Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 27
TCSC Characteristics and Control

Welcome to our NPTEL lecture series of Flexible AC Transmission System Device. Today we shall continue our discussion on the series FACTS devices, this will be our last lecture on the series FACTS devices. We were discussing on a previous class on TCSC operation this is also discussed, but we wanted to recapitulate also this phenomena.

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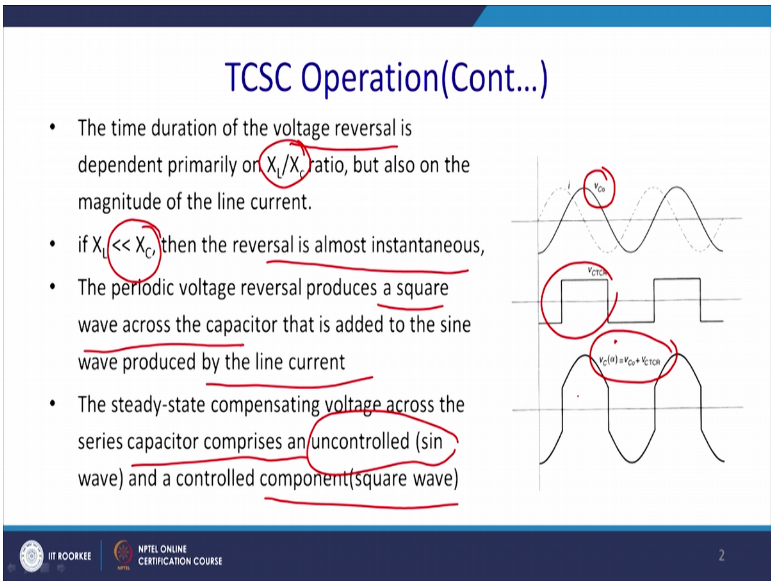

That day you know that the time duration of the voltage reversal depends primarily on the X L by X C ratio of this TCSC and also the magnitude of the line current. And for this reason if this logic is satisfied that when X C is much much greater than X L then, the reversal is almost instantaneous. And what happened then the periodic voltage reversal produces a square wave across this capacitor.

So, this will be the super imposed this is a TCR voltage and sine this is a V Co without TCR. So, this will be the superimposed voltage across the capacitor while TCR. So, what does happen the periodic voltage reversal produces a square wave across the capacitor and that is added up the sine wave to produce a line current. So, for this is a line current will be the same fashion, the steady state compensating voltage across the series capacitor comprises uncontrolled or the predating part of the sinusoidal waveform, that is uncontrolled sinusoidal form and a controlled component of the square wave; that is this part and that to both will add up and ultimately produce the V C alpha that will be a function of alpha.

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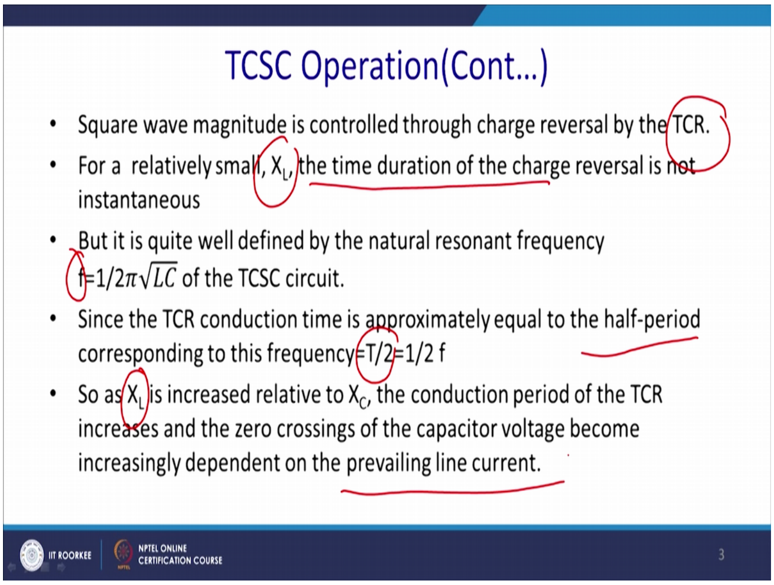

Generally the square wave magnitude is controlled through the charge reversal of the TCR and for relatively small value of X L the inductive inductance. So, time duration of the charge reversal is almost, reversal is not instantaneous, but it is quite well defined by the natural frequency and that is the frequency that frequency is given by 1 by under root of LC of the TCSC circuits.

Since TC conduction time is approximately equal to the half period of the corresponding frequency then it will be T by 2 equal to 1 by f. So, what happen if X L increases related to X C the conduction period of the TCR increases and the zero crossing of the capacitor voltage become increasingly dependent on the line current. So, you cannot change this capacitor voltage as your wish, on the other hand for this is we should have a less value of the inductive reactance small X L is advantageous.

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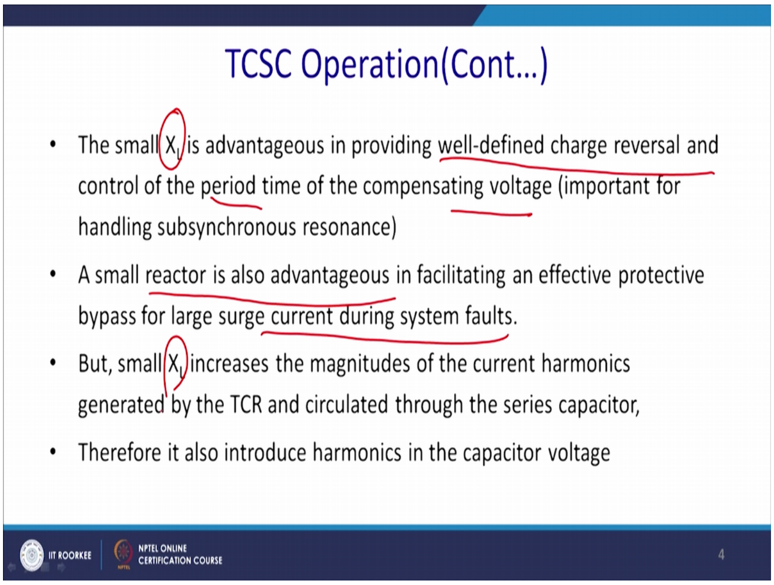

And in providing the well defined charge reversal control of the period, control of the time period and corresponding to the compensating voltage, this is essentially you know this reactance acts like a electrical inertia inductive reactance. So, it does not allow to the change of the polarity of the capacitor which is required for the X L is successful operation of the TCSC. On the other hand small reactor is advantageous, why its facilitates or facilitating the effective protective bypass of the large surge current in case of the system fault and also it require for the di dt protection.

