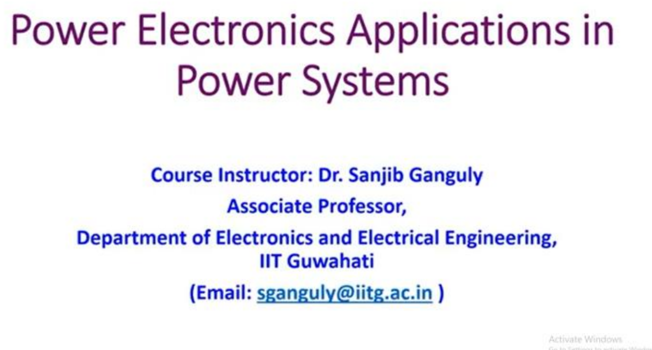
Course Name: Power Electronics Applications in Power Systems

Course Instructor: Dr. Sanjib Ganguly

Department of Electronics and Electrical Engineering,
Indian Institute of Technology Guwahati

Week: 09

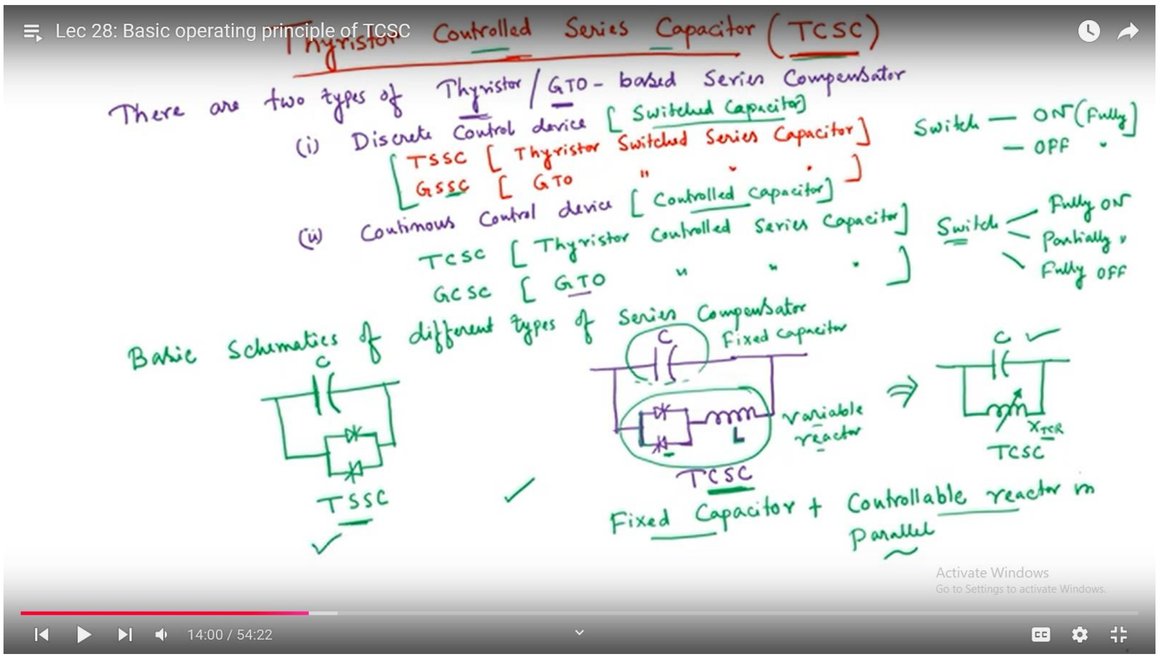
Lecture: 01



Lec 28: Basic operating principle of TCSC

Welcome again to my course Power Electronics Applications in Power Systems. Today I am going to start a new module. So far our discussion was limited to the shunt type of compensator and that is basically a static var compensator. In this particular module, I am going to discuss a kind of series compensator. In my earlier discussion, I already explained the difference between the shunt and the series compensators. This particular module gives you an idea of how this series compensator is different from the shunt compensator, what is the basic operating principle of the series compensator, and how we can control this, what are the applications of the series compensators and so on. But remember these series compensators are not of a single device. There are different kinds of series compensators. Today I am going to discuss a specific type of series compensator which is named as thyristor controlled series capacitor. So let us move.

So today I am going to discuss thyristor-controlled series capacitor and it is well known with its acronym TCSC. TCSC, thyristor-controlled series capacitor; Now, looking at this particular terminology, thyristor-controlled series capacitor, you may be surprised because I already discussed that capacitors cannot be controlled with semiconductor switches or there is no concept of a control capacitor. So, that is why when I discuss thyristor control capacitor, I explain why that philosophy does not exist. Rather we have the thyristor switch capacitor. So, if it is so, one may be surprised with the terminology that why it is thyristor control switch capacitor, how a switch capacitor can be controlled with the thyristor. But this I am going to discuss today and we will see here basically although the name is thyristor control switch capacitor but the thyristor is not controlling the capacitive reactance rather thyristor is controlling something else by which the overall impedance is controlled. So, this is I am going to discuss right now. So, basically there are two types of thyristor or GTO. You know GTO is a kind of switch like thyristor, its full form is gate turn off. So this is used instead of thyristor in some of the types of series compensators, we will come to that.



