Flexible AC Transmission Systems (FACTS) Devices
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Lecture - 23
GCSC and SSSC

Welcome to our lectures on Fact Devices. Today we will continue with the GCSC from where we left in previous lecture. So, the let us recall our previous discussion.

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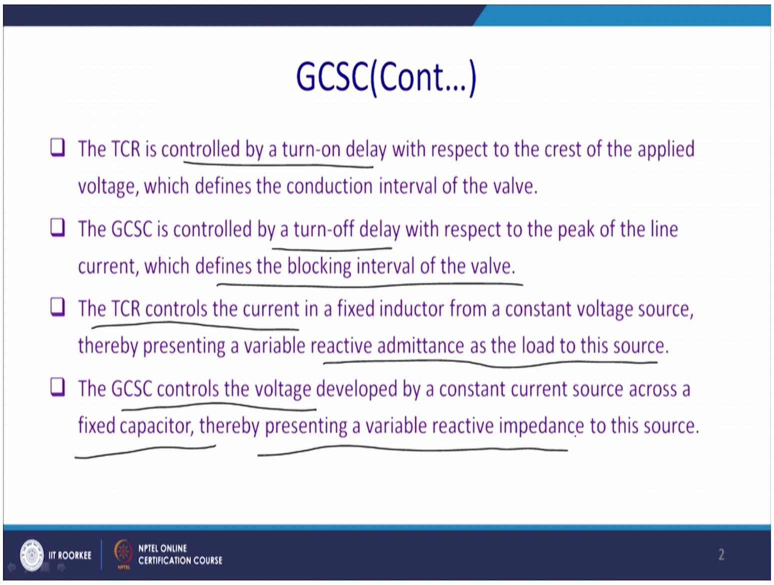

There actually the TCR that is Thyristor Controlled Reactor is controlled by the turn on delay. So, please, you please recall your TCR in your shunt compensation with respect to the crest of the applied voltage that is at the peak of the applied voltage which defines the conduction interval of this thyristors on GTO, or that can be actually term as valve, because it can be a combination of the series and parallel combination to meet that voltage and current requirement.

The GCSC is controlled by turn of delay. So, this is a one of the basic difference. So, far this is we require GTO, not the thyristor with respect to the peak of the line current. So, it will be actually it will be measured from this actually turn off time and which basically defines the blocking interval of the valve and what are the other difference, though it seems look similar. This TCR controls the current in a fixed inductor for a constant voltage source. This is a TCR, and representing a variable reactive admittance as a lesser load and a source.

On the other hand, GCSC controls the voltage developed by a constant current source, constant current source across a fixed capacitor and thus thereby representing the variable impedance source. So, this is the basic difference of a TCR and GCSC.

So, similarly you know you please recall our expressions in current. So, you had a same kind of term that is I f l equal to I 0 by 1 minus lambda by pi one by same term will be there.

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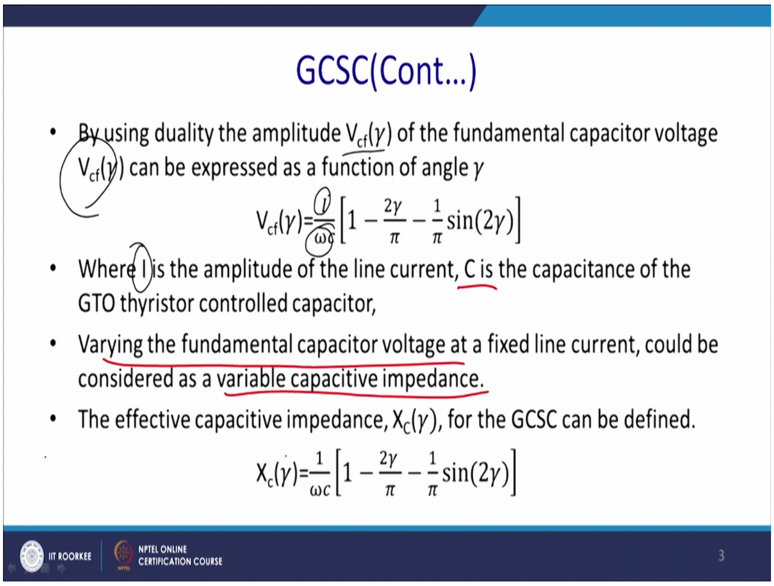

So, there here it will be the voltage. So, it is I by omega C that is a impedance of the line, by using the duality of the amplitude of C lambda the fundamental capacitor voltage cf can be expressed as a function of the angle lambda. So, there used to write alpha, here you will write lambda. So, cf lambda equal to 1 by omega C 1 minus 2 by pi into lambda 1 by pi sin 2 lambda. Again this equation has to actually you have to solve this equation, this is a non-linear equation and you have to solve this equation by the iterative method. While definitely is this is stabile statement where I is the amplitude of the, let me change the colour of the ink to red.

So, amplitude of the line current and C is the capacitor of the, capacitor that connected across GTO and moreover varying the fundamental capacitor voltage at a fixed current could be considered as a variable capacitor impedance. So, you should have a variable capacitive impedance. And thus, we can rewrite this equation of the variable impedance as X c that is function of the lambda is 1 by omega C 1 minus 2 by pi lambda minus 1 by pi sin lambda. So, let us see the contour and the V I characteristics of GCSC.

