Flexible AC Transmission Systems (FACTS) Devices
Dr. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture – 13
Static Var Compensator

Welcome to our courses on Flexible AC Transmission System, we shall continue with our discussions with Static Var Compensator in this class. So, we shall see that actually three type of static var compensator here.

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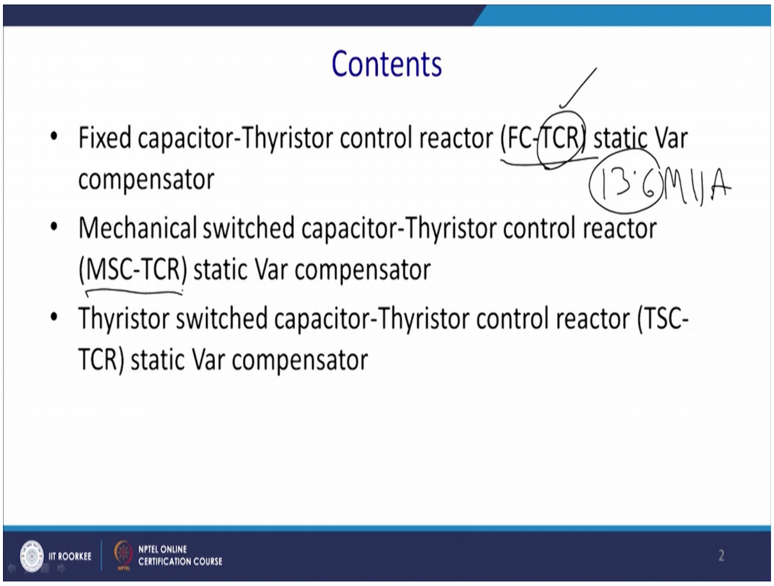

That is fixed capacitor thyristor control reactor. So, where actually the capacitor is fixed with it and thus it gives a kind of compensations and with there actually you got a TCR that will introduce the actually negative var, and in that actually you can have a variable compensator is something like that you require to have a 13.6 positive MVR.

So, fixed capacitor will have a capacity of the 14 MVR and minus point MVR will be actually supplied by the TCR. And next is actually same thing instead of the fixed capacitor, we can have a mechanically switch capacitor. So, you can put on and off whenever it is required, but it has a limits of how many time you can use it. So, this is called MSC-TCR and of course, you can also have a thyristor switch capacitor where you can frequently insert or take out this actually the capacitive compensations by the switching.

But their transient phenomena is actually very prevalent, we have to see the switching sequence to actually operate it properly. So, these are the own advantage and disadvantage and we are actually showing this actually this in a something like chronological order and also with a level of sophistication. So, level of sophistication is very less in fixed capacitor, thereafter next is a mechanically switched then definitely the sophistication is more in case of the TCSC TCR.

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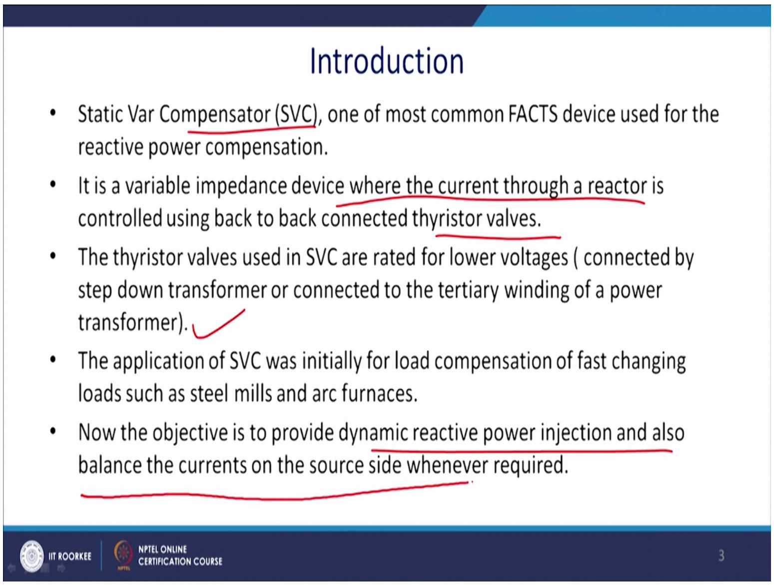

So, we have seen you know static var compensator SVC is one of the most common facts devices used for the reactive power compensation, that we have discussed in the previous section. And is available for impedance device where current through the reactor is controlled by using a back to back connected thyristor valve. Thyristor valve uses SVC's are rated for the lower voltage connected by mostly via step down transformer or tertiary winding of the power transformer. So, that it does not see the total rating this is one of the advantage of the shunt devices. The application of the SVC was mainly to load compensation for first changing loads such as steel mill, arc furnace and any at adjustable speed drive and all those issues.

Now, object is to provide dynamic reactive power injection and also balance the current on the source size whenever required.

