Power Quality Improvement Technique
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Lecture – 32
Shunt Active Power Filter – IV

Welcome to our NPTEL courses on the Power Quality Improvement Technique. Today will be fourth class on the Shunt Active Power compensation and today we will discuss about some topological improvement on the Shunt Active Power Filter.

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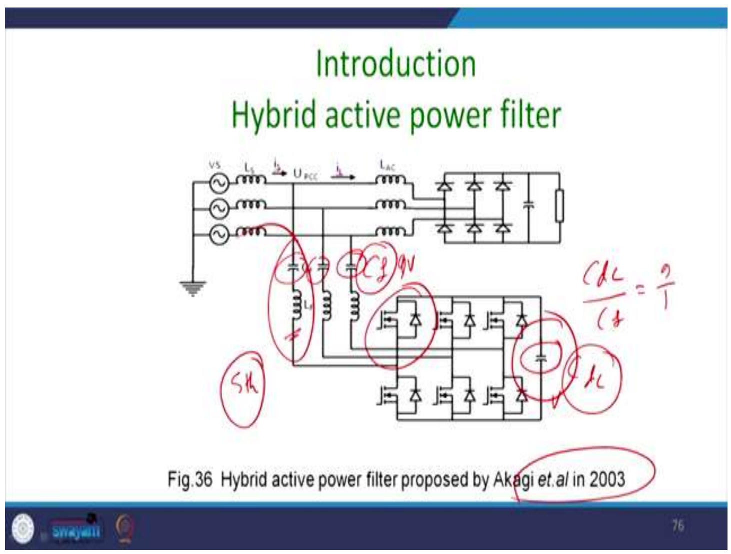

Essentially, this is a three phase three wire system and you see that it is not IGBT, it is MOSFET and thus power handling capability will be less and this is one of the example of the hybrid filter and if you bypass this capacitor, then it is a normal shunt active power filter.

Akagi proposed this topology without this capacitor in 1984 and Akagi proposed these circuits in 2003. So, quite newer compared to this the first reporting. So, he used this. We have taken a thorough discussions on the passive filter. Now you are aware of it. How to design that double tuned single tuned filters?

This capacitor and the inductor are been tuned to the particular frequency. Then what happened? Due to that a particular harmonic will be mitigated by the passive devices and then the loading on it will decrease and another big advantage is that, the C_1 let us say C_{dc} and this C_f will have some ratio. So, this is a series circuit. If the size of the capacitor is more, then voltage across this capacitor will be less. It is a series connection.

If C_{dc} and C_f have a ratio of 9 is to 1, then V comes here, then 9 V will come there and ultimately the total voltage of this point to this point will be 10 V of this capacitor voltage. Thus, this capacitor voltage will see the one tenth of the voltage stress of this devices and for this reason of course, Akagi came out with the simulated with the 6 KV network and that can be used instead of the multi level converter. You can use the normal IGBTs.

This is one of the major topological advancement in the sector of the hybrid active power filter. What happened then? It is a transformer less topology. Of course, you can do it with a transformer, but it is a transformer less topology and you bring down the cost. But one aspect is, there is a challenge because it offers a huge impedance.

Generally, it is tuned to the 5th harmonic, if the huge impedance is been offered for the real power flow. So, reactive power handling capability of this shunt active power filter is degraded. Otherwise, if you use as a frequency compensator (that means, that shunt active power filter only compensate the harmonics) is a beautiful economic solution.

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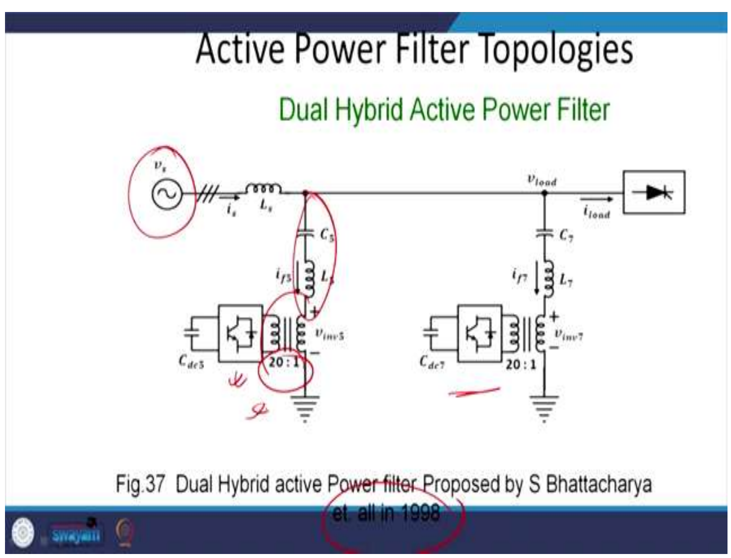

So, another example. Let us go back. Little history. This is the topology of 2000, 1998 by Professor Subhasis Bhattacharya. He is a professor of North Carolina University. He does pioneer work in the shunt active power filter like Akagi. So, this v_s and L_S you see that is a multi-entity and this one has a ratio of 20 is to 1.

Since it is tuned to the 5th harmonic, and once the frequency increases, the volume of this transformer is low and it handles only the reactive power. The size of this transformer is all not bulky and rating of this devices is also low and why? Because of the simple reason that this 5th harmonic current is generally one 5th of the load current and this is a combination of the passive filter and with the active filter that will mitigate. Similarly, you can have a 7th harmonic mitigation and so on.

Thus, you get a total compensation. But it is a discrete solution then we can say it is a banded method. So, you put an active device. If 5th harmonic is dominating, you put it thereafter 7th harmonic and so on. You just try to mitigate it and you know that sometimes there is a ferro-resonance. That also can be mitigated by these combinations.

