Course Name: Power Electronics Applications in Power Systems

Course Instructor: Dr. Sanjib Ganguly

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

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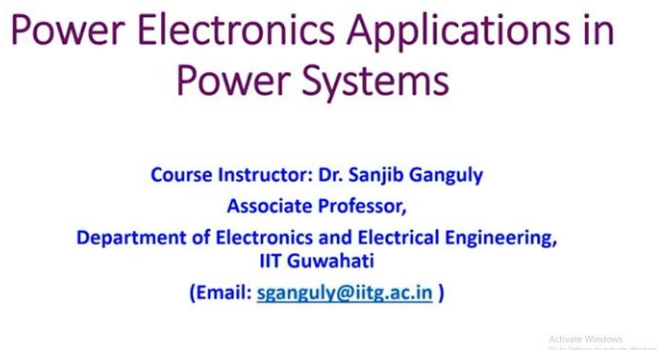


Lec 16: Operating Characteristics of TCR

So, hello everyone welcome again in my course Power Electronics Application in Power Systems. So, in last couple of lectures I started discussion on static power compensator and I said that static power compensator is a kind of shunt reactive power compensation devices and this is a family. And there are many, many different types of SVC exist. So, I started the initial discussion with thyristor controlled reactor whose acronym is TCR. And in the first two lectures, I discussed the basic operating principle of the TCR, and the harmonic behavior of the TCR and the constructional detail of the three-phase TCR because you have to understand at this point is if I even if I do not mention all the reactive power compensation devices are of three-phase. So, one needs to understand the three-phase constructional detail such type of compensator, okay.

Now, I will continue the discussion in this lecture as well, we will try to understand the voltage current characteristics or VI characteristics of the TCR and we will discuss some of the important aspect on it. So, let us start. So, today I will discuss the operating characteristics of TCR. So, if you have followed my last lecture, I have discussed that the equivalent circuit model of the TCR.

This is the equivalent circuit model of a three-phase TCR. Although this is a single-line diagram model and in the power system, we assume that the unbalance or imbalance of transmission line is very less. Therefore, we consider it is a relatively balanced system which is always true. And therefore, we represent all these different lines, different compensators, generators in a single phase equivalent form. In short, it is called single line diagram.

So, this is a single line diagram of equivalent circuit of a TCR. So, it is nothing but a variable reactor. Now, one need to understand that this variable reactor is represented with a variable susceptance where this B TCR is a variable susceptance and this variable susceptance is basically representing the whole TCR itself. And the question is how can we vary the susceptance value? This is possible by varying the firing angle control of the bidirectional switch or thyristor which are used to design this TCR. So, here in the very first lecture, I have shown you the single line diagram of this SVC.

Here you can see these are the typical switches and these are the typical switches. We are basically operating these switches either fully on mode or fully off mode or partially conducting mode. So, whenever you will operate it a partially conducting mode, you need to vary the firing angle. So, this is the concept of firing angle I discussed. And I discussed also that there are different books where different instant of time is considered to measure the firing angle.

So, we follow here the Mathur-Verma's concept where alpha is measured from zero crossing voltage instant. That means this instant in this particular figure, this instant in this particular figure. Now, what we can see over here is that when this thyristors of the TCR partially conducting in nature, then this current which is drawn by the TCR is non-sinusoidal in nature or distorted sinusoid in nature. Therefore, there exist certain harmonics and in the last lecture I discussed the harmonic behavior. Now, here is the diagram of the plot of this fundamental current which is drawn by the TCR and in our analysis in particular design this fundamental current is an important aspect.

And here you can see that when this both the switches are fully on then current this TCR current will be at its peak value and then it will slowly get reduced to 0 when the switches are fully turned off. And in between this to this, that means when the firing angle, this is what the firing angle. So, when this firing angle is changes from pi by 2 to pi, then you can see that this current magnitude is getting changed. Now, if you consider so, then it is actually happening because of the change of the susceptance value, because system voltage where this TCR is kept, that may remain constant. We will assume that it remains constant.

So, therefore, this due to the variable susceptance values of the TCR, this fundamental current is getting changed. Now, today we will try to understand this voltage current characteristics of the TCR. Now you know that as we discuss over here that we consider that this TCR as a simplified model ignoring the step-down transformer. So, this is supposed the single line diagram of the TCR. This is what the representation of variable susceptance.