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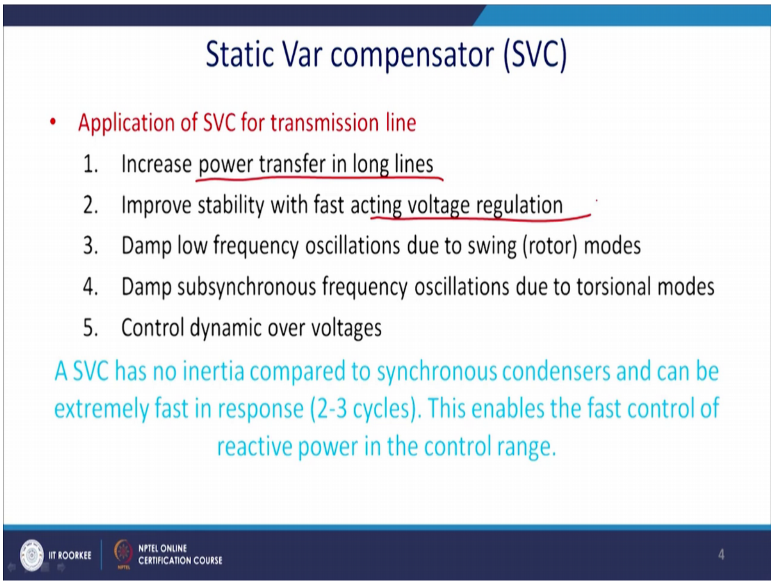

Application of SVC of transmission line, increase power transfer in long lines; so, this is one of the applications of the SVC. So, where power factor delayed by feed because for the length of the delta, because delta changes with the length and we will have a sending end and receiving end will have a huge phase difference. Import stability that we will see with the first acting power regulations, damp out the low frequency oscillations this is definitely a challenge in a power system because power system is essentially a low pass filter; if there is a under frequency oscillation it will actually enhanced, damp sub synchronous frequency oscillation due to the torsional mode and control dynamic voltages. These are the actually application where actually SVC can find its requirement to be fulfilled.

SVC has one of the most advantages that, it does not have any rotatary part it is generating that reactive power by switching by actually manipulating the angle between voltage and current. And so, no inertia compared to the synchronous condenser and can be extremely fast in response and require just 2 to 3 cycles to compensate and this enables fast control of the reactive power in whole control range.

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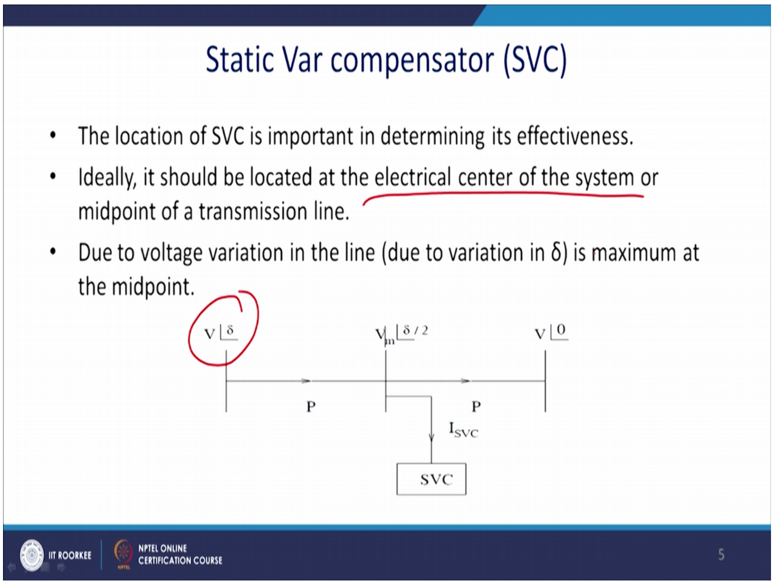

So, this is our convention one line diagram, where actually the sending end voltage is V delta and these are midpoint shunt compensation is put it here.

And here the receiving end voltage. The location of this SVC is important in determining the effectiveness, because it has to be put where actually voltage sack is maximum. So, for this is and we have seen the enhance power handling capability midpoint shunt compensation increases the power handling capability by two very simple way. Ideally it should be located at the electric system, for the or the midpoint of the transmission line for this two model system this is a two model two machine model. Due to voltage variation in the line and due to variation of the delta and it should be actually put into the midpoint.

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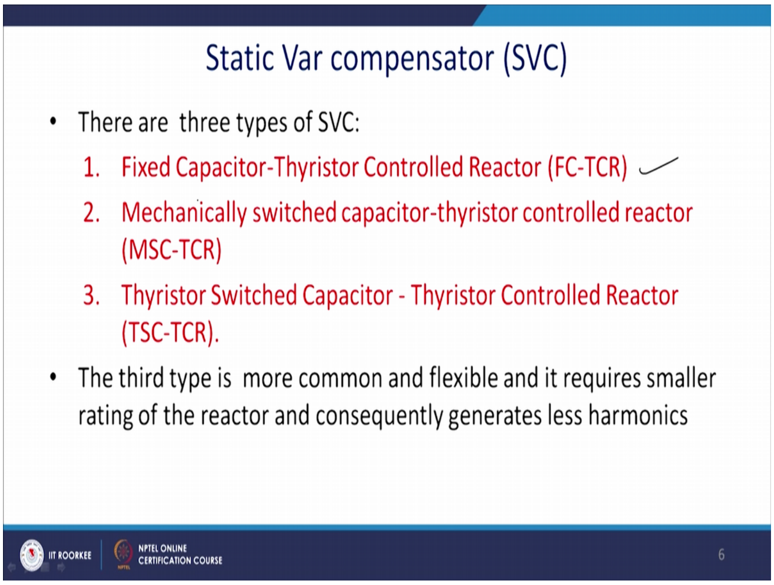

There are three types of SVC that we have also already discussed in our introductory slides, that is fixed capacitor thyristor control reactor.

