Power System Dynamics
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Lecture - 35
Voltage Stability

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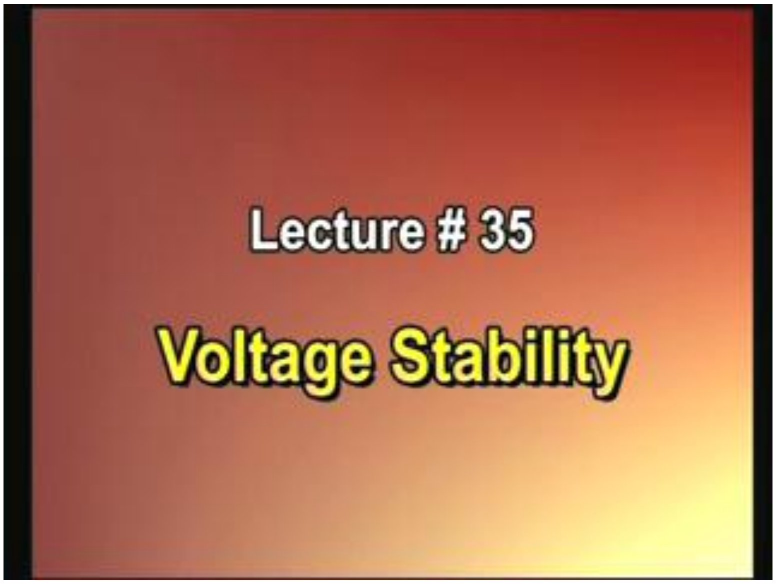

Friends, so far we have studied the angle stability of power systems. In the previous lectures we have studied the basic concepts of ah transient stability, dynamic stability modeling of the components and various techniques for analyzing the transient stability and dynamic stability of a system.

Today, we shall study another very important form of stability that is called voltage stability of a power system. This subject has been the subject of concern over the last two decades and over the last two decades a lot of research work has been conducted in the area of voltage stability and the standard resource material for this subject is available in chapter 14 of this book power system stability and control written by Prabakan, Prabha Kundur. This chapter 14 deals with the voltage stability of the power system then there is one more book which is exclusively written to deal with this subject that is power system voltage stability by Carson W. Taylor, this book is exclusively written and addresses this voltage stability problem.

The resource material for my presentation is drawn mainly from these two resources and we will study this voltage stability problem in somewhat detail in the coming lectures. The voltage stability sub problem, we will actually examine by studying the following aspects of the subject that is we will examine the basic concepts of voltage stability and while while trying to understand the concepts we will study the characteristics of the transmission lines, characteristic of the generators, load characteristics which forms a very important important aspect that is the load characteristics affect the voltage stability to a large extent then we will study the characteristics of reactive compensating devices.

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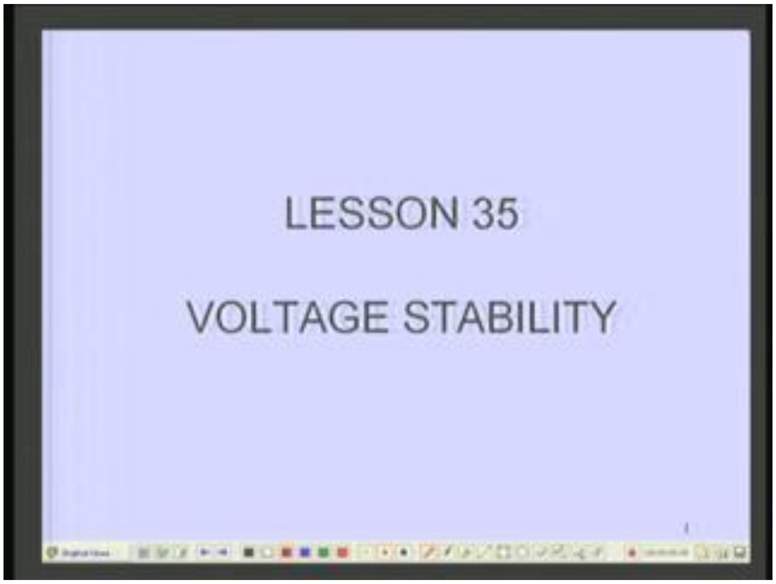

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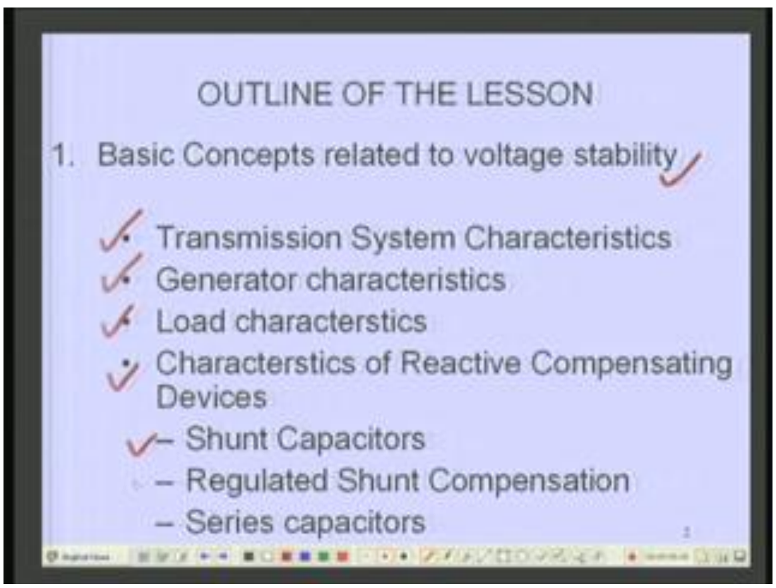

The reactive compensating devices are shunt capacitors; regulated shunt compensation when we talk about regulated shunt compensation under this category comes the static var compensators and STATCOM. We shall study the characteristic of series capacitors and we will also study the effect of control series compensation that is thyristors control series capacitors and the static synchronous series condenser.

