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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Lecture: 03

Lec 26: SVC in voltage control of power systems: Control characteristics

Welcome again to my course Power Electronics Applications in Power Systems. So, in the last class, I discussed how an SVC can be used in the voltage control of a power system. So, we will continue to that, continue our discussion here also in this particular lecture and I discuss the control block diagram of an SVC in very detail so as to have an idea of how an SVC can be used in controlling the voltage of a particular bus where it is located. Also I will discuss the specific nature of the control characteristics, which I discussed partly in the last lecture. So, let us proceed. So, what we did in the last lecture? So, let us summarize first.

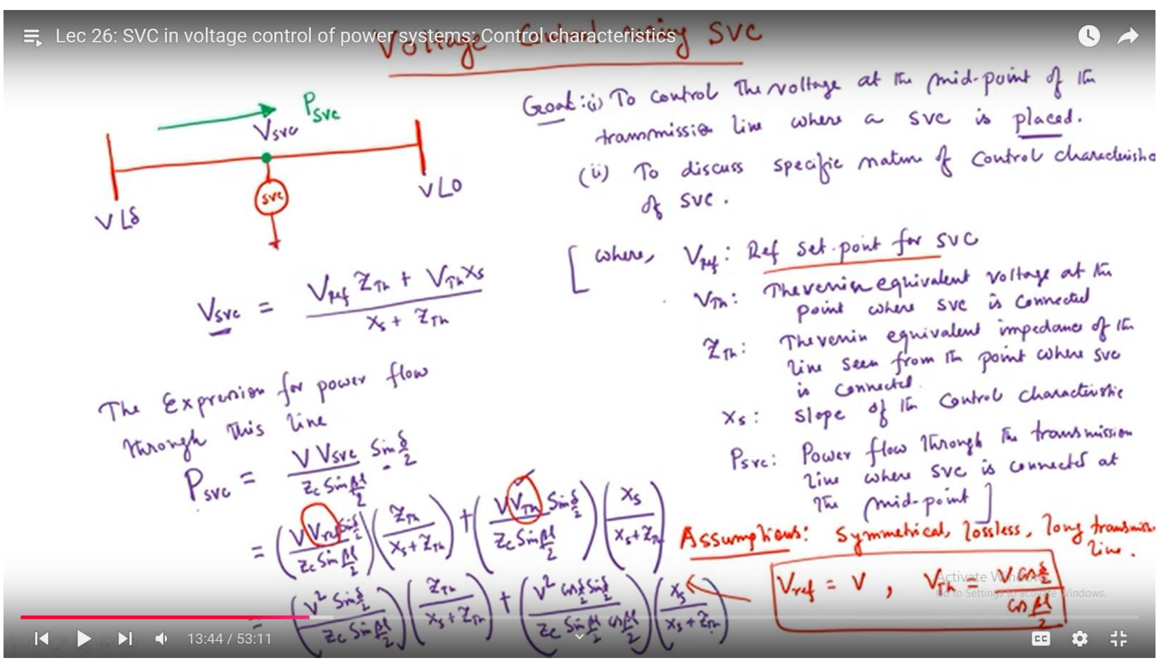
So, we are here in voltage control using static Var compensator or SVC. So, what we consider here is that we have a transmission line, we have a transmission line over here. It is a long transmission line and at the midpoint of this line, we will be having an SVC, static Var compensator. Now, suppose the voltage at this particular bus is V at an angle delta, the voltage at this particular bus is V at an angle 0, then the voltage at this SVC bus, it is supposed represented by V SVC.

Now, what is our goal is to control this voltage at this particular point. So, the goal is the goal is here to control the voltage at the midpoint of the transmission line, where an SVC is placed. That is our goal. So, the goal of this discussion is as well. In addition to that, this is supposed if our first goal, the second goal is to discuss the specific nature of control characteristics of SVC.

So, these two we will try to do in this particular lecture. Now, let us go back and see that we have derived in the last lecture, the expression of voltage at SVC with respect to or as a function of V reference, which is basically the reference point of the SVC control characteristics. And, Z Thevenin represents the Thevenin equivalent impedance of the line. V Thevenin is the Thevenin equivalent impedance of the point where the SVC is located. Xs is the basically slope of the control characteristics.