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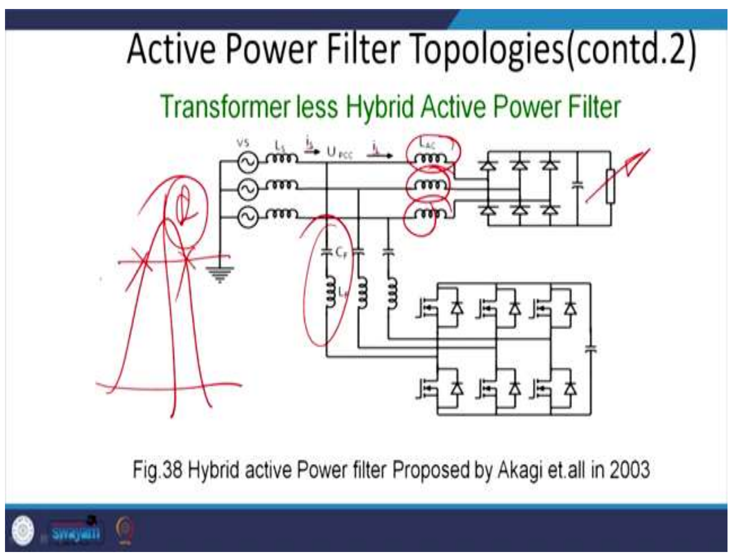

Now, let us go back to the same paper of the Akagi, same work of Akagi and here we required to soften that a little. We require to put some amount of the source inductance apart from it. Otherwise this circuit is same and it may have the features of the load change.

It will be tuned to some harmonics to mitigate it. Generally, it may be tuned to you know that if we tune effectively to the 6th harmonic, though it is not present here because it is a three phase three wire system. So, you tune in such a way so that this is your 5th and this is your 7^{th}. So, both will be mitigated by this. By selecting the proper value of the Q.

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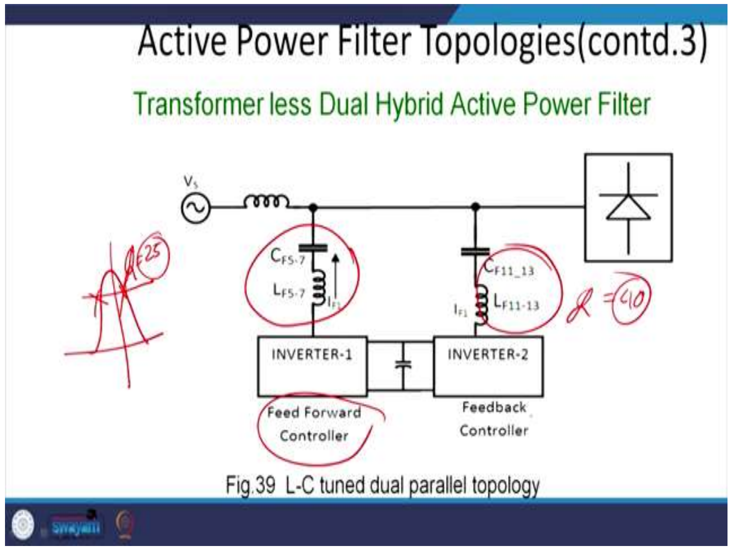

Fig.39 L-C tuned dual parallel topology

Now it is another example of this transformer less feature. So, here we have combined it the same way in between 5th and 7. We have kept the Q around 25 here and there is a reason behind that. It will mitigate the harmonic 11 and 13. We have kept the Q around 40. It is the sharpness of this value.

So, it will mitigate these quantities and we have to use a little more wire and we will use it. There is a reason behind that. Why to use as a feed forward and the feedback controller?

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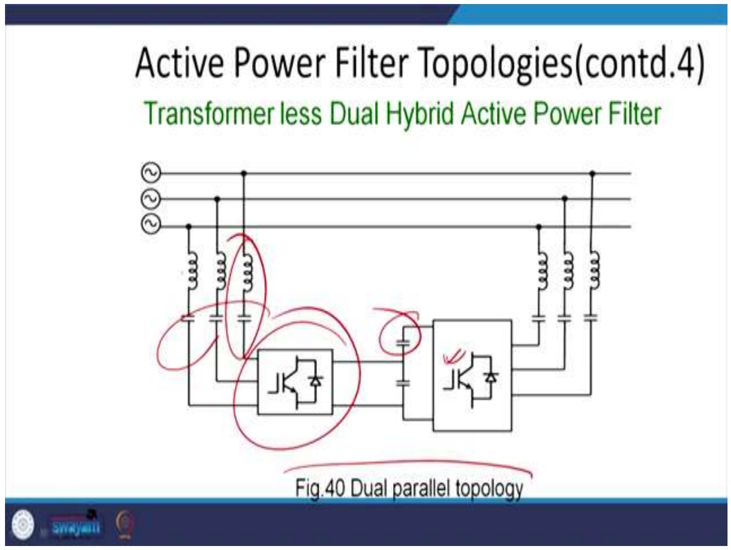

Let us see that, this is a combination and also you can have another possibility of split capacitor. Let us say lower harmonic and the active power filter and for this reason you may require a little more DC bus voltage.

This one may be connected to the lower DC bus voltage and ultimately this device can maintain the DC bus voltage and thus you can compensate rightly. Since, this part mainly does the harmonic compensation and it can be MOSFET based and thus rating of the device will be low and also this will partially mitigate the dominating harmonics. Thus, you can have a more effective solutions instead of the normal shunt active power filter.

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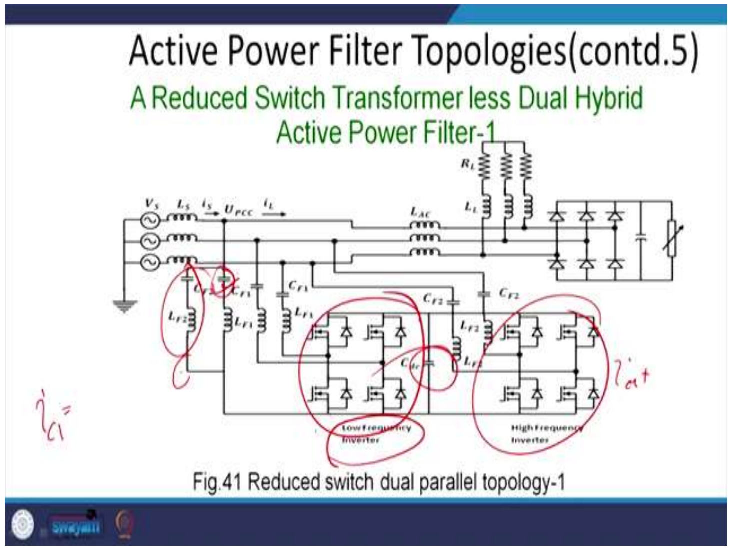

This is one of the topologies. Since you have three phase three wire system, we have reduced the number of switches. You can see that, this one. This topology has been corrected here since i_a, since for this current let us say i_{C1} of ‘abc’ is 0. If you can control ‘a’ and ‘b’ then automatically ‘c’ has been controlled. So, rest of the current has to flow through this path if you can control a and b. Thus, what happened? We can reduce the number of switch because if you have less number of switch then you have lesser cost.

