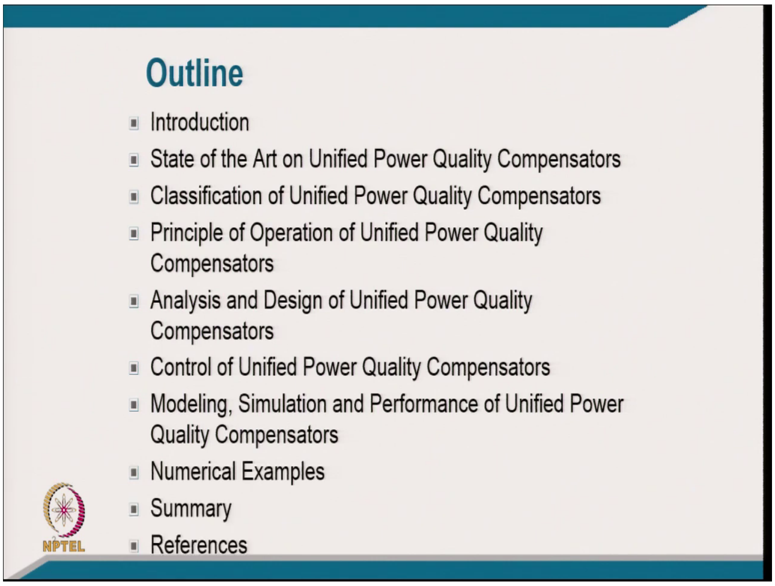
Power Quality
Prof. Bhim Singh
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Lecture - 12
Unified Power Quality Compensators

Welcome to the course on this Power Quality; I mean today we like to cover the topic on Unified Power Quality Compensator; it is also called typically unified power quality conditioners. Well, the outline of today presentation we will start introduction; then we will talk about state of art on unified power quality compensators.

(Refer Slide Time: 00:43)

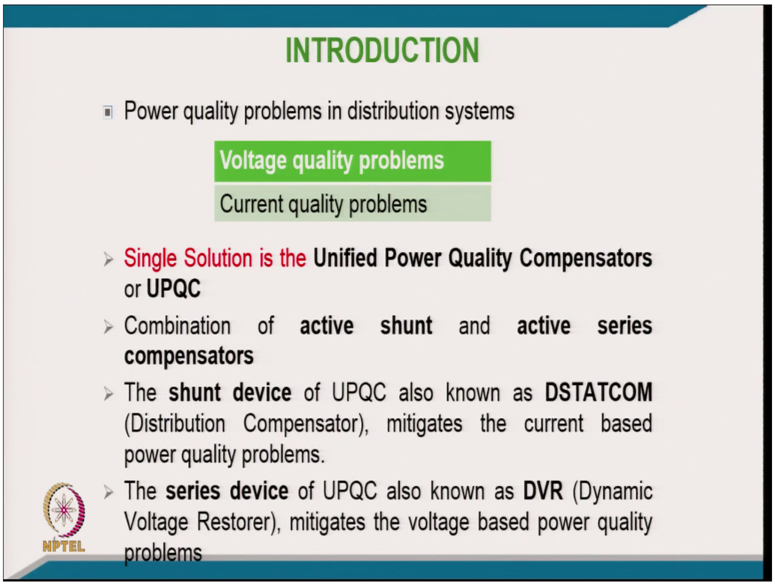


Then we will give a classification of UPQC, then the principle of operation of UPQC, then analysis and design of UPQC, then control of UPQC, and modelling, simulation and performance of UPQC with a numerical examples, and we will like to summarize the presentation with references like.

(Refer Slide Time: 01:03)

[FL] The objective of today presentation is the typically we like to discuss the requirement and applications of UPQC; then we go we will go to the configuration of UPQCs, then we like to discuss analysis and design of these UPQCs and then we will discuss the control algorithms of UPQC and then method of modeling and control of UPQC like.

(Refer Slide Time: 01:28)



[FL] Coming to like a the power quality in the distribution system, we already discussed about that; I mean the in AC power system, we have a power quality at in different part of like a generation, transmission distribution, utilization, but mainly it is on utilization side in distribution system with the mode severe.

And this power quality problems are we have already classified, but the major power quality problems are voltage based power quality problem, which can be either both the way; whether it is in supply system due to the natural causes. We discussed in detail or it is due to the probably the cause by the main means, because of the load and other reasons like.

[FL] That is about how voltage power quality problems covers; typically like voltage distortion, the voltage unbalance, voltage sag swell, and then voltage fluctuations. And then the current based power quality problems also can be like typically your current unbalance, then reactive currents.

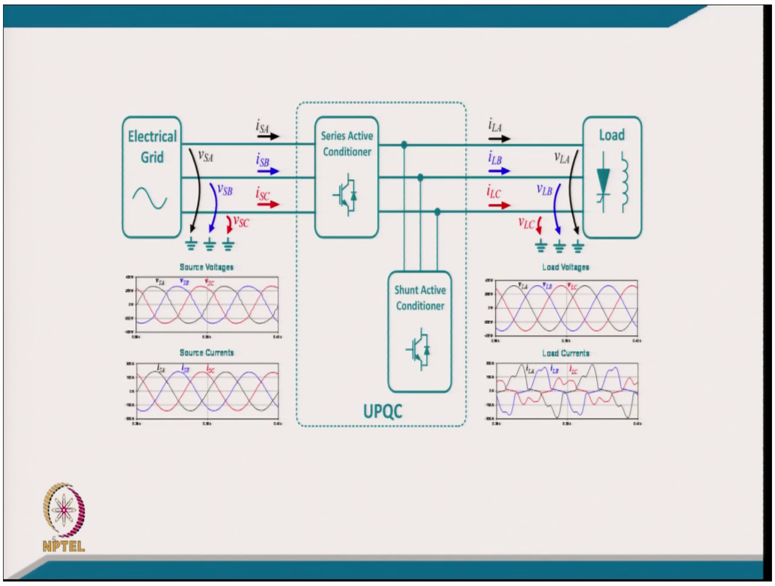
I mean because majority of the loads are inductive load, [FL] they draw the lagging power factor currents. And then if it is go to like a three phase system, then it go to typically you can call it like a unbalanced current and if it is a four wire system, then you have a even the presence of neutral current also like I mean.

[FL] We can call it the single solution for both, we discussed already the solution for current based power quality problem, which we discussed in DSTATCOM; then we discuss the voltage power quality problem compensation in the series active series compensation or you can call it like a DVR. But, now today we like to discuss as a single solution for those both of these problems in the this unified power quality compensators or in short we call it UPQC.

[FL] This UPQC is a combination of active shunt and active series compensators; it consists of both, because we will like to have a by active shunt compensation to mitigate the current power quality problems and by series compensation you will like to mitigate the voltage power quality problems like [FL].

The shunt device of UPQC, also known as the DSTATCOM, Distribution Static Compensator mitigate the current based power quality problems and the series device of UPQC also known as DVR, Dynamic Voltage Restorer, mitigate the voltage based power quality problems like.

(Refer Slide Time: 03:54)



This is the typical you can call it the a block diagram of UPQC [FL]; you can say we have a supply, I mean the typically the distribution grid, in which you can call that we have a normally the voltage based power quality problem. Voltage based power quality problem we discussed earlier also, it may be like a voltage unbalance. As you can say in three phase, it can be like a voltage unbalance, voltage distortion or you can have a voltage sag, voltage swell, voltage fluctuations.

These are the voltage based power quality problem; but still we want the grid current should be balanced sinusoidal and at unity power factor, that is given the below what is the requirement here like I mean or see you can see. Similarly, if you look into the load side, the most of the loads are very sensitive; I mean they are designed that, this will have a balanced sinusoidal supply voltage across them, however many of the loads draw the non sinusoidal current.

I mean they because of the solid state control into them or I mean because why we are using a solid state control, we already discuss earlier; because the many appliances where we are using this solid state controllers, I mean they are offering a lot of energy conservation to us like, I mean even a starting like a single phase.

We talk about like either lighting system, LED lighting system or you are using a typically like a brushless DC motor, fans or in three phase system you are using adjustably speed drive, like for air conditioning or many process like.

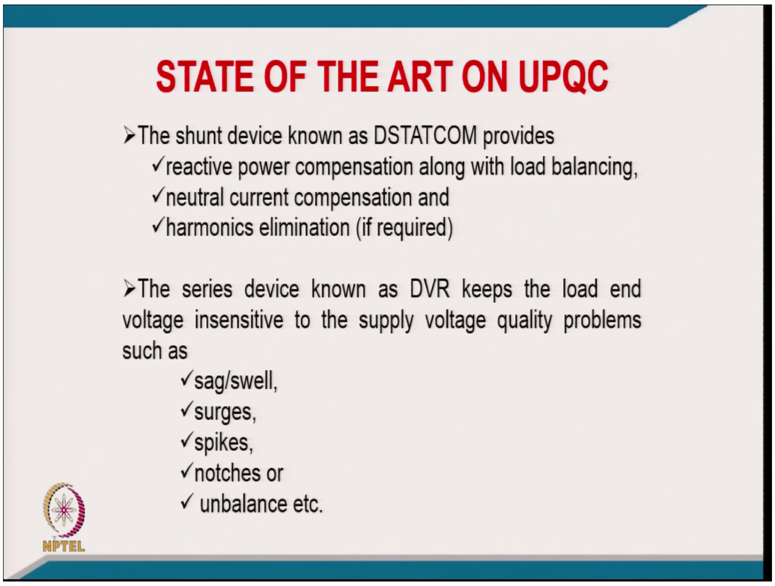
[FL] They might have a typically like a load unbalanced current, they might have a lagging power factor load, then unbalanced current and might be having a harmonics also as well as neutral current like. But we want that the voltage across the load should be sinusoidal [FL]; looking the requirement of the load that, you must have a regulated sinusoidal voltage balanced voltage across the load and in spite they might be drawing them let us say not ideal current I mean.

But on the grid side our requirement even the quality of the grid is not good as far as voltage is concerned, but we want the grid current should be sinusoidal. [FL] We connect a device here, in between you look into that there are two voltage source converter here. One is a series active conditioner, another is shunt active conditioner, which is a combination of both is we call it UPQC [FL] that takes care the, I mean both the problem.

[FL] Load would get a good voltage quality, in a spite it does not draw good current quality; because it is a it is a load of different varieties. Similarly, on the grid side, I mean you have a very may not be a good voltage quality; but you expect that the this the consumer should draw sinusoidal balance supply current in spite of that at unity power factor like.

(Refer Slide Time: 06:36)

(Refer Slide Time: 06:38)



[FL] That is the basic operating principle of this UPQC what we want; of course there are many manufacturer who are manufacturing now UPQC, it is already in practice use and there is a typical art that on this shunt device known as DC shunt, provide the reactive power compensation along with the load balancing.

It also provide neutral current compensation and if required, it might be harmonics elimination also or you might have a like harmonics also in your load current. The interesting part of it, the design of this shunt compensator or the voltage source or compensator is used for the shunt is rating differed for these requirement; like I mean if you want more features, certainly you have to certainly allowed to add the cost of this compensator for more features.

