Power System Dynamics
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Lecture - 36
Voltage Stability (Contd…)

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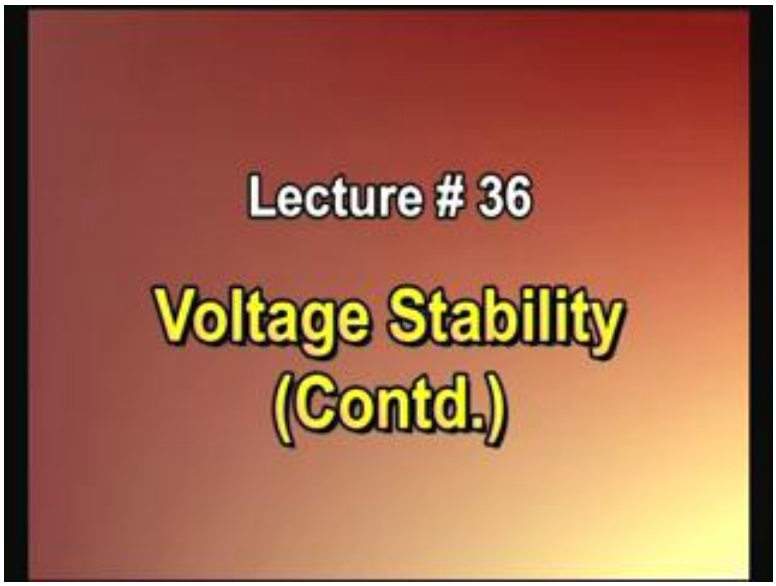

Friends, we continue with the study of voltage stability.

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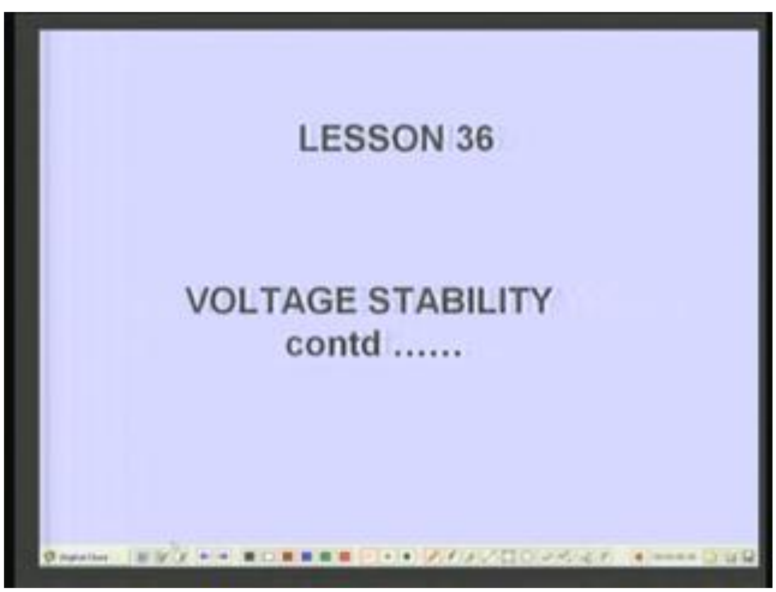

In the previous lesson we have discussed the basic concept of voltage stability and I have discussed the transmission line characteristic, I have also talked about the VP curves for understanding the voltage stability problem then I discuss a problem which I still reiterated again about the large system. Suppose for a large system if you have to plot the VP curve how do we plot the VP curve for a large system.

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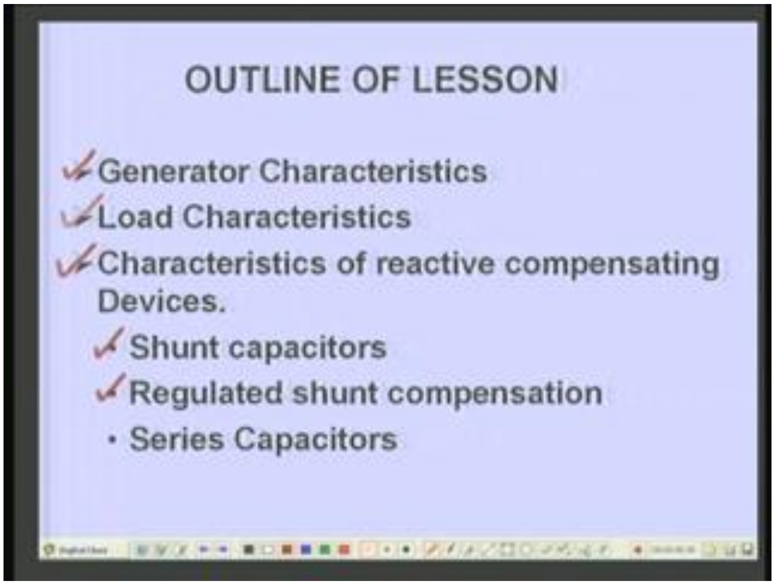

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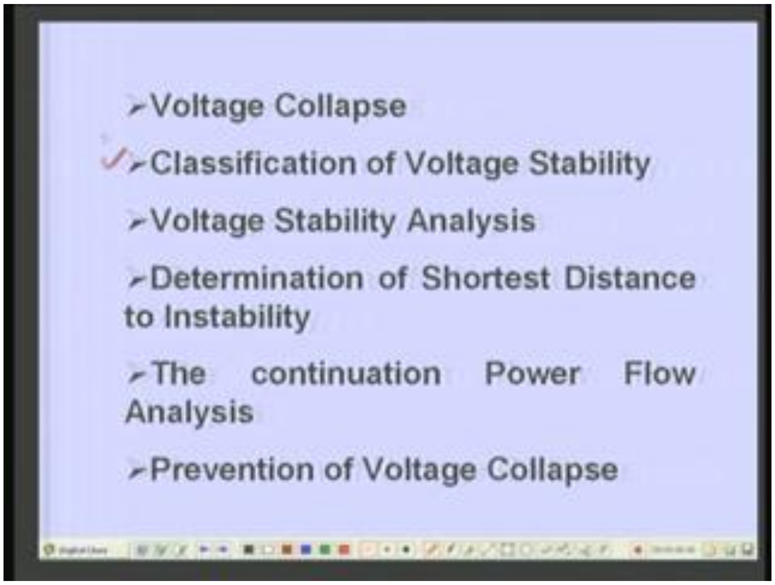

Today, we will specifically discuss the generator characteristics, then load characteristic and discuss the characteristics of reactive compensating devices such as shunt capacitors, regulated shunt compensation under this regulated shunt compensation we talk about the

SVC and STATCOM. We will also talk about series capacitors we will also discuss briefly about the regulated series compensation like thyristor control series compensation and synchronous, static synchronous series compensators and so on. Then we will discuss the voltage collapse phenomena, how the voltage collapse takes place in the system what are the sequence of events that take place which may cause the voltage to collapse. Then the next point which we have to discuss is the classification of voltage stability, voltage stability analysis then determination of shortest distance to instability the continuation power flow analysis and ultimately the prevention of voltage collapse.

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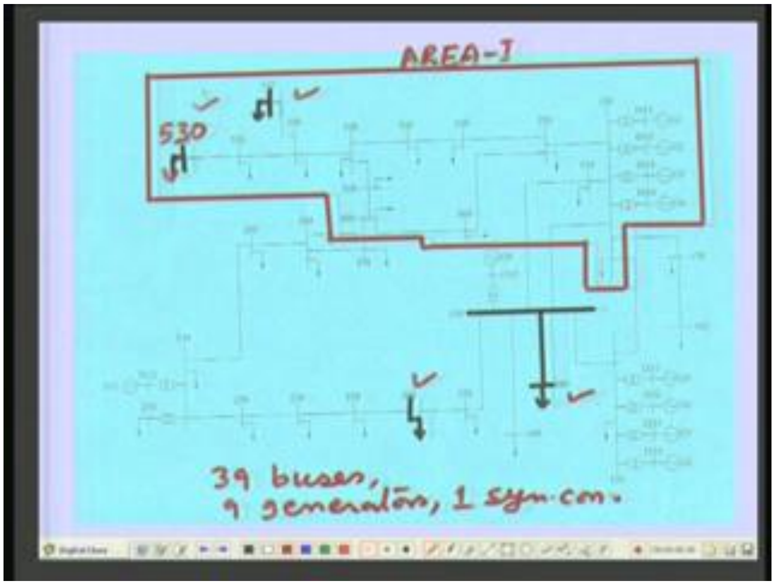

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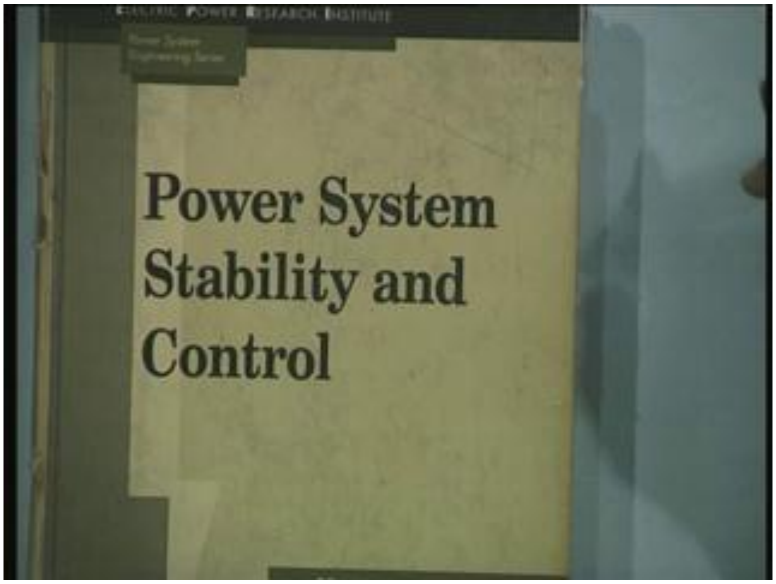

I intend to cover these topics in two lectures the the material which I am covering today and in the subsequent lecture is mainly drawn from this book on power system stability and control by Prabha Kundur. In this book he has discussed one one large system voltage stability analysis problem the system considered is shown here this system has 39 buses, 39 buses and 9 generators and 1 synchronous condenser, synchronous condenser. Now for this system first step is that suppose for a particular area, the area which has been identified is marked here this is the area called as area one this is the area one.