But small X L what does it do? There is a demerit of it increases the magnitude of the current harmonious. Since, it will allow the current to flow and thus you harmonic content will be move. Generated by the TCR and circulated to the series capacitor therefore, it is also introduce harmonics in the capacitive voltage and the ripple will be there in the harmonic voltage due to this harmonic current.

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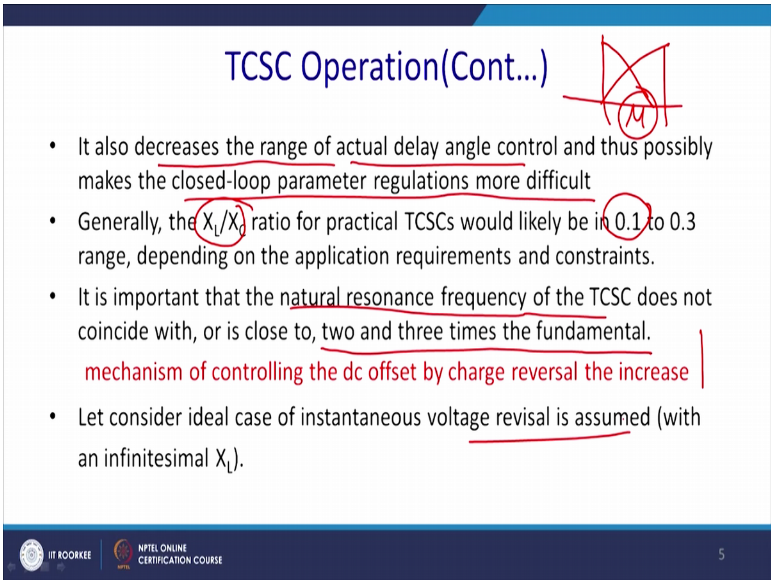

And apart from it this small inductor also decreases the, actual there is a over lapping (Refer Time: 05:19) called mu. You have studied into the effect of the source inductance in case of the power electronics converter. Range of the actual delay angle control and thus it is possible to make closed loop parameter regulation more difficult because there will be a current will decayed for the ongoing thyristor, there will be a current for off going thyristor.

So, there is a overlap angle that is called mu, in case you will have studied in the all lecture in case of the source inductance, same principle is applied here. Generally the value of X L and X C, X C ratio for practical TCSC would like to be 0.01 to 0.03, 10 percent or 30 percent in range. Depending on the practical requirement and the constraints we shall discuss in our final discussions some time case studies there you will find it out how, what how the limit had been chosen.

It is important that the natural resonance frequency of the TCSC. So, you have you know that actually if inductor is little more then it will oscillate in a natural frequency of oscillation. So, we have a constraint on the natural frequency or TCSC does not coincide or close to the two times or three times of the fundamental. Then triplet harmonic will be the actually a dominating factor, mechanism of controlling DC offset by charge reversal is recur to be increase frequently. So, that is something we have to keep in mind and for ideal consider, consideration let us consider the ideal case instantaneous voltage reversal is assumed.

So, that actually value of the X L is very very small then we can actually we can use this TCSC more better way, then what we can do?

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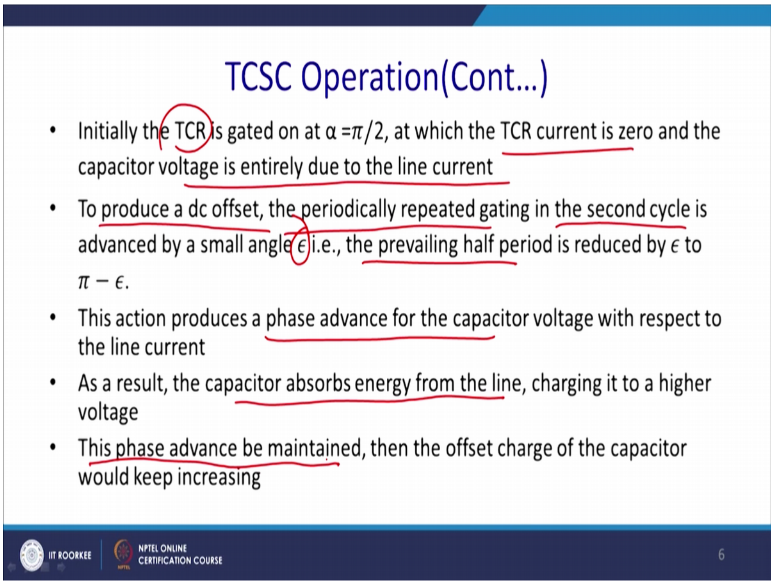

Initially the TCR can be gated on 90 degree phase shift that is alpha equal to pi by 2 at which the TCR current is zero because it is lying when tentatively and the capacitor voltage is entirely due to the line current. So, that is a advantage, if it is very small you can change the polarity of the capacitor at your will.

And to produce the DC offset the periodical repeated of the gating sequence in the second cycle is advanced by a small angle eta, will see to it. That means, the prevailing half period is reduced to, reduced by the actually the either proportional angle of eta to pi minus eta that becomes a new conduction angle. And this action produces a phase advancement of the capacitor voltage with respect to the line current and what happened due to that as a result the capacitor absorbs energy from the line charging the capacitor at a higher voltage.

So, real power will flow and thus it will actually swell up the capacitor voltage, for this reason this phase advance is maintained and it is actively controlled. So, that capacitor voltage does not go to the very high value, then the offset voltage of the capacitor would keep increasing. So, this is the way it has to be actually maintained. So, see that what happen. So, this is a line current and there will be a 90 degree phase shift.