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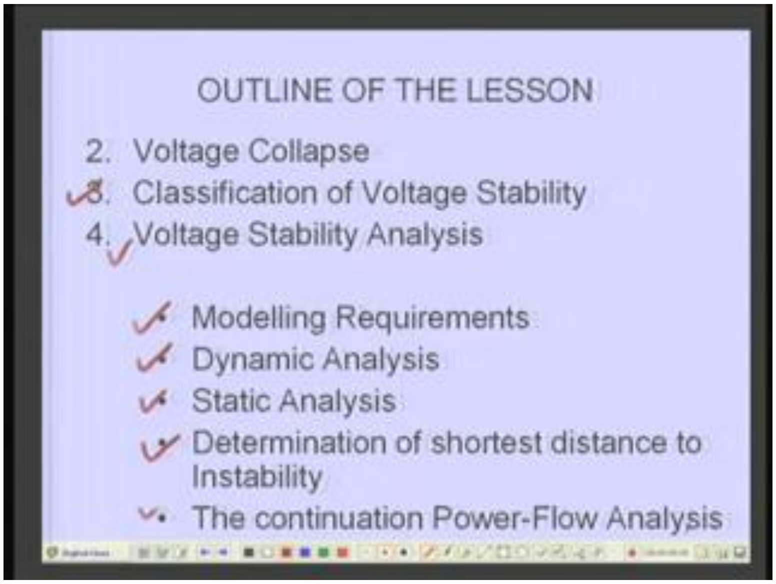

Then after studying the characteristic of these devices which affect the voltage stability we will examine the voltage collapse phenomenon that is how the voltage collapses takes place in a power system. The next point which we will examine is the classification of voltage stability that is the voltage stability problem is generally divided into 2 sub categories, one is called the transient voltage stability problem and one is called small signal voltage stability problem.

It is also divided into the two another 2 categories, one is called the static voltage stability problem and another is the dynamic voltage stability problem. Therefore, this subject will be dealt in detail then for any given system one should know how to analyze the stability therefore we will examine the techniques which are available for analyzing the voltage stability of a system.

Now while analyzing we will deal with the modeling requirements of the system then we will talk about the dynamic analysis that is the static analysis that is as I have told you that we divide this stability problem, voltage stability problem into 2 main categories, the static stability and another is the dynamic stability therefore we will examine the static and dynamic stability analysis techniques then there is a concept of the determination of shortest distance to instability that is when you are operating operating at a certain point how far we are from the instability point that is what called the shortest distance then we will just address the continuation power flow which is used for analyzing the stability problem.

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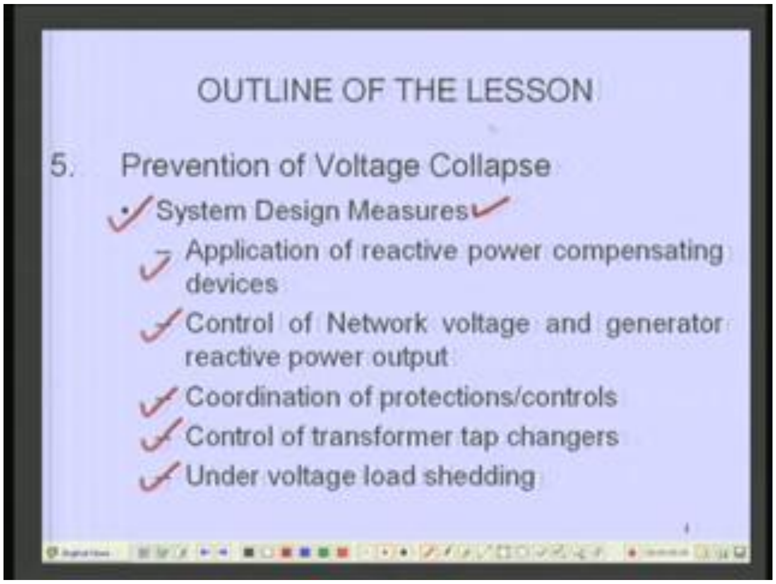

Then at the end we will examine the techniques which can be used for prevention of voltage collapse the various measures which can be used for for avoiding the voltage collapse are put under major headings like system design measures that is when you design the system you must take care of that the system is operated and so that so that we are we avoid the instability of the system that is right at the design stage we incorporate certain features so that the voltage instability problem does not take place.

The various design measures are application of reactive power compensating devices control or fixed then control of network voltage and generator reactive power output because generator becomes a very important source of reactive power. So that we should know how to control what techniques can be used to control the network voltage at various points and also the generator reactive power output. Then protection plays very significant role in the power system stability therefore one has to incorporate certain features which have a coordination between the protection and control.

When I talk about control means control of generators control of shunt and series compensating devices like this, then we also examine the control of voltage transformer tap changers then under voltage load shedding for for improving the transient stability of the system that is angle stability we have some phenomena called the under frequency load shedding. Similarly, for for avoiding the voltage instability phenomena one can resort to under voltage load shedding that is when the voltage is less than the certain level then you can shed some of the load or disconnect some of the load this is called under voltage load shedding.

Now these these measures are basically the measures which are to be to be incorporated right at the design stage of the system that is when you design your system you incorporate these features. So that you can appropriately control the network and the voltage instability problem can be avoided.

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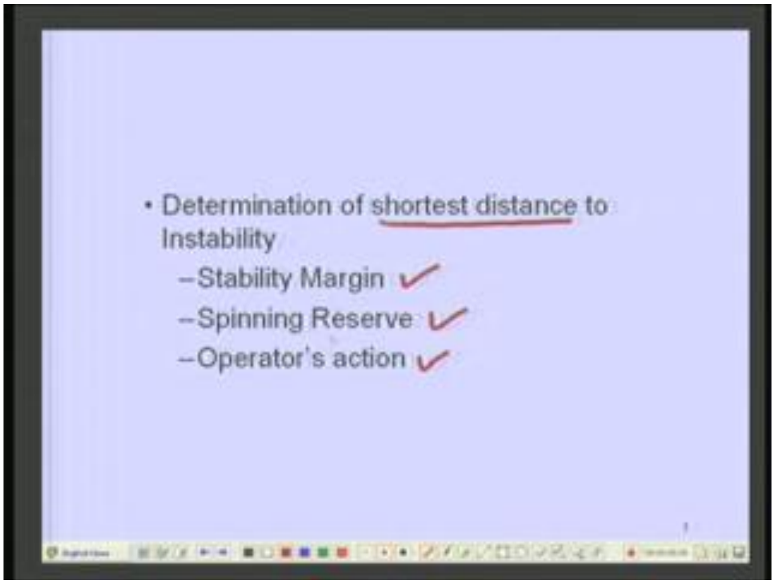

There is there are certain ah measures which can be adopted that you operate the system you maintain certain stability margin that is the shortest distance to stability that is you have to maintain the stability margin, you maintain certain spinning reserve and there should be trained operators to take appropriate action in time. So that instability problem does not occur.

