Course Name: Power Electronics Applications in Power Systems

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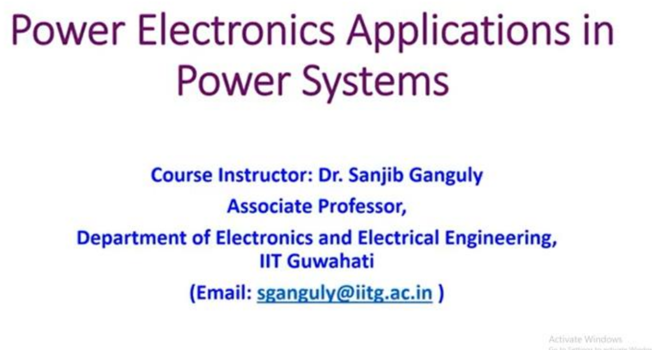


Lec 33: Basic mathematical modelling of STATCOM

Welcome again to my course Power Electronics Applications in Power Systems. So, in this particular course so far, I have discussed several types of power electronic-based compensators. Today I am going to start a new module of this course in which I will discuss a specific type of power electronic-based compensator which is completely different than whatever power electronic-based compensators we have learned so far. So, let us have a broad categorization again of this power electronic-based compensator so that I can show you the difference between the particular power electronic-based compensator which I am going to discuss today with the previous counterpart. So, let us start. So, broad categorization of power electronics-based compensators: So, if we categorize this power electronic-based compensator into two groups, one you know will come under shunt compensators.

Another will come under series compensators, which is something you have learnt so far. So, for shunt compensator, there is another classification. One will come under control impedance base, control or rather control susceptance-based compensators. Another will come under converter-based compensators. Similarly, for series compensators also, we will have two categories. One is, of course, controlled impedance-based or reactance-based impedance or reactance-based compensators, another will be converter-based compensators. Control Susceptance-Based Compensators we have already learned with.

We have, we called it as SVC. And you have seen there are various types of SVC like FCTCR, then MSCTCR, then TSCTCR and so on.

We also have TSC and TCR as well. So, this was already discussed in this previous module. So, these are already discussed in the previous modules. Now, similarly, for this control impedance or reactance-based compensator, we have already discussed, there might be different groups like thyristor-based series compensator, thyristor control series compensator, that is TCSC or it could be TSSC, thyristor switched switch capacitor or it can be GCSC, that is gate turn off control series capacitor, GTO control series capacitor. So, this is already discussed again, this is already discussed in the previous module.

So, what is new in this particular topic is converter-based compensator which I am going to discuss in this particular module and I will continue to this discussion at the end of this course also. Now, you know that this SVC static var compensator, we represent effectively it is like a variable susceptance. So, this is suppose V SVC, this is V SVC and the current drawn by it let us say is ISVC. So, we represent it as a variable susceptance. So, its equivalent form is equivalent simplistic form of representation of SVC is like a variable susceptance. Similarly, here we already discussed that this TCSC, it is nothing but a representation of a variable series variable series impedance or variable series reactance. So, its value is ZTCSC and it is to be connected in series with that particular transmission line, whereas it is to be connected in the shunt, that is why they are actually. So, this is something we have learnt so far. Now, what is to be understood in this particular module is something called converter based compensator, something called converter based compensator. The philosophy behind this converter-based compensator is quite different than the control susceptance-based or control impedance-based compensators. And they themselves represent a reactive power source. And if I represent this converter-based shunt compensator, I will show you that it is popularly named as STATCOM. So, its representation is something like this. There is a variable current source rather, yeah, variable current source which represent this STATCOM. So, its representation, so STATCOM is a type of this converter-based compensator.

Now, what is the full form of the STATCOM? I will come to that. But, its representation, simplistic way of representing or simplistic equivalence electrical model of the STATCOM is something like this. So, it draws or it injects a certain amount of current, which lets us consider it is I-STATCOM from the system voltage, wherever it is to be connected, that is P star com. So, therefore, this representation and that representation are quite different. Now, I will discuss the basic operating principle of this in more detail, once I discuss different types of converter based compensators. Similarly, this converter based series compensators, converter based series compensators can be represented like this, and we have a controllable voltage source like this, which will inject certain amount of voltage to the network. And one of the example of this converter-based compensator is SSSC. What is the full form of this? I will come to that. It is, its full form is static synchronous series compensator. And I will come to that.

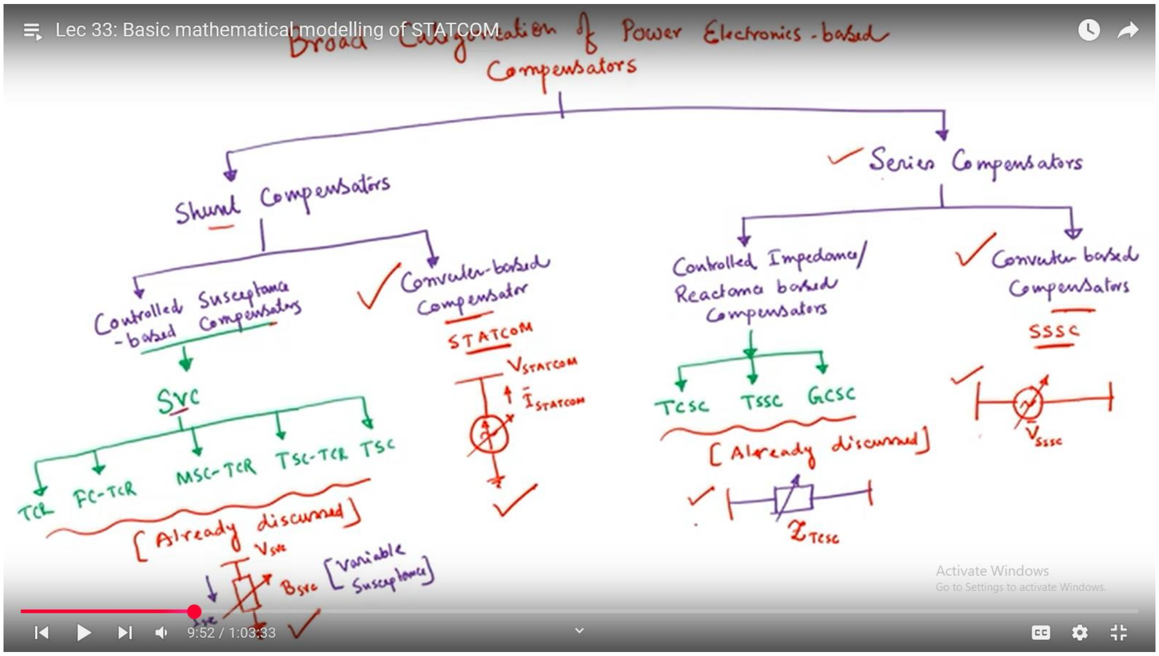
But if you look at this representation and that representation, this is quite different. So, that is why you need to study this and there are several advantages of the converter-based compensators over this control susceptance or control impedance-based compensators which also I am going to discuss. So, the goal of this today's discussion is I will introduce a new concept. It is not a new, but it is new in the sense that we have not discussed it in this particular course so far. So, I will discuss this basic concept of this converter based compensators.