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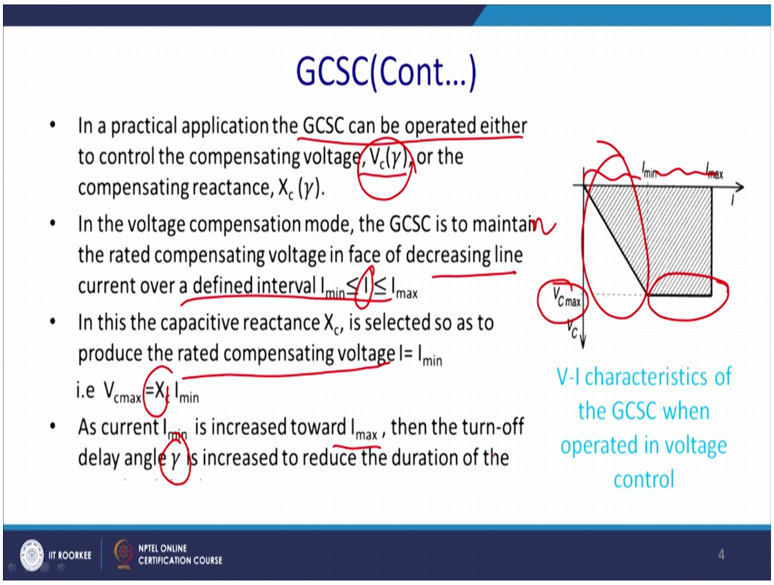

In a practical application, the GCSC can be operated either to the compensating voltage V c or the compensating reactance. So, you can have a both the operation and we can choose one the operation, in case of the voltage compensation mode; that means, this mode GCSC has to maintain the rated voltage, the rated voltage in face of the decreasing the line current over the defined interval of time. So, it is changing, so you have to maintain the desired voltage level.

So, it is I min should be. So, actually have to control this I within this range, in that capacitive reactance range X c it is selected so as to produce the rated compensating voltage. So, that should be I equal to I min; that means, V cmax is equal to X c into I min. So, this is the operation, this is the V cmax this is the; I min and this is I max. You can control in this region this is the constant impedance mode, you can control in this mode this is something like you recall in V c mode there is a constant torque region and constant power region is something like equivalent to that.

So, here actually it is operated in constant voltage mode. So, here voltage remain constant and here the slope remain constant and thus impedance remains constant. As the current I min is increased towards I max, then that turn off angle delay lambda is decreased to reduce the duration of the conduction.

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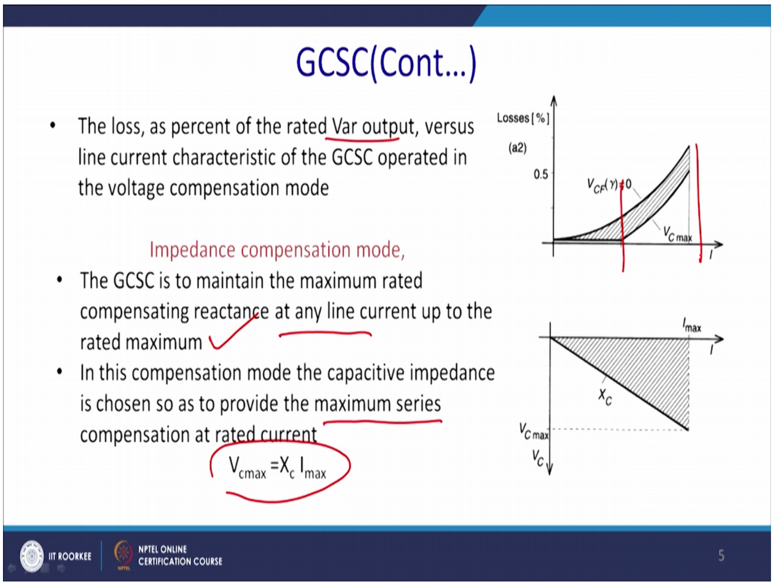

Now, what is the loss? The loss, as percentage of the rated Var output, versus current characteristics of the GCSC operated in the voltage compensation mode is shown here. So, what happened? You know in GCSC to maintain the maximum rated compensating reactance at any line current up to the maximum, up to the current up to the rated maximum.

So, in this compensation mode the capacitive impedance is chosen so as to provide maximum series capacitance compensation. So, that will be actually V cmax equal to I c into I max. So, this is actually the V cmax value and ultimately this is the constant impedance shown and this is a constant voltage shown.

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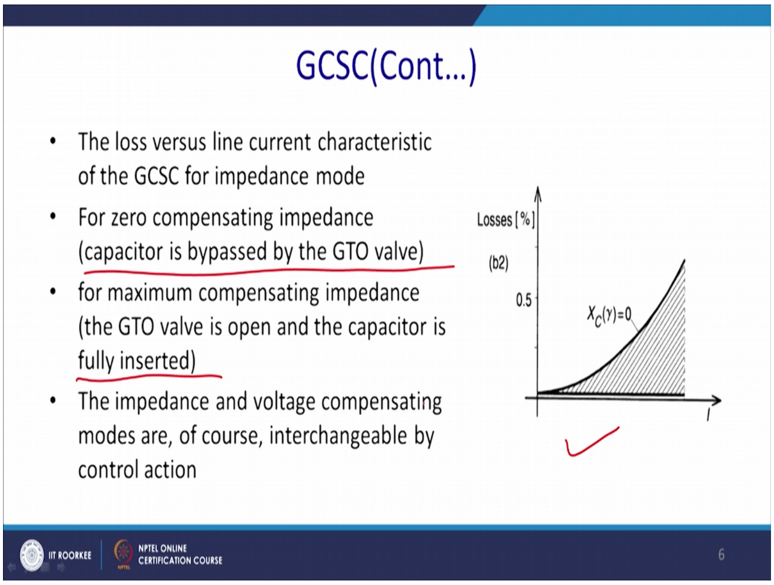

So, loss versus line current characteristics of the GCSC for the impedance mode it is being shown here. So, this is x axis is I and y axis is basically the losses, for zero impedance, for zero compensating impedance capacitor is bypassed. So, you got a very low losses basically, the capacitor is bypass by the GTO value. For the maximum compensating impedance the GTO valve is open and capacitor is fully inserted, the impedance and the voltage compensating modes are of course, interchangeable in control action. So, this is the operation of the GCSC and we can see that with increase of the current since there is a, since actually there is a fix drop, fix conduction drop across the GTO.