Now here in this area some some buses which are likely to we can say suffer the voltage instability problem are identified the buses which are very far off from the loads are likes a 530, this bus number is 530 this is one typical bus which has been identified.

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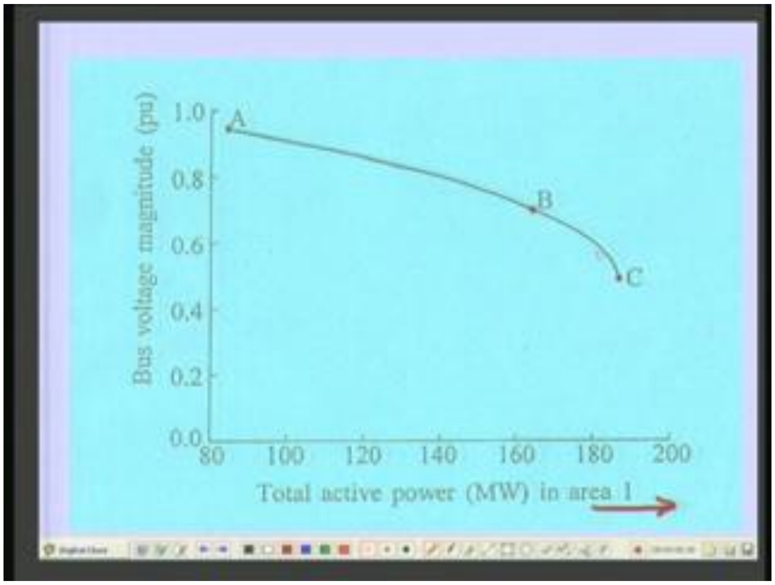

Now for this system the first step which has been done is to plot the VP curves for this multi-machine system, how do we perform the obtain the VP curve. The approach which has been considered here is that in this area one we increase the load in small steps that is at all the buses you increase the load in this area one and and to meet this load, we correspondingly increase the generation at all the generating stations in proportional to that to their sizes right and then a load flow is conducted to find out what is the voltage at this point that is you perform repeated low flow for different loading condition in this area area to plot a VP curve corresponding to the bus number 530 okay.

Now this figure shows the VP curve obtained for area obtain for bus 530 considering the load change in area one that is area one has number of buses right and at each bus the load is increased in small steps and to to meet that load the generations also increase correspondingly and then load flow is conducted then for each of the loading condition you find out what is the voltage at this bus 530 which is considered to be the critical bus and is the found to voltage in stability.

Now this curve is similar to what we have seen for a a single a single bus system or we can say radial transmission system where load is at only one bus right. Now we can see here as the load in area one increases the voltage at the bus number 530 decreases and at this point C we will find actually that beyond this point if you want to increase the load we are not in a position to increase the load, the load flow will not converse right and therefore we have generated actually in this in this example the VP curve for a 39 bus system considering a particular area and a particular bus.

Now while plotting this plotting this VP curve the power factor at the at the buses the load power factors are assumed to be constant that is when we increasing p you may increase correspondingly value of q also. Now here there are three points are identified one operating point A which is called normal operating load which is less than 100 mega watt and more than something like 80 megawatt around 85 megawatt in the normal load. Another point b on this curve is identified where the load is more than 160 megawatt, this point B is very close to the critical point and C is the critical point in the system.

Now to understand the voltage collapse phenomena one very important approach is to examine the qv curves because we know actually that the voltage is related mainly to the reactive power injection at that buses right therefore for this system which we have examined the QV curves are generated.

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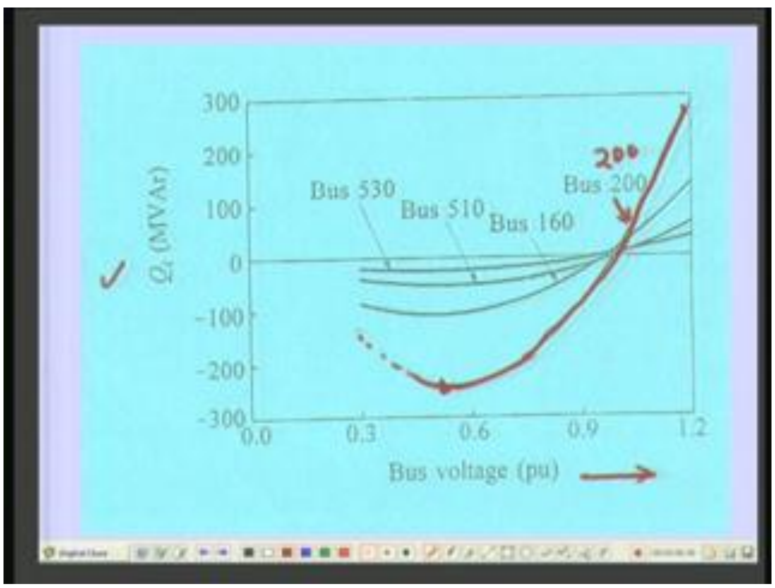

Now for generating the QV curve the approach is that we go to the system let us say that we want to generate QV curve for say bus 530 QV curve what we really do here is that we inject a curtain amount of reactive power at this bus, curtain amount of reactive power at this bus or other way around we say that we want to maintain curtain voltage at this bus then compute what is the reactive power injection required that is you assume that bus number 530 is a PV bus right and perform the load flow analysis and then compute what is the reactive power required at this bus to maintain the voltage at that level.

Now this exercise has been conducted for four different buses in the system. The buses identified are bus number 160, bus number 200, bus number 510 and bus number 530 that is for the complete system under the normal operating condition right the the QV curves are to be generated. Now for generating this QV curves again 3 different loading conditions are considered, one is corresponding to the point A which is shown here, another is corresponding to point B and third is corresponding to the critical point C in the system for for this the point A which is the normal operating condition right the QV curves plotted are shown here.

Now these QV curves are shown for different buses like this is the QV curve I will just redraw it more really here this is the QV curve plotted for bus number 200. Now if you examine this QV curve that is on this side we have put the injected reactive power and on this side we are putting the bus voltage in per unit. Now you can see here actually that this QV curve shows as the bus voltage increases the increases initially the injected reactive power decreases it comes to a point where we reach a minimum point if it is a minimum reactive power injection required to maintain this voltage at this level then to maintain the voltage at any other level beyond this point again we have to increase the injected reactive power.

Therefore we can see this curve then this curve is basically a V curve type thing where when the voltage is very low we have to inject curtain amount of reactive power if the if the desired voltage is more reactive power required injection is less right. Now in this similarly this QV curves have been generated for other buses likes say bus 530, bus 510, 160 all these curves have similar pattern. Now let us examine this curve that is a QV curve for bus number 200, this is the QV curve.

Now you can see here actually that this is the point where if you find out the slope that is dq by dv then this dq by dv is 0 that is at this point the slope of this curve is 0. Now dq by dv 0 means actually here here if you increase the increase the reactive power injection voltage does not change right. Now if you go from this point onwards then this dq by dv is positive that is from this point let me call this mark from this point onwards then dq by dv is positive and therefore the any operation on this part of the curve will be stable operation in the sense that dq by dv is positive means that when I increase the value of reactive power injected the there is a increase in the voltage at that bus but now if I see the left part of this curve then the slope of this curve slope or slope of this slope that is dq by dv is negative it means if you when you increase the reactive power injection then the voltage drops right and therefore this portion of the curve of course we write I take this extended portion like this then this portion is unstable operating point. On this portion, we cannot operate because if you just increase the the reactive power voltage drop rather than increasing.

Now this is the different type of q curves which have been shown and as we have see in our further discussion that this the slope of the slope of this curve or you can say the qv sensitivity will be very important term or indicator for for analyzing the voltage stability of a system okay.

