Course Name: Power Electronics Applications in Power Systems

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Week: 08

Lecture: 04

Lec 27: SVC in voltage control of power systems: Numerical example

Welcome again to my course Power Electronics Applications in Power Systems. In the last few lectures, I discussed the voltage control approach using static var compensator, right? This is the last lecture on this topic. So I will conclude the application of static var compensator in power system in this particular lecture. In this particular lecture, I will discuss a numerical problem related to the voltage control of power system using SVC. So let us proceed. So voltage control of power system using SVC in numerical example: So this is a numerical example on this particular topic, which I am going to discuss.

In fact, this I already have discussed in the last two, or three lectures. So there is a numerical problem. Let me write this numerical problem. A three-phase 400 kV 400 kilo volt, 50 hertz, 800 kilometer long transmission line is operating with V s that is you know sending on voltage equal to V r is equal to 1 per unit, 1 per unit. Remember here the base voltage is 400 kV. So, 1 per unit means it actually in terms of voltage they are operating at 400 kV. The rated load of the line corresponds to the delta is equal to 45 degrees. So, it means that this is the value of delta, the load angle for which the rated power will flow through this line. The line inductance is given as 1 milli Henry per kilometer and the capacitance is 6 nanofarad per kilometer.

❖ Voltage control of power system using SVC: A numerical example

Problem: A 3ϕ, 400 kV, 50 Hz, 800km long transmission line is operating with $V_S = V_R = V = 1\,pu$ and $\delta = 45°$. The line inductance is 1 mH/km and the capacitance is 6 nF/km. An SVC is to be designed to be placed at the mid-point of the line. The limit of the control range corresponds to $\delta = 30°$ and $\delta = 90°$.

a) **Find the limits of SVC susceptance in p.u., if the slope of the control characteristics is**
   i. **$X_S = 0$**
   ii. **$X_S = 0.05$ p.u.**

b) **Determine the maximum power flow in the line in p.u. for the slope of the control characteristics is**
   i. **$X_S = 0$**
   ii. **$X_S = 0.05$ p.u.**

Solution:

$$I_{SVC} = \frac{V_{th} - V_{ref}}{X_S + X_{th}}$$

At rated load, the mid-point [SVC bus] voltage is considered to be the reference voltage

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

$$V_{ref}|_{p.u.} = \frac{V_{ref}}{V} = \frac{\cos\frac{\delta}{2}}{\cos\frac{\beta l}{2}}$$

$$\beta = \omega\sqrt{LC} = 2\pi \times 50 \times \sqrt{1 \times 10^{-3} \times 6 \times 10^{-9}}\,rad/km$$

$$\beta = 7.6953 \times 10^{-4}\,rad/km$$

$$\beta l = 7.6953 \times 10^{-4} \times 800\,rad = 0.616\,rad = \left(0.616 \times \frac{180}{\pi}\right) = 35.29°$$

$$V_{ref}|_{p.u.} = \frac{V_{ref}}{V} = \frac{\cos\frac{45°}{2}}{\cos\frac{35.29}{2}} = 0.9695\,p.u.$$

$$X_{th} = \frac{1}{2}Z_c\tan\frac{\beta l}{2}\ \Omega \implies X_{th}|_{p.u.} = \frac{X_{th}}{Z_c} = \frac{1}{2}\tan\frac{\beta l}{2} = \frac{1}{2}\tan\frac{35.29°}{2}$$

$$X_{th} = 0.159\,p.u.$$

Determination of SVC susceptance at maximum VAr absorption limit ($\delta = 30°$)

i. **$X_S = 0$**

At $\delta = 30°$,

$$V_{Th}|_{\delta=30°} = \frac{V\cos\frac{\delta}{2}}{\cos\frac{\beta l}{2}} = \frac{1\cos\frac{30°}{2}}{\cos\frac{35.29°}{2}} = 1.014\ p.u.$$

$$(I_{SVC})_{\delta=30°} = \frac{1.014-0.9695}{0+0.159} = +0.28\ p.u.$$

$$(B_{SVC})_{Absorption\ limit} = -\frac{I_{SVC}}{V_{SVC}} = -\frac{0.28}{V_{ref}+I_{SVC}X_S} = -\frac{0.28}{0.9695+0} = -0.289\ p.u.$$

ii. $X_s = 0.05\ p.u.$

$$I_{SVC} = \frac{1.014-0.9695}{0.05+0.159} = 0.213\ p.u.$$

$$(B_{SVC})_{Absorption\ limit} = -\frac{I_{SVC}}{V_{SVC}} = -\frac{0.213}{0.9695+(0.213\times 0.05)} = -0.217\ p.u.$$

