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

Lecture - 36
UPQC Introduction and Classification

Welcome to our NPTEL courses on Power Quality Improvement Technique. Today, we are going to discussed UPQC that is Unified Power Quality Conditioners and its introduction and classification. So, UPQC is one of the main entity of the power quality mitigation improvement.

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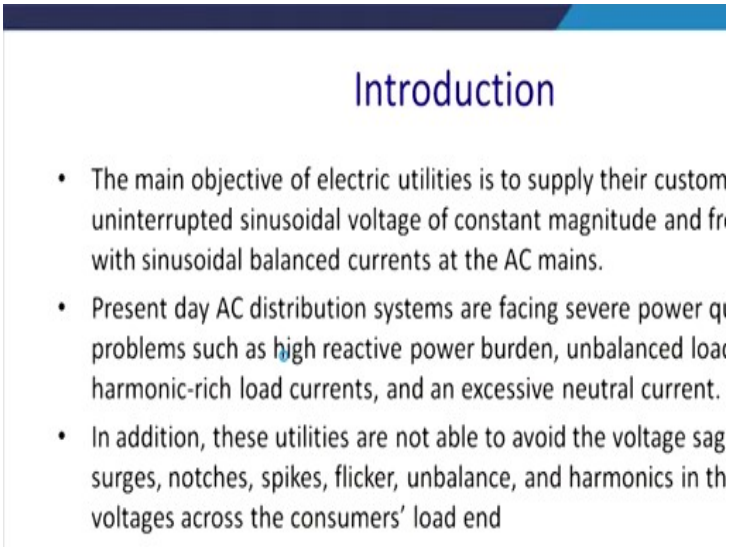

The main objective of the electrical utility is to supply their customer uninterrupted sinusoidal voltage of constant magnitude and frequency with constant balanced current in AC mains. This is the power quality.

But, as I told you in a several time before, due to the fact that present day AC distribution systems are facing several power quality problems such as high reactive power burden are for the industrial loading and most of this are the induction machines and the power quality due to the reactive power comes and it may be due to three phase four wire system for the household applications we have and due to that there is a unbalanced loading and harmonic rich load for adjustable speed drive.

This problem is that induction machines are the constant speed machine as a constant frequency and for this reason to effectively run this machine, we require variable frequency. The moment we have adjustable speed drive with a variable frequency we have in between AC to DC to AC conversion and that leads to the harmonic rich current and with the excess neutral current.

In addition, there are utilities and they are not able to avoid voltage sag. Maybe you know there is a high voltage line and the trees is touching this high voltage line and from there it is a high current sink through the ground and thus there will be a sag. Also due to the wind maybe it is touching and going back. So, there will be a pattern of the sag in the voltage of the consumer end or there might be any other reasons.

There will be a sag or maybe all of a sudden, some consumer over through a heavy load and due to that voltage will swell off. Surges: that can be phenomena like thunder strikes anything lightning strikes, notches, spikes, flickers, unbalanced and harmonic supply in the voltage across the consumer end of the load.

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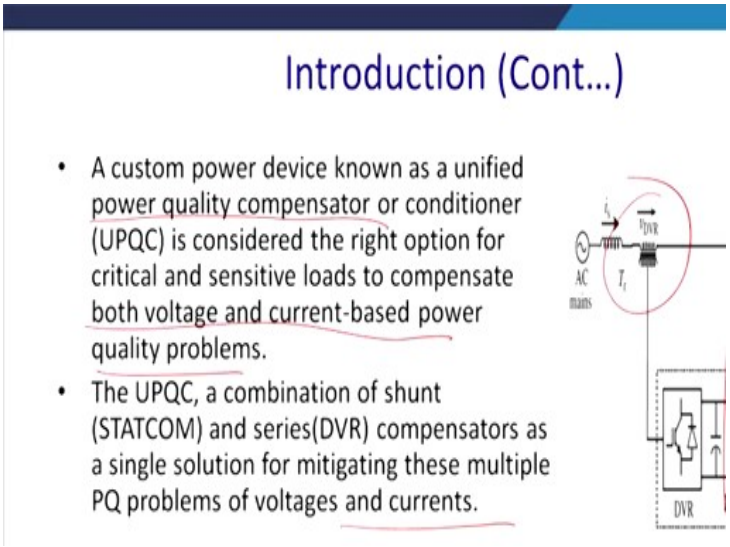

So, a custom power device like as I told you that is unified power quality conditioner are the sometime called compensator, also considered as a right option. It is sometime called the banded option. So, you put where the it is needed most. For critical and the sensitive load to compensate both voltage and current leads to power quality problem.