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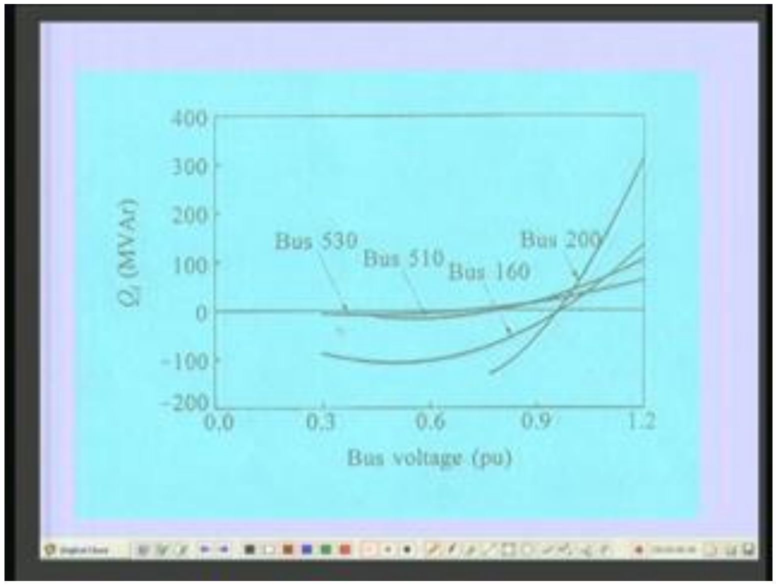

Now this shows the QV curves generated for loading condition corresponding to B on the nose curve or on the VP curve. Now the you can examine you can see that now the curves or you can see shape of the curves have drastically changed.

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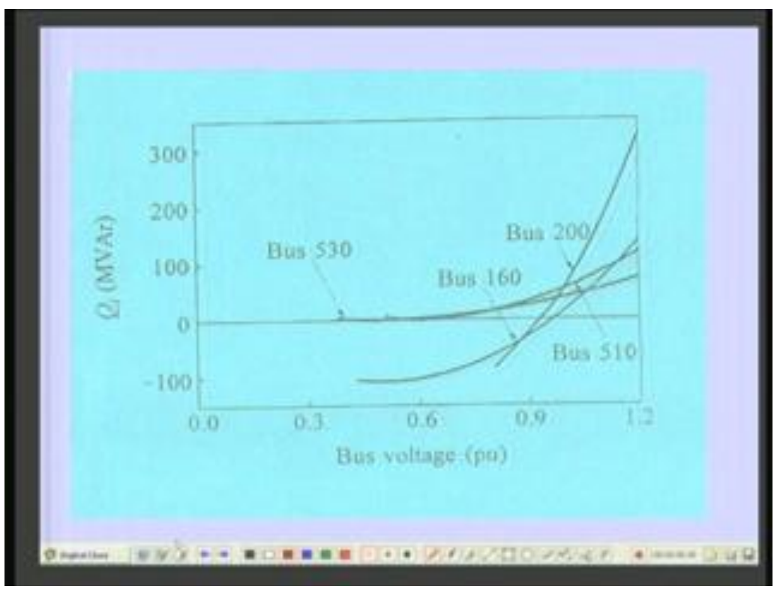

Similarly, for the last case that is the operating condition corresponding to the point C again QV curves are plotted and you can easily see that the curves have completely changed therefore the what we conclude here is that the QV curves for different buses depend upon the loading condition on the system and the QV sensitivity is different at different loading condition.

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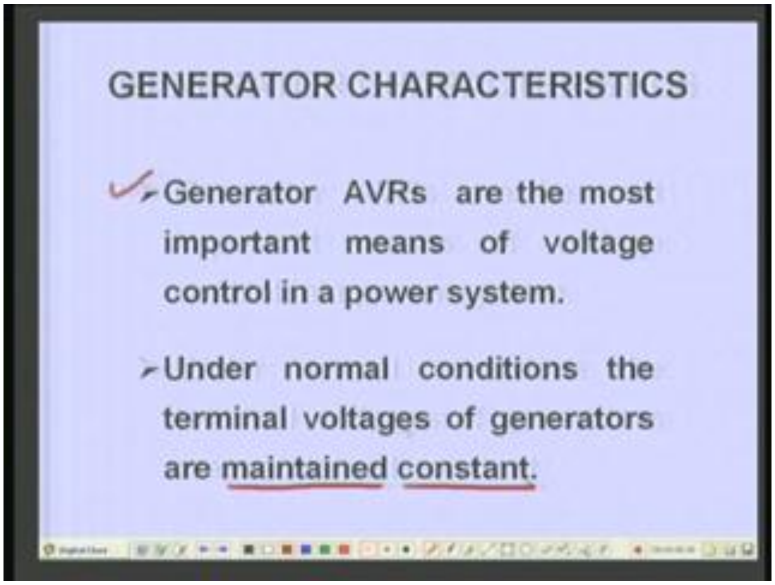

Now after this we, let us examine the characteristics of various components of the power system which would affect the voltage stability of the system. In fact the voltage stability depends upon the complex interaction between the various components of the power system. Now we start with the characteristic of generators it is very well known actually that a generator is a source of reactive power, it can generate reactive power, it can observe reactive power and it can generate real power also. Therefore, now let us to to study the study the generator characteristics particularly in response to voltage stability phenomena phenomena we we see that all generators have automatic voltage regulators and these generators are the generator AVRs are the most important means of voltage control in a power system.

When we talk about the voltage control in a power system then the devices which are available for voltage control are automatic voltage regulators of the generators that is by regulating the excitation of the generators. We control the voltage by tape changing of the transformers we control the voltage by by reactive power injections. The reactive power may be injected by synchronous condenser or may be by SVC or may be consider by shunt compensators or static capacitors or so on but these are the means for regulating the voltage therefore in generators the AVRs will regulate the voltage under normal conditions the terminal voltage of generators are maintained constant that is as the loading condition changes the terminal voltage is maintained constant by the

Now, during conditions of low system voltage because because voltage stability problem comes when the system voltage becomes low. The reactive power demand on generators may exceed their field or armature current limits this is very important point I will explain here that that whenever you increase the reactive power demand on the generator then we have to increase the excitation current right and therefore in case suppose reactive power demand becomes such that the you cross the field current limit right.

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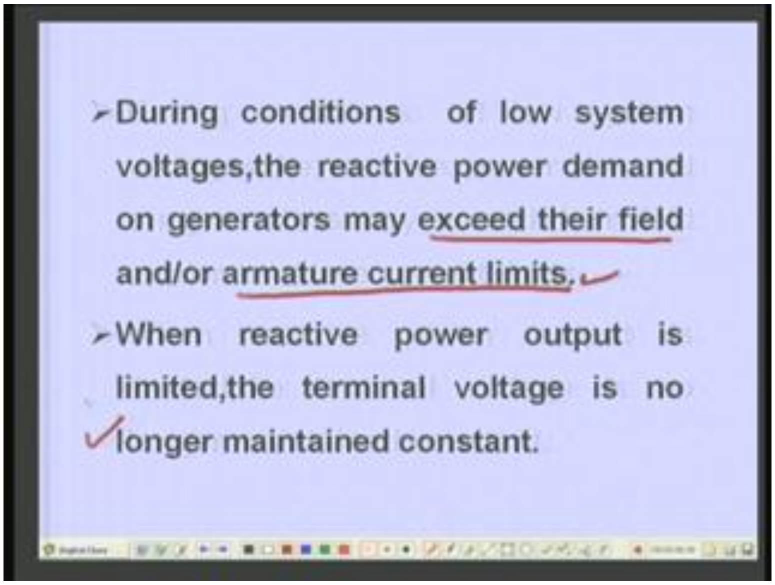

Now the field current limit is an important limit actually one has one should not violate the field current limit similarly, the armature current limit should not be violated therefore any generator is concern. In case in case suppose you come to a situation where we exceed the field or armature current limits then then we will not be in a position to regulate the voltage beyond that. Suppose the field current reaches the upper limit it means now we will not be in a position to regulate the terminal voltage of the generator current limit reaches its maximum value.

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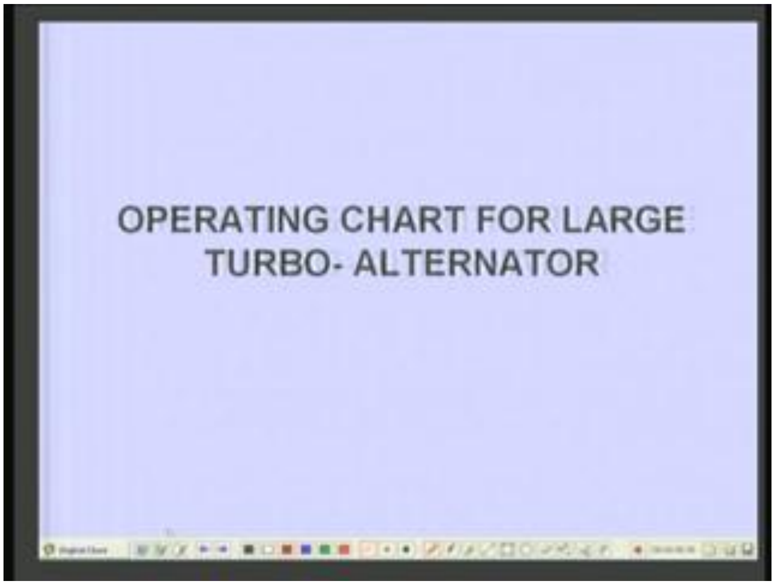

When reactive power output is limited the terminal voltage is no longer maintained constant, see the in any system the generators are the are very important voltage control devices but movement actually you you reach the field current limit then that particular generator will no more be voltage controlling device it will have actually fixed internal voltage right. In which basically you are you are in a position to maintain a voltage which is constant behind a synchronous reactance right.

