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

Lecture - 12
Shunt Compensator TCR and TSC - II

Welcome to our 12th lectures on FACTS devices. Today we will continue with our TCR and TCSC thereafter. So we were continuing in 11th lectures on TCR. So, let us continue with the same point where we have left. So, let us do the little bit of analysis of the harmonics, that will be present an ultimately this is also the issue of the power quality, because even though actually when you are changing alpha, essentially you will have a displacement power factor.

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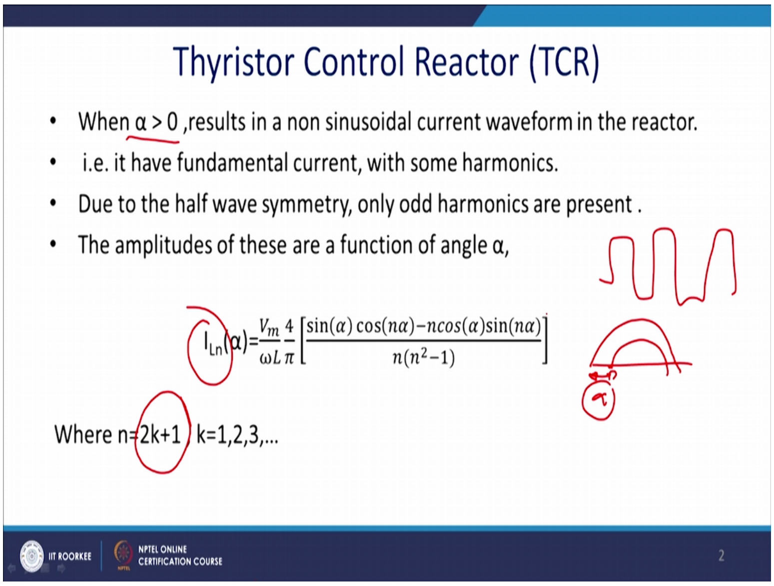

So, this is alpha, so you will have a displacement power factor when alpha that is what it is. So, when alpha is more than 0, so it is a non sinusoidal. And we can do the furrier series analysis current wave form in the reactor the fundamental current will be contaminated with the presence of the harmonics.

And we know that due to the half wave symmetry only the hot harmonic are presents and we require to consider the lower order higher stunt harmonic because you know pauses them itself is a low pass filter we do not bother about higher order harmonic, but lower order harmonic may cause pause a thread into the power quality. So, for this reason you know so for L n, so nth harmonic will be given by v m by v m by omega L n by 4 by pi sin cos alpha into cos n alpha minus n cos alpha into n sin alpha by n into n square minus 1, where this value will be given by you know 2 k plus 1. So, where k can be any harmonics that is k can be any integer 1 2 3 4 5 6 something like that.

So, we can also actually eliminate selective harmonics which pause a threat on it, so that is also the we can play around we can choose the alpha in a such a way that particular harmonic may be removed. So, only 1 harmonic can be removed by it so as we have studied in case of the selective harmonic elimination when you have actually only 1 triggering ones. Once you got this kind of on and off in half cycle, then we can L t eliminate multiple of the multiple of this kind of harmonics, but we can eliminate only one harmonic here.

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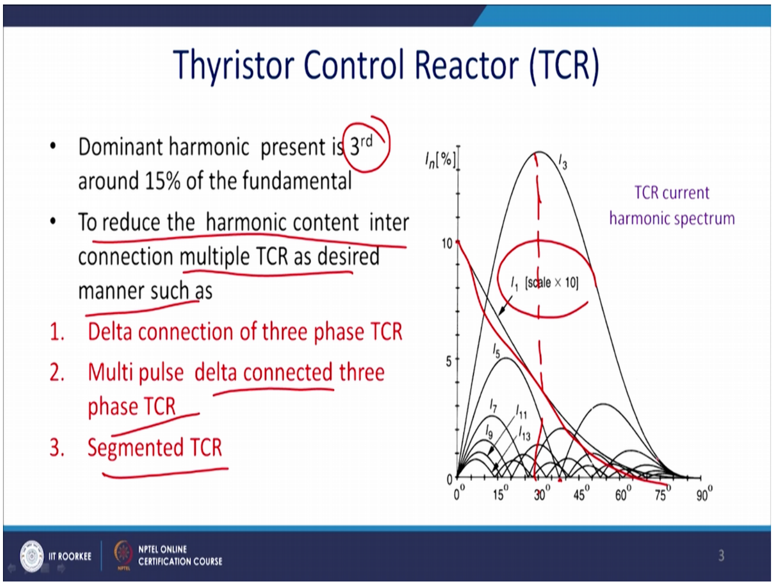

So, let us see what happened we shall see the actually demerits of using this TCR and how it will increase the contamination due to the harmonics. The dominate harmonic is definitely k equal to 1. Thus it will be the third harmonic and that strength will be around actually 13 15 percent of the fundamental and thereafter to reduce this harmonic content. The connections multiple TCR are is used that we will see in a next slide. So, one way essentially can be delta connections, so that is does not go to the line it will be restricted and circulating current inside the delta. And these are there can be another solution that is called multi pulse delta connected 3 phase TCR and segmented TCR all is 2 basically to suppress the third harmonics, which will have a huge strength on it.

So, see that this is the essentially this is the alpha in y x x axis is clotted with the delay angle alpha and this is a strength of a different kind of harmonics here. So, this is basically scale of I 1, strength of I 1 multiplied by 10. So, we can see that this is the I 1, it will be gradually going down please recall our expressions in case of the fundamental. So, that will be the same and third harmonic strength you will see that you will have a optimality just below 30 degree or around 30 degree and it will be actually the most dominating harmonic, we require to suppress it and unfortunately you can see within the any angle between 0 to 90 degree, it cannot be suppressed.