Similarly, here also the same thing. Here you have a two leg and ultimately rest of the current of the second leg will follow through this line. Generally, this is a low frequency inverter with the higher power rating. It can be GTO and it can also compensate the reactive power. This one is for the higher order harmonic. It has been tuned to the 5th and 7. This one has been tuned to the 11 and 13 and the nobility of it that you it can handle higher frequency. That is it can compensate the higher order harmonics quite accurately.

So, these combinations you know. These are the few topological variant of the shunt active power filter that we are looking for. So, that we can have optimized performance and the economic solution. These are the two major objective of this topological studies and advancement and power electronics engineers wish to contribute in this field with a multi level inverter. Look you require to meet this higher voltage level. We have used a single level.

We have used the two-level. Sorry. Extremely sorry, but it can handle the same PCC voltage. Ultimately, buck has been passed to this capacitor. So, switching is been done around 10 times less power rating. So, normal IGBTs can be well fitted into that case and system is less bulky because it does not have any transformer placed in between it.

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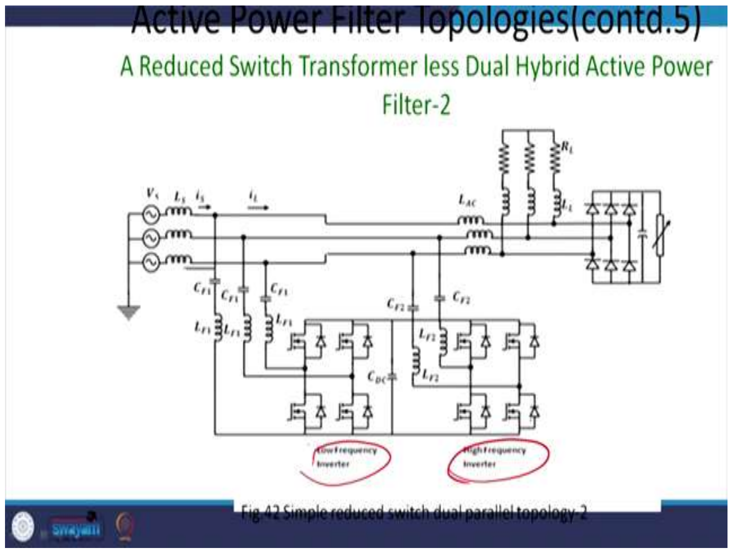

Similarly, we can have a simple reduced switch of the dual topology too. You see there is a change in the topology. You see that it has been connected like this and here it has been connected to this point.

Otherwise there is a Δ change in it, but it is a high frequency. It is a low frequency and here you can split the capacitor and this capacitor can be part of this circuit where we required a higher reactive power compensation and this you can split it to the lower value of the capacitor, where it will handle the harmonic part of it.

Let us see how you design? This is a quite interesting feature. I have discussed in the tuning of this inductor. This is the calculation you require to do.

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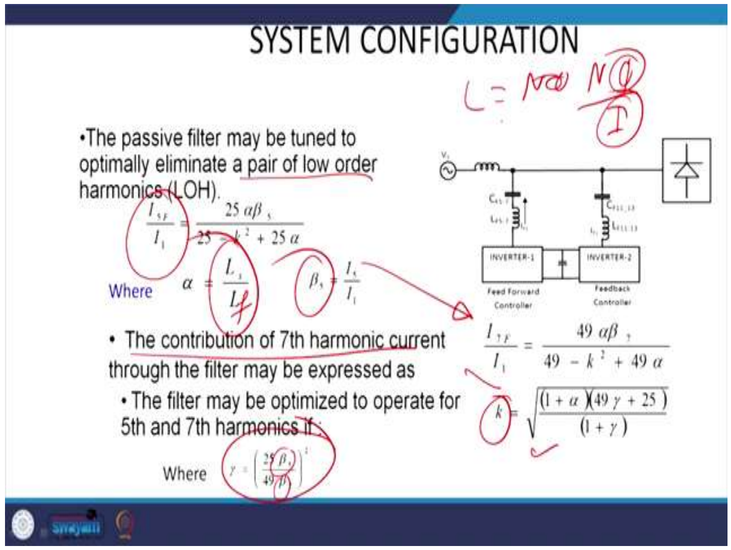

The passive filter may be tuned optimally. Nowadays people take this paper and apply GA to find out the optimization. That is fine you know. Of course, you can get a paper on it, but let us see that how practically it can be done. Optimally eliminate the pair of the lower order harmonics. It is 5th and 7.

So, this is a 5th and I should have a ratio. Let us consider that. It is $25\alpha\beta$, where α is the ratio of L_S/L. Where L_S is a source inductance and you can write it also L_f. So, that is the active power filter inductance and similarly β is your I_5/I_1. That ratio. So, you can tune it properly and you can optimize it. Same thing can be done with the I_7 and you find it out the value of the 'k'. So, the contribution of the 7th harmonic current through the filter can be expressed. So, the 5th harmonic may be optimized to operate fifth and then we require to optimize these two entities.

So, k is this. From there you can find it out. That $\gamma = (\frac{25\beta_5}{49\beta_7})^2$. So, from there you can effectively choose the value of this. Since these values are constant, you require to choose the value of γ and γ require to be optimized. This is a quadratic optimization. you need not have to apply the heuristic optimization technique, but anyway. So, you can get the value of the 'k'. it is $\sqrt{\frac{(1+\alpha)(49\gamma+2\ )}{(1+\gamma)}}$. From there you can get the value of the k.

Some people also work on that because of the loading there is a variation of the inductance and they have got some kind of tolerance. We have taken the constant value for the sake of the simplicity. But in practical cases what happens? The value of the inductor changes because its loads current. Because $L = \frac{N\phi}{I}$. So, generally ϕ does not change. Current varies. So, what happened then? The value of the inductor will change inversely proportional to the current and thus you have to have some kind of non-linearity and if you take this non-linearity, then you can apply a heuristic optimization technique.