Now to explain this point I will just briefly talk about the operating chart of a large turbo alternator, all generators generators when they are operated right an operating chart is used. So that the operator always maintains the the generator operation within the operating chart.

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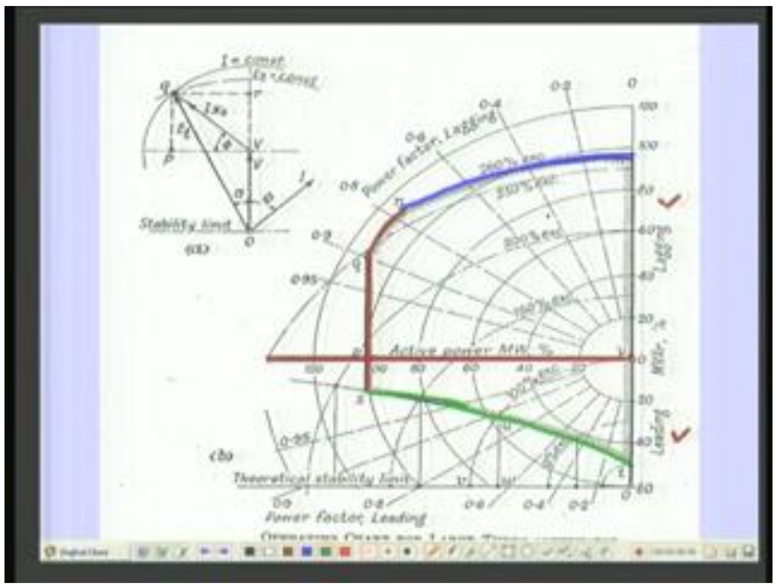

The typical operating chart of a generator is shown here where, on this on this axis we have shown the reactive power reactive power supplied by the generator that is this is the base point I will just highlight some lines. This is our x axis and this is the y axis, the on x axis we have marked the real power input in megawatts on y axis we mark the reactive power output in MVR that is this positive part of this axis so the lagging reactive power, lagging reactive power and on this side it is the leading reactive power the the the region in which the generator is to operate is confined by some considerations, one consideration is the the maximum real power output that is the that is that is determined by the turbine capability.

For example, here this line which is drawn here shows that the the this is the maximum real power output with a generator cantilever right let me just draw it here. Okay that is this is the maximum real power output which one can generate then then in the same mark we have in same actually operating chart this portion of the curve shows, this portion of the curve shows the stator current limit that is in case you go beyond this side then the stator current will be more than the rated current then this portion you can see here this portion of the curve I will show by a different color here shows basically the the field current limit right, field current limit. Then this part of the curve which is shown here is is to represent the stability consideration.

In fact this graph is plotted in fact this line, this horizontal line shows actually the situation where the phase angle between the terminal voltage and the internal voltage will become 90 degrees and that is we cannot operate when the the power angle is more than ninety degrees right and this graph is plotted considering a stability margin of 10 percent and therefore the operating reason is inside this graph or inside this curve which is shown here which has we consider a four different segments, one segment of the curve represents the stability stability limit consideration and this is basically we are operating in the leading power factor condition.

This vertical lines shows actually the real power output condition that is the turbine limit, this segment q to n is corresponding to the stator current limit and this from n to this point n to m it represent the field current limit right. The moment you operate within this within this the generator will be regulating the regulating the terminal voltage but the moment you reach actually the limiting condition, terminal voltage can no more be regulated right.

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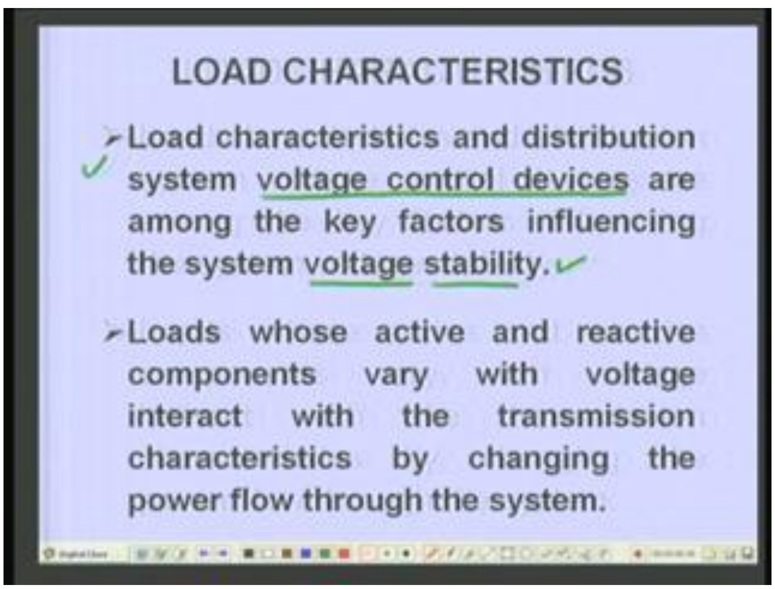

The next important components of the power system which affect the voltage stability is the loads and their characteristic I have discussed actually in the previous lecture the load characteristics there are certain loads which which can be consider as a constant p and constant q loads that is equal to p loads then there are certain loads which which are which can be characterize as a constant impedance loads, there are certain loads which can be characterized as constant current loads and in general a load in a power system will have some component which may behave as a constant impedance load, some component may behave like constant current load, some may behave as a constant pq load right.

Therefore, normally the composition of the load is very important and it affects the affects the voltage stability to a great extent load characteristic and distribution system voltage control devices are among the key factors influencing the voltage stability that is we have talked about the load characteristic another important aspect which we have to understand is the the voltage regulating devices in the distribution system. In any distribution system we have some voltage regulating devices that is the voltage regulating devices along with the loads have a significant affect on voltage stability.

Now when I talk about the voltage control devices the one of the most important voltage control device is the is the under load tape changers, in the distribution system we have under load tape changers and and as a as and when the terminal voltage or the voltage at the load point decreases then this control device will tried to bring the voltage to the required value or try to regulate the voltage. Therefore, the behavior of this voltage control devices and the load characteristics have a very significant affect on the on the voltage stability. Loads whose active and reactive components vary with voltage interact with the transmission characteristics by changing the power flow through the system. This is very important point actually those you have done some studies of the power system and if you want to account for the load loads depending upon the voltage that is load dependent voltage, I am sorry voltage dependent loads.

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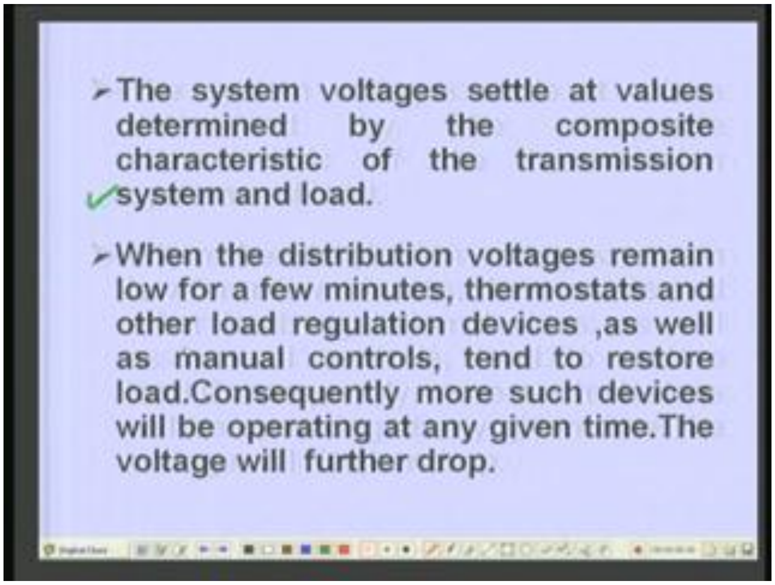

If you perform load flow analysis, load flow analysis consisting the voltage dependent loads right then the then the solution of the load flow will be different then a case where you consider consider the constant pq loads right because in the moment the load at a particular bus depends upon the applied voltage then then the the net voltage which you get resultant voltage will depend upon the composite characteristic of the transmission line and the load characteristic.

The system voltages settle at value determined by composite characteristic of the transmission system and the load. Now another aspect is when the distribution voltages remain low for a few minutes which is another interesting aspect by suppose due to some reason the voltage are at low level right. Then what happens is that we have many loads which are thermostat control the examples are particularly even the you can say air conditioning load or the fridge they are all thermostat control.

Now when the system voltage is low right then these devices will remain on the system for longer time to achieve the same level of temperature right. Therefore, this the when a distribution voltage remains low for a few minutes thermostats and other load regulation devices as well as manual controls tend to restore load restore loads means actually the more loads will be there on the system.