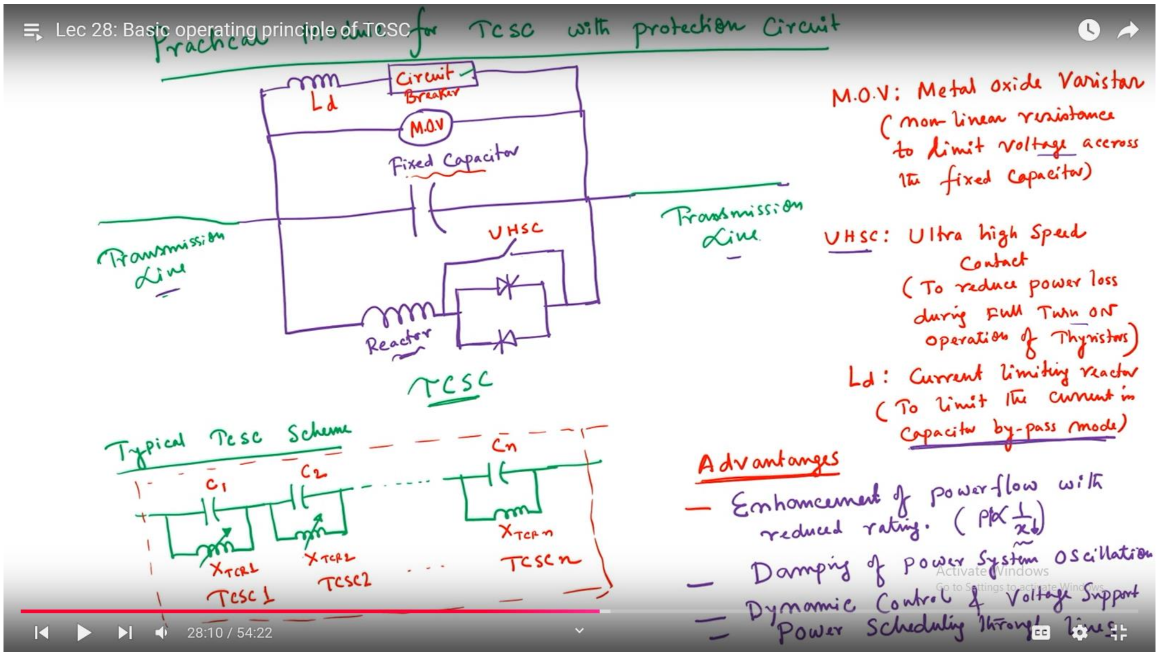
So there are two types of thyristor or GTO based series compensator. Number one is a discrete type of compensator, a discrete control device. And this is, you know, the example is, the example is TSSC, which is thyristor switched series capacitor or G S S C GTO switched series capacitor. Now, there is another type of device which is called a continuous control device. The examples are: TCSC which is already I mentioned that it is a thyristor control series capacitor or GCSC that is thyristor or this is GTO controlled series capacitor.

So, in discrete control you know I hope that you understand at this point the difference between the control capacitor and the switched capacitor. So, a control capacitor means the switch would be used in on condition, off condition, and also partially on condition. So, that means the switch whatever it would be used can be used for partial conduction mode and thereby it will control the entity which is connected with the switch or impedance which is connected with the switch. In the case of a switched capacitor, so this is a kind of switched capacitor, we do not have any partial conduction mode of the switches. So, this is switched capacitor.

So, in the switched capacitor, we do not have a partial conduction mode, whereas in a controlled capacitor, we have a partial conduction mode. So, here either switching operations would be done either fully on or fully off. Here switch will be switching operation will be three different types one is fully on another is partially on, and another is fully off. This is I believe that you understand with this terminology. So, this is something you are already aware of that a switch device means it is just capable of turning on and turning off.

A control device means the switches would be used in fully turn on, in fully turn off as well as partially turn on, okay. So, that is already discussed several times when I discuss static var compensator. Now, let us draw some basic schematics of these different types of series compensators. So, schematic-wise, this TSSC, it is something like this. We have a capacitor. We have a bidirectional switch. So, the symbol I have drawn is the specific type of switch that is thyristor you know. So, this is capacitor, this is bidirectional switch and this scheme is TSSC that is thyristor switched capacitor. Here you can see if both the switches are on, then it will create a short circuit path and it will bring out the capacitor from the system. And when they are fully off, the capacitor will be in the system and it will act as a fixed capacitor. So, both the switches are turned off, it will act as a fixed capacitor. When both the switches are turned on, it will act as a bypass capacitor or it will act as a short circuit. So, this is the mode of TSSC and in TCSC, in TCSC, we also have a fixed capacitor and we have a bidirectional switch like this, along with a inductor. So, this is the schematic of TCSC. In GCSC, just the switch would be different than is GTO, but the overall configuration would be the same.