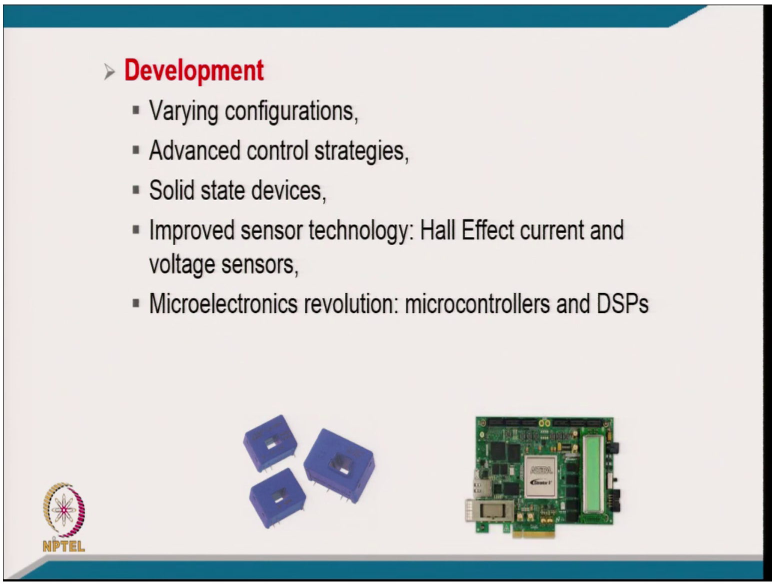
Typical example I can give you here, if you really do not need harmonics; then probably the switching of the devices at around 1 point kilo, 8 kilo Hertz or 2 kilo Hertz will be enough to generate the fundamental current, whether it is for your negative sequence current or it is a reactive current or it is typically neutral current.

But if you really want to have a harmonics current generation; then the switching frequency should be at least double than the you're the, I mean the harmonics you want to eliminate it like I mean. But it should be much higher than the, I mean if you want to eliminate the higher order harmonic; then certainly it is required that the switching frequencies should be much higher, not only 2 kilo Hertz, but it might be 5 kilo Hertz or 2; 10 kilo Hertz.

Then the your switching losses in the devices increases, which increase the loss not only the losses; but your thermal design of the converter also have to be enhanced, like a heat sink, size increases, cooling fan and although it also, [FL] cost is certainly getting affected. I mean as a principle circuit will be looks like a same, but the rating consideration default like I mean.

Similarly, the series device known as DVR, Dynamic Voltage Restorer keeps the voltage load and voltage insensitive to the supply voltage quality problems, such as on supply side you might have a voltage sag and voltage swell, the voltage surges, voltage spike, voltage notches and an unbalanced voltage. But the on the load end you have to keep the ideal voltage, balance voltage, sinusoidal voltage, and regulated voltage like; that is the job of your series compensator part like called DVR like I mean or so.

(Refer Slide Time: 08:45)

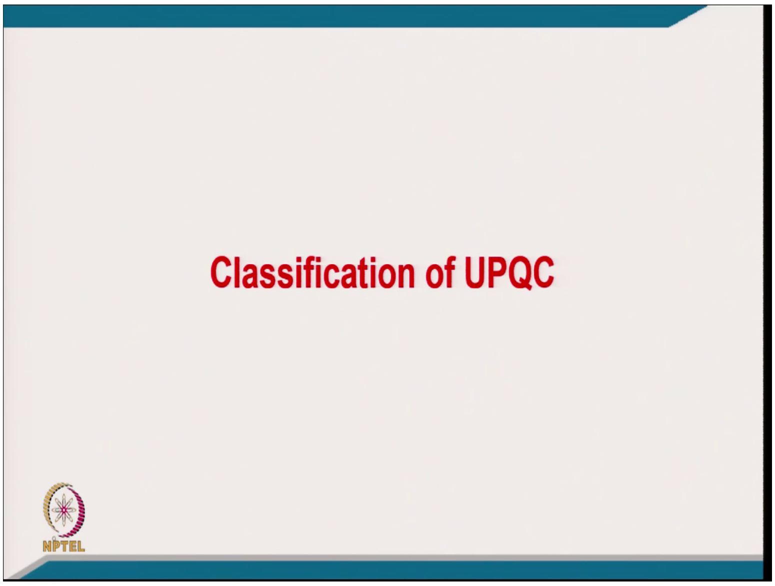


[FL] Well, as far as development is concerned, this UPQC have been developed in varied varying configuration and we have a many advanced control technique for this UPQC. Then there are different solid state devices are used for different ratings in those converters, then you have a improved sensor technology like a.

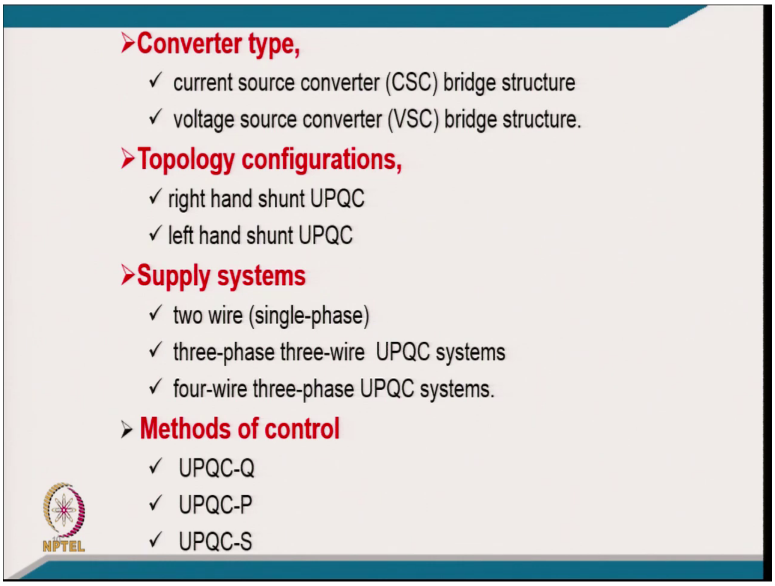
Because we need all the feedback for control like a current signal and voltage signal and they certainly have to be sensed with the quite accuracy and without distortion in their waveform and because it is a only the compensation on that, [FL] normally we use the hall effect voltage sensor and current sensor for that. [FL] Of course, they are available at the now at reasonable price; [FL] there is no difficulty of.

Similarly, your microelectronics revolution like typically microcontroller and DSP are also available now at reasonable cost. [FL] We can afford for developing of this; [FL] this is typically the photograph of current sensors and these are the typical photograph of a DSP on which we implement the control algorithm like I mean.

(Refer Slide Time: 09:39)



(Refer Slide Time: 09:44)



Coming to the classification of unified power quality compensators, I mean that these can be classified based on the converter type; whether you are using current source converter, I mean or you are using voltage source converter in the configuration of UPQC. [FL] That is one kind of classification.

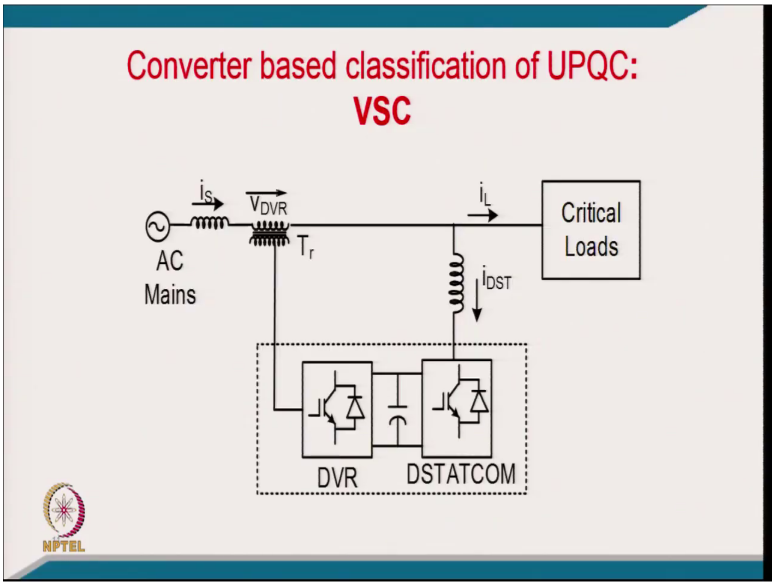
The another classification can be the topology based classification, whether you are putting right shunt UPQC; I mean right shunt UPQC mean in the sense that you are you putting a DSTATCOM part on the right side, on the load end. Or you are putting the UP typically left hand shunt means; you are keeping a DSTATCOM part on the left side of tip series is on the load side and your shunt is on the left side or so, or you can call it grid side.

Then the supply system, you might have a requirement like you are going to have this UPQC for single phase system like a two wire system or you are going to have a UPQC for three phase three wire system. I mean typically or you have a UPQC required for three phase four wire system, where neutral current neutral is also associated there, [FL] there is a another classification for which you require this UPQC like.

And then method of control, there is interestingly here, whether the UPQC have to control it called UPQC Q. UPQC Q in the sense the injection of the series compensator is at the quadrature the only through reactive power; Q means for represent for reactive power. [FL] We control that the series compensation, for series compensation we are using only reactive power; UPQC we are using a for series compensation only active power, we are injecting active power I mean and by which we are compensating or UPQC S. UPQC S means we are using the for series compensation, the injection of the voltage at different angle which may consist P and Q both.

Why this concept is there? The rating differs of this series compensator as well as shunt compensator, in all three these controls like I mean. In a practice might be, most of the cases we might be operating UPQC S; but in many situation you will find, the rating will be less in UPQC P, even operational I mean losses might be reduced by operating in some of these modes like I mean or so. [FL] That is the reason this concept of control have come for these three kind of manner.

(Refer Slide Time: 12:02)

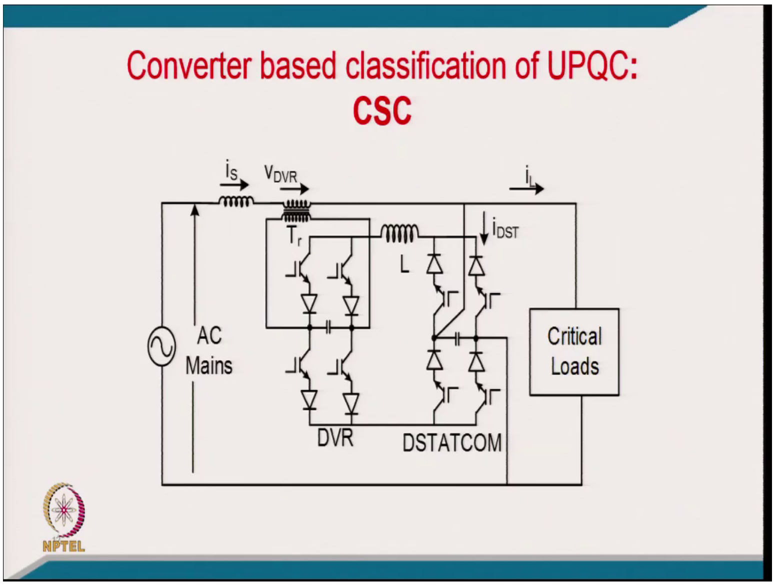


[FL] This is typically the block diagram in general block diagram, which may be applicable either for single phase three phase three wire, three phase four wire [FL]; it is we can call it the kind of converter based classification, we will talk about. But however, we already discussed is it right hand kind of shunt compensator; because DSTATCOM we are keeping on the load side and series compensator we are keeping on series type like.

And of course, if you using the voltage source converter, which is preferred, we discussed already; that nowadays we are preferring the voltage source converter in place of current source converter, we will discuss in the name maybe next slide. Here the reason being that the device only either diode conductor or IGBT conductor, losses in the device is less and on DC link we are putting a electrolytic capacitor, which is very cost effective, low cost, low size, small size and almost negligible losses.

But if you are taking a current source converter, then you have to use a series inductor which is costly, bulky, noisy, and lossy [FL] and even create also like I mean, [FL] it causes the reasonable difference. And moreover I mean we will talk about like this is like a current base or you can call it current source, converter base UPQC.

(Refer Slide Time: 13:09)



[FL] You can see there are two current source converter here and energy storage between a through inductor, I mean reactor or inductor. And designing a DC inductor it is not so easy, because normally inductor with the DC will saturate; [FL] you have to certainly put like a some a small gear gap in the inductor, so that the value of this inductor does not change even the on DC.

