expressed in this format that is the let us assume that it is X where X is not impendence please do not be split. So, V L minus V L C square minus D V R by L C where actually compensating voltage is this, where X represents the voltage sag for the compensation D V R is injected voltage by D V R and L C is the load voltage after compensation.

So, this is the voltage sag ultimately you understand this is a load voltage V L, where you have to make V S equal to V L with unity power factor and this was basically your I L.

And you know it will actually inject the D V R voltage in quadrature and thus you know you will get this voltage. So, V S become equal to V L and voltage is injected by with a by quadrature. This is a simple principle of the operation of this UPQC-Q type.

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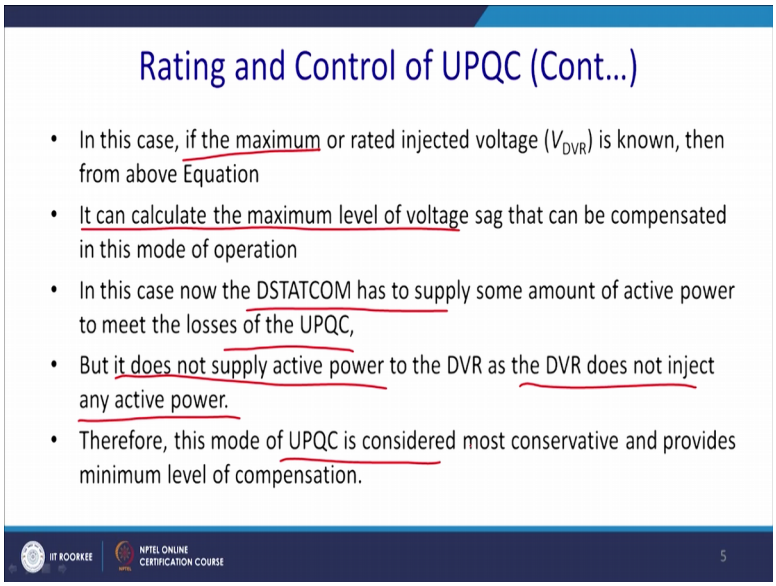

In case of if maximum in this case if the maximum or the rated injected voltage, our D V R is known then from this above equation, then amount of the sag it can compensate can be calculated.

That is it can calculate the maximum level of voltage sag that can be compensated by this mode of operation. So, it has a limited capability to correct the voltage sag. And, in this case now the DSTATCOM has to supply some amount of the active power to meet the losses of the UPQC.

So, real it has to consume little bit of active power for switching and other losses. Since, you know there is no one to supply real power. So, it will come from actually it will come from the mains only. So, for this session you required to maintain the DC bus voltage.

So, what happen let see, but it does not supply the active power to the D V R as D V R does not inject any active power. Therefore, in this mode UPQC is considered most conservative and provides the minimum level of compensation. You required to maintain the little bit of active power to maintain the capacitor voltage. And, that is something by little change also you can do it and you can optimally use the UPQC-Q.

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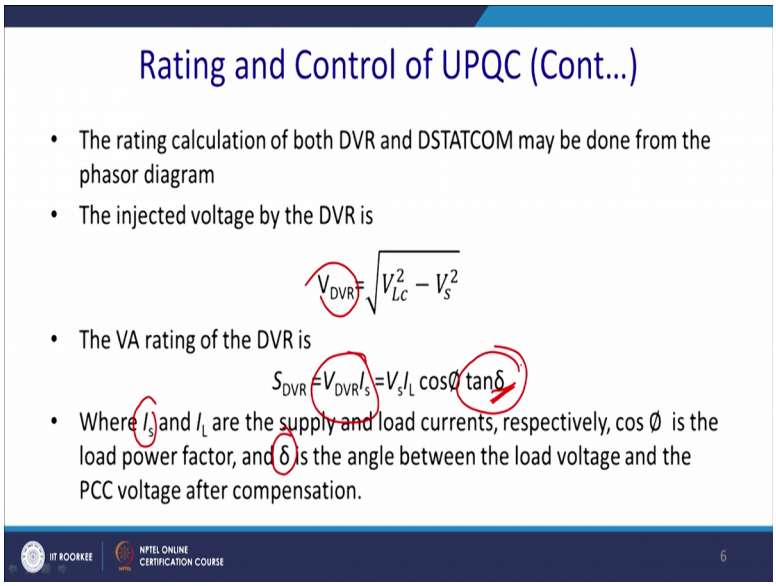

The excuse me the rating calculations for D V R in the STATCOM may be done from the phasor diagram, you see that this is a phasor. So, ultimately this is a amount of the injection you are doing and what is the amount of this actually the reactive current you are fitting?