So, thereafter fifth harmonic you can see that fifth harmonic will have a 0 here. So, we can choose to eliminate fifth harmonic you can choose the angle of alpha in between 30 to 45 degree if require. So, this is a fifth harmonic fifth harmonic will have this kind of pattern, there are to seventh harmonic, they are to ninth harmonic, they are to 11 and 13 harmonic this will be the harmonic spectrum of the TCSRC.

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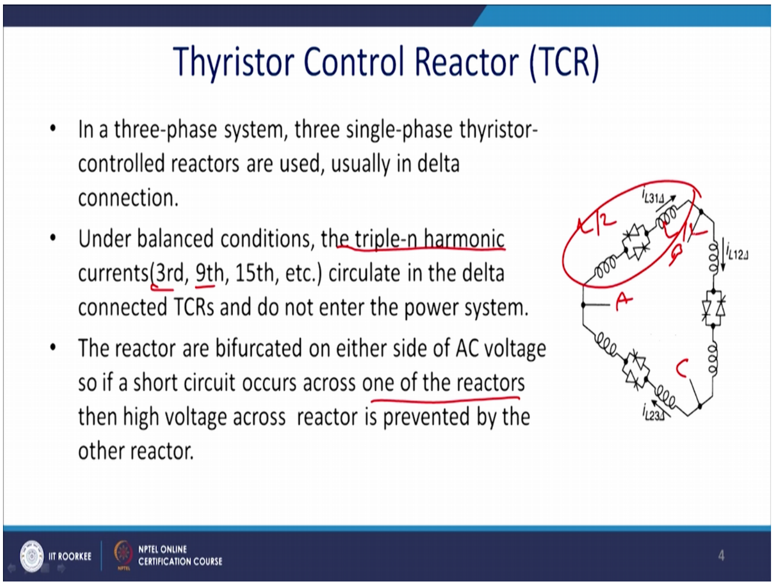

So, we require suppress the third harmonic that is our main concerned in case of the TCR. So, 3 phase system we can put it into the delta, so this is the delta configuration A B and C and this is a delta configuration, if the 3 phase system 3 single phase Thyristor control reactor are used and the inner delta connection so that third harmonic will be restricted and is circulating within this line.

Under balanced condition, the triplet harmonic that is third fifth third ninth fifteenth and so on circulating in the delta connection and TCR does not have into the line and the reactor are bifurcated in either side of the AC source and so that actually if the short circuit occurs in one of the Thyristors or one of the reactor, then the voltage across the reactor is prevented by this actually the inducted present it to the system for this is an L by 2 and L by 2 will be splitted in every connection. This is the overall architectures of this delta connected TCR where the third harmonic has been eliminated in from the line. So, thus what happen? So we will have a harmonics, so it will be shifted.

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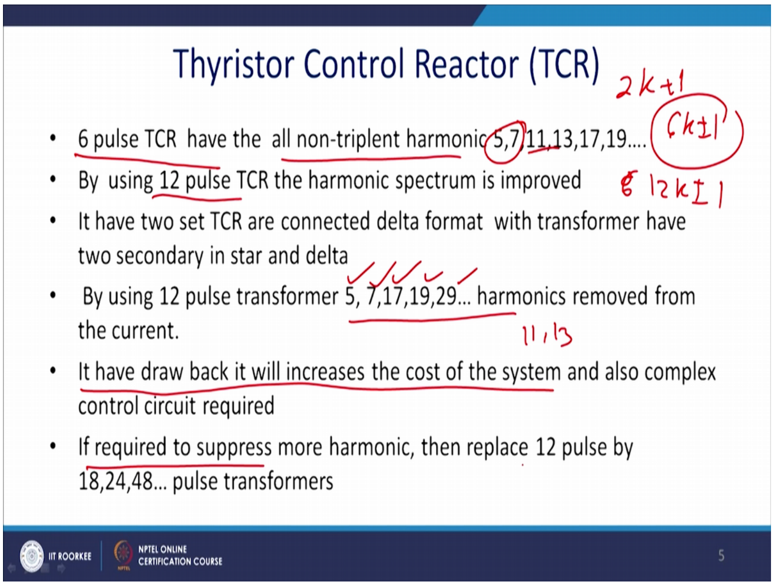

Previously harmonic content was 2 k plus minus 2 k plus 1 and now we will have a 6 k plus minus 1 this will be the shift and for this is it is called the 6 pulse TCR and we will have harmonic content 6 k plus minus 1 that is 5 7 11 13 17 19 and so on and non triplent harmonic. Similarly if you using a 12 pulse TCR we will see the structure in next slide that harmonic spectrum will be improved to 12 k plus minus 1, so instead of having 5 7 we will have a actually 11 13 thereafter 23 25 and so on. So, there is a huge shift of the spectrum and ultimately we know that the low pass filter pauses the essentially low pass filter it will eliminate the higher order harmonics very simply.

So, by using this harmonics so these are the harmonics will be removed, so 5 7 17 19 29, so what will be left with? It is 11 13 thereafter so on and we have a drawbacks of the increasing, so what happen you know if you make it a pulse better we can make it also 24 pulse. So, what happen the number of switches will be drastically increase and the complexity will be increasing and so you require to have a optimal solution depending on the power quality requirement of the power quality issues. So, for this reason, it will have a drawback and it will increase the cost of the system because, you have to put the lot of Thyristors and we require a very complex circuitry to control those Thyristors and though we can find out that actually required to suppress harmonic, then we sometime replace this 12 pulse by 18 pulse 24 pulse 48 pulse transformer and so on.