The UPQC is a combination of the shunt. This is the shunt path and the series that is DVR, compensates and it is integrated and makes as a one single solutions for mitigating this multiple PQ problem of voltage and current. So, this is one single solution. Ultimately if there is a voltage sags or swell or the harmonic problem, this will be mitigated by the series compensations and if there is an unbalanced load there will be harmonic problems or the reactive power problem.

Ultimately D-STATCOM will inject the current. It is a voltage controlled current source inverters and makes this load current sinusoidal, as if this load will behaves like a resistive load. So, it will be all mitigated from the voltage and current quality problem.

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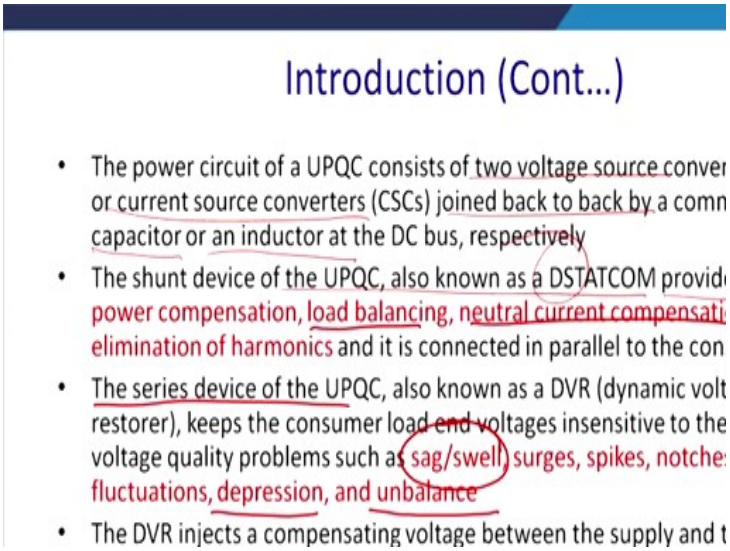

So, the power circuits of the UPQC as I shown you consist of the two voltage converters or voltage control current source or current source inverters. Generally, current source is prepared for the shunt part of the compensations, joined back to back by a common DC link capacitor in case of the VSC or with an inductor in case of the CSC as a DC bus respectively.

So, shunt devices of the UPQC is known as the D-STATCOM because we have studied FACTS. There we used the STATCOM. Where that is connected in the transmission level and, generally it is connected in a distribution level at consumer side. For this reason, it is called D-STATCOM or sometimes it is referred only this part of it. Shunt

compensation is called the shunt active power filter which provides you know all those compensations. That is reactive power compensations or load balancing.

If the load is unbalanced, then it can balance the load even in the single phasing. The neutral current compensation. If it is a three phase four wire system this call arises. Neutral current can be compensated by this D-STATCOM and elimination of the harmonic mostly this is the task of the shunt active power filter and it connects parallel to the consumer load. It is something like over excited conditioner or condenser, but it can mitigate not only the reactive power, but also the unbalanced as well as the zero-sequence component of the current and harmonics. For this reason, this gives a total solution for the problem arises due to the current.

Same way the series devices are also known as DVR. The full form of the DVR is Dynamic Voltage Restorer. Mostly in India the problem is the sag. For this reason sometime we have a sag compensator, but it can help, it can act both as a actually sag compensation or swell mitigator. It keeps the consumer loads and the voltage ends sensitive to the voltage supply and it gives the quality voltage to the consumers and so, it mitigates sags and swell, surges in the voltage, surges spikes, notches, fluctuations that is basically depression.

Depression is a long-time sag. There is a definition we have already discussed in our previous classes. The unbalanced of the voltages that it is coming due to the source end, DVR injects the compensating voltage between the supply and the consumer load and restores the load voltage to its reference value. This is the task of the DVR.