Determination of SVC susceptance at maximum VAr production limit ($\delta = 30°$)

$$V_{Th}|_{\delta=90°} = \frac{V\cos\frac{\delta}{2}}{\cos\frac{\beta l}{2}} = \frac{1\cos\frac{90°}{2}}{\cos\frac{35.29°}{2}} = 0.742\ p.u.$$

i. $X_S = 0$

At $\delta = 90°$,

$$(I_{SVC})_{\delta=90°} = \frac{0.742-0.9695}{0+0.159} = -1.431\ p.u.$$

$$(B_{SVC})_{Production\ limit} = -\frac{I_{SVC}}{V_{SVC}} = -\frac{-(-1.431)}{V_{ref}+I_{SVC}X_S} = \frac{1.431}{0.9695+0} = 1.476\ p.u.$$

ii. $X_s = 0.05\ p.u.$

$$I_{SVC} = \frac{0.742-0.9695}{0.05+0.159} = -1.089\ p.u.$$

$$(B_{SVC})_{Production\ limit} = -\frac{I_{SVC}}{V_{SVC}} = -\frac{(-1.089)}{0.9695+(-1.089\times 0.05)} = 1.19\ p.u.$$

(b) Power flow through SVC compensated power transmission line,

Maximum power transfer corresponds to capacitive mode of SVC operation $\delta = 90°$

$$P_{SVC} = \frac{V_S V_m \sin\frac{\delta}{2}}{Z_C \sin\frac{\beta l}{2}} = \frac{\left(\frac{V_S}{V_{base}}\right)\left(\frac{V_m}{V_{base}}\right)\sin\frac{\delta}{2}}{\left(\frac{Z_S}{V_{base}{}^2}\right)\sin\frac{\beta l}{2}} = \frac{(V_S)_{pu}(V_m)_{pu}\sin\frac{\delta}{2}}{\left(\frac{1}{P_C}\right)\sin\frac{\beta l}{2}}$$

$$\left(\frac{P_{SVC}}{P_C}\right)_{pu} = \frac{(V_S)_{pu}(V_m)_{pu}\sin\frac{\delta}{2}}{\sin\frac{\beta l}{2}} \qquad \{P_c \Longrightarrow surge\ impedence\ loading\}$$

i. $at\ X_s = 0$

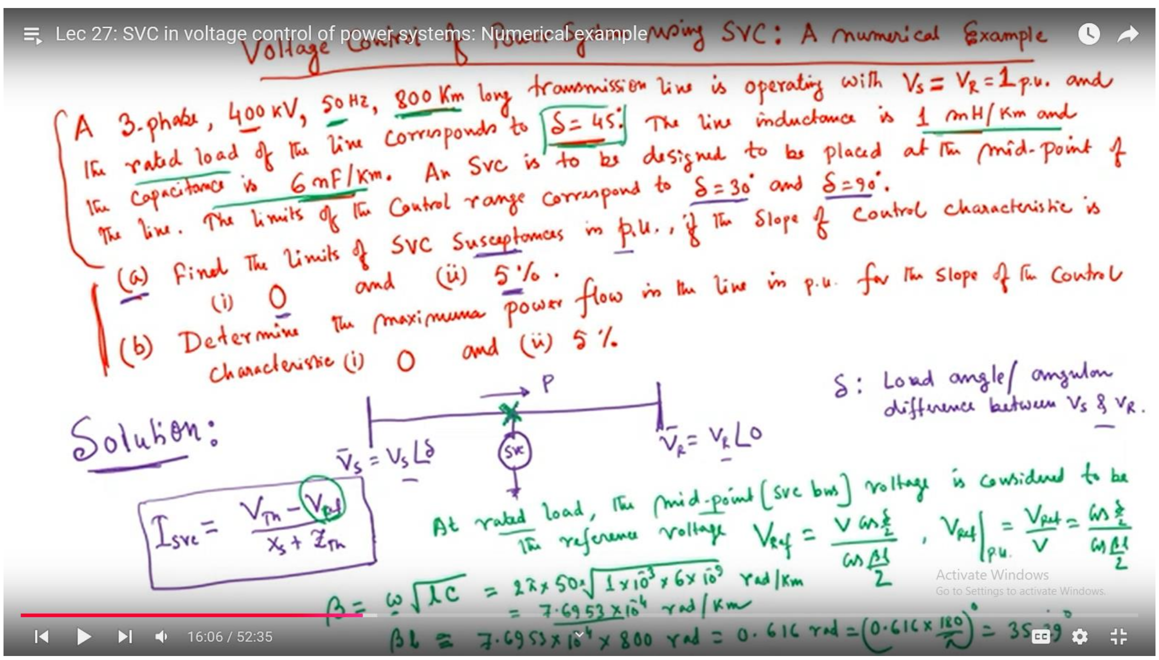
$$\left(\frac{P_{SVC}}{P_C}\right)_{pu} = P_{SVC}|_{p.u.} = \frac{1 \times \left(V_{ref} + I_{SVC}X_s\right)}{\sin\frac{35.29°}{2}} = \frac{(1)(0.9695 + 0)\sin 45°}{\sin\frac{35.29°}{2}}$$

$$= 2.26\ p.u.$$

ii. $at\ X_s = 0.05$ pu

$$\left(\frac{P_{comp}}{P_C}\right)_{pu} = P_{SVC}|_{p.u.} = \frac{(1)(0.9695-1.089*0.05)\sin 45°}{\sin\frac{35.29°}{2}} = 2.135\ p.u.$$

The maximum power flow of SVC compensated line gets reduced when X_s is considered to be 5% as compare to that of $X_s = 0$.