I will also discuss the classification of converter based compensators. I will also discuss the difference of this converter-based compensators over this series and some counterparts like SVC and TCSC. And also I will discuss the basic operating principle and the control characteristics or VI characteristics of such compensators. So, let us proceed. So, here we will start with converter-based compensators.

So let us have a broad categorization of this. This compensators transfer, as I mentioned at the very beginning of this course, when I talk about the terminology compensator, you have to understand it is a kind of power electronics based compensators. So which I am not going to discuss or which I am not going to tell again and again. Now, converter-based compensators can be classified or can be categorized into two parts. In fact, whatever I am discussing right now, these compensators are useful for power system because our goal of this course is to discuss these compensators which are usually used in power system for various reasons.

So, this converter based compensators are can be classified into two categories. One type of compensator which are used in power transmission systems. These types of compensators are also named FACTS devices, F-A-C-T-S devices, which means F stands for flexible, A and C stands for AC, and T stands for transmission systems So, these converter-based compensators are also named as FACTS devices or flexible AC transmission systems. In fact, you might have heard this terminology in the basic power system course as well. So, these are the power electronic based or power electronic converter based compensators which are traditionally used in power transmission systems.

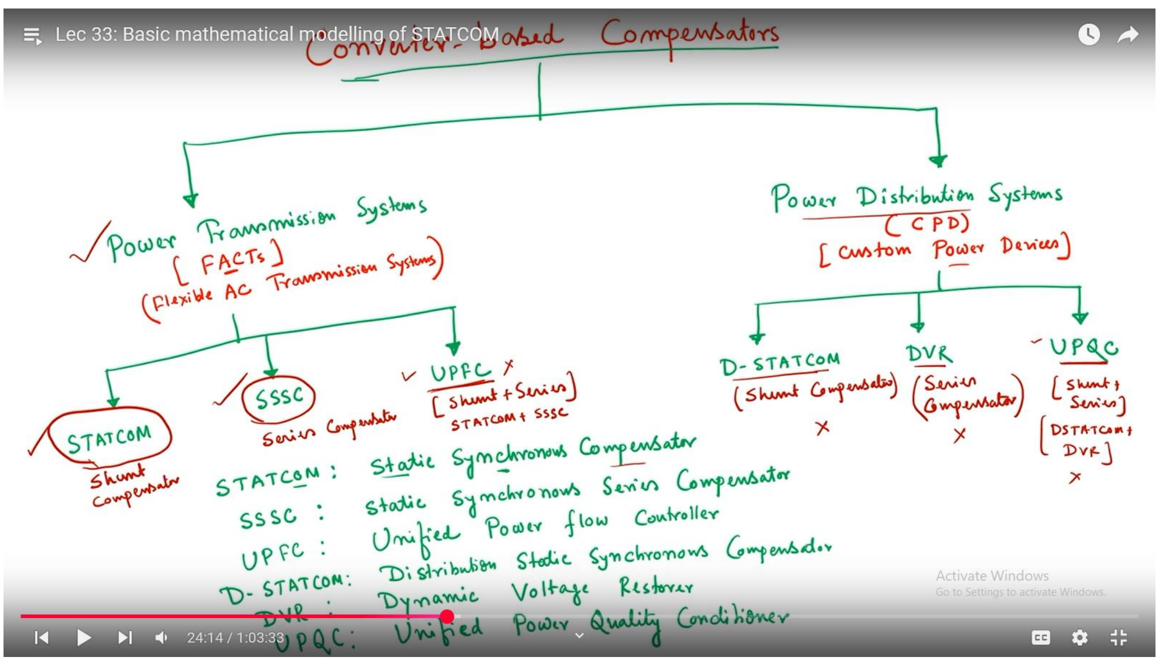
Similarly, we have some converter-based compensators which are used in power distribution system. So, these devices are often called this custom power devices, CPD. The full form of it is custom power devices. They are also compensators, they are also power electronic-based compensators, they are also converter-based compensators, but they are used in power distribution systems. Now, there is a difference between this power transmission system and the power distribution system in terms of various electrical aspects like R by X ratio, and resistance to reactance ratio, in terms of this the amount of voltage unbalance or voltage imbalance happens in terms of the several other power quality problems, which are more predominant in power distribution systems.



Also in terms of the topological consideration, a power transmission system is usually a very bigger and longer network with a highly meshed type of topology, whereas a power distribution network is usually of radial with relatively shorter. So, apart from the usual difference of the voltage levels, there are so many differences in view of the electrical aspects between the power transmission systems and the power distribution system. So, therefore, the same type of compensators that could be used in a power transmission system may not be useful in a power distribution system. This is the goal of my discussion is to make you understand that. So, there are various types of power transmission or rather converter-based compensators used in power transmission systems.