And this is what the voltage of the bus at which it is placed. This is the bus at which this is placed. And the current drawn by this particular TCR, let us represent it by ITCR. Now, what will be the relationship of this voltage, current and this susceptance? This we can get from the basic electrical engineering course that we know that this I TCR would be equal to this V multiplied by B TCR. Now, this B TCR is the higher, this B TCR is the susceptance of TCR, V is the voltage where TCR is placed and this I TCR represents the current drawn by the TCR.

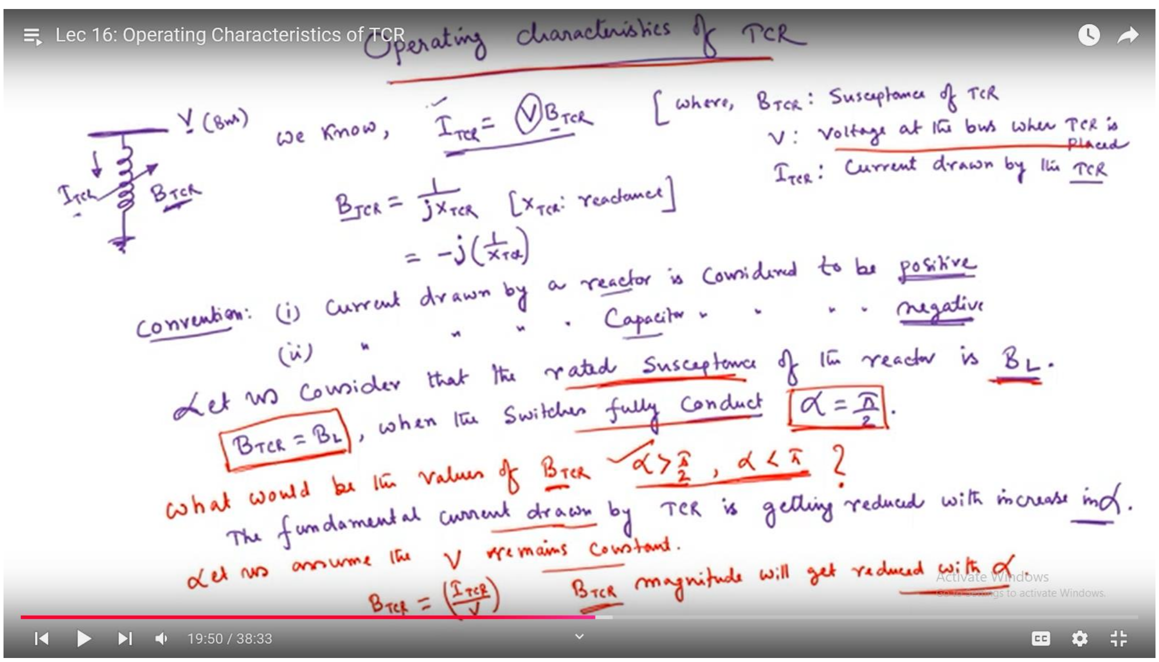
Now, what is the susceptance? We know the susceptance is the reciprocal of the reactance. So, we know that B TCR is basically equal to 1 upon j X TCR, where X TCR is the reactance of the TCR. Now, since j is the complex operator which is in the denominator, so basically this B TCR can be represented by minus of J multiplied by 1 upon X TCR. So, 1 upon x TCR is having a positive value and it is being multiplied with this term j. So, basically the susceptance is a kind of negative quantity when it represents the susceptance of a reactor.

So, susceptance of a reactor is a negative quantity because minus j is getting multiplied with that. And, that is why if you consider this equation and if you put this BTCR over here, then this current will be also negative. But, there is a convention which is followed in most of the books either in Hingorani's book or Mathur Verma books or a similar kind of book. That is, the current drawn by a reactor is considered to be positive, and the current drawn by a capacitor is considered to be negative. So, the convention is, convention is current drawn by a reactor is considered to be positive, whereas the current drawn by a capacitor is considered to be negative.

Why it is so? You know that this current multiplied by voltage for a reactive device like a reactor or a capacitor represents the reactive power of that particular power absorbed or delivered by that particular device. Now, if the current is positive and of course, voltage is always positive, then the multiplication will also be positive. So, therefore, this reactor, whatever reactive power it draws would be positive, which is true. We consider that all this load, whatever is present in particular this inductive type of load, we consider they consume reactive power. So, we consider consumption is positive.