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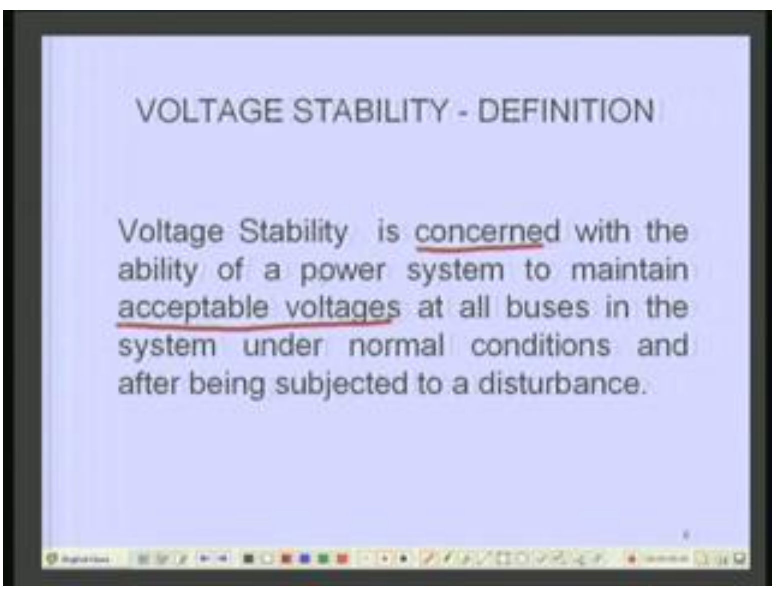

Now let us look into what is the basic definition of voltage stability, the voltage stability is concerned voltage stability is concerned with the ability of a power system to maintain acceptable voltages at all buses, in the system under normal conditions and after being subjected to disturbance this is very standard definition that is voltage stability is concerned with the ability of the power system to maintain acceptable voltages at all buses in the system under normal operating conditions and after being subjected to disturbance, suppose some sort of disturbance occurs like some generator dropping or some line dropping right or some fault occurring and fault being cleared and these are certain disturbances therefore under normal operating condition as well as after the disturbance has occurred in under both these conditions the power system should have the ability to maintain acceptable voltage level.

Then we say that this is the voltage stability of the system let me again read it voltage stability is concerned with the ability of the power system to maintain acceptable voltages at all buses in the system under normal conditions and after being subjected to disturbance.

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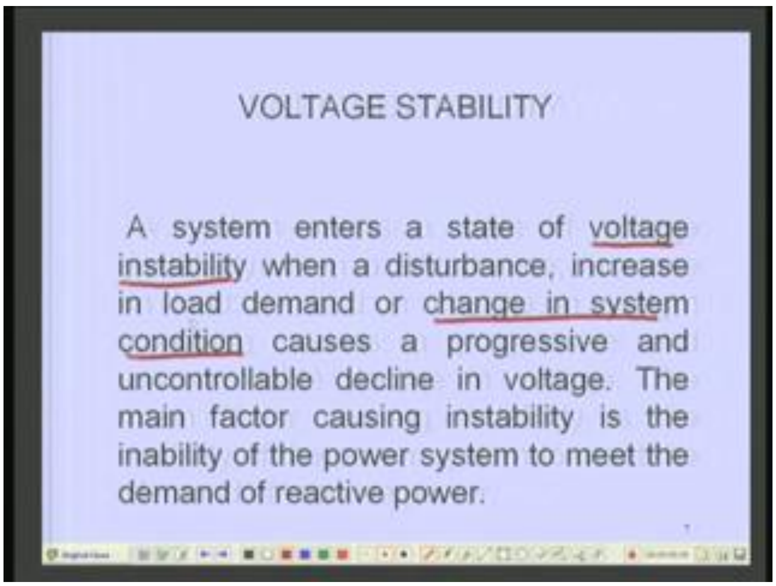

Now a system enters a stable a system enters a state of voltage instability a system enters a state of voltage instability when the disturbance the disturbance may be in the form of increase in load demand or change in system condition causes a progressive and uncontrollable decline of voltage that is that is suppose you have a system right and in that system suppose there is a there is a increase in load or there is some sort of system change there is a dropping line or some change in the system takes place, network topology right then in case suppose this disturbance will cause a progressive and uncontrollable decline of voltage then this type of situation is the voltage instability problem that is the voltage will decrease continuously and progressively and we are not in a position to control and and stop the decrease or hold the decrease.

The main factors causing instability the main factor causing instability is the inability of the power system to meet the demand of reactive power this is again very important point the crux of the whole problem is that the power system is not in a position to meet the reactive power demand that the any power system as we talk about the angle instability occurs because of because of unbalance between the generation and load.

Similarly, here if there is a there is a situation where the reactive power demanded from the network is not equal to the reactive power supplied by the network that is the power system is not in a position to meet the reactive power demand that is the main problem.

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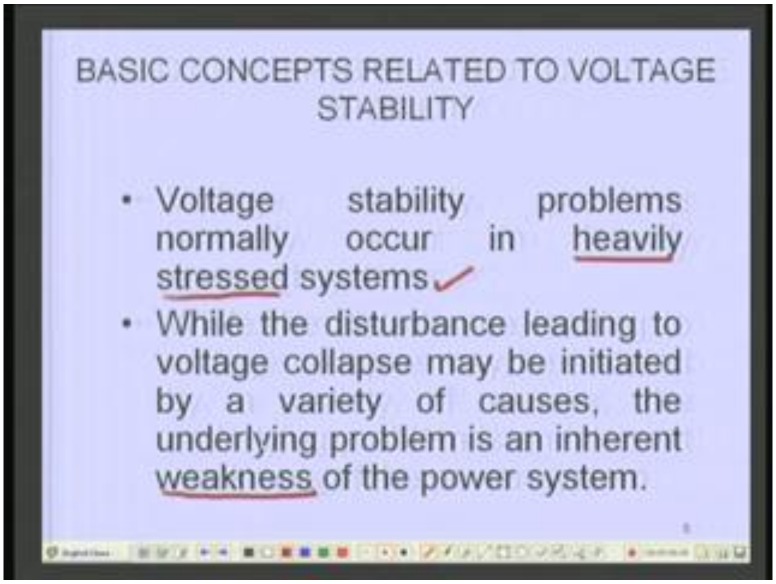

Now here let me again mention that under what circumstance this problem occurs because generally when a power system is operating right then in case a power system heavily stressed, heavily stressed in the sense that is heavily loaded right then there is a possibility of voltage instability occurring that is voltage stability problems normally occur in heavily stressed systems while the disturbance leading to voltage collapse voltage collapse may be initiated by a variety of causes the underlying problem is an inherent weakness of the power system as I told you actually the one is that the power system is not in a position to meet the reactive power demand.