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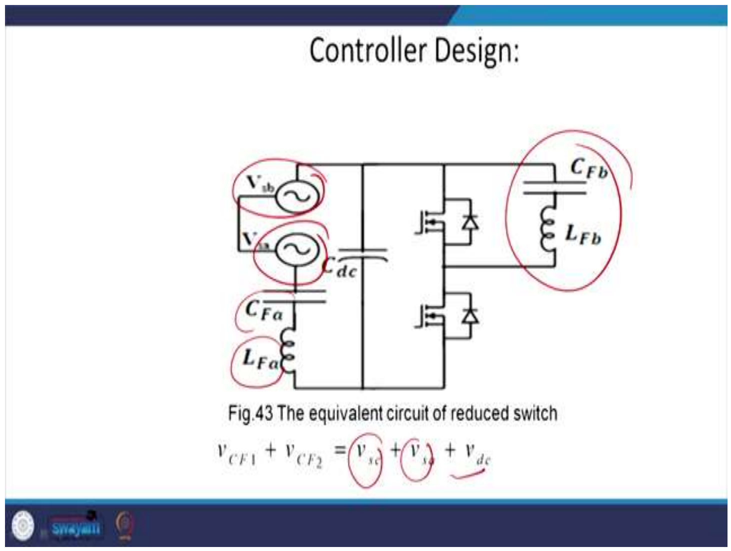

So, then if you put in to this block diagram. With the control designer has to be done on it. So, it is I_{sb} and I_{sa}. So I_c is missing because you have already shorted. So, it is L_F and L_F and C_F and these are the switches and parallelly you have C_F and L_F. So, stress current gets divided across it. From there you can write that $v_{cf1} + v_{cf2} = v_{sc} + v_{sa} + v_{dc}$.

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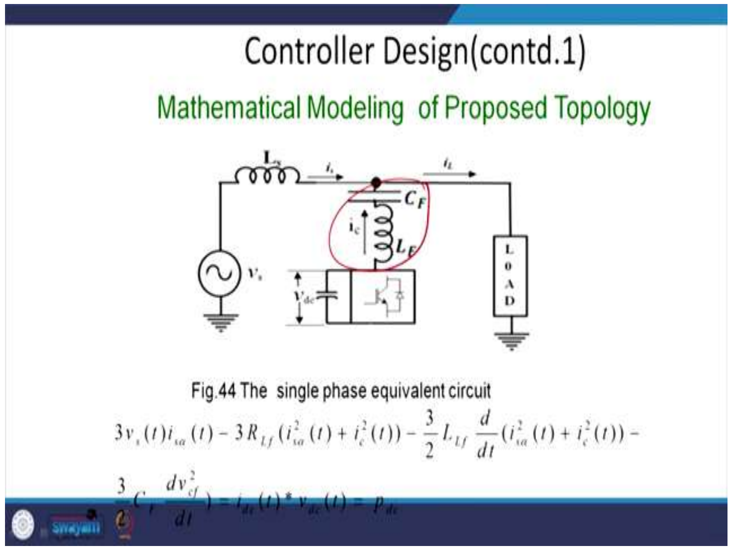

So, from there you can again equate these equations and thus you can find it out. This is your system. This is your value of L and this is the L and L_F and this is a load.

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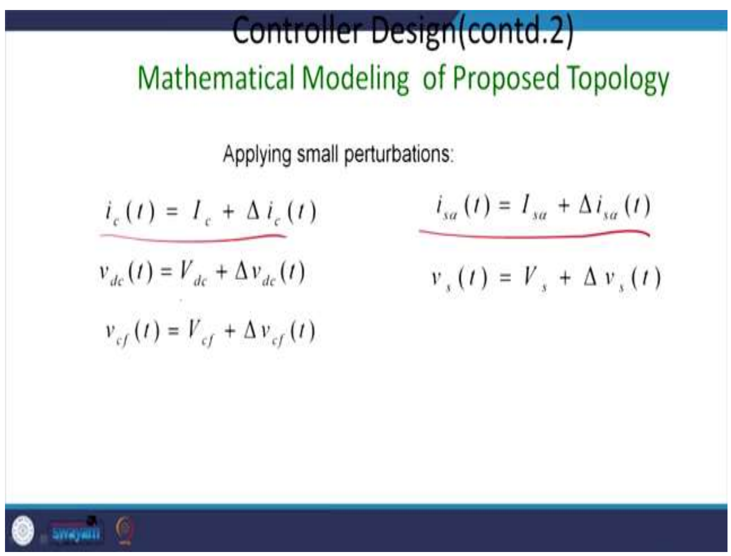

Look I was trying to have a small signal analysis. This is part of your control circuits and let us take the total non-linear control. This is a linear control. So, you have perturbed all the quantities.

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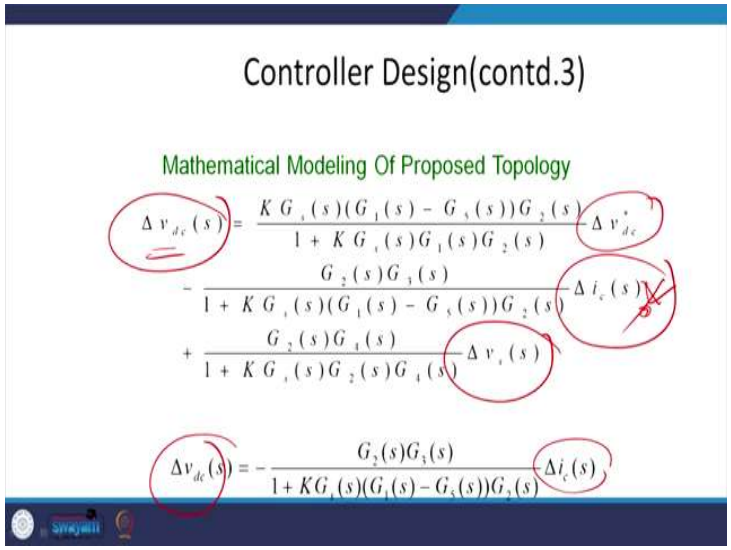

After perturbing, you get a v_{dc}. Essentially since the DC bus voltage is very low sudden change of the load on the source disturbance can overthrow a DC bus voltage into the zone of the instability. For this reason, maintaining the DC bus voltage is a main challenge here. It was the proper functioning of this shunt active power filter.

For this reason, you can refer this paper. It is published in 2012 in IEEE industrial electronics. Detail has been there. Ultimately you came across this transfer function and there we will not consider the perturbation of this i_c. We will consider the perturbation of i_c, sorry and we will not consider the perturbation of the source voltage and we will not also consider the perturbation of the variation of the reference of the resealing voltage. You can also change that.

