Power Quality Improvement Technique
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Lecture - 35
Hybrid Shunt Active Power Filter

Welcome to our NPTEL courses on Power Quality Improvement Technique. We are going to discuss about the Hybrid Active Power Filter. This will be your 3rd lecture on the hybrid active power filter. We have seen many of the hybrid active combinations. This is one practical circuit. This has been reported by Akagi in 2005.

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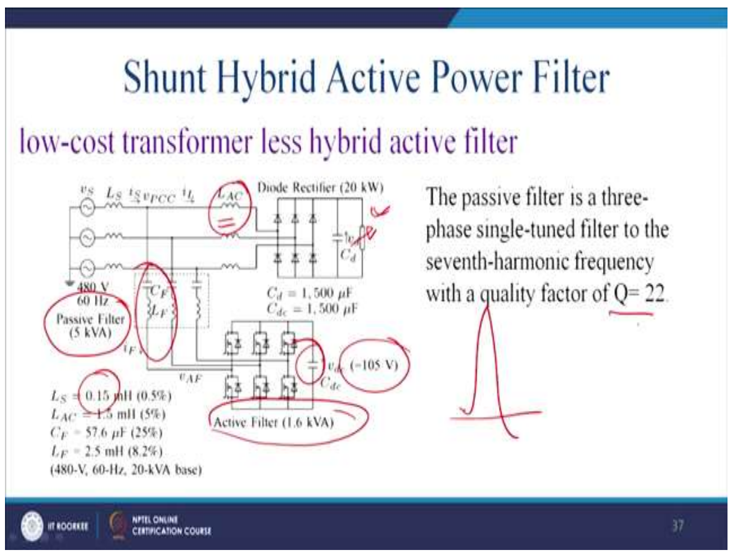

It is a low-cost transformer less Hybrid Active Power Filter and you can see that it is 480 volt 60 Hertz supply and dc bus voltage is maintained to the 105 volt and this is a filter and this has been tuned to the some desire frequency 5th or 7th. It has been tuned to the 7th and the passive filter power rating is 5 kVA and the Diode Rectifier Power rating is 20 kVA.

With these combinations you know the active power rating of the Active Power Filter will be reduced to 1.6 kVA and we assume that source inductance will have around 0.15 milli Henry. That is 0.5 of the base value.

We take this as a base value, 480 volt 60 Hertz and only disadvantage of this topology is that you require to put one extra inductance. That is an inductance to smooth out the ripple. Essentially when you have a load change, then this part will smooth out the rate of change of the load and thus capacitor gets little more time to settle down. Thus, this extra entity we require for this configuration is essential.

Thereafter you have C_F that value has been depending on the 60 Hertz supply and it has been tuned to maybe the 7th harmonic and L_F value is 2.5. These combinations will be essentially removing some amount of the 5th or 7th harmonic and you cannot have very sharp Q factor here. Here Q factor of this filter required to be maintained at 22, so that some portion of the 5th harmonic also get eliminated.

Also, it is a required to have a real power exchange and you should not offer very high impedance for it considering that the Q factor have to be optimally designed.

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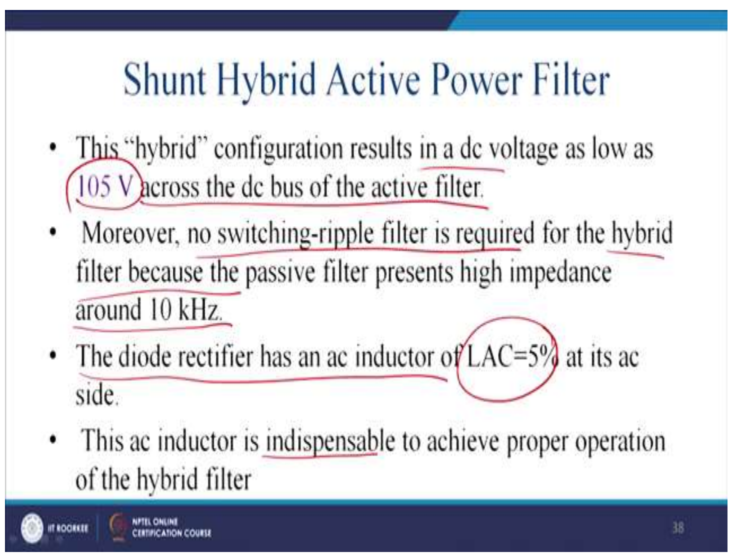

So, whatever I discussed let us put that into the small structure form. This hybrid configuration results in, a dc voltage as low as 105 volt across the dc bus of this active filter, since the rating comes down to as low as 1.5 kilo Watt. Even you can use MOSFETs and thus you can have a very high switching frequency and also the cost of the component is quite lowered. Moreover, no switching ripple filter is required for the hybrid filter. Since you can use MOSFETs or a high frequency IGBT of lower rating, the hybrid filter because of the passive filter offers high impedance at 10 kilo Hertz.