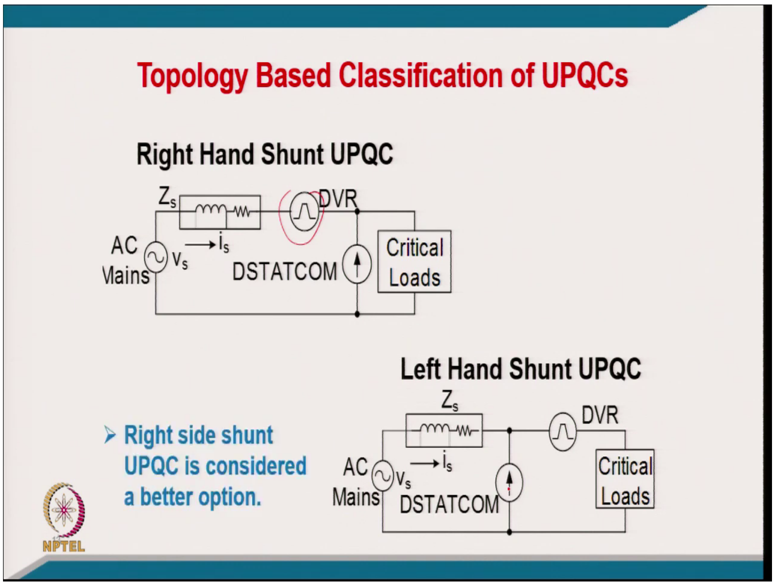
[FL] Certainly this inductor will be costly, bulky as well as having a heavy weight [FL] the and losses also. Moreover when device conduct, because the IGBT cannot have a reverse voltage blocking ability; you have to connect a series diode in addition to that, [FL] it means when device conduct the losses of not only IGBT. But the losses are of IGBT plus your diode also, [FL] losses of both the elements are there in that case. Moreover, you have to have a typically the mandatory the capacitor here.

I mean you can just see the capacitor here it is, I mean this is a mandatory component which is not necessary required in case of voltage source converter. [FL] These are relative merits and demerits; of course so if you look into this UPQC, it was first presented in 1980 89 by Benen.

However, later on according to the technology; because when I am talking about like a 89 around that, that time the current source converter were more popular, I mean compared to the voltage source converter. But with the time of course, the technology changes according to the benefits of the converter or so.

But this is the circuit which can easily operate also for the same kind of compensation, but relative merits and demerits certainly give the weight for the typically for voltage source converter base compensation.

(Refer Slide Time: 14:34)



Now, coming to the like a topology based classification which we are talking about; I mean here if we have a symbolic that, we have a source, then we have a source impedance, we have a like a here the typically kind of a DVR and we have a shunt compensator called DSTATCOM.

Well, this topology is preferred in this typically in case of the UPQC, which are used in distribution system; the reason being that, normally your load having a current based power quality which are compensated by locally by putting DSTATCOM in shunt of that, I mean by DSTATCOM. Now, the current going into the DVR will be minimum; because your load may require reactive power, load may require like a negative sequence current or maybe even in a harmonics also neutral current, which is compensated by shunt compensator.

[FL] Whatever is going into the now in flowing into the let us say into DVR or series elements, it is a good quality or minimum current you can call it, [FL] rating of the your DVR will be certainly minimum. And of course, I mean this DVR responsible that because the grid voltage of the source impedance is not a good quality, might have a voltage sag swell, voltage unbalance, voltage fluctuations, but this inject the voltage like.

[FL] This configuration is preferred, because the rating of shunt as well as series will be minimum in this configuration; I mean the all the power current which are responsible for current based quality problem are not flowing into the DVR I mean or so. And the voltage, another reason is now the voltage across the DSTATCOM is also regulated voltage.

But, if you put the DSTATCOM on other side, we will discuss with another topology here; [FL] it means here the voltage rating of the you can call it the DSTATCOM is minimum and the DVR current rating is also minimum, that is the reason of course, you can call it the rating of overall UPQC also will be minimum.

[FL] This is preferred topology for UPQC as far as distribution system is concerned. The another topology if you look into the which called left hand; left hand in the sense DSTATCOM is left hand on supply side and DVR on the critical load side.

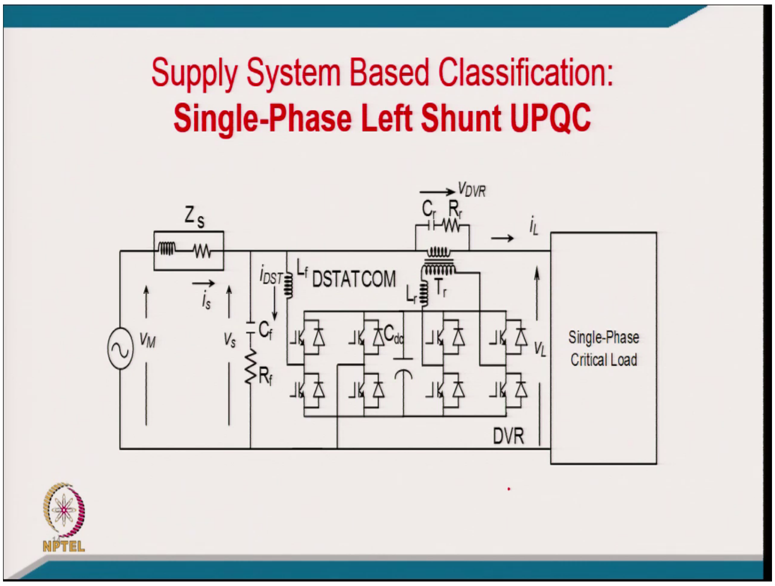
This is the topology which preferred in transmission system, I mean because where it came the concept, it also called custom board devices. But first this fax devices, this is a category of the fax devices, they came first for transmission system. And transmission system we put a DSTATCOM on substation and DVR in series with the line; [FL] there this topology is preferred, because we have to provide the compensation in the line.

But in case here in distribution system, this topology is not preferred, because the DVR rating, I mean like will increase why? Because here the current I mean which are to be compensated that also flowing in throughout the DVR. And the DSTATCOM current rating have to be designed corresponding to the maximum voltage, because the voltage here across the typically of the grid is fluctuating, [FL] you may have a voltage swell; it means

DSTATCOM voltage will also increase, [FL] voltage rating of DSTATCOM will increase like, of course for current it is due to be designed.

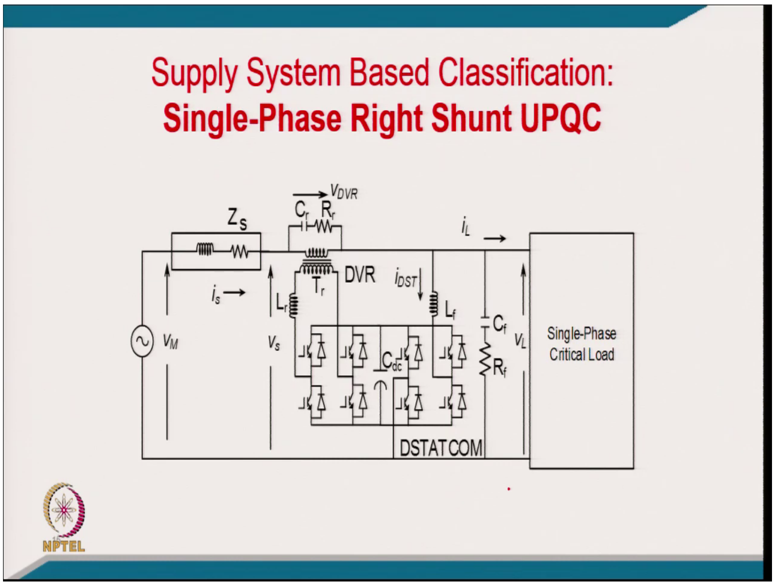
[FL] Here in this topology, you can call it the current and voltage rating both will increase like I mean; [FL] you may find, I mean this is good for transmission, but this is certainly good for distribution, [FL] this topology is more preferred in that case like I mean or so. [FL] Right hand side UPQC is considered a better topology; means that is the better topology for distribution system that is the conclusion of that.

(Refer Slide Time: 17:55)



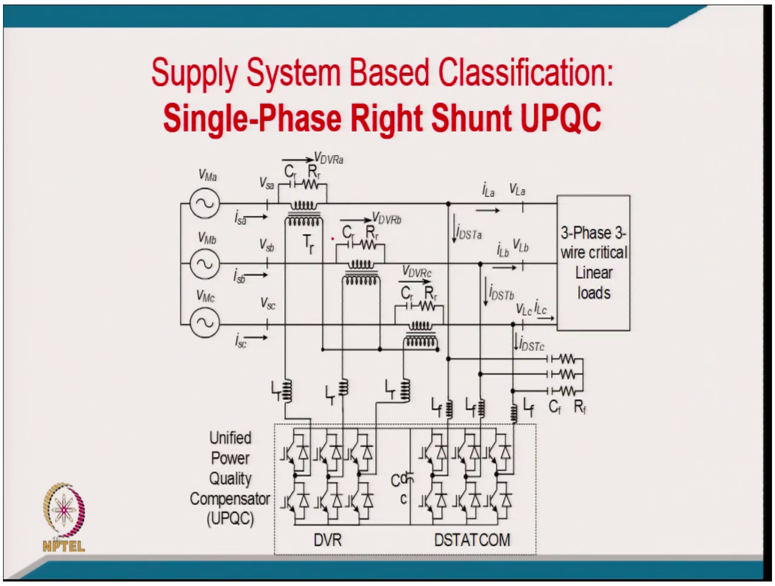
And this is the typically actual topology of the you can call it left hand kind ok; because you are putting a left hand on the DSTATCOM, how to look like a single phase configuration and we have a like a here the injection transform or so, injecting the series voltage or so, [FL] this is just like to have a single phase shunt, you can call it left shunt like here.

(Refer Slide Time: 18:14)



And this is your typically right shunt, [FL] you are keeping the DSTATCOM on right shunt. [FL] This is the topology for single phase and you have a ripple filter here ok typically and as well as a ripple filter here that is we discuss it; because you can call it like a, this is suppose to improve the voltage profile across the, I mean across the load and here also you have to improve the voltage profile inject of the injected voltage in the series with the line, so that the switching harmonics are not injected into it like I mean or so.

(Refer Slide Time: 18:41)



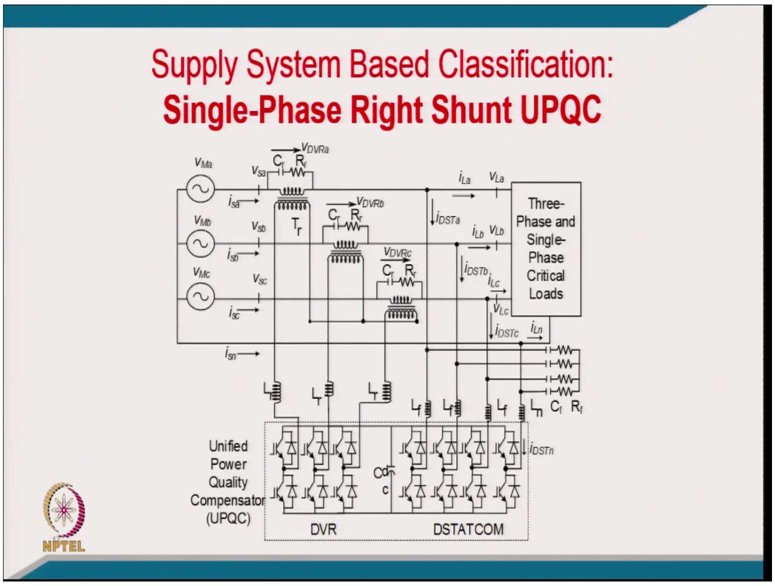
Then we have a of course, the expansion of three phase circuit, I mean this is your DSTATCOM with the ripple filter interfacing inductance, which we are connecting directly across the load and the current based power quality to problem it is mitigating. Locally as far as the voltage across the load as well as the DSTATCOM that remains the fix that, causes the I mean you can call it minimum rating of voltage rating minimum.