Then also there is a change of sequence and thus relation between these two entities can be established. Once its load changes, the value of the axis changes and this value of v_{dc} changes and from there you can have a transfer function. It is your known domain of the linear control circuit. Thus, you do the any treatment like Nyquist's and all those control technique and from there, you derive the different functions and it will have a control.

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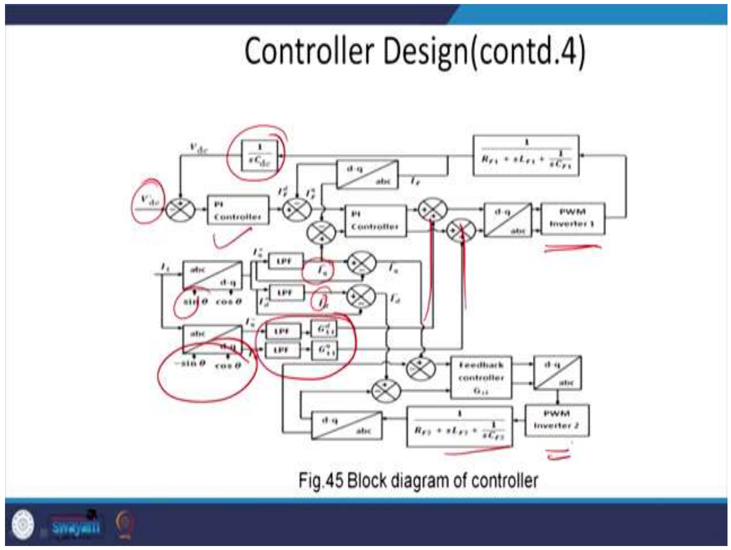

Fig.45 Block diagram of controller

This is the overall block diagram of this control and v_{dc} is the reference. There after you have a V_{dc}^*. Thereafter the PI controller. You have $\frac{1}{sC_{dc}}$. Then you subtract these two entities in a 'dq' frame and here you have RF plus L_F plus C_F also. This is for the first filter and your PI controller and from the PI controller, you can have 'abc' to 'dq' frame. You feed it to the PWM block.

Similarly, I_L will have abc to 'dq', $sin\theta$, $cos\theta$. You have a low pass filter. You have $\bar{I}q$ and you have $\bar{I}_d$ and you can also compensate. That is what I was saying. If you want to compensate the negative sequence, then you have to put it the minus Θ and $cos\theta$ because $-cos\theta = cos\theta$. Ok. So, you have to reverse the rotation, 180-phase shift. So, $sin\theta$ and $cos\theta$, it will be $-sin\theta$ and $cos\theta$. So, you feed it. This one is dangerous.

Generally, if you want to compensate the unbalance, you required to handle huge amount of power and for this reason generally feedback network acts slowly. Then what you will do? You have a feed forward network that will add here and ultimately this system will can handle more amount of power. Thus, it will be added with that and then harmonic part of it for the higher order harmonics. So, it will come here and this will compensate the higher order harmonic and in this way this will work. Ok.

Then let us see that. You know we have done this abbreviations. So, these abbreviations are been presented here.

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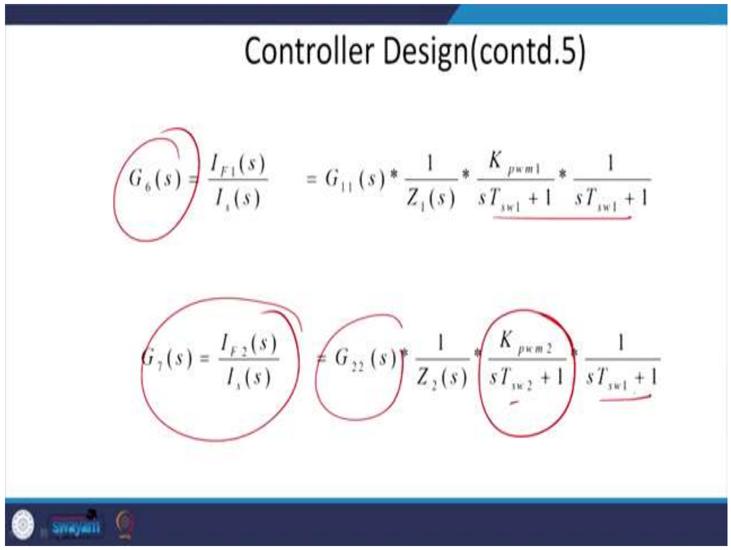

So, it is $G_6(s) = \frac{I_{F1}(s)}{I_s(s)}$. Refer to the previous slide. It is G_{11} equal to G_{11} into one by $Z_1(s)$ into that is K pwm into this one. G_7, essentially it is $\frac{I_{F2}(s)}{I_s(s)}$. Here, Z_2 is a impedance. Basically, it gives a switching frequency. So, it did not. Then it will be e to the power something. There is a delay. These entities, then this is equal to delay. This is the switching frequency of this another transformer.

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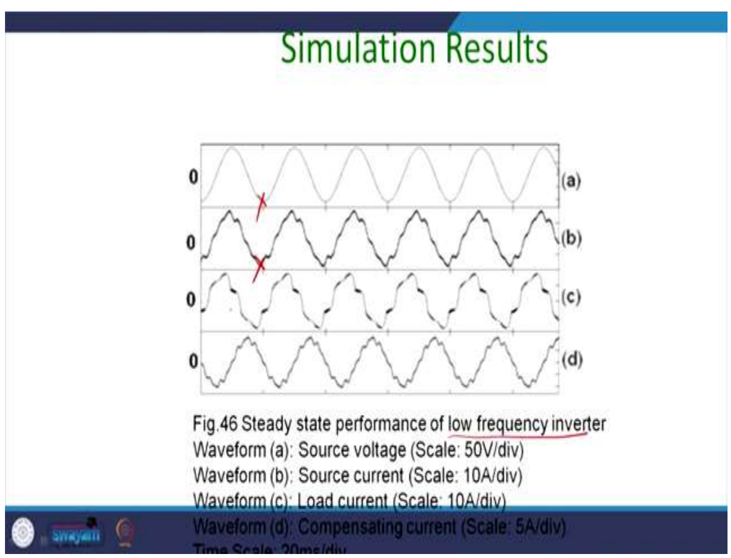

So, now let us come to some simulations and the experimental results. Now, this is a steady state operation of the low frequency inverter. Here low frequency inverter essentially is not operated for the reactive power compensation or the unbalanced compensation. It is not meant for the harmonic composition and for this reason you can see that. This is a source voltage and the source current and the load current and the compensating current.

