Course Name: Power Electronics Applications in Power Systems

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Lec 18: Mechanically Switched Capacitor TCR (MSC-TCR) and Thyrisor Switch Capacitor (TSC)

So welcome again in my course power electronics application in power system. This is another lecture. So, in the last lecture, I discussed this different types of static var compensator, different types of static var compensator. And I said that there are two types of static var compensator, one is one which absorbs the reactive power, another is one which can deliver or produce the reactive power. Of course, one is inductive type of reactive power, another is capacitive type of reactive power. And in this particular course, we will discuss all these different type. For example, this TCR thyristor control reactor, which is one type of reactive power compensator, which is one type of static var compensator, I discuss in very detail. And in the last lecture, I discussed this FCTCR, which is a combination of fixed capacitor and this TCR. So, the advantage of FCTCR over the normal TCR is that in FCTCR, since we have a fixed capacitor bank, so we have a flexibility of having reactive power delivery and reactive power consumption both. So, therefore, these VI characteristics of this fixed capacitor TCR is having this flexibility of non-zero production limit. Whereas, in normal TSR, normal TCR was having a zero production limit which I discussed. But the disadvantage of having this fixed capacitor is that there will be a circulating current which will always flow in between this fixed capacitor and this TCR when they are operating. So therefore, there would be some additional losses. To alleviate that, we need some switchable capacitor. It is because of the presence of fixed capacitor, there would be some circulating current which will always flow through the fixed capacitor unit and the TCR unit.

To alleviate that, we need a switchable capacitor and as we have seen, there are two types of switchable capacitor. One is mechanically switched capacitor, another is thyristor switched capacitor. Now, when we have a mechanical switched capacitor coupled with this TCR, this thyristor control reactor, then the unit would be called as MSC-TCR, that is mechanically switched capacitor thyristor controlled So, let me discuss briefly what it is actually. So, in today's presentation, I will first start with this mechanically switched capacitor control reactor. So, it can be acronymed as MSC mechanical switched capacitor TCR that is thyristor control reactor.

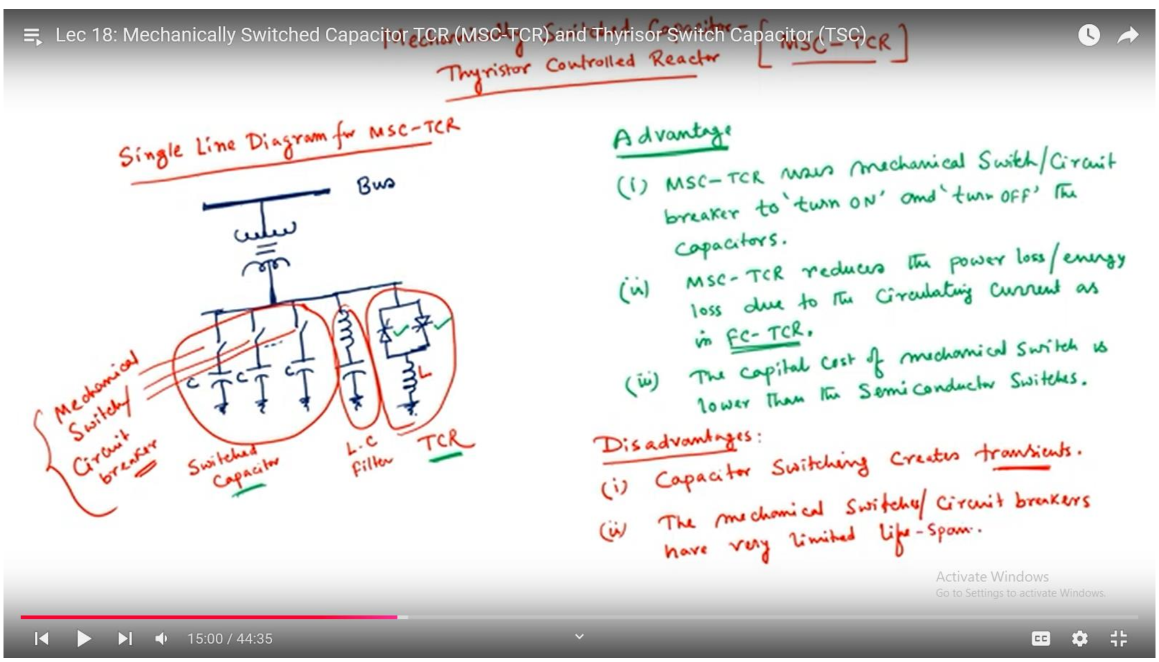
Now we know the basic operating principle of a thyristor control reactor that is why I started the discussion of SVC with this TCR only. So, therefore, it would be easy for us to understand what is M S C T C R. Remember, the basic goal of developing this M S C T C R is to have a switchable capacitor instead of having a fixed capacitor. So, therefore, the configuration, the single line diagram for this M s c T c r is something like this. we will be having a bus, this is suppose representing the bus at which this whole unit would be placed.