Now, if the consumption of reactive power is positive, then delivery of the reactive power would be negative, naturally. So, therefore, if the consumption of a reactor is positive, then whatever reactive power is delivered by a capacitor that has to be negative. So, and that is why when you multiply this capacitor current which is a negative, with the system voltage, so the reactive power becomes also negative. That means this negative sign shows the capacitor is not, is negatively consuming or I should say that the capacitor is negatively consuming the reactive power, which implies to that a capacitor basically delivering reactive power. So, that is something you need to understand at this point.

So, that is what the convention we will also use here. Now, another thing that you should know that this reactor, let us consider that the rated susceptance of the reactor is B L ok. So, B L is the rated susceptance of the reactor and this B TCR is the susceptance of the reactor which is variable due to the variation of the firing angle of the thyristor switches ok. So, there should be a relationship of this B TCR and B L, B L is the rated susceptance. So, therefore, the B TCR would be equal to B L when the thyristors or the switches fully conduct that means, this corresponds to this firing angle alpha is equal to pi by 2 according to the Mathur Verma convention, Mathur Verma convention. If you go back and see, then we already discussed that in Mathur Verma convention, this range of this alpha is pi by 2 to pi and when it is pi by 2, alpha is equal to pi by 2 that is this, that is this, then the switches are fully on. Now, when the switches are fully on, then this whatever this susceptance of the TCR is, that is the rated susceptance of the reactor. And let us represent it by BL here. So, whenever this alpha is equal to pi by 2, that means, switches are fully conducting, then B TCR will be equal to BL, which is the rated susceptance of the reactor.



Now, the question is, what would be the values of B TCR then for any other value of alpha? Now, the question is, so what would be? the values of values of B TCR when alpha is greater than pi by 2, but alpha is greater lower than pi. So, in between this you know that these switches are of partially conducting mode, switches are operating as a partially conducting mode. So, what would be the values of V TCR when this happens? So, this relation shows that these switches are of partially conducting mode. Then when there is a partially conducting mode, what would be the value of this V TCR? Now of course, this V TCR would be different than V L. Now, the question is whether this BTCR value would be higher than VL or lower than VL. In order to understand that, you have to go back and see the plot of the fundamental current with respect to this alpha. So, this is a plot of fundamental current. So, this is multiplied by this, this is considered to be a constant. So, in fact, only this is variable. So, only we took the variable part of it.

So, this gives a relationship of plot of this ITCR fundamental versus this alpha. Now, you can see when this alpha is increasing, this fractional quantity is getting reduced and it becomes 0 when alpha is equal to pi. So, it means that actually this fundamental current of the TCR or fundamental current drawn by the TCR is getting reduced with the increased value of alpha. So, this is something we can note down. So what we can note down here is the fundamental current drawn by the TCR is getting reduced with increase in alpha.

So, that means the current value is getting reduced. In fact, overall current is getting reduced when you are delaying this firing angle, when you increase this firing angle. So, if this current is reduced, we know that this voltage it does not have any relationship with this firing angle control of this TCR. So, voltage let us consider it always remains same. So, let us assume that, let us assume that, let us assume that, that this V which represents the voltage at the bus where TCR is placed, V remains constant, V remains constant.

Then if it is so, then this B TCR is a ratio of I TCR divided by V. So, when I TCR is basically reduced because TCR current this is getting reduced, so B TCR will also reduce. So, B TCR magnitude will get reduced with alpha. So, that is something you need to understand. So, BTCR magnitude also will be reduced with respect to alpha.

And when alpha is equal to pi by 2, that is when these switches are operating at fully conducting mode, then only this BTCR would be equal to BL, that is the rated susceptance as I discussed. But apart from that, in any other value of this alpha, for example, when alpha is increased from pi by 2 to pi, then This V TCR magnitude also will get reduced, that is something one need to understand. Now, let us plot this, because our main goal is to plot the operating characteristics of the TCR. So, what we will do is, let us plot this V, that is the voltage versus I TCR. Now, how would be the plot? So, the plot would be something like this.

Now, I would also like to say that I will revisit this relationship that ITCR is equal to V multiplied by B TCR. So, let us write ITCR is equal to V multiplied by B TCR. Since ITCR is positive and B TCR is negative, so in order to make this ITCR positive, we will consider V as a negative or we may use a negative term over here. So, that is what the idea is. So, this relationship we will use to make I TCR positive.

Now, if we consider that this axis is, let us represent it I SVC or I TCR and this axis, let us represent V TCR. Then you can see that this relationship gives, since I is positive and V is also positive, So, this since B TCR is negative, so negative-negative will be multiplied by and it will be equal to positive. So, it will be a straight-line relationship with y is equal to mx. So, here we have only thing you have to note down is that here we have interchange this axis. here i TCR is our x axis and v TCR is our y axis.