So, you need not required to have extra filters to suppress the switching harmonics. Only demerit is that we require an extra component. That is the diode rectifier has an inductance value of this. It is 5 percent at its ac side. This ac inductor is indispensable. So, you require to put it. Then you cannot have the desired power quality of IEEE 519 standard, IEEE 1151 or IEEE 514.

Whatever the standard you are trying to achieve, without this inductor you would not be able to achieve that and also you will have a sustained oscillations into the dc bus because if the rate of change of the load current is very high then and the value of i_c cannot change very fast because of the high impedance. Thus, what happens? It may collapse the dc bus voltage and for this reason it is advisable to put the ac inductor here and this has been implemented by Akagi by all the three controllers.

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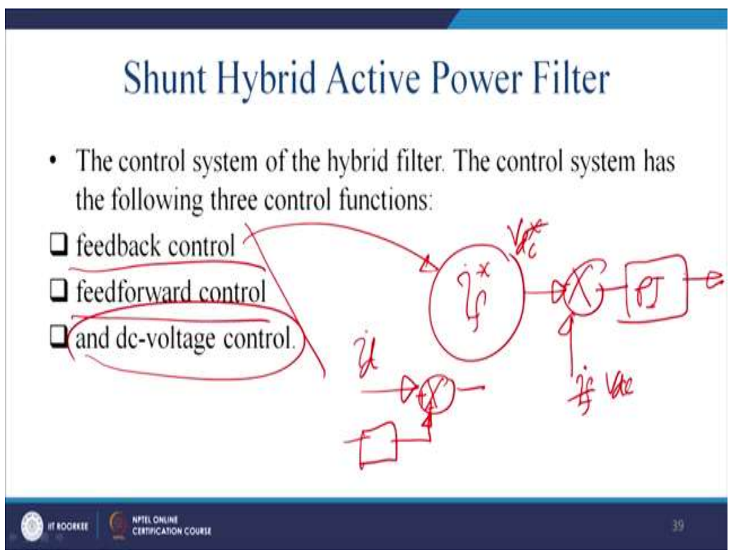

Whether it is an optimal control or whether all are required to be placed or not that is a matter of research, but considering that paper we are going to discuss all this feedback. The control system of the hybrid filter can be feedback control and I will show that. Ultimately as you have seen throughout our discussions you have i_f or i_c^*.

From there you actually have a sum-up and you will subtract the i_f and thus you will put to the PI or the hysteresis band. This part essentially your feedback controller. Similarly, you may have something like feed forward controller. They will see that you have some i_d

that is the d axis current of this and you can add may be with a block of the 5th and thus you add up.

So, this will be an addition and this will be a feed forward control op-amp in a hysteresis loop. Essentially a feed forward control and thereafter you have dc bus voltage control because again it is nothing but a feedback control. Here you will have V_{dc}^* and here you will have V_{dc}. From there you will have PI and you will add up with the i_d component of this shunt active power filter.

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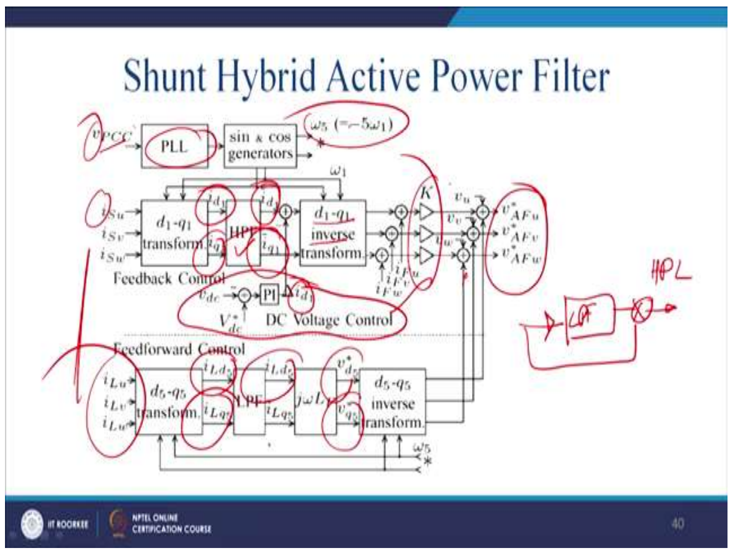

Thus, this is the overall control strategy reported by Akagi. So, you have the uPCC that is nothing, but a grid. That is the voltage or let us tell vPCC basically. Essentially, the voltage at the point of common coupling. In some literatures generally if you see the German notation, they write 'uvw' instead of the 'abc'. These are two synonymous entities. Voltage at PCC will be fed to the PLL. PLL will generate the fundamental as well as the 5th harmonic component of it. So, 5ω as well as the ω_1.

