Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 11
Shunt Compensator TCR and TSC

Welcome to our 11th lectures of Flexible AC Transmission Systems FACTS Devices. We have in previous lecture number 10, we have discussed actually the principle operations of the shunt compensations equal area criteria and stability issues. Now, we shall see what are the devices available to compensate the this shunt compensation or the fact devices.

Today actually we shall discuss the shunt compensator best on the thyristors. Thyristor is really well fitted into our FACTS devices because of its actually high power rating, high current rating and very simple principle of operation even though is a half control switch, it is you can turn it on you cannot turn it off, it is generally naturally commutated. So, today we shall discuss three type of shunt compensator thyristor by shunt compensator, these are namely these are namely TCR that is called thyristor control reactor.

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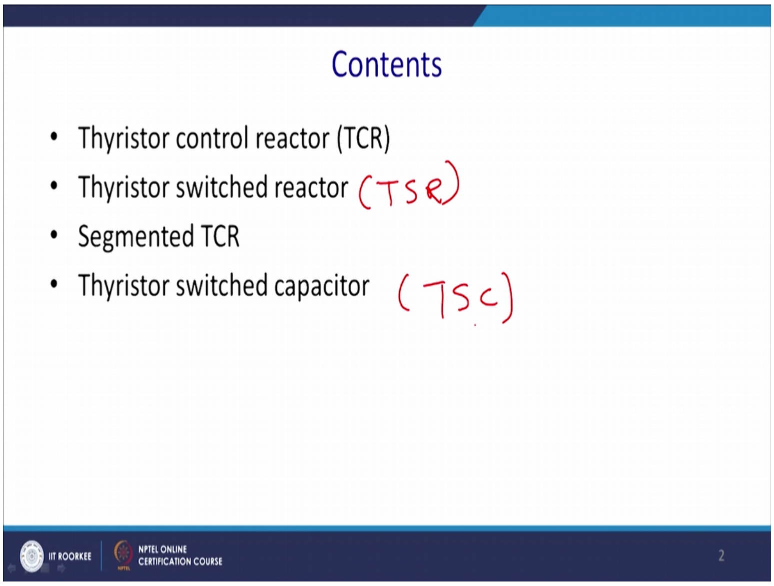

Another is actually thyristor switched reactor or we can abbreviate as TSR or there is a another version of the thyristors control reactor that is called segmented TSR and also we have thyristor switched capacitor or TSC. So, we shall see this principle of operations and its topology is in next few minutes; Now, little brief introduction of about the TCR that is Thyristor Control Reactor.

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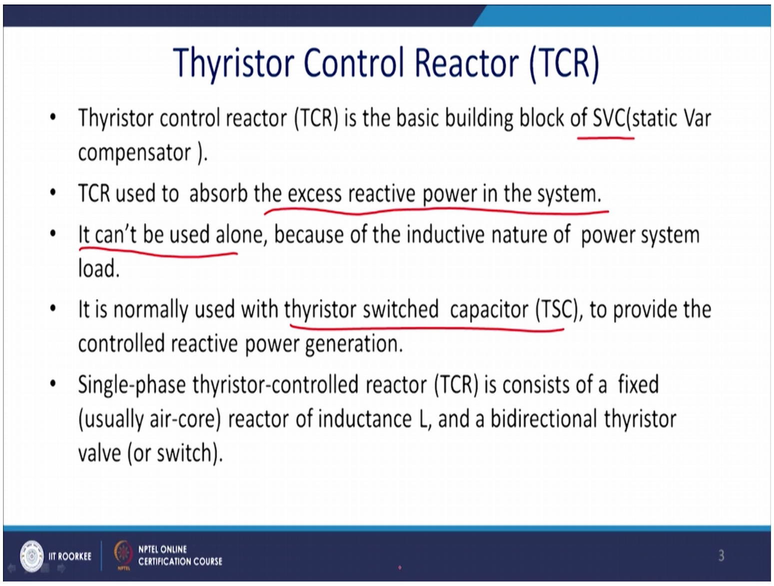

Thyristor control reactor is a basic building block of SVC that is static var compensator; we can have a STATCOM and SVC. So, we have to find it out that where it should be applied. So, for the static var compensator, you will we will find a different kind of topology and if it is SVC then actually this static var compensator finds is usefulness. TCR is used mainly to absorb excess of the reactive power into the system. Generally we will see the switching and we will see that how it will absorb the extra reactive power into the system and thus is improves this actually power factor and other related issues to the power quality.

Generally it cannot be used alone because of the inductive nature of the a power system load and most of the loads are drives based and since these are inductive in nature. It is normally used with a thyristor switch capacitor to provide the controlled reactive power generation. So, we shall see to it that why it is alone, not competent enough to actually enhance the capability of the power transmission we require a support of the TCSC with the TCR, to effect to effectively utilise the power handling capability of the line. Single phase thyristor control TSR is consisting our fixed or generally this is our lower power rating, air core reactor inductance L and with a bidirectional thyristors it is connected the anti parallel fashion let us see its topology.