So, these are all continuing and you know it is in a same phase. Power factor is unity, but there is a problem with the THD. Because it is not operated to compensate the harmonic.

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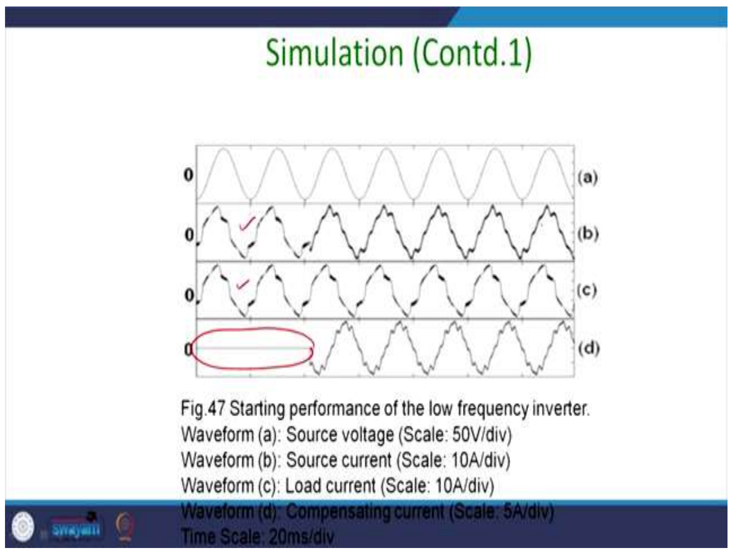

Now this was the load current and this was a source current and now at this moment, you start your low frequency inverter and you can see that its ‘0’ crossing matches or the peak matches and thus it is a unity power factor. But the it is corrupted with harmonics. So, harmonic compensation has not been used here.

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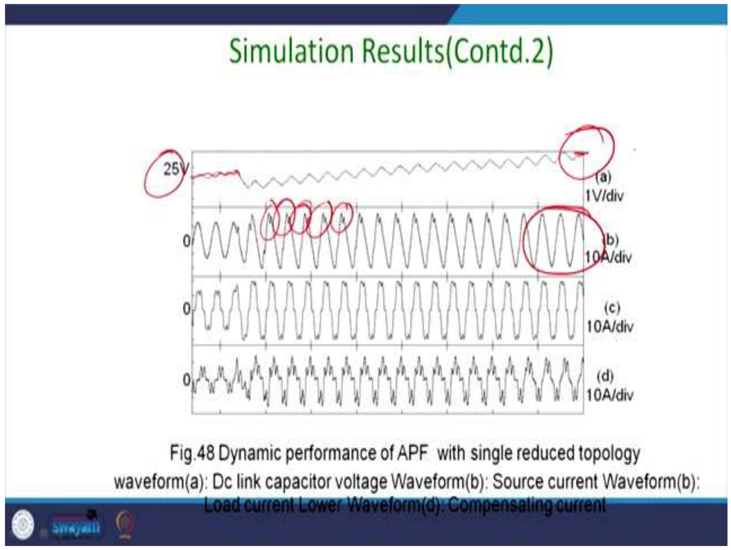

Now, this is an example of the dynamic APF and it is maintained at a 25 Volt. Only one entity is connected. It was almost sinusoidal. Now load changes and also it takes lot of time you know to mitigate properly, once it reaches to this value. Again, you can see that it does not reach the stability. This is one of the control challenges. So, it was maintaining around 25 Volt. You have a load change here, then this DC bus swells. Thus, what happened? It is cleared here. These notches. But it will continue to work like that. This is a problem only when single switch waveform is operating.

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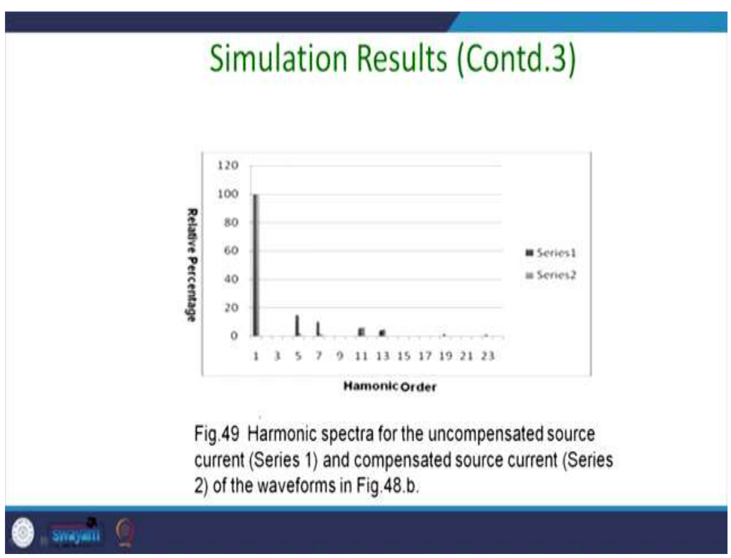

Then this is the harmonic spectrum of it and you can see that there the is a harmonic spectrum is quite good. This black one is essentially the load current or the uncompensated source current and the gray one is the source current.

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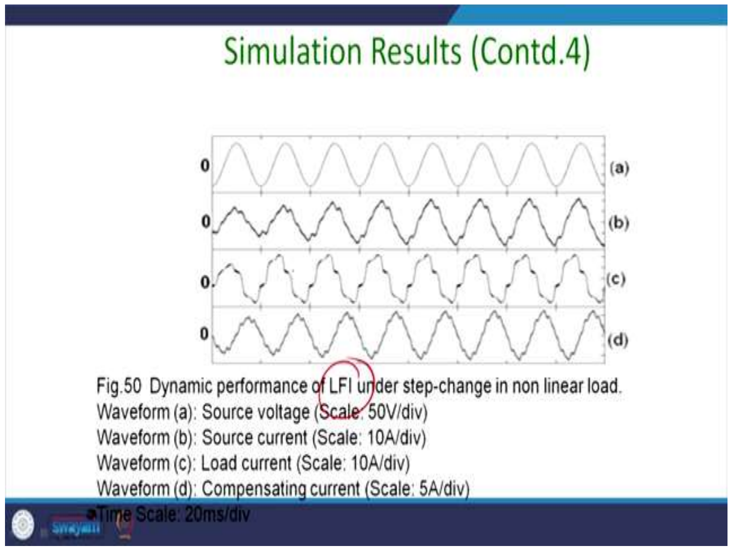

Similarly, this is a case of the dynamic performance of the low frequency inverters step change. So, this will work fine in a load change. But since harmonic compensation has not been done, it will have a problem of the THD.