And similarly the series compensator which are I mean connected in series, it is drawing now current flowing through the series compensator is minimum. Because the whatever current based power quality problem is there, that is already compensated by shunt compensator. What we are going to save here? We could have used one DVR and one DSTATCOM; what we save that, we put the capacitor in common.

Putting a capacitor common, we are saving one capacitor; [FL] another benefit is now we can flow the active power in this way or this way, which we cannot do in DVR, I mean DVR we have discussed either you have to have a rectifier supported or battery supported or self-supported, but in that case there was a limitation, where the active power cannot flow so freely.

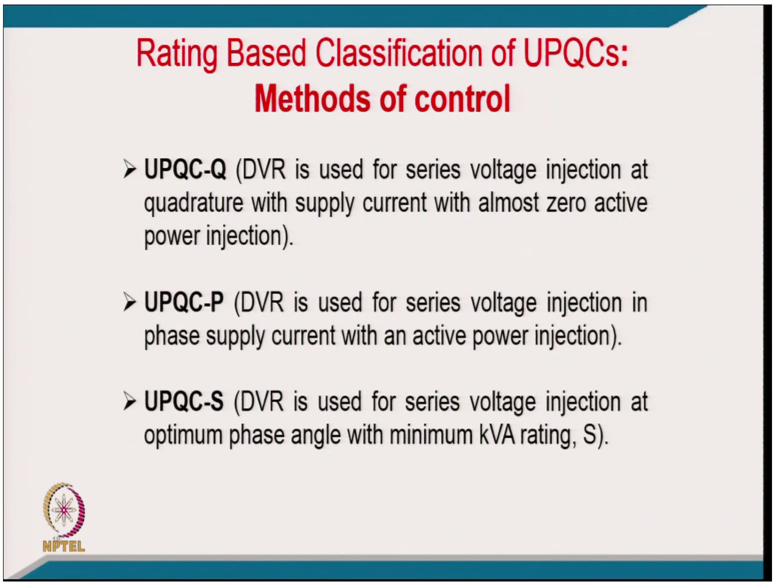
Here you can have a only injection of active power or you can inject this voltage at any angle 0 to 360 degree; that give you a reasonable freedom, I mean for this circuit configuration in that case. [FL] That is the reason UPQC considered to be a quite good solution, probably you can probably afford the cost of typically so having a two compensator into one line, but you save certainly some part of the component here.

(Refer Slide Time: 20:03)



And this is you can think about like a here, I mean series is of course three wire then; but the DSTATCOM you are considering four wire system to compensate globally the neutral current also. Because that is something like you can think about, I mean supplying the with the this UPQC system like I mean or so.

(Refer Slide Time: 20:22)



Now, that was about the circuit configuration. Now, coming to the rating based classification of UPQC, I mean which is really differed in the method of control; that UPQC Q, the DVR used in series with the series injection at the quadrature with the supply current with almost zero active power injection. That is the reason we call it UPQC Q mean, the voltage in series is injected at the 90 degree with the current supply current, so that I mean you do not have a typically any active power injection for series compensation.

May be applicable, may not be applicable for all condition, for some condition; but in some condition it might give the rating also reduced one. Another is a UPQC P ok; [FL] UPQC P means now DVR is used to for series injection in power supply, supply current is in active power injection means series compensation we are doing only through active power injection into it.

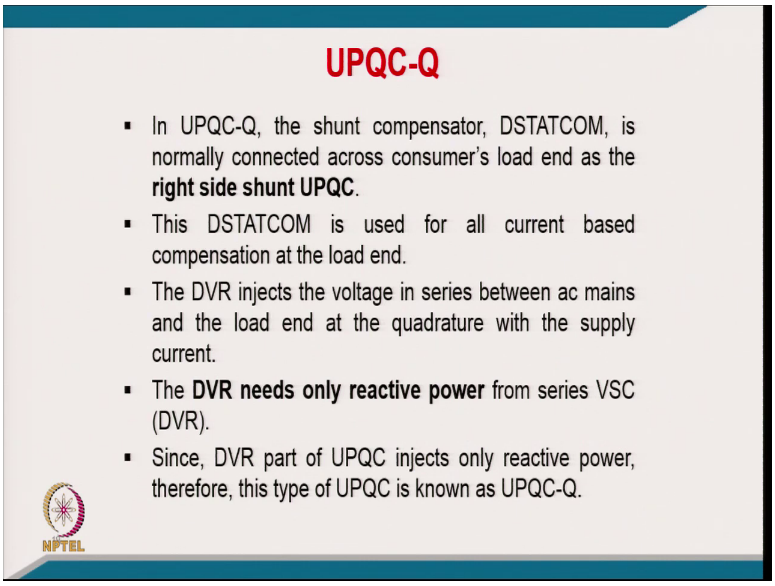
Because now the if need the for series capacitor or DVR, we need some active power if we can certainly take from DC link and that is provided by the shunt compensator or by DSTATCOM to this. [FL] I mean practically it is possible that you can inject in phase with your supply current also, I mean typically.

Of course, in many situations it will give you the minimum rating of your series compensator; I mean because you are having a minimum voltage injection and current of course depends on the supply current how much power you are drawing or so.

Another is UPQC S, I mean this is very versatile combination; [FL] DVR is used for series voltage injection at optimum phase angle with minimum kVA rating. [FL] There may be many (Refer Time: 21:58) what you really we like to use for UPQC S; I mean you will like to have a minimum VA rating or you will like to put any at particular angle the injection of the voltage I mean in series, I mean that you can do that, I mean in this UPQC P like.

Because that is I mean all these modes are possible even as because you can certainly draw the active power or you can feed the active power on the DC link, which DC link voltage regulation is a responsibility of series shunt compensator to allow the bidirectional power flow. Series compensator is supposed to do the job for mitigating the voltage based power quality problem by injecting the voltage in series with the line like I mean or so.

(Refer Slide Time: 22:38)



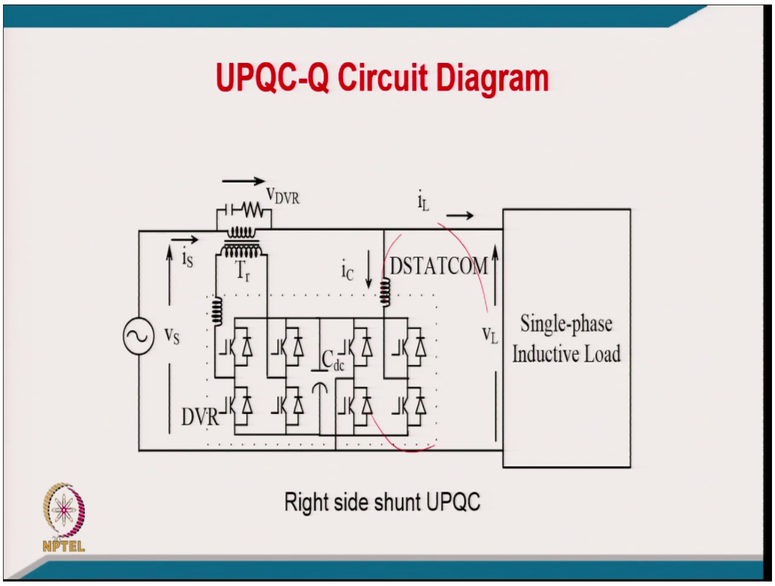
[FL] Coming to the in first category of UPQC Q, in UPQC Q the shunt compensator DSTATCOM is mainly connected across the consumer load at the right hand UPQC. And DSTATCOM is used for all current based compensation of the load end. And DVR inject the voltage in series between the ac mains and the load and at the quadrature with the supply current.

And DVR needs only reactive power from the series compensator, which voltage source converter can generate locally; I mean active power it is supposed to take from dc link, but the reactive power it can generate locally I mean like or so. And the since the DVR part of UPQC inject only reactive power, therefore the type of UPQC is known as UPQC Q.

Here of course, the active power we are not circulating through DSTATCOM; of course we might have a some active power to meet the losses of both the converter. I mean as well as interfacing transformer as well as the you can call it interfacing inductor and ripple fitter apart from the switching losses in the devices and the dielectric loss in the dc link capacitor.

[FL] Apart from, I mean living apart from the losses which you have to feed certainly from through shunt compensator or shunt VSC. But I mean we are not circulating any active power from shunt to from DVR, DSTATCOM to DVR or DVR to DSTATCOM in this control like.

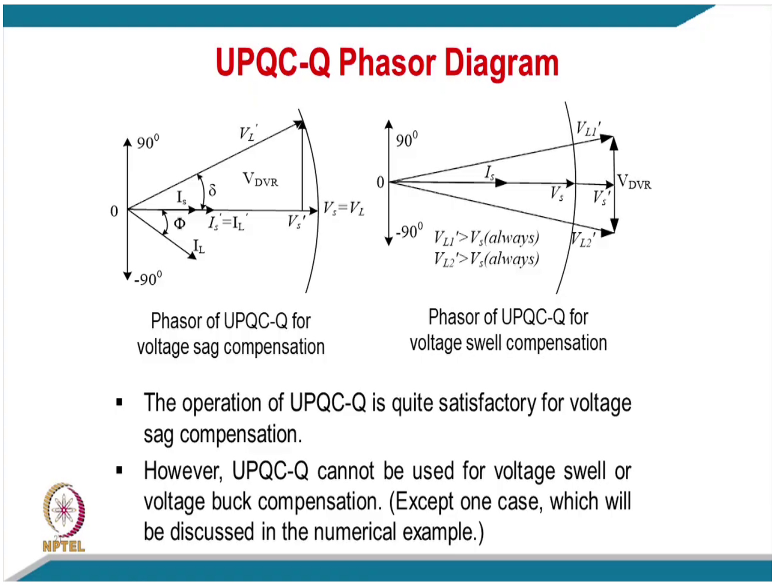
(Refer Slide Time: 23:58)



And this is typically the you can think about the configuration, I mean on right hand side which we really suggested why we select it; I mean there is no restrictions that you cannot select it another configuration, but this is the right hand the DSTATCOM is typically on the right shunt here we are connecting it and DVR is on the left side and we have a dc link common like.

But of course, what we are saying that, you can generate the reactive power locally, this injection is through reactive power, you are not taking any active power; but only you are regulating the DC link voltage with the help of this shunt compensator, which you normally you are doing otherwise into DSTATCOM, [FL] the control goes in that phase simplified manner or like a single phase load like.

(Refer Slide Time: 24:34)

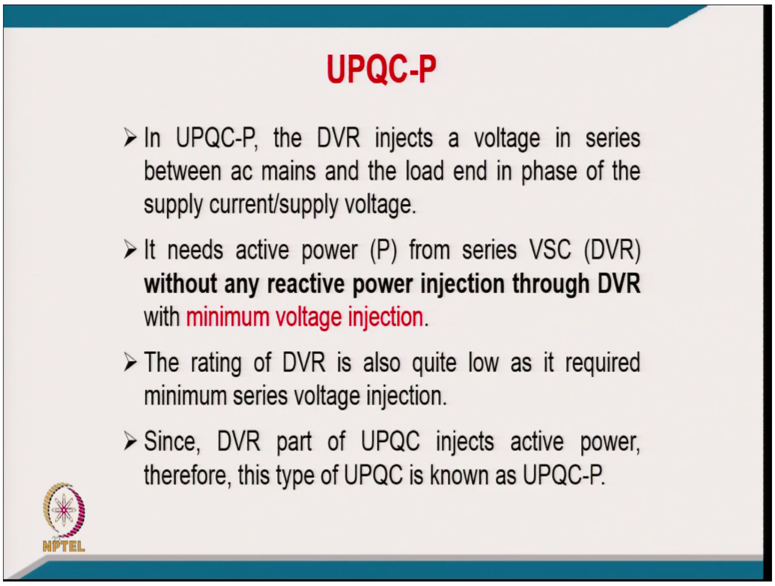


And the typically you can call it the phasor diagram, I mean you can look into the voltage here and if it is a sag comes; then you have to regulate the voltage, [FL] you have to only inject the voltage which is at 90 degree. [FL] Shunt compensator is supposed to maintain the unity power factor ok, you can see clearly the unity power factor. The voltage your current is in phase with the voltage and now shunt compensator job is, a series compensator job is that to inject the voltage at 90 degree with this current, so that you do not associate any active power for series compensation.