Thereafter mechanically switched capacitor thyristor controlled reactor, that is called MSC TCR and this a and this is actually most modern thyristor switched capacitor with thyristor controlled reactor. The third type is more common and flexible and here it requires smaller rating reactor than the fixed capacitor and the mechanically switched capacitor.

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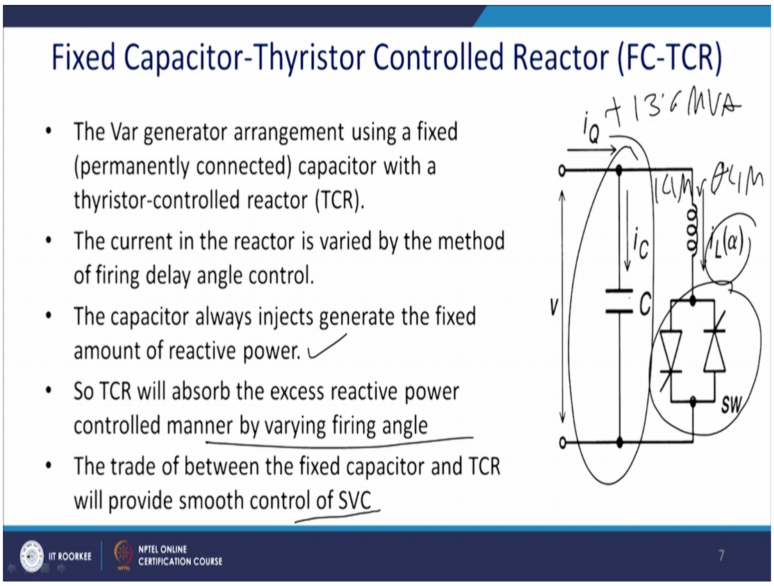

This is basically a fixed capacitor configuration, you have a capacitor that is fixed to the line and ultimately whatever the value of the inductor is required you get it here.

So, let us say we require 13.6 into that MVR to be injected plus and its capacitive. So, this should have a rating is around let us say 14 MVR and the it will be switching in a such a way and so, it will generate basically minus 4 MVR 0.04 MVR and thus you get the effective compensation. So, what is advantage of it? Simplicity so, let us see that what happens, the var generator arrangement using a fixed or permanently connected capacitor with a thyristor controlled TCR has been shown. The current in the reactor is varied by the method of firing delay angle of this thyristor. So, you have a TCR angle to be valid for this is an i L is function of alpha. The capacitor always inject generate the fixed amount of the reactive power.

So, TCR will absorb the excess reactive power control manner by varying firing angle. The trade-off between the fixed capacitor and TCR will provide the smooth control of the SVC. So, we will have a bulk compensations by this actually fixed capacitor and whatever the actually the requirement small amount of requirement, we have to compensate more and remaining will be actually compensating and thus you get the actual rating.

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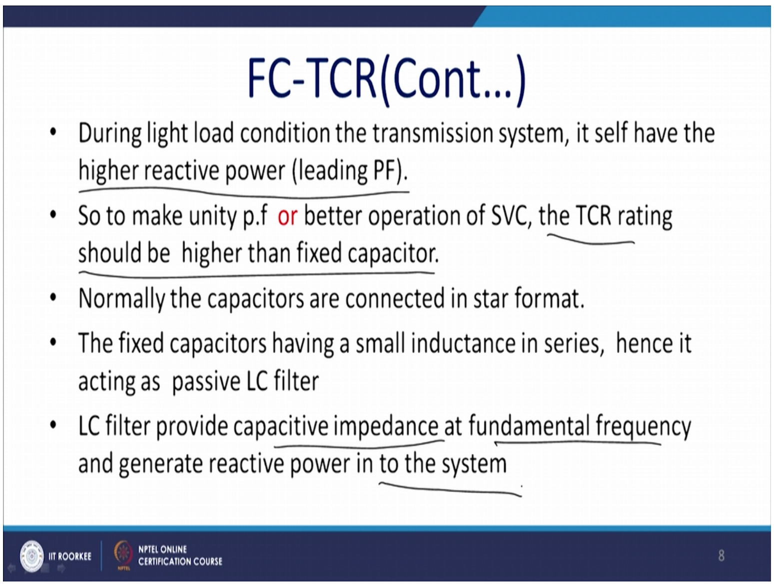

So, there is a problem, you know during the light load condition of the transmission system itself has a higher reactive power or the leading power factor.

So, to make the unity power factor of the operation of SVC, the TCR rating should be higher than the capacitor because what I was saying that you know 0.4 required to be compensate, sometime you know by since this capacitor is placed and power factor is really to the unity. So, it will be again leading. So, you know power rating of this TCR has to be very high. This is one of the major disadvantage of this fixed capacitor TCR normally this capacitor are connected in star format.

The fixed capacitor having a small inductor in series and hence it also excess a passive filter to actually wipe out a particular dominate harmonic let say fifth or seventh or something like that when the three phase three wire system. The LC filter also provide capacitive impedance at fundamental frequency and reactive power into the system. LC filter provide lower impedance to the selected harmonic as I am told you because since, it is a 3 vars c phase 3 vars system most of the cases 6 n plus minus 1 is the harmonic content. So, it is 5th 7th 11 13 and so on.