So, where M S C T C R unit would be placed, then we will be having a step down transformer as we discussed to step down the voltage level to a much reduced voltage level than the transmission level voltage. Then in this low voltage bus, we will be having mechanically switched capacitor like this. So this is, this is this mechanically switched capacitor. So, normally they are of identical rating depending upon the number of units we will be having in parallel. Then we will also have this LC filter.

You know that purpose of this LC filter is to filter out the harmonics, some of the dominant harmonics generated by this TCR and then we will be having normal TCR unit. Here we have a bidirectional switch, like this. Here we will have a bidirectional switch, here we will have a reactor. So, therefore, this unit is this switched capacitor, switched capacitor unit. This is LC filter. What is the purpose of the LC filter? To filter out the harmonics generated by TCR operation and this is the TCR, thyristor control reactor. So, this is the inductance, this is bi-directional switch and this symbol represents mechanical switch or circuit breaker. So, this is a very simple construction, constructional detail or single line diagram of MSC TCR. Now, the only difference of this with the fixed capacitor TCR is that we have a number of mechanical switch or circuit breakers which can turn on and turn off of these capacitors whenever they will be required, that is the difference. So, the advantage of this type of configuration is number 1, MSC-TCR uses mechanical switch or circuit breaker to turn on and turn off the capacitors.

So, thereby it will elevate the problem when that we have a system, a power system is operating at light load condition and thereby there is a creation of over voltage. So what we can do? We can disconnect this capacitor so that there is an excessive reactive power available in the network cannot be increased further. So that the presence of this capacitor during this light loading operating condition of the power system cannot further enhance the over voltage. So we can do so. Similarly, we can turn on this capacitor bank when the system is operating at peak load condition, whenever system requires Eventually this TCR is, as you know, because we have this thyristor switches, so these two thyristors already we have, so they can be turned on and turned off whenever is required.

And during this peak loading condition, we can fully turn off this TCR unit and we can fully turn on the capacitor unit, so that we can produce and we can inject certain amount of var to the network, so that this under voltage due to this peak load or very high load condition can be mitigated. So, this is one of the advantages. Then the second advantage that MSC-TCR reduces the energy loss or power loss due to the circulating current. So, this is already I discussed one of the main advantages is of this MSCTCR is to alleviate the circulating current as in the fixed capacitor TCR. Then the third advantage is regarding the capital cost of the mechanical switch is certainly lower than the semiconductor switch.



The capital cost of mechanical switch is lower than the semiconductor switches. So, therefore, between these two switchable capacitor options, one is TSC that is thyristor switched capacitor, another is mechanical switch capacitor that MSCTCR is advantageous as far as the cost or capital cost is concerned. So, these are the advantages.

Now, there are many disadvantages as well for this configuration. What are the disadvantages? Let us see.

Number 1, the first disadvantage is that capacitor switching, that means turning on and turning off the capacitors creates transients. So, that is one of the disadvantages as compared to FCTCR. In FCTCR, we are not doing any switching operation of the capacitor. Therefore, we are basically avoiding the transient happening due to the capacitor switching. So, this is one of the major issues in case of this TSC that is thyristor switched capacitor.