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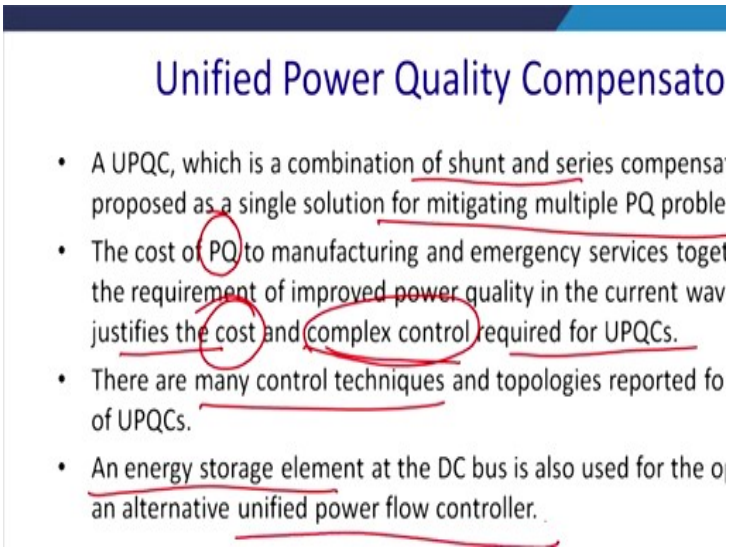

Now, if you integrate these two entities, then it comes with a single package. Then we call it UPQC. UPQC which is a combination of the series and shunt compensators proposed as a single solution for mitigating the multiple power quality problem which we were telling from the initiation of this courses.

The cost of the PQ that is the power quality to manufacturer and the emergency services together with the requirement of improved power quality in the current waveform justifies the complex. I once said the complex control technique. Now we have this case to be told around 20 years ago while writing a FPGA code was a big challenge and very few skilled professionals were available.

This complex control implementation of the complex control is now a well proven technology. Cost of this switching devices now drastically coming down and, thus now we have a greater financial validity for going to the UPQC solutions.

Now, next part comes. That is how you control? We are saying that it is a complex control. So, we require to see that what are these controls? It is mentioned here. Many control techniques and the topologies are reported for the control of the UPQC. We shall discuss few of them. It is not possible to take up the all the control technique already reported and hence we shall take few important techniques. The energy storage element at a DC bus is also used for the preparation of an alternate unified power flow condition.

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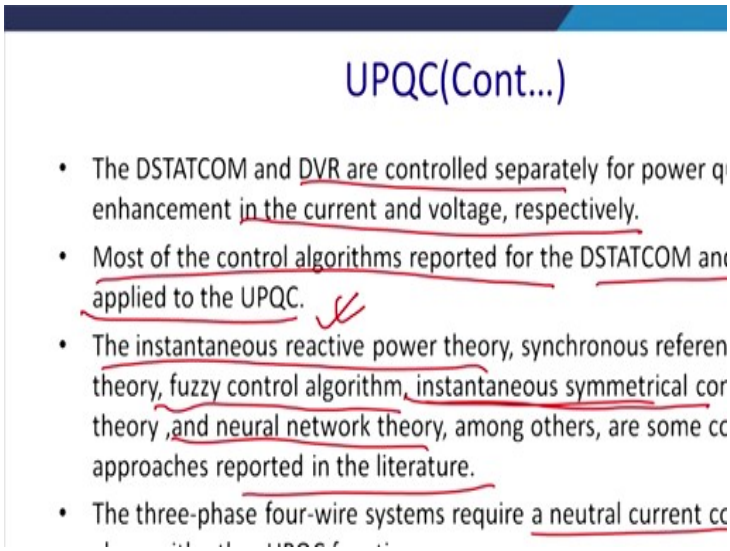

The D-STATCOM and a DVR are controlled separately for power quality enhancement in the current and voltage respectively. Shunt for the current and series for the voltage. Most of the control algorithm reports the D-STATCOM and DVR are combined and works as a UPQC.

There are many solutions. Few of them are time domain, few are in voltage domain. For example, this is a famous theory. It is proposed by Akagi in 1984. So, it is already 35 years. Instantaneous reactive power theory and synchronous reference frame theory. Mostly it is proposed by Deepak Divan and others. Thereafter from this, we have a soft computing technique-based algorithm. That is fuzzy logic algorithms and thereafter little later Akagi and Nabae proposed instantaneous symmetrical component theory.

This instantaneous reactive power theory is valid for three phase three wire system. As you have seen that the generally UPQC works in the domain of the D-STATCOM, then we required to incorporate three phase four wire system. For this reason, we have found that zero sequence component compensation is not good in instantaneous reactive power theory. For this reason, we refer to go back to the instantaneous symmetrical component theory and thereafter we can track. We can generate the reference by the neural network theory which is among others and are some control approaches reported in the literatures.

