Course Name: Power Electronics Applications in Power Systems

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Lecture: 04

Lec 20: Design of TSC-TCR: Numerical Example

Welcome again to my course Power Electronics Applications in Power Systems. So, in the last few lectures, I was discussing different types of static power compensator, right? In the last couple of lectures, I basically discussed a specific type of static power compensator, which is named as thyristor switch capacitor or TSC in short, right? When I discuss different types or different categories of static VAR compensators, I said that there are two different types of compensator or static VAr compensators, one which can absorb the reactive power, another which is delivering reactive power, which can deliver the reactive power. So, in general, we merge this together to form a unified kind of static VAr compensator which can capable of supplying reactive power as well as absorbing reactive power. So, in general, this TSC or thyristor switched capacitor. is also used another type of this static var compensator which I already discussed that is thyristor control reactor and they constitute a single device and that device can capable of providing as well as absorbing the reactive power. So the objective or goal of today's discussion is to understand the combined operation of thyristor switched capacitor, thyristor control reactor as a static var compensator unit.

So let us proceed that. So in today's discussion, we will discuss thyristor switched capacitors, in sort TSC, along with thyristor control reactor. In short, it is TCR. Usually, this unit is named as TSC-TCR. Now, what I will discuss today is the basic operating principle of TSC-TCR. Since the operating principles of this TSC and TCR are already discussed separately, it is it will be easier to all of you to understand the operation or basic operating principle of TSC, TCR when they will be combined and act as a single static var compensator unit, right? So, what we will do is we will draw the single-line diagram, remember this is also a three-page device, but we will consider it is to be balanced and we will consider the system to be balanced and we will draw here is a single-line representation of TSC TCR. Suppose this is the bus at which we will place this TSC-TCR unit. So, then what we will have, we will have a step down transformer as usual to step down the voltage level to a reduced voltage level.

This is we followed in all the different types of the static bar compensator. Then we will have multiple TSC unit as well as multiple TCR unit. So, that let us assume that we will be having three numbers of TSC units like this. So, in TSC unit as we know the single line representation is we have a small reactor and we have a capacitor, right. So, let us consider we have a three identical TSC units connected in parallel. This is a small reactor and this is the capacitor unit. So, there is another such unit like this. This is the mole reactor and this is the capacitor. And these three units are identical as you know.

Then what we will have is the LC filter. This is required specifically for TCR operation that I already discussed. And then we will be having TCR unit. This is the bidirectional switch. We consider it is a thyristor and we will be having the reactor. So, here if you look at, these are TSC units, TSC units, this is LC filter, LC filter, to suppress some of the harmonics, dominant harmonics, which will be generated by this TCR unit. This is TCR unit. This is the reactor of this TCR unit. These are the LC filter, LF and CF. These are the capacitors which are represented by let us say C 1, C 2 and C 3, assuming that all these are identical, C 1, C 2, C 3 are identical.

So, this is what the single line diagram of a TSC TCR unit. So, this is single line diagram of TSC TCR unit. And as you know, this is step down transformer, this is step down transformer and this we keep so that the voltage level as of the TAC, TCR will be much lower than the system voltage level. Now, system voltage level can be a transmission line voltage level, in India it is you know 220 kV, 400 kV and 765 kV. These are pretty high voltage levels.

So, in this voltage level if we need to design this kind of static var compensator, then the compensator cost would be very high. So, what we can do is that since it is a shunt connected device, we can step down the voltage level to much lower voltage level and we can design the static var compensator. Now, usually A TSC-TCR, a TSC-TCR consists of multiple TSC units all are identical, all are identical and single or multiple TCR unit. Usually this number of TCR unit is kept less so that the total harmonic generation by this TCR operation is also less. In fact, normally the common practice is that even if in this case of TCR we keep some of the thyristor switched reactor that is TSR and some TCR.

only one or two as TCR, so that the total harmonic generation by the TCR would be less. Now, the thumb rule is, the thumb rule is to select in identical TSC units and 1 TCR unit. As I said, the number of TCR unit is kept less. So, that the total harmonics generation would be also less because one of the major bottleneck of the operation of TCR you know that the harmonic generation. So, the next is the TCR rating is chosen such that its rating is one nth of the total rating of TSC.

This is a thumb rule, not necessarily that you have to follow this rule, but this is a thumb rule in designing TSC, TCR. So, basically as I said that the number of TCR unit is kept less, so that it is used to be a single or maximum 2, so that the total harmonic generation of the whole unit is less. Now, here what we will do is that. We will design a TSC TCR so that we can understand its basic operating characteristics that is voltage-current characteristics in very well. So, what we will do? We will consider a design problem.

So, let us design a TSC TCR unit which can provide one per unit of capacitive compensation, capacitive compensation and 0.3 per unit of inductive compensation and assume that the susceptance of the step down transformer is 6 per unit. 6 per unit. We usually consider the susceptance of the step down transformer as B sigma. So, since it is 6 per unit, it means that B sigma is equal to minus 6 per unit. Remember, the susceptance of the step down transformer is an inductive kind of susceptance because we assume that a transformer is modeled with this leakage reactance because this unit will be considered to be a lossless. So, our assumption is that the whole unit is lossless. If it is so, then this susceptance of the step down transformer basically the reciprocal of the leakage reactance of a transformer and it is considered to be 6 per unit. Since you know the leakage reactance is a kind of inductive reactance, so the susceptance of an inductive kind of reactance is negative as already I discussed. So, therefore, this V sigma is minus 6 per unit.

