Course Name: Power Electronics Applications in Power Systems

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Lecture: 01

Lec 17: Categorization of different types of SVC and Fixed capacitor TCR (FC-TCR)

So welcome again in my course power electronics application in power system. In last three lectures, I discussed a particular type of static var compensator which is named as thyristor control reactor. But in general as I said before that it is not only a type of static var compensator rather we have a number of different other types. In today's lecture, I will discuss firstly a categorization of different types of static power compensator. Then I will discuss the differences among these different types of static power compensator. And also I will discuss a particular type of static bar compensator, which is similar to TCR or thyristor controlled reactor, but it is, there is a difference with TCR and this type of static bar compensator.

So, let us proceed. categorize the static var compensator. So, here var stands for reactive power. So, if we categorize it, there will be two different types. One is inductive type of static var compensator Another is capacitive type of static power compensator. In inductive type of static power compensator, in inductive type of static power compensator, the goal is to absorb the reactive power. So, here the goal is to absorb reactive power. In capacitive type of static power compensator, the goal is to deliver or to produce the reactive power, deliver reactive power. Now, there are different categories of inductive type of static bar compensator, which may include fixed reactor type, which may also include thyristor switched reactor and thyristor control reactor.

So, in last couple of classes, I discussed this thyristor control reactor in very detail. Now, the acronym of thyristor switch reactor is TSR and thyristor control reactor is TCR. There is a difference between TSR and TCR which I am going to discuss today. Similarly, in capacitive type of SVC, so this acronym that which we use to represent this static bar compensator is SVC. So, capacitive type of SVC also can be of three different types, one is of fixed capacitor we can call it as an acronym FC. Another is thyristor switched capacitor. It is known as its acronym as TCR. Another is mechanically switched capacitor. It is known as its acronym MSC, M for mechanical, S for switched and C for capacitor. Now, in my previous lecture, I discussed thyristor control reactor.

So, one should have a fair idea what is thyristor control reactor, TCF. Now, fixed reactor stands for, fixed reactor and fixed capacitor stands for, there is no switch involved in it and they are always connected to the system. So, when we have this fixed reactor or fixed capacitor, it implies to that there is no need of turning on or turning off operation, as if this capacitor and reactor will be always turned on with the system. okay. And there are some disadvantage of this specific type of this SVC.

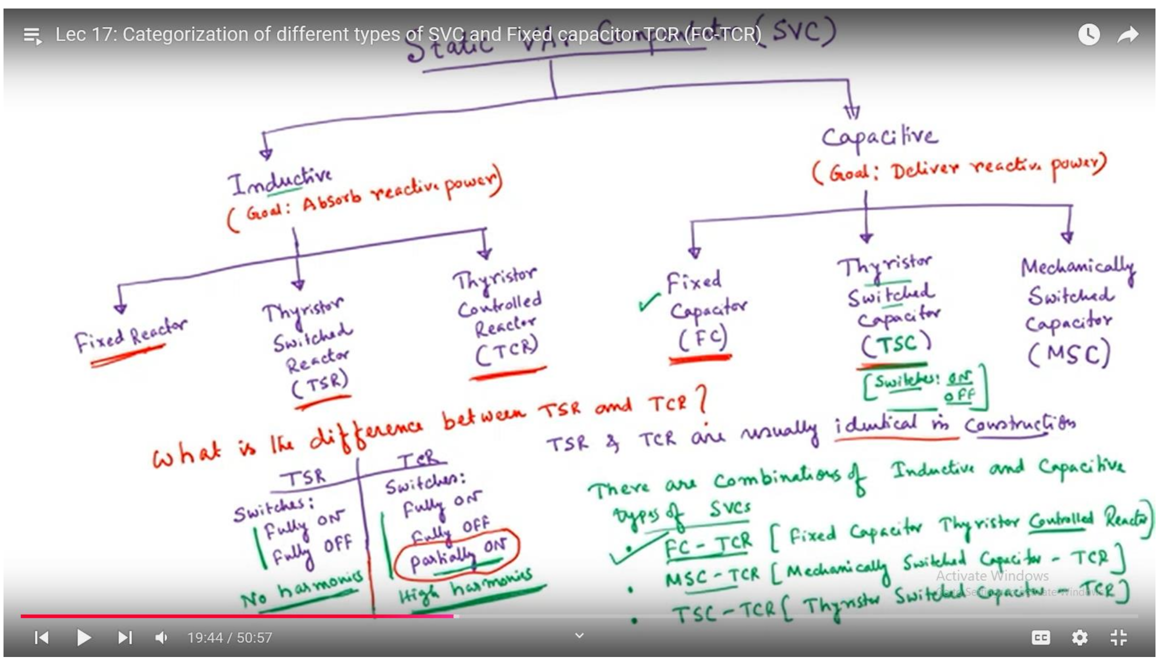
One is of course as you know that in a typical power system the load which specifically demands the reactive power that is why we need reactive power sources or that is why we need reactive power compensation that load dynamically varies throughout the day. So, that is something one needs to understand with the example of the devices a person uses throughout the day. For example, as a person, if someone is having a room, then one can identify that sometimes that that room is using all its electrical appliances. Sometimes, all electrical appliances are turned off. Sometimes, some of the, there are some particular type of electrical appliance which is always turned on and never turned off, for example, electric refrigerator.