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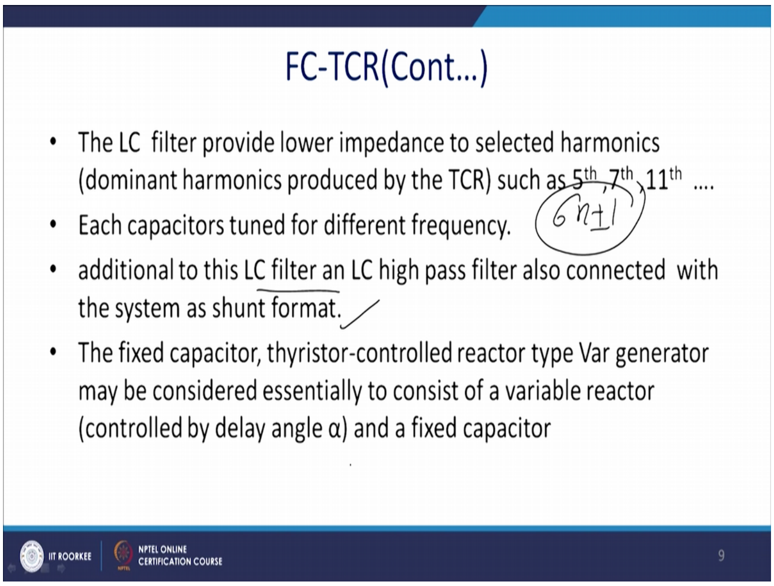

Each capacitor is tuned for the different frequency. Additional to the LC filter an LC high pass filter is also connected with the system as shunt format. The fixed capacitor thyristor controlled reactive reactor type power compensator may be considered essentially to consist of a variable reactor controlled by a delay angle and the fixed capacitor.

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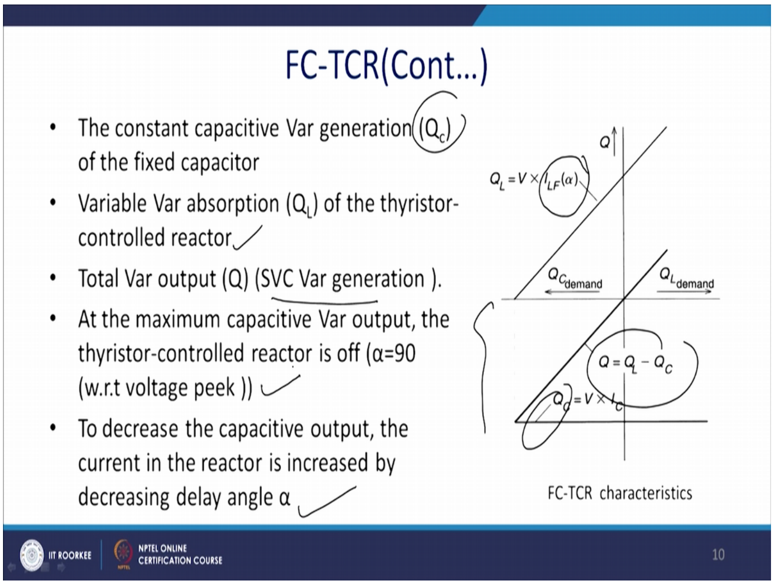

The constant capacitor var generated Q c of the fixed capacitor the variable absorption Q L of the thyristor controlled reactor.

So, you have the Q L that V into I FL and ultimately according to this the current, the rating of this reactive power compensation will change and so, it will have a variable absorption. So, variable absorption of Q L of the thyristor control reactor. Total var output that is Q of the generation has been shown here is Q equal to Q L minus Q c where this is one basically the Q c.

So, it will be shifted; to decrease the capacitor output, the current of the reactor is increased by decreasing the delay angle alpha. So, accordingly this value of the Q L will change, the maximum capacity var the is actually occurring when alpha equal to 90 degree. So, that will be at the peak voltage, this is one of the actually instant to be triggered of the TCR.

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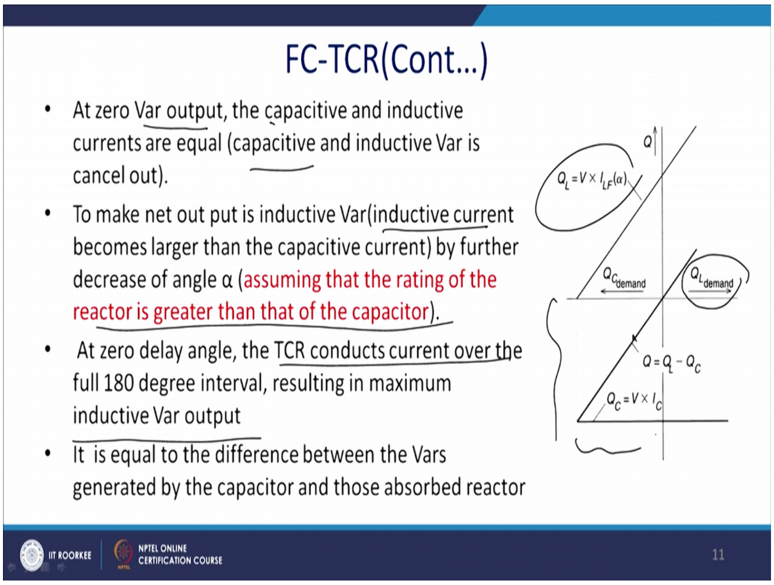

At zero var output voltage the capacitor this is a one of the challenge you know, the capacity when the inductive current are equal and they are high also. So, capacity var and the inductive var will cancel out, but they will consume current. To make the net output inductive var, the inductive current becomes larger than the capacitive current by further decreasing the delay angle assuming that the rating of this reactor is greater than the capacitor, that is one of the one of the constraint you have to put it for the fixed capacitor.