The three phase four wire system require a neutral current compensator along with the other UPQC to function. So, we require extra switches in case of the D-STATCOM. Extra leg rather. Classification of the UPQC. The this is the classification of the UPQC.

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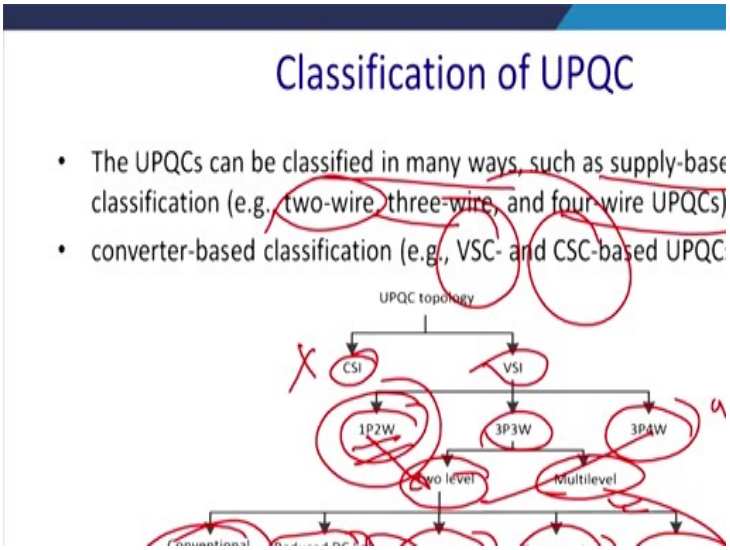

UPQC can be classified in many ways such as we have followed that is supply based. What kind of topology? Or what kind of supply it gets? For this reason it may have a single-phase AC that is two wire system. It may have a three phase three wire system. It may have a three phase four wire system. That is in a distribution level and also the converter based, that is whether it is using the voltage source converter or it is using current source converter. For this example, UPQC can have a CSI or VSI. Generally, the cost of the inductor is quite high and for this reason, we generally do not go for the CSI for its commercial viability

We can go for the single phase two wire system. Here mostly power capability is limited and generally in India, maximum possible load can be around 3 kilowatt because 15 ampere you have a power for the single phase and 220 volt. Maximum load can be around 3 kilowatt. For this reason commercialization has a great challenge to use UPQC for this level and we generally prefer three phase four wire system with a neutral connected and we mitigate load for the three phase four wire system. There we may have a different kind of voltage level.

Generally, three phase four wire system has a 440 volt line. There we can have a load up to around 10 kilowatt or more than that. Three phase three wire system generally it is a distribution level and it has a different variety of the voltages. It can be 11 kV, it can be 3.3 kV, it can 6.6 kV. It can be 440 volt. For this reason, voltage rating required to be different and to cater that voltage level, we require a different kind of topology. For little lower voltage side, we have a two level here. These two levels also is used for single phase as well as mostly for the three phase four wire system.

But in case of the three phase four wire system since transmission voltage can be varied in a different voltage level, we require to use the multilevel inverter. Because we know that cost of the IGBT goes high at the rate of the square of the voltages rating. So, 11 kV IGBTs now a days is available and 100 and 1000, 11000 volt IGBT is also available. You will find that the voltage rating is ten times more, but you will find cost is 100 times more. This is one of the challenges and for this reason we try to have a multilevel inverter. Voltage stress across the switch gets reduced.

Nowadays with the penetration of the SIC based devices, we can expect that it can straightaway throw away the power enhancement capability by 1000 times. Generally, IGBT can handle the power of less than 100 kilowatt. If we use the SIC based device, it can go as high as around 1 meg level

In a multilevel domain many researcher are working to reduce the voltage stress and to reduce the component count and all those issue and optimization. For this reason, we may have a conventional 12 switch UPQC that is been proposed. Thereafter we may have a reduced DC link voltage based UPQC. There we try to reduce the DC link voltages by putting the capacitor in the shunt path, but real power handing capability is been decreased. That is one of the problems and we have reduced switch. That is nine switch UPQC instead of the 12 switches. Their number of switches is been reduced, but what happens? The conductions of the switches get increased.