Now, what is interesting to see here is that this bidirectional switch is connected to the capacitor in parallel along with an inductor. And here this is something like we have a fixed capacitor and we have a variable reactor. And both are connected in parallel. So, this schematic is something like this. We have a fixed capacitor and we have a variable reactor. Now, the reactance of this reactor is controlled by the switches over here. So, therefore, this is the overall basic schematic diagram of TCSC. So, we have a fixed capacitor, we have a variable reactor, this reactance we can consider it is as a XTCR. You know that by suitably choosing this firing angle of the switches, we can control the reactance which is in parallel with the capacitor. So therefore, here this controlled series capacitor is actually a control reactor with this fixed capacitor. So that means this scheme is nothing but a fixed capacitor plus a controlled or controllable reactor in parallel. And here as this name is controlled series capacitor, which is somewhat misleading I believe, rather this overall impedance of the device is controllable with the control of this inductance or reactance of the variable reactor, which is connected to parallel with the fixed capacitor. So, here capacitor would be, would act as a fixed capacitor, but in parallel to that we have a variable reactor, which in turn controls the overall impedance of the device. And that is why it is called control series capacitor. Basically, the switches are not responsible to control the capacitive reactance. Rather, the switches are meant for this control, switches are meant for controlling the overall impedance of the device. How it is possible? By controlling the reactance of the reactor, which is connected with the fixed capacitor in parallel. So, that is what the whole philosophy is. So, here we have a fixed capacitor along with a controllable reactor in parallel and this makes the scheme TCSC. Now as I said the TSSC scheme we will not discuss over here.



You can understand it is similar to this switched capacitor. Sometimes it will be turned on. When it is turned on then it is acting as a bypass mode and sometimes it will be turned off then it will be a fixed capacitor. So there is nothing to discuss over here. As such the switching action is very simple. But here we will discuss this TCSC scheme in more detail. Let me show you the practical module for TCSC with a protection circuit. Now, this practical module of TCSC includes many other entities, and many other different devices, particularly to protect the whole system for different operating conditions of the power system. So, let me draw the basic schematic diagram of this, so that you can understand that what are the components involved in it. So, we have the fixed capacitor this is a fixed capacitor. Then we have, as I have shown, we have a variable reactor. We have a bidirectional switch. I am drawing it TCSC, so the switches are of thyristor. If it is GCSC, the symbol of the switches would be different. Then this is connected in parallel with the fixed capacitor. So, this is the reactor. And as you know, since we have the bidirectional switch, this will be used to control the reactance of the reactor. But in addition to that, we have many other devices. One is ultra high speed switch. So, we have an ultra high speed contact over here. Here, UHSC stands for ultra-high speed contact or contactor.

So this is a kind of switch if you can understand that if you turn on the switch it will bypass the whole semiconductor switch and this would be required when you have fully turned on the operation of the switches. So, to avoid forward conduction loss, this UHSC would be turned on as soon as this full, this both the switches are fully turned on, just a few time after few microsecond or few millisecond after the both the switches are fully turned on, so that you can save the forward conduction loss. So, this UHSC is to reduce power loss during full turn-on operation of thyristors. So, we have UHSC, this is additional device which is connected in parallel to the semiconductor switches. Now, apart from that we also have many other device, one is there is a MOV, I am just writing.

So, this is basically M O V. Now, what do you mean by M O V? M O V stands for metal oxide, oxide varistor. Now, what it is actually? This is a non-linear resistance, this is a non-linear resistance to limit voltage across the fixed capacitor. So the philosophy behind this MOV is to protect this fixed capacitor from the sudden rise in voltage or from sudden over voltage. So for this MOV is to protect this fixed capacitor. The basic purpose of this MOV is to protect the fixed capacitor. Now what else is involved in it? We also have an inductor here and a circuit breaker. So, this is an inductor, I will come to that what is the purpose of the inductor and this is a circuit breaker. Now this purpose of the circuit breaker is to bypass the whole unit, whole TC unit, TCSC unit from the system whenever we require that, okay? So the circuit breaker will act as a bypassing switch of the overall unit whenever we require that, okay? So we need, we have various operating conditions, we will require that, okay? So this LD is a current limiting reactor. This is to limit the current in capacitor bypass mode. Now what do you mean by the capacitor bypass mode? As I said in fact in the next lecture I will discuss the different modes of operation of TCSC but in one of the modes would be capacitor bypass.