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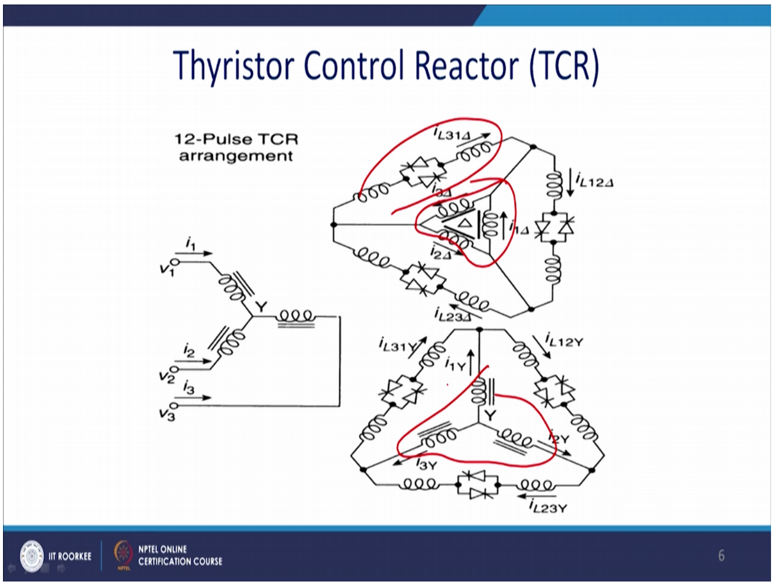

So, this is the example of the 12 pulse TCR and it will be assignment for the actual online student to draw the circuits for that 24 pulse TCR. So, essentially upper part is same and you will have a internal delta and you will have a internal star, so this the you will have a you have studied the effected group and they will have a d y 11 or d y 1 some kind of effected group will be operating and accordingly this. And these will cancel out the third harmonic and multiple of the third harmonics and essentially you are left with the other harmonics. So, this is the configuration of the 12 pulse TCR.

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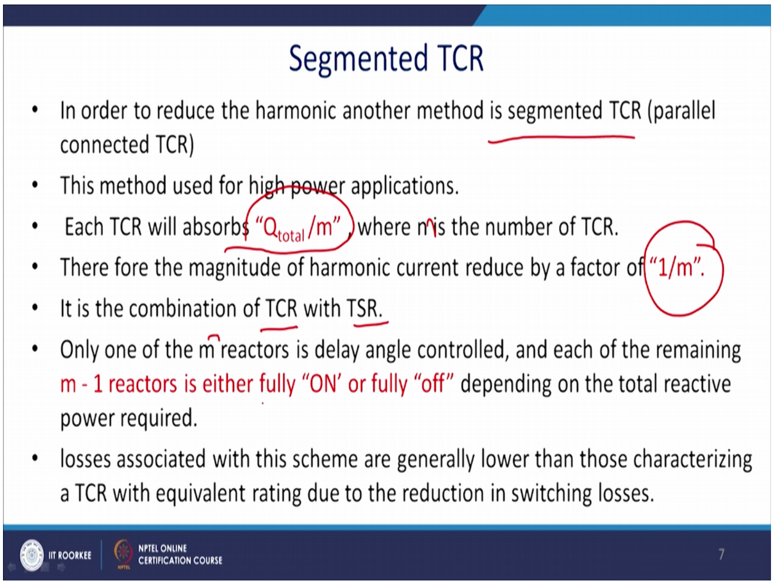

Now, what is segmented TCR? So in order to reduce the harmonic another method is to segment the TCR that mean you put a parallel path of the TCR, this method is used for the high power application because you may once you have a very high power rating then we required to put the Thyristors into the parallel combination, thus definitely it makes sense to use this actually the segmented TCR and each will absorb some amount of reactive power. So, TCR will be absorb the reactive power equal to the total power by m, so total power will be Q total and one component will be have a m. So, what does it gives? It gives a redundancy in one of the blocking does it working. So, it will be m minus 1 ultimately the whole system will work, where m is the number of TCR sorry it will be m not n.

So, therefore the magnitude of the harmonics will be reduced to the factor of 1 by m for non functional 1 and it is combination of the both that is TCR and TSR. Only one of the TCR only one of the m reactor is having a delay angle controlled and each other remaining m minus reactor only will have a off and on control. So, this control is very easy, one will have a masters where you can change it and other will have just on off control depending on the total reactive power require. The losses associated with the schemes are generally lower than those are characterised by the TCR because, they all there will be only on and off of other module except one will have basically a delay angle control and thus switching losses are reduced here in this configuration.