So, what happens? The switches are over loaded and accordingly you have to take care of the cooling. Commercialization, reliability and redundancy are the issues and for this reason, we have to see that their effectiveness of the nine switch UPQC. We can also have a ten switch UPQC. Comptonization is that you get a one switch more, but what about the reliability and other issues. Same way we got a eight switch UPQC. So, these

are the few topologies that can be used in case of the UPQC and many researchers are working for the optimizations of the UPQC switches.

Now, we can have classification based on the topology. For the example. If you refer back to the first circuit here. There is a shunt. Now here shunt is at the right side, it can also be at left side. Based on the right or left, we can have a classification of the shunt.

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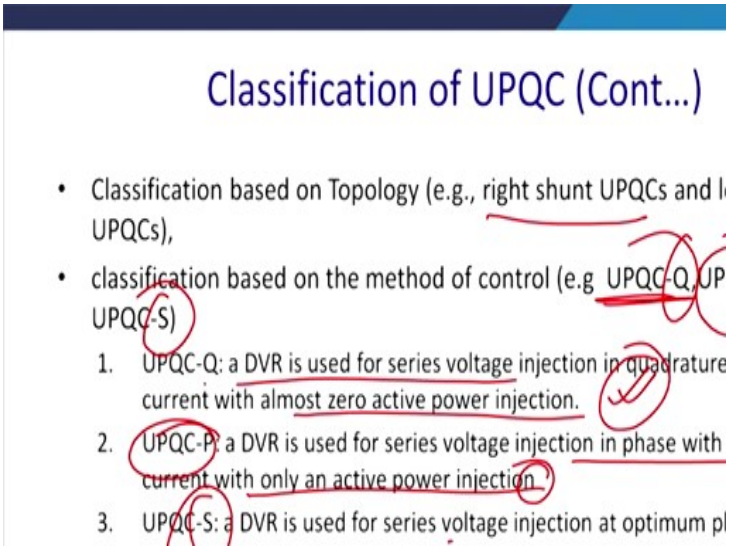

Example is the right shunt topology and the left shunt topology. So, classification based on these methods of control and we can have a classification of the UPQC based on that of the control of this UPQC. If it is just to compensate the reactive power, it has to act as a over exited synchronous generator. Then you know it is UPQC-Q. It will inject the voltage 90 degree to the supply voltage and all those things. So, that it does not take any real power. For this reason, real power handling capability of these devices least.

Same way, we can have a UPQC-P, that only compensate the real power. It injects the voltage and all those in phase. Then what happens? We can have a UPQC-S. That is we try to optimize the kVA rating of this circuit. It can play either of the role. UPQC-Q is a DVR used for the series voltage injection in quadrature with the supply current with almost zero active power injection and it require to just meet the loses of the switches and other non-linearity like inductor and capacitors. All having a series resistance. Those loses has to be accounted for. Thus, power consumption is least, but it can only compensate the reactive power.

Then second case is UPQC-P. It uses the in-phase series injections. That is all about with the supply current and with only active power injection. It cannot compensate the power factor. We want that everything to get a solution and we can have a limited capability of enhancement of the power factor. Similarly, UPQC-S DVR by series injections and it generally inject not only quadrature of phase, it can also inject in any angle. But its apparent power rating is constant. So, you can shift. Depending on the situation, you can take more P or more Q.

Ultimately you can act totally as Q and you can act totally as P, and you can act in between also. But your apparent power rating will be constant. Based on that this is the overall pictures of this UPQC.

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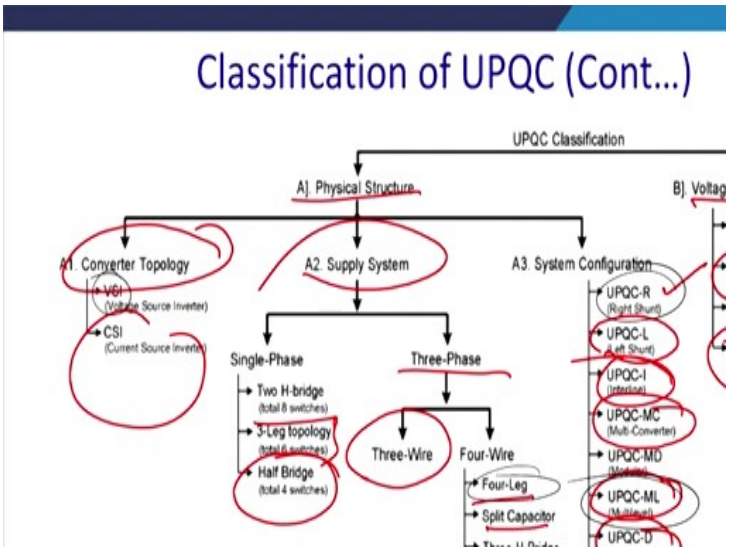