So, which I will come to that a couple of minutes after. The second another disadvantage or bottleneck is that the mechanical switch or the circuit breakers have very limited lifespan. This the life of this mechanical switch a circuit breaker would be reduced based upon the total number of operation of the turning on and turning off okay. So there are some finite number of turning on and turning off operation is possible for a mechanical switch and if we do it very frequently then it life time would be reduced. That is one of the bottlenecks of having this mechanical switch.

So, these are the advantages and disadvantages for this MSCTCR. The characteristic wise, the VI characteristic of this MSCTCR is similar to fixed capacitor TCR, but we have discrete control range in this maximum production time. So, this I am going to discuss whenever I will discuss TSC Thyristor Switched Capacitor because in principle is VI characteristic wise or this V_{SVC} I_{SVC} characteristic wise MSC TCR and TSC TCR are similar. So, I am going to discuss this operating characteristics of TSC TCR in very detail whenever I will cover that. So therefore, I am just skipping this MSCTCR VI characteristic.

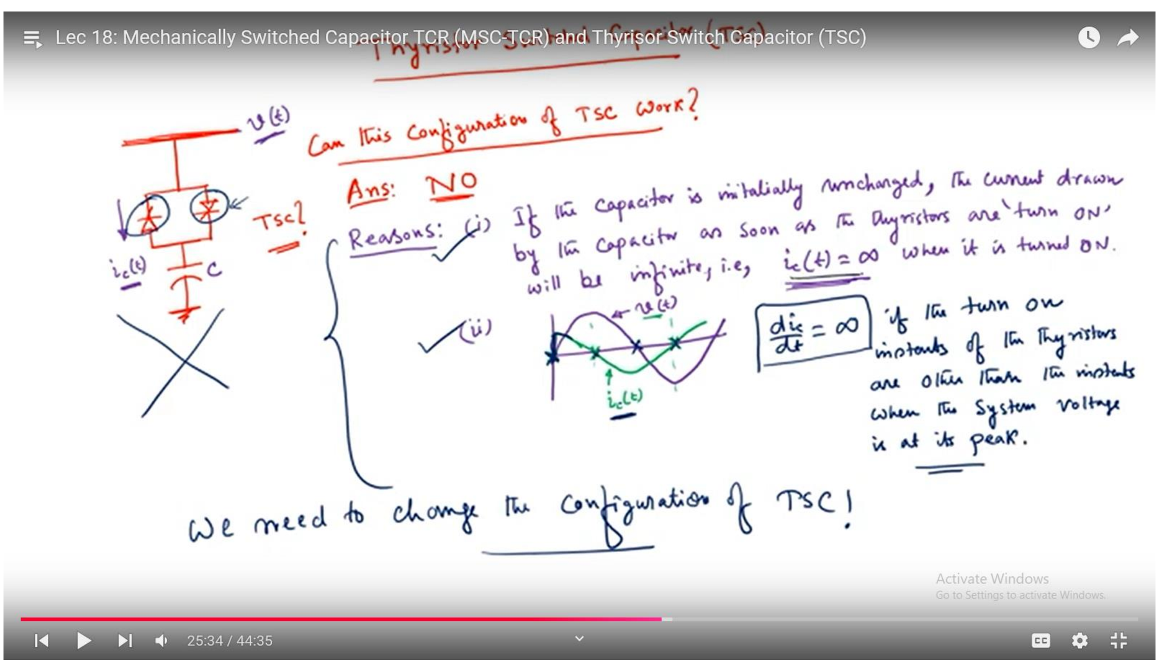
But one should understand that the VI characteristics or voltage current characteristics of this M-SCTCR would be similar to TSCTCR. So, in short this is what this mechanical switched capacitor TCR. So, we covered these first two. Then the third one we will cover that is TSC TCR. Now, before that one needs to have a idea that what is thyristor switched capacitor.

So, because we know that the basic operating principle of TCR in very detail. So, if we understand that the basic operating principle of TSC that is thyristor switched capacitor then it would be easier for us to understand their combination that is TSC TCR which is more sophisticated type of SVC used. So, let us start with thyristor switched capacitor. Thyristor switched capacitor or its acronym is TSC. Now, as per my discussion in this particular course, one may think of that simple TSC configuration is something like this.