They can be categorized as STATCOM, then SSSC, they are often very popular with this acronym also, but I will write their full form as well, and UPFC. Similarly, this custom power devices can be categorized into three different broad categories one is called DSTATCOM, one is called DVR, one is called UPQC. Now, what are the full forms of this STATCOM, SSSC, UPQC? Let me write. The STATCOM, the full form is static synchronous, although this stat means, stat is the first four letter of the static. Synchronous part is somewhat omitted over here, but it is a very, you know, useful terminology for describing this STATCOM. And then, com means compensator. So, STATCOM, its full form is Static Synchronous Compensator. Similarly, SSSC, SSSC stands for Static Synchronous Series Compensator. Now, full form of this UPFC is unified power flow controller. DSTATCOM stands for distribution static synchronous compensator. DVR, is called, its full form is dynamic voltage restorer. And UPQC stands for Unified Power Quality Conditioner. So, in this particular, you know, this course, I will basically discuss two different types of converter-based compensators. One is STATCOM, another is SSSC. Now, what is STATCOM? STATCOM is static synchronous compensator.

In this module, I will discuss the basic operating principle of STATCOM and its control characteristics and its application in power systems. And also I will discuss what is the basic difference between the STATCOM and SVC, because both are effectively shunt compensators. So, STATCOM is a type of shunt compensator. Similarly, SSSC is a kind of series compensator. So, STATCOM is a type of shunt compensator SSSC is a type of silage compensator. Now, I will also discuss the basic operating principle of SSSC in the last module of this course and the control characteristics of SSSC and its fundamental difference over this impedance-based compensator like TCSC which I already discussed, and its application to power systems in very detail. Now, apart from these two, there is, you know, as I said, a specific type of converter-based compensator used in the power transmission system, which is named as UPFC. Its full form is unified power flow controller. It is nothing but a combination of shunt and series compensator. So, often, this is also named as STATCOM plus SSSC.



So, they use STATCOM plus SSSC. Now, since this course is all about the applicability of this compensator in power systems or to be more precise in power transmission systems, I will basically discuss STATCOM and SSSC. But UPFC I will leave, if someone is interested, he or she can go through this with a self-study. Now similarly, this in power distribution system, this DSTATCOM is its constructional wise quite similar to

STATCOM. It is also type of shunt compensator. But, its functionality wise is quite different, this STATCOM, because power distribution networks or power distribution systems are quite different than the power transmission system. So, therefore, STATCOM cannot be directly used.

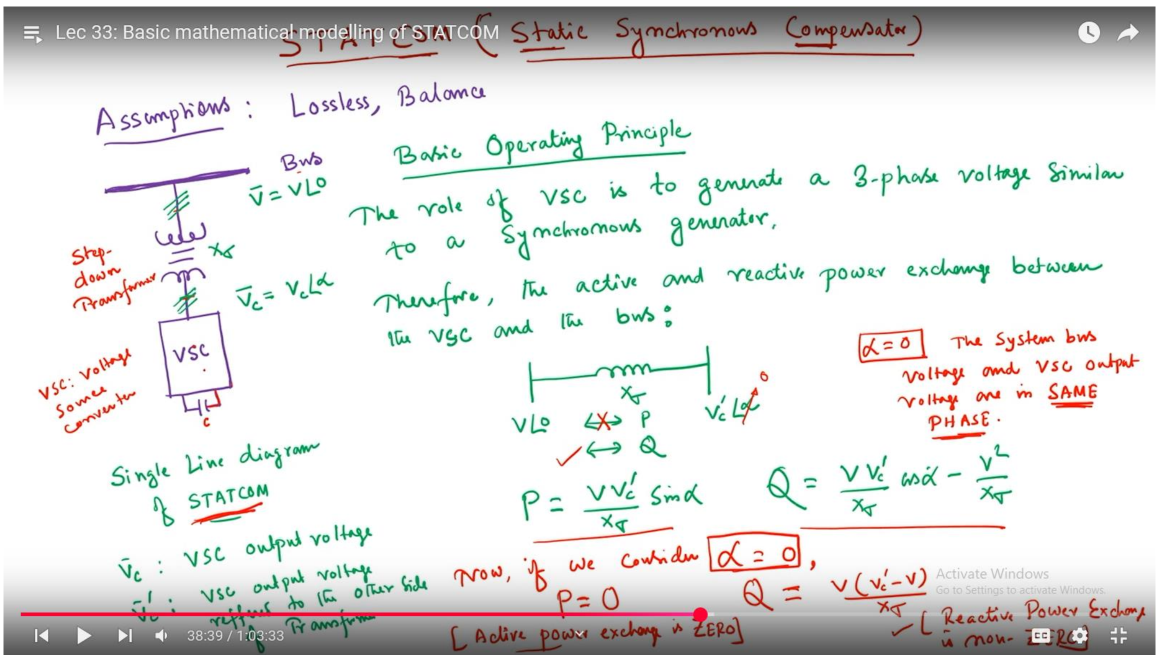
So, we have device, this power electronic and power system communities power engineering communities they device this DSTATCOM which is applicable in power distribution systems for similar task which is doing in by the STATCOM in power transmission system. But of course, the DSTATCOM functionalities are much more than the STATCOM. So, those things I am not going to discuss over here. Similarly, this DVR, it is a kind of series compensator. It is a kind of series compensator similar to SSSC. But of course, functionality wise, they are quite different and constructional wise, there is a difference. But the basic goal is same. Now, this UPQC, similar to UPFC, it is a combination of shunt, plus series compensator. Sometimes this is similar to this combination of DSTATCOM plus DVR. So, constructional-wise is similar to UPFC, but functionality is quite different.

And the basic goal is of course, much similar to this UPFC. And in this particular course, I am not going to discuss this, this STATCOM DVR and UPKFC, even UPFC, but I will discuss this STATCOM and SSSC in very detail. So, let us proceed for discussion to STATCOM in this particular module and SSSC I will discuss in the next module. So, let us start with STATCOM. As I said, its full form is static So, first four letters stands for this first four letters of static, then we have a synchronous term which is very important, why it is so important I will come to that and then we have compensator.