We will consider the system voltage, system voltage is 1 per unit. It means that the whole design would be done considering the system voltage or bus voltage as 1 per unit. Now when you consider so, what does it mean actually? If you consider the system voltage 1 per unit, then 1 per unit of capacitive compensation which is mentioned over here stands for 1 per unit of the capacitive compensation stands for 1 per unit of the total of the whole TSC, TCR unit when it is operating at the maximum production limit. This is something one needs to understand.

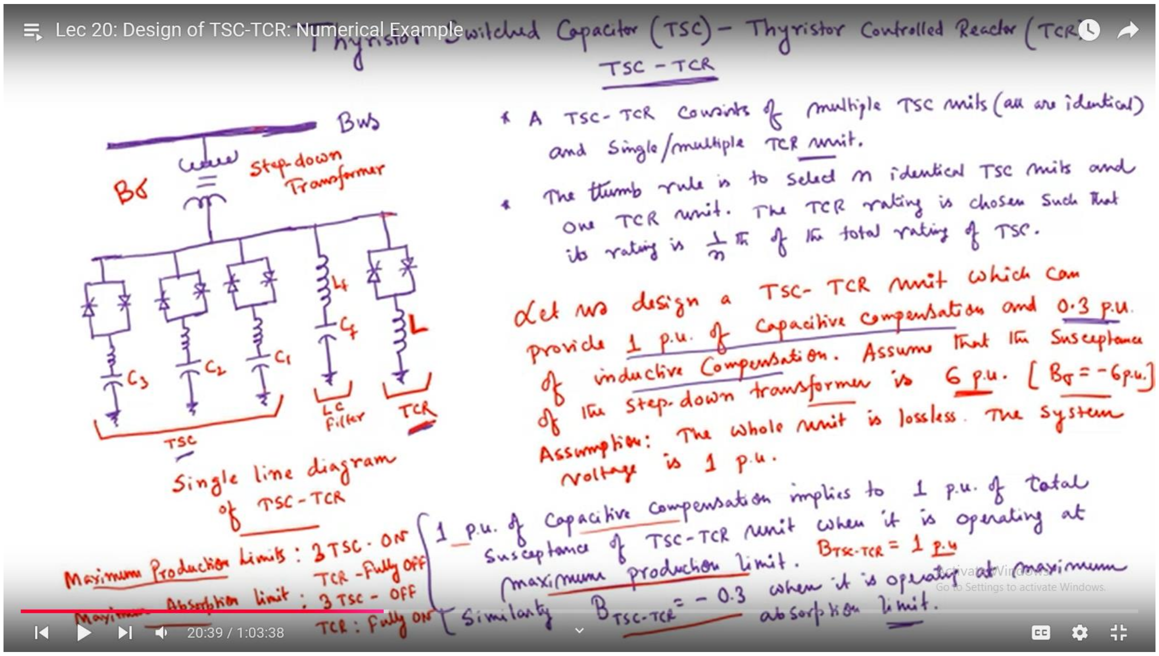
So, I will write it. So, it implies that 1 per unit of capacitive compensation means, capacitive compensation implies to 1 per unit of total susceptance of TSC TCR unit when it is operating at maximum production limit. This is something that is very important to understand. Similarly, this 0.3 per unit of inductive compensation stands for susceptance of the whole unit is equal to 0.3 or is equal to minus 0.3 when the whole unit is operating at maximum absorption limit. The susceptance, if we consider the susceptance of the whole unit is considered to be B T S C T C R is equal to minus 0.3 when it is operating at maximum absorption limit. This is something one needs to understand and also one needs to understand that when this TSC TCR will operate at its maximum production limit then TCR should be turned off and all this TSC units will be turned on ok. If I write so here maximum production limit, production limit corresponds to 3 TSC are turned on full. Because TSC is thyristor switched capacitor, it can be either turned on or completely turned off. There is no partial turned off operation. I explained the reason. And this TCR is fully off. Then only this whole unit can operate at the maximum production limit.

It means that all these three capacitors will be turned on and the inductive unit that is TCR unit will be fully turned off. So, then we can operate it as a maximum production limit. Similarly, maximum this absorption limit absorption limit means that 3 TSC unit will be off and TCR will be fully on. This is something one needs to understand. This is something one needs to understand very clearly that when the whole unit will be operated at maximum absorption limit that means that we need to turn off all the TSC unit and the TCR unit would be fully turned on.

Then only it can be able to absorb the rated amount of var from the system and that corresponds to this B TSC TCR is equal to 0.3. Whenever this 1 per unit of capacitive compensation to it implies to that at this particular operating condition when it is operated at maximum production limit B TSC TCR is equal to 1 per unit. Now, based upon that, we need to design the reactance value of the reactor of the TCR unit and also the capacitances of the capacitor unit. Remember, although I wrote this C1, C2, C3, but they are identical. So, C1 is equal to C2 is equal to C3. That is something one is to understand. Now, what we will do is, we need to find out corresponding to these two conditions, we need to find out what would be the maximum rating or maximum susceptance of the TCR and what would be the maximum susceptance of each of the TSC unit. So, in order to find that, so if I write again that what we get it that B TSC TCR when it is operating it at maximum production limit.

It is equal to 1. Now, what does it mean? This TSC TCR will be operated at maximum production limit, then it will be a combination of this three susceptance of the TSC unit. And, it will be in series, there will be this susceptance of the step down transformer. So, this single-line diagram would be something like that, under this condition, it will be something like that. We have a B sigma and we have 3 BC in parallel. So, this is equal to B sigma which is given as minus 6 per unit.