Similarly, electric load is some entity which is always varying and it is always dynamic and time-varying in nature. So, therefore, when there is a very high load demand, we call during that time system is operating at peak demand or close to peak demand, during that time we need capacitive type of compensation so that we can deliver some amount of reactive power to the network, okay. So, this will be useful in order to mitigate the undervoltage during that time when we have very high load demand. So, this is I discussed in my previous lectures. Similarly, when there is a very light loading condition, for example, during midnight, when most of our appliances are turned off, during that time there is a situation of over voltage and that over voltage need to be mitigated.

And we need a reactor who can absorb some amount of reactive power and thereby it will help to mitigate this over voltage, okay. So, over voltage and under voltage occur in a particular time of the day, but it will not sustain for a long time and it is not a sustainable type of event. So, therefore, when you have a fixed reactor or fixed capacitor, then they may have negative effect. For example, when we have an under-voltage in a network and if you have a fixed reactor, then the presence of the fixed reactor further deteriorates the voltage level. Similarly, when we have over voltage primarily occurs when we have a surplus amount of reactive power to the system.

During that time, if we have a fixed capacitor connected, this will also increase the amount of overvoltage. So, they will have some negative effect. So, that is why they are, although their usage is very simple, we do not have any sort of sophisticated power electronic converters and so, but their operation creates some sort of negative effect, okay. So, that is why they are not used or popular in power system operator, to the power system operator. But they can be used along with some switchable devices.

Now, look at this type, thyristor switched reactor and thyristor switched capacitor. Now, one may have a question that what is the difference between switched reactor and controlled reactor? So, what is the difference between TSR and TCR? This is an obvious question. And similarly, what is the difference of thyristor switched capacitor? And if there exists, although thyristor control capacitor does not exist due to some reason, I will discuss in my future lecture. But if it exists, for example, hypothetically, if we assume that it exists, then what is the difference between the switched capacitor and control capacitor? Now, this is something one needs to understand. So, the answer is very simple.



So, if we consider that TSR and TCR side by side, so both are identical in construction. So, TSR and PCR are usually identical in construction. However, there is a difference between the usage of the switch or thyristors which are present in both the compensator, both type of compensator. In TSR, the switches are operated such that they are fully on fully turn on or fully turn off. So, there is no partially turn on mode of operation.