So, since it is a long line, so these parameters are considered to be distributed and these are the values. Then an SVC is to be connected or is to be designed to be placed at the midpoint of the line, midpoint of the line. The limits of the control range correspond to the delta is equal to 30 degrees and the delta is equal to 90 degrees. So, that is what the problem statement is. Now, you have been asked to determine in question number A, find the limits of SVC susceptances in per unit, per unit is written as P full stop U full stop.

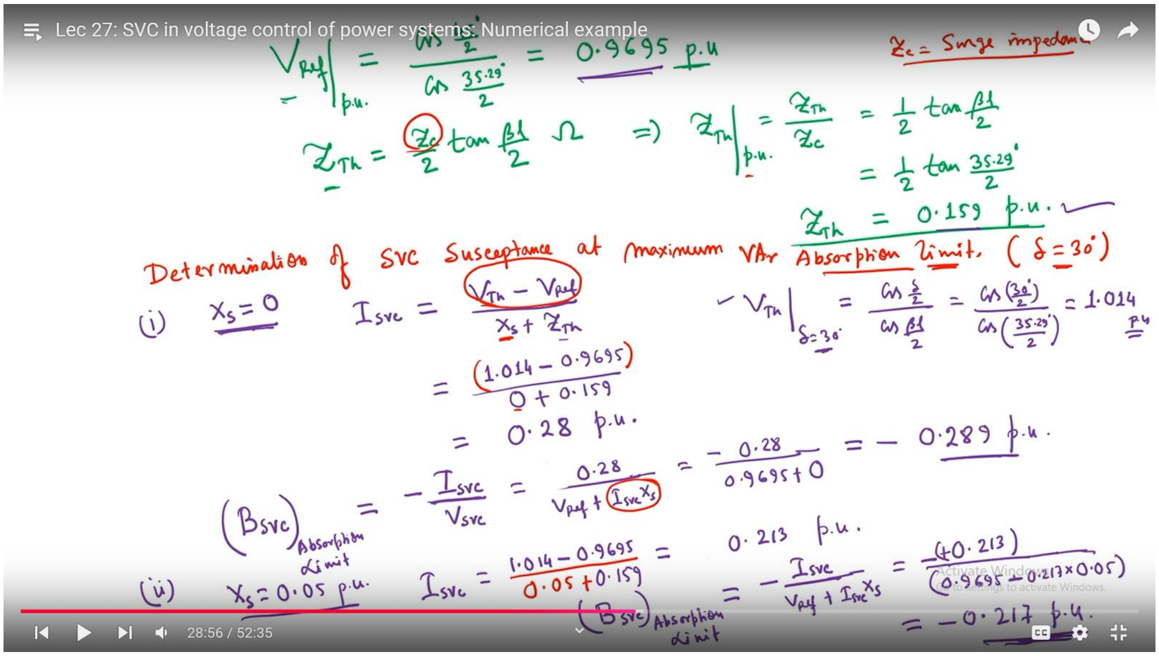
If the slope of the control characteristic is question number A, 0 and question number 2, 5 percent. This is question A. There is another question that is question B. Question B says or asks you to determine the maximum power flow in the line in per unit for the slope of the control characteristics question number A is again 0, and question number 2 is 5 percent. So, this is the questions or problems asked. Now, we have to solve this. So, let us do the solution. Now, before you start solving one thing you should understand that, this whole analysis means that we have a long transmission line model like this. This is the sending end voltage, Vs. This is the receiving end voltage, Vr.

So Vs, as you know, it is considered to be Vs at an angle delta. Vr, we consider as a reference voltage. And here, at the midpoint, we have an S V C connected at this midpoint. Now, as you know, this SVC is modeled, traditionally modeled as a variable susceptance. So, therefore, if you look at this first question, question number A, you have been asked to determine the SVC susceptance in per unit with the two different control characteristics slope. One is 0 percent, another is 5 percent. This is the first question and second question I will come later on. Now how to find out this? That means we have to find out the SVC susceptance range. One is that, what do you mean by SVC susceptance range? If you can go back and see the control characteristics of a SVC which is drawn many times while discussing this SVC in this particular course. Then you can see this SVC is operating under two conditions. One is an inductive mode of compensation, another is a capacitive mode of compensation, right? So, under these two conditions, there exist two different value of susceptances. So, the limits on the susceptances mean, these two extreme values of the susceptances correspond to this control range, which is given as delta is equal to 30 degrees to delta is equal to 90 degrees. So, here as you know delta is basically the load angle or you can write it as an angular difference between V s and V r. So, you can see over here. Now, this delta, how it varies? Delta varies according to the load or delta varies according to the power flow of this particular transmission line.