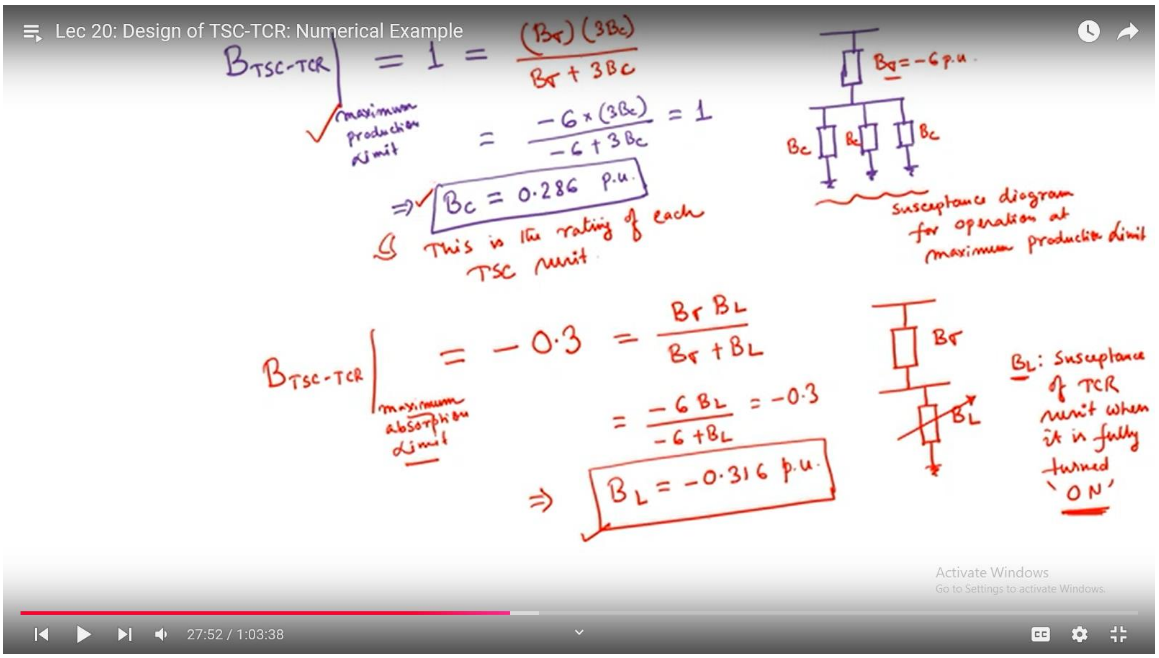
These are 3 BC which are in parallel. This will be the susceptance diagram, susceptance diagram for operation at operation at maximum production limit. Now, if these three susceptances are in parallel, then what is the total susceptances as a whole? It will be equal to 3 multiplied by B c and it should be in series with this B sigma. So, then this one will be equated with B sigma multiplied by 3 B c divided by B sigma plus 3 B sigma. Now, if you put these values, because we know this V sigma is equal to minus 6. So, this will be minus 6 multiplied by 3 BC divided by minus 6 plus 3 BC.



This is equal to 1. So, this gives the value of this BC is equal to how much? This is equal to 0.286 per unit. This is what the susceptance rating of a particular TSC unit. So, this is the rating of each TSC unit. Now, next what we will do, we will consider this the other extreme operating condition. So, this was maximum production limit and that will be the maximum absorption limit. So, B TSC TCR when it is operated at maximum absorption limit, it is given as minus 0.3, according to the problem statement that we, that you can find over here. So, BTCR TST is minus 0.3, when it is operating at maximum production limit, this is according to this problem statement.

So, what we can write is this is equal to now when this will be operated at maximum absorption limit. So, then all this TSC would be turned off as I mentioned over here, and the maximum absorption limit of all this TSC will be turned off and TCR will be fully turned on. So, then this single-line diagram of the susceptance would be something like that will be having B sigma which represents the susceptance of the step-down transformer and we will be having the susceptance of this TCR unit which is considered to be B L. So, here B L represents the susceptance of the TCR unit when it is fully turned on. This is something you need to understand because basically, this is representing a variable susceptance, but we consider the extreme operating condition that is the maximum absorption limit.

So, at that condition, the susceptance of the TCR would be the maximum susceptance that it can provide and that is the operating condition corresponding to the TCR unit being fully turned on. So, if it is so then it will be equal to B sigma multiplied by this B L because they are in series divided by B sigma plus B L which is as already we know that B sigma is given as minus 6 per unit minus 6 B L divided by this B sigma is minus 6 plus B L which is equal to minus 0.3. So, from this one can find out what is the value of B L. And, as per my calculation, it should be equal to minus 0.316 per unit. So, we got this susceptance of the TCR unit. We got the susceptance of each of the capacitor units. So, this is how we determine the ratings of the each TSC unit, susceptance rating to be more precise and also the maximum susceptance rating or the rated value of the susceptance of the TCR unit. Now we will find the operating conditions, different operating conditions. So there are different types of operating conditions for this kind of TSC TCR unit as a whole.



Numerical Example:

Let us design a TSC-TCR unit with 3 TSCs and 1 TCR unit which can provide capacitive compensation with susceptance of 1 p.u. (i.e. $B_{SVC} = 1\, p.u.$) and inductive compensation with susceptance of 0.3 p.u. (i.e. $B_{SVC} = -\,0.3\, p.u.$). Assume that the susceptance of the step-down transformer is 6 p.u. ($B_\sigma = -\,6\, p.u.$). The TSC-TCR unit is considered lossless and the system voltage V is 1 p.u.