From there you can calculate. The injected voltage of the D V R is essentially you know, it is under root of load voltage after compensation, that is V L C square minus V S square, thus the V a rating is of the D a V R is D V R into I S, where I S is a source current as it will see the total rating of it. So, V S into I L cos phi into tan delta will come into the picture.

So, let us go back and let us understand, what is actually tan delta component of it? So, this is the angle V L prime and you know this is basically the V L C. This angle is delta, this angle between the V L prime or V L C with I S. And, this component is essentially is the phi that is uncompensated I L with V S. So, now, while compensation I S become I L and defiantly V S become V S prime.

So, ultimately tan delta is essentially D V R by V S. So, from this phasor we can see that. So, ultimately you can write we can substitute D V R in terms of the V S. So, that is a system rating of it so, V S I L cos phi into tan delta.

Since that is that is what it is written I S and I L are supply by the load current load and the source current respectively and cos phi is the load power factor. And, delta is the angle between the load voltage and the voltage after compensation. So, that is what we have found that voltage after compensation.

So, from there actually you can calculate that what should be the rating of the D V R. So, D V R rating will definitely depend on the tan delta and which is non-linear.

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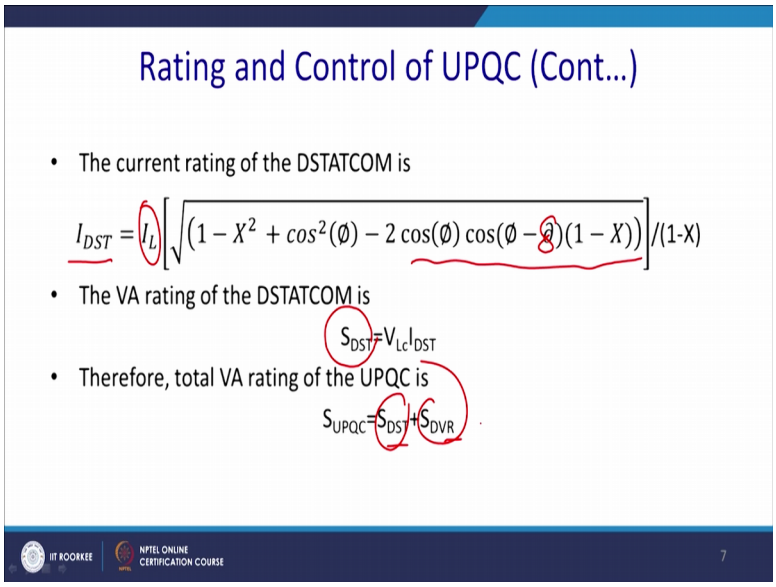

So, now let us come to the current rating of the DSTATCOM.

So, that is a I L that is a inductive portion of it that required to be compensated. So, that is actually DSTATCOM current rating essentially it is basically the fraction of compensation, that is X 1 minus X square plus cos square phi minus 2 cos phi cos minus sigma into minus X by 1.

Where, actually this has to be changed by delta actually this is the equation that has to be governed. So, you know if these terms actually depend on the amount of the compensation you are doing X and of course, the difference between phi and delta.

So, assuming that the actually the V a rating of the actually is basically I S D T equal to voltage load voltage after compensation implied D S T. So, therefore, the total rating of the UPQC will be the sum up of these 2 rating, that is I D ST the DSTATCOM rating and the D V R rating.

So, total will have a same rating. So, remember that actually while talking about few topologies, I was discussing the normal topology is a 12 switch for the 2 level inverter and we have reduced switch topologies.

So, ultimately when you are reducing the switches, then what happened you know actually the stress across the switches will be increasing? Because, you know this is the sum of this tool rating, ultimately if some switch, if it is actually providing both series as well as shunt compensation, then rating of the switch required to be higher.