Now reactive power demand meeting is one of the most requirement but at the same time suppose the system is heavily loaded right and now you increase the load beyond a certain point then system is not in a position to maintain the required reactive power and the voltage will decline and may continuously decline or continuously decrease may not be controllable. In fact actually in some systems the main cause of voltage instability used to be the long transmission lines right or if you have a well you know interconnected system and the system is loaded heavily and if you put additional load then the possibility of voltage collapse may occur. In fact these two terms voltage instability and voltage collapse are used interchangeably many voltage collapse phenomena have occurred during the last 3 decades and where the some sort of disturbance occurs and you will find actually that the voltage at most of the buses in the system will go below certain acceptable level, it is called the voltage collapse phenomena and it it occurs actually in a very in a very very different type of manner.

In the sense you start some you you trigger some sort of disturbance voltage drops and then it continue to drop we are not in a position to bring it back to the if we are in a position to control the system after disturbance and bring back the voltage to the required level then it becomes a voltage stability not the voltage instability problem right therefore to maintain the system voltage stable we have to have fast reactive power controls in the system. Now let me just sum up what are the basic factors which contributes to voltage collapse.

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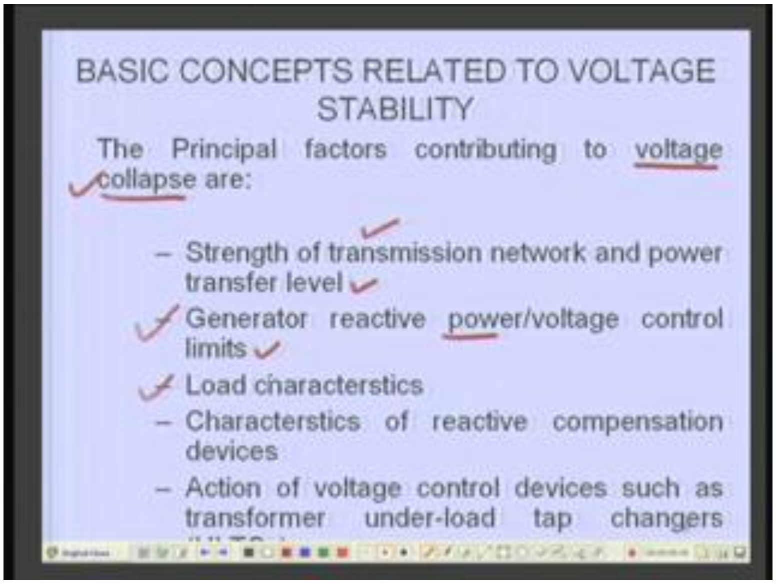

Basic factors which contribute to voltage collapse are the strength of transmission network and power transfer level. When I talk about the strength of the power power transmission network in the sense that when the transmission network is short and it has a it has a high power transfer capability right then we say that the transfer power transmission network is strong its inherent reactance is low and in if this power transmission network may be strong and it may be supplying huge amount of power. So that it may be operating near the limiting condition.

Therefore, one of the reason is the strength of the transmission network and the power transfer level at which you are operating then the next important component is the generator reactive power or voltage control limits a synchronous generator synchronous generator is to be always operated operated such that such that its a certain parameters are within the limits.

For example, the armature current should be within the limits the field current should be within the limits and therefore the condition or under what how the power generator is to be operated is always determined by the the operating chart, there is a operating chart of the generator right. So that in within that chart one has to always operate right. In case you are operating such that if you supplying the maximum reactive power output then there is no scope for further increase in the reactive power output.

I shall discuss this generator reactive power voltage control limits these aspects we will discuss in detail later on, then comes the load characteristics, most of the loads which we come across are voltage dependent that is the loads are voltage and frequency dependent and as the system voltage increases the real power and the reactive power absorbed by the load varies right and therefore how how the real and reactive power absorbed by the load varies it affects the voltage collapse phenomena right.

The load characteristic the the load characteristics sometime we have constant power loads so that the even the voltage is fluctuating the p and q does not change there may be constant impedance loads where the power consumed is proportional to V square right there may be constant current loads right. Therefore, we have normally the composite load where part of the load is constant impedance load, part of the load is constant power load, part of the load is constant current load and therefore the load characteristics affect the voltage collapse phenomena to a very large extent.

As I have already mentioned the characteristics of the reactive compensation devices I have told you the reactive compensating devices are basically synchronous condenser, the fixed capacitors, switch capacitors and continuously control devices like SVC STATCOM then other series devices like TCSC, triple SC and so on that the characteristic of these devices also affect a lot. Then, one of the very important devices which affect the voltage stability is the action of under load tap changer of the transformers.

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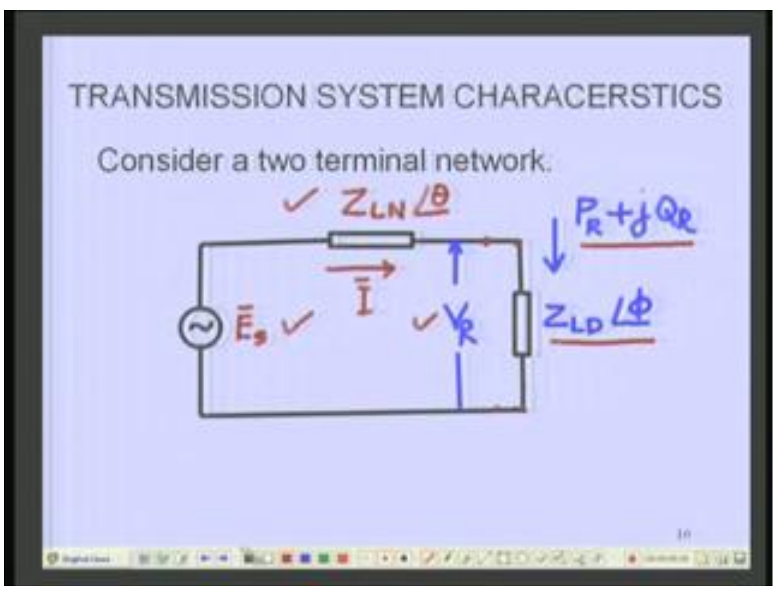

In any power system we have the under load tap changers these are called ULTC or sometimes we call the on load tap changers and the function these on load tap changer is to maintain the voltage at the load terminals and many a times it is seen depending upon the load characteristics, characteristic the the ULTC may help in improving the stability or sometimes it acts in a adverse way we will discuss this effect of ULTC on voltage collapse phenomena separately.