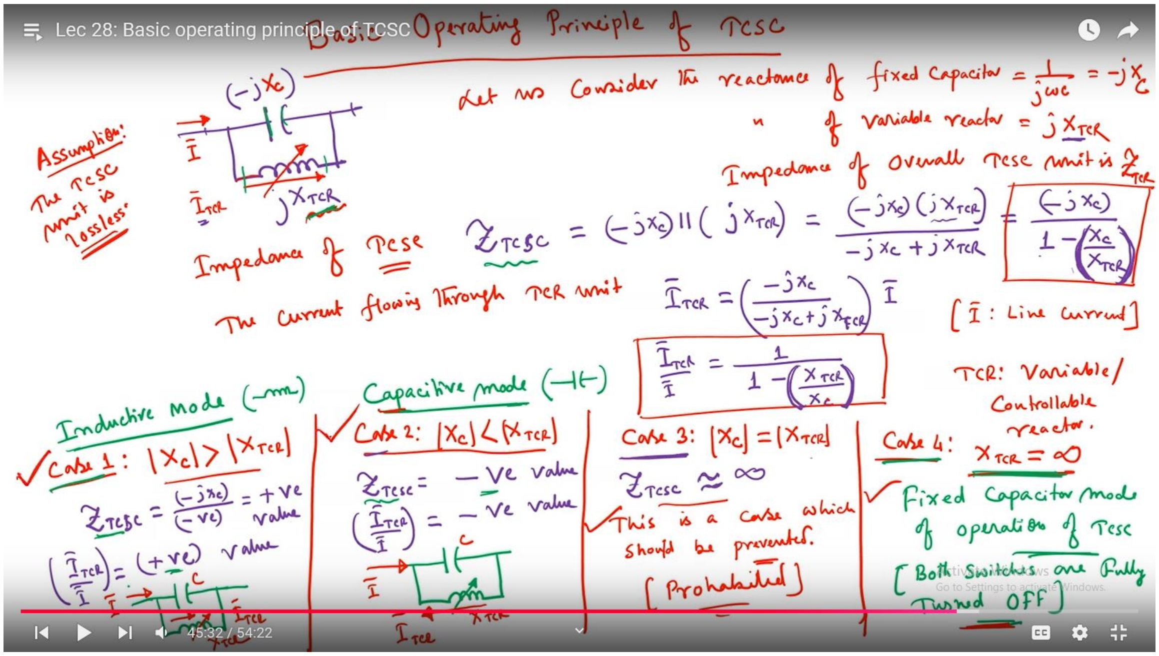
During that mode what we will do? We will just simply turn on the circuit breaker and thereby we will bypass the whole TCSC unit and this is a kind of protection and thereby we will save it from certain operating conditions. So, this is what the task is. So, as you know UHSC is for reducing this power loss or energy loss during full turned on condition. It will be turned on when this semiconductor switch will be fully on to save the forward conduction loss. This reactor is used to provide a variable reactance in parallel to the fixed capacitor. So the overall impedance of the whole unit would be controlled with the firing angle control of the switches and by controlling the reactance of the reactor as we know and this MOV is you know it took for protecting this fixed capacitor to limit the voltage across the capacitor and the circuit breaker will act as a this bypass mode of operation of the overall device. So, this constitutes the overall TCSC unit. This will be connected in series with the transmission line. So, this is a transmission line.

So, this is a transmission line. So, since it is a kind of series compensator, it will be connected in series at any point of the transmission line. But we also have this bypass mode of operation by using the circuit breaker and we have separate different protection units in this particular system. However, a TCSC unit does not consist of a single TCSC unit, rather it consists of a number of TCSC units connected in series. So, actual TCSC unit, typical TCSC scheme is something like that, we have one TCS unit, I am just representing it with a fixed capacitor and variable reactor. So, suppose this constitutes a TCS unit C 1, this is X TCR 1. And similarly, we have the same identical unit, multiples such kind of identical units in series like this. Okay. So, we can understand that this is C2 fixed capacitor 2, this is X TCR2, and this is CN X TCRN. So, we have this is TCSC1, this is TCSC2 and similarly we have TCSC2. N number of TCSC units which will be connected in series to form a single TCSC scheme.

So, this is how this, the practical schemes or typical scheme of TCSC. And next, I will come to that, what is the advantage? What this TCSC does? Before I discuss the basic operating principle, what a TCSC does? Now what are the advantages? I will discuss this TCSC application in very detail whenever I will complete the basic discussion of the operating principle of the TCSC or mathematical modeling of the TCSC. But you should know at this point what are the typical advantages of TCSC. The advantages are, or why should we use TCSC in a practical power system. So the advantages are it enhances enhancement of power flow with reduced rating.