[FL] Certainly might be that you can call it this DVR voltage injection maybe a little higher, we will just look into other case and, but the voltage you can call it is the same regulated voltage which are on this arc. [FL] Load voltage will be equal to the source voltage, I mean even you might have a sag or so, which is regulated voltage. So that load is not affected by typically by any power quality problem in the supply system also caused by voltage sag on.

[FL] This is the case say typically your think about like a voltage sag and this is the case of typically of voltage swell compensation; that voltage increases and you have to reduce the voltage to again to coming to the back to the same level like or so. [FL] The operation of UPQC is quite satisfactory for voltage sag compensation and however, UPQC cannot be used for voltage swell for buck operation; except one case, which will be discussed in the numerical example.

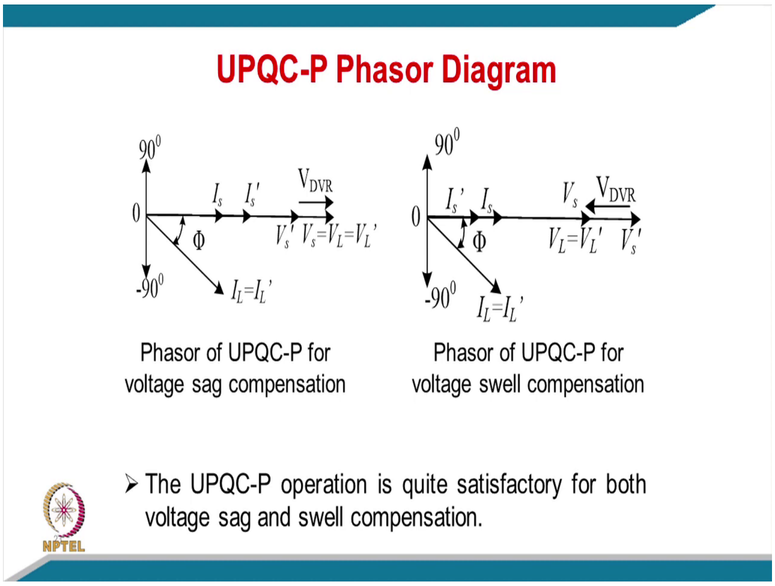
(Refer Slide Time: 25:56)



Now, coming to the UPQC P, in UPQC P, the DVR inject the voltage in series with the in between ac mains and the load and in phase with the supply current and supply voltage. It needs active power from the series voltage source converter operating as a DVR without any reactive power injection through DVR with a minimum voltage injection like.

And the rating of DVR is also quite low as it required minimum series voltage injection. And since DVR part of UPQC inject active power, therefore this type of UPQC known as UPQC P like I mean.

(Refer Slide Time: 26:25)

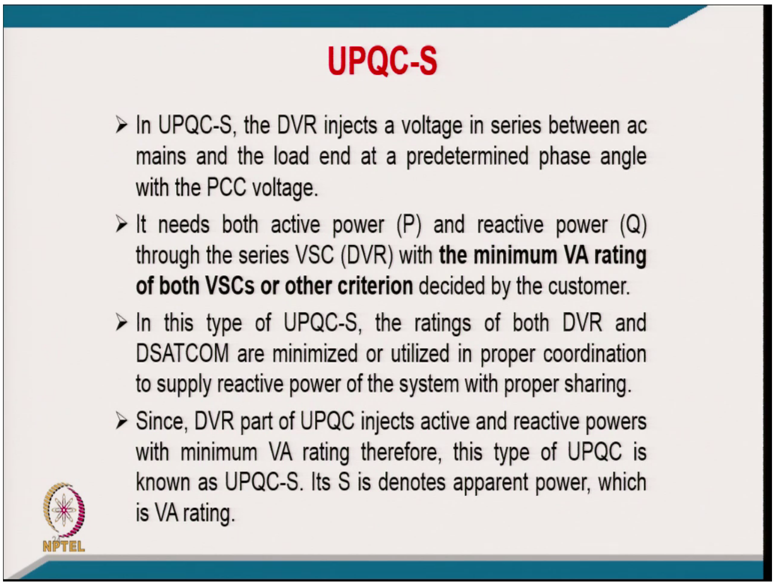


[FL] Well, this is the typical case you can think about, like if there is a voltage sag. I mean ideally voltage should be this much, but it reduces because of voltage sag; [FL] you have to inject this voltage in series with this I mean by DVR, so that your voltage is regulated across the load. [FL]

You are you are putting like in series, I mean shunt compensator beginning this current; I mean typically I mean grid current in phase with the voltage, but now series compensator is only doing this active power from where this active power is coming. It is coming from active this active power through dc link only, coming from DSTATCOM itself, [FL] you can call it the your this active power is circulating between the two line.

I mean this is a case of voltage swell, I mean you can think about that voltage is going to be a; [FL] you are going to reduce the voltage with the help of putting this through injection by reducing this voltage to back or so. [FL] UPQC operation is quite satisfactory for both voltage sag and voltage swell compensation.

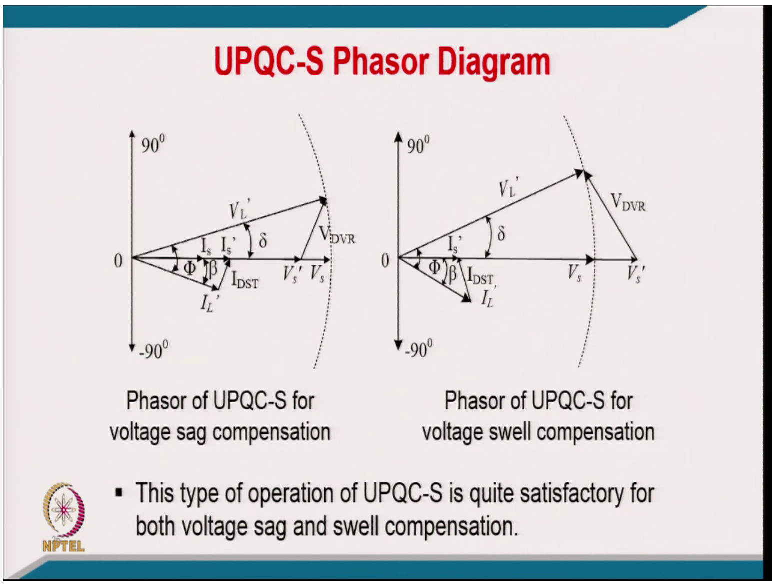
(Refer Slide Time: 27:29)



And in UPQC S, the DVR inject a voltage in series between the ac mains and the load end at a predetermined phase angle with the PCC voltage. And it needs both active power and reactive power through the series DVR with the minimum rating of both VSC or other criteria decided by the customer.

And in this type of UPQC, the rating of both DVR and DSTATCOM are minimum or utilize in a proper coordination to supply the reactive power of the both with proper say proper sharing. And series and series DVR part of the UPQC, inject active or reactive power with a minimum VA rating; therefore this type of UPQC is known as UPQC S and the S depends on apparent power, which is VA rating like.

(Refer Slide Time: 28:17)



And the typical phasor diagram you can think about like, you can put like a typically if you have a voltage sag, the voltage is reduced over here. Now you can inject the voltage at any angle and bring the same voltage on this arc, so that voltage is regulated like. [FL] It means this you can call this voltage injection is not at the 90 degree or in phase with the current, you can have at any other angle, for which you can understand the how this.

This is not so interesting, so easy to find out that, the reason being why the rating will be affected of the shunt, I mean when you are injecting the volt typically of series? Because the active power of the required for series is coming through the shunt. [FL] Once it is the active power flowing through the shunt; it means the shunt rating will increase, I mean that is in case of UPQC P.

Of course, series you might be having minimum, but the shunt rating will increase; [FL] somewhere this should be a kind of optimum concept that ok rating of both should be and normally in general the inventory of these converters are the same. [FL] You might be keeping like a both rating of the both same in general.

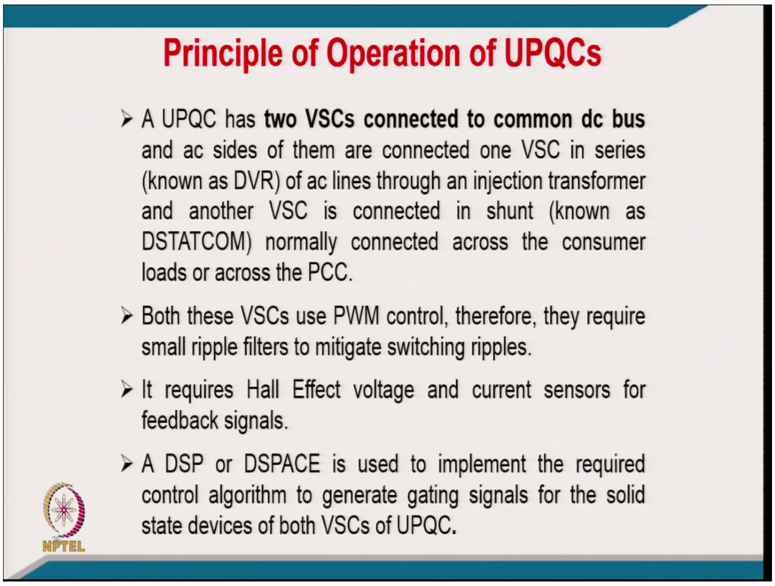
Then the question is that you have to utilize the rating of both also, I mean because the some part of reactive power of required for load, you can divert that responsibility for these series compensator also, not necessarily entire reactive power have to be supplied by DSTATCOM.

So, that feature is also possible in this like and this is certainly you can think about like we have a voltage swell, in place of this voltage is going up.

Now, we have to inject the voltage in such a manner that, it voltage comes to the same level like ok; [FL] you are injecting this voltage in that manner like I mean or so. [FL] It means you can have a sag compensation as well as swell compensation, all compensation is possible by UPQC S; because you can inject the voltage from 0 to 360 degree, I mean with respect to the current, I mean or voltage.

Normally we consider the shunt compensator is already providing the unity power factor operation, [FL] series will be able to inject volt voltage at any angle with respect to the current; because now reference for the injection of the voltage normally consider the current with the current, because that active power, reactive power what we discussed it already like I mean or so. And the type of operation of UPQC S is quite satisfactory for both voltage sag and voltage swell compensation.

(Refer Slide Time: 30:24)

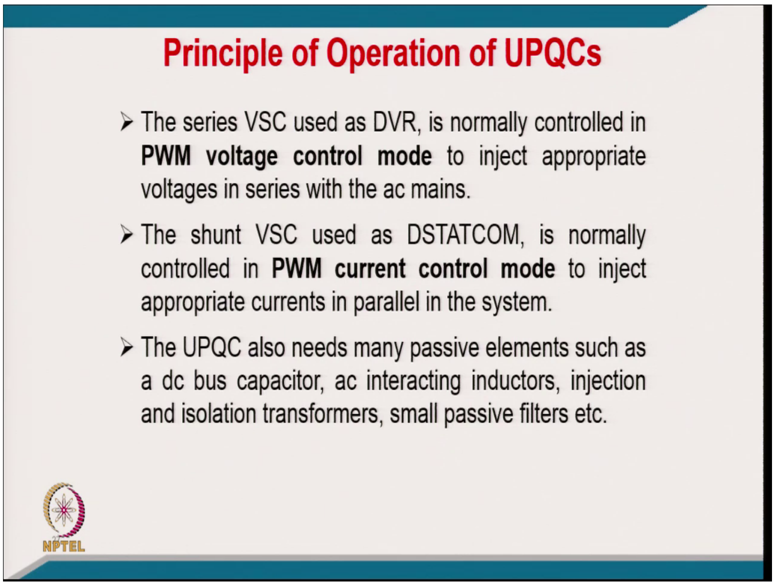


And typically coming to the principle operation, a UPQC has two VSC connected to common dc bus and ac side of them are connected one VSC in series known as DVR of ac line through the injection transformer and another VSC is connected in shunt known as dc shunt, normally connected across the consumer loads or across the PCC.