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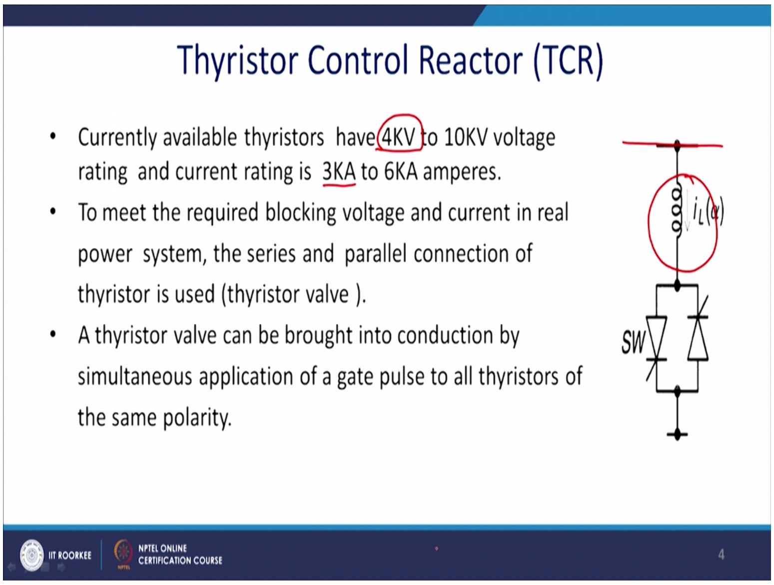

So, generally it is connected in it is a shunt device. So, ultimately you can control the current depending on the switching angle of this thyristors. And generally thyristors are available with a quite high rating and of four point of 4 KV or 10KV most of the cases you know actually there is a factor of safety, for 6.6KV 10KV voltage rating or thyristor is chosen, and of the current rating of 3 kilo ampere or 10 kilo ampere.

So, that is a standard rating available with the thyristors and we did not have to series or parallel any of the thyristor you can directly fit into this configuration. And sometime to meet the required blocking voltage and the current real posses time, why it is a it has to handle that power in the range of the thousands of the megawatts or mega var then series parallel connections of the thyristors are used, and these are called the thyristor valves. See in hingorani book you will find that few case studies were actually few mega volt of the power handling capabilities TSR has been reported.

Thyristors valve can be brought through by conduction by simultaneous application of the gate pulses are all the thyristor of the same polarity. So, we can put into the operations and with there is actually a factor of safety because if the one thyristor is on seen if it is consider the we have studied in a power electronic stat is a this a what are the problem associated with the actually series operation of the thyristor. If one thyristor is on another thyristor is not on, then voltage stage goes to the actually off thyristors and that can damage and for this is in properly voltage balancing network is required to be placed, and all those things were been put for and these had been put into the system, that is called basically the thyristor valve.

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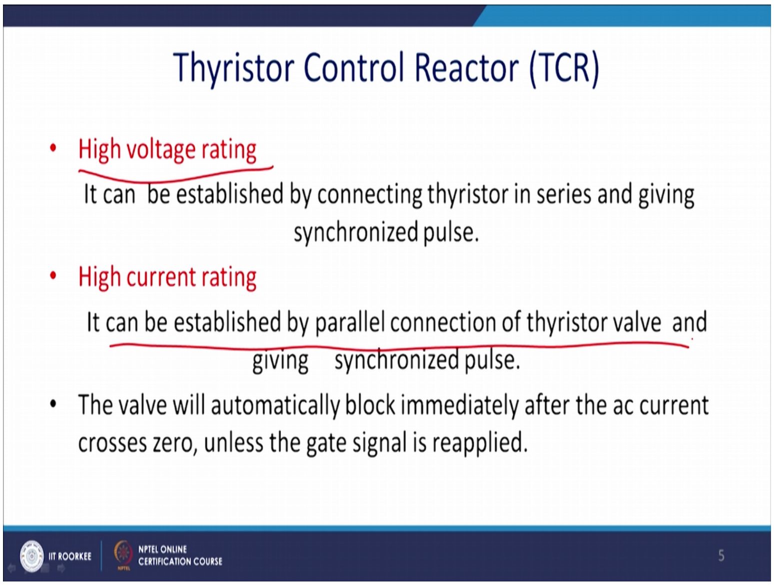

Now, let us talk about thyristor control reactor. So, it can what is a advantage of it? Advantage of it that it has very high voltage ratings since it is a made of thyristors, it can block very high voltage. So, it can be established by connecting thyristors in series and giving synchronization of the pulses. So, that it can turn off and turn on and so, this can be operated for a very high value of the voltage voltage blocking capability.

Same way thyristor can be put into the parallel and that can increase the current handling capability. It can be established by the parallel connection of the thyristor valve and with giving this synchronized pulses and it has will be simultaneously on the parallel path of the thyristors; valve will automatically block immediately after 0 crossing; so, we will have a natural computation and unless it is reapplied.