Whereas, this thyristor control reactor also have switches, semiconductor switches or thyristors. They are operated either as fully on mode or fully off mode or partially on mode. So, this is what the difference between this TSR and TCR. In spite of having identical in construction, this TCR can be, this switches can be partially turned on whereas in TSR there is no partially turned on. So, that is what the difference that is something one needs to understand ok.

So, therefore, in case of TSR which is called as thyristor switch reactor, here is our thyristor switches will be operated as a simple mechanical switch where we can either turn it on or you can turn it off, but we will never partially turn it on. So, therefore, in this TSR we do not have any harmonics. So, that is why here there is no harmonics, whereas this TCR always has high harmonics And this high content of harmonic is one of the major limitation of the operation of TCR, which I already discussed in the last two lectures. And there should be some mitigation approaches as well for this type of harmonics, specifically this higher order harmonics like third harmonics, fifth harmonics, seventh harmonics and so on. So, the difference between this TSR and TCR is that there is no harmonic generation in case of TSR because switches are operated only in two modes, one is fully turn on mode, another is fully turn off mode. Whereas, this TCR can be operated as either fully turn on or fully turn off or partially turn on mode. And therefore, due to this partially turn on condition, there exist harmonics in the TCR, which I discussed already. So, in general, when we have a, this switched reactor or controlled reactor type of static var compensator, both TSR and TCR are used simultaneously. In fact, if we have n number of units for static var compensator, Then, n minus 1 number of units are used as a TSR or thyristor switched reactor and only one unit is kept as a control reactor. This is purposefully done to reduce the harmonic.

So, both TSR and TCR are used at a time in a particular location where we need this reactive or reactor or inductive type of compensation. So, that is something one needs to understand. Now, similarly this thyristor switched capacitor also operates, here the switches are also operated in either fully turn on mode or in fully turn off mode. Here also we do not have any partially turn on mode of operation because of some reason which I am going to discuss when I will discuss this thyristor switched capacitor. So, I am sorry that this is not TCR, this is thyristor switched capacitor.

So, this is basically TSC, the acronym is TSC instead of TCR, okay. So, in case of thyristor switched capacitor, the switches are operated either on fully turn on mode or fully turn off mode, there is no partially turn on mode of operation. So, why it is so I will discuss, whenever I will discuss TSC. Now, there are combination of inductive and capacitive type of SVCs, which include FCTCR, which stands for fixed capacitor thyristor control reactor. It stands for fixed capacitor thyristor controlled reactor.

So when you have this control term, then you can understand that there is a kind of hiding angle control or the reactance or the susceptance value of that particular device is controlled. That is why it is control reactor. There also exists this MHC-TCR. So, M S C T C R means mechanically switched capacitor T C R. So, this is means mechanically switched capacitor TCR.

I am going to discuss what is the difference between this FCTCR and MSTCR in next lecture. Then there also exists TSC TCR which stands for this thyristor switched capacitor thyristor controlled reactor which stands for thyristor switched capacitor TCR ok. So, these are the different types of these are the different types of SVCs exist and I am going to discuss each of them one by one. So, in this particular lecture, I will discuss the FCTCR type of this static var compensator. And, we also will try to understand the difference of FCTCR with only TCR, which already we have studied in the last lecture.