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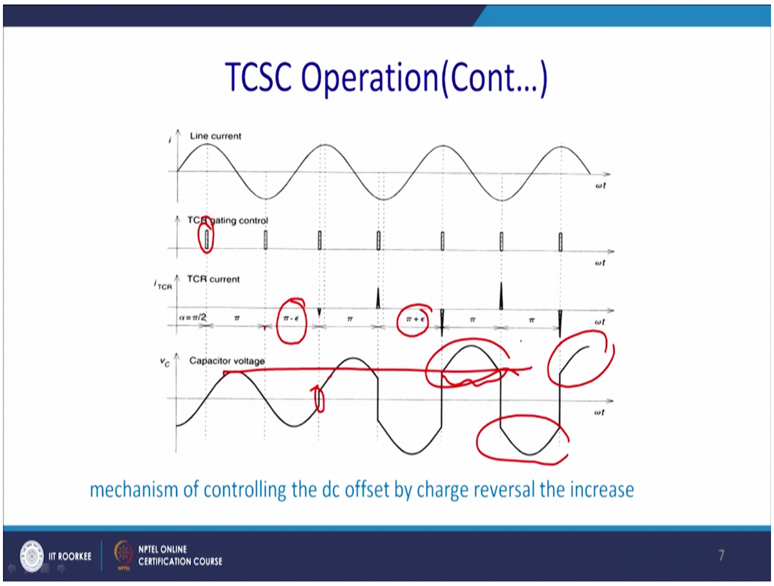

So, TC has controlling signal, so this is actually pi equal to alpha and this is pi, then you have a normal operation of the thyristor, normal operation this is this will be the pattern of the voltage of this voltage across a capacitor.

But then you give a delay angle so actually it will pick up this voltage and the conduction angle is been reduce to sigma actually eta time. So, now, conduction angle is pi minus eta. So, what happen then you have triggered here and it will conduct till pi and then again you have actually given eta plus pi in this half cycle. So, what happen gradually you will find that DC offset voltage get increased.

So, this is the problem voltage of the capacitor will swell up and this amount were the amount you have put into the TCSC. Then, how can you reduce this DC offset, mechanism of controlling then DC offset by charge reversal and it decreases. So, you have added actually conduction angle to some other level.

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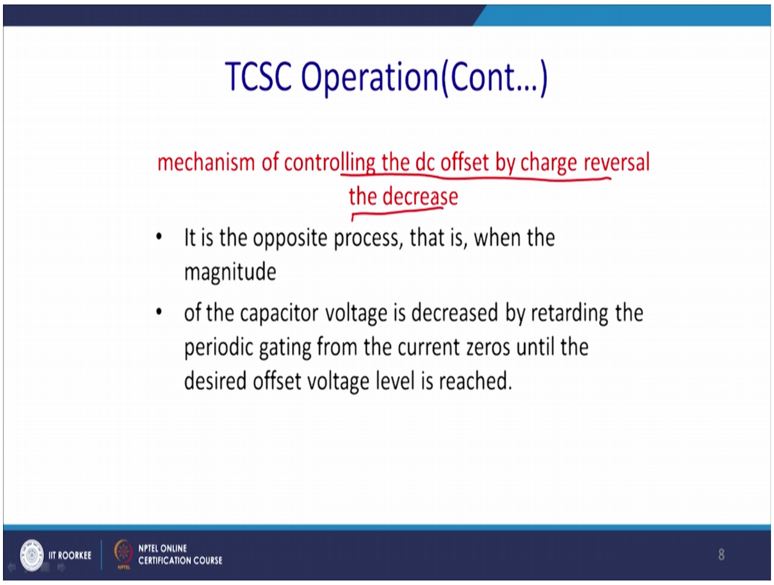

So, you can have add to the other polarity also, it is opposite process that is when the magnitude of the capacitor voltage decreased by returning the periodic getting from the current zero, until desired offset is deserve is desire. So, you have to wait till the time then only you trigger it and this way you can compensate a DC offset. So, this is the case, let us assume that this is the same line current and you will give a trigger.

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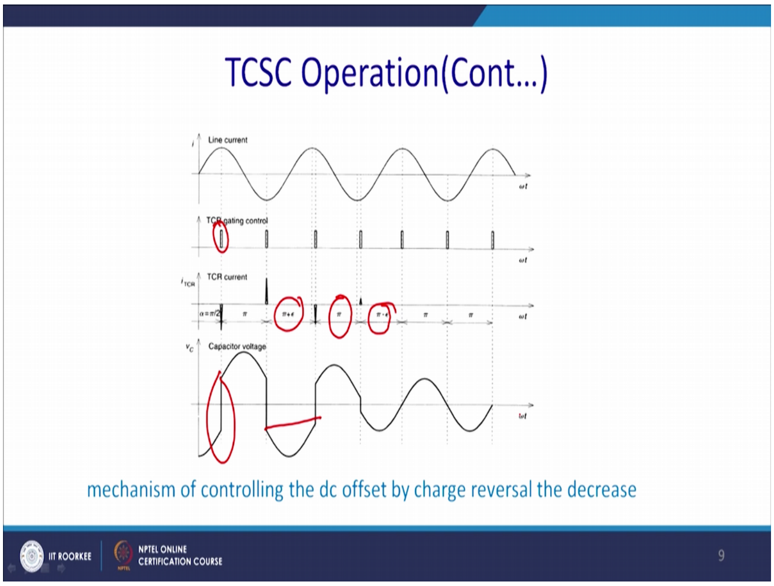

Add 90 degree to it when it is at peak. So, what happen, here we had change occurred for alpha equal to pi by two and it will have a conduction and it already have the offset.

Now, what happen you can see there is offset. So, due to that, so ultimately you got a DC offset here.

Now, here you make it pi and thus again it will carry the offset, to negate the offset here you have to make here you have to make the conduction angle pi plus eta and here you have to make the conduction angle in, in this configuration negative sequence pi minus eta. So, then it will actually reduce the offset ultimately voltage become sinusoidal, in that way actually offset of this TCSC can be removed. So, let us conclude it, so what are the operation of the TCSC? So, therefore, continuous variables series capacitor compensation can be achieved by TCSC circuit structures.