Now, you have the source current of 'abc' or 'uvw'. Then it has been transformed to the 'abc' to 'dq'. First 'αβ' thereafter 'dq' frame of resonance and thus you get the fundamental of i_{d1} and i_{q1}, then you pass this high pass filter, but realization is by subtracting with the low pass filter. Generally, you have that Low Pass Filter LPF and from there you subtract. You can say that this block is essentially high pass filter and thus you essentially got $\tilde{\imath}_{d1}$ and $\tilde{\imath}_{q1}$ and this part is essentially the dc voltage control.

So, you have V_{dc} actual minus V_{dc}^*. You have PI controller and thus you have the small amount of i_d. You generally say i_{Sd}. This will add up with the i_d, first fundamental component of the i_{d1} and thus you can have this i_{d1}, i_{q1} and it will be added to that $\tilde{i}_{d1}$ and this amount will be essentially your reverse, is a quadrature axis and then, you will calculate the current to be injected by the shunt active power filter. That is in 'abc' or the 'uvw' i_f and you will subtract it. Then from there you will have a gain and generally you may be required some kind of scaling and thus you get this v, u, v, v, then v, w.

This feed forward will be carried out like this. You will sense the load current but not the source current of the any of the two phases because you can of course generate another phase by subtraction with a 0. Then this ω will be feed here and you will have 'dq' transformation, but for the ω_5 and thus you get the 5th harmonic component of it and this 5th harmonic component you can calculate. This will be 'v_{d5}^*' and the 'v_{q5}^*' and you feed this component and add up with here. because this is the component present in the load current and this is the component present in the source current. Both require to mitigate.

You have decided that your passive filter will mitigate. For this reason, there will be a difference and you add up. Ultimately this will be the actual PWM signal for your hybrid shunt active power filter.

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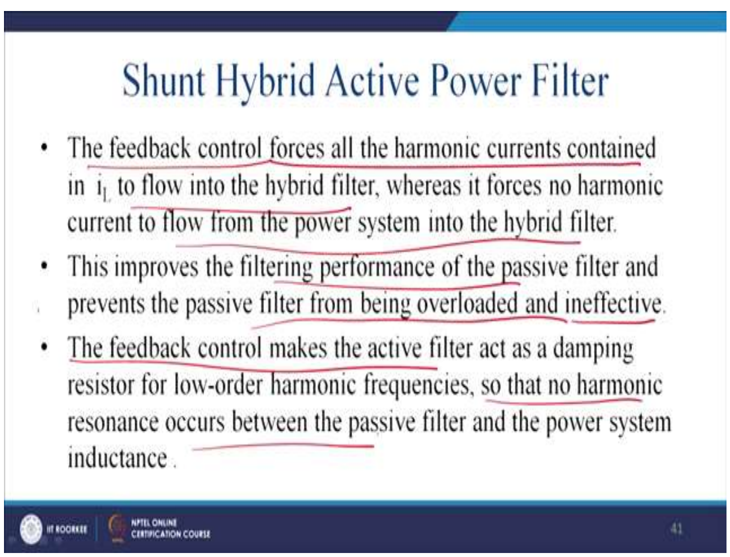

Thus, we can say that the feedback control forces all the harmonic current content in i_L. That is load current to flow through the hybrid filter. Whereas, it forces no harmonic current to flow from the power system into the hybrid filter. This improves the filtering performance of the passive filters and prevent the passive filter from being overloaded and ineffective. So, this is the way you have to take all those aspects of the passive filters into consideration and thus we require the three kind of controls.

First let us talk about the feedback control. The feedback control makes the active power filter acts as a damping resistor for the low order harmonics. So, that no harmonic resonance occurs between the passive filter and the power system inductance. This is how active damping can be achieved by this feedback control.