So, this is what the, suppose power flow. Now, we know some of the equations. What are the equations we know? So, we know that this I SVC is equal to V Thevenin minus V reference divided by Xs plus Z Thevenin. So, this is already I discussed in the last two lectures. Now, what is V Thevenin? V Thevenin is the Thevenin equivalent voltage and Z Thevenin is the Thevenin equivalent impedance seen from the point where SVC is connected right.

Now, how do we find out the V Thevenin and Z Thevenin? I am coming to that. First, you have to see that how do you find out this V reference, how do you find out this V reference. So V reference is the reference voltage of the control characteristics corresponding to the conditions that SVC is providing zero compensation. Now, how do you find out this V reference? This V reference is usually found out by considering the rated load of the line, which is this, that is delta is equal to 45, that is the rated load. So, at rated load, rated load, the midpoint voltage, midpoint means SVC bus, where the SVC is connected, this one, this midpoint voltage is considered to be, to be the reference voltage. Now what is that actually? So V reference is, this V reference is now is equal to the midpoint voltage corresponds to the rated load, which corresponds to the rated load. So, that is why it is equal to this V multiplied by, we know that at the midpoint this voltage expression is V cos delta by 2 divided by cos beta L by 2. Now, what is to be done here is this delta corresponds to this rated load that is 45 degrees. So, V reference in per unit is this actual V reference divided by V. So, this is equal to V reference divided by V, which is equal to cos delta by 2 divided by cos beta L by 2.

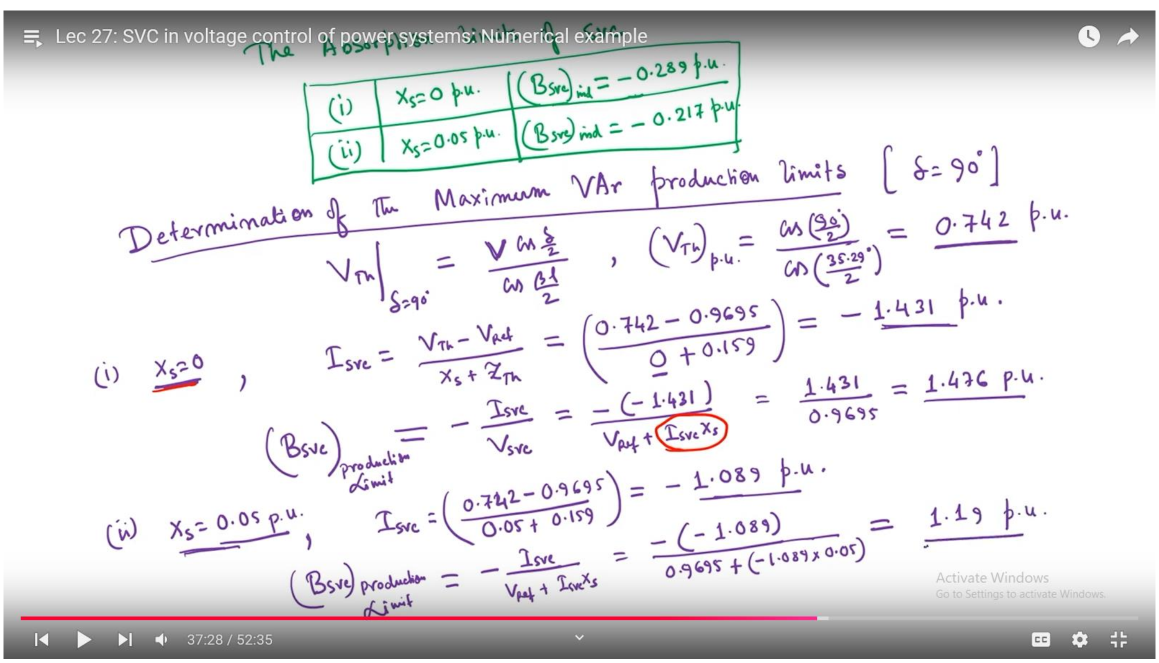
Now, we know this delta, but we have to find out what is beta L. To find this beta L, we have to use these line parameters, i.e. line inductance and line capacitances. Now, what is this beta? Beta, as you know, it is equal to omega root over L multiplied by C, where L is the line inductance and C is the line capacitances. Now, omega is, you know, 2 pi multiplied by frequency. Frequency is given as 50 hertz. So, this is 50 hertz multiplied by the square root of this line inductance which is 1 milli Henry. So, 1 milli Henry means 1 multiplied by 10 to the power minus 3 Henry and multiplied by C, C is given as 6 nanofarad. So, 6 nanofarad means 6 multiplied by 10 to the power minus 9 nanofarad. Now, this whatever you are getting, this is in terms of radian per kilometer. So, then this beta L would be equal to, so this value if you calculate, this is coming out to be 7.6953 into 10 to the power minus 4 radian per kilometer. Now, this beta L is basically this multiplied by this line length, which is given as 800 kilometer. So, 7.6953 multiplied by 10 to the power minus 4 multiplied by 800 is that much of radian. If you calculate, then this comes out to be 0.616 radians. Now, if you convert it to degree, then you have to multiply 0.616 with 180 divided by pi. So, that much of degree. So, this is coming out to be 35.29 degrees. So beta L is coming out to be 35.29 degrees. So therefore V reference in per unit is equal to in per unit is equal to this cosine this delta by 2 and delta we consider rated load. So, this is 45 degree divided by 2 divided by cos beta L by 2. Now, once we already get this beta L is equal to 35.29. So, I will put it this here. So, 35.29 degree divided by 2. So if you do this calculation, then it will come out to be 0.9695 per unit. So that is the reference voltage. Now we also need to find out this Z Thevenin as well. Now what is Z Thevenin? Z Thevenin already we discussed. Z Thevenin is equal to this, Z Thevenin is what? It is the Thevenin equivalent impedance seen from the point where SVC is connected. So, that is this point, this point, this point, where this SVC is connected.