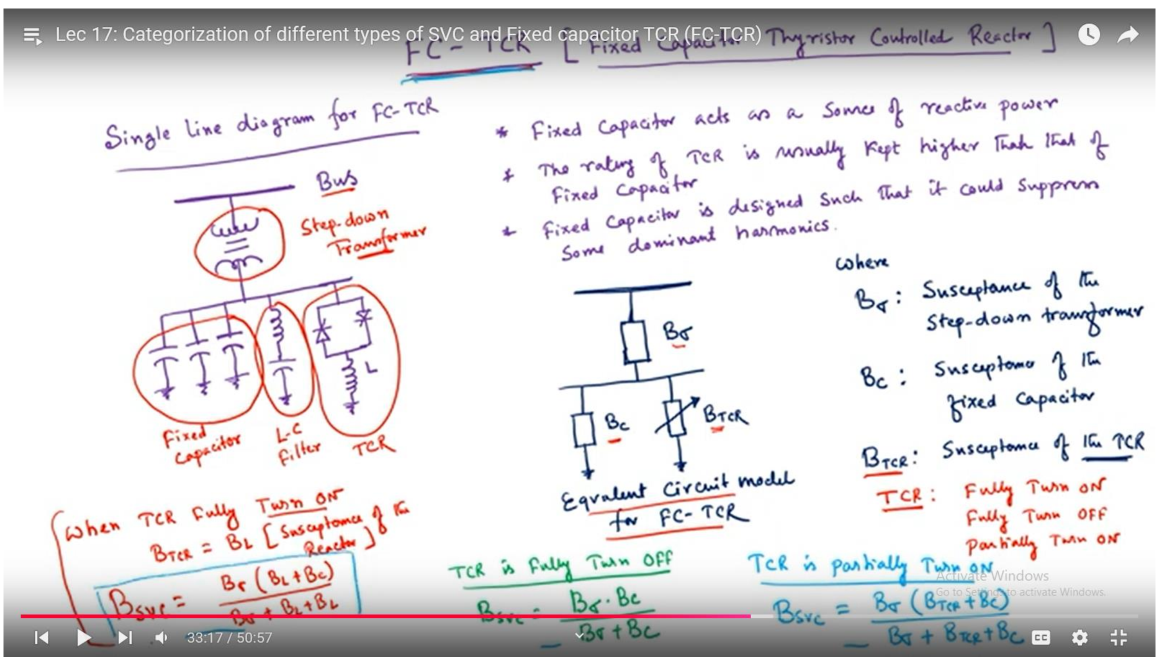
So, let us move forward. So, FCTCR. So, it stands for fixed capacitor thyristor control reactor. Now, let us draw the single-line diagram for FCTCR. It is something like that. We have a bus at which we will place this FCTCR.

Let us consider this is the bus. Then we have a step-down transformer. We have a step-down transformer which is represented by this symbol. Then we have a number of capacitors which constitute a capacitor bank and they are fixed like this. So, this is the symbol of capacitor as you know. Then we have LC filter then we have this TCR unit and you know the TCR unit consist of a bidirectional switch like this, it could be thyristor, it could be any other switch, semiconductor switch and we have a reactor like this.

So, here this is basically fixed capacitor. This is as you know step down transformer. Now what is the role of the step down transformer? Already I discussed in the last lecture, the step down transformer is used in static var compensator to step down the voltage level from very high voltage. For example, transmission level voltage in India, it is 220 kilovolt or 400 kilovolt to relatively lower voltage level, it could be 11 kV even lower. So, the purpose of this step-down transformer is that while stepping down the voltage level, it facilitates the reduced rating of the semiconductor switches which are used in TCR. Because, you know that this TCR cost or price will depend upon what are the ratings of the semiconductor switches, what are the ratings of the reactor we are going to use.

And off course, by stepping down the voltage level to a reduced voltage level, we could reduce the cost significantly. So, this is the LC filter. You know what is the role of the filter because TCR here is a type of device which generates the harmonics and this LC filters are tuned in such a way that these could suppress some of the dominant or higher-order harmonics. Then, this is a TCR unit, which is already discussed in the last three lectures. So, FC-TCR essentially consists of a step-down transformer to reduce voltage level, to a reduced voltage level, then we have a fixed capacitor, we have a LC filter, we have a TCR.

They are connected in parallel or in shunt. So, that is what a very basic schematic diagram or single line diagram of a fixed capacitor. Now what is to be done, we need to model this type of FCTCR appropriately and then our goal would be to draw the operating characteristic or control characteristics of this FCTCR so that we could understand the difference between the basic operation of only TCR and FCTCR. Now, here some important notes are here fixed capacitor acts as a source of reactive power. Then second point that one should understand that the rating of TCR is usually kept higher than that of fixed capacitor. And another advantage of having fixed capacitor is that the fixed capacitors are designed in such a way that they can also be used to suppress some of the dominant higher order harmonics.