So, we will come to this, let us write this expression once again. So, what we get? We get V SVC is equal to V reference Z Thevenin plus V Thevenin Xs divided by Xs plus Z Thevenin. Now, as a quick recapitulation, let us write what this symbol signifies. This V reference is the reference voltage or reference set point for SVC. V Thevenin is the Thevenin equivalent voltage at the point, Thevenin equivalent voltage at the point where SVC is connected.

So Z Thevenin is the Thevenin equivalent impedance or the Thevenin impedance of the line seen from the point where the SVC is connected. Now, what is left? Xs is left here, Xs is the slope of the control characteristics. So, this is what we obtained in the last lecture. So, we will work out with this and come up with the expression of the power flow of this through this transmission line when this SVC is connected at the midpoint. So, we know that the power flow, the expression for power flow, for power flow through this line is equal to let us say P.



So, this is this power flow through this line along with this SVC. So, I just keep renamed this as a P SVC. So, this P SVC doesn't mean that the active power drawn by the SVC, P SVC is the P SVC is the power flow through the transmission line where SVC is connected at the midpoint. So, this we can, we know that for, so therefore, we can show that this PSVC is power flowing through this particular line with the presence of SVC. So, this can be rewritten as this voltage V, V SVC divided by ZC sine beta L by 2 sin delta by 2.

So, here you can understand that although, in this particular lecture, I have not mentioned that here also our assumptions are we have considered symmetrical lossless long transmission line. So, what we will do now is we will put the expression of VSVC in this particular expression. If I put it, then what we will get, let us see. So, this will be equal to V reference divided by z c sin beta L by 2 multiplied by this z Thevenin divided by X s plus z Thevenin plus. So, when I put this over here, so this will be equal to V Vth divided by Zc sin beta L by 2 multiplied by one thing I missed over here is there is a sin delta by 2 term is also here due to this sin delta by 2.

So, here also there will be a sin delta by 2 terms multiplied by this that X s divided by X s plus Z t h. So, let us remember what this V Thevenin that we determined was in the previous lecture. If you look back and see that we already determined the expression of V Thevenin, which was nothing but the open circuit voltage at the midpoint. So, this is the expression for V Thevenin. So, we will put over here. So, we will replace this V Thevenin with the expression that we know. We will replace this expression of V Thevenin. We will consider that this V reference, what is V reference? V reference is basically the reference set point of the SVC. That is basically this point corresponds to the control characteristics where you will get this, you do not require any compensation. This point corresponds to 0 compensation required from the SVC.

So, what we will do is that we, let us consider that V reference is equal to V. And, we know this V thevenin is equal to V. What was the expression of V thevenin? If you look back and see, this was the expression of V thevenin. So, therefore, it is equal to V cos delta divided by cos beta L by 2. So, this is equal to V cos delta by 2 divided by cos beta L by 2. We will put these in this particular expression. Then let us see what we will get. So, with this we will get this expression is v square sin delta by 2 divided by z c sin beta L by 2 multiplied by this that is z Thevenin divided by X s plus z Thevenin. Now, when you put this V Thevenin expression over here, what we will get? We will get V square cos delta by 2 sin delta by 2 divided by Z c sin beta L by 2, this cos beta L by 2 multiplied by X s divided by X s plus Z Thevenin. Now, you know that if we just multiply this numerator and denominator with this 2, then this will become this 2 cos delta by 2 sin delta by 2 will become sin delta and 2 sin beta L by 2 cos beta L by 2 will become sin beta L.