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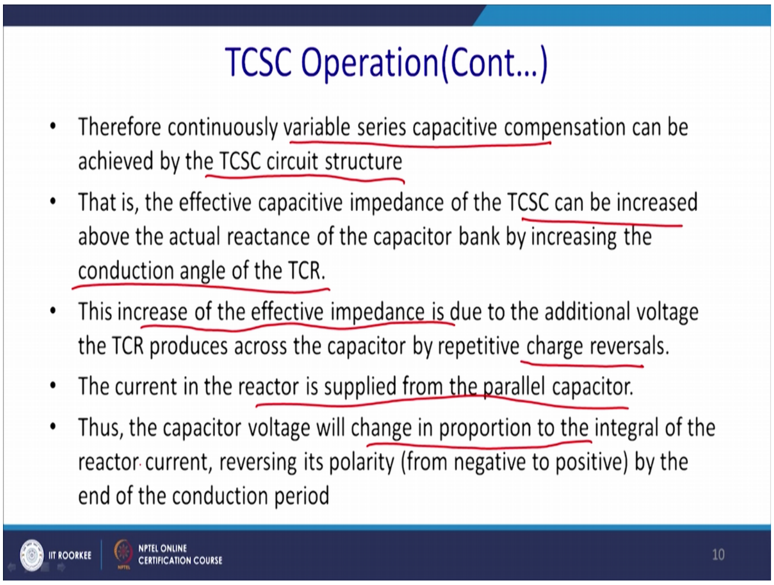

So, it can we can see in that, it can compensate the var that is the effective capacitor impedance of the TCSC can be increased above the actual reactance of the capacitor bank by increasing the conduction angle. This is the one of the prevalent features of the TCSC and what happened then? This increase of the effective impedance due to the additional voltage the TCR produces across the capacitor by repetitive reversal of the capacitor voltage of the V C, the current in the reactor is supplied from the parallel capacitor, thus what happen.

The capacitor voltage will change in proportional to the integral of the reactor current and reversing polarity from negative to positive by end of the conduction period. So, this is the v c s c TCSC characteristics V i characteristics, so this is actually the alpha minimum.

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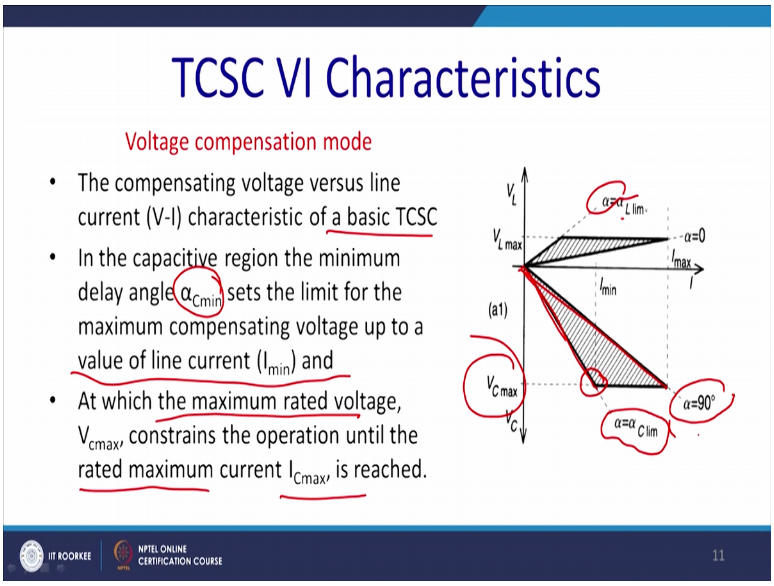

So, you have a maximum compensation inductive compensation and this is alpha 0 and this is the I max and this is the wave you can limit and this is for the case for alpha you can make in 90 degree and gradually and this is a limit for alpha C the compensating voltage versus line VI characteristics of the basic TCSC is shown in this figure.

In the capacitive region the minimum delay angle is C min sets the limit for the maximum compensating voltage up to the value of the line current of I min because there is no inductive current and at which the maximum rated voltage of V C max, this is the V C max. Constrained the operation until the rated maximum current I max is reached so this is the thing so it will reach at I max and.

So, this curve will be followed (Refer Time: 14:55) and it will reach to the I max, but you can actually make it alpha equal to 90 degree by inductive operation and then this is the way you can reach, in the inductive region the maximum delay angle is I alpha min.

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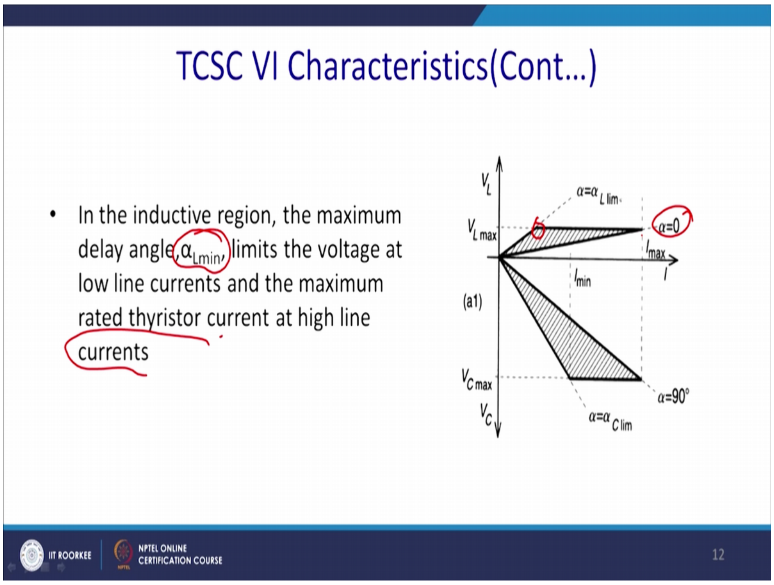

Limits the voltage at the lower voltage, at low current and the maximum rated of the thyristor current at high and at high line current; So, this is the limitation of it, where this is the slope of I min and this is the case of alpha equal to 0 it will be limited by the I max value of the devices.