We have a bus where this TSC would be placed. We may have a step down transformer, I am skipping that. And we also have a bidirectional switch like this. Then we have a capacitor. So this is a configuration of TSC. But is this a configuration of TSC which will work? So is this configuration of TSC or can this configuration of TSC work? This is the question that I want to set first. Can this configuration of TSC work? The answer is certainly no. This will not work due to various reasons. Now what are the reasons that for which this configuration will not work? This is I am going to discuss. So what are the reasons? So first reason is that if you have this configuration, then suppose this is this voltage, instantaneous voltage at the bus at which this TSC unit is kept and this is what the current drawn by this, this capacitor whenever it is connected to this particular bus.

Now, as soon as this thyristor will be turned on, what would be the current that will flow through this particular circuit? This is a simple capacitive circuit as if we are basically connecting the circuit to a source and let us consider it is an AC source. Assuming that the capacitor is initially uncharged, so therefore if the capacitor, if the capacitor is initially uncharged, then how much current that will flow as soon as we will turn on the switch. So the current drawn by the capacitor as soon as the thyristors are turned on will be infinite. So, that is I c t would be infinity when it is turned on. So that is what the first reason that we will be having a very infinite current.

In theoretical it is infinite current. If we assume that this capacitor is an ideal capacitor, so there would be infinite current that would flow through the circuit which makes it infeasible. Second is that when we turn on the switch, suppose this is what the voltage waveform and this voltage waveform represents this instantaneous voltage of the bus at which this is placed. Now, what would be this current that will flow through the circuit? As you know, this current will lead 90 degree. So therefore, this current will flow, this current drawn by this capacitor will be something like this.



Now, you can see except this capacitor is turned on at the peak voltage, there in any other instant, for example, if the capacitor is turned on when this voltage waveform at its 0 crossing, like this instant. So, during that instant, this I of c, I c t, what it will be? It will increase from 0 to this value and it will keep on increasing, because capacitor current can instantaneously be changed. So, therefore, if it happens, then d I c d t would be infinity, if the turn on instance turn on instance of the thyristor are other than other than the instance when the system voltage is at its peak. So, there will be infinite di dt that would be developed because you see that this I of c t would directly jump from 0 to that particular finite value if you operate it any other instant other than this peak value of the system voltage. So, therefore, these two are the main bottlenecks for which this configuration will not work.

So, we need to change the configuration of TSC. So, therefore, the conclusion is we need to change the configuration of TSC. So, we need to change the configuration of TSC. And so you need to understand that these are the two reasons for which this configuration will not work. Because no practical switch can withstand infinite amount of current. No semiconductor switch can instant infinite change of the current, infinite amount of di of dt. So, therefore, it is not possible that we will have a capacitor directly switched with some thyristors. So, we need some other devices which can control this current, which can control the di dt across the switch as well. And you know that if we simply connect a inductor, very small inductor in series with this capacitor, this problem can be elevated. So, therefore, the practical TSC configuration is something like this.

Suppose this is the bus at which we will connect this TSC unit, this is the bus at which we will connect this TSC unit, then we will may have a step down transformer to step down the voltage level. This is suppose the step down transformer, then we have the bidirectional switch as in TCR, as in TCR and we have the capacitor along with a small inductor or reactor here, okay. So, as you know this is step down transformer this is thyristor switch. This is the capacitors and this is a very small inductor. This constitutes a practical TSC configuration.

This is of course single line diagram and a practical this three-phase TSC configuration will be something different which I will discuss in the next lecture. Now, suppose the voltage, suppose the voltage at the bus at which this TSC unit would be placed. So, the voltage at this bus is V of t. So, voltage of this bus is V of t, which is representing a pure sinusoidal waveform, V m sine omega t, where V m stands for the peak value of the sinusoidal voltage and omega is the frequency, power frequency of the system. So, V m is here peak value of supply voltage and omega is power frequency.