The expression for power flow through line

$$P_{SVC} = \frac{VV_{SVC}}{Z_C \sin\frac{\beta l}{2}} \sin\frac{\delta}{2} = \frac{V \sin\frac{\delta}{2}}{Z_C \sin\frac{\beta l}{2}} \left[V_{ref}\left(\frac{X_{th}}{X_S+X_{th}}\right) + V_{th}\left(\frac{X_S}{X_S+X_{th}}\right)\right]$$

$$V_{ref} = V, \quad V_{th} = \frac{V \cos\frac{\delta}{2}}{\cos\frac{\beta l}{2}}$$

$$P_{SVC} = \frac{V^2 \sin\frac{\delta}{2}}{Z_C \sin\frac{\beta l}{2}}\left(\frac{X_{th}}{X_S+X_{th}}\right) + \frac{V^2 \sin\frac{\delta}{2}\cos\frac{\delta}{2}}{Z_C \sin\frac{\beta l}{2}\cos\frac{\beta l}{2}}\left(\frac{X_S}{X_S+X_{th}}\right)$$

$$P_{SVC} = P_{comp}(1-k) + kP_0$$

$$P_0 = \frac{V^2 \sin\delta}{Z_C \sin\beta l} \qquad P_{comp} = \frac{V^2 \sin\frac{\delta}{2}}{Z_C \sin\frac{\beta l}{2}} \qquad k = \frac{X_S}{X_S+X_{th}}$$

$$P_0 = power\ flow\ through\ the\ line\ with\ mid - point\ compensation$$

$$P_{comp} = power\ flow\ through\ the\ line\ without\ mid - point\ compensation$$

Therefore, the power flow expression, can be written as,

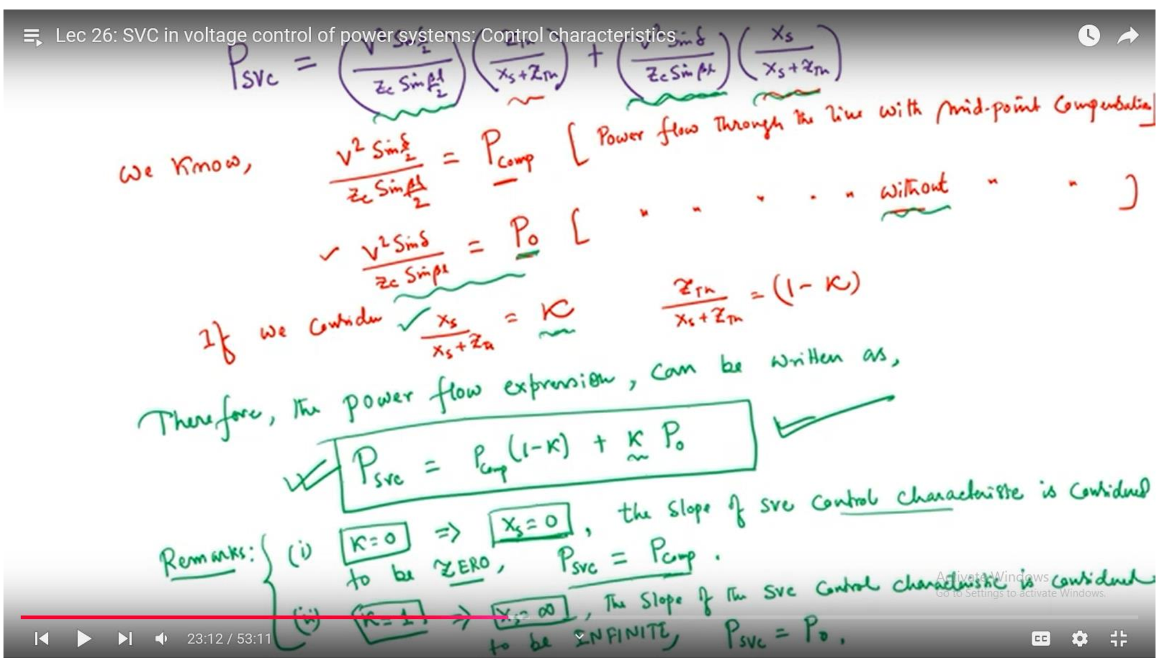
$$P_{SVC} = P_{comp}(1-k) + kP_0$$

<u>Remarks</u>

i. $k = 0 \implies X_s = 0$, the slope of SVC control characteristics is considered to be zero, $P_{SVC} = P_{comp}$
ii. $k = 1 \implies X_s = \infty$, the slope of SVC control characteristics is considered to be infinity, $P_{SVC} = P_0$