This is the physical structures. Based on the physical structures, we may have a VSI or CSI. Whereas current source inverter or the voltage source inverter, based on the supply system, we may have a single phase. Generally, we require two H-bridge since it is a low voltage. We require the two H-bridges thus 8 switches. Thereafter we may have a 3-legs. Whereas this is a little compensation instead of the 8.

We have 6 switches and the 3-legs and total is that half bridge or the four switches. Three-phase, we may have a three wire and we may also have a four wire, four legs, split capacitor and three bridges and the system configurations. We may have UPQC-R that is the right shunt and that is preferred because voltage first generally compensate the

voltage related problem, then current will take over and ultimately it will compensate that current related problem.

But same way we can have a left shunt. Left shunt generally is not been used because we want that voltage sag or swell to be mitigated. There is no problem in the voltage side and then current gets rectified. But if we want to use current shunt, there is a single advantage that is sometime it will see the less rating in case of the swell and all those things.

You may have a interline UPQC. That we will be discussing in detail in futures and thereafter it is connected in between the two lines and mostly it is connected in a transmission system in between. Thereafter we can have a multiple converter. That is a modular structure and you go to any level. Thereafter you got a multiple conversion. Thereafter you have distributed for conversion. You can have a distributed system and mostly now due to the UPQC it can be integrated with the solar or other energy sources or the battery. Then we can say that UPQC-DG.

Based on the voltage sag compensations, they can be further classified on UPQC-P, UPQC-Q. That is for the real power compensation. This one is for the reactive power compensation. This is basically the kV optimizations. It will have a minimum VA and this is UPQC-S. That is an active reactive power. That amount is constant. You can choose any compensation. Mostly this mode of operation is preferred.

If I go back, what are the preferred mode of operation? Let us take a different color. Preferred mode of operation is VSI. Generally, we have three phase four wire system and for the distribution level where it is used. Here it is right shunt and it is the preferred mode for this one. Otherwise, you may have a multilevel inverter. That is also a preferred mode.

Nowadays you may have a generating unit which is been incorporated with the power quality. So, that can be also be part of the system and generally this is the preferred UPQC. That is the active reactive power compensation both integrated into the single solution.

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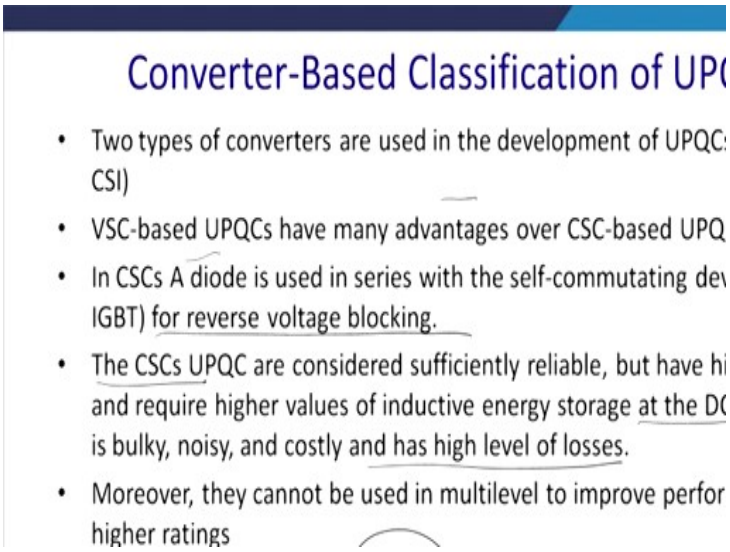

Now, as I told you, the two types of converters are used. That is VSI and the CSI. I have told you that this, VSI are used preferentially because it has many advantages. One definitely is that we require to put the DC link capacitor. DC link capacitor is generally less bulky than the iron and copper made inductor. As well as the cost of the capacitor is less than the cost of the inductor.

In case of the current source, a diode is used in series with the self-commutating devices of IGBT and we require a reverse blocking voltage. So, that is something. It adds up the cost. It is not there and generally IGBT has anti parallel diode. So, we require the bidirectional current operation in case of the VSC, voltage source converter. That is automatically provided.