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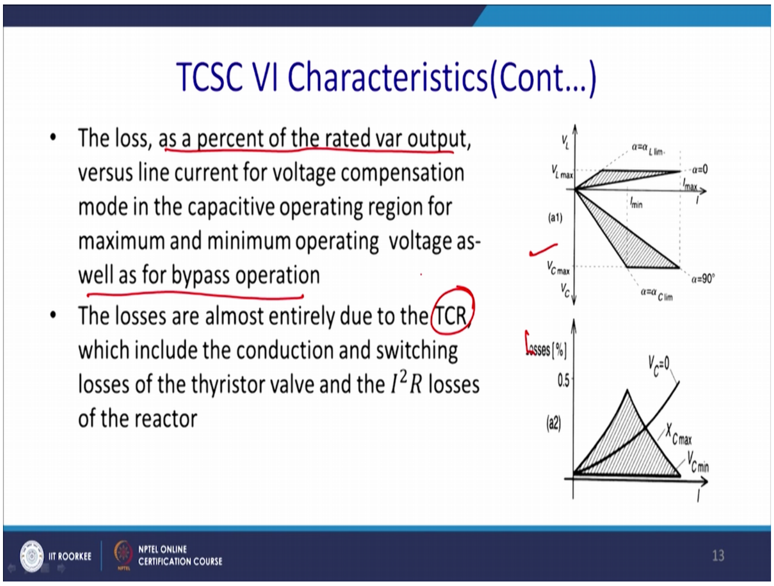

So, if you can combine these two so what will be the losses. So, the loss as a percentage of the rated var output is been plotted in this curve. So, what happen, the output versus the line current for the voltage compensation mode in the capacitive operation region for maximum and the minimum operating voltage as well as the bypass operation it is been shown. The loss are entirely due to TCR so you can see that loss are due to TCR.

Because there will be switching losses which include the conduction as well as the switching losses of the thyristor valve of the I square losses of the intrinsic resistance. So, loss will be entirely for the TCR, this is the case.

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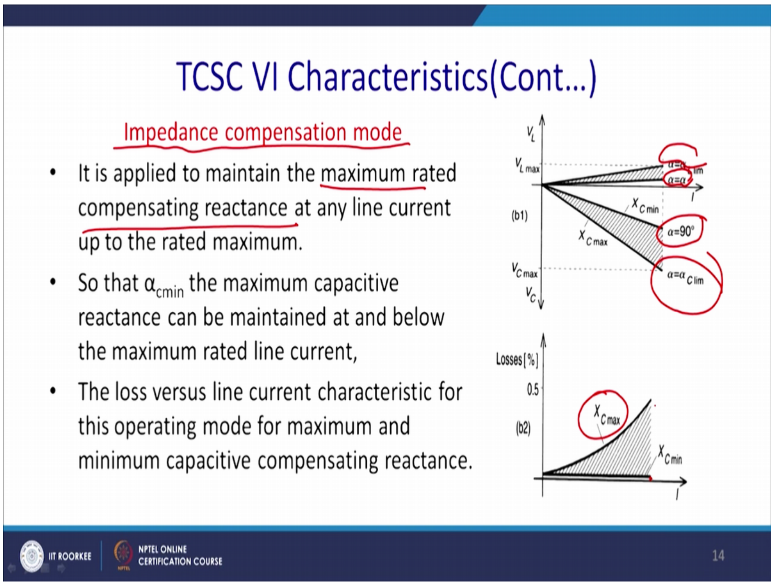

So, if it is running in a impedance compensation mode, then it is applied to maintain the maximum rated compensating reactance at any line current up to the rated maximum line current.

So, that what happened the same i alpha and this is I alpha min and this is for alpha equal to 90 degree and this one is basically alpha equal to alpha C min. So, it is a minimum alpha for the capacitor, so see that losses how it will increase. So, this is the value of the C max and this is the value of the C min. So, changing the capacitor will actually according to the value of the I, this value will change.

So, that the C min, the maximum capacitive reactance can be maintained at the below of the maximum rated line current. Moreover, the loss versus line current characteristics because you know that there is a loss predominantly on the TCR characteristics for the operating mode for maximum and the minimum capacitive compensating reactance is been shown here.

So, this is for X C max and this is for this line for the X C min. So, we can say one thing that voltage and the impedance compensation mode are interchangeable in control action. So, you can use actually either of them and it can be switchable to the one mode to another mode very easily. So, what are the drawback of the TCSC?

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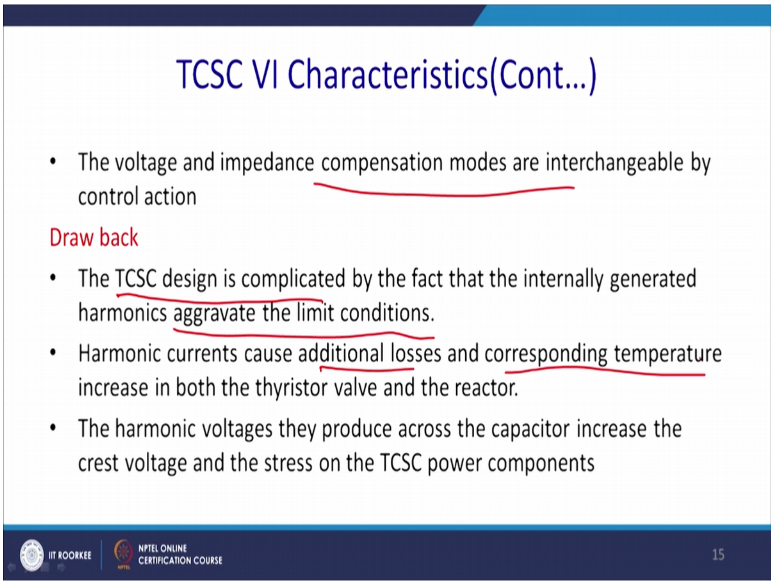

The TCSC design is complicated by the fact that, that the internally generated harmonics aggravate the limit condition and mostly it rises from the TCR, the harmonic current cause additional losses corresponding to the temperature increases both thyristors valve as well as the reactor.

The harmonic voltages they produce across the capacitor increases the crest voltage and stress of the TCSC power consumption and they are and voltage triple in the capacitor. So, let us discuss the control of it.