Note: Inductive susceptance is considered as negative and capacitive susceptance is considered as positive (as previously mentioned).

Maximum production limit:

This situation when all TSCs are ON and TCR is OFF corresponds to the maximum production limit. The maximum production limit corresponds to the maximum capacitive compensation of TSC-TCR unit. At maximum capacitive compensation $B_{SVC} = 1\ p.u.$

$$B_{SVC} = \frac{(3B_C)B_\sigma}{3B_C + B_\sigma} = 1$$

$$\Rightarrow \frac{(3B_C) \times (-6)}{3B_C - 6} = 1$$

$$\Rightarrow B_C = 0.286\ p.u.$$

<u>Maximum absorption limit:</u>

The maximum absorption limit corresponds to the maximum inductive compensation of TSC-TCR unit. At maximum inductive compensation $B_{SVC} = -\ 0.3\ p.u.$

$$B_{SVC} = \frac{B_L B_\sigma}{B_L + B_\sigma} = -\ 0.3$$

$$\Rightarrow \frac{B_L \times (-6)}{B_L - 6} = -\ 0.3$$

$$\Rightarrow B_L = -0.316\ p.u.$$

- ***<u>Case 1: (3 TSCs are ON):</u>***

(a) <u>TCR is OFF:</u>

$$B_{SVC} = 1\ p.u.$$

$$I_{SVC} = -V.B_{SVC} = -1 \times 1 = -1\ p.u.$$

(b) <u>TCR is ON:</u>

$$B_{SVC} = \frac{(3B_C + B_L)B_\sigma}{3B_C + B_L + B_\sigma} = \left(\frac{3 \times 0.286 - 0.316}{3 \times 0.286 - 0.316 - 6}\right) \times (-6) = 0.596\ p.u.$$

$$I_{SVC} = -\ V.B_{SVC} = -\ 0.596\ p.u.$$

Since, $I_{SVC} \in [-1, -0.596]$, the SVC operates in VAr production range.

- ***<u>Case 2: (2 TSCs are ON):</u>***

(a) <u>TCR is OFF:</u>

$$B_{SVC} = \frac{(2B_C)B_\sigma}{2B_C + B_\sigma} = \left(\frac{2 \times 0.286}{2 \times 0.286 - 6}\right) \times (-6) = 0.632\ p.u.$$

$$I_{SVC} = -V.B_{SVC} = -1 \times 0.632 = -0.632\ p.u.$$

(b) <u>TCR is ON:</u>

$$B_{SVC} = \frac{(2B_C + B_L)B_\sigma}{2B_C + B_L + B_\sigma} = \left(\frac{2 \times 0.286 - 0.316}{2 \times 0.286 - 0.316 - 6}\right) \times (-6) = 0.267\ p.u.$$

$$I_{SVC} = -V.B_{SVC} = -0.267\ p.u.$$

Since, $I_{SVC} \in [-0.632, -0.267]$, the SVC operates in VAr production range.

- ***<u>Case 3: (1 TSC is ON):</u>***

(a) <u>TCR is OFF:</u>

$$B_{SVC} = \frac{(B_C)B_\sigma}{B_C + B_\sigma} = \left(\frac{0.286}{0.286 - 6}\right) \times (-6) = 0.300\ p.u.$$

$$I_{SVC} = -V.B_{SVC} = -1 \times 0.300 = -0.300\ p.u.$$

(b) <u>TCR is ON:</u>

$$B_{SVC} = \frac{(B_C + B_L)B_\sigma}{B_C + B_L + B_\sigma} = \left(\frac{0.286 - 0.316}{0.286 - 0.316 - 6}\right) \times (-6) = -0.030\ p.u.$$

$$I_{SVC} = -V.B_{SVC} = 0.030\ p.u.$$

Since, $I_{SVC} \in [-0.300, +0.030]$, the SVC operation ranges from VAr production to VAr absorption.

- ***<u>Case 4: (All TSCs are OFF):</u>***

(a) <u>TCR is OFF:</u>

$$B_{SVC} = 0 \Rightarrow I_{SVC} = 0\ p.u.$$

(b) <u>TCR is OFF:</u>

$$B_{SVC} = \frac{B_L B_\sigma}{B_L + B_\sigma} = -0.3$$

$$I_{SVC} = -V.B_{SVC} = 0.3\ p.u.$$

Since, $I_{SVC} \in [0, 0.3]$, the SVC operates in VAr absorption range.

I will discuss this one by one. So what are these operating conditions? So the operating condition, operating conditions of TSC TCR unit. So, if I just divide it among different category or different types, then let us consider case 1 corresponds to when 3 TSCs are turn on. TCR is also turned on but TCR can be partially turned on. The second operating condition is when two TSCs are turned on along with this TCR plus TCR operation.

This is case 2. Case 3 corresponds to only one TSC unit is turned on and plus TCR operation. And case 4 will be the case when only TCR is turned on. So, these are the 4 different cases. So, in this case 3 all the TSCs are turned on plus TCR will be in operation. Case 2 only 2 TSC unit out of 3 will be turned on that means 1 TSC unit will be turned off and the TCR will be in the operational. Case 3 will be only 1 TSC unit will be turned on along with this TCR unit. Case 4, when no TSC unit will be turned on, that means all the TSC units are turned off, only TCR unit is operational, ok. So, during each of the cases, we will also get some sub ranges, some sub range of this production and absorption, ok. Now, let us discuss this one by one. This is for case 1, this is for case 2, and this is suppose for case 3.