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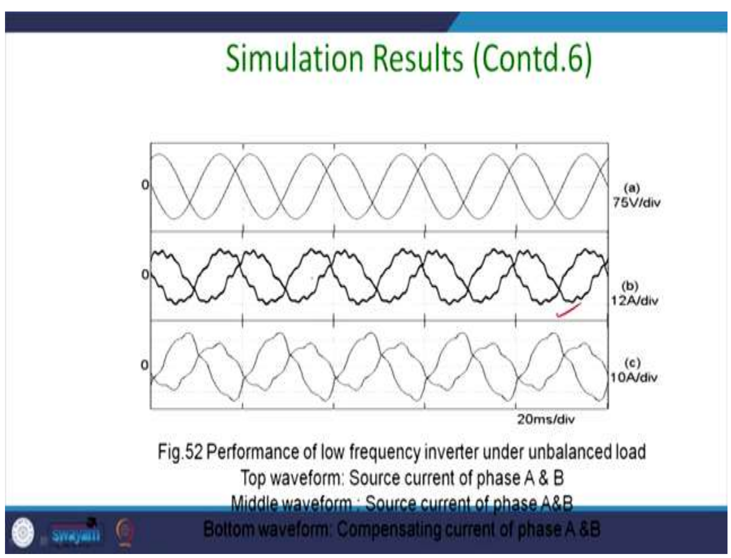

Now, here you can see. It is quite interesting. This is a voltage and current. The load is unbalanced. Source current has got harmonic because of the absence of the harmonic compensation but the source current is balanced. Just it contained the harmonic.

Now this is a condition. This is the steady state performance of the high frequency inverter. You can see that there is a phase shift. So, it is not a unity power factor operation, but reactive power has not been compensated. Although it has got a very good waveform as far as the harmonic is concerned.

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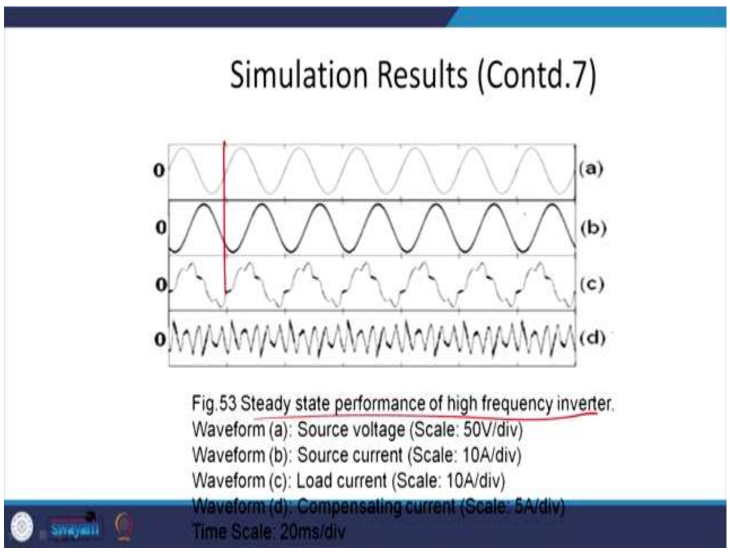

It has a got a lower power factor, but THD is less.

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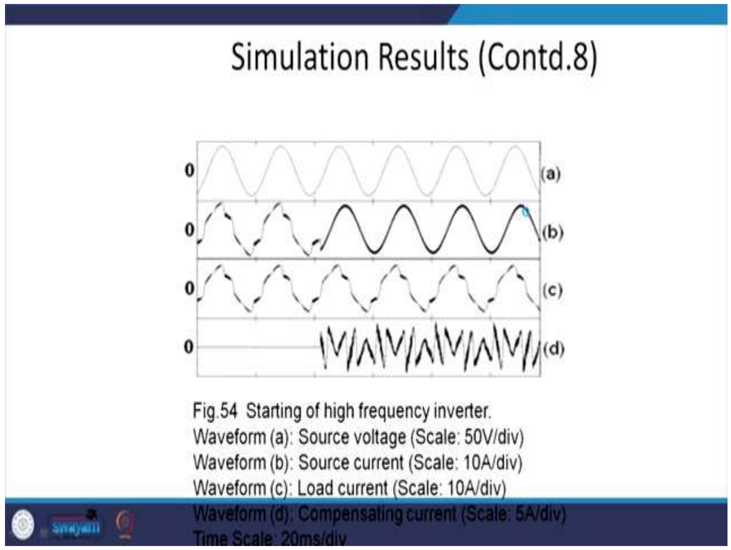

Here this is the starting of the high frequency component of it.

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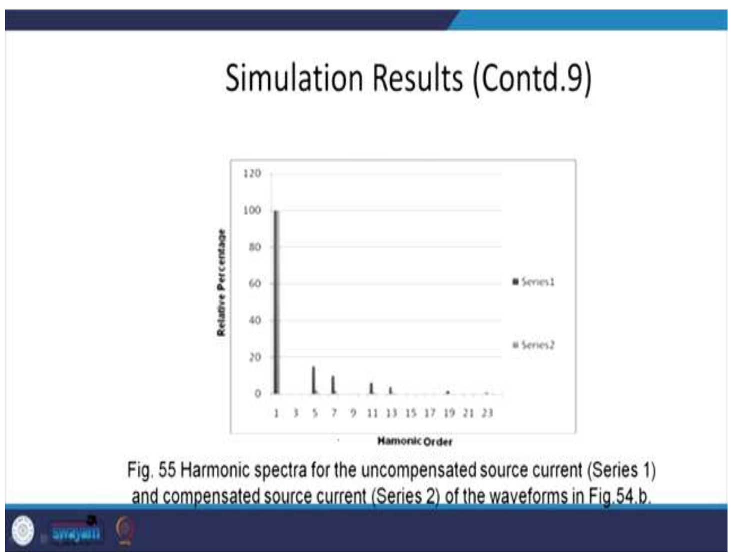

Then you can get the THD. It is quite satisfactory compared to this thing.