So, therefore, our expression will be this PSVC, again I am telling you again that this PSVC does not represent the power drawn by the SVC or power delivered by the SVC, rather this PSVC is representing the power flow through the transmission line when SVC is located at the midpoint, right. Now, so PSVC expression would be equal to V square sine delta by 2 divided by Z c sin beta L by 2 multiplied by this multiplication factor Z Thevenin divided by X s plus Z Thevenin. That is Z Thevenin divided by X s plus Z Thevenin plus this will become, as we have discussed, this will become V square sin delta divided by Zc sin beta L. So, as we know that 2 sin delta cos delta is, as we know 2 cos delta by 2 sin delta by 2 is nothing but sin delta, and 2 sin beta L by 2 multiplication of cos beta L by 2 is sin beta L. So, this is what the expression is and the multiplication factor would be Xs divided by Xs plus Z Thevenin.

Now, as we know this expression, we know this V square sin delta by 2 divided by Zc sin beta L by 2 is basically representing the compensating power due to the SVC. So, it is basically representing the power flow through the line with midpoint compensation. This expression I hope that you remember, you have seen it before. This V square sin delta divided by Zc sin beta L, it is basically representing P naught that is power flow through the line without midpoint compensation. So, that means without this midpoint compensation, this is the power flow. With midpoint compensation, this is the power flow. And if we consider this factor that is X s divided by X s plus Z Thevenin, this factor, this multiplication factor is represented by small k. So, then Z Thevenin divided by X s plus Z Thevenin will be equal to 1 minus small k, because the summation of this and this will be equal to 1, that you can see from the mathematical expression. So, therefore, the power flow expression can be written as P SVC is equal to, we can write it as to P comp multiplied by 1 minus k plus k P 0, So, this is what the power flow expression is. Now, what is that basically representing? It is representing the power flow through the transmission line when you have a SVC at the midpoint to control the midpoint voltage, irrespective of the line loading, irrespective of the other parameter variation.