Now, when this, let us start with this first case, when all these three TSCs are turned on along with this TCR unit. So, during that time, the maximum production, maximum production of the var corresponds to maximum production of the var corresponds to this 3 TSCs are turned already on, when this TCR is off. So, during that moment of time, so this I SVC, since it will be in the capacitive region, so would be equal to, so, what would be when this TCR is fully turned off, then the net susceptance of the whole TSC TCR unit or whole SVC will correspond to this 3 times of the individual susceptance of each of the TSC unit with or in series the susceptance of the step-down transformer. So, this will be equal to this, since we consider this voltage as a minus 1 per unit. So, 1 multiplied by the susceptance of the BSVC, let us say.

So, BSVC we can calculate as 1 multiplied by this would be equal to 3 plus b sigma divided by sorry, this 3 BC multiplied by B sigma divided by 3 BC plus B sigma because when this at maximum production TCR is off. So, TCR susceptance will not appear in calculating the overall susceptance of the whole unit. So, this will be the thing. So, then this will be coming out to be, if you do it, this will be coming out to be 1 per unit. So, this is the maximum capacity or I should say that maximum this production limit, max production limit, then there will be another case when all the TSC units will be turned on and TCR is fully also turned on.

So, that means, that minimum production for this case will be equal to when this TCR is fully on. So, during that time, this ISVC minimum would be equal to minus 1 multiplied by, now you know that we have this TCR unit fully turned on. So, along with this 3 BC, there will be the susceptance of the TCR that also needs to be considered. So, this will be then 3 B C plus B L multiplied by B sigma divided by 3 B C plus B L plus B sigma. So, if you do this, if you put all the values of B C, B L and B sigma which are already determined in the last, this page B L, B C and this B sigma, B sigma is already given.

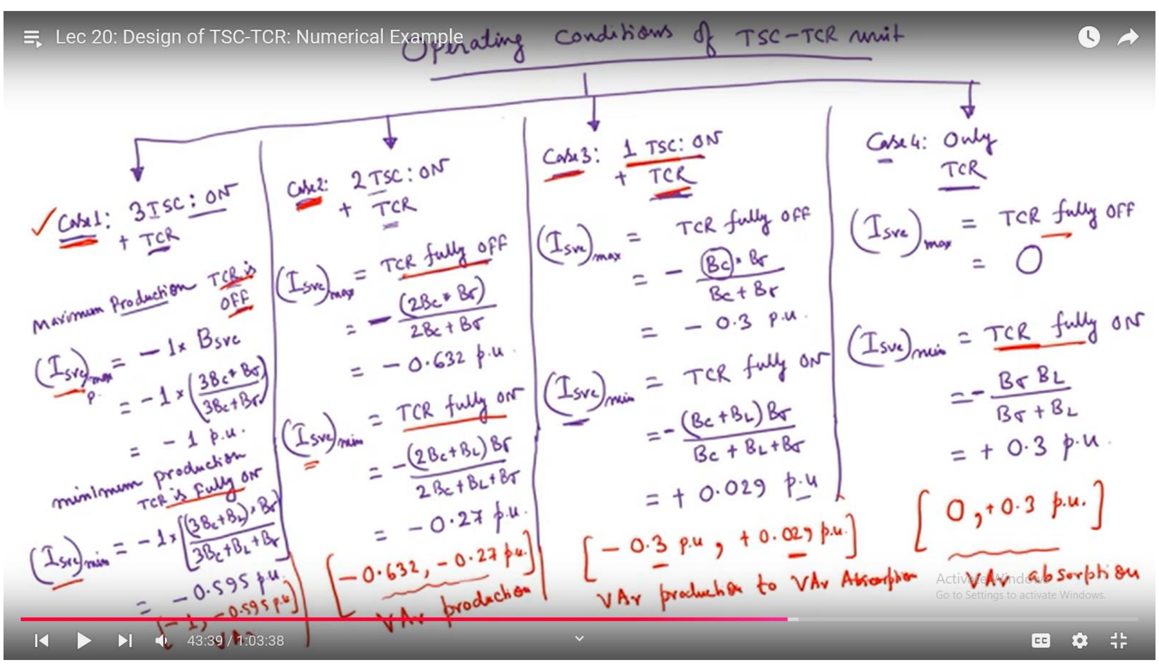
So, if you put all these values then it will be coming out to be minus 0.595 per unit. Now, remember, since this TCR we know that its operation is similar to a variable susceptance. So, it can be operated at partial conduction mode as well. So, these two values of this ISVC and ISVC max and ISVC min and for this particular case correspond to two extreme possible case operations of this TCR, one is fully off another is fully on. So, that means when TCR is partially on, it can produce var starting from this range minus 1 to minus 0.595 per unit. Any value of this var within this range is possible by using TCR control in case A. So, that is something one needs to understand.

Then similarly, we will derive this case as well that is case 2. So, in case 2, so I S V C max corresponds to T C R, this corresponds to T C R fully off. So, this is equal to minus this 2 v c plus multiplied by B sigma divided by 2 BC plus B sigma. So, we consider minus this symbol as already we discussed in order to bring this capacitive current positive and inductive current negative. Remember the capacitive susceptance is positive, but capacitive current we will plot in negative region of the axis. So, in order to do so, we consider this a negative sign. So, if you solve this, then it will be coming out to be minus 0.632 per unit. Similarly, the mean corresponds to TCR fully on. So, this is equal to minus 2 BC plus VL multiplied by V sigma divided by 2 BC plus VL plus V sigma. If you put all these values, it will be as per my calculation, it is coming out to be minus 0.27 per unit. So, therefore, one can conclude that we consider these two extreme ranges, one is TCR is fully up, another is TCR is fully on. So, by partially conducting this TCR, it is possible to have a range of this compensation any value in between 0.6322 to 0.27 per unit in this particular case. So, that means in this particular case when we keep two TSCs are turned on and a TCR which can be fully turned on or fully turned off or partially turned on, we can vary the var production from minus 632 per unit to minus 27 per unit.