So, far this is what happened so conduction drop will increase linearly, with the conduction time and thus increasing I generally this losses increases.

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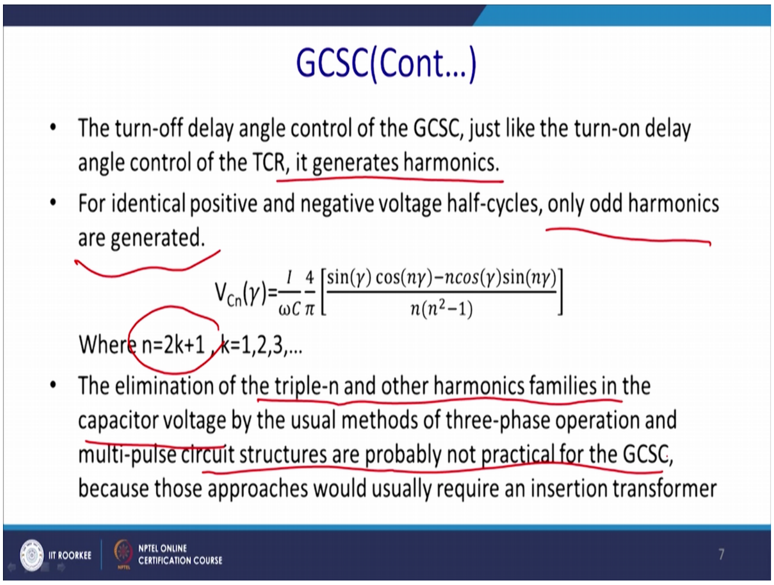

Now, to the turn of delay angle control of GCSC, is just like you know same of the turn on delay control of the TCR and it relate the same thing harmonics. For the identical positive and the negative voltage half cycle, this odd harmonics is generated, it is something like this you have assume that your odd symmetry and this kind of harmonic content will be generated. So, V c and lambda is given by 1 by omega C 4 by pi is a fundamental. So, there after you have other harmonic and generally the harmonic content will be fast hard and so on, that is the content is actually n k plus 1. So, you have a actually this kind of harmonics.

So, we required to eliminate that harmonic that is also important things. So, we had eliminated the harmonic by different kind of delta connection in case of the TCR, same principal can be used here. So, to elimination of the triplet and other harmonic families in the capacitor voltage by user method of the three-phase operation and multi-pulse circuit structures are probably not practical in case of the GCSC, because you required to insert a transformer, delta transformer, because those approaches would usually required insertion of a transformer. So, how can we get rid of those harmonics then?

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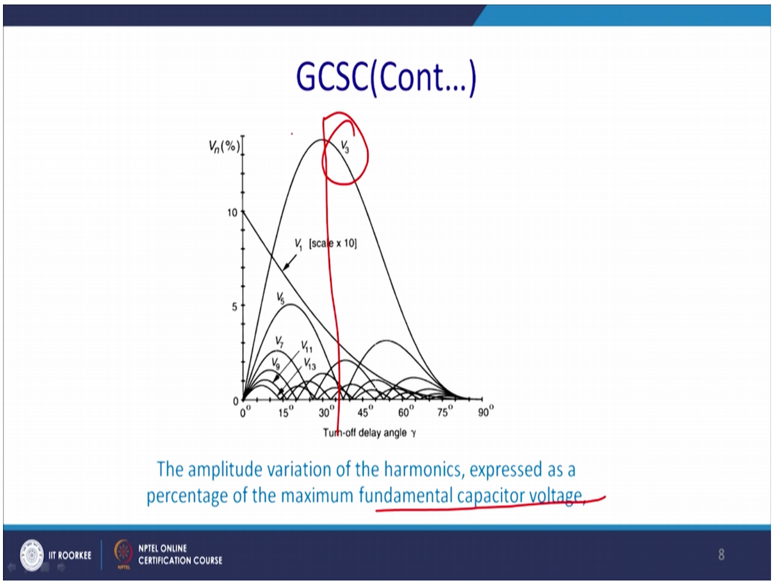

So, so, this is basically the harmonic spectrum of the GCSC, this is the fundamental, fundamental will decay as the trigger angle changes and you can see that actually add on 37 degree you will have a peak of the third harmonic. And accordingly different values you have a different content of the harmonics, the amplitude variation of the harmonic is expressed as a percentage of the maximum fundamental of the capacitor voltage source. So, this is almost same as TCR.

So, what should we do them to do they get rid of this dominating hormone you can see that, you know if you see that observe this previous slide you know that thermo third harmonic content is much more than the fundamental when it when it speeds occurs. So, we required to reduce the third harmonic, the effect of this harmonic may be relatively small except the third harmonic definitely.

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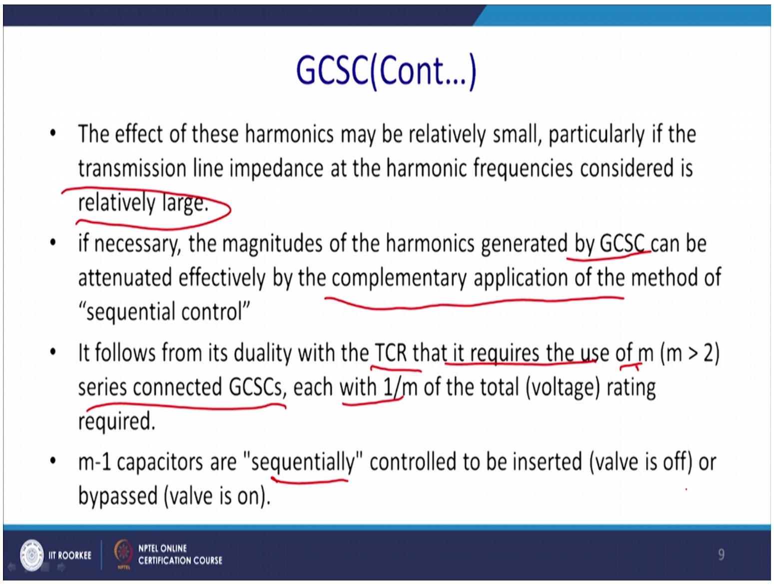

Particularly if the transmission line impedance frequencies is considered to be relatively large, if necessary the magnitude of the harmonics generated by GCSC can be attenuated effectively by the complementary application method of the sequential control. What is sequential control? We should actually, I have a pulse we should have a actually common mode chock those kind of things, that will basically cancel out the positive and the negative fluxes. Since, we call that fifth and seventh are the positive and negative sequence.