Now to understand some of the basic features of a certain concepts of voltage instability or voltage stability. We consider a very simple network let us say there is a voltage source Es connected to a load whose impedance is Z_{LD} angle phi and this load is supplied through a transmission line whose impedance is denoted as Z_{LN} angle theta, this is the impedance of the transmission line network or transmission line, this is the impedance of the source or you can even look actually that this is Thevenin equivalent of the network looking into the two terminals at the load is connected because in that case E_s becomes the Thevenin voltage and Z_{LN} becomes the Thevenin impedance.

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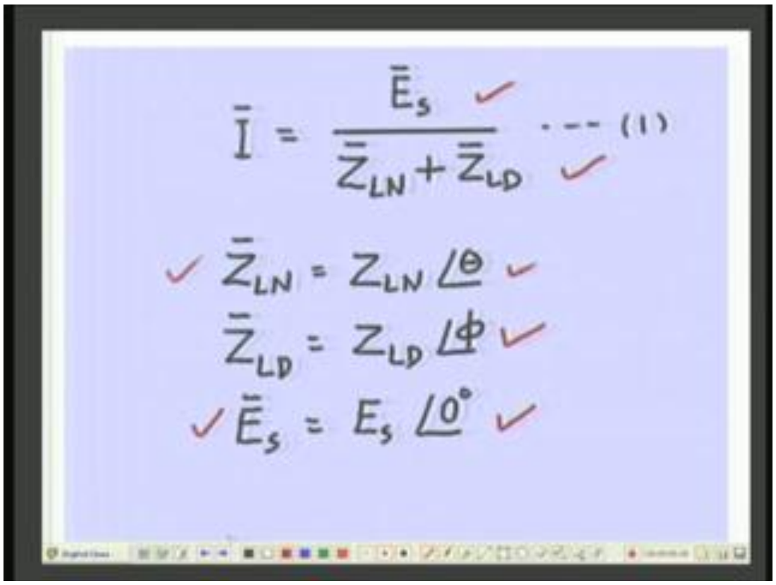

We will denote the power consumed or the complex power consumed by this load as P_R plus j times Q_R. Now, we will first derive the expression for the received voltage V_R in terms of the various parameters of the network. The current I which flows in this network we will, I will denote the current I I call this I bar right this current I bar is written as the voltage divided by some of the two impedances the line impedance plus the load impedance right where we denote the line impedance as Z_{LN} angle theta or in the complex form Z_{LN}, angle Z_{LN} bar similarly, the load impedance we will denote as Z_{LD} bar as Z_{LD} angle phi and this voltage E_s will be taken as reference that is E_s angle 0 degrees.

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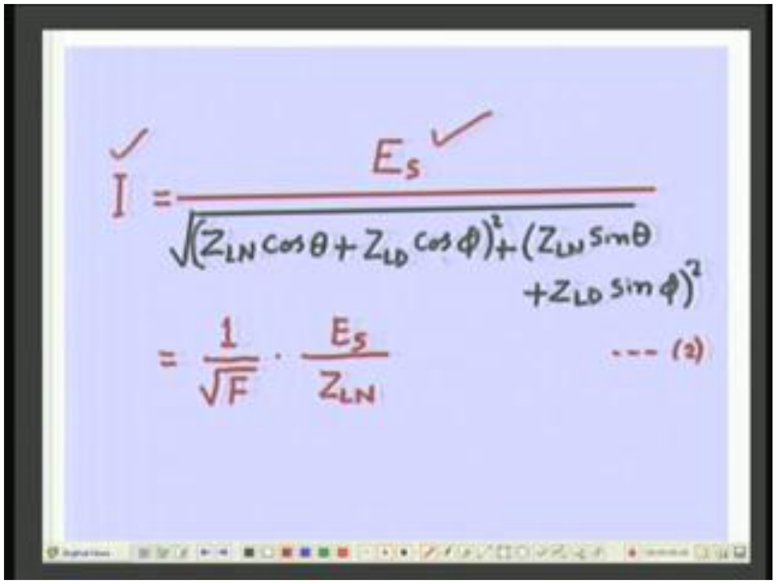

The expression for the magnitude of current, now here this is the expression for magnitude of current can be written in terms of the source voltage E_s and the parameters of the line and load impedance that is Z_{LN} cos phi plus Z_{LD} cos this is cos theta cos phi whole square plus Z_{LN} sin theta plus Z_{LD} sin phi whole square this can be derived by substituting the expression for Z_{LN}, Z_{LD} and then you can write down the expression for the magnitude of the current okay. Now this expression for this current can be written as one by square root of F into E_s by Z_{LN} where F is devind defined as F is 1 plus Z_{LD} by Z_{LN} whole square plus 2 times Z_{LD} by Z_{LN} cos of theta minus phi.

Now the voltage at the load end that is the receiving end voltage V_R the magnitude only can be written as the magnitude of the load impedance multiplied by magnitude of current, Z_{LD} Z_{LD} into I, you are writing only the magnitude. This can be written as one by square root of F Z_{LD} by Z_{LN} into E_s that is you substitute here the expression for I right you will get the expression for voltage at the load end in this form and the power received by the load the real power received by the load is V_R into I cos phi where, V_R is the voltage across the load I is the current and since I have consider actually the the phase angle of the load impedance as phi.

So that the received power is written as V_R into I into cos phi okay or the P_R can be written in terms of the other parameters like load impedance and this expression F this the this this F, E_s upon Z_{LN} whole square into cos phi, in fact to understand understand the behavior of the simple network what we are interested is we want to know that how the this two important parameters one is the voltage across the load and the power which is derived by the load drawn by the load right are are are affected by the impedance and other parameters of the network.