When it is as long as this var or this i is coming out to be negative that means that it is basically producing var. Now, we will go for this third case that is this case. So, here this i SVC max corresponds to TCR fully of So, for this case, this whole, this susceptance will be B C multiplied by B sigma divided by B C plus B sigma. Now, remember here only one TSC is turned on. So, overall susceptance of this TSC is B C only. So, if you do the calculation, then it will be coming out to be minus 0.3 per unit. Similarly, ISVC mean corresponds to when TCR is fully turned on. So, in this case, this BC should not appear. So, along with this B c, this v l should appear. So, this will be equal to Bc plus v l multiplied by B sigma, negative sign is already there, then B c plus B l plus B sigma. If you put the values of B c, B l and B sigma, this will be coming out to be 0.029 positive per unit. Now, when this ISVC current drawn by this SVC is coming out positive, then according to our convention, it is a kind of inductive operation.

So, it is basically absorbing VAR. for this particular case that is in case 3 when only one TSC will be operational or it will be turned on and TCR will be turned on. So, it can provide this range of this var 0.3 per unit to plus 0.029 per unit. So, under this particular case, we can also produce var and absorb some amount of var as well. So, this is how this case 3 can be understood. Now, let us come to the last case when only TCR will be operational. So, in that case, this I SVC max will be equal to when TCR is fully off which means ideally it is having 0 this current Although there would be some amount of hard absorption due to the susceptance of the step-down transformer, but let us ignore it. So, then it will be 0 and I S V C mean corresponds to TCR fully on. Under these conditions, this var would be equal to B sigma multiplied by BL divided by B sigma plus BL. Since B sigma BL both are negative, this is already there is a negative term here. B sigma and B L both are negative. So, this total will be coming out to be a positive. So, this is coming out to be 0.3 per unit.

So, for this particular case, it is possible to vary this ISVC from 0 to 0 plus 0.3 per unit. by varying this TCR susceptance. Because you know these two cases for each case we consider two extreme conditions. One is TCR is fully turned on, another is TCR is fully turned off. But remember TCR can be also partially turned on. So, by operating so we can change the value of the susceptance of the TCR to any value in between 0 to B L. So, by doing so, we can provide some controllable var, either we can absorb some controllable var. So, this is a case of var absorption, this is a range of var production, var production to var absorption. This is a case of var production and this is a case of also var production. So, this is how we can operate this TSC TCR unit and this is how we can control this TSC TCR unit as well.



Now, what we will do next is we will plot of the voltage current characteristics. The plot of the voltage-current characteristics is this. So, what we will do is, we will plot this V SVC and I SVC characteristics. This is, in this axis we will consider V SVC, in this axis we will consider I SVC. Now, I SVC can be positive as well as can be negative. ISBC positive corresponds to the case that the var is absorbed and ISBC negative corresponds to the cases the var is produced. By doing so, what we can do, let us come to this case 1 first. So, let us come to the case 1 first. So, in case 1, we know the range is minus 1 to minus 0.595. So, let us consider that this is corresponds to minus 1, this is corresponds to minus 0.595. So, these are the ISVC range. Now, what we can do is that this is the maximum range. production range and this is the minimum production range for the operation of this SVC. So, that means the operating characteristics of this would be from here to, from here to here. So, this is the maximum production limit and this is the minimum production limit for this case 3.