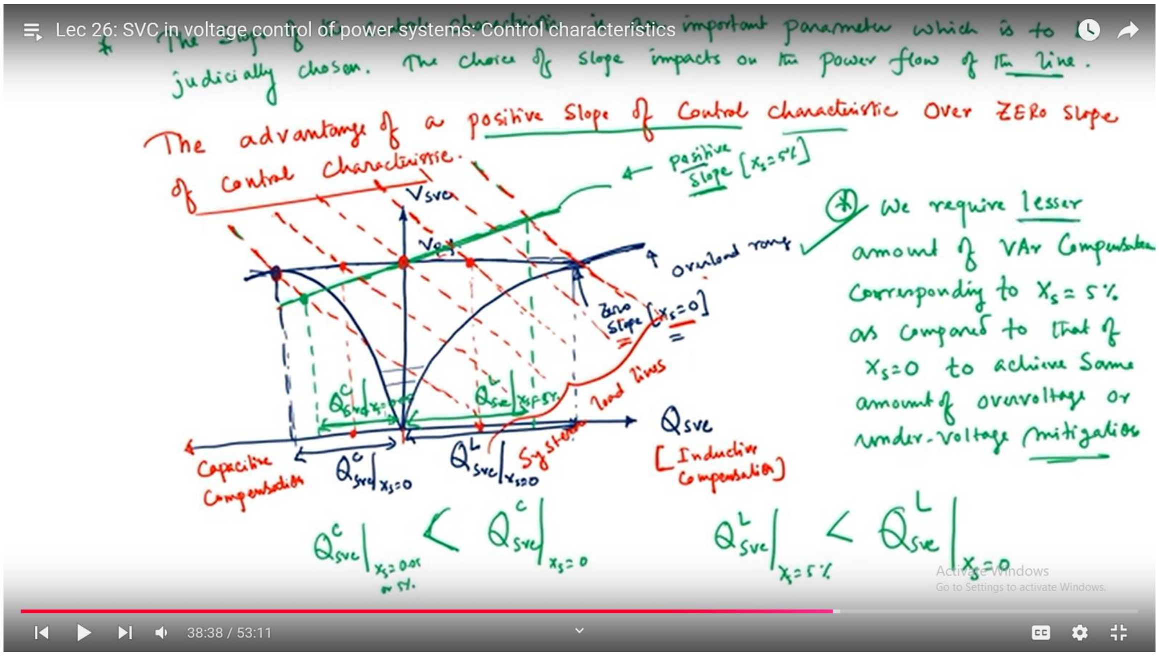


Now, what would be our remark through this analysis? So, this remarks will be this. Now, this k is a parameter which can vary between 0 to 1. So, number 1 condition when k is equal to 0, what does it mean? That k is equal to 0 means it stands to xs is equal to 0. You look at k is equal to 0 means, it means xs is equal to 0. So, that means the slope of SVC control characteristics is considered to be 0. So, when it happens, then P SVC is equal to P 0. So, P SVC is equal to P 0. Look at this expression once again. So, if we go back and see this expression. So, this is basically equal to P comp. This is basically representing this P comp which is the power flow through this transmission line with the midpoint compensation and this is representing this P or P naught, which is the power flow through the transmission line without this midpoint compensation. Now, when we consider k is equal to 0, that means when k can be equal to 0, because Z Thevenin cannot be equal to infinity. So, k can be equal to 0 when x is equal to 0. So, when k is equal to 0, that Xs is equal to 0, then the slope of the, which implies to the fact that the slope of the SVC control characteristic is considered to be 0. Under this condition, that P SVC will be equal to P comp, not P naught. So, this is the first remark. Then the second remark is that when k is equal to 1.

When it happens k is equal to 1, when x is equal to infinity, which means the slope of the SVC control characteristic is considered to be infinite. So, during that time, this P s v c is equal P naught. So, this is another important remark that we can find out. Now, what essentially these two pieces of information are giving is that the slope of the control characteristics is an important factor for SVC to control the voltage of this particular point as well as to control the power flow as well. So, that is what an important message that we can see over here, that this, when your slope of the control characteristic is changing, actually it is influencing the flow of the power through the transmission line. So, therefore, the slope of the control characteristic is to be judicially chosen. So, what we can write over here is that the slope of the control characteristic is an important parameter which is to be, which is to be judicially chosen. The choice, of this slope impacts on the power flow of the line. So this is what an important message that we can see over here. So, this is what an important message.

So, therefore, this already I told you that these control characteristics can be either having 0 slope or having a partial slope or positive slope and I will discuss that is the advantage of having some positive slope of the control characteristics over and above the 0 slope of the control characteristics. There are some advantages, those things I am going to discuss right now. So, the advantage of a positive slope of control characteristics over 0 slope of control characteristics is. So, this is what I am going to discuss in our previous discussion in today's lecture, you have seen that the slope is having the choice of the slope is having an important impact on the power flow of the line. So, if we consider the slope is 0, power flow will be equal to similar to the control characteristics of a midpoint compensation, when this voltage is kept constant at the midpoint as the voltages of the both ends.

Another is that when we consider the slope of the control characteristics infinite, this power flow will be reduced to the actual power flow of the transmission line without having the SVC. This shows that this slope of the control characteristic has an impact on the power flow through the transmission line. So, that is what you have learned. But apart from that, this slope of the control characteristic has having some advantage. A positive slope is having some advantage over the zero slope. So, this is I am going to discuss right now. Now, as you can see, this is the QSVC versus VSVC characteristics, why this is such a specific characteristics I explained in the last lecture. So, in today's lecture, I will consider it directly to explain what is the advantage of the positive slope over the zero slope. So, to do so, let us first draw the control characteristics. So, this is, here is V SVC, here is Q SVC.



So, this is the control characteristics. With zero slope, the control characteristics are something like this. So, this corresponds to V reference. Now, you can see over from this characteristic is that, as the system voltage is getting changed, the ability of the compensation that this SVC can provide is also getting changed, because ultimately you have seen that, we know that the basic model of a SVC is nothing but a variable susceptance. So therefore, when the susceptance will get changed, this compensation will get changed. However, if the voltage of the supply or voltage at the point where SVC is placed gets changed, the amount or the ability of the compensation that the SVC can provide that also gets changed. So, these characteristics corresponds to the zero slope characteristics. So, this is corresponds to zero slope characteristics and this is what the overload region. In fact, this overload region will not be so much large. So, this is up to this.