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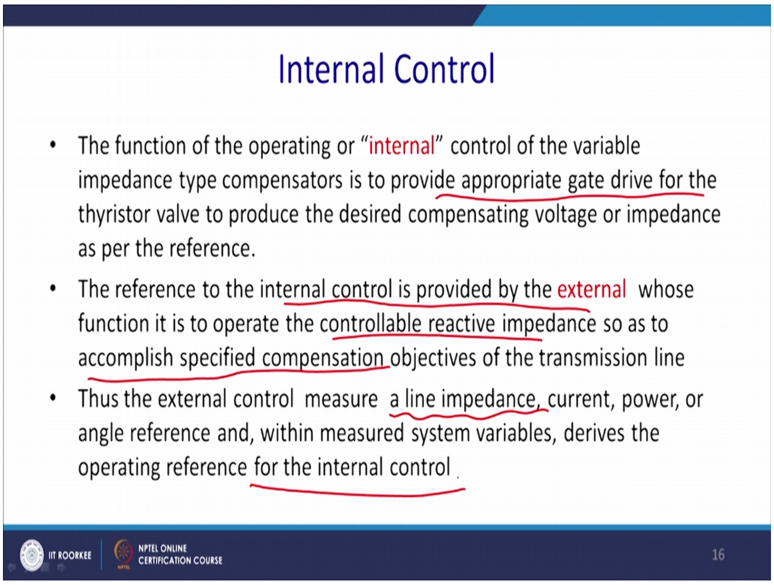

Function of the operation on the internal control of the variable impedance type compensator is to be provided with appropriate gate drive for the thyristor valve to produce the desired compensating voltage or impedance as per the reference. The reference to the internal control is provided by external voltage loop, external whose function is to operate the controllable reactive impedance so as to accomplish the specific compensation objective of the harmonic of the transmission line.

Thus, what happen external control measures this parameters, line impedance current power or the delta of angle reference within a measured system variables and then derives the operating reference of the internal control. Let us see right now and power circuit of the series compensation compensator operated by rigorously synchronizing line current conduction and blocking control so you have to sense the line current. So, their signal is high very much needed and in the source of the reference, it is not only define their effective impedance at the power frequency.

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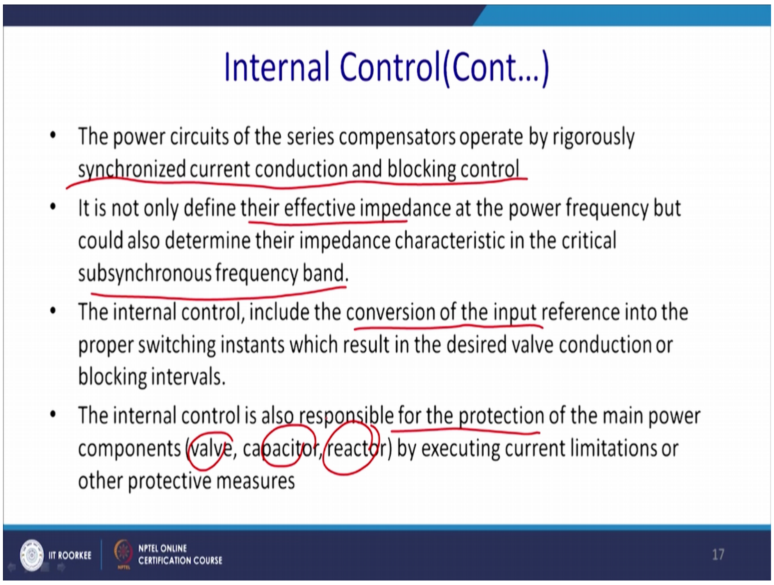

But also determine that impedance characteristics in the critical sub synchronous frequency band because you know that actually there might be a natural frequency oscillation. So, you have to damp out the sub synchronous frequency.

Internal control include conversations of the input reference into the proper switching instances of the switching logics, which results in a desired valve conduction or blocking interval, that is you have to control alpha, measure the alpha sigma X L. And internal control is also responsible for protecting for protection of the main power components like valve capacitor reactor by executing current limitation or other protective measures.

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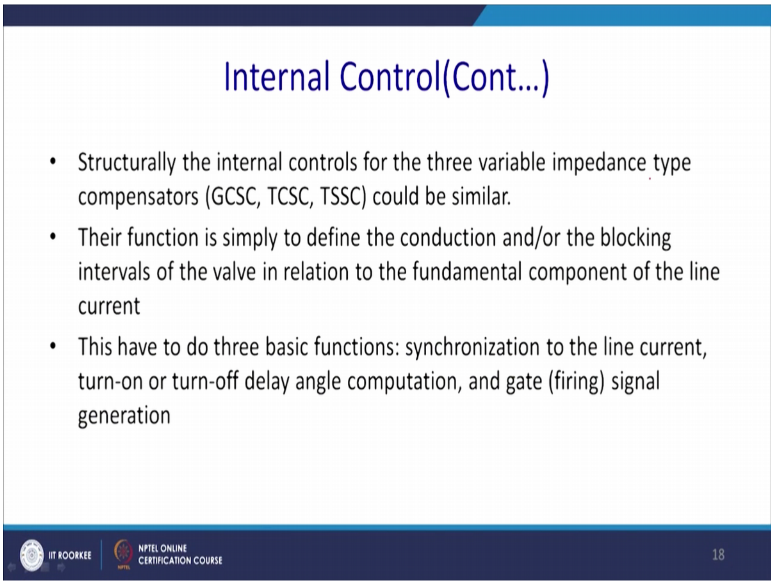

Structurally the internal control for the three variable impedance by the compensator are definitely we have discussed all that is GCSC, GTO controlled switch, TCSC and TSSC and these are all almost similar. Because this we require to measure the current voltage and then from there may be phase angle and the power and from there we require to find it out desired gate in signals. Their function is simply to define the conduction and the blocking interval of the valve, in relation to the fundamental component of the line current.

So, this is the way it operates and this valve do three basic functions, one is synchronization of the line current this acts as a parallel in this case of the TCSC and it controls the turn on or turn off delay mostly in GCSC can control, turn off delay also turn on and turn off delay angle computation and get fire in signal generation. So, let us see that what is the internal scheme for the GCSC.