Now one should understand very easily any student who has done the basic power system course can understand why it will increase the steady state power transmission capacity or power flow through a particular transmission line. Since you know that this power flow through a particular transmission line is inversely proportional to the reactance of the line. So, when you connect TCSC in series with a transmission line, what it will do? It will reduce the reactance. And therefore, when this denominator is getting reduced, power flow will definitely get increased. So, basically it is because that power flow is inversely proportional to x, x is the overall reactance of the transmission line and this TCSC can reduce the value of x. So, reducing the x will increase the p. So, this is very simple to understand. Now, second is, it can provide damping of power system oscillations, power system oscillations. How it provides damping, I am going to discuss at the end. And also, it provides dynamic control and voltage support. There are some other you know roles of the TCSC which I am going to discuss when I will discuss the application of TCSC in power systems in very detail.

One of this role is to when we have multiple transmission lines in parallel, a TCSC compensated line can ensure the constant power flow through this line or maybe it is one of the parallel line. So, it is also be helpful in power scheduling. So, one of the advantages of it is to power scheduling through transmission lines. So, these are the typical advantages. There are disadvantages as well, I am going to discuss at the end of this. However, right now I am going to discuss the basic operating principle of a TCSC in very simplistic manner. Basic operating principle of TCSC. So, what we will do here is, we will consider TCSC just by a fixed capacitor and a variable reactor. So, this is fixed capacitor, this is variable reactor. So, what would be the reactance offered by the fixed capacitor will be 1 upon j omega c, so that is basically minus j omega c.



Basic Operating Principle of TCSC

Assumption: The TCSC unit is lossless

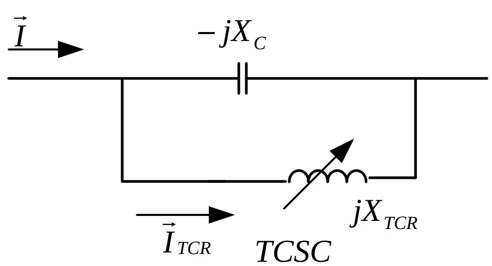


Fig. 1 Single line diagram of TCSC connected in line

Let us consider a TCSC connected transmission line as shown in Fig. 1.

The reactance of fixed capacitor= $\frac{1}{j\omega C} = -jX_C$

The reactance of variable reactor= jX_{TCR}

The impedance of overall TCSC unit is Z_{TCSC}

Now, $Z_{TCSC} = (-jX_C)//(jX_{TCR}) = \frac{(-jX_C).(jX_{TCR})}{-jX_C+jX_{TCR}}$

Impedance of TCSC $(Z_{TCSC}) = \frac{(-jX_C)}{1-\frac{X_C}{X_{TCR}}}$

The current flowing through TCR unit $\vec{I}_{TCR} = \left(\frac{-jX_C}{-jX_C+jX_{TCR}}\right).\vec{I}$ [$\vec{I}$: Line current]

$$\frac{\vec{I}_{TCR}}{\vec{I}} = \frac{1}{1-\frac{X_{TCR}}{X_C}}$$ [TCR: Variable/controllable reactor]

- Case 1: When $|X_C| > |X_{TCR}|$,

$Z_{TCSC} = \frac{(-jX_C)}{(-ve)} = positive\ value$

$\left(\frac{\vec{I}_{TCR}}{\vec{I}}\right) = positive\ value$

⇒Inductive mode of operation (TCSC behaves as an inductor connected in series with the line)

Direction of current flow in TCR is similar to the line current as shown in Fig. 2.

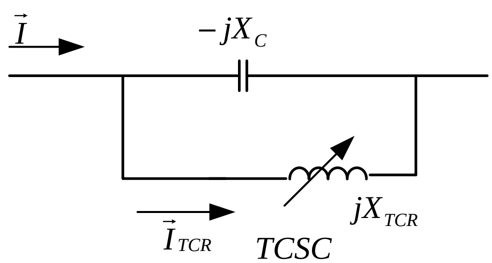


Fig. 2. Current flow direction in inductive mode of operation

- Case 2: When $|X_C| < |X_{TCR}|$,

$Z_{TCSC} = negative\ value$

$\left(\frac{\vec{I}_{TCR}}{\vec{I}}\right) = negative\ value$

⇒ Capacitive mode of operation (TCSC behaves as a capacitor connected in series with the line)

Direction of current flow in TCR will be opposite to the line current as shown in Fig.3.