The capacitor rating should be capacitor compensation will be less and the this reactor inductive compensation will be more. At zero delay angle TCR conducts the current over the full 180 degree and resulting maximum inductive for the inductive var it is equal to the difference between the var generated by the capacitor and those who absorb.

So, this is the figure; this is the figure by changing alpha and ultimately this is actually the Q L demand actually. So, effectively you get this one that is nothing, but a Q L minus Q c the shift is basically the Q c.

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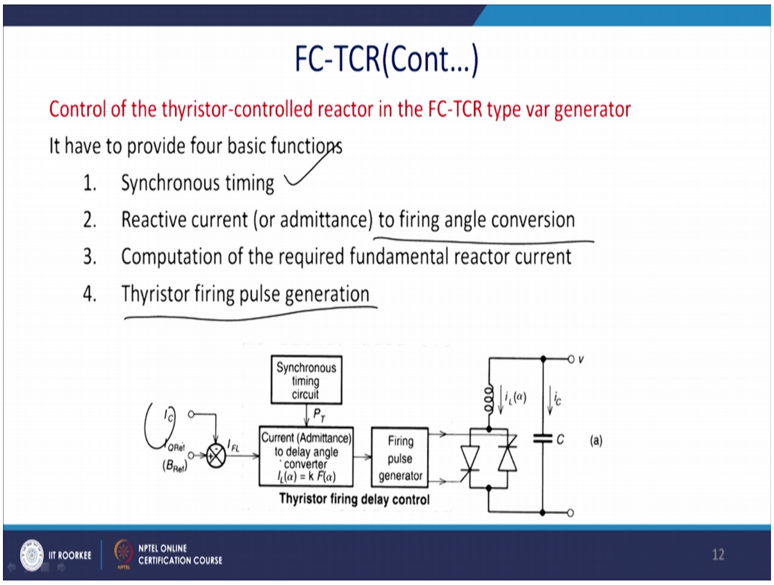

So, how you will generate the control circuit so, first of all we have a four blocks one is synchronous timing. So, that will get from the PLL thereafter reactive current and the current or the admittance for the firing angle conversion, computations of the required fundamental reactor current, thyristor firing generation.

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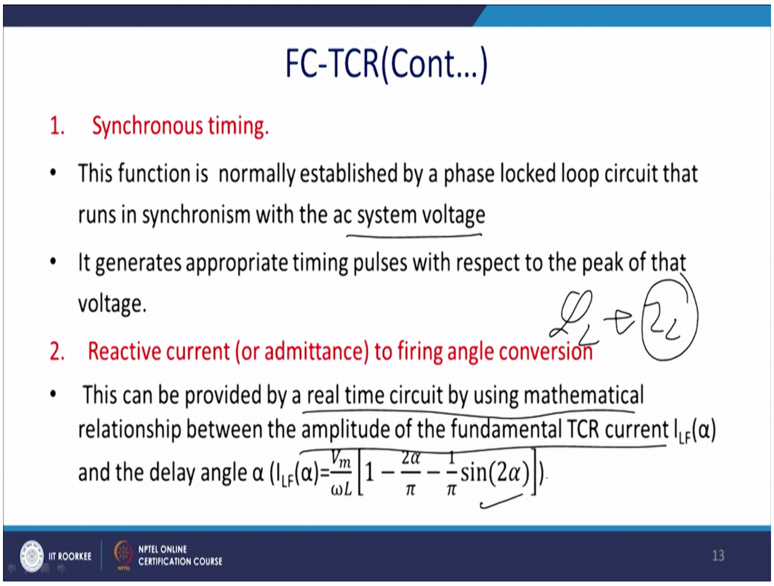

The function is normally is to establish by a phase locked loop circuit, that runs in a synchronism with the ac system, ultimately this is a PLL. It generates the appropriate timing pulses with respect to the peak of that voltage. So, it will start from actually 90 degree.

So, reactive current admittance angle firing angle conversion. So, there will be a actually we required to we first of all we require to calculate, what should be the value of Q L from there we will calculate the value of i L that is the current flow through the TCR and from there we require to compute what will be the firing angle alpha. Thus this can be provided by a real time circuit by using a mathematical relationship, mind it you have to compute online or you may have a data stored in a e promp for the all the values in the memories, the amplitude of the fundamental TCR current i FL alpha and the delay angle alpha is given by 1 minus 2 alpha by pi minus 1 by pi sin 2 alpha.