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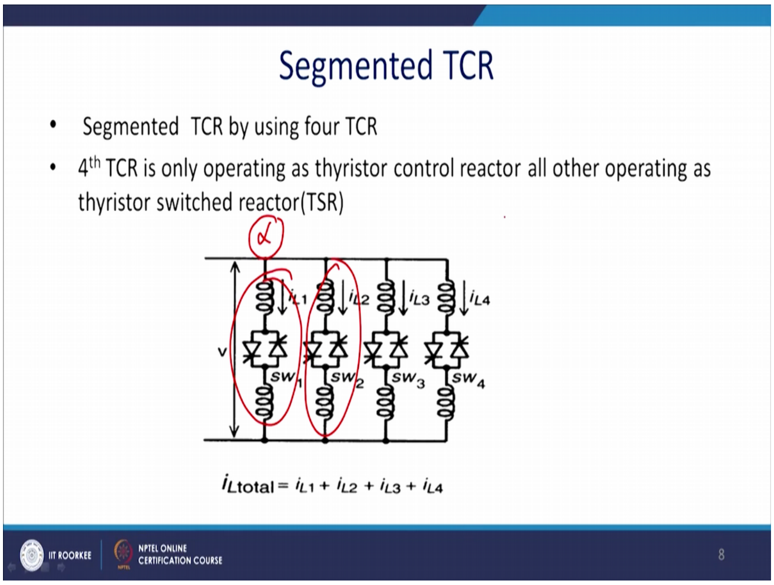

So, this is the case of the segmented TCR, so one will have the alpha other just on and off most of the cases. So, it other will have a delay angle only alpha equal to 0, so this is called a segmented TCR. So, what happen you know see these will gives raise to all if it is on, then no third harmonic will be there third harmonic will be arising only from this component others, because this have a alpha control let us say other will have on off control.

So, harmonic source of the harmonic will be generated by this element only of the TCR, other will be actually handling the power of (Refer Time: 14:51) So, fourth TCR is operating Thyristor control all other operating as TCR, so this is the principle operation and total current will be basically I 1, I 2, I 3, I 4 and accordingly it will change. So, this is the very simple and effective solution for high power and high current application.

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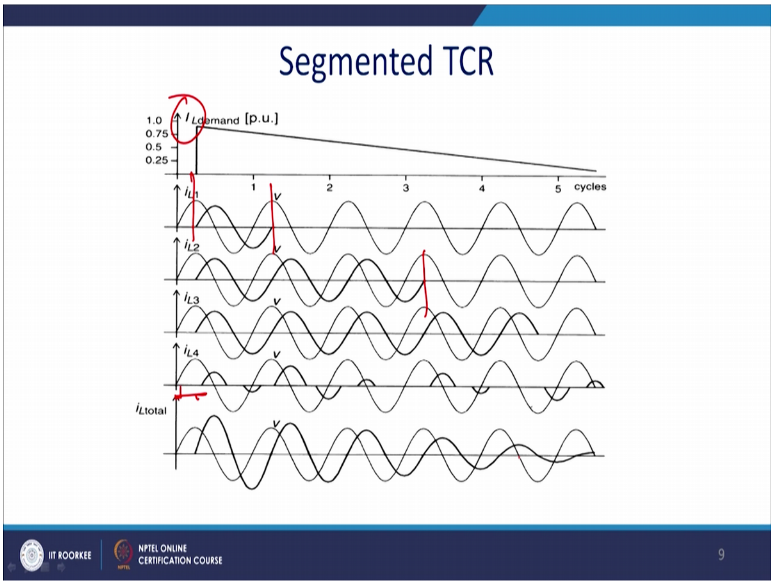

So, what happen here let us see how TCR works? So, this is the value of L and you have a delay of 90 degree, so this is L 1, thereafter this is L 2, thereafter L 3, thereafter L 4 and L 4 will have a alpha control you can change the alpha. So, what happen here you had you have operated L 1 till this point there thread it is off and you have operated L 2 till this point there, thread is off similarly L 3 and so on.

So thus, gradually you can find that your current flying through devices get ready used and it is almost sinusoidal because, you know only this fourth element will have alpha control other will not have alpha control. So, for this is in gradually current got damping, so it can be effectively damped in this way. And thus, you can handle the power quality as well as the reactive power demand as required by the devices.

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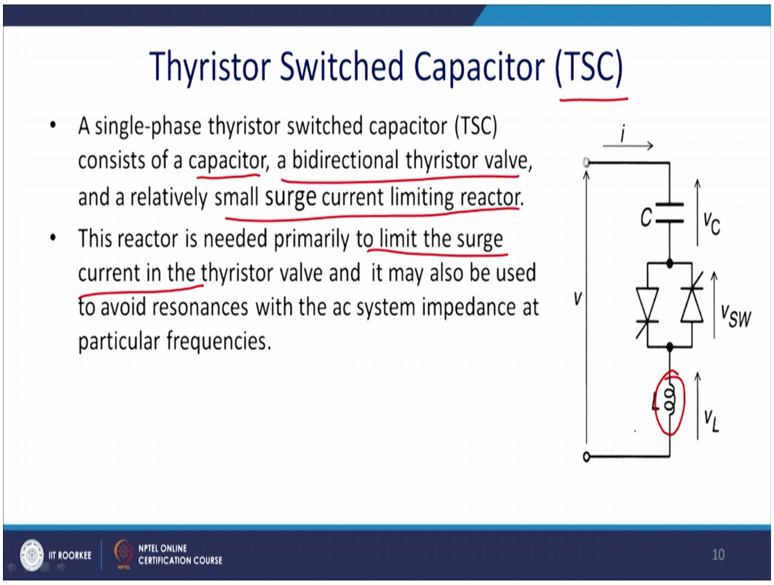

So, now let us see another shunt compensator that is TSC Thyristors switch capacitor. So, single phase Thyristor switch capacitor consist of the capacitor a bidirectional Thyristor valve and a relatively small surge current of the reactor. So, what happen generally inductor required to be placed to block the high in rush of the current of the Thyristor and it is generally the capacitors will be switched on and switch off and thus it will deliver the var most of the cases instead of the absorbing var and it will control the reacting power in that fashion.