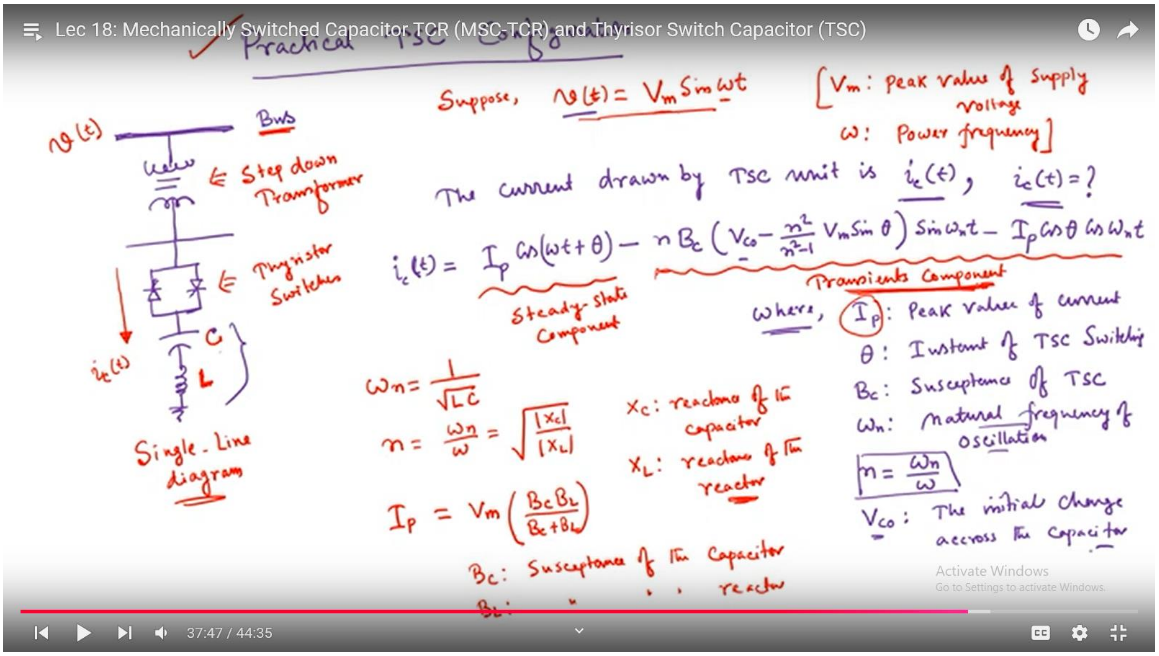
Now when you energize this circuit with the system voltage whose instantaneous value is V of t, then what would be the current that will flow through this TSC unit? Suppose the current flowing through this TSC unit is I of c, Ic of t, so the current, the current drawn by TSC unit is I of c t. You can see from the representation that they are instantaneous current. So, this is instantaneous voltage. So, this is instantaneous current. Then the question is what would be the expression, what would be the expression of I c of t? This expression one can derive because this is simple LC circuit.

So if you consider LC circuit, assuming that there would be certain amount of charge in the capacitor whenever we are turning on the switches, then what would be the expression for the current drawn by this LC circuit? So, usually in my class I asked my student to derive the equation. So, this is not difficult and but in this particular lecture I will straight away write down the expression instead of deriving because this is of no use. So, this I of c t is equal to this I peak cos omega t plus theta minus n B of C multiplied by VCO minus n square divided by n square minus 1 Vm sin theta all right multiplied by sin omega n t minus i of p cos theta this is bit longer equation cos omega n t. This is a bit longer equation having lot of different variables. Now, here this i p is peak value of the peak value of current.

I will come to that this expression for I of p. Theta is the instant of TSC switching. So, theta is the angle of the instant of TSC switching, b c is susceptance of TSC unit Now, omega n is basically representing natural frequency of oscillation. Remember, this is a LC series circuit. So, there will be a natural frequency of oscillation. And this n is a number which representing the ratio of omega n to omega, which is basically the ratio of natural frequency of oscillation to the power frequency.