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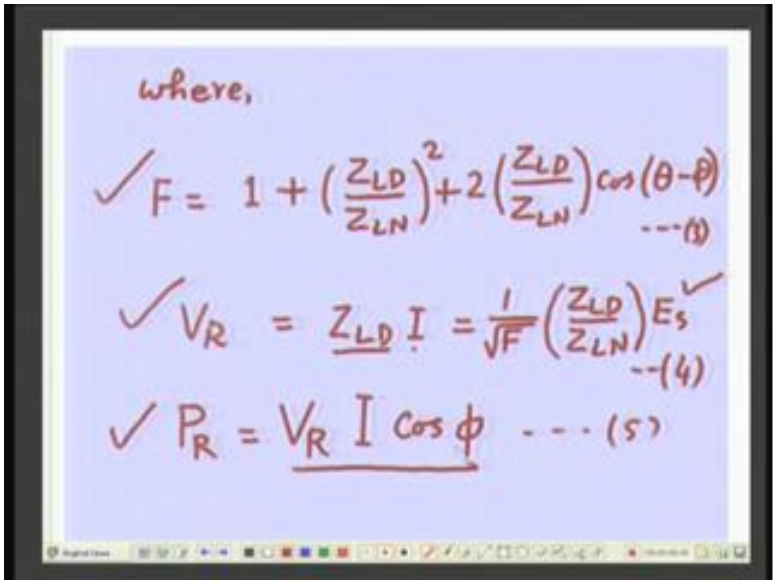

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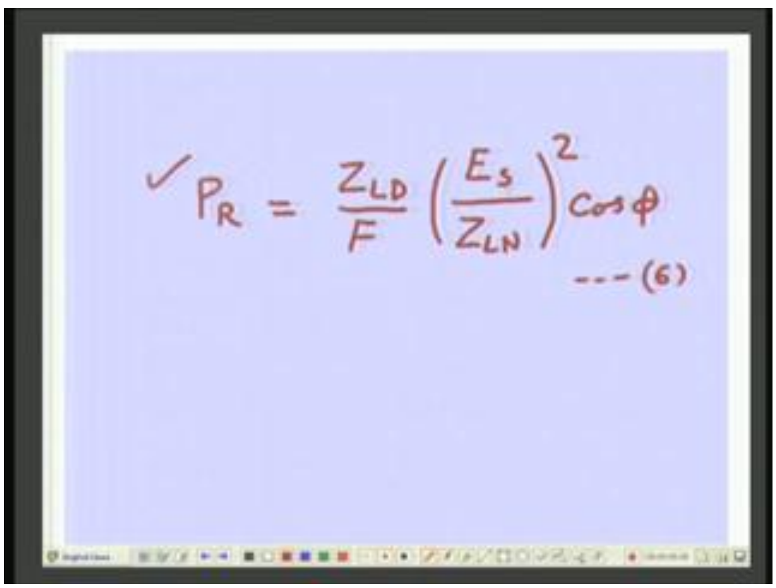

See after deriving the expression for receiving end voltage and the power received by the load, we plot the variation of the receiving end voltage and receiving end power in terms of a normalized impedance that is we we use actually this quantity Z_{LD} upon Z_{LN} on the x axis that is the normalized impedance and then plot the variation of the receiving end voltage V_R and we plot the variation of the receiving end power P_R and the current I.

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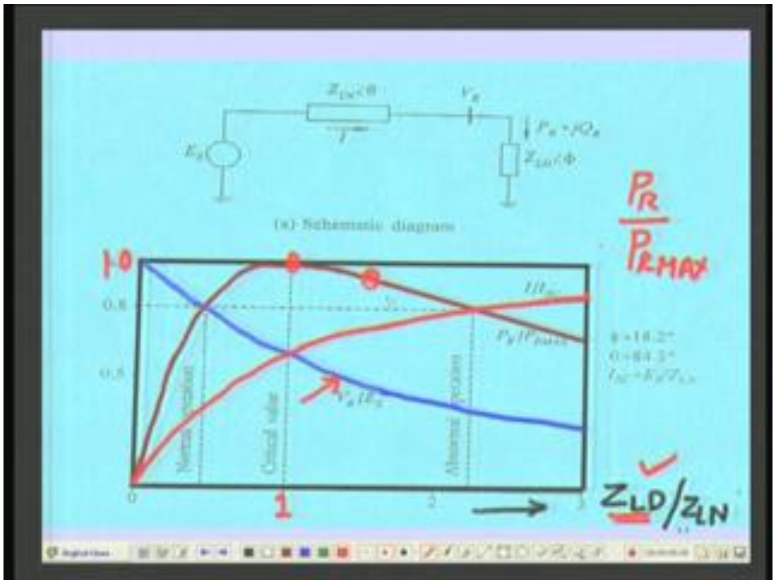

Now these three quantities that is current I and the power and this voltage they are again again again plotted as normalized quantities that is the receiving end voltage V_R, this graph shown, this graph shows, this blue graph shows the variation of receiving end voltage with the variation of Z_{LD} by Z_{LN} therefore this receiving end voltage is shown as V_R divided by E_s that is the what is plotted is the value of receiving end voltage in per unit considering the system voltage E_s as one per unit or the base quantity therefore you can easily see here that as the as the impedance Z_{LD} that is the impedance of the load increases increases the the receiving end voltage decreases continuously.

Now the receiving end power is concerned receiving end power is plotted as a ratio of the actual power P_R divided by P_{Rmax} that is the maximum power, what is plotted here is P_R divided by P_{Rmax} that is the maximum power and you can see here actually that this graph shows the variation of variation of this quantity P_R upon P_{Rmax} that is when this power received becomes maximum then this ratio is equal to 1 therefore this quantity is one here this is the maximum power reaches that is what we see here is that as the magnitude of this impedance Z_{LD} increases the receiving end power first increases at a fast rate and then attains a maximum value then it start decreasing right.

Now we can see here actually that this is the maximum power which is received by the load and for power to be received maximum load, maximum power the the ratio of Z_{LD} to Z_{LN} is 1 that is when this the magnitude of load impedance is equal to the magnitude of the source impedance right then the power transfer to the load becomes maximum, this is the maximum power transfer theorem also that is if you have actually a source whose whose internal impedance is equal to Z_{LN} and supplying power to a load whose impedance is Z_{LD} then the condition for maximum power transfer is that these two impedances should be equal in magnitude right.

Therefore this is what is happening when this ratio is equal to one the power transfer is maximum. Now generally the operating condition is on this region of this curve on this portion of the curve that the power increases when the load impedance is increased right. Now when we see that from this point onwards when we increase the load impedance the power decreases right. Therefore, now suppose when you come actually at any of these points let us see this point in case the load is offering a constant impedance load, if the impedance of the load is constant then this is also a stable operating point that is you can operate anywhere on this curve right in case the load is a stable load is a constant impedance load.