But if you are applying this at high voltage, maybe that one shunt also sometimes we use the transformer for purpose of isolation and voltage matching; I mean it depends on the requirement of the consumer if you are going to use this UPQC for very high voltage application. But power electronics you want to design at optimum voltage, which is lower voltage than what really your system is having, where you are going to connect based in UPQC like I mean.

[FL] Both these VSCs use the PWM control; therefore they require a small ripple to mitigate the switching ripples of both the converter. And it requires certainly hall effect voltage sensor and current sensor for feedback signal for the control algorithm, for providing the your switching off the both the converters. And the DSP or like a similarly another kind of DSP called DSPACE is used to implement the required control algorithm to generate the gating signal for the solid state devices of both voltage source converter of UPQC.

(Refer Slide Time: 31:45)

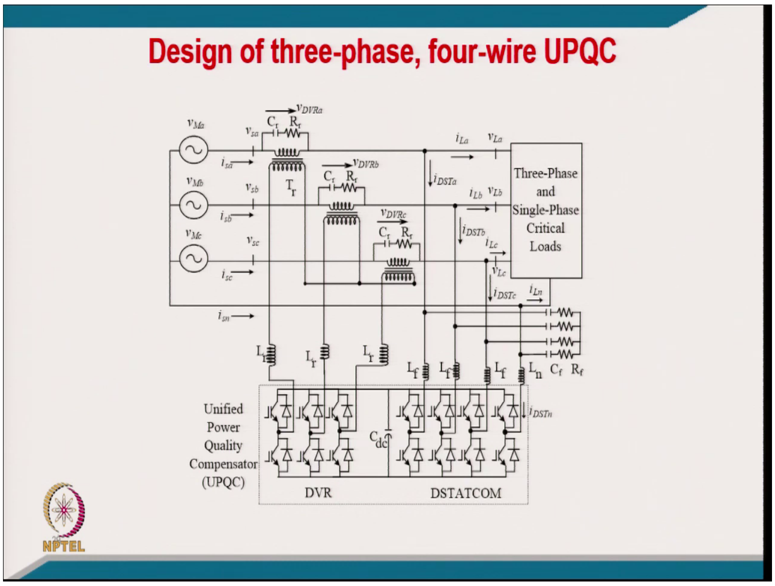


And the series VSC use the DVR, normally controlled in a PWM voltage control mode; because you are injecting the voltage, to inject the appropriate voltage in series with the ac mains. And the shunt compensators, shunt VSC is used as DSTATCOM, is normally controlled in PWM current control mode to inject the appropriate current in parallel to the load in the system like.

[FL] UPQC is also known also needs many passive elements such a dc capacitor dc link bus capacitor, ac interfacing inductor; because you are generating PWM voltage and you have a sinusoidal voltage on the either on across the load or a in the line, [FL] certainly you need the typically you can call it like a ac inductor to interface this and you require a injection transformer, and isolation transformer depends on series for series compensation and shunt compensation we talk about and a small passive typically filters across the switching filters kind of thing.

(Refer Slide Time: 32:41)

(Refer Slide Time: 32:51)

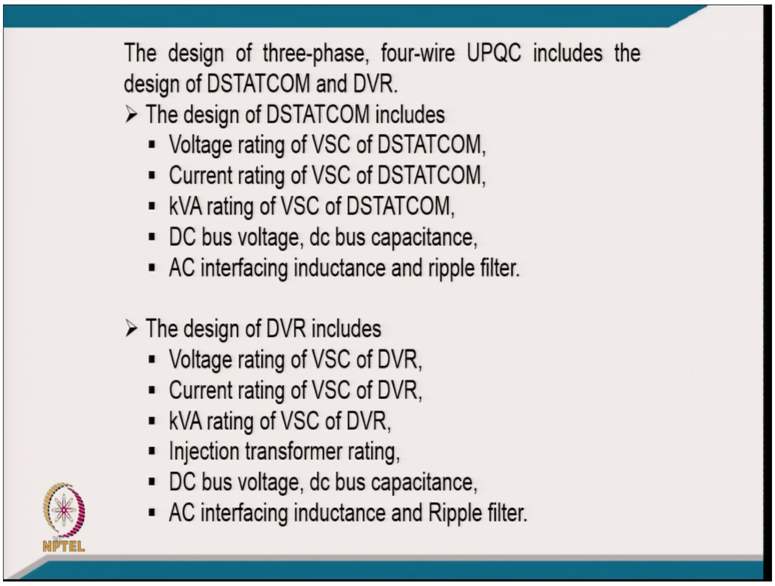


Coming to like an analysis and design of this typically of UPQC. [FL] Now, in this case for looking a design, we will like to take the example of three phase which is normally used or the shunt for three phase typically four wire; we have like a neutral current compensation also by four lag, which we already discussed in shunt DSTATCOM.

And for series of course, we have to inject the voltage in series in line of the series, but many cases in operationally not necessarily you have to inject the voltage in all maybe like you will like to; if voltage unbalance there, it may be I mean typically maybe the injection may be required only in two line, not necessary in third line. But dc link is a common, which exchange the response typically of active power; [FL] responsibility of regulating the dc link voltage is again the DSTATCOM.

I mean in the sense that DSTATCOM support to supply the active power required by series compensator or active series compensator it realises the active power, it had to take back the active power to the system back like I mean. [FL] This dc link voltage regulation is a part of your control part of the DSTATCOM; the series compensator is support to only inject the right voltage, so that the voltage quality are maintained at the point of common coupling across the load.

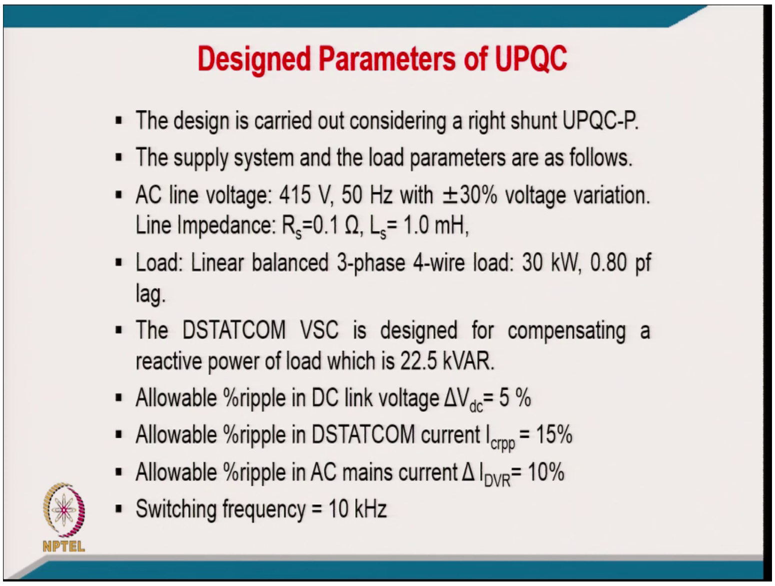
(Refer Slide Time: 33:57)



[FL] Design of three phase four wire UPQC include the design of DSTATCOM and DVR. And design includes the voltage rating of the voltage source converter of DSTATCOM, current rating of DSTATCOM, kVA rating of DSTATCOM, DC bus capacitor calculation, AC interface inductance and ripple filter calculation.

And design of your DVR or series compensator include the voltage rating of the voltage source converter of DVR, current rating of voltage source converter of DVR, a kVA rating of voltage source converter of DVR, injection transformer rating; of course its voltage and current rating of both the side and transformer ratio, and DC bus voltage of dc bus capacitor, interfacing inductance and ripple filter design.

(Refer Slide Time: 34:41)



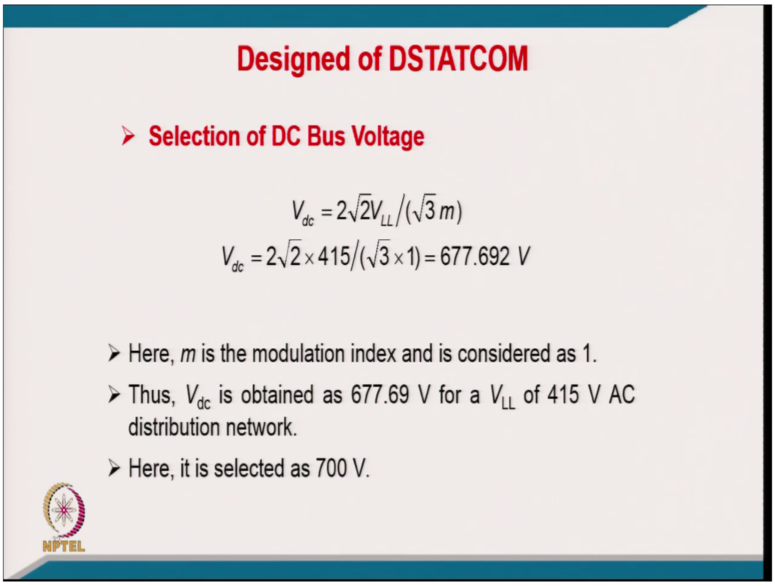
[FL] The design parameters of UPQC, the design is carried out considering a right shunt UPQC P. Of course, you can have a design corresponding to any, but you have to here take only one some typical example, which you should be able to modify according to your common. Supply system and load parameter are as follows.

[FL] We consider the supply in nominal supply is 415 Volt, 50 Hertz with the plus minus 30 percent voltage variation, which may consist the sag swell in this range as well as the unbalance and the line impedance of course, we are considering some typical value of point 1 Ohm resistance and inductance of the source is 1 milli Henry.

And the load we are considering, that is a linear balanced load of a 3 phase 4 wire load of 30 kilo Watt at 0.8 lagging power factor, is also nominal power factor load in general I mean in practice. And DSTATCOM VSC designed for compensating the reactive power of the load, which is you can calculate from the load I mean 30 kilo Watt at 0.8 lagging power factor; means the reactive power certainly you can calculate from this.

I mean by taking a 30 divided by 0.8 will be a kVA multiplied into 0.6 or under root 1 pf square will be the reactive power; [FL] reactive power comes 22.5 kVAR. And allowable ripple in DC link voltage is certainly delta V dc at 5 percent and allowable current rating typically ripple current in the DSTATCOM is around like a 15 percent or so. And the allowable ripple in the AC current I mean 10 percent, which is responsible and switching frequency of higher order of 10 kilo Hertz like.