So, here fixed capacitor is designed such that it could suppress some dominant harmonics. Now, let us model this FCTCR. So, in order to model this FCTCR, what is to be done? So, this is suppose the bus at which it is placed, we will model this step-down transformer as a fixed susceptance, as a fixed susceptance which is represented by this rectangular box. And let us consider that value of the fixed susceptances B sigma. Then we will be having this susceptance of the capacitor, fixed capacitor, which is represented by B c.

And this, we also will have the susceptance of this TCR, but we know that TCR susceptance is variable and let us represent by B TCR. This is the equivalent circuit model for FCTCR, where B sigma stands for susceptance of the step down transformer BC is the susceptance of the fixed capacitor and BTCR is susceptance of the TCR unit. And as you know this TCR unit usually operated in three modes, one is fully turn on mode, another is fully turn off mode, another is partially turn on mode. So, in TCR we have three mode of operation, one is fully turn on, one is fully turn off, another is partially turn on.

Now, this is known to us. Now, when this TCR is fully turn on, then this B TCR is equal to the susceptance of the reactor which is used in this particular TCR. So, when TCR is fully turn this B TCR is equal to B L, which is the susceptance of the reactor. So, this is I discussed in the last lecture. So, therefore, when the TCR is fully turned on in this condition, the overall susceptance of this SVC will be equal to this, if you look at this equivalent circuit diagram, then when it is fully turned on, then B TCR will be equal to BL and this BL and BC are in parallel and it is connected with series by this B sigma but these are susceptance. So, therefore, when they are in parallel, so overall susceptance will be additive.

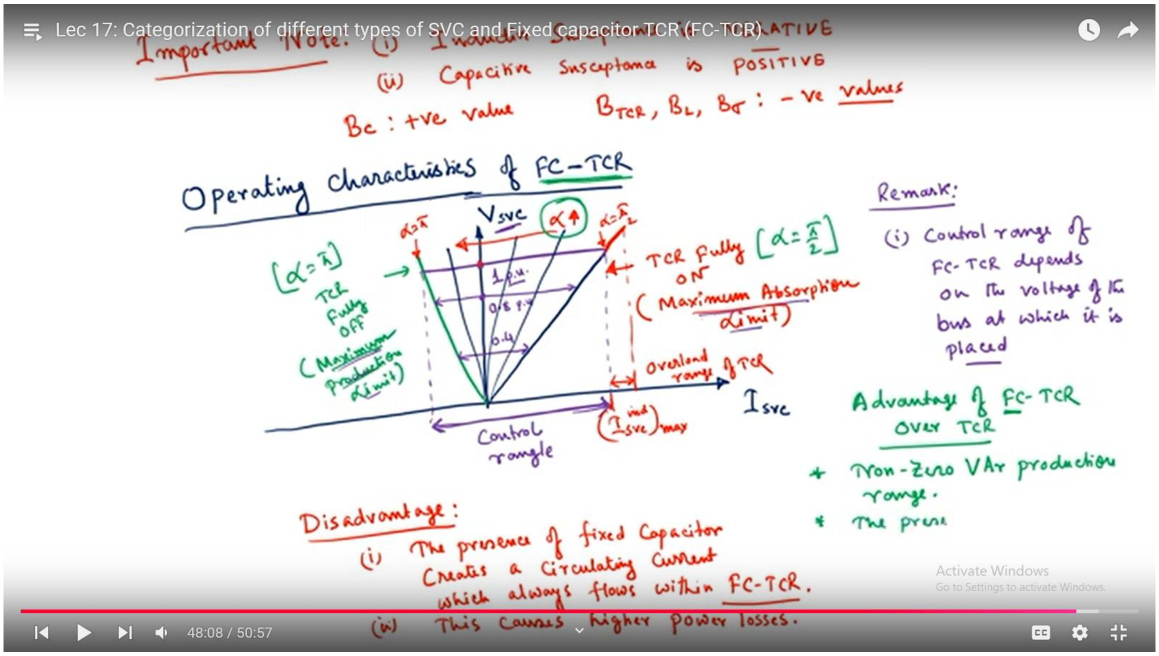
So, therefore, this overall this SBC susceptance will be equal to this B sigma multiplied by BL plus BC divided by v sigma plus v L plus v C. This happens when their TCR is fully turn on condition. Now, when TCR is fully off condition, fully turn off condition during that time what would be B TCR? B TCR would be 0. So, therefore, BSVC will be equal to B sigma multiplied by BC divided by B sigma plus BC.