So, first four terms of comp will come under this. So, with this first four letters of compensators and first four letters of static this acronym is built that is STATCOM. So, to discuss the basic operating principle of STATCOM, let us also discuss what the assumptions we take are. This is the usual assumption we usually take throughout the course consistently. So, our assumptions are, the whole unit is lossless, balanced, lossless, and balanced for this time being. Now, let me draw the basic schematic diagram of STATCOM. So, suppose this is the bus, where the STATCOM is to be placed, it could be at the midpoint of the transmission line, which I discuss many times while discussions with this SVC. So, this is what the bus at which the STATCOM is to be placed. Then we will be having a step-down transformer, similar to this. This is a step-down transformer. Then we will be having a converter. This converter is we consider here voltage source converter. As you know there are two types of converter voltage source and current source. So, here we assume that we have a voltage source converter.

So, this is this step-down transformer. Why we kept this step down transformer? To step down the voltage level from the bus voltage to a much lower voltage. So that our VSC would be rated to a much lower voltage level than the system voltage level. Now system voltage level usually transmission level voltage like 220 kV or 765 kV is quite high. Whereas, this VSC level or this TATCOM level voltage would be much lower than that. It could be 11 kV, it could be even lower. Now, this voltage, VSC stands for voltage source converter and this is a DC voltage, DC source. So, this is a DC side. There is a capacitor just to hold this DC voltage constant. So, now, the basic operating principle is The basic operating principle is, so unlike this impedance or susceptance-based compensator where we have seen that basically this the role of the power electronic switches wire to vary the susceptance or impedance of the SVC and TCSC, respectively. But here the role of this power electronic switch is quite different.

The role of the power electronic switches here is to generate a three-phase voltage, a three-phase voltage similar to a generator. So the role of Vsc is to generate a three-phase voltage similar to a synchronous generator. Now, you know that this is a, of course, I have drawn the single-line diagram of STATCOM but it is eventually of three-phase. So, I am just giving a symbol, these three parallel lines to represent that it is of three-phase device. So, the role of VSC is here to generate a three-phase voltage similar to a synchronous generator.



Now, suppose this bus voltage at any point of time, this is equal to V at an angle 0. And if we just represent this step-down transformer with its reactance X sigma, the way we did in case of SVC as well. And this here, we have this VSC, it is also generating a voltage which is represented by VC bar. So VC represents the voltage generated by VSC, it is of course a three-phase voltage. We are representing the single-line diagram here. Let us consider that it is representing that Vc at an angle alpha. So, it represents a voltage magnitude Vc at an angle alpha. Now, what would be the net active and reactive power exchange between this bus and this Vsc? The active and reactive power exchange between the VSC and the bus would be. Now, if we consider V c is the converter output voltage, if we consider V c as a converter V s c output voltage, then, V c dash, let us consider, is V s c output voltage, refer to the other side of, another side, that is, this bus side, another side of the transformer. So, the V c dash is basically representing the voltage on the other side of the transformer.

So, basically we can model this whole configuration as something like this. We have the system bus voltage, which represents V at an angle 0. And we have a step-down transformer leakage reactance, which is X sigma. Here we have this V c dash at an angle alpha, which represents the output voltage of V s c referred to the other side of the transformer. Then, the active power which will exchange between this, suppose it represents p, and reactive power exchange between this, let us represent q, then active power exchange would be equal to v, vc dash, as we know, divided by x sigma sine alpha and reactive power exchange would be equal to v, v c dash divided by x sigma cos alpha minus this v square divided by x sigma.

Now somehow if we can, so this is we know. So this expression we already derived many times. So this would be the active and reactive power exchange between the voltage source converter VSC and the system bus. So now if we consider alpha is equal to 0. That means, this alpha is equal to 0. Then what would happen? If you put alpha is equal to 0, p will be equal to 0. However, q will be equal to v, vc dash minus v divided by x sigma. So, what will happen if we consider this alpha is equal to 0, P is equal to 0. What does it mean? What does it imply to? So, P is equal to 0 implies to that active power exchange is 0, active power exchange is 0. And why what this Q is equal to this representation or Q is equal to this expression imply to? This implies to that this reactive power exchange is non-zero.

That is something very interesting. So, if we make this alpha is equal to 0, there will be no active power exchange, no active power exchange, but there would be reactive power exchange between the VSC and the system bus. And that is what our goal is. Here, we devise, our goal is to devise a device which can exchange the reactive power. And that is why it is reactive power compensator. Now, so therefore, by considering this alpha is equal to 0, it is possible to have no active power exchange, but there would be some amount of reactive power exchange possible.

Now, what is the physical interpretation of alpha is equal to 0? The physical interpretation of alpha is equal to 0 is the system bus voltage and VSC output voltage are in same phase. They are in the same phase and that is what the necessity, that is what the requirement, or that is what the essential conditions for developing this TATCOM. So, we should have a VSA output voltage which is in same phase of the system voltage, so that there will be no active power exchange, but there would be reactive power exchange.

So, that is the basic operating principle of this STATCOM. Here STATCOM unlike this SVC, does not use its switches to control the reactance or the susceptance of an inductor or a capacitor.

Rather, it is used to generate a voltage source, it is acting as a voltage source. And thereby, it is, what type of voltage source it is? Its output is a kind of voltage source, which is, which will be in the same phase or no phase difference with the system voltage. And, thereby there would be no active power exchange, but reactive power exchange would be possible, which is our primary goal because we know that this power electronic based compensators which I am discussing with so long time are essentially a type of device which can exchange the reactive power to the network. Now, let us see how this reactive power exchange would be essential or how can we do this reactive power exchange for this STATCOM. So, we are discussing STATCOM here. So let me again draw this single line diagram, which I have drawn over here, this single line diagram. So we have a system voltage V at an angle 0, that is bus voltage. We have a step-down transformer, it is modeled as its reactance X sigma and we have V c dash is. It will be in the same phase as the system voltage.