The reactor is needed primary to limit the surge current that is what I am saying and the valve otherwise high current will flow and actually it may damage the Thyristor and Thyristor valve and it may also use to avoid resonance with the system. So, ultimately it is this will be used as actively damping these devices because, this capacitor and the inductance in the power system may cause resonance. And thus we require to prevent that resonance for this result, we have placed an inductor into the system. So, under steady state condition when Thyristors valve is closed the current is flowing and it is giving a voltage v, so v should be actually V m sin omega t by X L plus X c.

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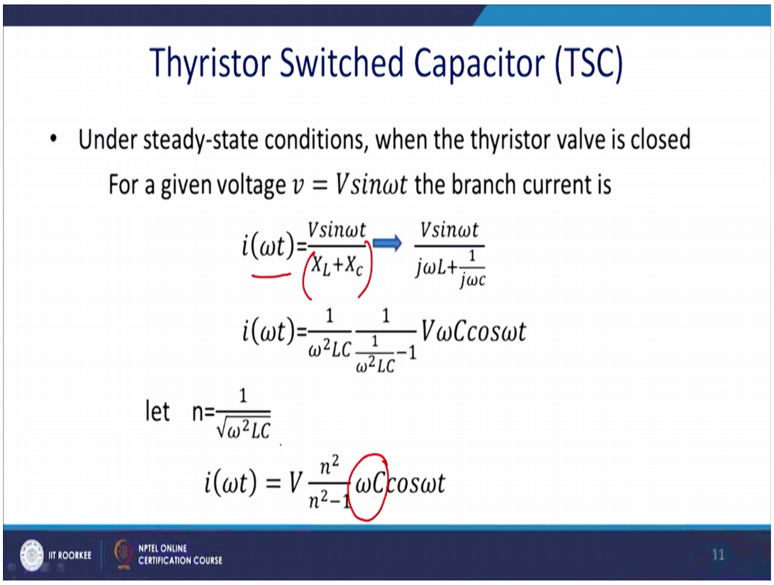

So, ultimately you get the current equal to V n square n minus 1 omega C that is where nothing but x c into cos omega t, where m is given by the resonance frequency that is omega square into L c.

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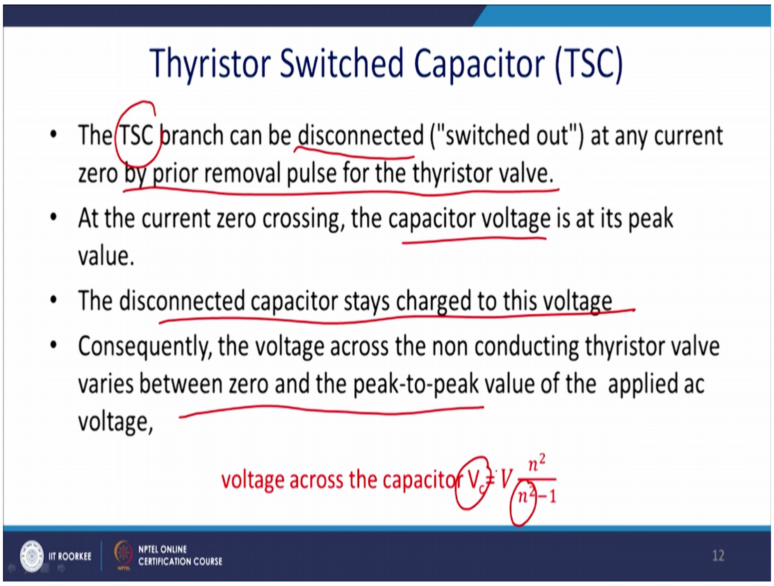

So, the TCSC branch can be disconnected or switched out at any current any current 0 by priorly removing the pulses of the Thyristor valve, this is 1 of the biggest advantage let us understand what does it set.

This branch can be disconnected or it can put it off any time because, it has a leading power factor at any current 0 by prior removal of the pulses of Thyristor at 0 current crossing the capacitor voltage is at peak value. So, we have to we have to keep it mind this things.

So, capacitor is holding the maximum value when you are actually switching of the Thyristors, thus what happen? The disconnected capacitors stay charged at this voltage and you require to find n all turn actually safety mechanism to discharge the capacitor. So, that is extra effort you require to put it to discharge the capacitor once it is put it off. Consequently the voltage across the non conducting Thyristor valve varies between 0 and the peak current value and a applied AC voltage and a voltage across the capacitor will be V c will be equal to V n square n square minus 1, so if n is quite large this can be neglected. So, V will be equal to VC so what happen when it is switched.

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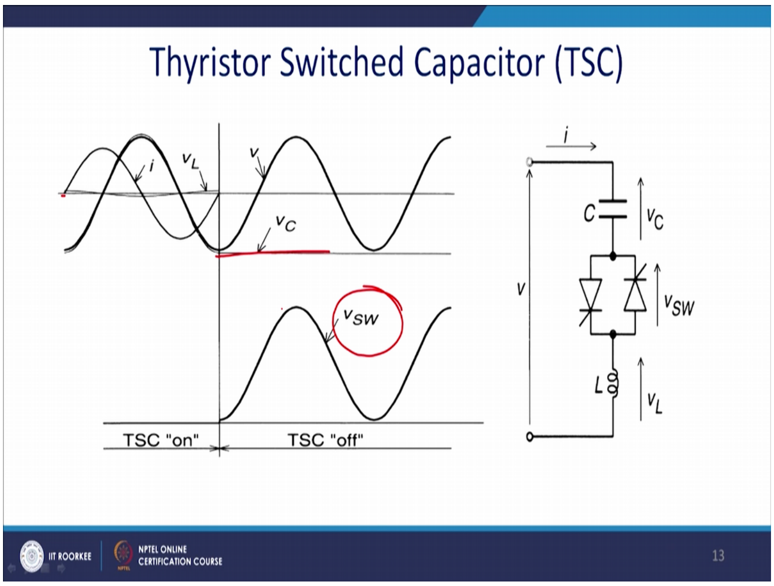

So, this is the current where current is almost lying by 90 degree and this small value is the inductor voltage and what happen here this is the supply voltage and here you have put it off. So, capacitor will maintain this voltage and thus switch will be subjected to this oscillation and we will never stress off actually of the TCSC of this voltage value equal to V. If value of n that is quite logical will be very high, so n square minus 1 is almost equal to n.