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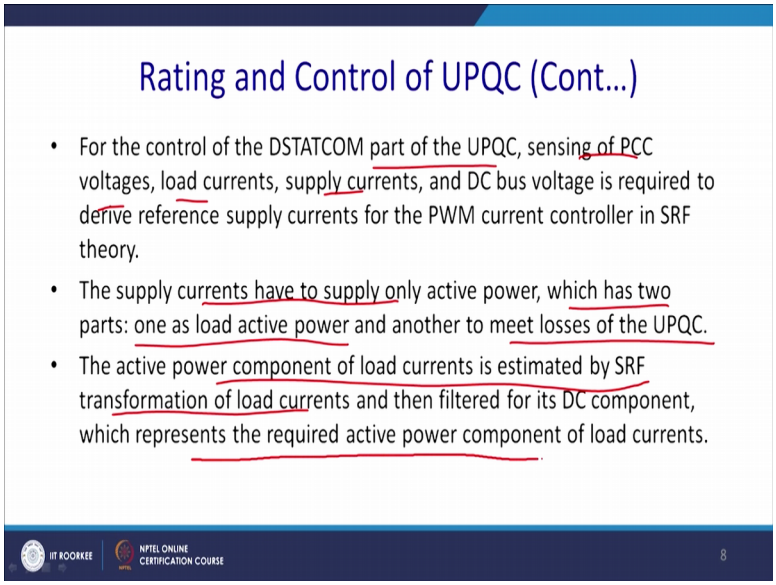

The for the control of the DSTATCOM, the part of the UPQC DSTATCOM what are the UPQC? The sensing of the P C C voltage these are the requirements, these are sensor you required, sensing of the P C C voltage load current supply current and the DC bus voltage is required to drive to actually find it out the reference of supply current for the PWM control, according to the SRF or instantaneous reactive power theory or whatever maybe mostly in the time domain.

The number of sensors is almost same, but different kind of controller only smedley and et al actually proposed up PLL less control the number of sensor there actually get reduced, but there is a own limitations. The supply current have to supply only the active power.

So, that actually it will always see that see the resistive load is connected to it irrespective for the pattern of the load. Which has 2 parts; one has load active power and another to meet the losses of the UPQC, these are the 2 part you have to fed losses of the UPQC has to have a real power.

The active power component of the load current is estimated by S R F, S R F transformation to the load current and then filtered it is DC component. We shall see the above diagram of it which represents the required active power component of the load current.

We are describing it there after we shall show that how does it actually done by a block diagram.

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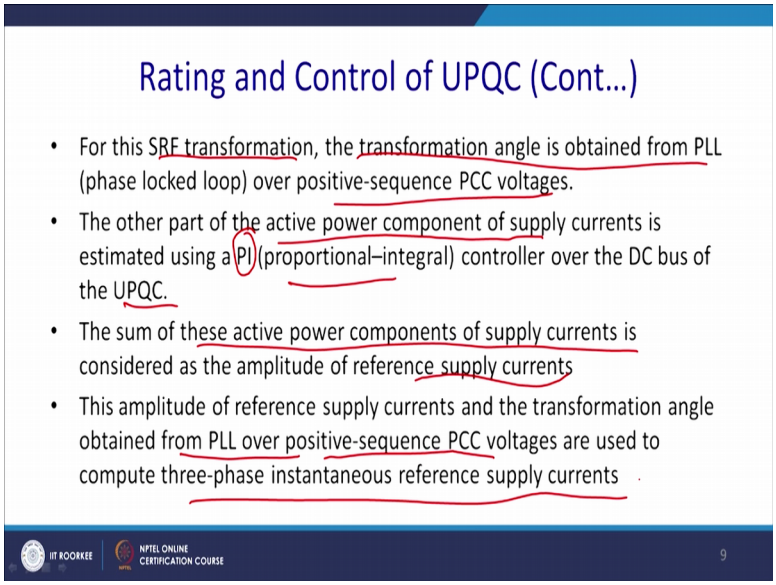

They, S R F transformation the transformation angle is obtained from the P L L phase lock loop over the positive sequence of the P C C voltages. Other part of the active component of the supply current is estimated by a using P I controller or P I D controller over the D C bus voltage of the UPQC.

So, after describing I will explain the block diagram of it, sum of this active power component of supply current is considered as a amplitude of the reference supply current. This amplitude of the reference supply current and the transformation angle obtained from the P L L over the positive sequence P C C supply voltage are used to

compute three-phase instantaneous reference supply current. So, within that way you can compute the three-phase reference supply current with a S R F.