So, if we want to represent in terms of this y is equal to m x, which is a straight line well known straight line relationship, then y is basically here is our v TCR and x is equal to our i TCR. So, therefore, m would be the slope which will be equal to 1 by B TCR. okay? So, that means that reciprocal of the susceptance will be the slope, okay? And this relationship will hold for this characteristic equation. So, therefore, we can plot it like a straight line passing through origin.

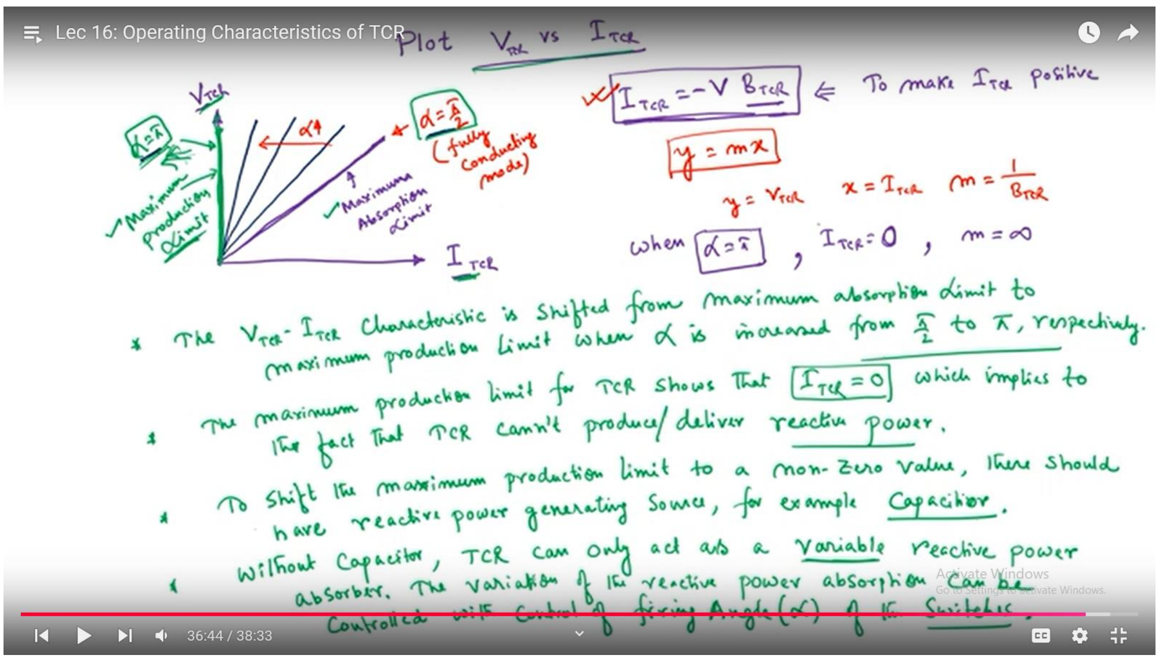
It is as simple as that. So, let us plot it like this. So, this is a plot of this V TCR versus I TCR, V TCR versus I TCR when this corresponds to a particular value of alpha. Now, we will consider this particular is considered at this alpha is equal to pi by 2, that means it is operating at fully conducting mode. Now, what would be the plot then for any other value of alpha? For example, alpha is equal to this some value which is higher than pi by 2 and some value which is lower than pi by 2. Now, we know that when alpha is equal to pi, when alpha is equal to pi, what is the value of ITCR? If you go back and see the waveforms of this voltage and current, you can see when alpha is equal to pi, then this current would be 0.

So, therefore ITCR would be equal to 0. So, that means this ITCR would be equal to 0. So, when ITCR is 0, Now, why I TCR is equal to 0? Because if you look at this relationship, that if I TCR is equal to 0, v cannot be equal to 0, then of course, this b TCR has to be equal to 0. So, therefore, if b TCR is equal to 0, then m would be equal to 1 upon b TCR, that will be infinity. So, therefore, when alpha is equal to pi, corresponds to the plot over here. So, this is the plot corresponds to alpha is equal to pi.

And for any other value of this alpha, this plot would be like this, this, this, and this. So, this as if this characteristics is being shifted from this point to this point, from alpha is equal to pi by 2 to alpha is equal to pi if you increase the value of alpha. So, as if these characteristics are being shifted to this side with the increasing value of this alpha. So, for any other value of this alpha, the characteristics will be this because for every different value of alpha corresponds to different value of BTCR, different value of the susceptance. Why different value of susceptance? Because the current is getting changed and current is changed due to the change of the susceptance.