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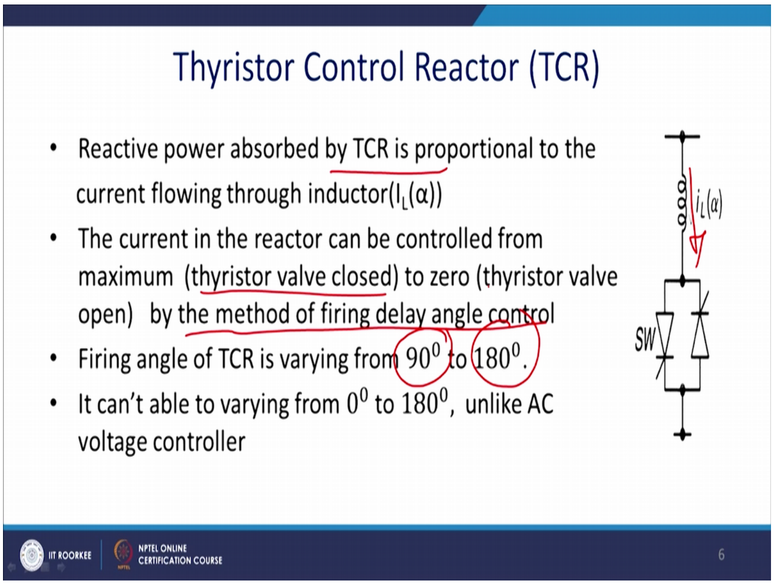

So, reactive power absorbed by TCR is proportional to the current flowing through this circuits. So, for this reason more current flow to the circuit I into omega L will be the voltage and of proportional var will be actually absorbed here. The current in the reactor can be controlled maximum thyristor close to 0 to the open that is 180 degree alpha equal to (Refer Time: 08:30) to 180 degree and by this method that by method of actually firing delay angle. Generally in this case that TCR is actually is operated in the range of 90 to 180 degree.

So, this only then only it will absorb the reactive power. And it cannot be operated 0 to 90 degrees since it is a normal actually we have studied that is that will be behaving like a basically simple converter. So, for this reason we will actually operate it 90 to 180 degree, and it cannot be varied in case of the AC regulator it is varied from 0 to 180 degree, but it will be should be varied to 90 to 180 degree. We shall see the expressions of it and from there we can actually understand why it is not possible to vary actually 0 to 90 degree at all, rather it has to be operated the second quadrant 90 to 180 degree.

Now, let us understand the wave form.

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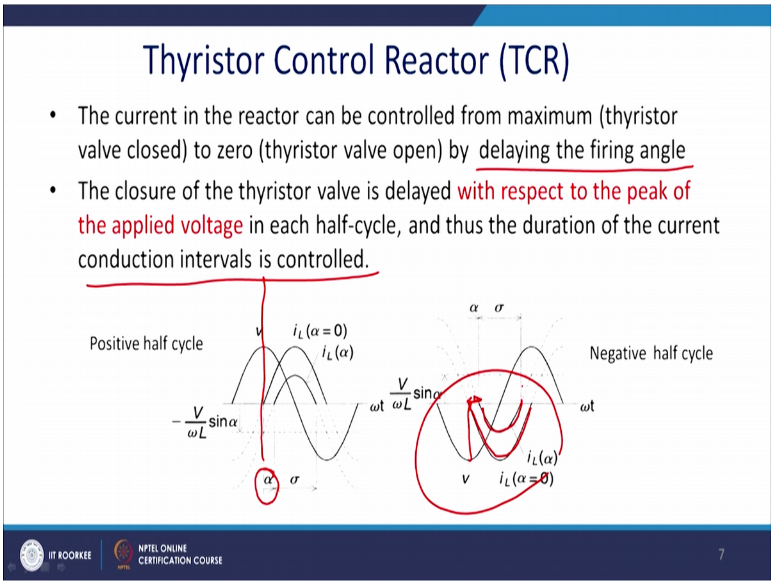

Since this current we have told you that alpha required to be 90 degree. So, and we are it is compensating the compensating the inductive current. So, definitely it will have a phase lack of 90 degree; so, of course, since there is a phase lack of the current by 90 degree. So, principle so, alpha can start after only 90 degree. So, thereafter you will give a delay this valve is alpha, their credit will starting conducting for the period of the sigma. So, from there we can calculate what should be the value of the current and how much reactive power is been absorbed or produced.

As reported earlier that current in the reactor can be controlled from the maximum to zero and by the by changing the delay angle or the firing angle. The closure of the thyristor valve is delayed with respect to the peak of the applied voltage; please understand that it has to give a 90 degree phase shift and since in inductor current actually lacks by 90 degree. So, it should be 90 degree lagging.

And thus the duration of the current is in a conduction mode can be controlled. So, this is the wave form for the positive cycle and this is the wave form for the negative cycle. So, this is the positive negative peak. So, here the current will start current will actually the wave form, but you give a delay angle alpha. So, ultimately this will be the amount of the conduction.