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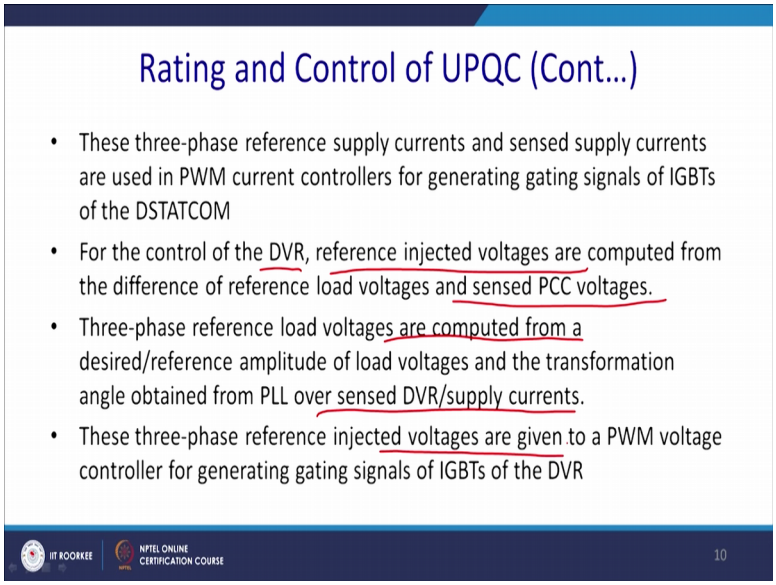

So, this three-phase reference supply current is sensed supply currents are used for the used in the PWM supply current, used in the PWM current control for the generations of the gating signals of I G B T of the DSTATCOM. This is the actually D V R this is a DSTATCOM part of the control by S R F technique.

Now, let us come to the let us come to this D V R part of the UPQC. The control of this D V R the reference injected voltage are computed from the difference of the reference load voltage, and the sensed P C C voltage this is required to be compare.

The three-phase reference load voltage are computed from a desired reference amplitude of the load voltage, and the transformations angle are obtained from the P L L over the sensed D V R's or power supplies. This three-phase reference injected voltage are given to the P W M voltage controller for the generating the gatting signal of the I G B T or D V R.

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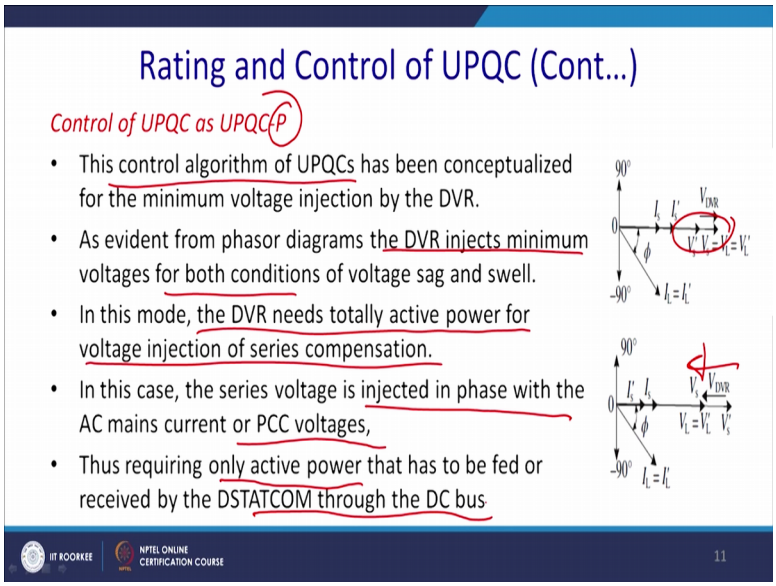

Now, let us come to the next topic that is the control of the UPQC P that is in phase, it will inject the voltage in phase. So, ultimately this is the D V R voltage that will apply the voltage, in phase or in 180 degree minus V R. So, it is a effective sag or the swell compensator and it does not have any power to compensate the reactive power essentially, it is a sag and swell compensator.

We shall discuss all the control technique there after we shall actually discuss this actually the block diagram of UPQC. This control algorithm of UPQC has been conceptualize for minimum voltage injection by D V R. As, it is obtained from the phasor that the D V R inject the minimum voltages for both condition voltage sag as well as a voltage swell, but most of the problems are associated with a swell sorry sag.

So, it is sometime it is said to the sag compensator. In this mode D V R needs the totally the active power voltage injected in series compensation. So, it will take the active power from the source and boost up the voltage or suck the power from the source to reduce the swell.

In case of the series voltage injected in phase with the A C mains or P C C voltages, thus requiring only active power that has to be fed or received by the DSTATCOM through the D C bus.