But the UPQC of current source convertors are considered sufficiently reliable, but have higher losses and require higher values of inductive current storage at the DC bus, which is bulky, noisy, costly and has a high level of losses. Moreover, they cannot be used in multilevel to improve performance of the higher rating. This is one of the biggest drawbacks.

CSI multilevel inverter. Output of the CSI is in pulsated format, that itself introduces little problem of the current compensation. We have seen that there is a huge amount of the harmonic content in highly pulsed current if you have a Fourier series analysis.

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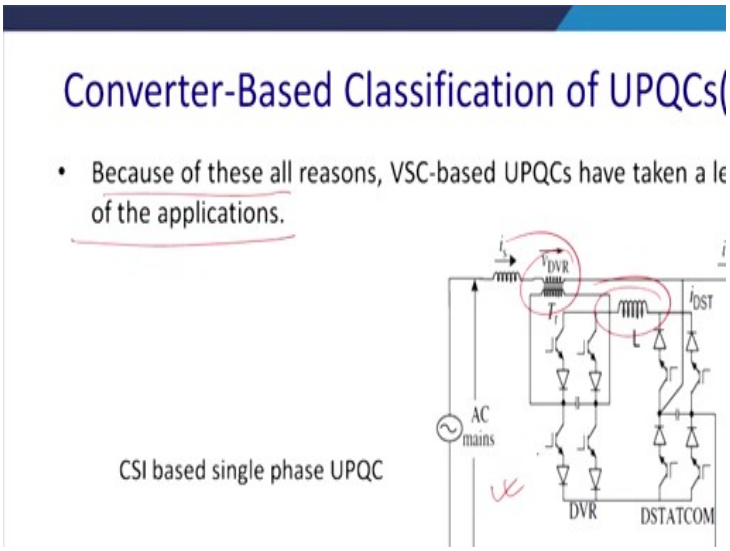

But if you have realized it with the current source inverter, this circuit would have been looking like this. Because of all these reasons the VSC based UPQC is been taken into the consideration and been used. But this is the way to implement with the CSI. You got a huge inductor. Thereafter you got a huge transformer and this is the critical path to be flown and, it is not possible to have such a bulky inductor in a high power rating and only single phase two wire connections has been shown here.

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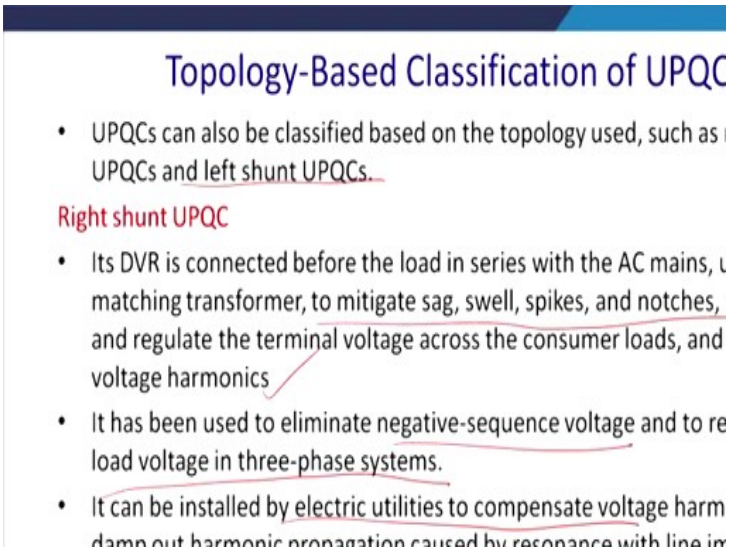

Now, UPQC can also be classified based on the topology such as shunt UPQC and the right shunt and the left shunt. This is the right shunt UPQC. In the DVR it is connected before the load in series with AC mains using a matching transformer to mitigate sag swell spikes, notches, unbalanced and regulate the terminal voltage across the consumer loads and to eliminate the voltage harmonics.

It has been used to eliminate the negative sequence of the voltage to regulate the load voltage in three phase system. This is extensively used for this reason and it can be installed by the electric utilities to compensate voltage harmonics and to damp out the harmonic propagation caused by resonance with the line impedance with the passive compensator.

Generally, what happens? When you have adjustable speed drive, then seventh harmonic sometime become very prominent and then what happens generally? You got a leakage inductance of the big transformer. That value is quite high, not negligible and in assignment you are required to solve this kind of problems.