So, this is the overload, overload range. And this is what the control range of the SVC. So, this is what the control range is. Now keeping the control range same, suppose this we consider some positive slope. This is what the positive slope we consider. Then the control characteristics will get changed like this. This will be the control characteristics, this will be the control characteristics with some positive slope. So here, so this is the correct control characteristic with some positive slope. That means Xs is let us say 5 percent. Here in previous characteristics, this corresponds to 0 slope which means Xs is equal to 0. So, Xs is basically the slope of the control characteristics. Now, what we will see over here is, we have not discussed so far the load characteristics along with the control characteristics of SVC. So, therefore, this I am going to discuss right now. Suppose this is the system load line, this is something like this. This is something like this. Usually, the system load line is something like this.

So, these are representing the system load-lines. Now, what does it mean actually? Suppose this SVC is connected to a particular system which is following this, this load line and at any point of time there is over voltage. So, when it will cut these control characteristics with SVC at this particular point, then, this SVC will provide this much amount of compensation. As you know, this positive QSVC implies to the inductive compensation and negative QSPC stands for the capacitive compensation. Now, this load, what this load line is representing is that, suppose the system characteristics follow this dotted line, as we have shown, this parallel dotted line, out of which this dotted line, it is basically representation of the system characteristics or load characteristics of the power system where the SVC is connected.

Now, there is an overvoltage. So, how this over voltage can be mitigated? At the point where this load characteristic will cut the SVC characteristics that would be the operating point and SVC will provide that much of var in order to bring down the voltage to the reference voltage that is this. So, that is basically the significance of the load lines. So, I repeat this explanation again. So, I have shown these characteristics. Now, if your system characteristic is like this, that means there is an under voltage over here and then this will be the operating point where these load characteristics cut or system characteristics cut this zero slope control characteristics of the SVC, then SVC will provide that much of compensation to bring, to enhance the voltage level equal to the V reference.

So that is how these SVC control characteristics work. Now you see, this is the system characteristics. Now if we can just take the two extreme system characteristics, one is this, one is this, another is that. One is this, another is that. Now, corresponding to these characteristics, if you consider this Xs is equal to 0, that control characteristics with 0 slope, then we require basically that much of reactive power or that much of capacitive reactive power corresponds to Xs is equal to 0. So, this is QSVC, capacitive corresponds to Xs is equal to 0.

However, if we just consider a positive slope like this, then for same, you know, load characteristics, this will cut at this point. So, we require that much of Q SVC capacitive corresponds to Xs is equal to 0.05. So, from this figure you can see that Q SVC capacitive corresponds to Xs is equal to 0.05 or 5 percent. It is lower than QSVC capacity corresponds to Xs is equal to 0. So, that means we required lower compensation for having some control characteristics with positive slope. Similarly, here you can see, corresponding to these load characteristics, to the extreme load characteristics, you can see that this is the amount of inductive compensation, that is Q SVC, let us say L corresponds to Xs is equal to 0. However, corresponding to the same system characteristics, if we accept some positive slope of the control characteristic, amount of compensation to mitigate the over voltage would be that much. So, this will be Q SVCL corresponds to XS is equal to 5 percent.

So, therefore, you can also see that this Q SVCL corresponds to XS is equal to 5 percent. That means there is a 5 percent positive slope of the control characteristic is considered is usually lower than this Q SVCL. Corresponding to the control characteristics, xs is equal to 0. So, therefore, one important remark that we can write over here that we require lesser amount of lesser amount of var compensation corresponding to xs is equal to 5 percent as compared to that of xs is equal to 0 to same amount of over voltage or under voltage mitigation. So this is one of the important point and this is one of the you know benefit or one of the motivation behind some positive slope of the control characteristics for SVC.