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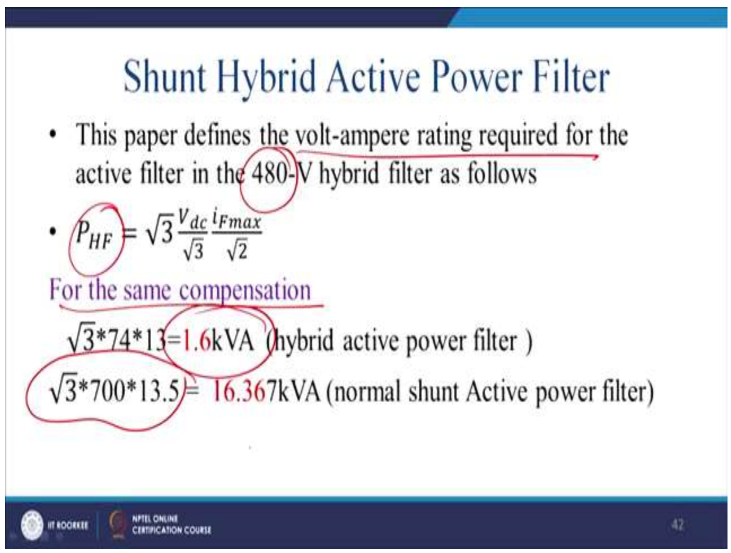

This paper that Akagi has put defines the volt-ampere rating required to be the 480 Volt. That is the standard in Japan. Hybrid power filter as follows. So, that is P_{HF} that is a power. That is $P_{HF} = \sqrt{3}\frac{v_{dc}}{\sqrt{3}}\frac{i_{Fmax}}{\sqrt{2}}$. From there for a same compensation for the hybrid filter you can calculate.

This require only 1.6 kVA and whereas, if you do the compensation for the 700 volt that 480 volt line required to be maintained, then the power rating required to be the 16.36 kVA for the normal shunt active power filter. But what you require extra? Apart from this LC branches. You just require that ac inductor extra and thus there is a 10 times reduction in the power rating. So, this is the great achievement in the field of the shunt active power filter. Let us now talk about the design of this passive part of this hybrid filter.

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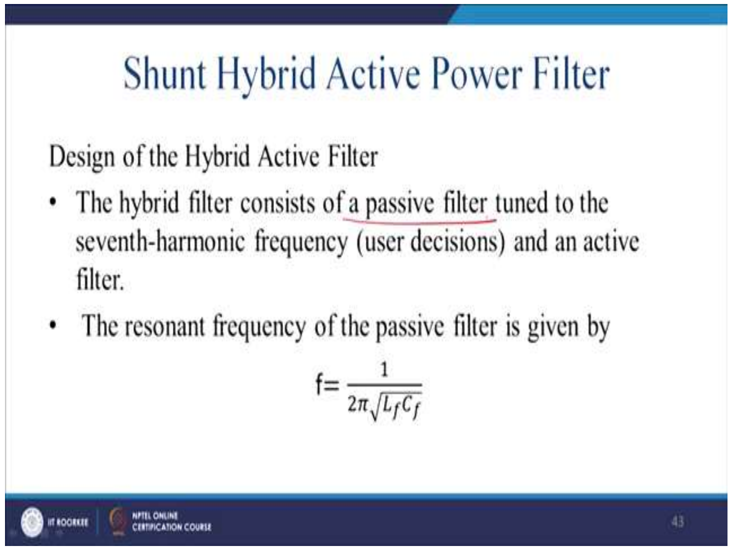

The hybrid filter consists of the passive filter tuned to the seventh harmonic. Look I have shown in the block diagram. That is the fifth harmonic is been extracted and put it like that and thus main chunk left out was the seventh harmonic. For this reason, passive filter is been designed for the seventh harmonic and this has been found to be optimal. Because of lack of time I cannot go to the detailed study. I personally done the study. Why not you do it here. You can go back to this block diagram side. This has been designed for the fifth harmonic.

We can do the same thing for the seventh harmonic and thus your filter required to design for the fifth harmonic. If you design for the fifth harmonic, the system will be more bulky and costlier and for this reason it has been found to be more optimal solutions. The resonance frequency of the passive filter as you know there is $\frac{1}{2\pi\sqrt{L_f C_f}}$.

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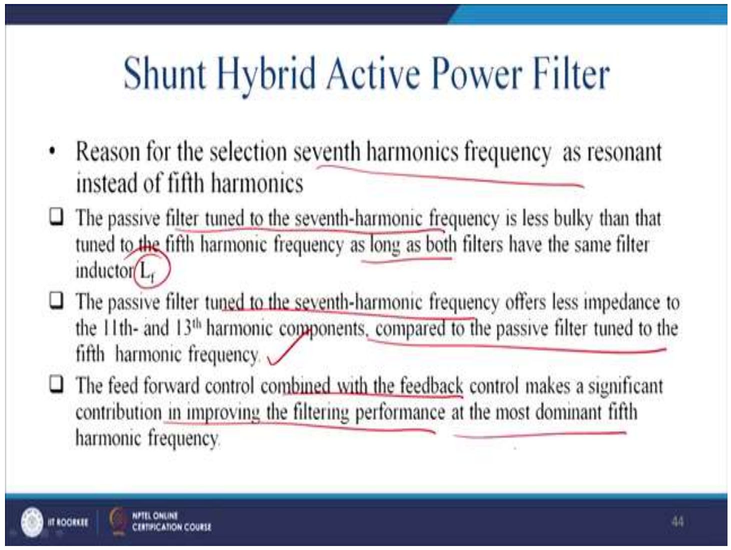