Consequently, more such devices will be operating at any given time and this will cause further drop in voltage, more the devices are operating in the system obviously the voltage will drop and if the voltage was low because the low voltage devices more devices are on the system, this in turn will cause further drop in voltage.

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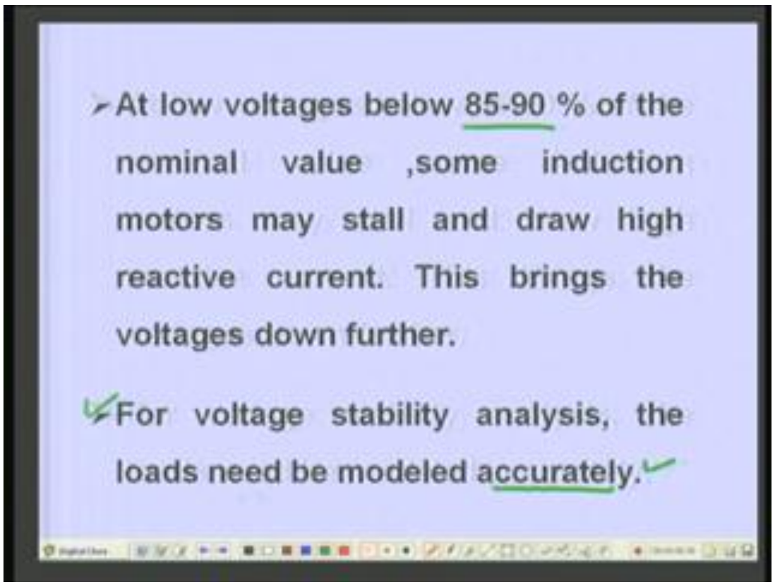

Therefore one has to examine the characteristic of the loads which are thermostatically control another aspect is that we have large number of induction motor loads and the induction motors will stall at a voltage which is below 85 to 90 percent of the normal voltage and suppose induction motor stalls and remains in the system it will cause further dropping voltage. However, what happens is that most of this induction motors have magnetically operated contactors so that what happens at that moment the voltage is low then the contactors will open and trip the load when the contactors open and take the load the voltage will be restored again right. Therefore, this type of phenomena takes place in the system that is voltage drops when the loads trip voltage will again go up. For voltage stability analysis loads need to be modeled accurately this is very important point when I talk about the voltage stability analysis one has to model the loads that is industrial loads may be induction motor loads have to be modeled then the thermostatically controlled loads have to be model.

We have to model actually the operation of the under load tape changers right then in addition to this one has to model the the behavior of the shunt capacitors which are there in the distribution system for for reactive power compensation. When the voltage is low then the reactive power injected by this capacitors which are there in the system will also becomes low it is proportional to be square of the voltage right therefore this whenever you examine the voltage stability problem one has to one has to model these loads in detail this is very important and the the dynamics of this load models is slow.

For example actually the thermostat opens and closes it is not very fast it takes few seconds and even sometimes minutes right therefore when you model this the voltage stability phenomena is to be examined over few minutes, did not like angle stability where we examine in first few seconds, 2, 3, 4 seconds system is stable or not that can be examined.

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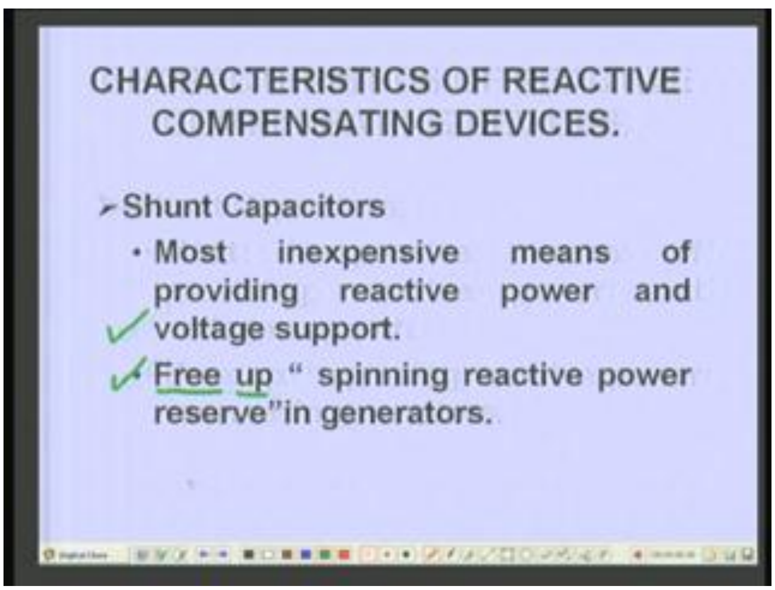

The next important device in the power system is the reactive power compensating devices and one has to model the behavior of the shunt capacitors and the shunt capacitors are the most inexpensive means of providing reactive power and voltage support that is although we have today more sophisticated reactive power compensation devices but the fixed shunt capacitor or series shunt capacitor they are the most inexpensive devices. When you use this shunt capacitors the one very important advantage which we get is that the generator spinning reactive power is made free that is suppose a reactive power demand is made by shunt capacitors naturally the generator the demand on the generator will be reduced.

So that the reactive power will have some spinning reactive power reserve which can be which can be used in a very short time okay, that is why the what you this the application of shunt capacitor will free up a spinning reactive power reserve because generator is already operating or spinning reactive power reserve.

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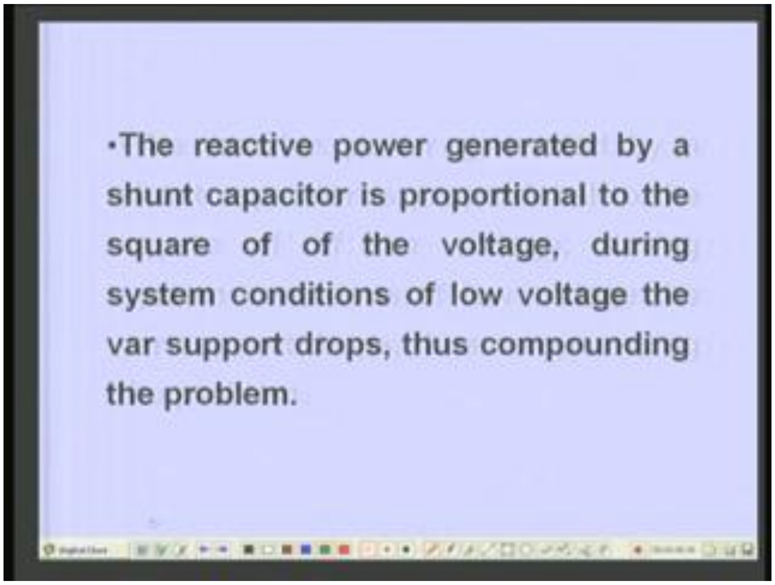

I have already mentioned that the reactive power generated by a shunt capacitor is proportional to the square of the voltage and during system conditions of low voltage, a very interesting part when the system voltage is low we want more of reactive power but on the other hand what happens if the reactive power injected by the capacitor decrease that is why during system conditions of low voltage the var support drops and thus compounding the voltage stability problem, say the voltage becomes low right the capacitors further you can say reduce actually their share of reactive power and therefore the problem gets compounded.

The next category of reactive power sources come under the heading regulated shunt compensation under the regulated shunt compensation we know about the static var compensators SVCs the another device is the STATCOM today which is available. Then these devices the difference between these devices is that within certain voltage suppose you talk about SVC I hope everybody knows about the characteristic of SVC that in the normal voltage regulating range range the SVC will be in a position to maintain the voltage constant but the moment.

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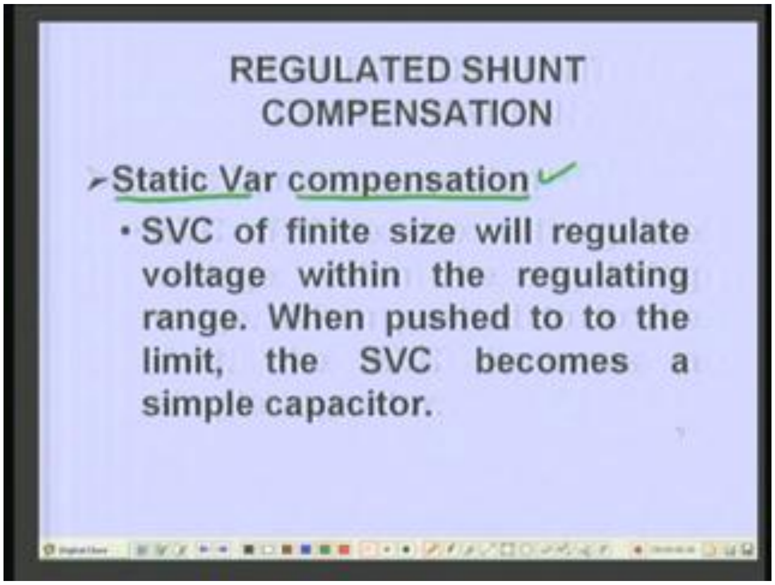

You go outside this voltage regulating range then the SVC will become a constant a capacitor a constant capacitor it will behave like a capacitor only just like a shunt capacitor because it is now no more in a position to regulate actually the reactive power right and the reactive power consumed by the shunt capacitor is proportional to the square of the applied voltage. Therefore that limit will become but within the voltage control limits it maintain the voltage constant this is very important point. Then another device is particularly the static synchronous condenser the STATCOM and synchronous condenser.