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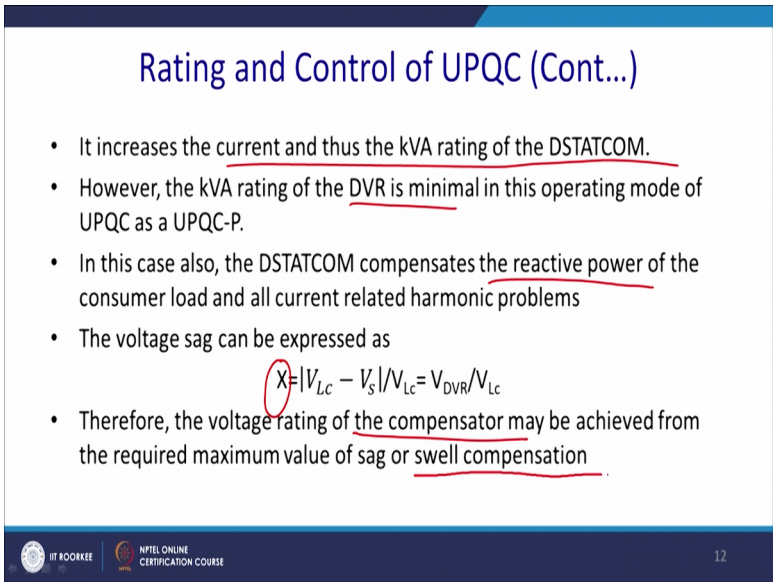

So, this is the principle of operation of UPQC-P, to increase and what happened then it increases the current and thus the k V A rating of the DSTATCOM. However, k V A rating of the D V R is minimal in this operation mode of UPQC as UPQC-P because it is only series a in phase component of the voltage.

And, in this case also the DSTATCOM compensate the active reactive power of the consumer load current and all the current, and the all the current rated problem with the harmonics.

So, voltage sags here also can be expressed this X equal to V L minus V S by V L. So, you can cancel it. So, ultimately you get since there in phase component D V R by L C in a simple way to compute for the phasor.

Therefore, the voltage rating of the compensator maybe achieved from the required minimum value of the sag as well as the swell compensation. The UPQC P mode of operation requires minimum injection voltage and thus minimum V a rating of the D V R, but at expense of the DSTATCOM rating.

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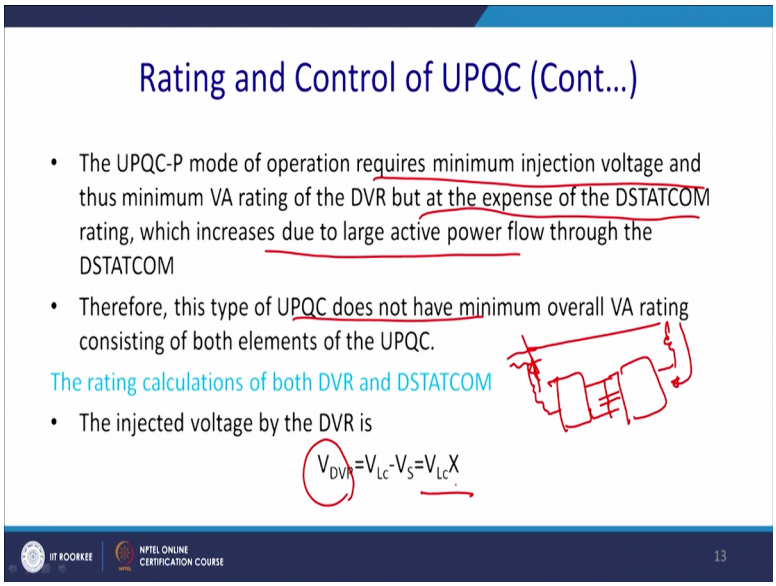

And, what happened which increases due to the large active power flow through the DSTATCOM.

Because, if you have a UPQC and I assume that is a right shunt compensation. So, real power will flow through the DSTATCOM and that will be injected by this D V R. This is the way of real power flow, thus rating of the DSTATCOM is going to be increased.

Therefore, this type of UPQC does not have minimum overall V a rating consisting of both element of the UPQC. And, rating calculation of the D V R and DSTATCOM can be you know D V R rating will be V L C minus V S, that is L C into X you have to design for how much sag occurs in to the particular place 40 percent sag 30 percent sag or something like that or same way the swell.