So, reasons for the selections of the seventh harmonic are as follows. These are the passive filter which is tuned to the seventh harmonic frequency (that is what I was telling) and it is less bulky than that tuned to the fifth harmonic as long as both filters have the same inductance L_f. Because if you put the value the L_f constant and you change the value of C_f, then of course, this capacitor will be bulkier

The passive filter tuned to the seventh harmonic frequency offers less impedance to the 11th and the 13th harmonic component compared to the passive filter tuned to the fifth harmonic frequency. This is also one of the reasons and we are going for the overall cost optimizations and the performance optimization, hence this topology fits rightly into the system. The feed forward control combined with the feedback control makes a significant contribution in improving the filtering performance at most dominating fifth harmonic frequency.

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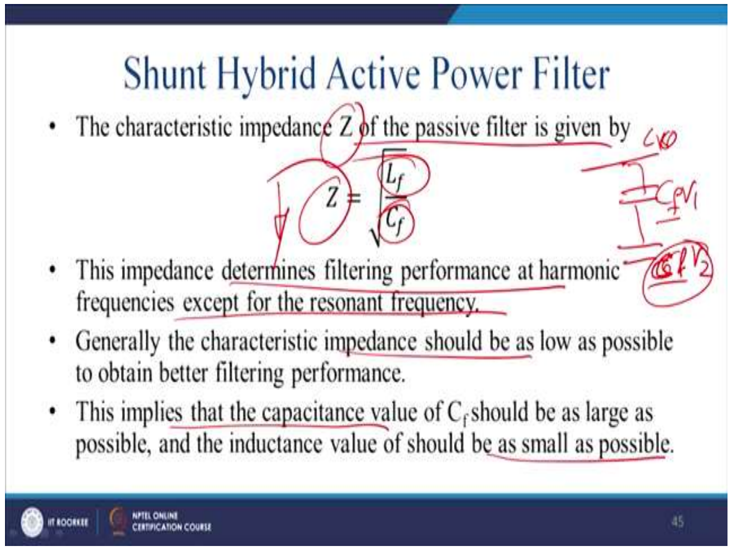

The characteristic impedance Z of the passive filter is given by $z = \sqrt{\frac{L_f}{C_f}}$. This is also called the sarge impedance and these we will see. This impedance determines the filtering performance because this will offer at the 50 Hertz. This impedance determines the filtering performance at harmonic frequency except the resonating frequency. So, resonating frequency maybe your seventh harmonic. What will be the impedance offered? That will be in this value.

Generally, the characteristic impedance should be as low as possible. Thus, what happens? You want to have a very high value of the inductor. That is one of the requirements, but there is an advantage of having small value of the capacitor because you are using C_f. You switch on C_f and C_{dc} comes in series. Thus, you got a voltage divided. Here this voltage is 480 volt RMS. If you multiply by root 2, then it is around 620 volt peak value.

This voltage will divide since you know that $C_1V_1 = C_2V_2$. So higher the value of the capacitor, lower will be the voltage rating and smaller the value of the capacitor, higher will be voltage rating. It will take the more voltage across the C_f. For this reason, it is desirable to have the lower value of the C_f. But what happens? You pay the penalty in the cost because cost of the inductor is higher. We can talk about that subject in detail but due to time constraint let us move forward.

This implies that the capacitance value C_f should be as large as possible and inductance value should be as small as possible, so that your sarge impedance become lower and but it is in direct conflict to rating of the device. Your rating of the device will be coming down if the value of the C_{dc} is more and C_f is less.

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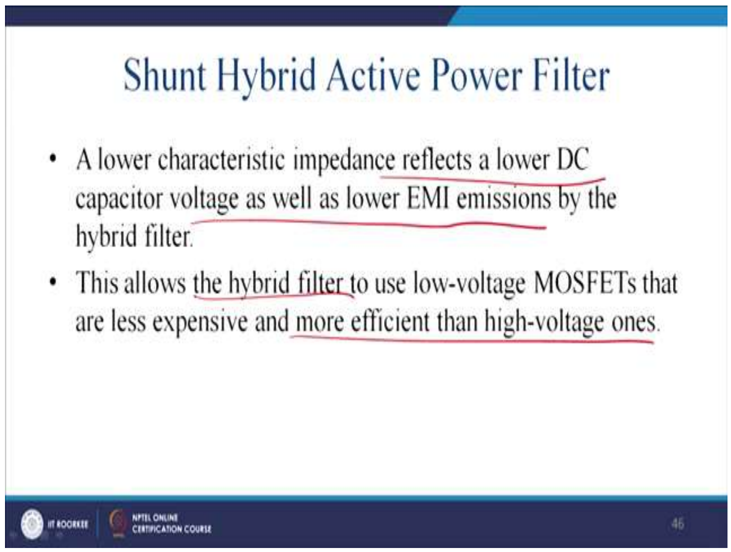