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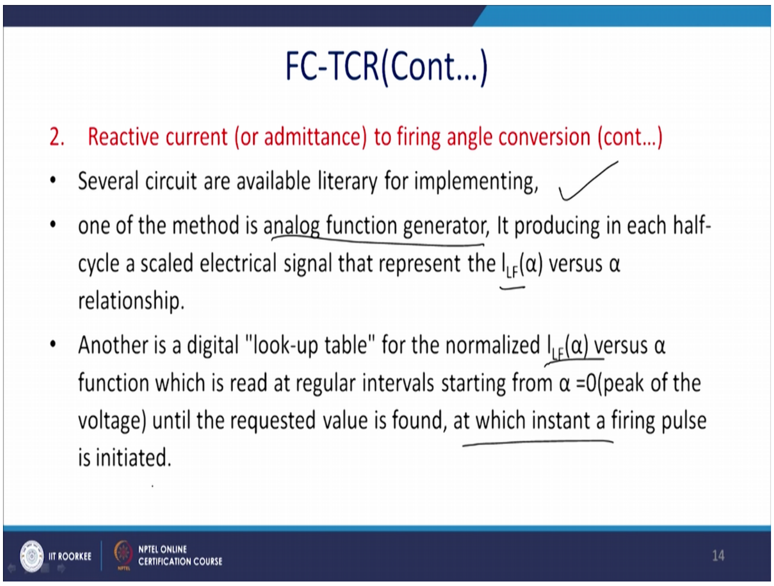

Now, reactive current to the firing angle conversion. Now this is actually we have if you refer to the book you know actually the several circuits. Several circuits are available for the implementation one of the method is for is basically the analog function generator, it will be producing the half cycle scaled electrical signal represent set by the IF alpha and ultimately you can calculate the alpha.

Others you have a digital look up table that is what it for the normalized value of the IFL versus alpha as a function, a regular interval starting from alpha equal to 0 to the alpha equal to 180 degree. Until the request value found actually it will be searching and at which the instant the first pulse is initiated.

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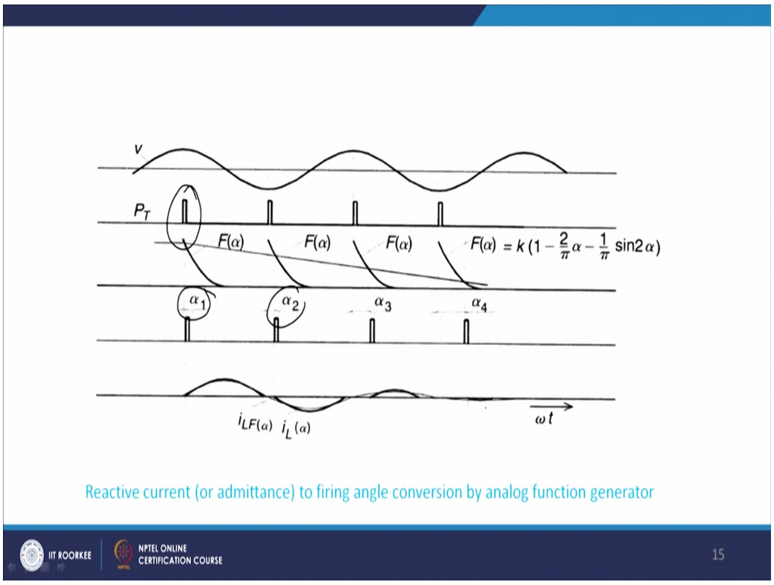

So, this is the voltage and this is the pulse synchronizer, that will come from the PLL and thus this is the amount of the reactive power compensation you require. So, what happen thus you have to change the value of the alpha 1, alpha 2 and so on in some cycles. So, gradually alpha 1 and alpha 2 will change and gradually the current through this inductor will change like this. So, this is the way of implementing this fixed capacitor TCR.

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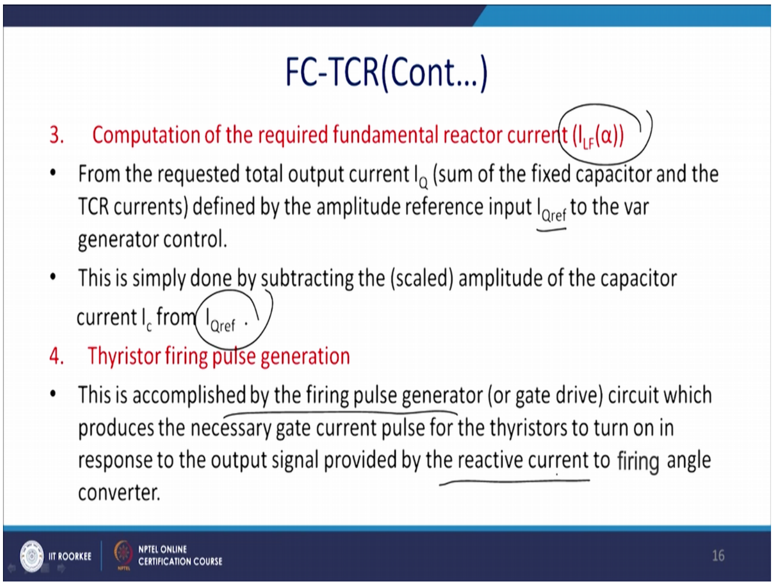

Computations of the required fundamental reactor of IFL alpha; From the requests the total output current Q the sum of the capacitor and the TCR current defined by the amplitude of the difference IQ ref to the var generator. This is simply done by subtracting the scaled amplitude of the capacitor current I C from IQ ref. Please refer to our this slide. So, I C and IQ ref from there you can compute this value.