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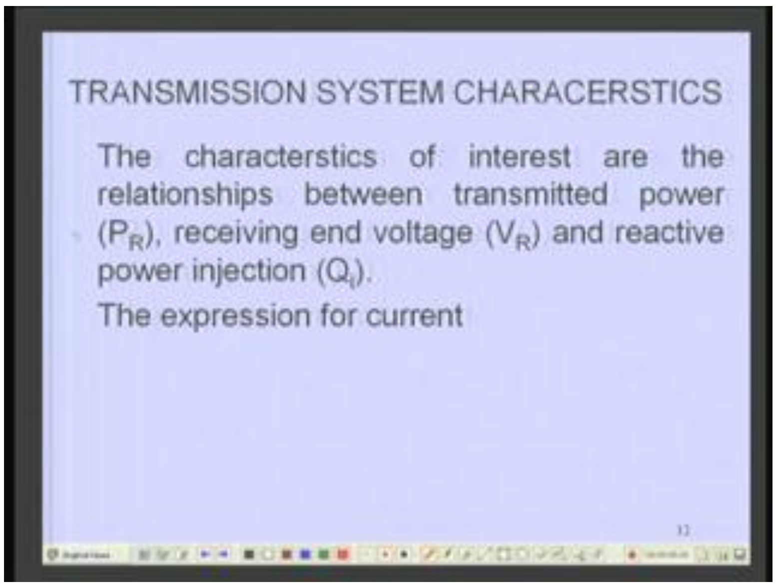

The another characteristic of interest generally is that we plot the P_R versus V_R that is we plot actually the receiving end voltage versus the real power rather than plotting the expression in terms of the load impedance, we plot the the receiving end power as if receiving end voltage as a function real power received by the load and how how actually this P_R and V_R are affected by the reactive power injection that is at the load point suppose we inject reactive power then how this reactive power is going to affect actually the variation of V_R with, the variation of variation of P_R with variation of V_R that is as you increase the value of P_R the voltage will vary.

In fact this graphs which you have plotted earlier they are plotted actually for considering considering the cos phi as .95 and the value of theta is such that tan theta is equal to 10 right the theta is the phase angle of the source impedance or the line impedance right and we know that that line impedance has a has a large phase angle therefore tan theta is 10.

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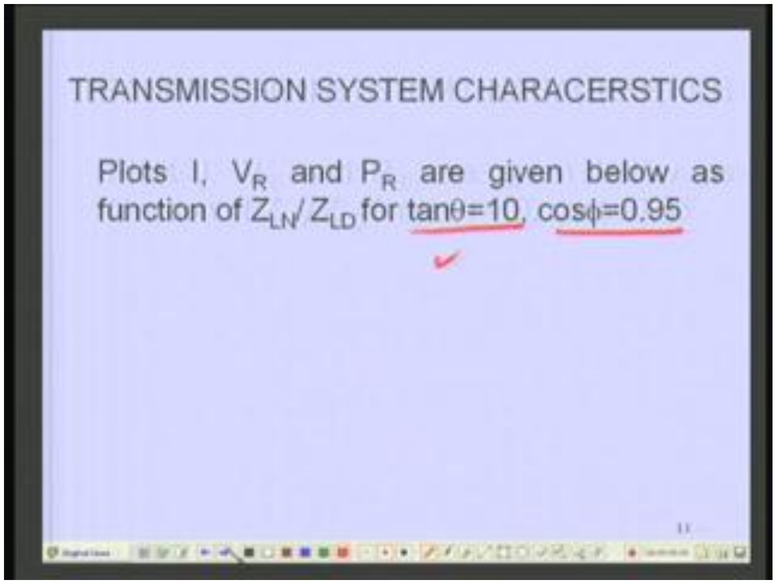

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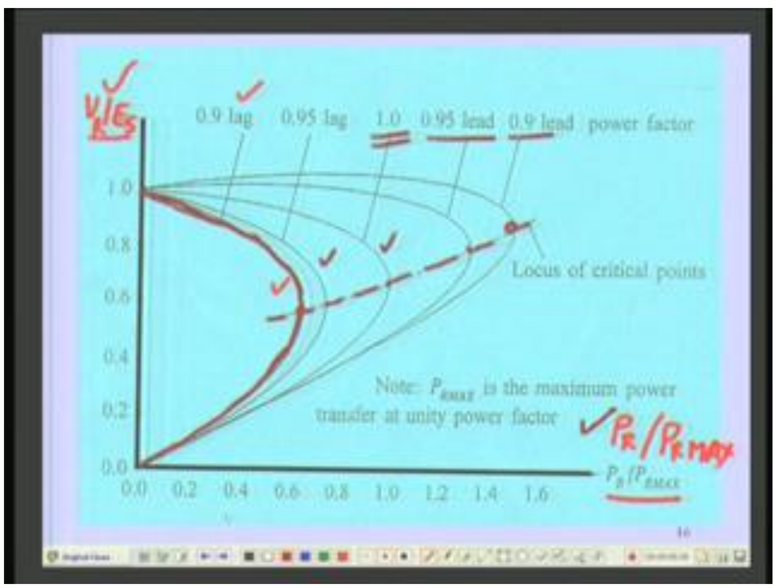

Now we show another very important actually form of characteristics where we plot the variation of receiving end voltage V_R as a function of P_R by P_{Rmax} that is earlier the the voltage power and current were plotted as a function of load impedance. Now we we plot here the normalized receiving end power that is P_R by P_{Rmax} this quantity is P_R divided by P_{Rmax} that is the maximum power. This is normalized power on this axis we put the normalized voltage V_R by V_R, E_s,V_R divided by E_s is a normalized receiving end voltage.

Now this graph is plotted for different power factors. Now here, if you can see here then this graph or this curve represents the variation of P_R and V_R there is a relationship between P_R and V_R for power factor equal to .9 lagging and I think let me make it more dark here. These graphs can be shown in the more 1 typical graph is plotted here for power factor equal to .9 lagging the graph looks like this, this is the graph I will show only one graph like this that is what we see here is that as this receiving end power increases, the receiving end voltage decreases and it comes to a point where the receiving end power increases and the receiving voltage also drops but if you if you try to you can say increase the power beyond this point you will find actually you will not be in a position to increase the power and the power will decrease and the voltage will decrease that is actually from this point to this point it becomes the unstable operating point, we cannot operate on this point.

Similarly, for different power factor this graph represents for .95 lagging this graphs represents the relationship between P_R and V_R for unity power factor. Then the graphs are plotted for leading power factor condition .95 and 9 lead therefore if you join these critical points which has the which is the maximum power which can be transmitted without without losing voltage, without occurring or without coming to the voltage instability problem right.