A lower characteristics impedance reflects lower DC capacitor. That is what I am saying. Capacitor voltage as well as the lower EMI emissions by the hybrid filter. This allows the hybrid filter to use low voltage because rating comes down to 1.6 kVA. Low voltage MOSFETs are less expensive and more efficient than the high voltage one because its conduction loses are quite low compared to this IGBTs and also turn on turn off loses are quite low and for this reason overall efficiency also improves with the MOSFETs.

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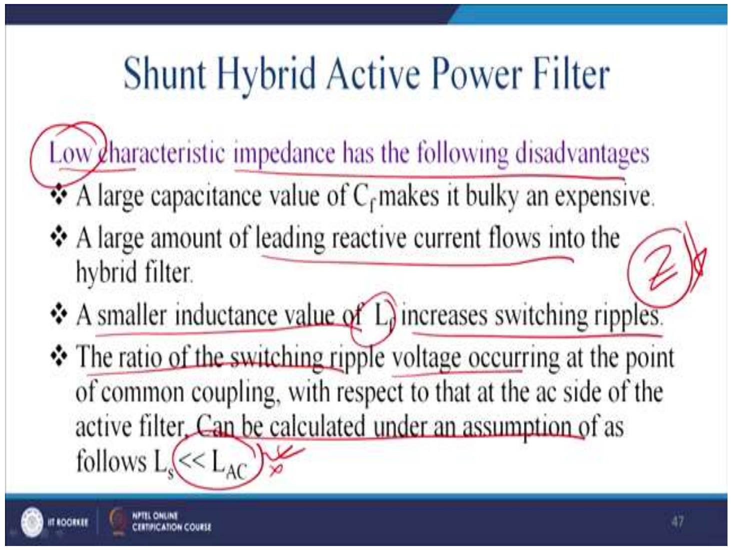

Now, low characteristics impedance has the following disadvantages. If you have a low value of the Z, then you will have the following disadvantage. Large capacitor C_f (that is what I said) makes the system bulky and expensive. Keeping the constant value of L_f of course, large amount of leading reactive power to be flown into the filter. How much reactive power handling capability you will have? that also will be governed by this C_f value. Smaller inductance value L_f will increase the switching ripples.

So, we cannot do that. You have to choose some optimal value, so that switching ripple does not reflect into the source current, because you have not put any extra high frequency filter. The ratio of the switching ripple voltage occurring at the point of common coupling with respect to that the AC side of the filter can be calculated under assumption. For this reason, it is essential and load side inductor is much greater than the source inductance.

This is something. It has to be valid and if you have a large transmission line, but generally it is not so, then you may have a high source inductance and there you may not require this condition to put the extra inductance before the diode bridge rectifier. Now some recent modification that has been aspired from the topology has been described. That is the combination of the power quality and the FACTS.

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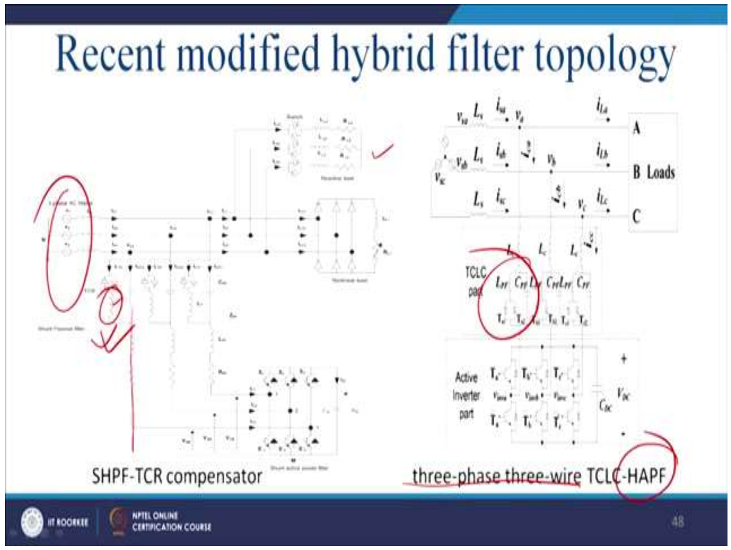

Essentially, you have a source and thereafter you put the FACTS devices like TCR and this is a Thyristor Controlled Reactor. Ultimately value of the inductance will depend on the firing angle of these thyristors. Please refer to my FACTS courses. There has been covered in detail and thus capacitors do this. Inductor values can be modified by changing the value of the thyristor. Thus, what happens?