Now, thyristor pulse generation as I have told you so, you generate alpha from there you will have a pulse generating circuit, this accomplished by the thyristor pulse generator circuit or the gate driver. Circuit which will produce the necessary gate pulses for the thyristor to turn on in response to the output signal provided by the reactive current for the firing angle converter.

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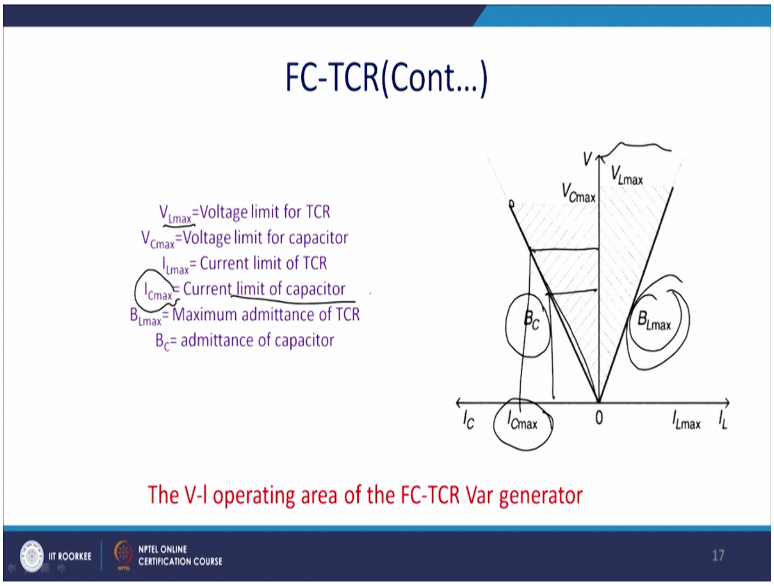

Now, this is the graph this is the fixed graph for this admittance since it is a shunt compensation. So, ultimately this is the I max and this is the BL max, please note that actually voltage (Refer Time: 17:40) of for the capacity compensation. So, for this is you cannot use actually the total rating, but generally voltage sacks for inductive compensation.

So, there actually terminal voltage can be higher that the rating voltage. So, for this is V L max will be higher and the V C max will be lower for the capacitor limit where IL max is the current limit for the TCR and I C max is a current limit for the fixed capacitor and BL max is a maxima admittance that is allowed for this inductive compensation and similarly, you say max is a maximum compensation is allowed for the capacity compensation.

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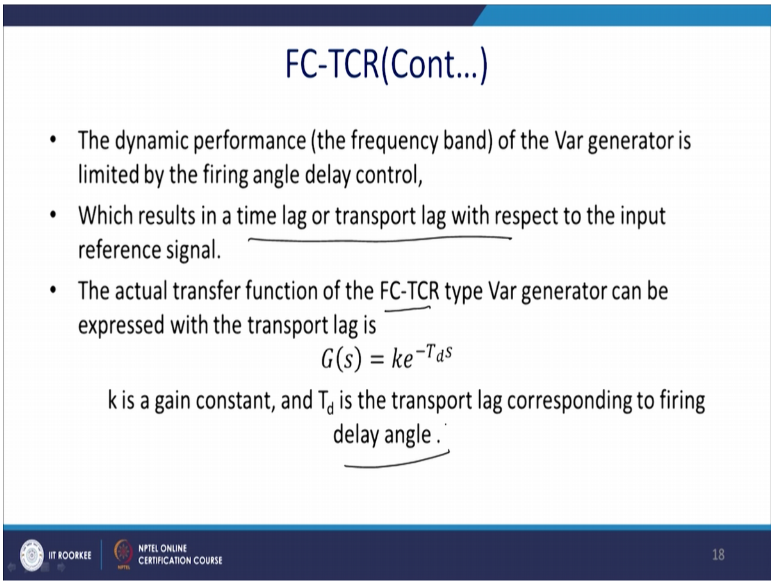

So, what happen here the dynamic performance of the a performance, the frequency band of the var generation is limited by the firing angle delay control. So, it will take a delay because once you have calculated because you are allowed to trigger thyristors after certain interval of time. So, what is in thus there will be a delay in compensation. So, it is a time delay system, which results a time lag or the transportation lag with respect to the input signal reference.

Because you cannot change like sin triangle p w m, the reference generation within a 1 second; The actual transfer functions of the FC TCR type var generations can be expressed that k e to the power minus T d s s; where k is a gain constant and t d is the transportation lag correspond to the firing angle delay.

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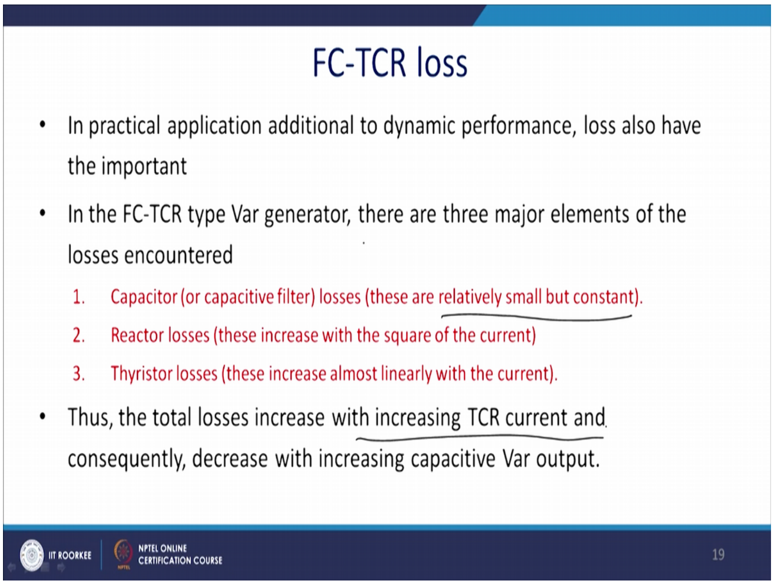