So, this happens when TCR is fully turn off. Now, when this TCR is partially turn-on, TCR is partially turn-on then, B SVC will be equal to B sigma multiplied by B TCR plus B C divided by B sigma plus B TCR plus B C. So, these are the three expressions for overall susceptance of the SVC as a unit. If you consider that FCTCR is a unit type of SVC, then this expression for this overall susceptance is something like this, something like this, under these three mode of operation. Now one needs to understand there is an important point which is to be noted that that already I discussed that when there is a capacitive type of such a susceptance so it is a positive susceptance because as we know that capacitive reactance is 1 upon j omega c. So if you take the reciprocal of that then its susceptance will be equal to j omega c which is positive. However, when we have an inductive type of susceptance, it is negative. So, therefore, this B c is positive, B sigma since it is a step down transformer is modeled with this leakage reactance. So, it is basically an inductive type of susceptance. So, therefore, it will be negative and the susceptance of this TCR would be also negative.

Important notes: 1) inductive susceptance is negative. 2) Capacitive susceptance is positive. So, therefore, B c is basically is a positive quantity, positive Whereas, this B

TCR or BL or B sigma, they are of negative values. Why they are so? Because they are all inductive type of susceptance. So, they are, thus, they are negative.

So, this is something one needs to understand. Now, let us draw the operating characteristics; let us draw the operating characteristics of FC-PCR. Now while drawing so, again what we will do, we will consider this horizontal axis represent ISVC and vertical axis or y axis is representing VSVC. So, this is also known as VI characteristics of the SVC and here SVC is FCTCR. Now, as we know that this TCR characteristics is something like this. And this corresponds to the full conduction mode of this TCR.



So, suppose this is the characteristics which correspond to fullly ON when TCR is fully on TCR is fully on. So, this is we consider, we discussed in the last lecture, this is called maximum absorption limit. So, when TCR is fully turn on this is the characteristics and now during that for that instant of time the VSVC is equal to this VSVC is equal to this. So, therefore, this is fully absorption mode. And when this TCR is fully off the characteristics will be something like this when TCR is fully fully off this is called maximum production limit.

So, this is maximum production limit. So, this is when TCR is fully up and this is TCR is fully on. So, therefore, this corresponds to alpha is equal to pi by 2, when our firing angle is equal to pi by 2, according to this Mathur-Varma convention, that book convention used and this corresponds to alpha is equal to pi. And for any other value of alpha in between pi by 2 pi, the characteristics will be in between this. So, basically these overall characteristics will be in between this depending upon the voltage level of the bus at which it is placed. Suppose this corresponds to one per unit of the system voltage, then the control range that means, the available amount of this reactive power generation or reactive power absorption is this.

So, this is called control range. And this FCTCR type of SVC can provide any value of this reactive power, either it can absorb any amount of reactive power or it can produce any amount of reactive power within this control range. So, within this control range, it can produce or absorb any amount of reactive power. Off course, if the system voltage is lower than 1 per unit, the control range will get shrinker. It will be this, suppose this corresponds to 0.8 per unit of the voltage. And if your system voltage level is further declined and reduced to 0.4. Then the control range will be further reduced and so on. So, therefore, depending upon the system voltage level, the control range of the FCTCR is basically decided by this maximum absorption limit and maximum production limit. So, some important remark is that: 1) control range of FCTCR depends on system voltage or on the voltage at which on the voltage of the bus at which it is placed.