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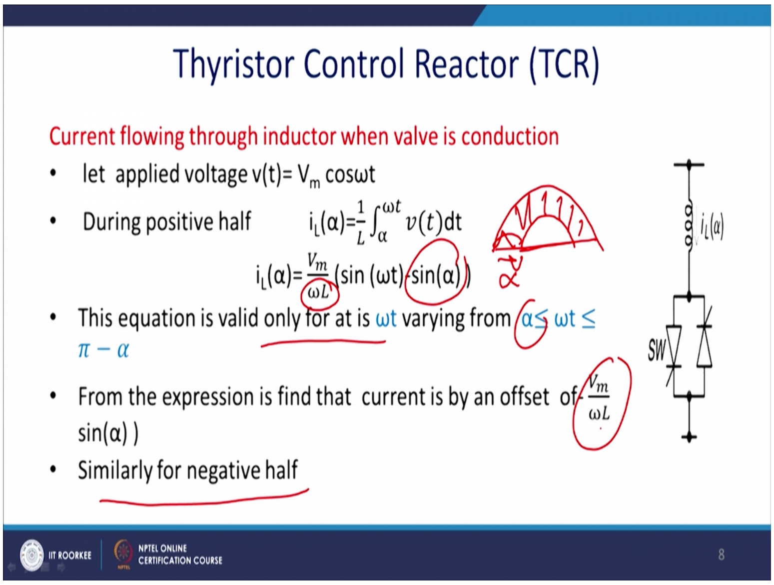

So, we can calculate that what is a value of L here. Since v t is equal to V m cos omega t and during positive wave cycle. So, you are varying i L which is a function of the delay angle will be 1 by L alpha to omega t ultimately this become V m by omega L that is nothing, but x l that is a impedance of this line into sin omega t minus sin alpha.

So, this equation is valid for omega t varied from alpha to alpha to pi minus alpha and so, we can find out that from this expression, there is an offset current that value is minus V m sin alpha because there will be a term associate with it. And of course, if this value will be the same if alpha equal to 90 degree, the you basically this will be 0.

So, similarly it is followed for the negative half thus this value basically will give a shift across the x axis. So, this is the actual current. So, if you change the angle alpha, this is the alpha. So, it will start like this. So, this will be this is the this area is the offset, that is given by you know wave by omega L into sin alpha and similar equation is followed into the negative half cycle.

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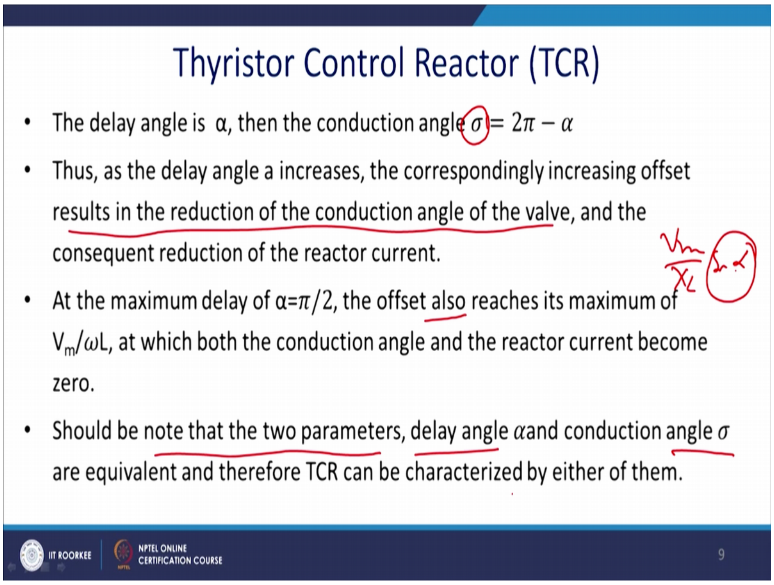

So, what is a takeaway from here? That delay angle is definitely here alpha and that conduction is actually the angle sigma, sigma is actually 2 pi minus alpha, thus as the delay angle increases corresponding the increasing the effect of the result in the reduction, in the conduction angle of the thyristors or valve and the as a consequent the reduction of the reactor current through this devices. At maximum delay that when alpha equal to pi by 2 offset reaches the maximum value that is what I was saying that value actually V m by XL sin alpha if sin alpha is 90, then that value is maximum.

That value is V m by omega L at which both the conduction angle and the reactor angle become 0. So, it does not absorb any power. It should be noted that these two parameter that delay angle alpha and the conduction angle sigma are equivalent therefore, TCR can be characterized either of them because there is a relation between alpha and sigma. So, you can write it in terms of alpha or you can write it in terms of the sigma.