Now, FC TCR losses so, since capacitor is connected fixed. So, losses quite will be low. The practical application additional to the dynamic performance losses is also very important. The FC TCR type var generation there are three major type of losses, the three major elements for the loss are encountered. The capacitive filter losses it is more or less constant because it has a e c s, thereafter reactor losses increases with the square root of current square of the current and the thyristor losses that is actually the conduction losses mainly and that will be actually increasing because you know with statistic is on that also actually they will be a top of around one volt. So, multiply with a thousand amperes.

So, this amount thousand watt will be the drop across each of the thyristors may be. So, and this is a linear with the current flowing through the thyristor. Thus a total losses increases increasing the TCR and consequently decreases with a decreasing the capacity var output.

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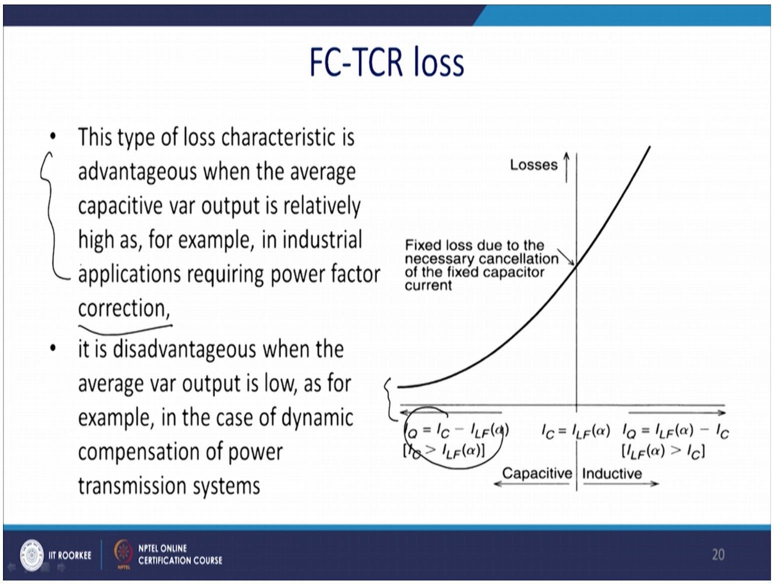

So, ultimately this is the case. So, here actually the effective Q this is the fixed losses where it is not compensating almost any inductive current flows as inductive current fixed. So, this will be the losses because value of the IFL will increase. This type of loss characteristic advantageous, when average capacity output voltage is relatively high as example in the industrial applications during the power factor correction and adjustable speed drive. And disadvantageous where the output when this average var is low for example, in case of the dynamic compensation of the transmission line. So, we shall find its application, where average capacity output is relatively high.

So, let us discuss a what is a left out here actually TCR this is basically the what are the takeaway, this is basically the simplest among this group and you know we will discuss that is a mechanically compensated TCR mechanically switched TCR, there actually capacitor is inserted or take out with the help of the capacitor. Here actually it is fixed add its value. So, for this reason so, what are the advantages of it? Advantages is that if the you have to compensate huge amount of the inductive power and fixed capacitor is require so, that will be find its application.

Otherwise we have a strong demerit to use it, because what happen you know, it may actually leads to the a leading power factor and thus what will happen you require to switch on TCR to make it unity power factor and unfortunately thus we will introduce the losses ok. And moreover we require to revisit actually this graph again you know this line actually this VC, it is a admittance line and it is basically a fixed because you know as long as the system if you assume that because this current whatever will flow will depend on the voltage.

If you consider that current is healthy, then the then this current flow through this actually the system will be the same. So, it will be simply depending on the amount of the voltage rating. But this value you know actually a can be limited or controlled and this is the maximum value of it. And you can actually reduce this value by changing the value of this alpha thus you know whatever is a maxim this actually what I want to say yes that.

So, you can see that it is VC. So, it is not VC max why because this actually inductive admittance is a function of the current. Whereas, the capacitive admittance is totally the function of the voltage supply voltage, as long as supply is constant it will track same amount of current. So, for this reason actually we can see that actually the this is the value of the and at the rated voltage. Whatever may be the amount of the current flowing through the capacitor that will be basically your limit of the capacitor current.

And in that way and same way there is a thyristor rating mostly, that will be actually governed the in most maximum inductive current and thus the value of the maximum admitted admititive compensation, admittance compensation inductive admittance compensation that is a BL max and this is the way it will occur. So, what we can conclude, it is basically the simplest among this group and it is put into the application where average inductive power into the power system is quite large.

Thank you. So, much for your attention we shall continue with the another type of inductive another type of actually capacitor based TCR will be discussed in the next class that is mechanically switched TCR.

Thank you so much for your attention.