So, it follows from the duality that TCR that requires to use of m where, m is greater than 2, the series connected GCSC each with 1 by m total such rating is required. So, you have to put them in series. So, m minus 1 capacitor sequentially control by inserted valve is on or off or bypass mode.

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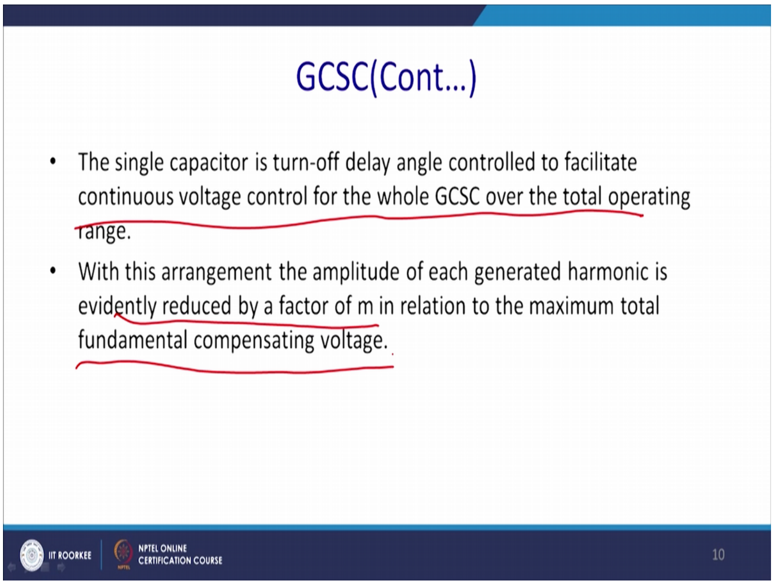

The single capacitor turn-off delay angle control to facilitate the continuous voltage control of whole GCSC over the operating range. This is advantage of it, with this arrangement the amplitude of the each generated harmonics is eventually reduced by the factor of m in the relation of the maximum total fundamental component of the voltage. So, you can increase the number of valve and thus you can eliminate or you can reduce the content by 1 by m times.

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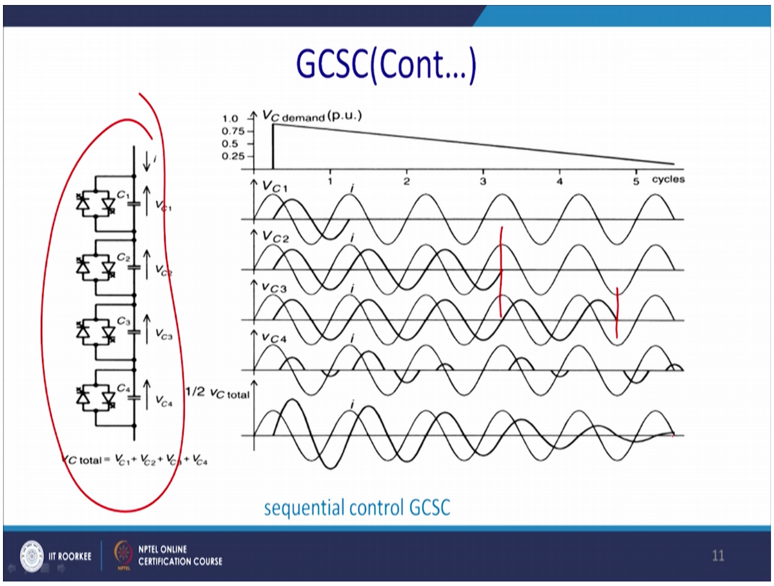

So, see that this is the way of operation. So, total voltage it is V C1, V C2, V C3, V C4 and these are the anti parallel GTOs are connected. So, this is the V C c in first cycle all valves switched on. So, the current will be actually flowing like this, there after V C2 is turn off after third cycle and there after V C3 is turn off here after fourth cycle. And V C4 will be actually, will have a this kind of alpha control sequence and thus over voltage and current will have this kind of nature. In that way you can actually eliminate also the harmonics.

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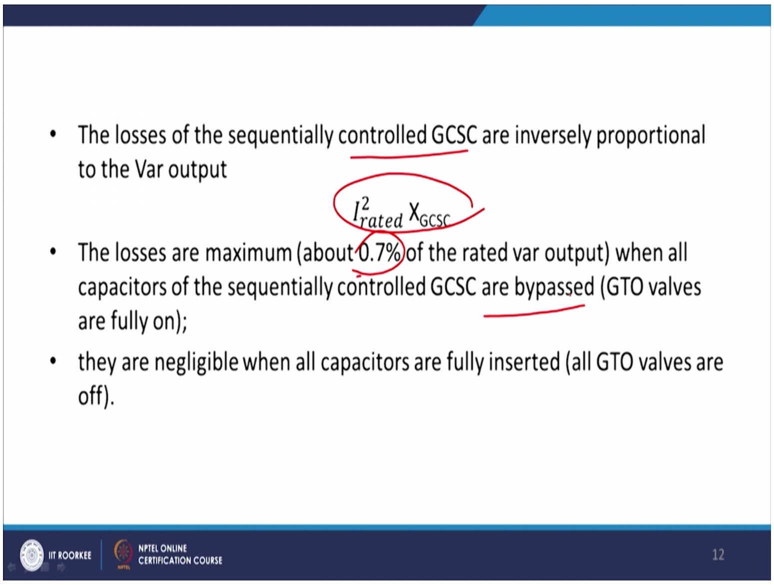

So, the loss of the sequential controlled GCSC are inversely proportional to the Var output. Since, it is depend on the current rating is a current controlled device so it is I square X GC. The loss of the maximum that mean about 70 percent of the rated var voltage when all the capacitor of the sequential control GCSCs are bypassed and thyristor is and this sorry the GTOs are fully on. They are negligible when all the capacitor are fully inserted, when all the actually GTOs are off. So, so what we can do then.