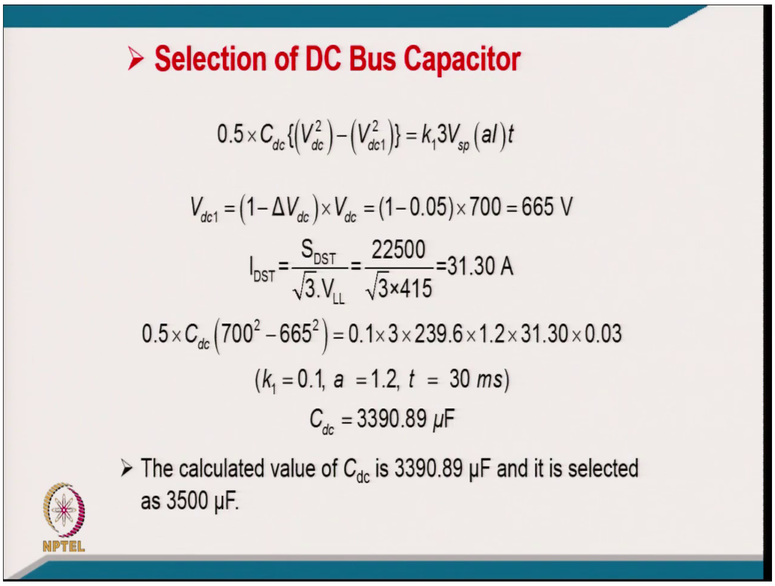
(Refer Slide Time: 36:11)



It is just like a guideline, I mean from the design formula; but of course, you have to apply your mind as expertise for this. [FL] Coming to as a dc link, this is a formula for voltage source converter that part is the relation between ac and dc link voltage; 2 root into V line divided by root 3 in into m, m is a modulation index, so you can take 1.

And it is a system voltage 415 is the line voltage, which can put; it comes 677.692; volt which you can round off around like a 700 Volt; [FL] 700 Volt is a reasonably ok voltage if you are really designing for 415 Indian distribution system like I mean or so. [FL] m is the modulation index and is considered 1 and thus a V dc is obtained as 67 for V LL of 415 Volt distribution network, hence it can be selected 700 Volt.

(Refer Slide Time: 37:01)

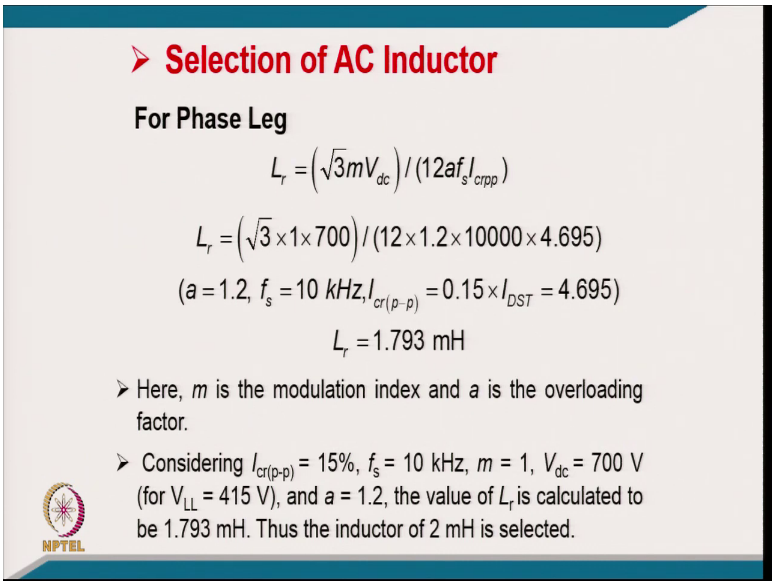


[FL] That is about the DC link voltage selection; once we have a voltage selection, we can find out the capacitance from this dynamic equation. Of course, this capacitor selection can be on so many criteria; but which give you the maximum value of capacitor that (Refer Time: 37:15). You can take based on second ripple harmonics ripple also of this DC link.

Because that load unbalancing or you can call it single phase load, you will have or voltage unbalance; [FL] second harmonics will be there certainly on the dc link of this UPQC. But probably dynamics will give you the more value; [FL] you can consider that in the dynamics that how much voltage reduction you can allow; [FL] we say that we can allow the 5 percent voltage reduction that is a reason, that the minimum voltage from the nominal voltage it comes, energy storage within how much period this will be recover.

[FL] By keeping this value all in this standard relation which we discussed earlier also; I mean we want in 30 millisecond in one half cycle to recover, [FL] this capacitor comes around 3090.89 micro Farad. And you can select the next higher value typically of 33 in select, you can select higher available value as a 3500 micro Farad like or. So, I mean you get to collect, these are design guidelines on and, but nearby you can select it like the value corresponding to that line.

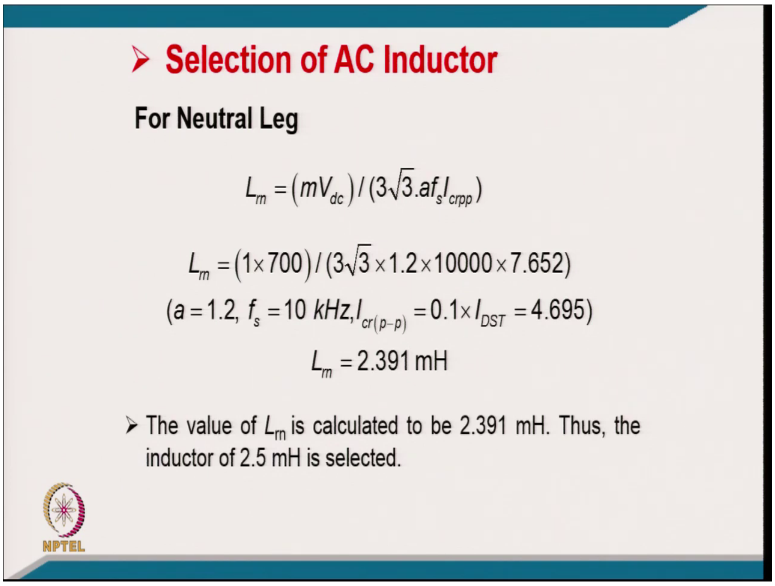
(Refer Slide Time: 38:20)



[FL] Coming to the select typically the selection of AC inductor for phase leg, when calculate L r from this standard formula, which is available in many of the text like root 3 m V dc divided by 12 a f f s into I ripple. And keeping the value, like we consider already you can have a 15 percent current ripple and you can calculate this inductance comes around 1.793 milli Henry; I mean order of that, like I mean for interfacing inductance for that line.

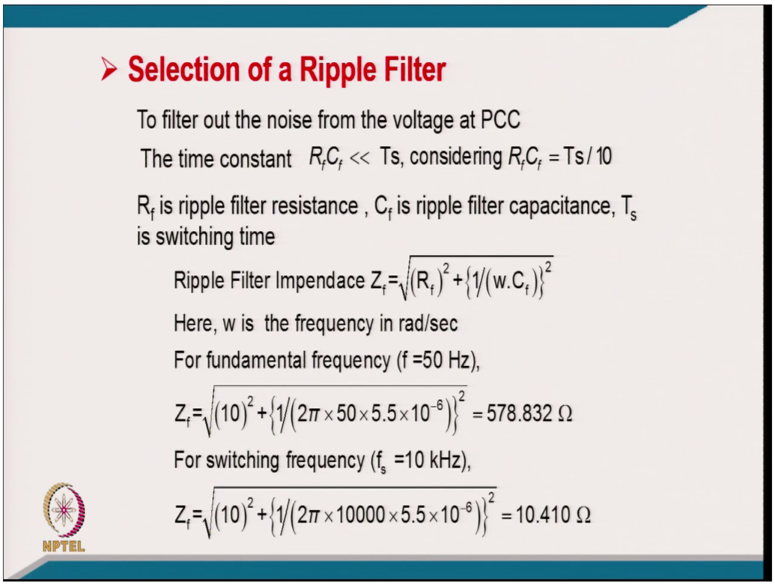
Hence, the here the modulation m is the modulation factor, a is a you are in considering the value of 15 percent, 10 kilo Hertz and V dc typically 700 Volt and line voltage 415. [FL] The value comes around 1.793 and normally rounded the value can select the 2 milli Henry for this UPQC like.

(Refer Slide Time: 39:07)



Coming to the neutral leg, I mean that is virtually we can call it what the voltage can appear across the neutral leg from this relation and putting the value, you get the typical value of 2.391, a little higher than the phase value. And corresponding to that you can select corresponding to around 2.5 milli Henry is selected like I mean or so.

(Refer Slide Time: 39:29)



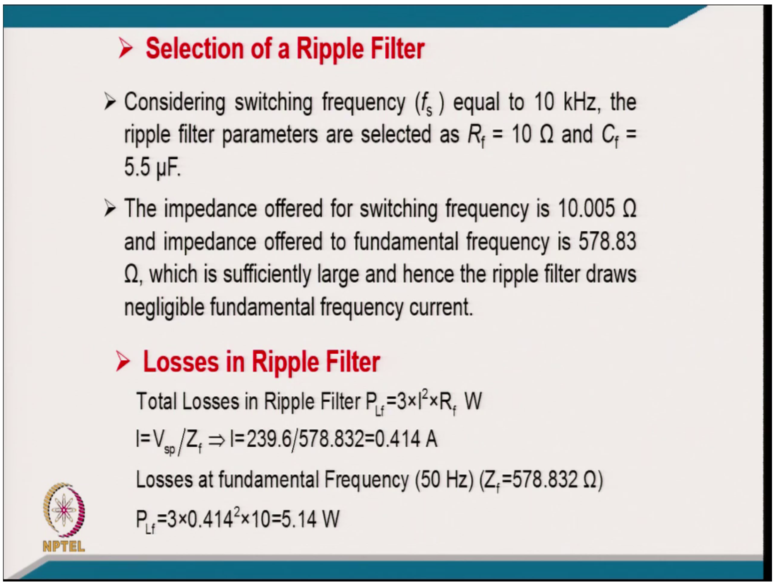
Well, coming to the selection of ripple filter, which we have again discussions DVR as we have all it is come to find out the noise from the voltage at PCC; the time constant I mean should be much lesser than the switching frequency to [FL] considering your time constant T s by 10. [FL] They are all normally be considered as a small capacitance and C r is the capacitance and T r is the switching corresponding to switching frequency; [FL] we can find out the impedance corresponding to that and we can find out this impedance should be quite high.

I mean normally we considered a typical value of maybe 5 to 10 Ohms and we can find out the capacitance also corresponding to that, so that impedance is quite low. [FL] You can find out corresponding to switching frequency, this impedance is very close to resistance that is 10 Ohm resistance, [FL] it comes 10.41 ohm and the capacitance value of typically order of, typically 5 micro Farad and that give you the impedance for fundamental frequency quite high 578.832 it comes across the phase.

[FL] You can call it, I mean the phase voltage is around 239 or 240 Volt and you divide 578 [FL]; it will be half like a typically ampere a less than a half ampere, when you take a square it becomes a quite quarter and the resistance you can call it quarter. [FL] It is resistance will be hardly typically 10 multiplied like a 1 by 4, [FL] around 2 3 hardly 2 3 bar loss irrespective of the rating, whether you are designing this UPQC 450 kVA or 100 kVA or so.

[FL] But that improve the voltage profile, because high all association harmonics, because of this very low ratio I mean impedance like of 10 Ohm all get sucked into; but it does not have a much higher energy associated with that, I mean that is more than important in this case like or so.