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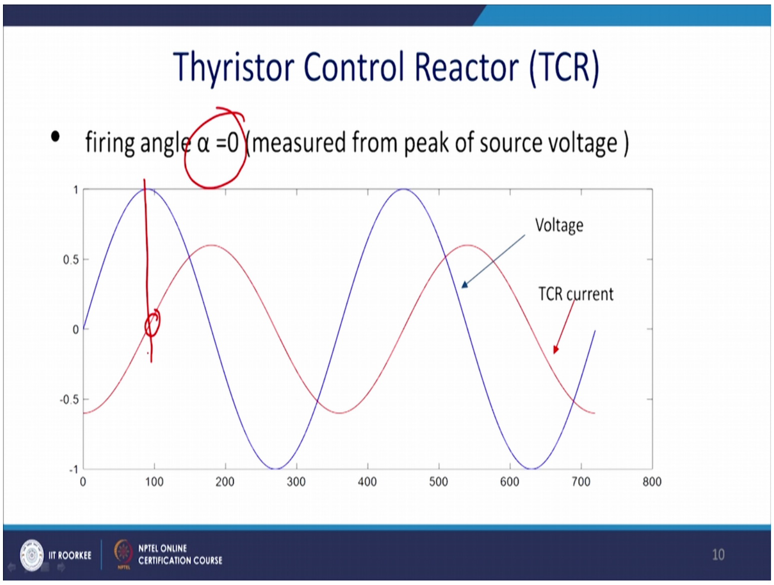

So, what happen here this is the voltage curve for firing angle equal to alpha equal to 0 degree, and this will be the current it will be almost touching the 0 because, but since there is a no pure inductance. So, it will be actually [FL] it is almost yes it is that 90 degree. So, this will be the current so, the TSR TCR at 90 at alpha equal to 0. So, how it will change for different values of alpha?

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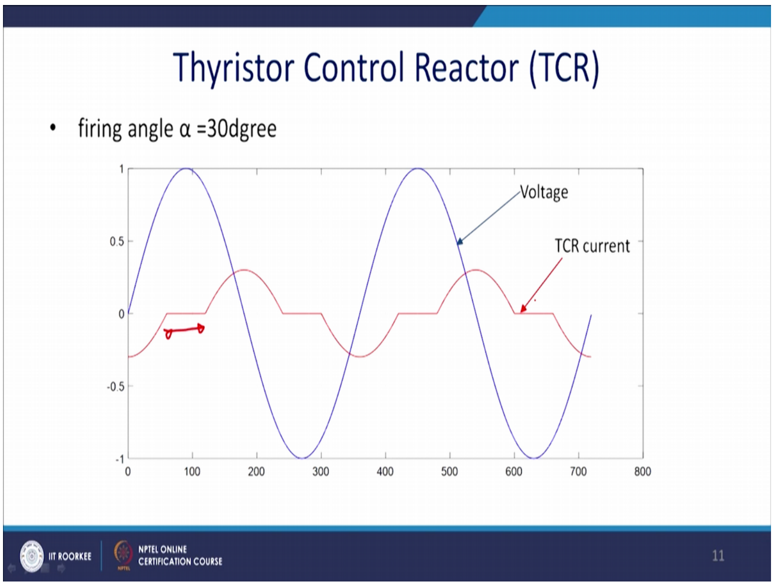

So, you will have that actually for that there will be a delay of 30 degree either side. So, it will be chopped in either of the sin of. So, you will get this kind of wave form. So, thus the you can calculate its analysis value and that is power reactive power whatever that calculations you will find that it is changing according to the conduction angle or the firing angle. So, same way this is for the 45 degree.

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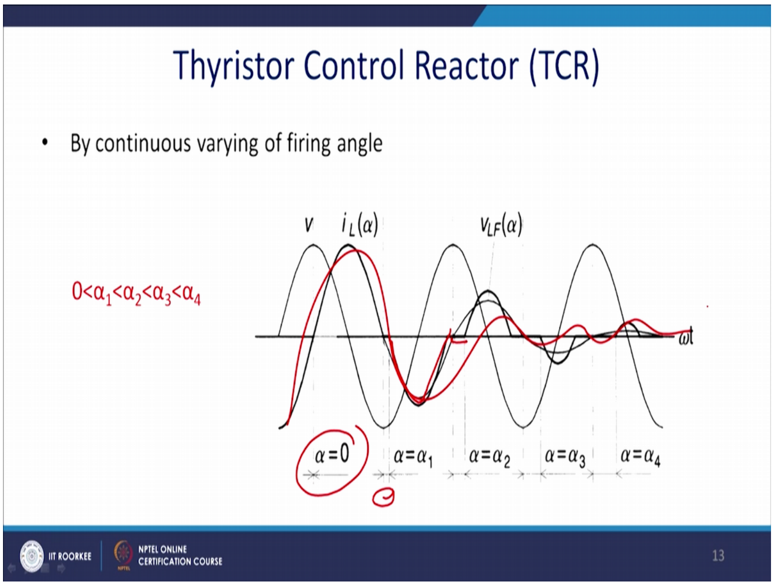

Now, let us see by continuous firing angle, if you gradually change the firing angle sometime it is required to damping purpose mostly. So, what happen we have start with alpha equal to 0. So, in first half cycle you get, it here there you have to introduce a small delay that is alpha equal to alpha 1 and thus you get this current similarly you change to alpha 2 little more.