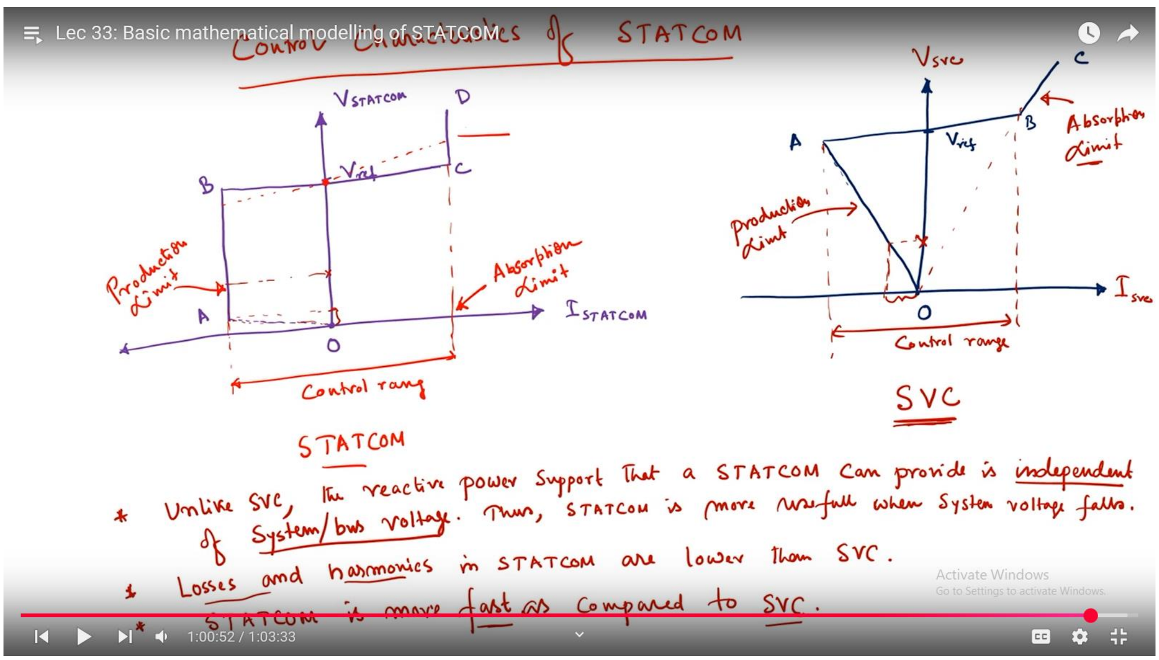
So, here this is bus voltage or system voltage. Here we have the output voltage of VSC referred to other side of the transformer. And suppose the current which is flowing from the system side to the VSC side is represented by I. So, I is the current flowing from one side to other side. Now, if we draw this, if we apply KVL, applying KVL. So, we can find out an algebraic equation, which is this v at an angle 0 minus this i. Of course, there will be j term over here. So, this will be i j x sigma is equal to this v c dash at an angle 0. So, this is our KVL equation. Now, there might be two possible cases. Case 1, v is greater than vc dash or rather I write vc dash is lower than v. And case 2, is V c dash is greater than V. Now, if V c dash is equal to V, so both would be equal and there will be no reactive power exchange also. So, either V c dash that is the output voltage of V SC referred to the other side of the transformer should be higher than the system voltage or should be lower than the system voltage. If that V C dash is equal to V as you can see from this equation there will be no reactive power exchange possible. So, V C dash is equal to V means Q is equal to 0. So, that is why I did not consider that case. So, V C dash cannot be equal to V because v c dash equal to v implies to q is equal to 0. So, this is something I hope that it is understandable to you. Now, when this v c dash less than v, then how would be the phasor diagram? So, let us draw this v. So, this is what the phasor diagram of v.

So, it is considered to be the reference. Now, since V and V c dash are in same phase, so the phasor which represent V c dash, since its magnitude is lower than V, so would be something like this. So, then what would be then this J i x dash, now you see from this particular equation I can find out this v at an angle 0 is equal to v c dash at an angle 0 plus J i x sigma. So, therefore, you can see this is our v at an angle 0, this is vc dash at an angle 0. So, vc dash at an angle 0 plus this drop will equate with the system voltage.

So, therefore, this should be our drop, that is J i x sigma. If this is the direction of J i x sigma, then what would be the, what would be this phasor of this i? Since you know J multiplied by i, J is a complex operator which makes this 90-degree phase shift, therefore, this phasor I would be somewhere here, which will lag 90 degrees with respect to system voltage and the VSC output voltage. So, here I lags 90 degree with respect to the VSC output voltage or system voltage. So, that is what this case 1. Now, in case 2, again this is what the phasor diagram you know. So, in case 2, let us draw this phasor diagram once again. So, suppose this is our V at an angle 0, since or I should draw it smaller because V c dash is now higher. So, this is V at an angle 0. So, this is considered to be reference. Now, V c dash would be higher than this with higher magnitude. So, V c dash would be somewhere in the same phase with system voltage, but magnitude will be higher.

Now, according to this equation, this v c dash plus j i x sigma drop is equal to this. So, therefore, to fulfill, to keep this equation satisfied, our j i x drop would be somewhere here. So, this will be j i x sigma drop. Now, if this is J i x sigma drop again I said that J is a complex operator which is responsible to have a 90 degree phase shift of with respect to the system current. So, therefore, this current direction would be somewhere this which is leading with respect to the system voltage or VSC output voltage 90 degrees. So, therefore, here for this particular case, I leads 90 degrees with respect to the VSC output voltage or the system voltage or the system voltage system bus voltage. This will happen when v c dash is greater than v and this was happening when v c dash is lower than v. Now, what is the essential difference between these two? Here you can see this i is lagging, so therefore you can see that here it implies to that this q what is getting exchange over here is So, what would be the direction of this Q, since your system voltage is above the VSA output voltage. So, Q is absorbed by or Q flows from the system side to the VSC side. And here, for this particular case, since VSC output voltage magnitude is higher than the system voltage, so therefore, Q is delivered by So, therefore, with the, by changing this magnitude of the, this output voltage of VSC, we can decide that this TATCOMs can be operated either in inductive mode or it can be operated as capacitive mode. So, if this mode of operation is a, if we call it inductive mode of operation and then this is capacitive mode of operation.