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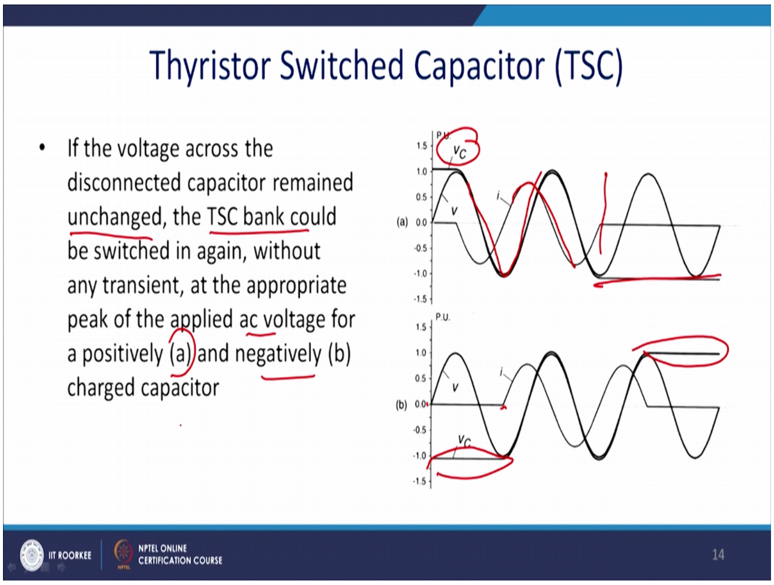

Now, let us consider the case why it was off and this is the voltage VC and it was holding that big value of the voltage and it is on thus voltage will be of the VC will be swinging like this, with the supply voltage and current will have current will be actually will have a showing by 90 degree phase shifted all of a sudden here you put this Thyristor of you have not cleared.

So, then what will happen then again it will hold the voltage of minus VC and what happen it was conducting initially? And it was not conducting initially, but it was holding a minus VC voltage initially then while off you will find that actually it will hold a positive voltage. So, this kind of feature you will be finding across the capacitor voltage in case of that TSC. In voltage across the disconnected capacitor remains unchanged. The TSC bank could be switched it again without any transient and appropriate pick value of applied to the AC voltage for the positive A and the negative at B when it is charged into the reverse polarity.

So, as such therein be no transient when it is switched on this is this is a one of the advantage of TCSC that transient phenomena is not been observed in case of the TCSC. So, generally what happen, we should be discharge the capacitor, normally the capacitor bank is discharged after disconnection.

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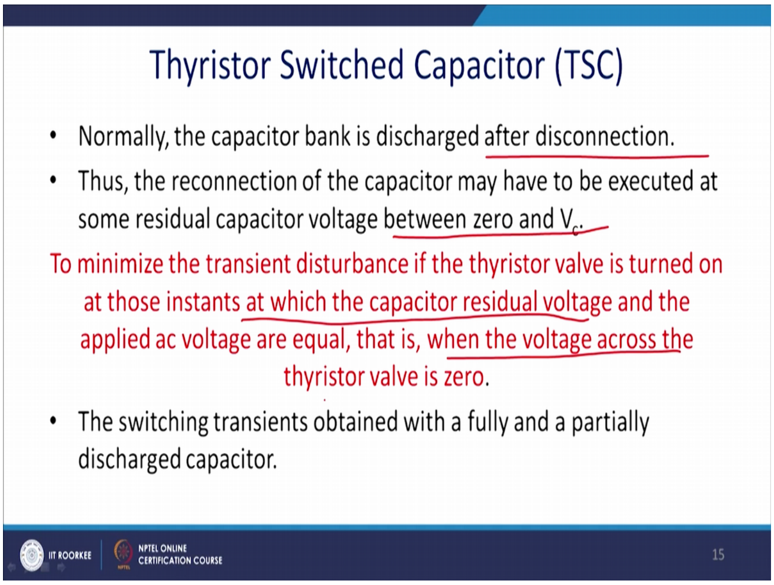

Thus reconnection of the capacitor may have to be excited some residual capacitor voltage between 0 to some value VC. To minimize the transient disturbance if Thyristor valve is turned on at those instant at which capacitor residual voltage and the applied voltage are equal, then we will find no transient right there is a if there is a disturb mismatch between the VC and the applied voltage then transient will occur. So, that is when the voltage across the transistor valve is due, so at that point we should try to switch on the switches. So, we will do not find any transient. So, we were basically switching on were the Thyristor voltage is 0, otherwise switching transient will be observed.

The switching transient is obtained the fully and a partial discharge of the capacitor generally unfortunately it is there. So, this is the first case we will discuss the fully discharged capacitor.