So, you get this current. So, what happen you know you can dynamically control the power required by the reactive power in every cycle by changing the alpha. So, accordingly you can actually see that, this is the current and ultimately what basically this current comes out to be? This current comes out to be this, this, this, this, this. So, gradually it is damping it can acts as a damper.

So, let us do the mathematical analysis of this current profile.

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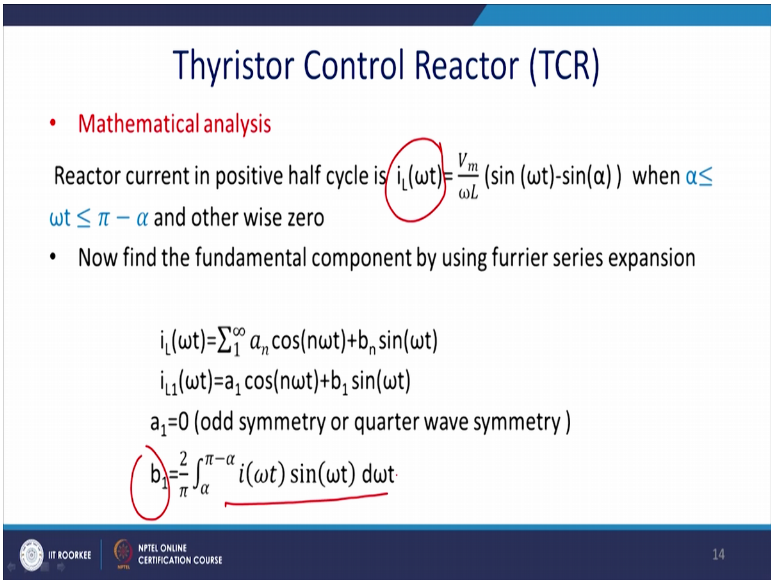

The reactive current let us consider the positive half cycle, that is given by i L omega t is V m by omega L sin omega t minus sin alpha, where alpha is alpha is less than omega t and greater than omega omega t and less than actually pi minus alpha otherwise omega t's value will be equal to 0.

So, let us do the furrier series analysis. So, we can write the furrier series and which assume that there is a symmetry, thus all the actually value of a 1 to a n will be 0 and which do not assume any d c component and thus b n can be all the b 1 will be given by the fundamental of it will be given by this.

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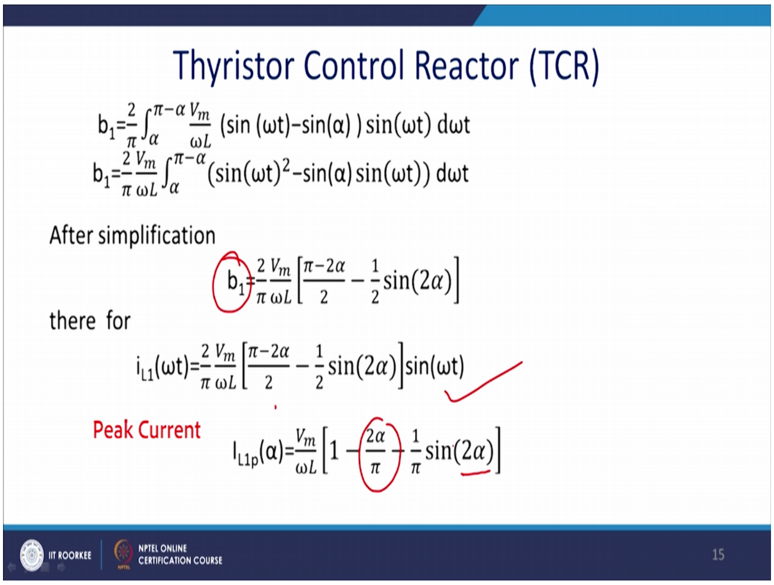

So, from there we can find that b 1 we can do this calculations and will be 2 by pi V m by omega L that is by x l that is pi minus 2 alpha by 2 minus half sin alpha. So, let us substitute it in b 1 that is a fundamental of i L 1. So, essentially what we will get it is 2 by pi V m by omega L, 2 pi minus 2 alpha by 2 minus half sin alpha into sin omega t. So, thus fundamental current of TCR is given by V m by omega L 1 minus 2 alpha by pi 1 by pi sin 2 alpha. So, you can find that how it is changing.

So, ultimately what you can see here you know what you can see here this value at 90 what will be value at 90? Let us substitute here 90. So, it is 180 degree. So, this value is essentially is 1. So, it is 1 by pi and here you will find you know and there will be a minus sin that will make it plus and ultimately here it will be again, it is actually pi and pi will cancel out ultimately essentially you will get the value to be 0. So, this is the value of the peak current and accordingly this is this value will change for different values of alpha, this is expressions of the peak current in case of the thyristor control reactor.