From this point, the net impedance seen of the line is basically the Thevenin equivalent impedance. So, Z Thevenin, we know its expression, we already derived, it is equal to Zc divided by 2 tan beta L by 2. So, this Z thevenin is in ohm. So, therefore, Z thevenin in per unit will be actual value of Z thevenin divided by the base value, here base value is Z c. Now, what is Z c? Z c is the surge impedance. So, this Z c is surge impedance. Now, since we are calculating this Z thevenin in per unit, we need not to find out this value of Zc. Rather, we can write this expression as this is equal to half tan beta L by 2 So, which is equal to half tan. Now we know beta L is equal to 35.29 degrees that is this 35.29 degree already we determined. So let us put this value 35.29 divided by 2 degrees which is equal to how much? That is 0.159 per unit. So, this is what Z Thevenin in per unit. I am not writing it again and again because we are determining every quantities in per unit.

So, we obtain this Z Thevenin. Then what is our next task? Now, our next task will be to find out the susceptance. Now, in order to find out the susceptance of the two extreme control characteristics, one is a control point, one is when the SVC will operate at full capacity var production zone or that is when the SVC will operate at the var production limit and another is the at the var absorption limit. So, let us first start with this determination of SVC at maximum var absorption limit. When it will happen you can see over the range of the control characteristics one corresponds to the delta is equal to 30 degrees another corresponds to the delta is equal to 90 degrees. Now delta is equal to 30 degrees corresponds to the situation that the line is lightly loaded, line load is lower than the rated load, rated load corresponds to delta is equal to 45 degrees. And delta is equal to 90 degrees corresponding to the condition that the line is heavily loaded. So, therefore, what we can start that at this particular absorption limit corresponds to the delta is equal to 30 degrees when the line is lightly loaded. Now in order to find this, so let us start with this first condition corresponds to the control characteristics, slope of the control characteristic is 0. So when x is equal to 0, I SVC will be equal to, if you go back and see the expression of ISVC, this is already I discussed. This we determine from this control characteristics and the Thevenin equivalent circuit.

So, this is equal to V Thevenin minus V reference divided by Xs plus Z Thevenin. Now, we know this Xs is equal to 0, Z Thevenin value is already we determined, V reference value is also determined. Now, you have to find out what is V Thevenin value. Now, V Thevenin corresponds to delta is equal to 30 degree is equal to cosine delta by 2. So, this is cosine delta by 2 divided by cosine beta L by 2. Now, corresponds to delta is equal to 30 degree, this is equal to cosine 30 degree divided by 2, divided by this cosine beta L is already we determine it is 35.29 degree divided by 2. So, if you calculate this, this is coming out to be 1.014 per unit. That means that much of the over-voltage we have is at the midpoint of the line. And the role of the SVC is to mitigate that overvoltage. So, therefore, we have this V Thevenin corresponds to this condition, we know Xs, we know Z Thevenin, we know the V reference, let us put all these values. So, V Thevenin is 1.014 minus, this V reference already we determine, this is equal to 0.9695. Xs is 0 as we considered and Z Thevenin already we determined 0.159 per unit, which is coming out to be, when we put all this file, according to my calculation, it is coming out to be 0.28 per unit. Now, when this happens, then what will be the BSVC limit, that is BSVC absorption limit, we know that BSVC is related to ISVC and VSVC. So, this is equal to, we use a negative symbol, already we explain it many times, to bring this current in positive plane of this X axis.