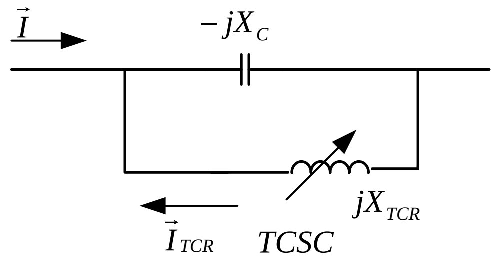


Fig. 3. Current flow direction in capacitive mode of operation

- Case 3: When $|X_C| = |X_{TCR}|$,
  $Z_{TCSC} \approx \infty$
  This is a case which should be prevented. [Prohibited]
  $\Rightarrow$ Parallel Resonance

- Case 4: When $X_{TCR} = \infty$
  This is a fixed capacitor mode of operation of TCSC [Both switches are fully turned OFF]

<u>Suppose:</u>

(i) $X_{TCR} = 1.5X_c$

$$Z_{TCSC} = \frac{(-jX_C)}{1-\frac{X_C}{X_{TCR}}} = \frac{(-jX_C)}{1-\frac{1}{1.5}} = (-j3X_C)$$

$$\frac{\vec{I}_{TCR}}{\vec{I}} = \frac{1}{1-\left(\frac{X_{TCR}}{X_C}\right)} = \frac{1}{1-1.5} = -2$$

$\Rightarrow$ Capacitive mode of operation

(ii) $X_{TCR} = 0.75X_c$

$$Z_{TCSC} = \frac{(-jX_C)}{1-\frac{X_C}{X_{TCR}}} = \frac{(-jX_C)}{1-\frac{1}{0.75}} = (+j3X_C)$$

$$\frac{\vec{I}_{TCR}}{\vec{I}} = \frac{1}{1-\left(\frac{X_{TCR}}{X_C}\right)} = \frac{1}{1-0.75} = +4$$

$\Rightarrow$ Inductive mode of operation

In both the cases, the impedances of TCSC are same. However, the TCR current is twice in inductive mode of operation as that of the capacitive mode. This is an important consideration in choice of the ratings of thyristors as thyristor should be designed according to maximum current carrying capability.

Similarly, what would be the impedance offered by this X TCR, it will be j X TCR. Now, suppose the current flowing through this particular transmission at any instant of time is I. And current flowing through this TCR is I TCR. Why I am calling it TCR?

Because it is similar to the thyristor control reactor. It is simply a reactance whose reactance value is controlled with the partial conduction of the switches connected in series with it. So, at this point, you have to understand. Now let us consider the reactance of the fixed capacitor is 1 upon j omega c, which is 1 upon j omega c, which is, this is not true, this is represented by j x c. So, this is represented minus j x c. Now, the reactance of the variable reactor is equal to J X T C R. And let us consider the impedance, impedance of the overall T C S C unit is Z T C S. Then what we can write that this Z T C S C T C S C is equal to this minus j X C in parallel with this j X T C R, X T C R, which is equal to minus j X C multiplied by j X T C R divided by minus j X C plus j X T C R.

This can be written as if we just divide this numerator and denominator with this j x d c r. So, the numerator will have j x c and the denominator will have 1 minus x c divided by x d c r. So, this is what This is what the net impedance of the TCSC. Here we know that we have already taken an assumption. What are the assumptions that we have taken? Our assumption is the whole unit, the TCSC unit is lossless. So, this is, even though I do not mention, you should understand at this stage that when we say so, that this fixed capacitor reactance is minus j x c, this variable inductor reactance is j x TCR, then already we consider this assumption that TCSC unit is lossless. Now, similarly, the current flowing through the TCR unit will be equal to I TCR is equal to as you know this I TCR it will be equal to this impedance minus j x e divided by this summation of both the reactants or impedance that is minus j x c plus j x d c r multiplied with I, where I is the line current, I is the line current. Now, again if we just divide it by minus j x c in numerator and denominator to bring this and also if I take the ratio of i TCR to i, then this would be equal to 1, 1 minus x TCR divided by x c. So, this is the ratio of the current flowing through this TCR unit.

Now, what is TCR? This TCR is basically the variable reactor. Here TCR stands for variable or controllable reactor. Now let us see that when we can vary this reactance of the reactor, there might be four different cases. The case one, it may so happen that this Xc magnitude is higher than Xtcr. So this is case one. In case 2, it may so happen Xc magnitude is lower than Xtcr. This is case 2. This is case 1. In case 3, Xc magnitude is equal with Xtcr. This is case 3. And in case 4, xtcr is considered to be infinite. When it is possible? When this is xtcr is open circuit, that is the thyristors are fully turned on, fully turned off. Now, let us see that what would be the consequence of these cases. Now, according to this first case, when xc is greater than xtcr, so that means xc and xtcr, this is the ratio. So, if xc greater than xtcr, this ratio would be greater than 1. Then 1 minus this something which is greater than 1 will give you the negative quantity.

So, therefore, the denominator of this would be negative. So, therefore, here ztcsc will have this minus j xc in the numerator and some negative quantity in the denominator, which will give you some positive value. What is the, you know, consequence of that and what does it imply? I am coming to that. But this is what will happen. Similarly, this ratio of this ITCR to i. What it will happen? Since this x c is greater than x t c r, so you can look at this is what the ratio that is x t c r to x c, but if x is greater than x t c r, so this ratio would be lower than 1, that is it will be fractional. So, therefore, 1 minus some fractional quantity would be also fractional, so this would be also positive. So, some positive value. Now, what will happen in case 2? In case 2, you can see this ZTCSC would be equal to, since xc is lower than xtcr, see xc is lower than xtcr, this would be fractional definitely. So, xc to xtcr ratio would be fractional.