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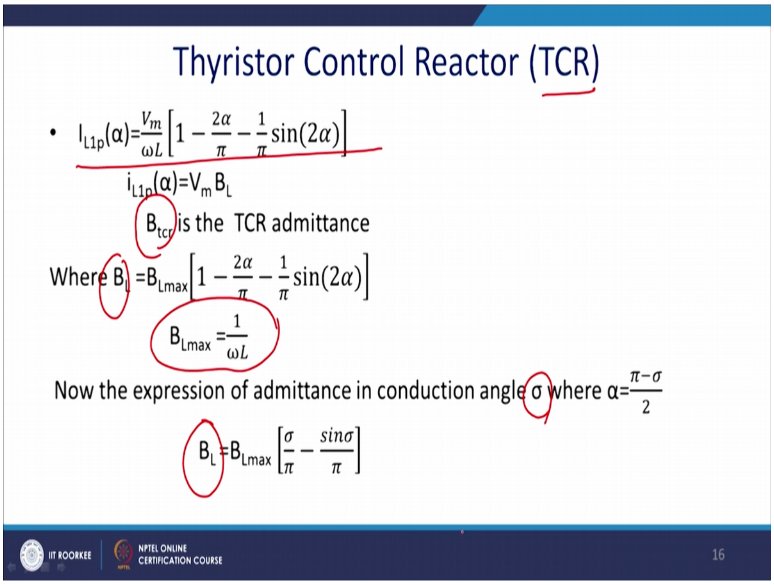

So, what should be the admittance of it? So, this is the expressions of the current and so, i LP 1 is the function of alpha is V m into B L where actually B tcr B suffix tcr that is basically the abbreviation of TCR is the admittance of the TCR. So, we can see that that can be also implemented in terms of the in terms of the firing angle alpha. So, where B L will be given by B L max 1 minus 2 alpha by pi same way, where the maximum value is definitely will be given by omega into x l and otherwise this value will change.

Now we can now the expression of the admittance in conductance angle you can change it. So, sigma equal to you know that actually where alpha equal to pi minus sigma by 2. So, from there if you can substitute so, B L will be B L max sigma by pi minus sin sigma by pi, this will be the expressions for the instantaneous value of the B L for a angle for the firing angle alpha or conductance angle sigma. So, you may require to calculate. So, what should be the amount of the impedance will be injecting to the system or admittance injecting to the system whatever may be. So, from there we can calculate that it should be the value of the admittance.

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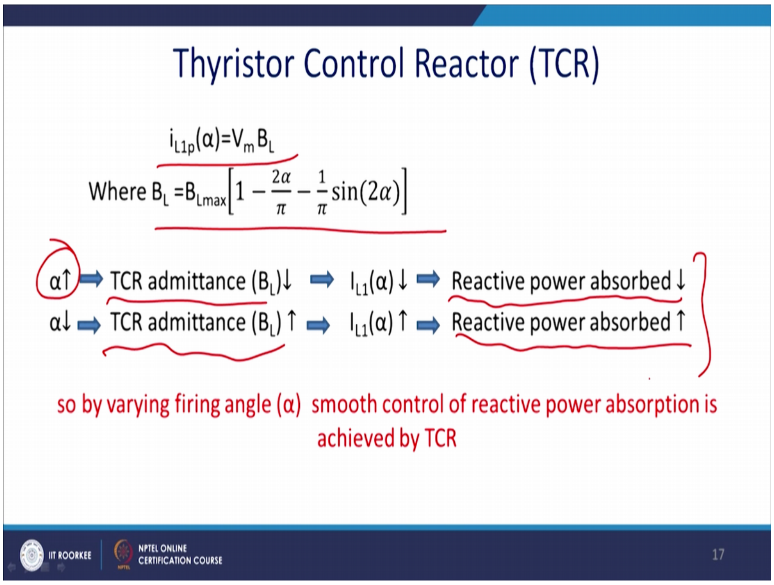

So, what happen we can rewrite this equation, the fundamental current of this TCR equal to V m into B L, where B L will have this kind of relations B L equal to B L max, 1 minus 2 pi 2 alpha by pi 1 by pi sin alpha. So, what happen if we increase the alpha? Effect of increasing alpha will be TCR admittance will be reduced and thus what happen? I 1 alpha1 will be reduced and reactive power absorbing capability will be reduced. If we increase the if we decrease the alpha, then what will happen? Then this admittance will be increasing and value of I L 1 will increase thus reactive power absorbing capability of the TCR will be increased.

So, we can see that what are the advantage and disadvantage of it. If you increase alpha then as current decreases power handling capability decreases. So, it is actually inversely proportional with the alpha and if alpha is increases, reactive power is absorbed more reactive power is absorbed. So, by varying alpha smooth control of the reactive power absorptions is achieved with the help of the TCSCR.