So, this is equal to minus I SVC by V SVC. Now, what is minus I SVC? It is already what we got that is 0.28 per unit. And what is V SVC? V SBC we know this is equal to V reference plus I S V C multiplied by X S as per the control characteristics. Now, since X S is equal to 0, so since X S is equal to 0, this part will be equal to 0. So, then what we will get this as a minus 0.28 divided by V reference already we determined this is 0.9695 plus this 0 because already Xs we consider 0 here. So, this is coming out to be as per my calculation 0.289 per unit. Now, let us do the second case again when excess is considered to be 5 percent that means 0.05 per unit. I hope that you understand this 5 percent corresponds to 0.05 per unit. So, 5 percent corresponds to 0.05 per unit. So, therefore, we will repeat these all analyses once again.

So, in that situation, This V Thevenin, V Thevenin already we determine that is 1.014 minus V reference, V reference is again 0.9695. So, the denominator of this ISVC will remain same as per the expression you can see. Numerator will be remain same as per this. But denominator will change because Xs is not 0 here. So, I am just writing denominator in a different color so that it should be distinguishable. So, this is now Xs is equal to 0.05 plus this is equal to 0.159, which is coming out to be, if you do this calculation, as per my calculation, it is coming out to be 0.213 per unit. Now, once you get that, then again for this condition also, we can find out BSVC absorption limit is equal to minus ISVC divided by VSVC. Now, VSVC already we know this is equal to V reference plus ISVC multiplied by Xs. Now, this minus ISVC let us put that is 0.213. Now, this divided by this V reference, V reference already we know, this is 0.9695 plus ISBC, ISBC is already negative, so this is minus 0.217 multiplied by this 0.05. Now, if you do this calculation, this is positive, again 0.213 multiplied and outside there is a negative.

So, this will be eventually negative. So, this will be equal to this minus 0.217 per unit. You can, you may verify this, this numerical values. As per my calculation, this is coming out to be this. So, therefore, if we summarize, so for what we get that we write the absorption limits of SVC. We have two cases, that is case 1, another is case 2. So, in case 1, Xs is considered as 0, in case 2, Xs is considered as 5 percent, that is 0.05 per unit. So, this is 0 per unit, this is 0.05 per unit and we get this V SVC inductive, this value we got corresponds to this Xs is equal to 0, we got is minus 0.289, minus 0.289 per unit. Here we get the BSVC inductive limit is equal to minus 0.217 per unit. So, these are the two answers that we get. Now, again coming back to the next question, so determination of, determination of the maximum var production limits. This is the next question and you know that at the var production limit delta corresponds to the maximum value that is 90 degrees. So, when the line is loaded with the highest possible loading that corresponds to delta is equal to 90 degrees. So, therefore, obviously this V Thevenin will get change. So, this V Thevenin corresponds to delta is equal to 90 degree is equal to V cos delta by 2 divided by cos beta L by 2. So, V Thevenin per unit is equal to this V thevenin the actual value of V thevenin divided by this base voltage which is V.

So, this is equal to cos delta by 2 delta is 90 degree. So, this is 90 degree divided by 2 that is 45 degree divided by cos beta L by 2. Beta L again we already have determined that is 35.29 degree. So, this will be equal to cos 35.29 degree divided by 2. If you do this calculation, this is coming out to be 0.742 per unit. Look at this voltage. This voltage is far below the 1 per unit. So, there is a severe undervoltage in this particular case. Now, the role of the SVC is to mitigate that undervoltage, right? So, therefore, again we will use the same expression to determine this ISVC. So, ISVC we know is equal to, so first we will consider the case that is Xs is equal to 0, that is the slope of the control characteristic is equal to 0. So, ISVC we know is equal to this V Thevenin minus V reference divided by Xs plus Z Thevenin. Now, this V Thevenin already we determined that is 0.742, and V reference is already determined at the very beginning. So, this is the V reference expression and we got this value of V reference is this that is 0.9695 per unit. So, we will put directly here. So, this is 0.9695 per unit divided by this Xs value is considered to be 0 first and Z Thevenin also will determine that is equal to 0.159 per unit. So, that is 0.159 per unit. So, if you do the calculation, as per my calculation, it is coming out to be minus 1.431 per unit. Now, we will find out this BSVC when it is operating at capacitive region. So, BSVC at maximum production limit.