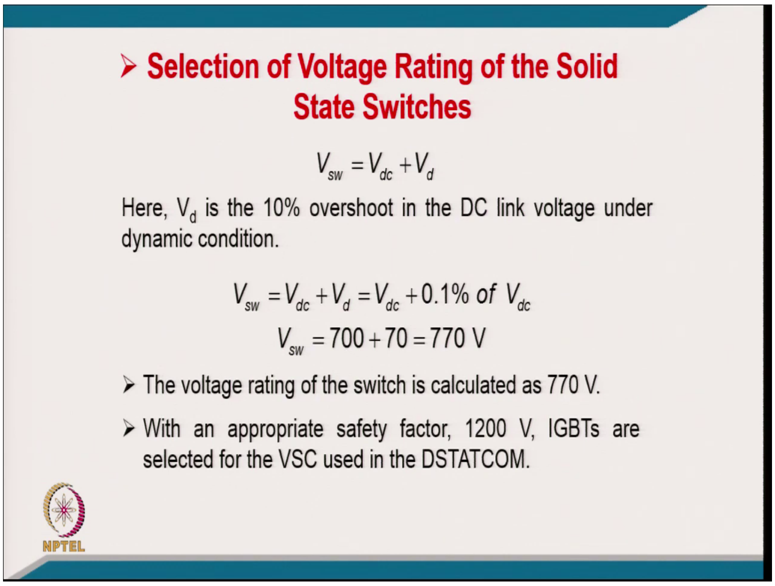
(Refer Slide Time: 41:04)



[FL] Selection for of a ripple filter, we already talk about 10 kilo Hertz we design and the ripple filter maybe 10 Ohm resistance and capacitance of 5.5 micro Farad. And the impedance offered for switching frequency is around 10 Ohm and impedance corresponding to fundamental you can see 578.83 Ohms, it is sufficient to large enough.

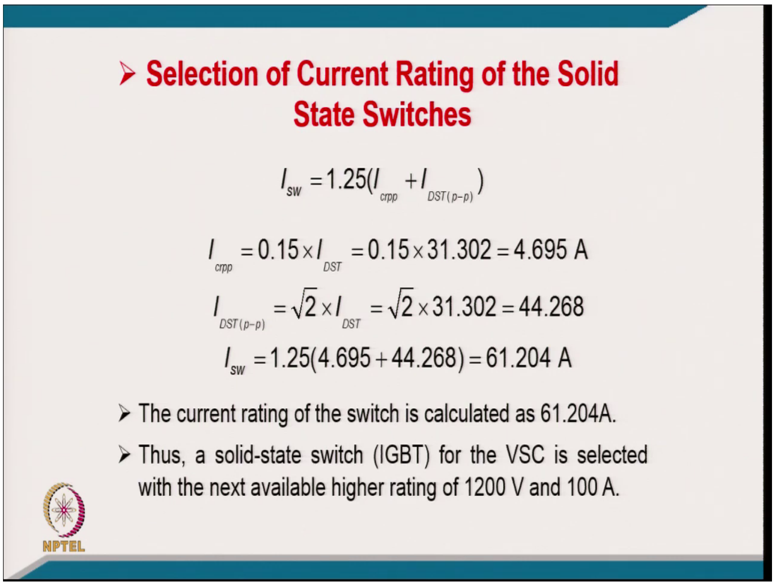
Hence the ripple filter draws negligible fundamental frequency current and the region in the losses are also negligible in ripple filter, I mean like or so. [FL] We can calculate even the losses in the ripple filter by calculating the power loss into it and you can find out the current term and divide voltage divided by the current; [FL] it comes 0.414 and the losses in at fundamental frequency will be hardly your 5 point all three phases, it is hardly around 5 bar, not more than that irrespective of the rating.

(Refer Slide Time: 41:51)



These are not rating related issues, it is only corresponding to the switching frequency like I mean. And selection of voltage rating of the solid state devices, [FL] you can call it like a you are taking a voltage that is maximum voltage in the circuit, the dc link voltage; but then you can have a little overshoot also into that maybe 10 percent, [FL] in place of 70 700 Volt, it will be like a 770 Volt. And normally we take a safety factor. We select the voltage rating of the DSTATCOM, IGBTs around 1200 Volt or so.

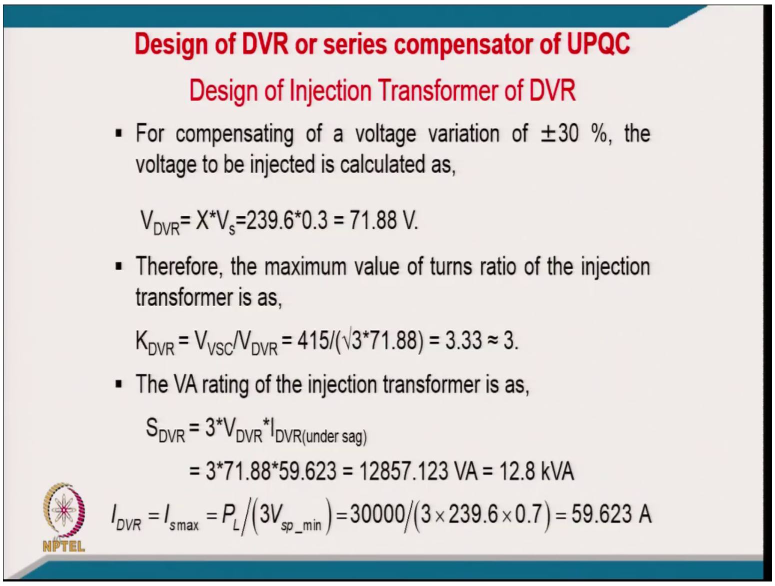
(Refer Slide Time: 42:12)



And current rating we already talk about that, you might have a typically the nominal current what we have designed plus the ripple current, which we have considered 15 percent and you can add this current with that and you get the peak current, I mean with the safety factor [FL] current rating comes around 61 Ampere.

And you can select the current rating typically for order of 100 Ampere; because these 100 Ampere is corresponding to like a 25 degree Celsius. But when you are operating this, I mean these devices around up to 75 degree centigrade; apart from that you are going to operate at higher the switching frequency, [FL] device have to be rated, that is the reason we select the device of 1200 Volt and 100 Ampere like I mean.

(Refer Slide Time: 42:51)

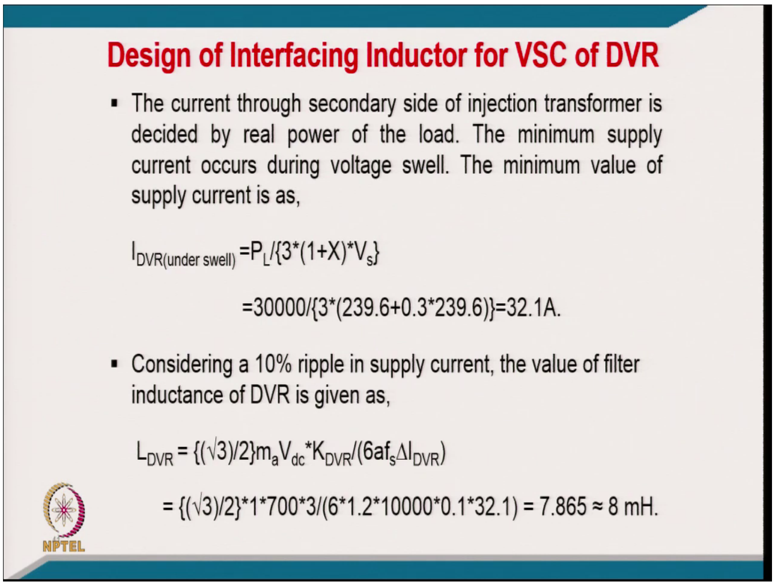


Similarly, we can do the calculations of DVR or series compensator UPQC, the design of injection transformer; [FL] injection transformer we can we already talk about that we want a voltage variation compensation of plus minus 30 percent, [FL] voltage to be injected will be order of the same, [FL] that comes around 71.88 Volt.

And then the current rating of this typically, [FL] that much voltage and how much you would like to keep on typically on the dc link; [FL] you can find out the transfer ratio for [FL] for that if. If dc link is decided by shunt compensator which is corresponding to 415 Volt like I said; I mean that much voltage is the this series compensator is generating like a 415 Volt, but you want only typically of 71 or 72 Volt.

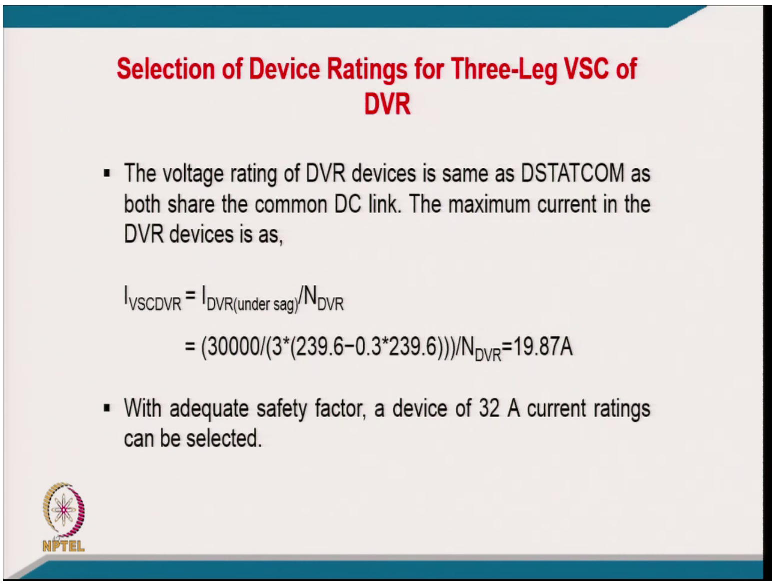
[FL] That will the turns ratio order of 3, you can have or the VA rating of the transformer you can find out 3 3 V DVR and I DVR; because that series current you know around like a 59.63 and voltage injection 71 into multiplied 3 fourth 3 phases, [FL] it comes like a 12.8 kVA, the rating of the series compensator or DVR like. And the you can find out the current how much it is the, that depends on the load current rating; because the unity power factor current flowing into the line, [FL] whatever the current is flowing that unity power factor in the line, that is the current rating of DVR.

(Refer Slide Time: 44:02)



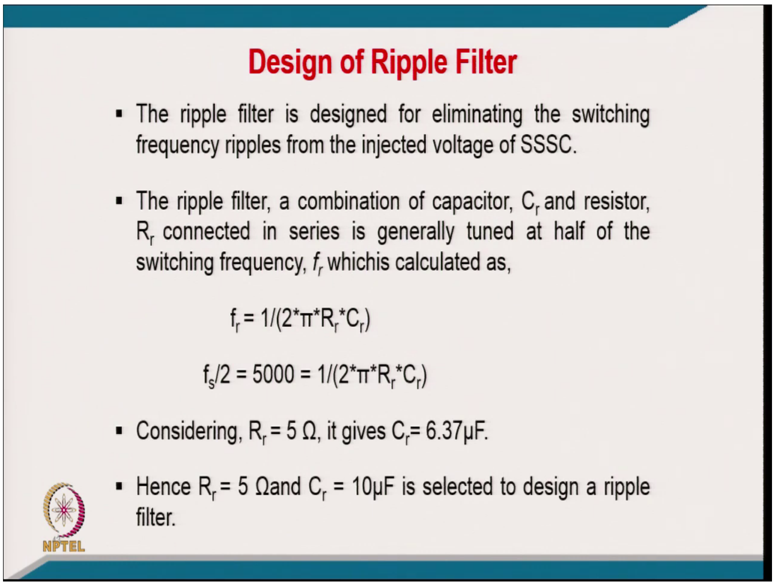
Now, coming to the interfacing inductance for DVR; [FL] you already have a like you can calculate current, which we already calculated and then you can find out the from this current ripple and the voltage is typically the and it comes out of like a 7.86, which you can take 8 milli Henry for this.

(Refer Slide Time: 44:21)



And typically you can find out now voltage rate, typically the voltage rating of the DVR and DSTATCOMs here the common DC link, [FL] that is the reason you can find; we already have a turns ratio, [FL] we can find out the current on the secondary side of the DVR. And then you have a typically with adequate safety factor the current rating of 32 Ampere, you can take on the in place of 19.87 Ampere.

(Refer Slide Time: 44:43)



And then you can similarly design the even the ripple filter, as we did for again considering the switching frequency of 5 kilo Hertz here for and selecting the value of 5 Ohm and capacitor is 6.34. [FL] We can select the 5 Ohm resistance and 10 micro Farad for the design of ripple filter or so. [FL] Well, this is now we are finishing the design.

Thank you very much.