So, here as if this VSC act as a capacitor and it delivers this reactive power to the system, it injects the reactive power to the system and this is where this VSC is acting as an inductor and it is absorb the reactive power from the system, that is what the difference is. That is what the difference is. So, VSC-based STATCOM can be operated either in the inductive mode thereby creating a situation that it can absorb reactive power from the system. It also can act as a capacitive mode, thereby it will create a situation that it can deliver some amount of reactive power to the system. So that is what the basic operating principle. And from this principle, you can eventually understand that this STATCOM is quite different to the SVC. So, here we are not using these switches just to operate the device either in partially mode or fully conducting mode or partially conducting mode or fully off mode. Here rather the switches of this VSC are used to generate a voltage, a three-phase voltage which would be in the same phase as the system voltage. However, the magnitude of this voltage can be varied to operate it either in this inductive mode or capacitive mode. So that is what the basic operating principle of STATCOM is. Now let us draw the control characteristics. Characteristics of STATCOM: Let us draw the control characteristics of STATCOM. How the control characteristics of STATCOM would be? So, suppose this is V STATCOM, this is I STATCOM. This is what the V reference.



So, the control characteristic of statcom would be something like this. Suppose, this is O, this is A, this is B, this is C, this is D. So, therefore, from this, you know, characteristics you can see, this is the control range, control range, this is, this is the absorption limit, this is the production limit, that is var production limit and var absorption limit. So, this is the control characteristic of STATCOM. Eventually, you know that this BC can be parallel to this horizontal axis or it can have zero slope or it can have a bit positive slope like this SVC which I discussed earlier due to the reason for the same reason I discussed in the SVC. However, looking at these control characteristics, if we draw the control characteristics of SVC once again, you can understand the difference between the operating principle of SVC and STATCOM or capabilities of STATCOM and SVC.

So, how was the control characteristics of SVC was, suppose this is V s reference. So, it was something like this. So, this is O, this is A, this is B, this is C, this was the control range, this was ISVC, this was VSVC. So, this is, this was the control characteristics of SVC. Why I have drawn it? Because you can understand the difference between the control characteristics of STATCOM and SVC. So, looking at this illustration one can understand that, unlike SVC, this STATCOM can provide a constant amount of this compensation irrespective of the system voltage. Or I should say that this, the STATCOM output or STATCOM, the reactive power support the STATCOM can provide is independent of the system voltage, unlike SVC. Unlike SVC, the reactive power support that a STATCOM can provide is independent of system or bus voltage. So, here you can see that the amount of reactive power support that this SVC can provide depends upon the system voltage. So, if the system voltage drops to here, only that much of support of reactive power that the SVC can provide. However, even if there is a voltage drop of the SVC to here, SVC can provide same constant amount of drop here.

So, basically you can see that this production limit of this and absorption limit of this SVC are system dependent, system voltage dependent. So, this production limit and this absorption limit of SVC, both the limits are system voltage-dependent. Whereas here, this is system voltage independent. Only this production of this SVC at very lower voltage would be somewhat not consistent with this AB characteristics. But other than that, apart from this small you know system voltage at any other system voltage it can provide a constant reactive power support.

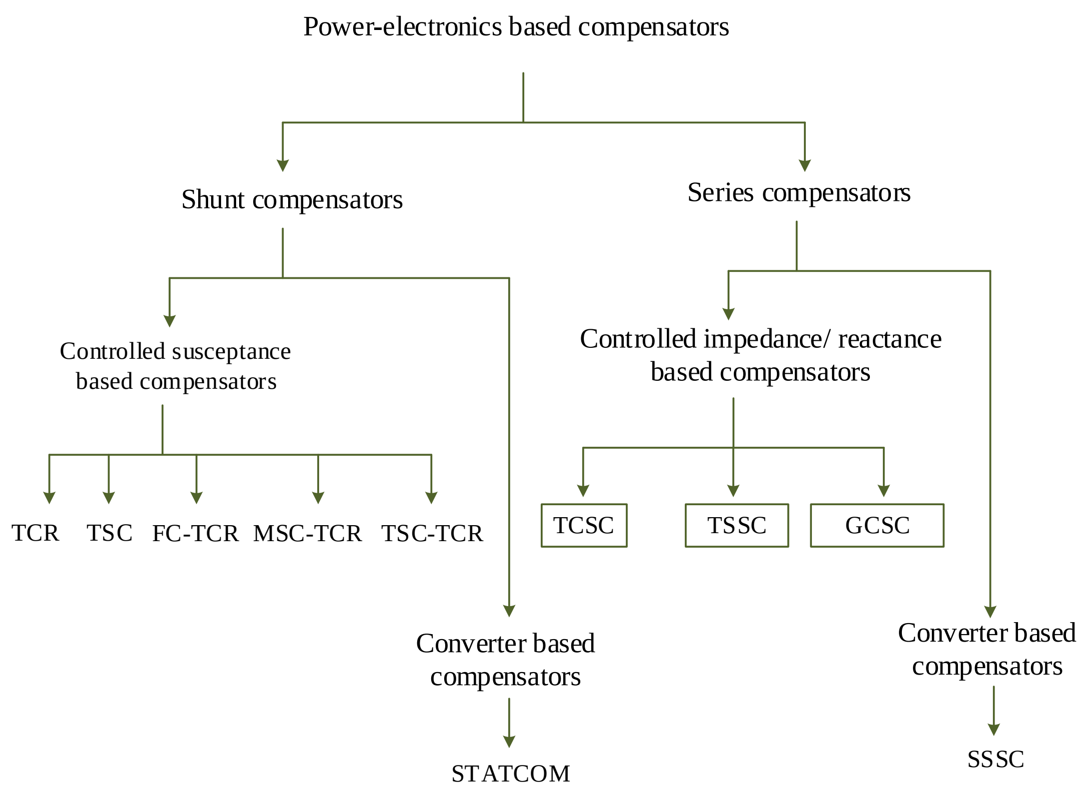
So, that is what very interesting and very important. So, thus STATCOM is more useful when the system voltage falls. So, the next thing that I should discuss is that the losses and harmonics in STATCOM are lower than SVC. Why it is so? Because as you know this losses and harmonics happened to SVC because of the switching of this thyristors to operate it partially conducting mode. Whereas the switching in a STATCOM is basically to generate the three-phase near to sinusoidal voltage source. So therefore, with the use of multilevel converters or advanced converters, it is possible to have a very lower harmonical voltage than to develop. And that is why the overall, you know, this harmonics in STATCOM is much lower, so as the losses also. Now, third thing is, which is very important, STATCOM is more fast. So, STATCOM operation is more fast as compared to So, due to these reasons you know STATCOM is having superiority in performance, in operating speed and in various you know aspects over this SVC which I am also going to discuss in the next lecture as well. But in this particular lecture you should learn what is the basic operating principle of STATCOM and how it is different to SVC because lot many times I devoted for this discussion with SVC and STATCOM its next phase of this development. So, you should understand the difference between the STATCOM and SVC.