So that is that I hope that this is understood to you. So we require a lesser amount of var compensation when you consider a positive slope instead of considering zero slope of the control characteristics for the same SVC. So, therefore, when we have a positive slope of the control characteristics, what we will achieve is, that you will require a lower amount of compensation. Therefore, you require a lower amount of compensation to have a same amount of under voltage or over voltage mitigation. So, therefore, the size of the compensator would be also lower. Or size of the compensator would be lesser than that of the case when you consider Xs is equal to 0 or slope of the control characteristic is equal to 0.

This is one of the important advantages. There are some advantages also. The second advantage that I want to show over here. In order to show that, let me draw these control characteristics once again. Suppose this is Q SVC, this is characteristics corresponds to X s is equal to 0, X s is equal to 0 means there will be no slope. So, control characteristics will be in parallel to the X axis or horizontal axis. So, these characteristics correspond to X s is equal to 0. Okay? Now, Now, these are the rating requirements of the, you know, this QSVC for this particular case corresponds to x is equal to 0. Now, considering same rated compensator, let us assume that the control characteristic is having some positive slope. So, this is what the control characteristics with some positive slope. This is what the control characteristics with some positive slope.

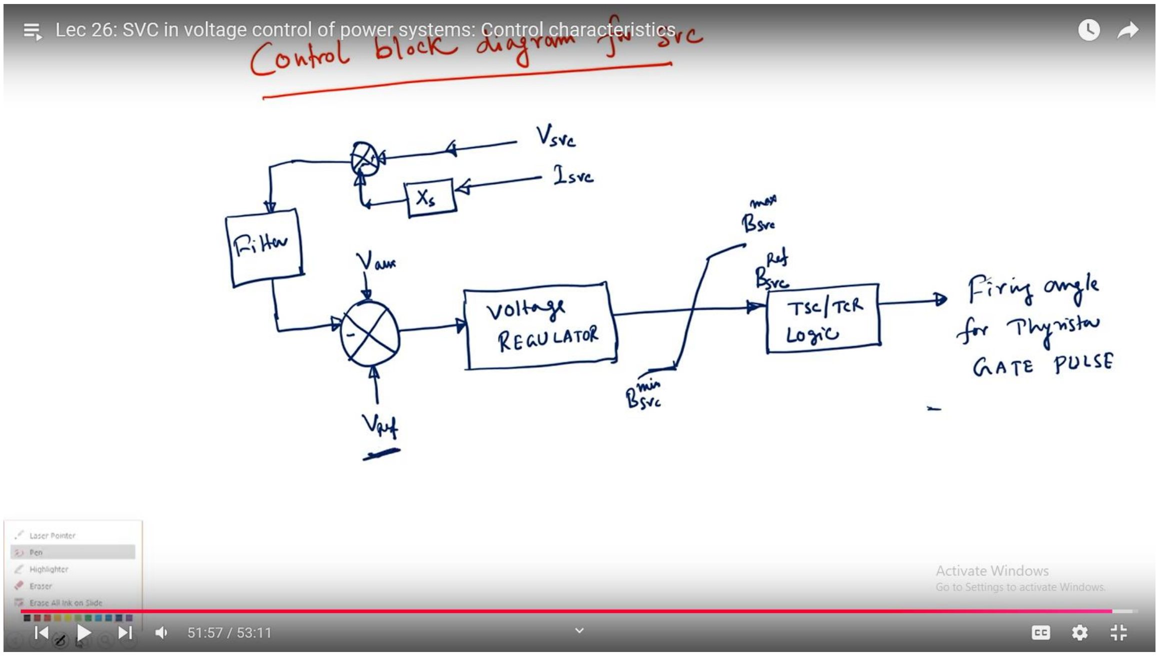
So, this corresponds to let us say excess is equal to 5 percent or 0.05 per unit. Now, you know that this is equal to V SVC. This point we consider as the reference voltage. So, I have drawn two characteristics. One is corresponding to x is equal to 0. So, this is basically SVC control characteristics, control characteristics considering x is equal to 0.