Then what happens? All of a sudden you know you maybe switch on or switch off the capacitor bank. That has been used for 100 years and that leakage inductance and little change of the capacitor been introduced and it may set to a system deviation or the perturbation.

Thus it sets to a natural frequency of oscillations and that natural frequency of oscillation if by chance become very close to the seven harmonics or the fifth harmonics, then there will be a fifth harmonic resonance or the seven harmonic resonance. It has the capability to mitigate or damp out this resonance. Ok? This is the underlying statement of it

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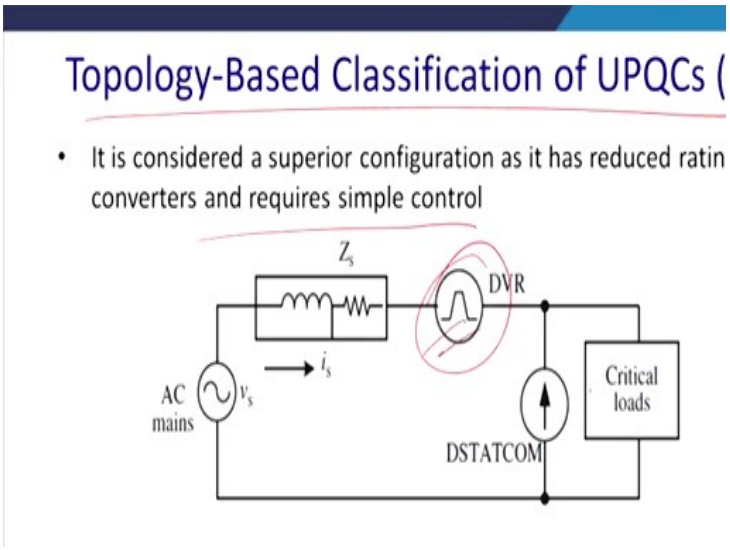

So now, let us have a discussion based on the classification of the UPQC, based on topologies. This is the right shunt UPQC. It consists of the superior configuration, as it reduced the rating of both converters and require a simple control. Because already what happened? You have mitigated the problem of the voltages. The control is simplified.

You can get a quality voltage source at unity power factor. You already have available quality voltage source. For this reason, unit template you can generate and do the compensations and generally if it is a swell, this swell has been mitigated. Rating of these devices are less and it is the healthy notch free. No disturbance from the voltage sides, but ultimately this DVR takes the bucks.

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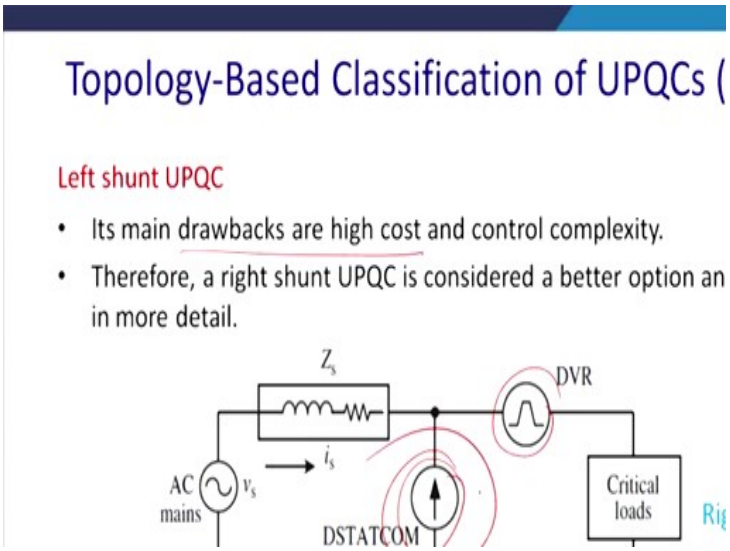

So, another one left is shunt. It has drawbacks of the high cost definitely because of the complexity required to be more and the generally voltage will be uncompensated. Here you inject the voltage. Here you inject the current and here you inject the voltage. For this reason, right shunt is considered as a better option to deal with. But sometime it has been preferred while we will see that the rating of the DVR is required to be reduced of this kind of cases. We prefer that kind of situation.

Thank you for your attention. We shall continue our discussion in our next class. Thank you for your attention. We shall continue our discussion with the UPQC in our next class.