Other than that, this functionality wise, this application wise, this SVC, this STATCOM is as good as SVC. However, it has superiority in terms of the fast response, in terms of lower harmonics, in terms of lower losses. But cost-wise, SVC might be cheaper. So, that is something you should understand and there are several works or there are several researches going on, and this the development of STATCOM in particular development of the topologies of STATCOM and also the development of control strategy for STATCOM. So, if someone is interested can go through the literature of the STATCOM in very detail. So, there are voluminous you know works you can find and still work is going on. Now, in the next lecture, I will discuss the application of STATCOM and application-wise how it is different from this SVC and performance-wise also how it is different from the SVC.

So, till then, let me thank you for attending this lecture as well. So, thank you very much once again for attending this lecture. I look forward to meet you in the next lecture.

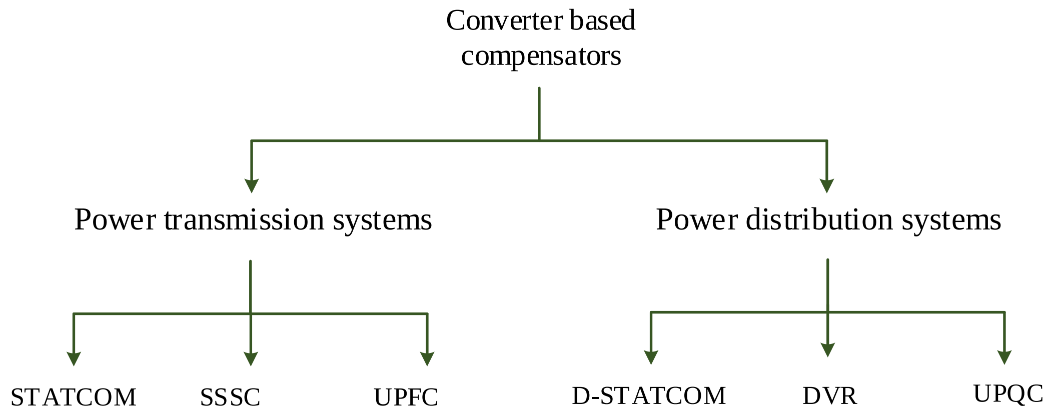
Static Synchronous Compensator (STATCOM)

The power electronics-based compensators can be broadly classified into shunt and series compensators. The broad classification is given below:



It can be seen from the above classification that the compensators studied so far are controlled either by controlling the susceptance (for shunt compensators) or by controlling the impedance/ reactance (for series compensators). However, the converter-based compensators do not control susceptance or reactance. Converter based controllers involve generating and controlling the output voltage, by proper switching operations.

Converter based controllers are used in both transmission systems as well as distribution systems. The generally used converter-based compensators can be classified as:



STATCOM : Static Synchronous Compensator

SSSC : Static Synchronous Series Compensator

UPFC : Unified Power Flow Controller

D-STATCOM : Distribution Static Synchronous Compensator

DVR : Dynamic Voltage Regulator

UPQC : Unified Power Quality Conditioner

➢ **<u>STATCOM (Static Synchronous Compensator):</u>**

A STATCOM is comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. The single-line diagram of the STATCOM is shown in figure 1. The voltage source converter (VSC) with a DC link is connected to the transmission system through a step-down transformer, to lower the rating of the STATCOM.

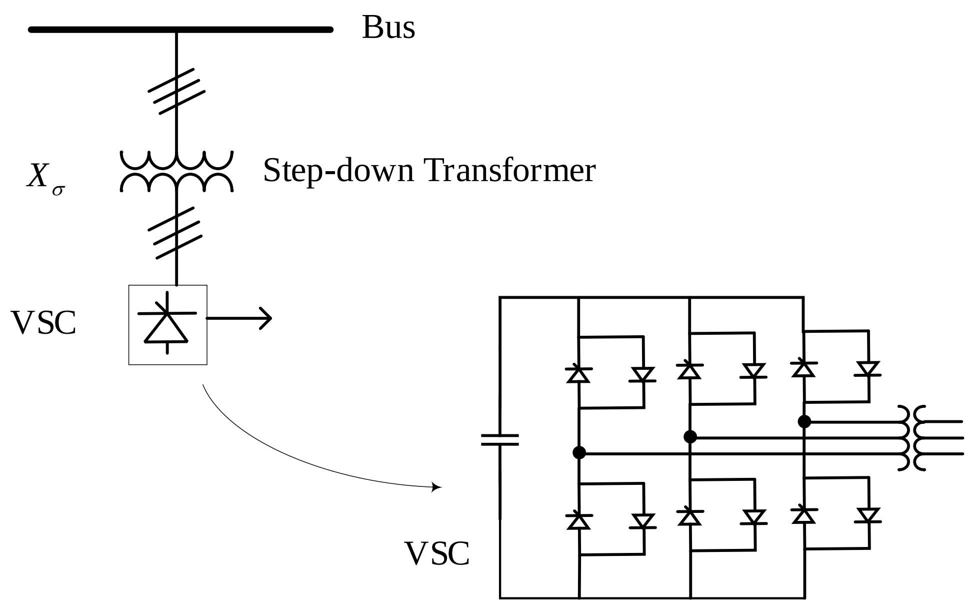


Figure 1:Single line diagram of STATCOM.

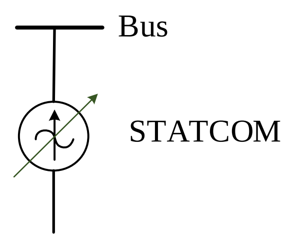


Figure 2: Representation of STATCOM.