Now, what is this? I will come to that. Now, what are the unknown variables? What else the unknown variable we have? This V co, this V co is representing the initial charge or voltage across the capacitor. So, this is the voltage at the instant of turning of operation across the capacitor. So, this summarizes the whole equation. Now, from this equation one can, if we just divide this equation into two parts, you can see this is a steady state part, steady state component. And these two parts represent the transient components. They appear due to the capacitor switching only and that is what I was discussing that the capacitor switching itself is a is a difficult task in view of the initial transients because of the this presence of the some charge in the capacitor even if the capacitor initially remains unchanged then also there would be some amount of transients. So, therefore this TSC operation is to be carefully done, so that this transient should be less, otherwise it may create lot of problem in operation of the TSC. So, one of the goals of this TSC operation is to keep this transient component of this current into an acceptable range or acceptable value.

So, how to do that, I will come to that. But now, we will also discuss this, what is this omega n. As you know, this omega n, that is the natural frequency of oscillation, it is nothing but 1 upon root over L c. So, if it is so, then we can show that n is equal to, which is the ratio of omega n to omega, it is equal to root of this Xc to Xl. So, here this Xc represents the reactance of the capacitor. And XL is basically representing reactance of the, this inductor or reactor.



$$i_c(t) = I_P\cos(\omega t + \theta) - nB_C\left(V_{C_0} - \frac{n^2}{n^2-1}V_m\sin\theta\right)\sin(\omega_n t) - I_P\cos(\theta)\cos(\omega_n t)$$

Steady-state component

$i_c(t)|_{steady-state}$

Transient component

$i_c(t)|_{transient}$

Here,

ω = System frequency

θ = Instant of TSC switching

$\omega_n = n\omega = \frac{1}{\sqrt{LC}}$ = Natural frequency of oscillation

B_c = Susceptance offered by capacitor

V_{C_0} = Initial voltage of capacitor (at switching instant)

I_P = Peak value of the current

$n = \frac{\omega_n}{\omega} = \sqrt{\frac{|X_C|}{|X_L|}}$; X_C = Reactance of the capacitor, X_L = Reactance of the inductor

$$\Rightarrow\ i_c(t) = i_c(t)|_{steady-state} + i_c(t)|_{transient}$$

From the circuit we have,

$$I_P = V_m\left(\frac{B_C B_L}{B_C + B_L}\right)$$

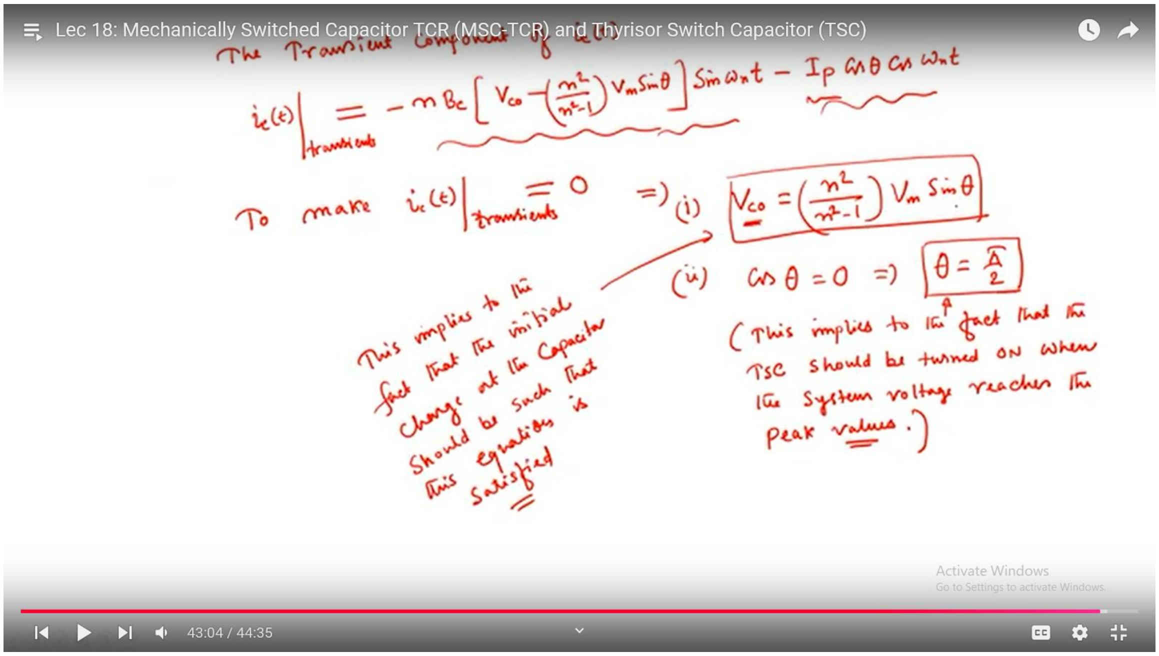
$$I_P = \frac{V_m}{X_C}\left(\frac{1}{1-\frac{X_L}{X_C}}\right) = \frac{V_m}{X_C}\left(\frac{1}{1-\frac{1}{n^2}}\right) = \frac{V_m}{X_C}\left(\frac{n^2}{n^2-1}\right) = V_m\left(\frac{n^2}{n^2-1}\right)B_C$$