These combinations also offer you the reactive power compensation. That is the task of the FACTS devices and apart from that these combinations gives you the Shunt active power filter and also you can have a switch of this kind of full control converter maybe. So, this is a combination of a shunt active power filter with thyristor-controlled reactor. This is the marriage of this power quality and FACTS devices and thus it gives you a better solution.

Same thing is possible with another FACTS devices, that is TCLC. This will take care of the reactive part and ultimately the harmonic part will be fed to this L & C. This will be tuned to the particular dominating harmonic and thus you can get rid of this. Essentially if you see L_c and C_{PF}. This is nothing, but the same topology. Within that you have a controlled inductor through the switching and thus you essentially have a three phase three wire TCLC of high pass active power filter

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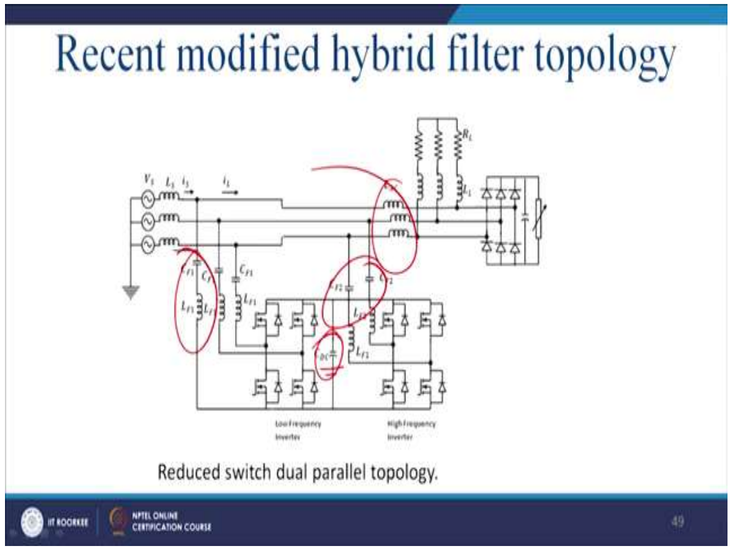

Now, this is the one of the topologies. That it is reported by me. So, here the main intention was of course in Akagi's paper. Here I have used one leg more, but that too has been drastically diminished the power rating. You can use the MOSFETs and ultimately these has been tuned to the fifth and seventh harmonic with the Q factor in around 40. So, that you can have a quite sharp resonance and this has been tuned to the eleven and thirteenth harmonic and we do not leave anything for the passive, because there is an issue of the detuning in case of hybrid filter also.

Because the passive part what you are trusting, casually it will decay and thus for this reason we leave everything with the combinations. This is the part that will compensate fifth and seven. This is the part that will compensate eleven, thirteen and we have found that value of L_c L_{ac}. Requirement is found to be less compared to this Akagi's work and we have reduced it since it is a three phase three wire system. One leg is connected to the end point of the dc bus, thus there is no fluctuations of the dc bus.

You can connect the midpoint of the dc bus to this leg. Then what happens? if there is an unbalance, there will be a problem of the dc voltage fluctuation. Instead of that we connect it in the negative half of the dc bus and thus the fluctuation gets eliminated and this topology works very fine. We have shown some results in our shunt active power filter. There is a topological improvement and it has reduced the cost compared to the solution of this Akagi's version. Same thing. There is a reduction in switch.

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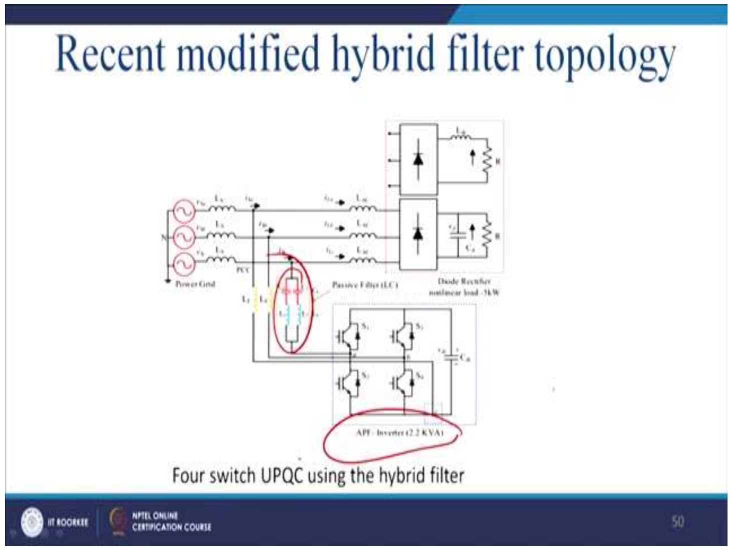