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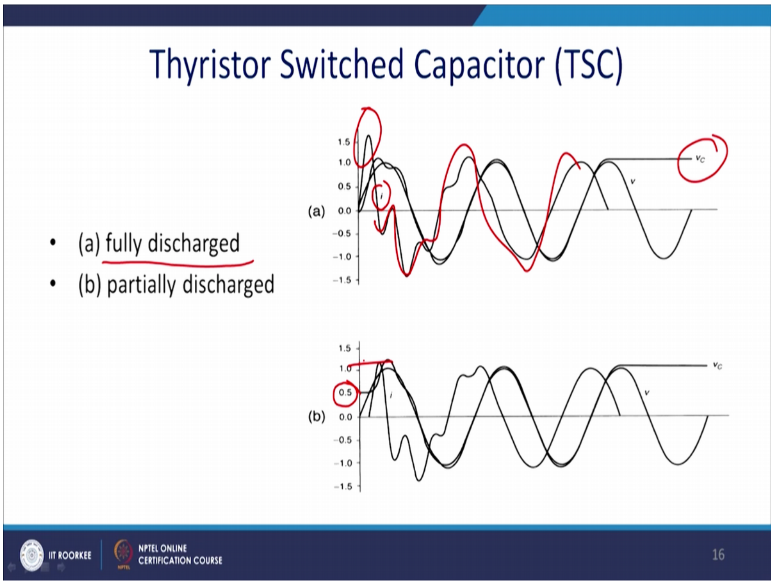

So, what happen? So this is the vc and this value is vi and once is partially fully discharged it has to built some voltage from 0 and thus high current will flow, so the capacitor and current will have a this kind of profile and it will be stabilized after sub cycle. And similarly assuming that this partially discharge and it is voltage is half of the supply voltage and then also you will have a peaky current.

But this peaky current will be little bit reduced it was 1.5 time the rated voltage, it will be little more than 1 that mean actually 120 to 120 percent and thus current will be flowing like this thereafter it will be stabilizing. So, this will be the condition once you turn it on, so this kind of transient phenomena will come across the picture we have discussed the transient stability. So, this system is transient this transient stability will come into the picture how will tamp out the oscillation of it in TCSC, that is a challenge of the good facts device designer.

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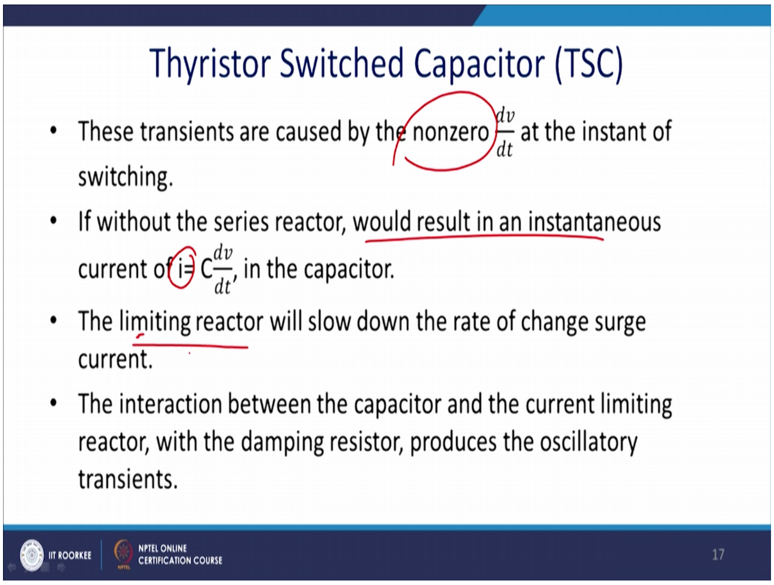

So, considering those thing we require to see few aspects, this transients are caused by nonzero d v d t, you can understand that nonzero d v d t at the instant of the switching. If voltage or current either it is 0 there is no problem. If without series reactor would results the instantaneous current value that is i value should be equal to i equal to C d v d t of the capacitor and to limit this current the limiting what does it do this limiting reactor actually limits this current.

The limit the limiting reactor will slow down the rate of change of the surge current, for this is we have to put a small inductor to actually to actually high rise of the i C d v d t. The interaction between the capacitor current and the limiting reactor with damping resistance produce the oscillatory transient and the control system. Now we are known of research control system is trying out the damping actively damping is oscillation.

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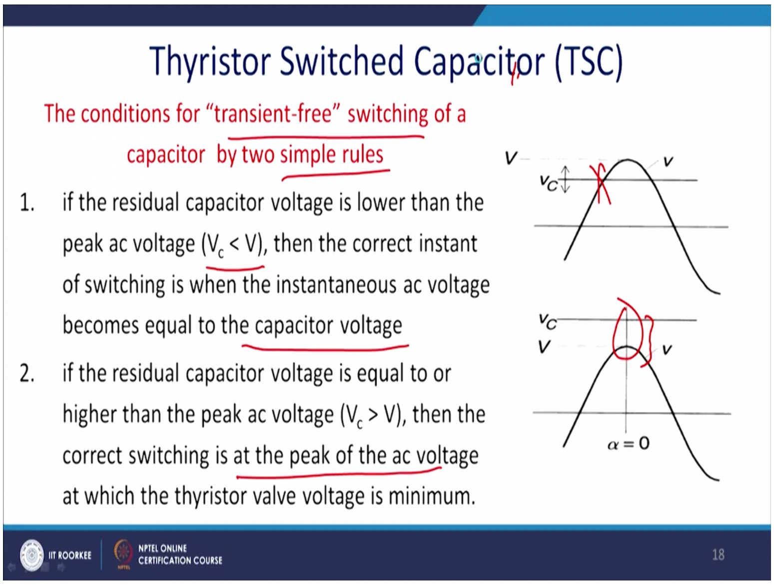

So, Thyristor switch capacitors what are they take away? We require to operate at the transient free operation. So, condition for the transient free switching is actually have a two simple rules to follow, if the capacitor voltage is lower than the peak voltage then correct instant of the switching is when instantaneous a c voltage become equal to the capacitor voltage, the moment it will cross you switch it on. If residual voltage is equal to or higher than the peak voltage of Vc really does not happen. Then correct switching peak will be at the minimum position what Thyristor valve will have a minimum voltage, so you should we should be switching on at the peak.