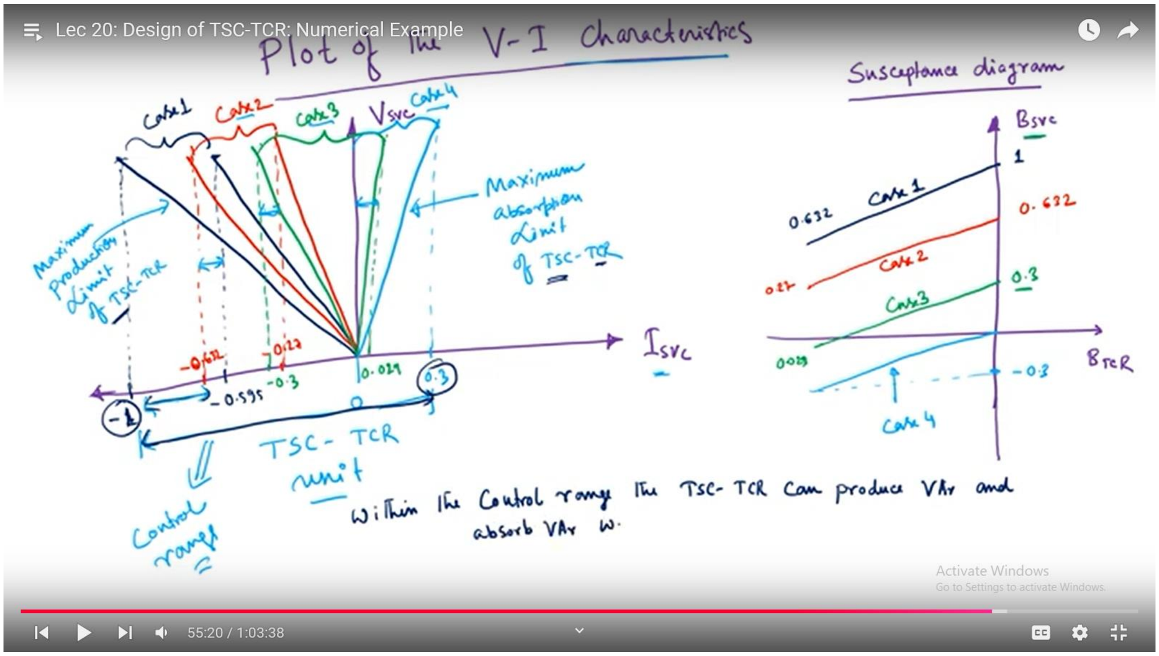
So, sorry for this case 1. So, this is what the sub range of case 1. So, any value of this var, you know, production is possible in between this to this by controlling this TCR unit. In fact, here the controllable parameter is TCR unit only. By controlling the TCR parameter, we can vary this. Now, let us come to the next case, where this is varying from minus 0.632 to minus 0.27. So, here suppose minus 0.632 and here suppose we have minus 0.27. So, that means in case 2, these are the two extreme ranges of the var. So, therefore, this maximum var production corresponds to this, minimum var production corresponds to that. So, this is the operating range or subrange in case 2. Now, let us come to the case 3. In case 3, you can see this is what the var production to var absorption limit. So, one is minus 0.3, another is 0.029. So, therefore, suppose this corresponds to 0.3, this corresponds to 0.029. That means the operating characteristics of this under this case 3 will be from here to here within this range. Then next would be the final, you know, this case, that is case 4, where this var absorption from 0 to 0.3. So, that means, this, so this is of course 0, this is of course 0.3. So, these are the two ranges under this particular case. So, therefore, the variation of this FAD production in case 4 is within this range. Now, this is what the plot of this VI characteristics for this TSC, TCR unit. So, this is the plot of the VI characteristics of TSC, TCR unit. One thing you can observe here is that there are some overlap ranges, one is this in between this case 1 and case 2, another is this that is in between case 2 and case 3, another is this in between case 3 and case 4.

So, these are the some overlapping area by suitable design, it is possible to have discrete operating regions also, but it is not advisable to do so in voltage control of this SVC, why it is so we will discuss in maybe in detail during this discussion of SVC in voltage control. But, this is what the VI characteristics or VSVC ISVC characteristics of this TSC TCR unit. So, with this TCR control, we can operate it either in case 1 and then or in case 2, which is this case 2 or in case 3 or in case 4 and we have a capability to provide here to here that much of this var, this is what is called control range. This is what the control range of this particular TSC, TCR unit. It is possible to provide any value of this var, either this var absorption or var production by controlling their TSC and TCR units.

And as you can understand, this is what the maximum production limit of the whole unit of TSC TCR and this is the maximum absorption limit. This is what the maximum absorption limit of the whole TSC TCR. So, one thing I also would like to plot that is basically is basically this susceptance diagram. So, this is called Susceptance Diagram. So, under this susceptance diagram, what we will do is, this y axis or this vertical axis, we consider to be the net susceptance of the SVC.

And since the controllable unit is here, only B TCR, so we will plot this total overall susceptance versus this B TCR susceptance. So, for this case 4, the plot would be something like this. Here suppose the susceptances, this is minus 0.3. So, the range of this plot would be from here to here. So, this is for case 4. Now, for this case 3, the plot, this plot would be from some value of this that is 0.029 to 0.3. Remember, this SVC susceptance is positive when it is a capacitive susceptance. So, it is vary from 0.029.3. Similarly, this for case 2, the variation of the susceptance would be from some value as you know that it is given minus 0.27. So, this is equal to 0.27 suppose. So, it will be here to here. So, it will be 0.27 to 0.632. Similarly, this is for case 2. This was for case 3.

For case 1, it will be varying from minus 6, 3, 2 to 1. This will be varying from minus 0.6322, that means 0.6321, the susceptance is that. So, this is what case 1. So, this is how, this is the variation of this susceptance would be. So, this is called Susceptance Diagram. So, we understood this voltage current characteristics. Also, we understood the Susceptance Diagram of the TST-TCR. Now, one should understand that this is the entire control range of this TSC TCR, it can produce var from 1 per unit and it can absorb var up to 0.3 per unit. So, it can also have a non-zero production and non-zero absorption because of this TCR operation and with the variation of TCR, it is possible to have a smooth control of this TCR susceptance in each of the cases and thereby we can be able to produce the var and this absorb the var within this control range to any value.



So, this is something one need to understand. So, within the control range, within the control range, the TSC TCR can produce var and absorb var with TCR control. So, this is something one needs to understand here. So, another last thing I should quickly discuss before I complete this lecture that is called losses in SVC. So, with this we will can conclude this our discussion to this static bar compensator. Now, what do you mean by losses? Losses stands for the power or energy losses which take place due to the SVC operation.