Because, ultimately this TCR is modeled as a variable susceptance. So, when alpha is increased from pi by 2 to pi, this characteristics would be shifted to this side. And this point, this point, this characteristic is called as maximum absorption limit. And this characteristics is called corresponds to alpha is equal to pi, this characteristics is called maximum production limit. So, these two are two extreme characteristics of this voltage-current characteristics of the TCR.

One is the maximum absorption limit, another is the maximum production limit and this VI characteristic is getting shifted from the maximum absorption limit to the maximum production limit when you change alpha from pi by 2 to pi. So, this is I can note down. So, the V TCR I TCR characteristic is shifted from maximum absorption limit to maximum production limit when alpha is increased from pi by 2 to pi. So, this is an important remark that you can note down that when we keep on increasing the value of alpha from pi by 2. Now, what is alpha is equal to pi by 2 corresponds to? It corresponds to the point when these thyristors are fully turned on.



Now, when you move on from this point to the point when both the thyristors are fully turned off, that means, if we keep on increasing the value of alpha from pi by 2 to pi, then the characteristics is being shifted from this maximum absorption limit to maximum production limit. Now, what is maximum production limit implies to here? Here you can see, it corresponds to these characteristics which is exactly superimposed with this y axis or the vertical axis. It means that actually this ITCR is not producing anything because this corresponds to the case that ITCR will always be 0 even if your system voltage is getting change, ok. So, it means that there is no production of the var or there is no production of reactive power in case of a TCR unit. So, this is another comment, the maximum production limit for TCR shows that I TCR is always 0, which implies to implies to the fact that TCR cannot produce reactive power, produce or I should say deliver reactive power.

So, that is why this is superimposed and this is superimposed to the y axis which implies to that to the fact that the var is never produced in TCL which is very natural because there is no capacitor or such a kind of system over here or device over here which can produce var. So, it is a simple reactor that is controllable, whose reactance is controllable, and whose susceptance is controllable. And by controlling so, we can only control the bar absorption, that is it. But we cannot deliver any reactive power here.

So, that is quite natural. So, from this point, one needs to understand that there should be some other this hard producing source over here in order to shift this maximum production limit to the non-zero point. So, basically in order to have a finite amount of var production, this maximum production limit needs to be shifted to this side, which implies to that there is a var production as well as var absorption. But it is not possible unless you have a source of var production system over here. And, that is why this TCR needs to be operated with some other hard producing sources, most commonly the capacitor. And, there are different types of TCR, then we will discuss for some of the, this kind of devices in the future lecture.

So, therefore, I should write to shift the maximum production limit to a non-zero value, there should have have reactive power generating source or reactive power producer generating source. For example, capacitor. So, if we have a capacitor along with this TCR, then we conceive this maximum production limit to the non-zero region. That means that then the whole unit can produce the VAR, produce reactive power as well as can absorb the reactive power.

And this is a different type of TCR. Regarding that TCR characteristics, I will discuss in the next lecture. So, in the next lecture, I will discuss different forms of TCR in order to specifically shift this maximum production limit to this zero axis or y-axis to the negative axis, which means that there should be some non-zero value of var that the whole unit can produce along with some reactive power absorption capacity or capability of the TCR. So, from this we can understand that this TCR can be operated from alpha pi by 2 to alpha is equal to pi and by operating so we can only control the var absorption. So, without capacitor, without capacitor, TCR can only act as a variable reactive power absorber. And the variation of the reactive power can be controlled by the firing angle control.

The variation of the reactive power absorption can be controlled with the control of the firing angle that is alpha of the switches. So these are some important remarks that one needs to understand at this point, that this TCR is a variable var absorber unit without having a capacitor or capacitive kind of source, it cannot produce any type of var, but it can absorb the var and the var absorption can be variable by varying this alpha or firing angle. And in order to extend the characteristics to the non-zero production limit, we need some sort of reactive power source or some device which can generate reactive power, for example, a capacitor. Now, the capacitor and the TCR can jointly act as a VAR absorber as well as this VAR producer unit. And, there are different types of such units, which will be discussed in the next lecture.

So, at this point, we understand the operating characteristics of TCR. In the next lecture, I will discuss different types of TCR units with non-zero var production limits. So, till then, thank you. Thank you for your attention.