So, the rate of d v d t is very low we have to make d v d t low, so that the currents that is c d v d t will be low. So, this is the principle of operation so we have to reduce the d v d t the next actually what are the takeaway.

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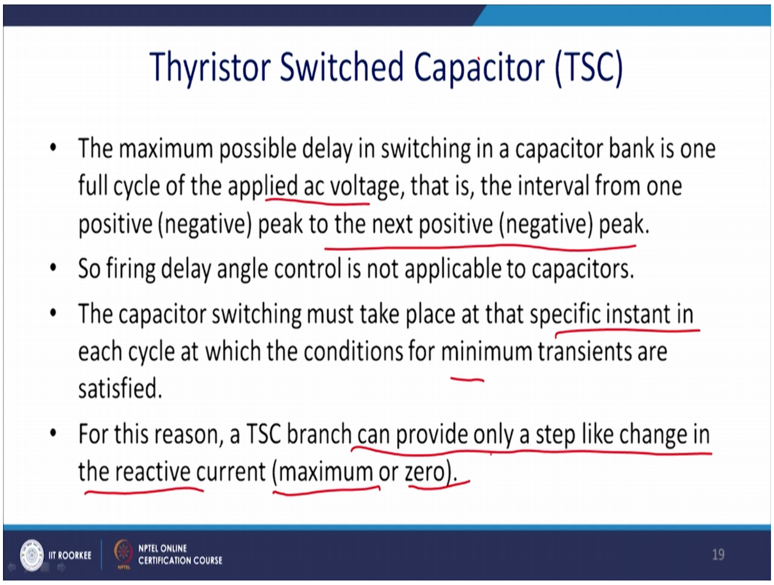

Thyristor switch capacitor the maximum possible delay in switching in the capacitor bank is one of the full cycle is applied to the ac voltage that is the interval of 1 positive or the negative peak to the next negative peak. So, around in case of the 50 s cycle it should be around the 10 millisecond. For firing delay control this not applicable to the capacitor.

The capacitor switching must take place at the specific instant in the each cycle, where there will be a condition of the minimum transient that mean where the applied voltage and the capacitor voltage become equal generally it happens in the twice in a each of the cycle. So, it will be alpha or 180 degree minus alpha, so we have to see that which where you can conduct. So, each cycle and condition of the minimum transient is satisfied and for this reason TCSC branch can provide only steps like change in the reactive current and the from maximum to 0. So, you can have a no linear actually ramp on, so we can have only the safe change in case of the TCSC. So, this is a principle or the features of the TCSC, ok.

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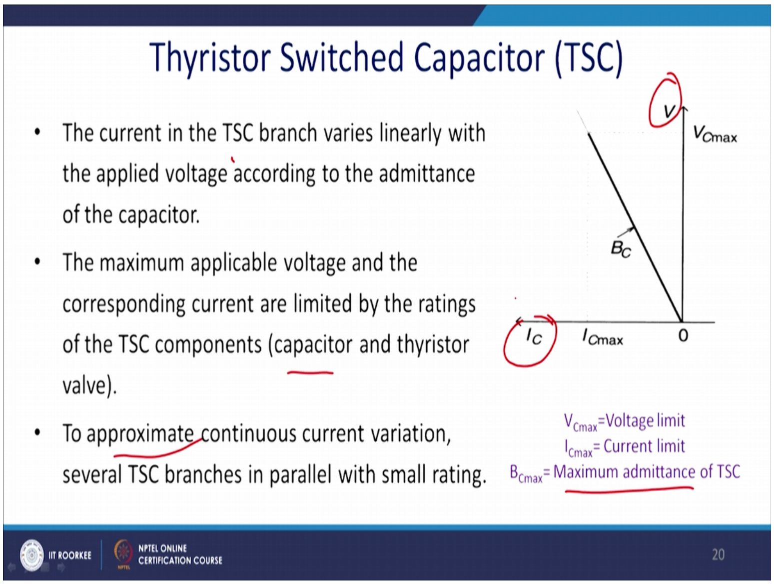

So, now let us see the Thyristor the current in the TCSC branch varies linearly with the applied voltage according to the admittance and it does not have a much problem with the harmonic also. Maximum applied voltage is corresponding to the current are limited by the rating of the TCSC components capacitor and the Thyristors valve.

So, this is basically the IC verses VC to approximate continuous current variation several branches of the small TCSC can be placed same way what we have seen actually the segmented TCR. So, Vc max will be given by actually this line, so tan theta of this line this is a maximum voltage rating of the capacitor and the Thyristors and this is a current handling capability of the Thyristor and accordingly we can find it out what should be the maximum admittance of the line.

So, we shall carry on our next class with another facts devices of the shunt compensation namely stack comp, and there have to we will compare with the all the three facts devices on the shunt compensation.

Thank you for your attentions. We shall continue our lectures on the facts devices.