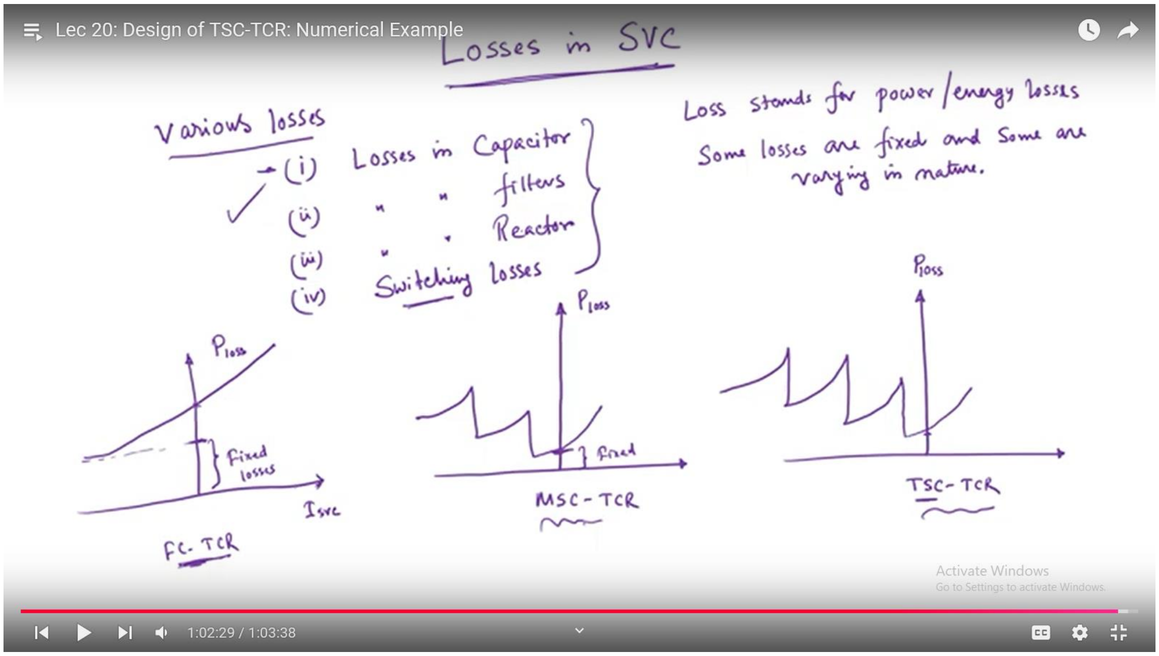
There are various types of losses in SVC that I am going to discuss over here. Now, so what are the losses? So, various types of the losses, various losses that takes place in the SVC is due to number of losses in capacitor, number 2 losses in filters because it is LC filter, number 3 losses in reactor, number 4 losses in or rather switching losses switching losses, switching losses at the thyristor units. So, so far our discussion is confined to the case that we assume that the whole unit is lossless, but it is true for some extent because some extent because this as compared to the rating the amount of losses is very less, but we cannot say that the losses would be 0 or we cannot completely ignore the losses. We can not ignore the losses because you know there is no ideal type of capacitor which will not have any type of energy losses in it that is not possible. So, as this reactor as well and there would be of course, switching loss due to the thyristor operation and due to this thyristor material.

So, those losses if you consider, so there should be certain amount of energy losses in the SVC. Now, here my goal is to discuss that the relative amount of losses in different types of SVC units. In particular, the three different types of SVC units we learned in these last few lectures. One is fixed capacitor TCR, another is MSC TCR, and another is TSC TCR.

So, let us plot this. So, what we will do is, we will plot these losses versus this ISVC. So, this is amount of power loss, P loss stands for power loss, this is ISVC. This is supposed for FC TCR. Similarly, there would be certain amount of losses in MSC TCR as well, which is mechanically switched capacitor TCR and there would be certain amount of losses in TSCTCR as well. Now, how these losses can be compared? So, you should understand that out of these different types of losses, some losses will be fixed, some losses would be variable.

So, losses stand for, losses stand for power or energy losses. So, P losses stand for this power loss and some losses are fixed and some are varying in nature varying in nature. So, what we will do over here is that we will find out this how this losses is varying. So, in general this fixed losses in fixed capacitor TCR usually higher. So, this is the amount of fixed losses, this is the amount of fixed losses and this is used to be higher. And the reason is that already I discussed that in fixed capacitor TCR, capacitors are always turned on and therefore there should be circulating current among this capacitor and this TCR units and which will constitute certain amount of losses due to this loop current.

So, this losses is usually varying like this from starting from a fixed losses to this. So, as this SVC current is increased, losses is increased. As the SVC current is reduced, losses also get reduced. In the case of MSC-TCR, the loss characteristic, fixed losses, this is the amount of fixed losses, let us say. So, the usual characteristic is something like this. So, this is, this fixed losses. Then, if we turned on different this is the fixed losses. If you turned on different types of, different discrete values of the capacitor, this losses will increase accordingly. Similarly, this TAC-TCR also, the characteristic is similar to TAC-TCR, but there would be additional switching losses due to this thyristor operation. So, the losses will be this fixed losses will be similar to this MSCTCR and the characteristics would be little bit of similar to this MSCTCR something like that, and so on.



So, this is the, these are the characteristics of these losses. So, these are the, you know, comparative loss characteristics of different types of this SVC. As I discussed, although we consider the whole unit to be lossless, there would be a certain amount of losses due to practical consideration of the capacitor, reactor, filter, and the switching losses of these thyristors and the characteristics will be something like this. So, losses we cannot avoid, but we can reduce this with the careful design. This concludes my discussion of the SVC or static VAr compensator as a whole. From the next lecture, we will try to understand the application of SVC in improving or enhancing various capacities or various dynamical properties of a typical power system. So, till then thank you for your attention for this lecture. So, thank you very much for your attention. Thank you.