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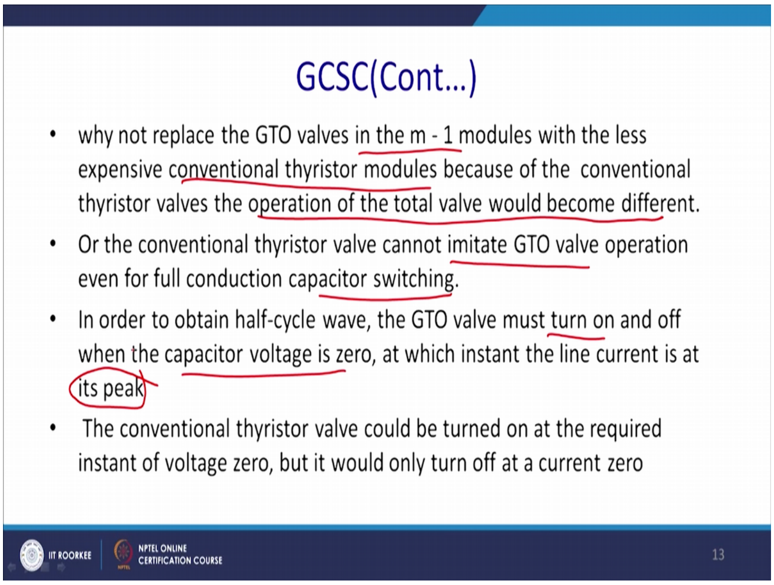

Why not replace the GTO valve in m minus 1 module with a less expensive thyristor module, because it is a current control device since you are turning off the GTO of the thyristor in series, in GTO in series. So, no current will flow to the thyristor and thyristor will automatically go off.

So, less expensive conventional thyristor module, because a conventional thyristor valves operation of the total valve will be, would be different or the conventional thyristor valve cannot imitate the GTO valve operation even full condition of the capacitor switching. In order to obtain the half cycle wave, the GTO valve must have, must turn on and turn off when capacitor voltage is 0 at which instant the line current is the at the peak. So, this is something we required to do it.

So, turn on, turn off control is required so it is only possible with the GTO. Thus, the conventional thyristor valve could be turn off at the required instant when voltage is 0, but it will only off at the current zone. So, that is something we required to keep in mind. So, it is not possible to replace always the GTO this thyristor, this GTO by thyristors.

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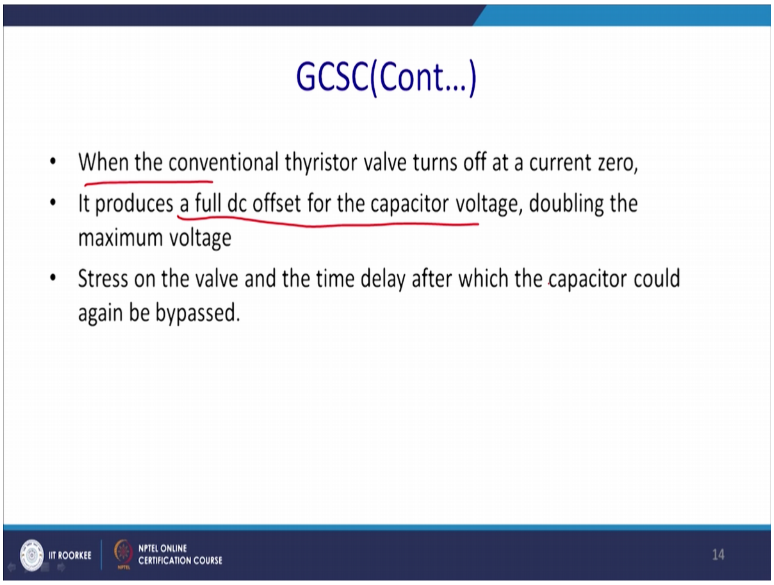

And thus, when this conventional thyristor valve turns off at zero current, it produces the full dc offset voltage to the capacitor and thus it doubling the capacitor voltage across the thyristor so, it doubling the maximum voltage. So, what will happen then the stress on the valve and the time delay after which the capacitor again will be bypassed will increase. So, we cannot actually put replace this GTO by a thyristor. Now, these are the discussion about the GCSC.

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Now, let us now go to the discussion on another static device of series type called Static Synchronous Series Compensator. So, it is equivalent almost statcom and a, but it is a series compensation. So, it is SSSC. So, what does it do?

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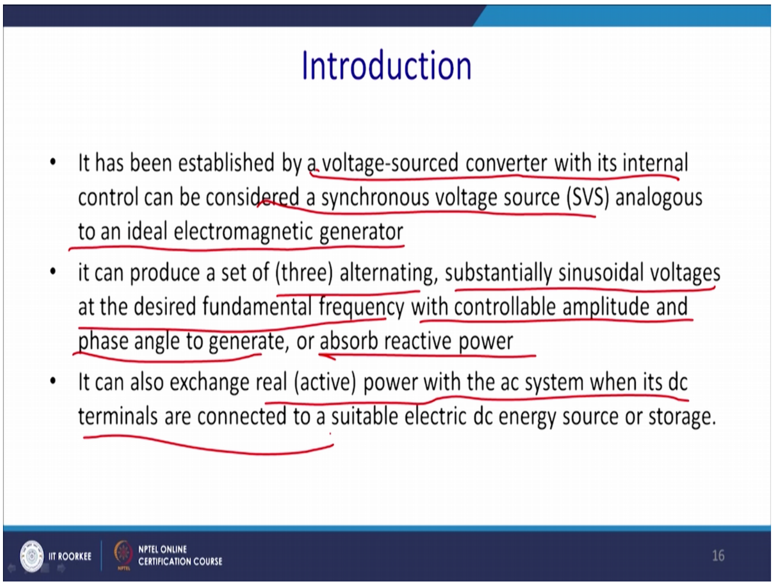

It has been established that voltage source converter with internal control can be considered as synchronous voltage source. And it is analogous to the ideal electromagnetic generator without any rotating part. Thus, does not have any inertia. It can produce a set of three alternating, subsequent sinusoidal voltages at the desire fundamental frequency with controlled amplitude and the phase angle generation and or absorb the real or reactive power.