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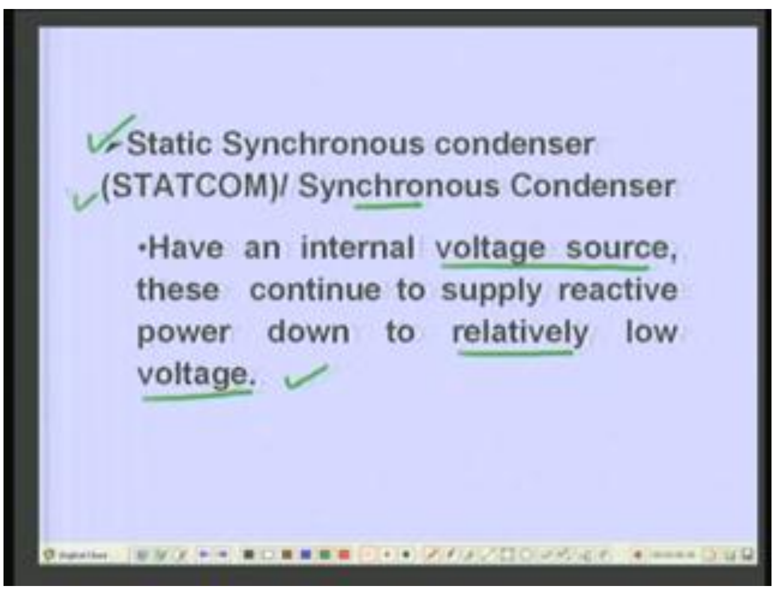

Now the characteristic of the synchronous condenser and characteristic of STATCOM are exactly identical, only difference is one is rotating device, one is static device. But the advantage of this devices is that even when the voltage is low they are capable of injecting reactive power that is have an internal voltage source and this continue to supply reactive power down to relatively very low voltage that is if you plot actually the plot the reactive power versus the voltage characteristic then the state common synchronous condensers have better reactive power injecting capability and they are fast also.

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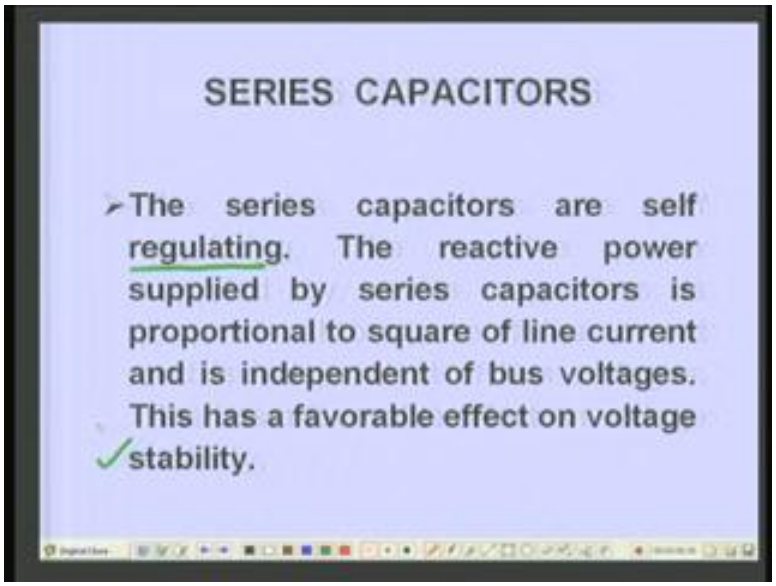

The another device which is very important here is the series capacitors, when I talk about the series capacitors we do not use series capacitors in distribution system but we have series compensation in transmission network the advantage of the series capacitors is that the reactive power generated by the series capacitors is proportional to the square of the current and therefore the series capacitors are self-regulating the reactive power supplied by series capacitor is proportional to the square of line current and is independent of bus voltage.

This has a favorable effect on voltage stability whenever you have actually certain problem of reactive power demand being not made because I have already talk to you that voltage stability is the problem of insufficient reactive powers available in the system, in insufficient reactive power sources right and particularly here series capacitors will be in a position to give you reactive power even the voltage is low but voltage it does not depend upon depends upon the current which is flowing and they are very helpful actually in.

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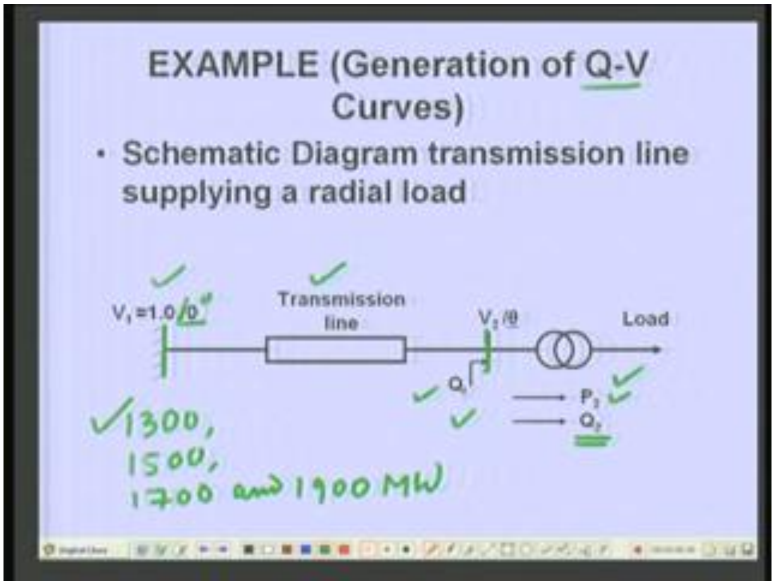

Now we will take one example of generating QV curves because as I have mentioned actually the QV curves play very significant role and I have also mentioned actually that the the the voltage at a bus will depend upon the interaction between the between the transmission line characteristic, it will depend upon the load characteristic and it will also depend upon the reactive power sources which are therefore to understand understand the basic concepts of voltage stability where I have mentioned that the QV sensitivity is very important that is dq by dv right therefore here. Let us study how do we generate the generate the a QV curves for this the example considered is transmission line supplying a load through a transformer, step down transformer.

Now the voltage V_1 this is the this is the infinite bus the voltage of this source is assume to remain constant equal to one and its phase angle is 0 degrees that is the voltage is one per and its phase angle is 0 the transmission line considered is a long transmission line and this example is discussed in the book on power system stability and control by Kundur in chapter 14 the we will discus the salient points of this example at the load bus where load is connected to a transformer we are injecting a reactive power Q_i, Q_i is the reactive power which injected at this bus our exercise is to plot the QV curves QV curves for fixed values of real and real power supply real and reactive power supply.

For this particular example the the loadings considered are at different levels like say 1300, 1500, 1700 and 1900 megawatt. These are the four different loading conditions are considered. For each loading condition the power factor of the load is assumed to be unity and the cubic curves are generated. Now for generating the cubic curve the approach is again what I have discussed earlier that is that is to maintain a certain voltage voltage with the given load you perform the load flow analysis and find out what is the reactive power injection required right. Now this diagram shows the QV curves plotted for this example considered.

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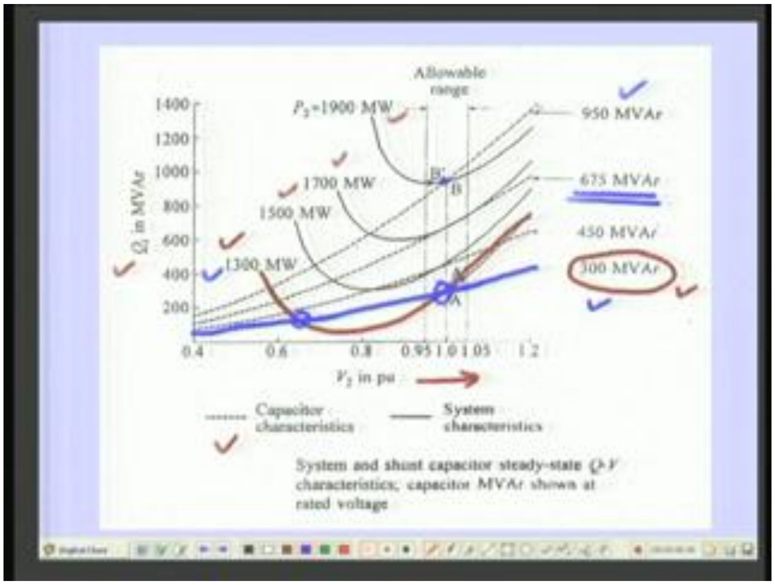

Now this graph I will again highlight it here and see this graph I will take this graph this is the QV curve plotted for load equal to 1300 megawatt on this axis. We are marking the reactive power injected and on this axis we are marking the voltage magnitude of V_2 that is magnitude of the voltage V_2 at the load point as we have seen actually the graph is having the same pattern as we have seen for a multi-machine system.