Here you connect almost same. There is nothing new here. From this topology. Just you take the two legs. There are four legs and thus you have truncated that portion and you will left with the fifth and seven and this is fifth harmonic low pass filter and this is seven harmonic low pass filter once you are mitigating.

Since you know that fifth and seventh will be mitigated by the passive filter, automatically. In three phase three wire system other phase get controlled and thus overall rating will drastically come down. It has been found that this rating is little higher with the same rating 480 volt of 60 Hertz system. This rating will be 2.2 kVA instead of the 1.6 and that is also acceptable. That is not a big deal on it. Same way we can combine the same thing in UPQC.

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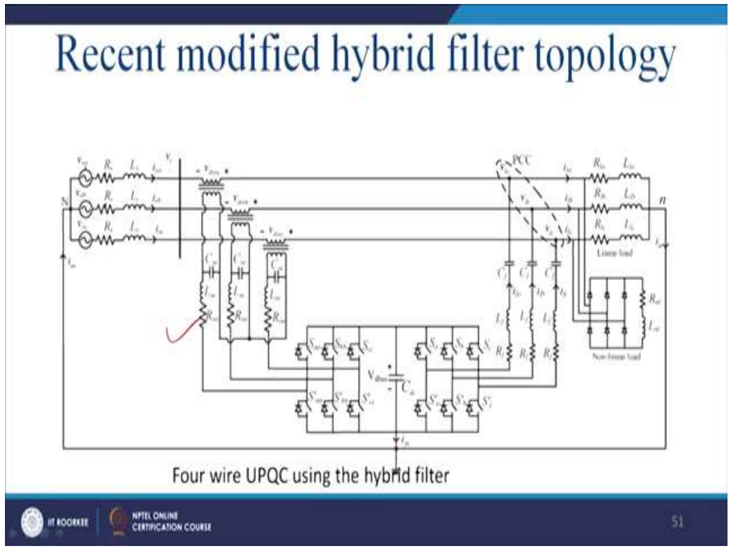

This is the three wire UPQC with the passive component connected in a series part of it and this is a shunt part of it and thus, overall rating of the UPQC can be brought far below than it. Generally, it will be 5 to 10 times.

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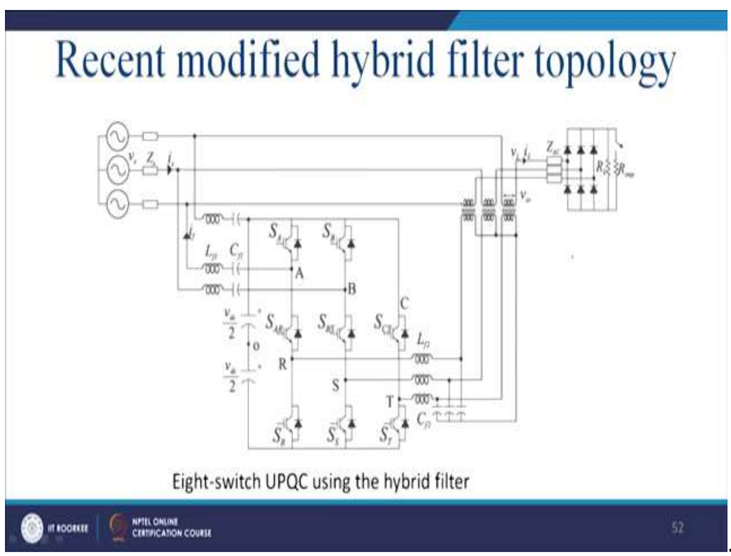

Another combination can be combination of the switch. Some portion of this topology will be common to the series and parallel with the hybrid filter topology and thus, you can see this topology just have these eight switches.

It is called the eight switch UOQC. This is with the hybrid combinations, but overall switch rating can be reduced, but stresses across the switch is generally brought down with the help of this L_c filter and some devices here are rated higher because of the conduction time of those switches which require to be more and thus there is many topological variation of this hybrid filter topologies. These are the few important examples I have sited here.

Thank you for your attention. Thus, I almost conclude this course and you are welcome to ask questions. We started with the journey from the Overview and with the modern development, then to the shunt active power filter, UPQC and its marriage with the FACTS devices.

Thank you.