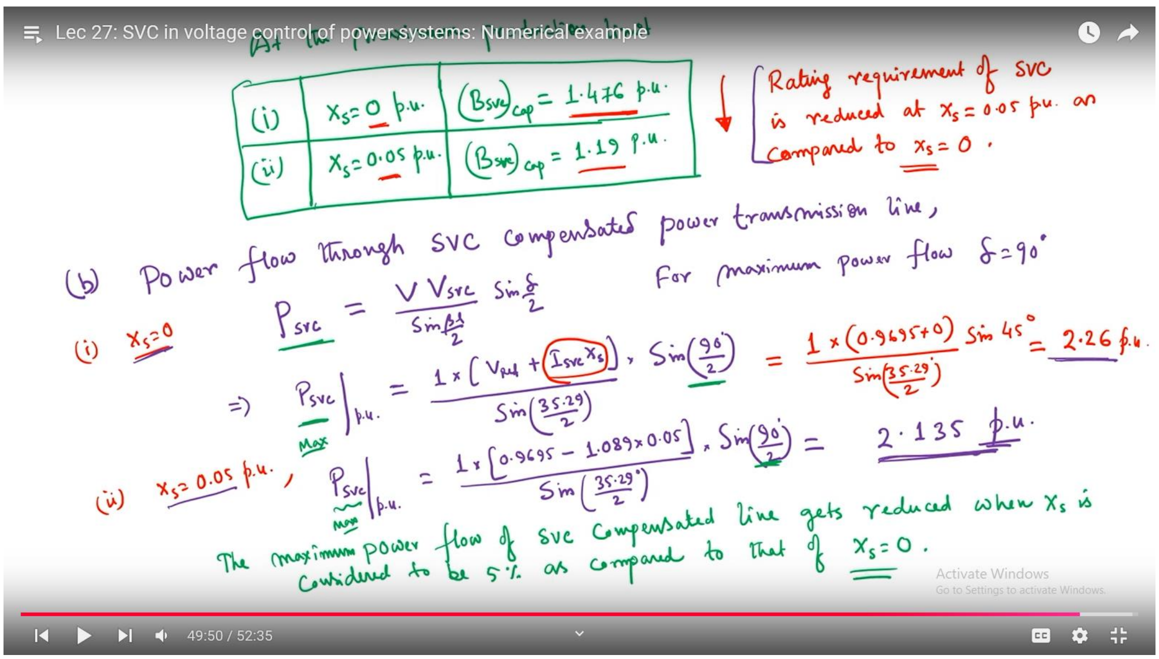
So, this is equal to what we know that minus ISVC divided by VSVC. Now, IS minus ISVC already we know that this minus of minus 1.431 per unit divided by this VSVC we know its expression is equal to V reference plus ISVC excess. So, this is equal to V reference plus I S V C X S. Now, we consider this X S to be equal to 0. So, then this multiplication will be also 0. So, therefore, the expression of this would be equal to 1.431 divided by V reference, V reference is considered, already determined as 0.9695. So, it is coming out to be 1.476 per unit. This is one. Now, the second case is corresponds to Xs is equal to 5 percent, which is equal to 0.05 per unit. So, in this particular case, again we will determine this ISVC. ISVC is equal to V thevenin. V Thevenin is already 0.742, you know. The numerator will be the same. So, that is 0.742 minus 0.9695, only denominator will change. So, this will be, Xs will be no longer 0. So, this will be 0.05 plus 0.159, which is equal to minus 1.089 per unit. So, once we get that, we will find out this B SVC production limit corresponds to Xs is equal to 5 percent which is equal to minus of this I S V C divided by V S V C, V S V C we know it is equal to V reference plus I S V C Xs.

Now, we already determined I S V C that is minus of minus 1.089 divided by this V reference, V reference is equal to already we determined that this is 0.9695 plus this I SVC multiplied by XS. So, ISVC already we determined this that is minus 1.089 multiplied by the XS is we consider 5 percent slope. So, this is 0.05. So, if you do whole calculation then it is coming out to be 1.19 per unit. Now, if we summarize once again that at the maximum production limit, if we consider these two cases, one is case 1 corresponds to Xs is equal to 0. That means, it means that we considered 0 slope in the control characteristics. Case 2 corresponds to a positive slope that is 5 percent slope which corresponds to 0.05 per unit. So, this corresponds to 0 per unit, this corresponds to 0.05 per unit. Now, when it is so, this BSVC capacitive would be equal to 1.476, BSVC capacitive limit will be 1.476 per unit and this is equal to BSVC capacitance is equal to 1.19 per unit. This is what the result we got. Now what would be our interpretation from this result? Look at this absorption limit of SVC. What you can see is that this control characteristic is influencing this rating requirement in fact of the SVC. So corresponds to x is equal to 0 if the rating requirement is 0.289 per unit, then, if you consider a positive slope of 5 percent, the rating requirement comes down to 0.217 per unit. This is exactly I discussed in the last class and this is numerically established here in this particular lecture. So, it means that there is a substantial reduction of the rating requirement. Now, what we mean by rating requirement? This absorption limit is the maximum var absorption capacity of the SVC. So, depending upon that value, we will design this particular SVC. And therefore, this SVC rating will directly depend upon two extreme condition. One is absorption limit, another is production limit. So, if you see, simple accepting a 5 percent slope in the control characteristics brings down the rating requirement from 0.289 to 0.217. So, that is what the advantage of having this positive slope of this SVC control characteristics as compared to the zero slope.