So, generally you have a over voltage and the under voltage delays. So, accordingly you have to take care of and use calculate the value of X.

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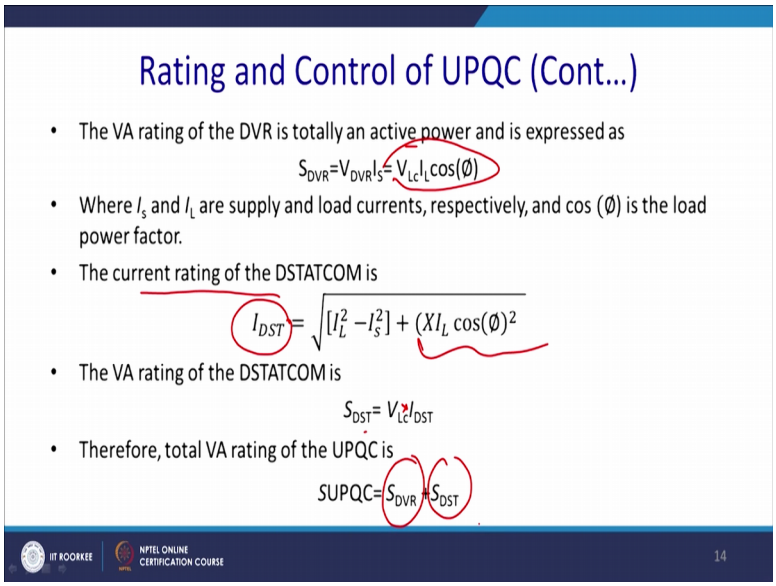

So, the V a rating of the D V R is a total totally an active power and is expressed as S D V R equal to V D V R into I S from there L C I L cos phi will come.

And, from there I S and I L are the supply load current respectively and phi is the load power factor here delta will not come. And current rating of the DSTATCOM will be given by I L minus I S square plus fraction of this sag compensator that is X I L cos phi square, from there actually V a rating of the DSTATCOM is V L C into I L C by D T.

So, it is a multiplication of this similarly therefore, their rating will be same D V R plus DSTATCOM, but generally DSTATCOM will actually will have a more rating than the D V R.

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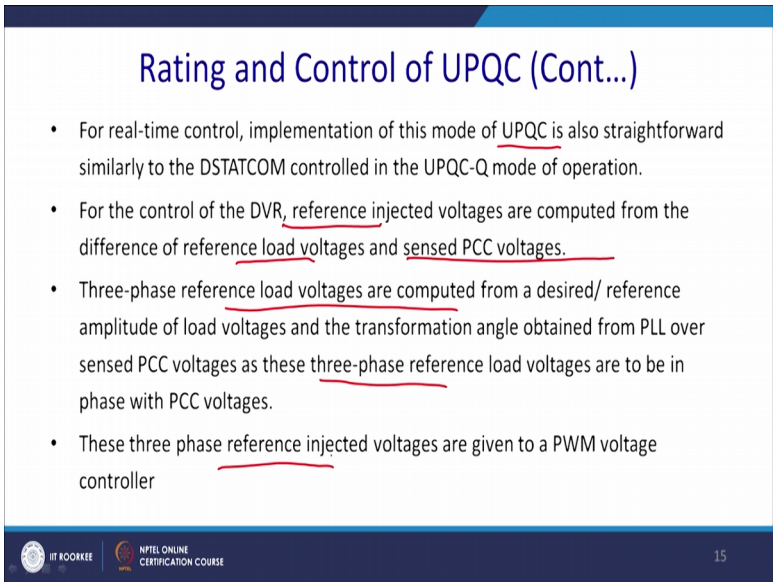

So, what we can conclude for the real-time time control and implementation of this mode UPQC is also state forward.

Similar to the DSTATCOM control into the UPQC mode of operation, for this control D V R actually reference is injected D V R, reference injected voltage are computed from the reference of the reference load voltage. And, the sense P C C voltage and it can only correct the sag mind it.

The three-phase reference load voltage are computed from the desired or the reference amplitude of the load voltage, and transformation angle is obtained from the P L L over the sense P C C as this phase reference at the load voltage are fed into the point of common coupling.

This 3 phase reference is injected, reference is injected voltage gives you the actually the P W M required to generate the reference for the voltage source converter; this is a way of operation of UPQC-P. So, we shall continue with our next class with the control and the rating of the UPQC S.

Thank you for your kind attention.