The STATCOM is represented by a variable current source as shown in figure 2. The basic functionality of VSC is to create 3-phase, balanced ac voltage like a synchronous generator. The voltage generated by the STATCOM is in synchronous with the system voltage. This is achieved with appropriate switching of power electronics converter.

Consider that the voltage generated by the VSC of lossless, balanced STATCOM is $\overline{V}_c = V_c \angle \alpha^\circ$, and the voltage referred to the grid side of the step-down transformer is $\overline{V}_c^{'} = V_c^{'} \angle \alpha^\circ$.The equivalent circuit can be represented as in figure 3.

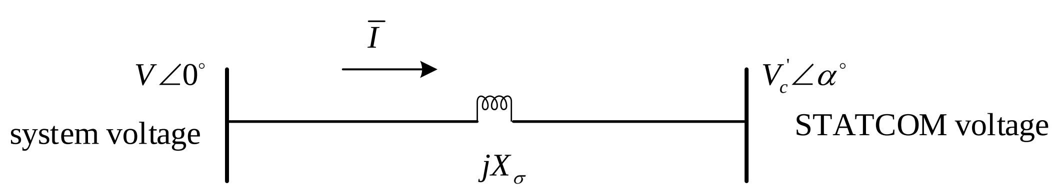


Figure 3: Equivalent circuit.

The complex power ($\bar{S}$) flow between the transmission network and the STATCOM is given by:

$$S = P + jQ = \frac{VV_c'}{X_\sigma} sin\alpha + j\left(\frac{VV_c'}{X_\sigma} Cos\alpha - \frac{V^2}{X_\sigma}\right) \quad (1)$$

$$\Rightarrow P = \frac{VV_c'}{X_\sigma} sin\alpha$$

$$Q = \left(\frac{VV_c'}{X_\sigma} Cos\alpha - \frac{V^2}{X_\sigma}\right) \quad (2)$$

If we consider $\alpha = 0$,

$$P = 0$$

$$Q = \frac{V(V_c' - V)}{X_\sigma} \quad (3)$$

$\Rightarrow$ The active power exchange between the STATCOM and the transmission system is zero, while as the reactive power exchange is non-zero.

Applying KVL in figure 3, we have:

$$\bar{V}\angle 0^\circ = j\bar{I}X_\sigma + \bar{V}_c'\angle\alpha^\circ$$

Since, the STATCOM exchanges only reactive power, therefore $\alpha = 0$.

$$\Rightarrow \bar{V}\angle 0^\circ = j\bar{I}X_\sigma + \bar{V}_c'\angle 0^\circ$$

Case 1:

If $V_c' > V$, the phasor diagram can be shown as below:

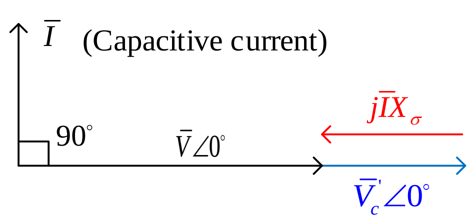


Figure 4: Phasor diagram for capacitive mode of operation.

The reactive power (Q) is positive as can be seen from equation (2). Thus, from the above figure 4, the reactive power is injected into the power system and the current is capacitive in nature. This corresponds to the capacitive mode of operation of the STATCOM.

Case 2:

If $V_c' < V$, the phasor diagram can be shown as below:

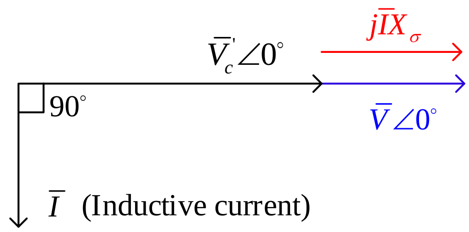


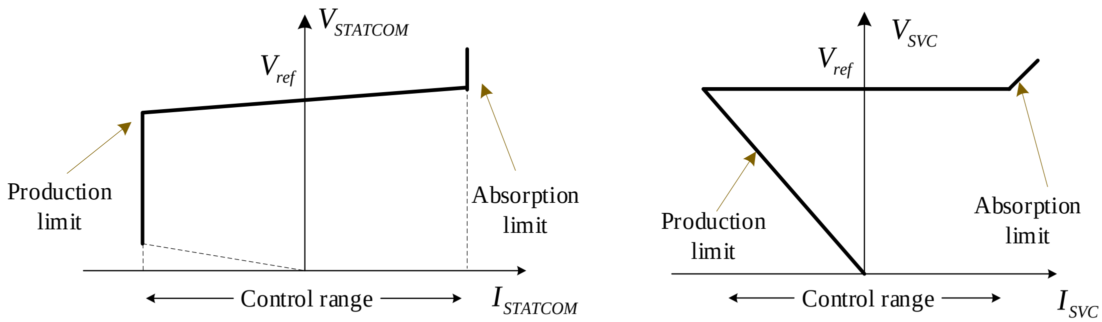
Figure 5: Phasor diagram for inductive mode of operation.

The reactive power exchange (Q) is negative. Thus, from the above figure 5, the reactive power is absorbed by the STATCOM and the current is inductive in nature. This corresponds to the inductive mode of operation of the STATCOM.

- It is to be noted that in order to control voltage or current in SVC, the switching is done to control the inductor and capacitor. However, in STATCOM we do not control the inductor or capacitor, rather a synchronous 3-phase voltage is generated and its magnitude determines the nature of the reactive power compensation (inductive or capacitive).

Control characteristics of STATCOM

The steady state control characteristics of a STATCOM are shown in figure 6. The STATCOM current is considered purely reactive. The negative current indicates capacitive operation and positive current indicates inductive operation. The limits on capacitive current and inductive current are symmetric.



(a) (b)

Figure 6: Comparison of control characteristics of STATCOM and SVC: (a) STATCOM (b) SVC.

The control characteristics show that unlike SVC, the reactive power support that a STATCOM can provide is independent of the system/ bus voltage. Thus, the STATCOM is more useful when system voltage falls.

Furthermore, the losses and harmonics are less in STATCOM than in SVCs.