Generally, it is made for absorb version of the reactive power, real power is automatically consume to meet the losses. It can also exchange real power with ac system when its dc terminals are connected to the suitable electric dc energy source storage cell.

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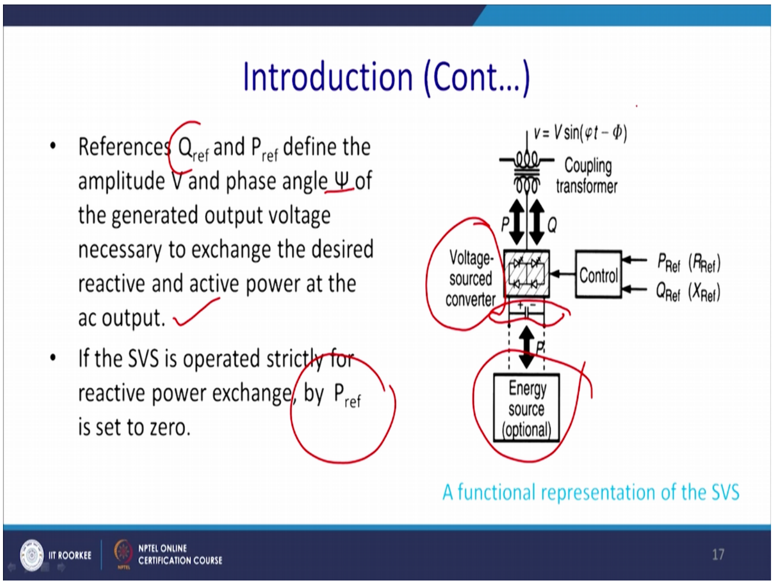

Now, this is the configuration. So, ultimately you got a coupling transformer, this is analogous to the statecom solution in the shunt for the series. So, this is a voltage source converter, according to the switch it will generate the reactive power and it come it if it is just comes with the capacity to meet the losses and the harmonics. Then it can inject the voltage and compensate the reactive power, otherwise if you have a storage device so it can also inject the real power. So, the reference Q ref and the P ref define the amplitude V and phase angle sigma is generated, phase angle psy is generated output voltage, necessary to exchange the desired reactive and the active power ac output.

So, if SVC operated SVS operated strictly for the reactive power exchange by setting P ref equal to 0, that mean you do not require any storage element. So, you have a V equal to V sin omega t minus phi and you have a coupling transformer. So, that will step down to the desired level. So, that the semiconductor switches can operate, semiconductor switch will generate voltage and current at in a desired phase shift as determined by the P ref and the Q ref and these voltage will be injected in series, choose the principle operation of this device SSSC.

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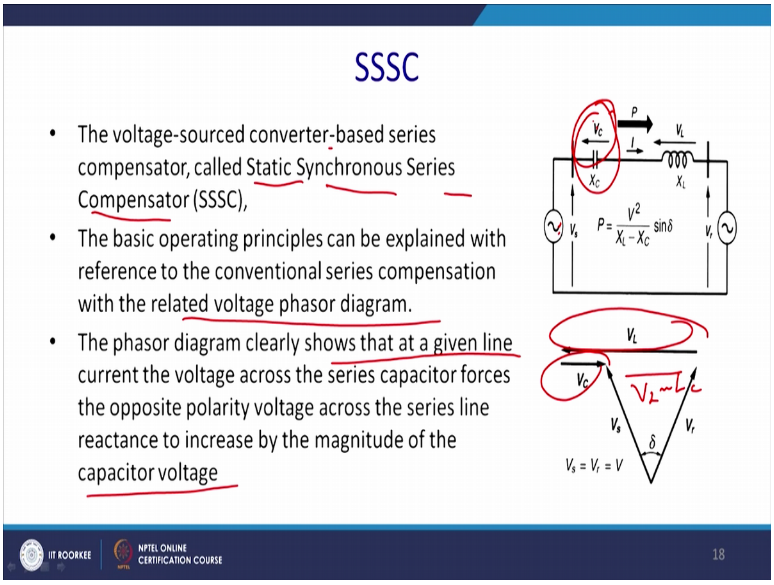

So, what does it do you know, the voltage source converter based series compensator is called Static Synchronous Series Compensator odd in abbreviation SSSC. The basic operation principle can be explained with the reference of the conventional series capacitor with the related voltage phasor diagram.

So, this is the, this thing this is the V C and this is the inserted impedance and this is excel and you know that in series compensation that P become V square X L minus X C into sin delta, the phasor and ultimately this one is V L and this one is V C. So, ultimately this difference differences is V L and V C. The phasor diagram clearly shows that at a given line current the voltage across the series capacitor forces the opposite polarity voltage across the series line reactance to increase the magnitude of the capacitor voltage.