So, this is the one of the advantage of TCSCR, what are that actually advantage? It is a very simple circuit and paralleling of thyristor is quite proven technology for past for t s and it is thyristor based and since it is naturally commutated you did not have to do much, and it has a huge power handling capability and it is very simple operation, you change the alpha and you get a direct reaction to it increase the alpha you get actual reduce reactive power, you actually decrease the alpha you get enhance power hand enhance absorption of the reactive power. So, this are the main take away from this TCR.

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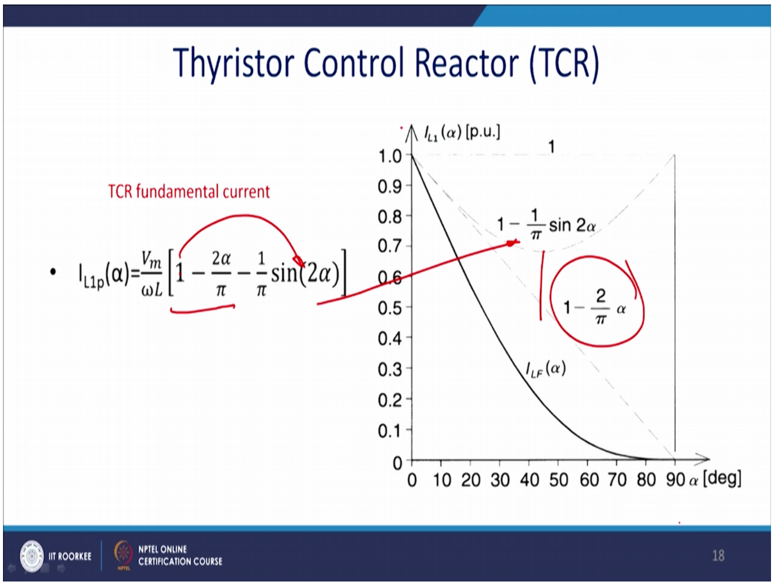

Now, let us see that actually the graph files, how it will work. So, this is the current value plotted in x axis plotted in y axis in terms of the alpha and this is the degree. So, alpha equal to 0 you get 1 and ultimately you will have what happen? This is the value of this part and this part corresponds to this.

So, you will have a actually 1 minus 1 by pi sin 2 alpha will have this contribution and this will have a linear contribution with alpha if you change alpha this part will have a linear contribution. So, here what happen? This will actually contribute less and this will be contributing more. So, at 45 degree and gradually what happen at 90 degree, this value reduces to 0; So, in that way actually the by changing the value of the alpha this value of the inducted current changes in this way.

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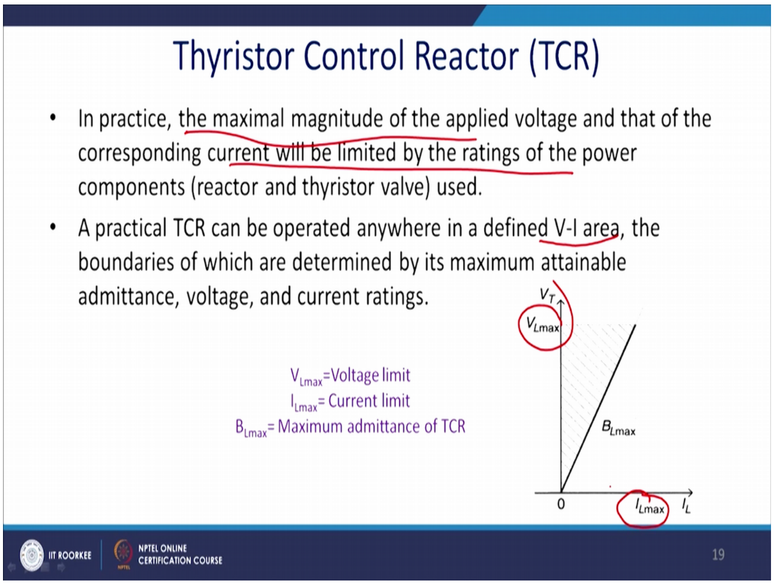

So, what is a thyristor control react? So, in practice what happen? The maximum maximal magnitude of the applied voltage and this corresponding current is limited by the power handling capability of the devices, that is what it is written current will be limited by the rating of the components, that is a thyristor valve in practical TCR can be operated anywhere in defined v a line.

So, this is actually the maximum value of the voltage blocking capability of the device and this is the maximum current can flow into the device and same the note line consent what we have used, in case of the transistors same thing can be done, but here plotted plot is actually is opposite here we have taken I in x axis. So, what happen? Here the practically TCR can be operated anywhere in the graph, and the boundaries which is retirement the maximum attainable admittance is basically this line. So, this value is basically the B L max.

So, we have to choose the operating point anywhere in between, we can choose the operating point basically it is nothing, but a tan theta. So, tan theta this theta should be less than this value and we can safely operate the TCR. This is the actually this is all about our TCR, we continue to our next lecture with different type of shunt compensated thyristor topologies.

Thank you for your attention, we shall coming out on the lecture number 12 soon.

Thank you.