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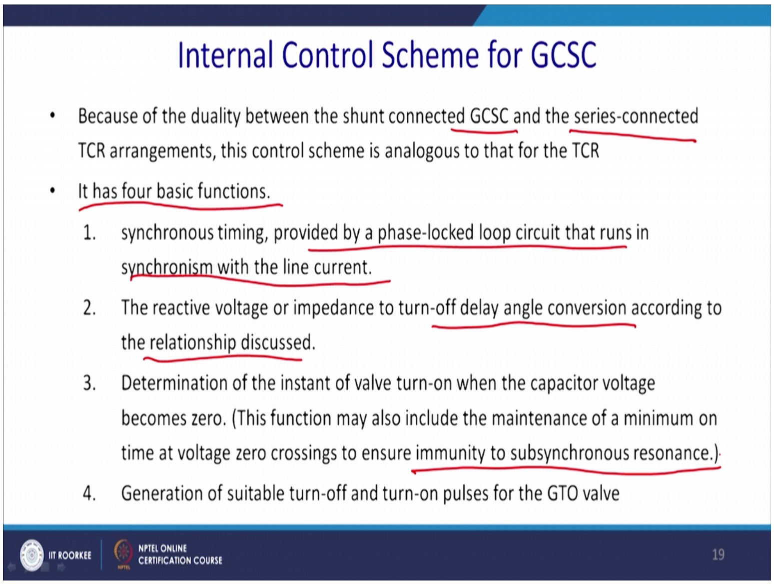

Because of the duality between the shunt connected GCSC and the [sit/series] series connected TCR, the control scheme is totally analogous is to the TCR and has four basic functions. That is you recur to ever synchronous timing, provided by PLL provided by the phase lock loop of the circuit that runs in synchronization with the line current. The reactive voltage of the impedance to turn off delay angle conversion according to the relationship discussed. Determination of the instant to the valve turn on when capacitor voltage becomes 0, this is a extra constraint it has been put.

So, those are non-available to the other two shunt compensator, this function may be include maintenance of the minimum, maintenance of a minimum on the time and voltage zero crossing, to ensure the immunity of the sub synchronous impedance; Generation of the suitable turn off and a turn on pulses for the GTO valve.

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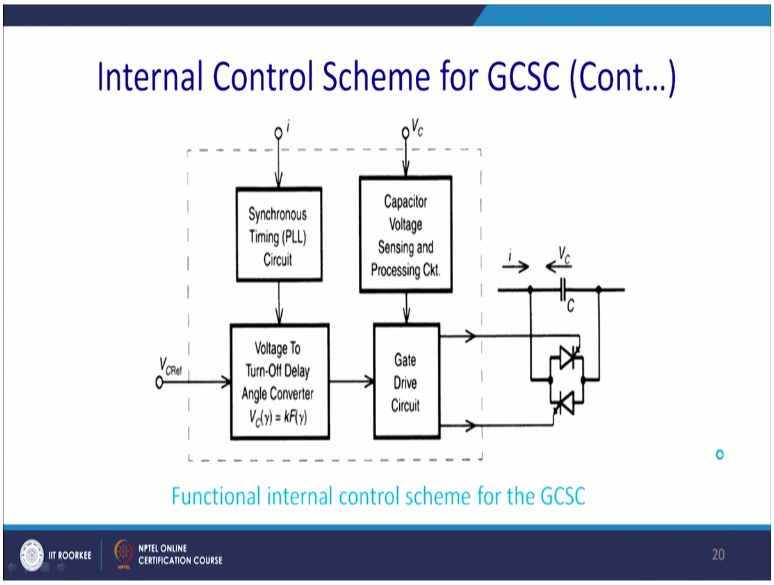

So, this is the internal control scheme of GCSC and it is almost same for the other, but in GCSC, so turn off logic also you require to compute. So, this is the V C reference from there you can sense and you have a current from there you got a PLL and thus theta comes out, voltage to turn off delay angle conversion and you get basically V C lambda is a function of kF y.

While actually that will be delayed by some angle and this is basically the capacitor voltage sensing and the processing kit. So, from there it will be compared and this is essentially calculate what should be the delay angle or the firing angle or the turn off time of this GST. Now, as I told you this methods are almost same for TCSC and TSSC.

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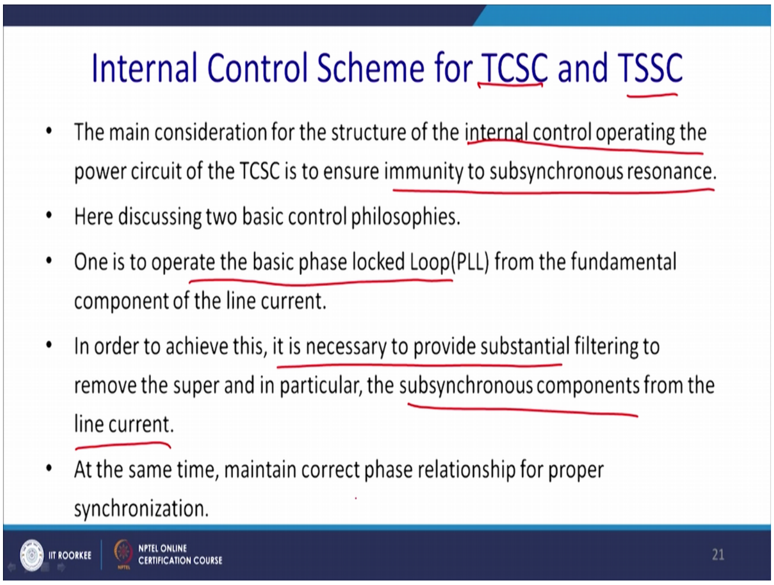

So, this basic difference will be it does not have a turn off control the main consideration of this structures of the internal control operating the power circuit of the TCSC to ensure immunity to the sub synchronous resistance. So, that is something we require to ensure, here we are going to discuss the two basic philosophies. One is to operate the basic phase lock loop from the fundamental component of the line current.