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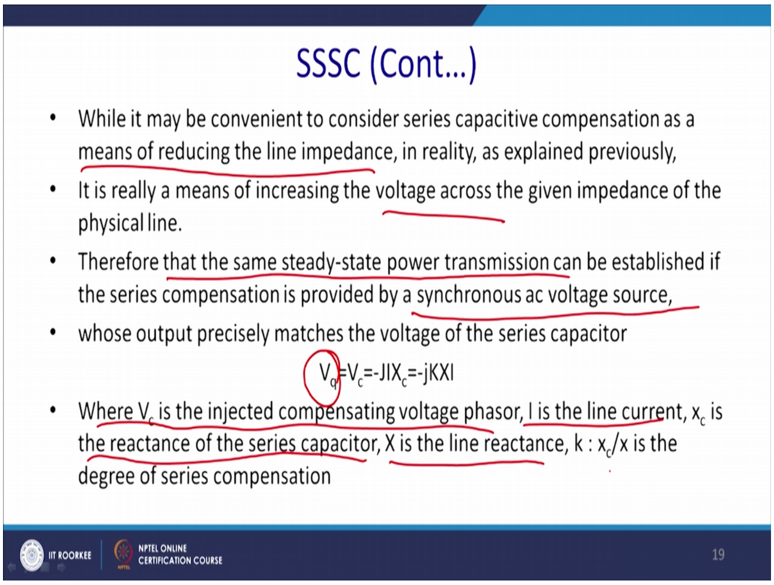

While it may be convenient to consider a series capacitor compensation as a means of reducing the line impedance, in reality, as explain previously, it is really means to increasing the voltage across the given impedance of the physical line.

So, here this will acts as a source and that will add on with it and that voltage source of course, is going to be in quadrature with phase, since it is a capacitor. So, therefore, therefore, that same steady state power transmission can be established if the series compensation is provided by a synchronized ac voltage source. That is the basic principle of operation of the SSSC, whose output precisely matches with the voltage of the series capacitor thus V q equal to V c equal to minus JIX c equal to minus jK into IX, K is the ratio of x c by X or XI. Where, V c is the injected compensating voltage phasor I is the line current x c is the reactance of the series capacitor, X is a line reactance and k is x c by x is the degree of the series compensation.

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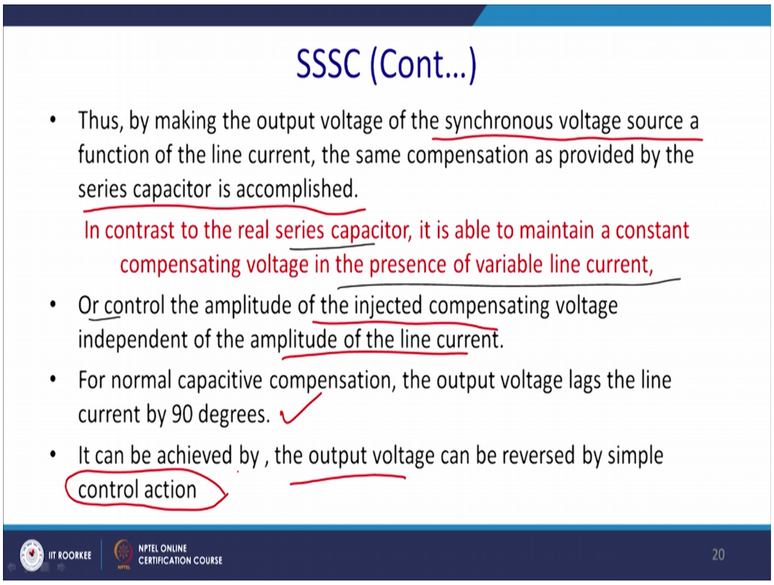

And thus making the output voltage of the synchronous voltage source a function of the line current, the same compensation as provided by the series capacitor can be accomplished. What is the difference? Difference is contrast the real series capacitor, it is able to maintain a constant compensating voltage V q that is the, previously you are compensating the impedance in your injecting the voltage, in presence of the variable line current that is the difference.

So, or control the amplitude of the injected compensating voltage the impedance of the amplitude of the line correct. So, what happened then for this, for normal capacitive compensation the output voltage lags the line current by 90 degree and it can be achieved by the output voltage that reverses the simple the control action, we see this in next slide.

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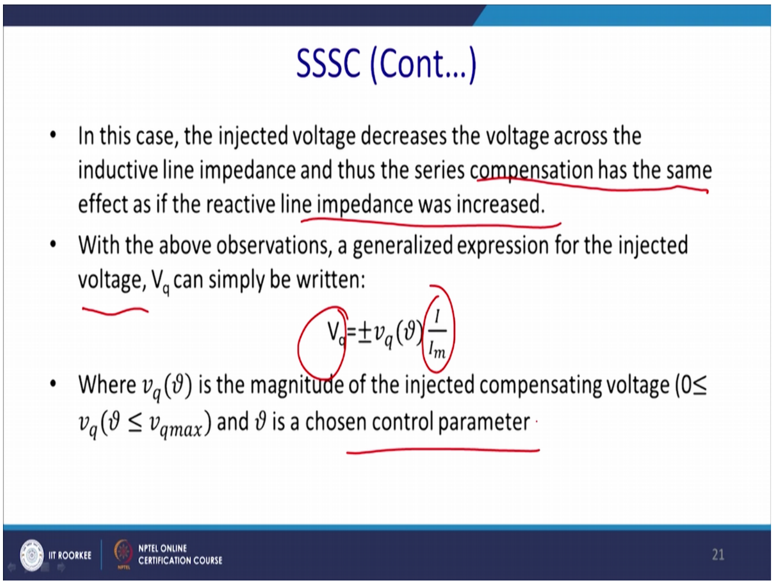

So, in this case the injected voltage decreases, the voltage across the inductive line impedance and thus the series compensation has the same effect as of the reactive line impedance was increased. So, this is the principle operation, with the above observation, a generalized expression for the injected voltage V q can be written that plus minus v q function V and by I by I m by unit vector. Where, v q is the magnitude of the injecting compensating voltage and within a range of zero to plus v q max. So, v is a choses as a control parameter.

So, we can we are about to actually in and last part of our class we will continue with the SSSC in our next class, considering the sending end voltage V lambda and the receiving end voltage V 0.