Similarly, we can plot curves for different loading conditions 1500, 1700, 1900. Now on the same on the same graph we are plotting the characteristic of the capacitors that is the reactive power injected by a fixed capacitor that is here what has been considered is that you take a capacitor whose value is say 300 MVR, it means this what we have assumed is that there is a capacitor who we can supply a reactive power of three hundred MVR when the voltage is one per unit right.

Now for this capacitor if we plot the voltage versus the reactive power injected then this is going to be it means its shape is going to be parabola right because as the voltage increases the reactive increase proportional the square of the voltage right. Therefore, let me just take one one particular characteristic. We can see this is the characteristic this is the QV characteristic of the shunt capacitor. Now when you I have already mentioned very clearly that for this when I specify that shunt capacitor has a 300 MVR rating means it it supply three hundred MVR, if the voltage across it is one per unit right therefore if the voltage deviates from one for example this is the one the voltage deviates from one it will absorb it will supply more reactive power and it when is less it will supply the negative power therefore this is the graph okay.

Now the operating point is determined by the intersection of intersection of QV curve of the load with with QV curve of the shunt capacitor. Now this point at this point if you see then it is slope of the QV curve of the capacitor then the slope of the QV curve of the capacitor at this intersection point is less than the slope of the QV curve of the of the load right that is at this point this point is a stable point reason is that suppose you deviates slightly from this point. Let us say that you deviate and come to this point it means what happens what happens the to stay at this point it will require more reactive power while the shunt capacitor is supplying less reactive power therefore it will move and come back to A right. However, if you take this point then this is not a stable point right this can be examined.

Now point here is that when you go from from loading equal to 300, 1300 megawatt to fifteen hundred megawatt you get the similar operating point when you go to 1700 megawatt then the characteristic of this MVR device which is put as 7, 625 MVR device this become just transient but if you have a MVR device or actually the shunt capacitor whose MVR rating is 950 MVR and the load is 1900 hundred megawatt the this is the intersection but this point is not stable. We can examine it what do we find here is that that at this point is slope of the slope of the QV curve of the system is less than the slope of the shunt capacitor that is if you deviate from slightly from this we will find that voltage will keeping on increasing right and therefore the the point which I want to highlight here is highlight here is that S by injecting a certain amount of reactive power we can operate the system at a stable operating point.

However, this reactive power sources of large capacity large capacity right then we will not be in a position to operate at a at a stable operating condition. Next point we want to illustrate through the same example is the effectiveness of SVC reserve the effectiveness of a fixed capacitor.

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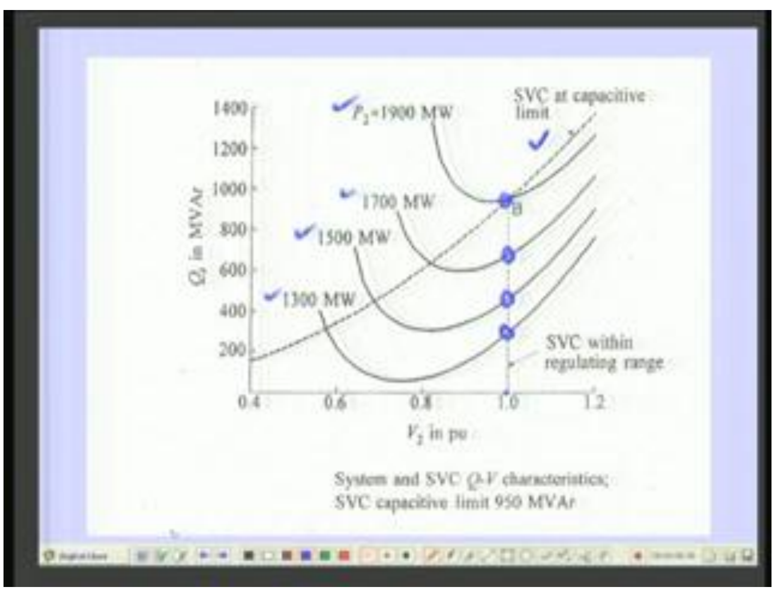

In this graph we have shown the QV curves of the same system at four different loading conditions 1300 megawatt, 1500 megawatt, 1700 megawatt and 1900 megawatt for different loading conditions and one typical SVC is shown here that SVC will be in a position to maintain the voltage equal to one per unit, you can just see in SVC this is the SVC characteristic shown.

So for the around this voltage equal to one per unit depending upon slight slope right. We will find actually that till the reactive power of the SVC is a reactive power limit of the SVC is reached it will be in a position to maintain the voltage at the same level whether the load is 1300, if it is 1300 this will be the operating point, if it is 1500 this is the operating point, 1700 this is the operating point. Now suppose the you reach at this point B where the SVC reaches its limiting condition, the moment it is said limiting condition it becomes a fixed capacitor and the capacitor SVC as a capacitor device as this characteristic as a capacitor.

So that this point B, B in case it is a it has reached the limit when this B again becomes a unstable operating point because the the slope of the capacitor characteristic or QV characteristic of the capacitor is more than the slope of the a system QV characteristic that is why actually the the we have importance of regulated reactive power sources right. Now I will just take one typical scenario of voltage collapse how the voltage collapse phenomenon takes place in the system the, first we have to understand what we mean by voltage collapse?

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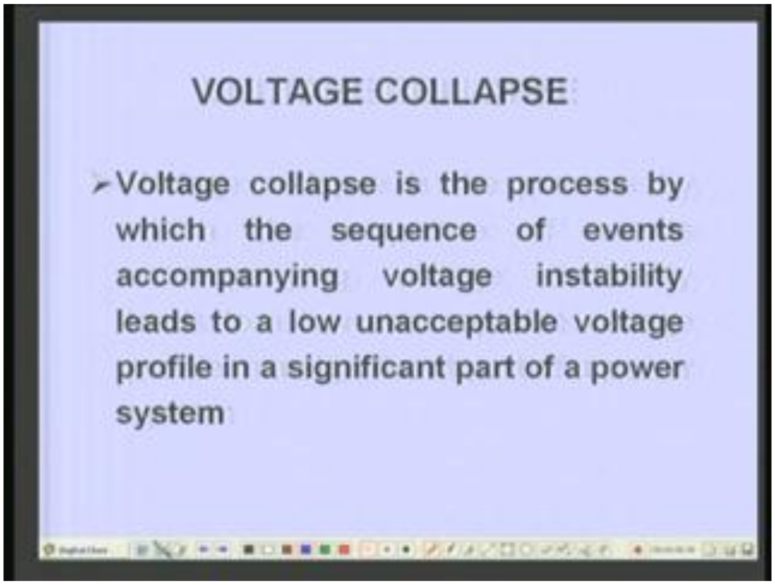

The meaning of this voltage collapse is voltage collapse is the process by which the sequence of events accompanying voltage instability leads to low unacceptable voltage profile in a significant part of the system. This is a very general definition that there may be certain sequence of events may takes place which will which will lead to unacceptable voltages in the significant part of the system, then say that the voltage collapse taken place. In fact voltage instability and voltage collapse are considered to be the synonyms now let me just explain how the voltage collapse takes place in any particular system.

Suppose a system is operating, now in the case the system is initially operating where its loading is heavy heavy loading in the sense actually the transmission lines are heavily loaded. We have limited reactive power source is in the system the generators are fully loaded or generators are quite away from the source. Now suppose a heavily loaded system is now subjected to some sort of contingency.

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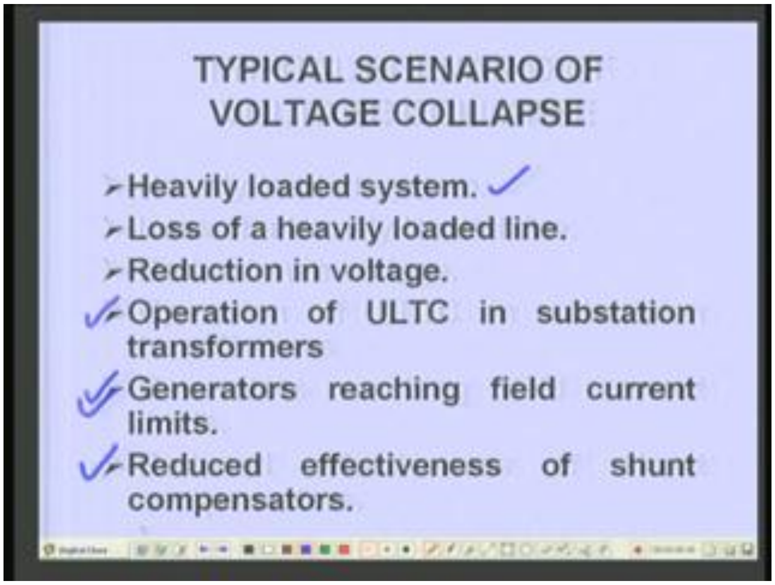

Now example of contingency may be that there is a one heavily loaded transmission line is tripped the movement this happens happens the other lines will be further loaded and the reactive power consumed by these lines will increase and this will cause reduction in voltage. Now the when the reduction in voltage comes the immediate thing which will happen is happen is that the under load tap changers will come into operation to retain the voltage and in case in case actually the ULTC in a portion to to stop the voltage drop voltage will be at a curtain level voltage drop.