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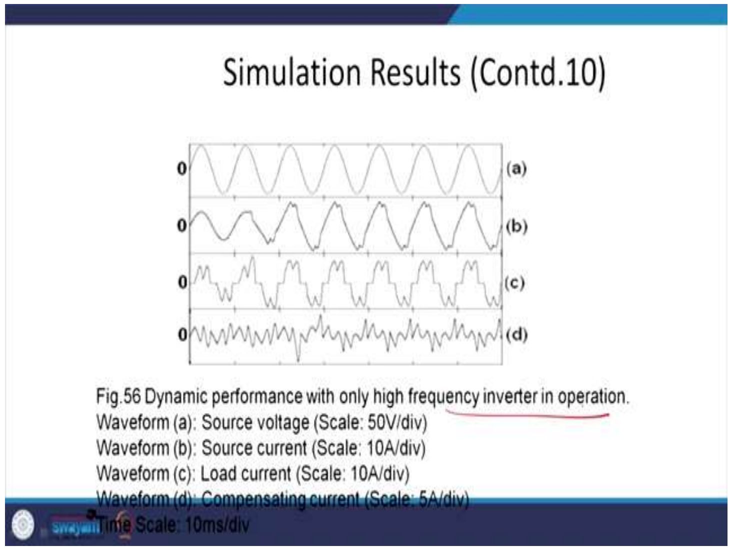

Now we have a few results. That is based on the dynamic performance on the only high frequency inverter in operation and there you have these notches, but you set a unity power factor.

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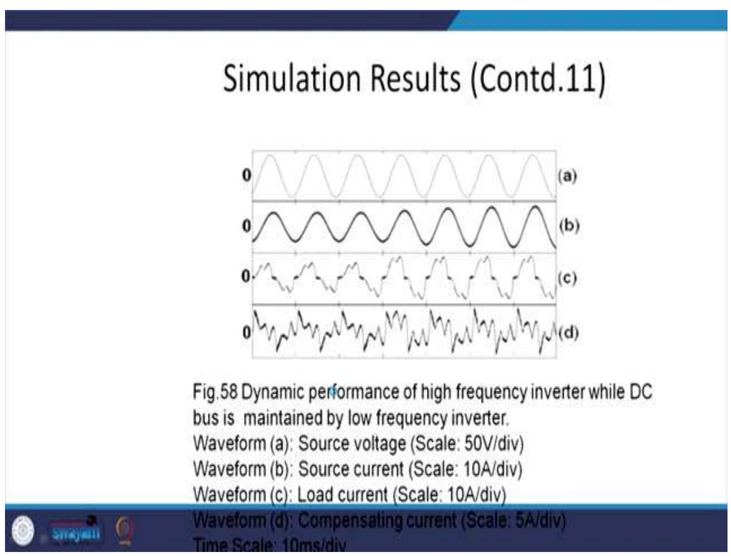

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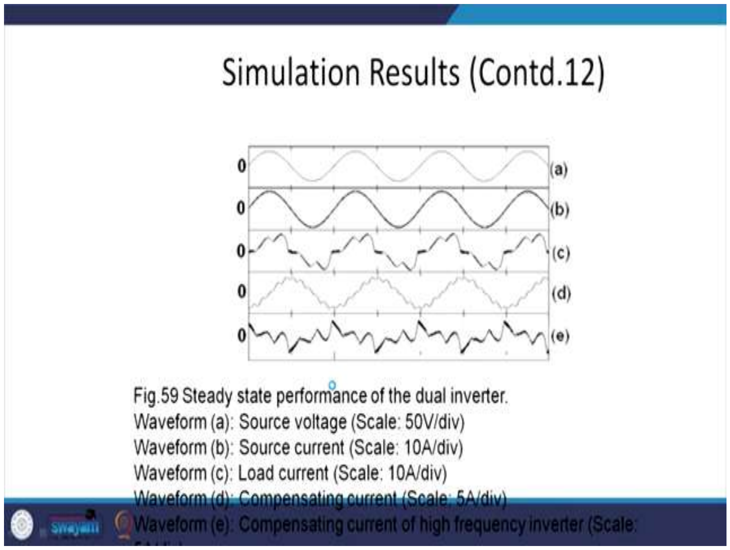

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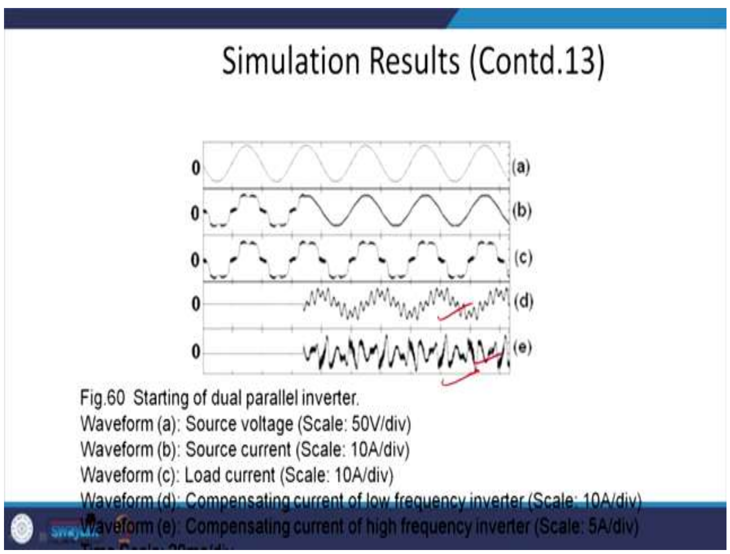

Now I just show both when high frequency and the low frequency are being operated. This is the low frequency harmonic and this is the high frequency harmonic and you can see that. This current is sinusoidal with a unity power factor. Where this injects harmonic and where this injects the reactive power and thus you have segregated the reactive power, as well as this active power.

So, thank you for your attention. I shall continue our discussion from where I left with a few portion of this shunt active power filter's results. So, I will show you some interesting results and analysis of the shunt active power filter in our next class. Then, we shall talk about the different aspect and integration of the shunt active power filter with the renewable energy application. That is also a new feature that has been incorporated.

Thank you.