In order to achieve this, it is necessary to provide substantial filtering and remove the super and in particular sub synchronous component from the line current, so we have to do the notch filtering. At the same time, maintain the correct phase relationship for the proper synchronization.

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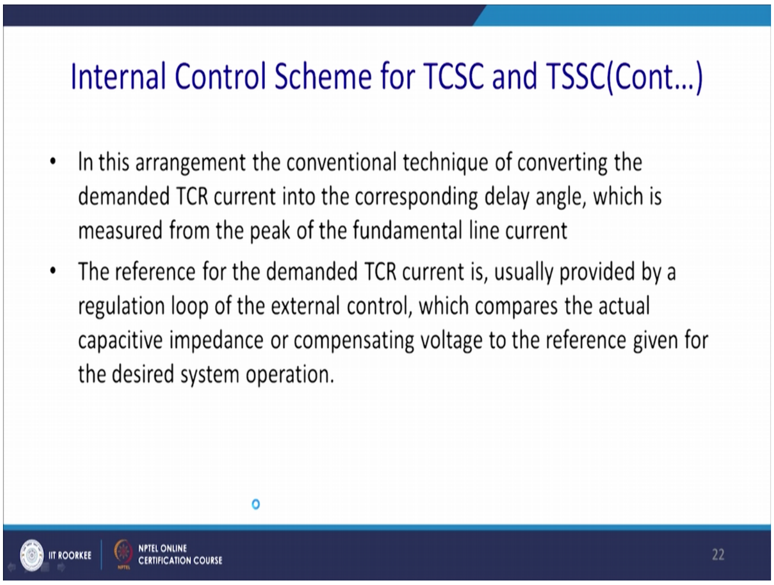

And this arrangement of the conventional technique of converting the demand of the TCR current into the corresponding delay angle which measured from the peak of the fundamental line current, is been ensured. The reference of the demand of TCR is, usually provided by regulation loop of the external control, which compares the actual capacitive impedance or the compensating voltage to the reference given for the desired system of operation.

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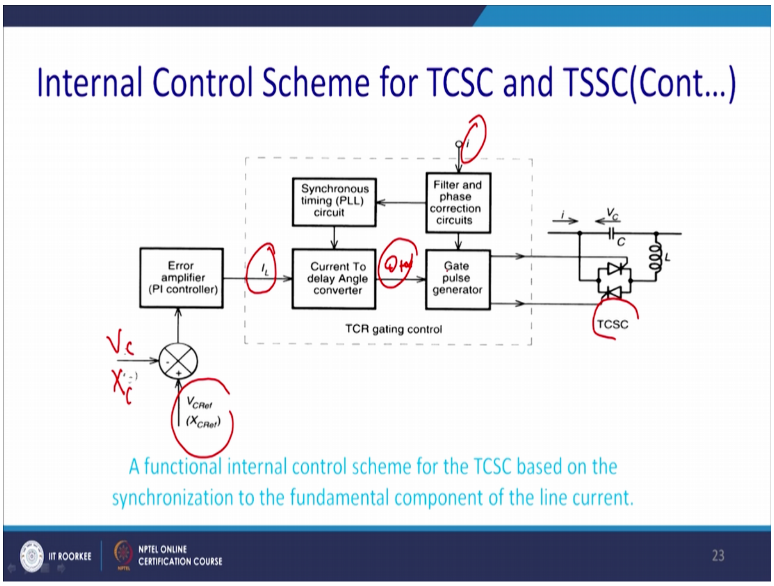

So, this is the internal control of the TCSC as well as the TSSC ultimately you got V C reference from there you can have a actual X or actual V C, whatever may be it can have a two mode of operation impedance mode and the voltage mode. So, you have a PI controller. So, ultimately you calculate I L, so you got a PLL current to the delay angle computation will be there.

How much the accordingly there will be a calculation of I L that is based on alpha and from the PLL actually it will generate the delay that will be theta plus alpha. This angle will be fed to the gate pulse generator and it will ensure also that current does not contain any sub synchronous and the super synchronous component of the line current. And this value will, be this information will effect to the delay angle to operate this TCSC as well as TSSC.

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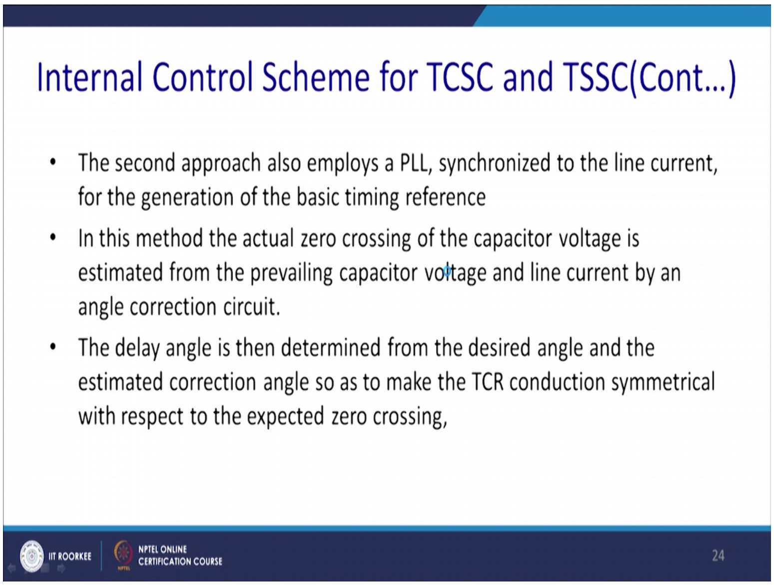

Thus, what we can conclude? The second approach also employs PLL synchronized with the line current, for the generation of the basic timing reference and this method the actual zero crossing of the capacitor voltage is estimated. So, it is more full proof, from the prevailing capacitor voltage and the line current by an angle correction and thus you can actually take a competitive action to DC offset.

The delay angle is then determined from the desired angle and the estimated correction angle is also to make the TCS conduction symmetrical with respect to the zero crossing and this way we remove the zero crossing.

Thank you for your attention, we thus conclude our discussion on the series controlled series FACTS devices and we shall control, we shall next class we shall started with the phase angle regulator.

Thank you.