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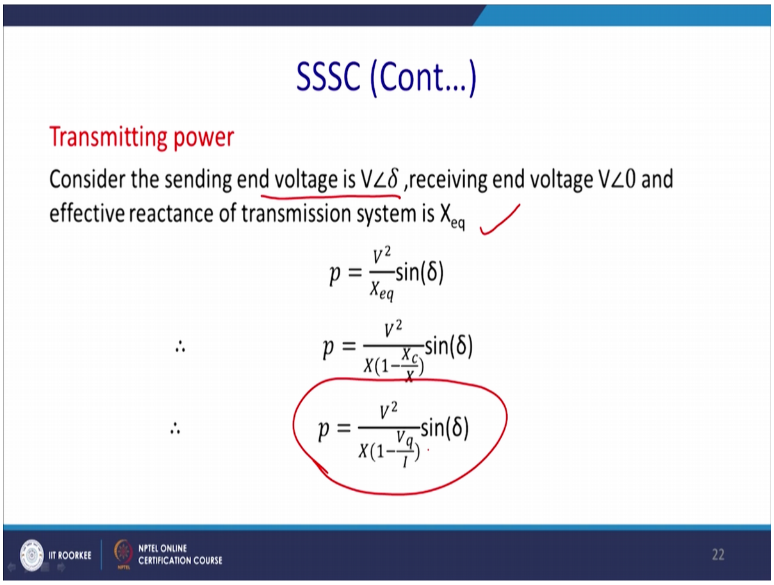

So, we can re write this equation. So, it is X equivalent we can write X equivalent and thus we can write the sending end power. So, the power sended by the line is V square by X 1 minusV q by I sin delta.

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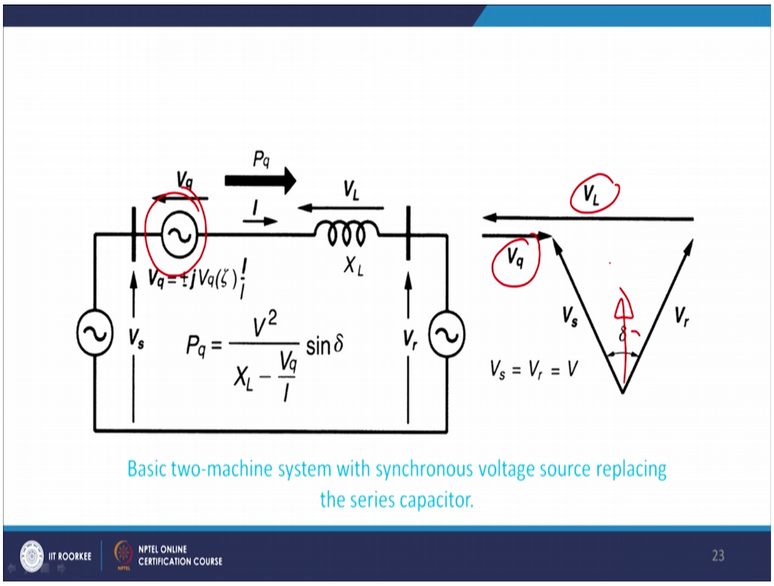

Basic two-machine system with synchronous voltage source replacing the series capacitor.

And thus we can model it as a voltage source which is perpendicular on quadrature with the V s and this is the power P q equal to V square X L minus V q by I sin delta this is a phasor where mod V s equal to V r equal to v. So, this is the delta and this is V L and this is a V q ultimately this become your actual voltage and this the perpendicular to this line I s. So, this is the case of the voltage injection.

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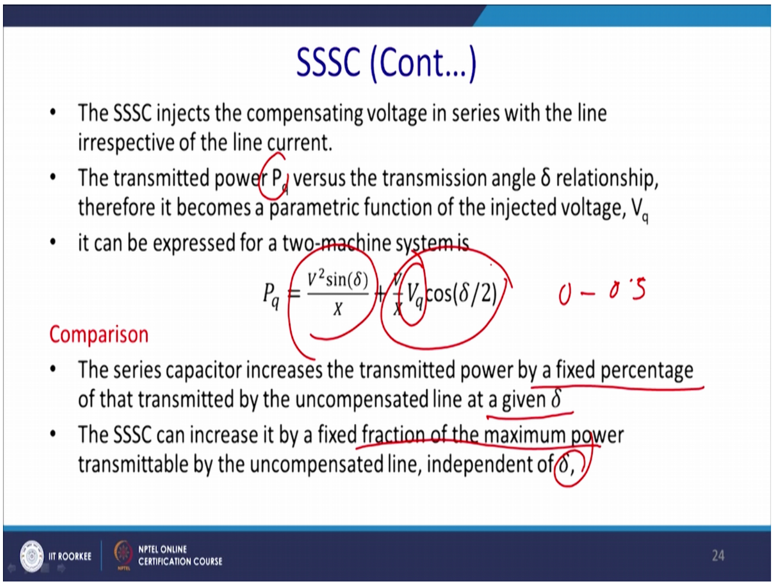

Now, the SSSC inject the compensation voltage in series with the line irrespective of the line current. The transmitted power P q versus the transmitted angle delta relationship is therefore, becomes a parameter function of the injected voltage V q. So, it will depend on the V q and it can be expressed for the two machine model, this part is same as the uncompensated line, there after this value will come v by, v by x V q, where, V q can be with vary to 0 to 0.5 per unit.

So, accordingly this power send by this limit will change and this is the V q constant. So, what is the comparison? Comparison is series capacitor increases the transmitted power by a fixed percentage of the transmitted power by uncompensated line at given delta. And SSC, SSSC can increase by a fixed fraction of the maximum power by transmitted power of the uncompensated line, by independent delta, because this term does not change by delta.

We shall continuity with a GCSC discussion in our next class. And then we shall discuss its characteristics over the GCSC.

Thank you for your attention.