And this is SVC control characteristics corresponding to Xs is equal to 5 percent. So, I have drawn over here. Now, similarly we will draw the load line. So, let us consider this load line like this, this representation by dotted line, parallel dotted line, this is one load line, this is another load line.

This is another load line and so on. So, this is another load line, this is another load. Now, suppose this load line corresponds to L1, this load line corresponds to L2, this is the load line corresponds to L3, this is the load line corresponds to L4 and this is load line corresponds to L5. So, this you know load line shows that there is a over voltage, much above the higher this reference voltage. So, what is the task of SVC is to bring down the voltage level by providing the compensation. That compensation amount will be the operating point where these characteristics cut the SVC control characteristics.

Now, this can be done also by this control characteristics by providing that much amount of var. But the difference between these two is that in this control characteristics, we assume that we will mitigate the over voltage or under voltage by bringing down the voltage exactly as the V reference, that is why it is a flat voltage profile. Whereas, in this particular case, we consider that there would be certain amount of higher, above this voltage of V reference and certain amount of lower value of the V references is acceptable. And therefore, we consider that little bit of a higher value of this V reference. or the voltage of little bit of higher value of the V reference and voltage little bit of lower value of the V reference are acceptable. And therefore, some amounts of over voltage and under voltage are already acceptable to us. Now, here you can see is that when we have Xs equal to 0 in this particular control characteristics, it can mitigate. So, if I write over here, so SVC with Xs is equal to 0 can mitigate over voltage and under voltage, under voltage corresponding to the system characteristics, take L2 to L4. However, SVC with Xs is equal to 5 percent can mitigate over-voltage and under-voltage corresponding to the system characteristics L1 to L5. So, that means the range of the system characteristics for this Xs corresponds to 5% is more than the range of the over voltage and under voltage mitigation corresponding to the system characteristics of Xs is equal to 0.

So, here, we have more range. So, therefore, what we can write is that the second advantage is that the SVC with positive slope prevents the operation more frequently to both ends of the control characteristics or also we can write the SVC with positive slope of control characteristics has a more wider range of overvoltage or rather has the capability of over voltage and under voltage mitigation and under voltage mitigation. There are mitigations for a more wide range of system characteristics. So, that is what another advantage of having some slope in the control characteristics. Now, these are the some important advantages of positive, having this positive slope of the control characteristics. And that is why this SVC control characteristic is considered to have some positive slope, not a 0 slope. And I will finish up this part of the lecture with, by showing you a typical block diagram so control block diagram for SVC. I will finish this part of the lecture by typically sketching this control block diagram of SVC. Already these different aspects of the SVC control is already taught to you. So, therefore, these things would be understandable right now.



So, what is done is, first signal is sought from this VSVC and ISVC. Now, ISVC is being multiplied with this the control slope that is Xs, and then what is done is that they are brought to a comparator, they are brought to a comparator. Then, what is done? Whatever the signal you will get, that may have several noises. So, the filter is required. Now, after filtering this symbol, whatever you can get, because you see the VSBC minus that is negative of this ISBC multiplied by Xs gives you V reference. This is basically compared with the actual V reference, which is being put by the operator the auxiliary symbol V aux.

Then whatever this signal you are getting that is placed in a voltage regulator block. Here we have the actual control controller to regulate the voltage level. Then it is, this regulator will give you this BSVC that is the reference value of this susceptance of this SVC. So, provided that this will lie within the limits of BSVC max and BSVC min. These are limiting factor depending upon the size of the SVC. Then we will be having a TSC or TCR logic circuit, the logic block which will generate the firing angle for the thyristor gate pulse.

So, it is basically, it will generate basically gate pulse. So, in short, this is the control block diagram. Now, this is the reference voltage and this auxiliary voltage is the voltage signal, which can provide some of the auxiliary control functionalities, which I already taught, which may include the damping of the power system oscillation, which also include several other similar kind of control objectives. But in general, this is what the control block diagram of the SVC and this is all about the our main task of this SVC voltage control. In the next lecture, I will discuss some numerical problem, basically one numerical problem regarding this.

Let me thank you for attending this part of the lecture once again. Thank you very much. Thank you.