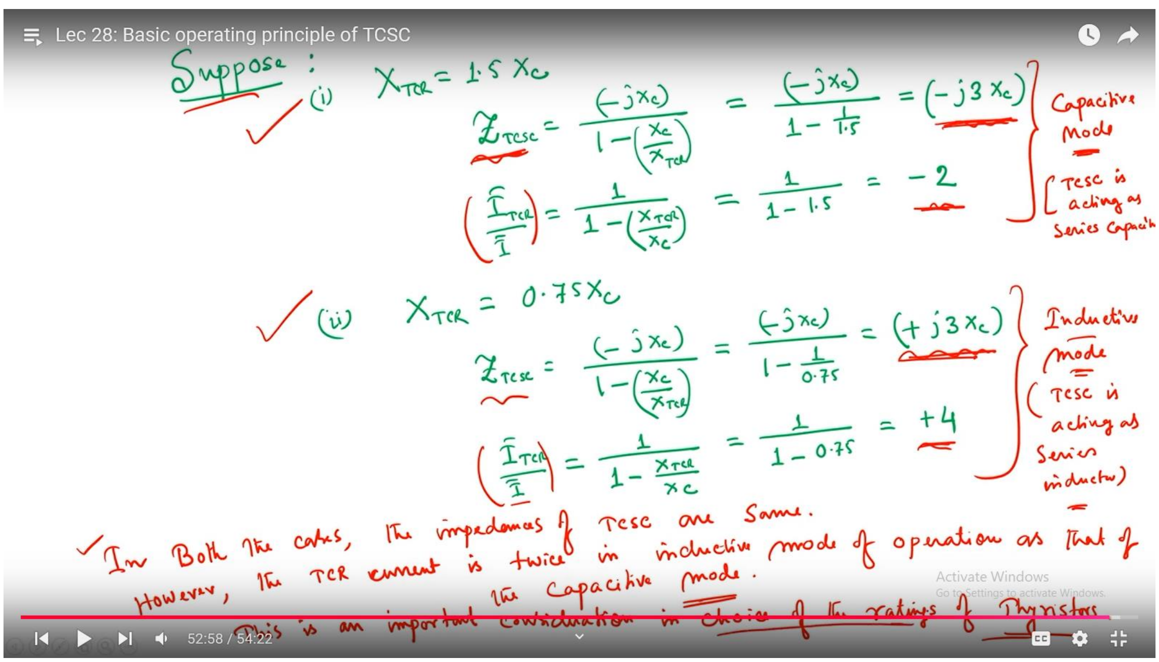
So, since xc is lower than xtcr, so this ratio would be fractional. So, 1 minus this would be So, in the denominator, we will have a fractional quantity, but positive quantity. In numerator, we have a negative quantity. So, therefore, Ztc will have negative value. And what about this ratio Itcr to i? This is the ratio of the current flowing through this TCR that is ITCR to the line current or this current flowing through the transmission line. This ratio since xc is lower than xtcr, so this ratio xtcr to xc will be greater than 1. So, then this denominator would be negative. So, numerator is already 1, so this would be a negative value. Now, what does it mean actually, I am coming to that. Now, this is a very interesting case, case 3, when xc is equal to xtcr. So, this would be equal to 1, this ratio, xc to xtcr.

So, in the denominator of ZTCSC, it will be 1 minus 1, which is 0. So, therefore, this ZTCSC will be close to infinity. It will be close to infinity. So, this is a special case and this is a special condition that we should not want to see because when ZTCSC is infinite that means since this TCS is connected in a series of the transmission line, wherever it is connected at the transmission line it is offering an infinite impedance. So, it is creating an open circuit that makes the line open, which is a situation that is not wanted. So, this is a situation, this is a case, this is a case which should not or which should be prevented, which should be prevented. So, this is one of the control constraints or design constraints such that this case will never attain. So, that is something that is interesting. Now, what about this particular case when X TCR provides infinite impedance as if there is an open circuit there. So, this is a case when it is the operation of fixed capacitor mode of operation of So, in case 4 if it attains that means if this is xtcr this variable reactance is infinite means switches are turned off that means this will happen when both switches are fully turned off. So, therefore, this is a very special situation which may be considered, this is not a situation which should be prevented, but it is a condition when there is no role of this TCR, there is no role of the variable reactor, rather this will be turned off and this whole unit will act as a fixed capacitor.

Now, coming back to this, this case 1, so ZTCSC is positive. So, when ZTCSC is positive, when we have both reactants, one is negative, another is positive, that is a kind of inductive mode of operation. So, this is a kind of inductive mode of operation. Similarly, overall impedance when it becomes negative, then it is a kind of capacitive mode of operation. So, this TCSC can be operated either in inductive mode, that means it is, as if operating as an inductor in series and it is, and it can be also be operated in capacitive mode as if there is an overall capacitor connected in series.