So, this is something one needs to understand. So, another thing that I should write that this what is this peak value that is peak value of the current. So, this peak value of the current it is its expression is equal to this peak value of the voltage which is V m multiplied by this B C B L divided by B C plus B L, where B C is susceptance of the capacitor and VL is the susceptance of the reactor or the inductor and basically this inductor is so designed that it is its size is lesser than this capacitor and its basic purpose is to limit this current as I discussed in the last page. So, its basic function is to limit this, otherwise you have to understand at this point that here the role of the reactor is not to absorb the var from the system, rather during starting it limits the current. The presence of this reactor is helpful to keep the initial current drawn by the capacitor to a reasonably acceptable value.

So that is what the purpose is. So other than that the main goal is to this reduce the transient. If we cannot avoid it completely at least we can reduce it. Now we will see that theoretically how can we reduce this transient and also we will see practically how we can do so. So, if you look at this equation, if I write down this transient component, so the transient component of I of c t if I rewrite again this is equal to I of c t transients which is equal to minus n V c multiplied by V co minus N square divided by N square minus 1 multiplied by V m sin theta multiplied by sin omega N t minus I of peak cos of theta was of omega n t. So, this was the transient component which I explain over here.

Now, how can we make this transient component 0? To make I of c t transients is equal to 0, if you look at this two component, if I have to make it 0, then what I need to do? I can write that VCO can be equated with n square divided by n square minus 1 multiplied by Vm sin theta. So, if you can do so, then this portion would be 0. So, this is the first condition. However, if you do so, this component would be again there. Now, how can we remove this component completely? Because omega n cannot be 0, it is representing natural frequency of oscillation.

So, therefore, I p cannot be 0, as I have already shown you the expression. So, therefore, cos theta can be made 0. So, second condition is that cos theta can be made 0, which stands for theta is equal to how much? Theta is equal to pi by 2. So, theta as I discussed it is the instant of the switching. So, that means if we can turn on the switch at the instant which is pi by 2 from the compared to the system peak value. So, that means we can turn on the switch corresponds to this peak value of the system voltage. So, this means that we need to turn on. So, this stands for this. This implies to the fact that the TCSC should be turned on when the voltage system voltage system voltage reaches the peak values.



It could be a positive peak or a negative peak. So this is the instant and this implies to the fact that, this implies to the fact that, this implies to the fact that the initial charge at the capacitor should be such that should be such this equation is satisfied. So, this VCO as I discussed in the last page that it is representing the initial charge across the capacitor or the voltage across the capacitor due to initial charge. So, it should be such that this VCO should be equated with this. This is one condition. Another condition is that we should turn on the switch when the system voltage will reach the peak values.

So, if you can keep these two conditions hold then only we will avoid the whole transient current, we can make it 0, which is our goal. So this is theoretically speaking, this is how we can make this transient component 0. So thereby your system current would be transient free. But practically will it be possible? We will see that in the next lecture. So, practically this is very difficult to satisfy both the conditions simultaneously.

Why is it so? I will discuss this in my next lecture. Then if we cannot satisfy that, how can we reduce the transient? This is also an important issue. That also, I will also discuss in the next lecture. Till then, thank you very much for your attention.