So, this can be seen over here. But, one thing that I should tell at this moment is that, this TCR unit can be operated, this above its rating to some extent and that is called overload range. So, if this is the, if this one is maximum this SVC, ISVC max. I SVC, this inductive max, then this TCR use can be operated up to a maximum overload range. So, this is, this maximum absorption limit can be extended to this. It means that even if the system voltage level is above 1 per unit, your TCR can be operated up to a certain value of this voltage and this is called overload range of TCR.

But eventually if the system voltage falls then accordingly this SVC maximum amount of reactive power that the TCR can absorb also gets declined. So, this is visible from this particular characteristic. And here you can see basically within this control range any value of this, you know, reactive power, this compensator can provide depending upon this different value of alpha. For example, if we keep on increasing alpha, then characteristics will be shifted to this right to left. if you keep on increasing the value of alpha from this point alpha is equal to pi by 2 till this maximum value of alpha which is alpha is equal to pi, then this overall control characteristics will be shifted from right to left of the operating characteristics.

So, this is something one needs to understand. So, this gives you the idea that the advantage of this or I should use this advantage of F C T C R over T C R is we have non-zero production range or I should say the var production range. So, basically the role of this fixed capacitor here is to extend this maximum production limit from this vertical or y axis to the left side, so that it is capable to provide certain amount of var whenever it is required to the system. So, here FCTCR can absorb var, it can also produce var because we have fixed capacitor to produce var and we also have reactor to absorb the, absorb var, but the var production and the var absorption can be controlled with this firing angle control of the TCR. This is something one needs to understand. Then what will be the disadvantage? When something is having an advantage, there is certain disadvantage as well.

So there are certain disadvantages the major disadvantage is that this fixed capacitor, the presence of fixed capacitor, the presence of fixed capacitor creates a circulating current, which always flows within FCTCR. So, it means that since these capacitors are always turned on and remained in the system then within this capacitor and with the capacitor and this TCR unit there would be some circulating current which will always flow. Unless this capacitor sizes are exactly identical and, even if it is so, then of course, there will be circulating current among this capacitor bank to this LC filter and the TCR, which will cause power losses or energy losses. So, this will cause higher amount of energy losses.

This causes higher power losses. So, therefore, we need to identify a strategy or option so that this could be avoided or the losses could be reduced. But however, this one obvious advantage is that there is a fixed capacitor over here, the fixed capacitor, the presence of fixed capacitor, fixed capacitor avoids the switching of capacitors which is a crucial point because when you turn on and turn off a capacitor, there exist certain amount of transients which I am going to discuss in my future lecture. And that is the main bottleneck of switching the capacitor for multiple times and that may create serious issues if this is not properly operated or proper attention is not paid on it. So, this is one of the disadvantages of switching of the capacitor.

So, fixed capacitor is the simplest option. So, it avoids the transient caused by capacitor switching. So, capacitor switching can reduce this power loss by reducing the circulating current, but it may cause certain amount of transient which need to be properly taken care of. So, these are the things I am going to discuss in my next lecture. But in this lecture, if I summarize what I have learned, first of all, we have learned this categorization of the static wire compensator. And, as we discussed that there are combination of this inductive and capacitive type of SVCs.

I am going to discuss all of them. Today, I discuss FCTCR. In the next classes, I will discuss MSCTCR. Also, I will discuss thyristor switched capacitor before I discuss this TSCTCR. So, I hope this FCTCR is understandable to you and this advantage and disadvantages are understandable to you and this is up to this for this particular lecture and let me thank you for your attention. So, thank you very much for your attention, we will continue this in the next lecture. Thank you.