Now, here also same thing is true. You can see, if we consider zero slope in the control characteristics, the capacity maximum var production limit of the SVC corresponds to the susceptance 1.476 per unit. Whereas, if you consider 5 percent slope in the control characteristics, the same susceptance limit is come down to 1.19 per unit. So, therefore, the rating requirement is reduced. So, we can conclude the rating requirement of SVC is reduced at Xs that control characteristic is 0.05 per unit as compared to Xs is equal to 0. So, rating requirement of SVC is reduced. That is one of the advantages of the positive slope of the control characteristic.

This is very important point. Now, let us determine the second problem. So, determine the maximum power flow of the line in per unit for the slope of control characteristic is 0 and that is 5 percent. Now, what do you mean this power flow? So, the power flow, this is question number b or solution for question number b, power flow through SVC compensated line. Remember, this is not the power flow through SVC, but it is power flow through SVC compensated power transmission line. Now, what was the expression for that? We represent it like P, when we have SVC compensated, that P SVC, which was in the last lecture I mentioned, this is equal to V, V SVC divided by sine beta L by 2 sine delta by 2. Now, it is asked that let us determine this power flow in terms of per unit. That is also important. You have been asked to determine the maximum power flow in the line in per unit. So, the maximum power flow is asked. So, maximum power flow happens when the delta is maximum that is delta is equal to 90 degrees. So, therefore, for maximum power flow, for maximum power flow, delta is equal to 90 degrees.

So, therefore, we can write this PSVC in per unit as equal to this V we know that is 1 per unit. V SVC will be, already we determined that V SVC is equal to V reference plus I SVC multiplied by X s. So, this is equal to V reference plus I SVC multiplied by X s. Sine beta L by 2 already we determine, so this is equal to beta L already we determine is 35.29 degrees, so, therefore, I will put it directly 35.29 divided by 2 that much multiplied by sine delta by 2, so sine delta by 2 is sine 90 degrees divided by 2. Now, we know that this V reference value is equal to 0.9695, already we determined over here 0.9695. So, this will be equal to 1 multiplied by 0.9695. Since Xs is equal to 0, we consider that case A, Xs is equal to 0. So, therefore, this part will be equal to 0 plus 0 divided by this sin 35.29 degrees divided by 2 multiplied by sin 45 degrees.



If you do the calculation, according to this my calculation, it is coming out to be 2.26 per unit. Now, when you consider Xs is equal to 5 percent, that is 0.05 per unit, then the same calculation would be PSVC per unit will be equal to, this V is again 1 per unit, already is base voltage. V reference is 0.9695. Now, ISVC multiplied by Xs would not be 0. So, what is that value? So, this value we can find out from this here, because it is operating at delta is equal to 90 degrees. So, corresponding to this Xs equal to 0.05 slope, this is what this ISVC. So, this is equal to minus 1.089, minus 1.089 multiplied by this Xs which is 0.05 divided by this denominator will remain the same that is sin 35.29 divided by 2 degrees multiplied by this sin 90 degrees divided by 2 that is 45 degrees.

If you do this calculation, so this is coming out to be 2.135 per unit. So, this gives you the answer or solution to all the questions which have been asked in that problem. So, that is this problem. This gives you the answers of all the questions have been asked in the problem. Now, one thing you should understand is that while solving this problem, these values of the numerical or the numerical values of different parameters are important to us. Most importantly, we can have an interpretation of these parameter values. So, therefore, the similar way we interpret this remark, we can also interpret this power flow from these two numerical values. One is 2.26 per unit when Xs is equal to 0, another is 2.135 per unit when Xs is equal to 0.05 per unit. So, if you compare this, then what we can write is the power flow of SVC compensated line, I should rather say the maximum power flow of course, and the maximum power flow because this is also considered to be maximum power. So, this is also is maximum power. This is also maximum power because that is why we consider this delta is equal to 90 degree in both the cases. So, the maximum power flow of the SBC compensated line gets reduced when Xs is considered to be 5 percent as compared to that of Xs is equal to 0.

So, that is another remark from this particular numerical analysis. So, we can have two remarks, one is when we have a consideration of some positive slope, here incidentally we consider a 5 percent slope, but that slope can be even 2 percent, 3 percent, 4 percent, 5 percent and so on. But when you do consider this, this rating requirement of the SVC would be reduced. However, this power flow that is maximum power flow through the line also will get reduced. So, if this is the benefit, this is the drawback of this consideration of the positive slope of Xs.

So, as you know, as a student of engineering, when something gives you benefits, there are some drawbacks also. So, I explain both the things here with this numerical example. One last thing I will say before I conclude this part of the lecture is, if you look at this whole numerical analysis starting from here, then you can see we can have a design of this SVC considering the different aspects which include the slope of the control characteristic, the slope of the control characteristics and we can come up with the different rating requirements of the SVC under different consideration of the slope and which may also give you the different amount of maximum power flow through the SVC compensated line. So, with this, I conclude this particular lecture and we will discuss some other topics of this particular course in the next lecture onwards.

So, till then let me thank you for your attention once again. So, thank you very much for your attention to this particular lecture. Thank you.