So, both the modes of operation are possible with the TCSC. So, when TCSC will attend this particular case, that means we have a simple inductor connected in series. And, when you have a this capacitor mode of operation as if we have a some capacitor connected in series with the line. So, this is what the difference of of that. However, there is another difference as well. If you look at this I T C R I are positive values. It means it will be something like this. We have a capacitor, we have a variable reactor. Now, when this is positive, it means, suppose the direction of the line current is this, this is what the direction of line current i. So, this current flowing through this variable reactor, which will be also in the same direction, that will be it is here as the line current.

So, the direction of the current flow would be similar to the line current. Whereas, when you have this ITCR to I ratio negative, it means that suppose this is your fixed capacitor, this is our variable reactor, this is fixed capacitor, this is variable reactor. This is fixed capacitor, this is variable reactor. So, when the current flowing through this is in this direction, when the whole unit will operate as a capacitive mode, the current flowing through the TCR would be just opposite to the line current. So, this will be I TCR. So, this is something is the difference between these two modes and normally in TCSC operation, this mode is prohibited.



This mode is also not likely to happen because in that case there is no control operation, but this may happen, this is a valid mode of operation. However, mostly these TCSCs operate under these two schemes, one is an inductive mode of operation, another is a capacitive mode of operation. And these two are two different mode of operations possible. Now, one more thing I am going to discuss regarding this different mode of operation Now suppose we take two cases or we take two points. One is let us consider that X TCR is equal to 1.5 times of XC that is reactance of the capacitor. So, this is one case. Another case is, suppose X TCR is equal to 0.75 of the X C. Now, what would be the Z TCSC here? So, Z TCSC you know that impedance of this whole TCSC unit, it will be equal to minus J XC divided by 1 minus, if I go back and see, this is equal to this ratio of XC to XTC here. So, this is x c to x TCR and this ratio of i TCR to i. Now, what does it means? This is the ratio of the current flowing through the TCR to the line current. It is equal to 1 upon 1 minus x TCR to x. Am I correct? So, this is 1 upon 1 minus the ratio of X TCR to X C. So, if I now put these values, this will be equal to minus j X C, the numerator will be as it is, the denominator will be different 1 minus X C to X TCR.

So, this is basically 1 minus 1 divided by 1.5. Now, if you do this, this will be coming out to be minus j3 xc. And if you put over here, so this will be 1 upon 1 minus xtcr to xc that is 1.5. So, that is equal to 1 minus 1.5 is 0.5. So, this is equal to minus 2. Now, what is the mode of operation it is? Without having seen anything, since overall impedance is negative, so this is a kind of capacitive mode of operation. Here, you know, the ratio of this currents is minus 2 and this is J3. Now, similar to this, let us consider this case. So, in that case, ZTCSC will be equal to minus JXC divided by 1 minus the ratio of XC to XTCR, which can be written as minus JXC divided by 1 minus So xc to xtcr ratio is 1 upon 0.75. If you do this calculation, this will be equal to plus j3 xc. And this ratio itcr to i is equal to 1 minus 1 upon 1 minus X TCR to xc which is equal to 1 divided by 1 minus x TCR to xc is equal to 0.75. So, this is equal to, this is 1 minus 0.75 is 0.25. So, this is equal to plus 4. And looking at this, you can understand that since overall impedance is positive, so this is an inductive mode of operation as if the whole unit will act as a series inductor. So, here whole unit as a series capacitor. So, it is acting as a, TCSC is acting as series capacitor. Here, TCSC is acting as series inductor.

Now, if you look at this JTCSC values, one is minus J3 xc, another is plus J3 xc. Ideally, both offer the same impedance. So, in both cases, the impedances of TCSC are same. So, that is you can see over here, one is minus j 3 x, another is plus j 3 x. However, the TCR current, if you look at this ratio, one is this, which is minus 2, and another is this, which is plus 4, that means TCR current is twice in inductive mode of operation as that of the capacitive mode. Now, why it is so important to have this case study? You can see that although in both the cases, the impedance offered by the TCSCs are same, but the current flowing through the TCR is double when we have the inductive mode of operation.

This is very useful in the choice of the rating requirement of the switches. So, this is an important consideration in the choice of the ratings of thyristors. So the whole philosophy behind this analysis of the case study is that when the choice of the rating requirement of the thyristors would be done, this consideration is to be considered that if it is operated in inductive mode, the current flowing through the inductor would be twice as that of the capacitor mode of operation having the same impedance. So, that is something very important to understand. So, with this, I will finish this first lecture of TCSC and we will continue this lecture in my future lectures as well to discuss this TCSC in more detail.

So, till then, thank you very much for attending this particular lecture. I look forward to see you in the next lecture.