Suppose voltage is dropping and ULTC start functioning and the voltage drop is stopped another thing which happens is that suppose the ULTC's reach their limits then they will not be in a position to regulate the voltage further. There is a possibility that generators may also reach the field current limits they are not in a position to further supply the reactive power, this will cause naturally the reaction in voltage was earlier generators were in a position to maintain the terminal voltage but the movement actually the reactive power demand has increased they reach the reactive power demand and therefore the the moment of reactive power demand limit is reached or reactive power limit of the generator which is reached then they will no more be regulating the terminal voltage.

Then the effectiveness of the shunt capacitors have reduced because when the voltage is low shunt capacitors supply less of reactive power and all these phenomena put together may cause the system to lose the voltage stability. Although some times what happens is that when the voltage drops then the some of the loads starts consuming less power because the the power consumed by the loads depends upon the voltage.

When they consume less power right there is a possibility that that the system will stabilize to a low voltage but at the acceptable level, voltage may be low but with the acceptable level. But the the sequence of events that take place in a very complex manner right and in that whole process process the if reactive power sources are weak we have less of reactive power then voltage may come down to very low level and we say it is a voltage collapse phenomena.

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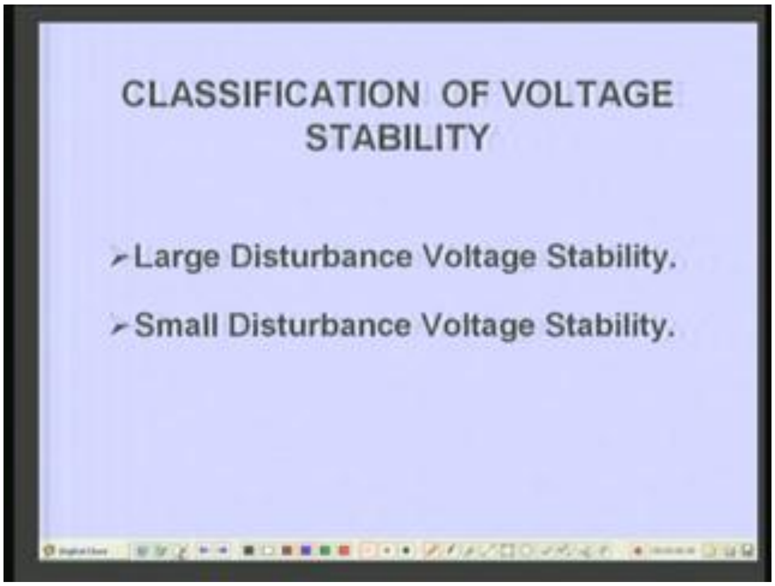

Now for studying the voltage stability we always divide this stability phenomena as a large disturbance voltage stability phenomena and small disturbance voltage stability phenomena the this classification is similar to that for angle stability we just define the large disturbance voltage stability. The large disturbance voltage stability is concerned with a system's ability to control voltages following large disturbances such as faults loss of load or loss of generation or loss of heavy loaded transmission lines right. But they are called large disturbances similar to our angle stability problem. We will discuss actually the large disturbance voltage stability analysis in the next lecture. I will talk about the modeling requirement of the requirements when we study the large stability problem.

The determination of this form of stability requires the examination of dynamic performance of the system over a period of time sufficient to capture interaction of such devices as ULTCs and generator field current limiters, large disturbance stability can be studied by using nonlinear time domain simulation which include proper modeling. In fact actually the angle stability and voltage stability the mathematical model required is identical accept that curtain details which are necessary for voltage stability may not be relevant for angle stability.

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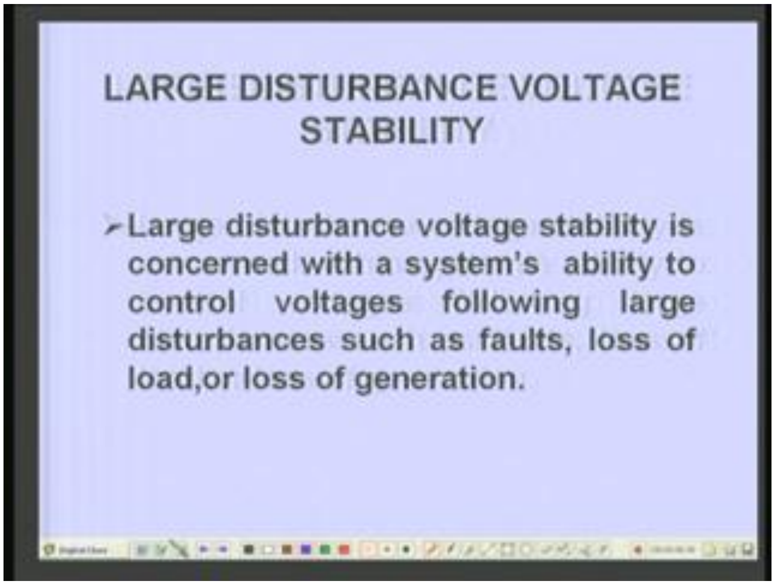

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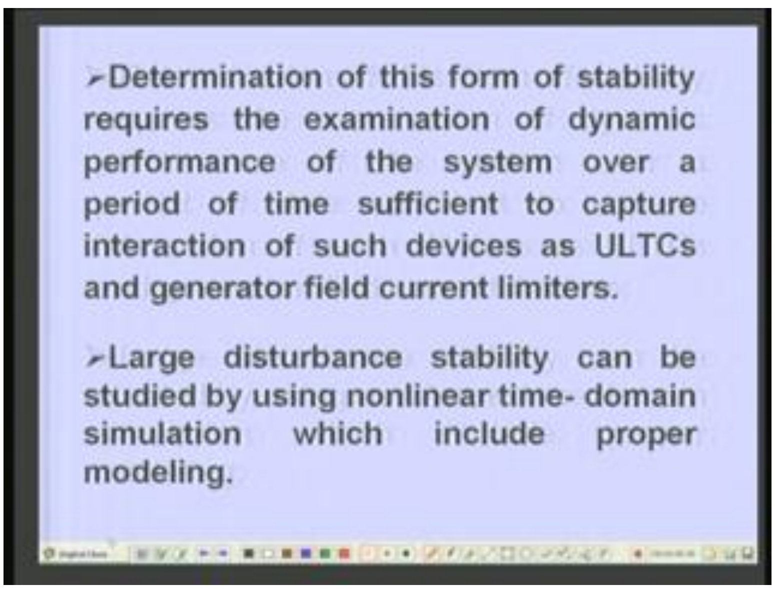

Small disturbance voltage stability, the small disturbance voltage stability is concerned with the system's ability to control voltages following small disturbances such as gradual changes in the load whenever, we talk about small disturbances means gradual changes in the load. Idea here is that the system is never never in static condition it is always in Quasi-static condition loads keeps on changing and when the loads keeps on changing right then if we are in a position to control the voltage, this small changes in load we say it is a it is a the system is small signal voltage stable. With this let me sum up what we have discussed today.

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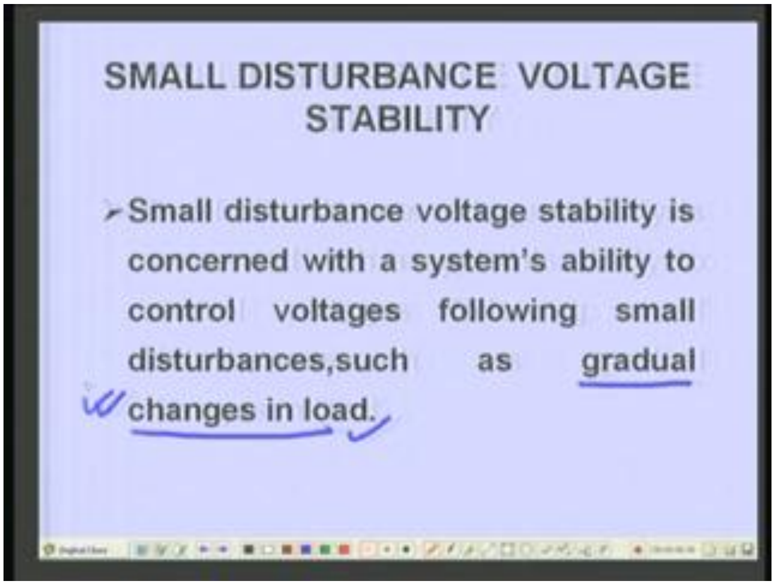

We have primarily discussed 2 important aspects, one is how to generate the QV curves for a system I have given you the example of generation of QV curves for a large system we have also plotted the QV curve of a of a machine infinite bus system or a load connected to a long transmission line. We have also seen the interaction between the QV characteristics of the system with the QV characteristics of the of the shunt regulating devices like fixed capacitors and and and actually regulated regulated static var devices. I have also define the voltage stability as small signal voltage stability and large signal voltage stability, I have also briefly mentioned about the voltage collapse phenomena how the voltage collapse takes place in the system we will continue with this in the next lecture. Thank you!