Now these points are when we join together these are given the name of locus of critical points right. Therefore for a simple power system looking at one particular bus that is you take a system and represent equivalent Thevenin network then we can always plot this type of ah graphs which are normally called actually the nose curves, they look like a nose therefore nose curves right and especially here this is the critical point right therefore, the operating point will always be away from this critical point.

Now suppose you have now a large interconnected system then for this large interconnected system how to draw similar type of graphs. Now to illustrate this phenomena what is done is that one has to perform load flow study for each and every operating condition therefore to illustrate actually for how we plot this type of graphs for a multi-machine system or for an interconnected network, a typical network considered is a 39 bus, 9 generator with 1synchronous condenser network. This is a very of course, this network is not very clearly visible but this network is given in both the reference books ah this is discussed actually in a by Prabha Kundur in chapter 14 taking this network that is 39 bus, 9 generator and 1 synchronous condenser. This network has also been discussed in this book on power system stability by Taylor right.

Now here to illustrate these voltage stability phenomena what is considered is that a portion of network is examined. Now a portion of network which is examined is I will just show you here it is a, it is a big network of having actually the 39 buses and some generators they are they are all generators and this is the synchronous condenser which is shown here right.

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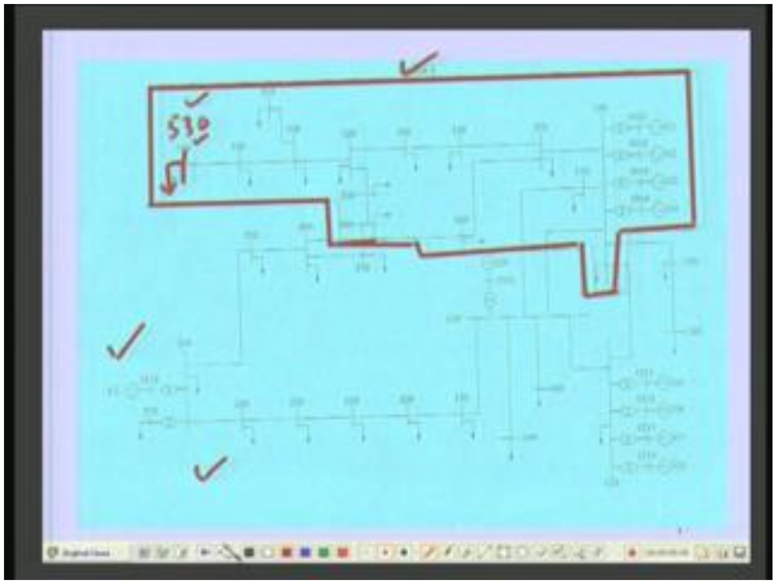

Now in this network ah in this network, this bus is the furthest bus and denoted as bus number 530 here in this network therefore to plot this the power output versus the versus the voltage characteristic what is done is that this is considered as one particular area in which the load is increased at all the load points slowly that is you increase small steps the loads at all the load points which are given here where about that all the buses which are enclosed in this area right and all the loads are increased in small steps. Then for each each of the loading condition a load flow program is run right and for running the load flow program what is done is that whatsoever is the increase in the load here the output from the generators are also increased in proportion to their capacity because we know that real balance is to be maintained if we increase the load the generator output has also to be increased right.

Therefore to analyze this this system the voltage at the bus number 530 is plotted for different loading conditions which are considered in this area. This is the area which is enclosed right and for this each of the loading condition load flow is run and when you run the load flow you will get the voltage at this bus 530 right.

Now this is the graph which is plotted for this particular network on this axis of this graph we are marking the total active power in megawatt in area one that is I have already specified that this this portion of the power system is considered as area one right therefore in this area the total total active power is varied right and for each active power loading right the load flow is carried out but when you have varied the active power the reactive power are also increased in the same ratio. So that the power factor is maintained at the same level that is at each bus the same power factor is maintained.

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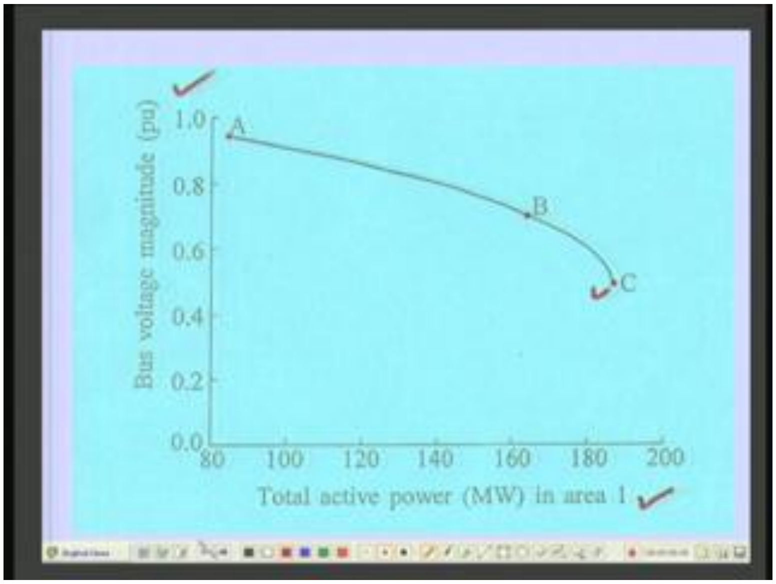

Now the graph which is plotted is here you can see that this is one point on the graph when the loading is something like 80 plus megawatt as you increase the load from 80 megawatt to 200 megawatt right what we see here is that voltage at this bus, the bus which is considered is the bus number 530 which is expressed in per unit this voltage drops it comes to point B, it comes to point C. At point C that is if the the total load in area one comes to the level of level of something like 190 megawatt.

We will find actually that the load flow will not converse it means actually, we have reached the critical operating condition and beyond that if you try to you can say load the system system will become unstable, voltage collapse will take place. This is the another very important characteristic which can be used to understand the voltage stability phenomena is the relationship between the voltage and the reactive power injected at a particular bus that gives actually the suppose I inject a reactive power right then how the voltage at that bus increases bus varies it may increase or decrease right therefore for the same system which we have studied that is 39 bus, 10 generator system here. You consider 10 machine system because 9 generators and 1 synchronous condenser that becomes the 10 machine system.

For this system one can plot the graphs relating relating the reactive power Q_i injected at a particular bus versus the voltage at that bus. Now this these graphs are generated for the for the different buses the for example bus number 530 which is the most critical bus in that area one of the of the 39 bus system on this axis we are marking the bus voltage in per unit and on this axis we are marking the reactive power Q_i in MVR right.

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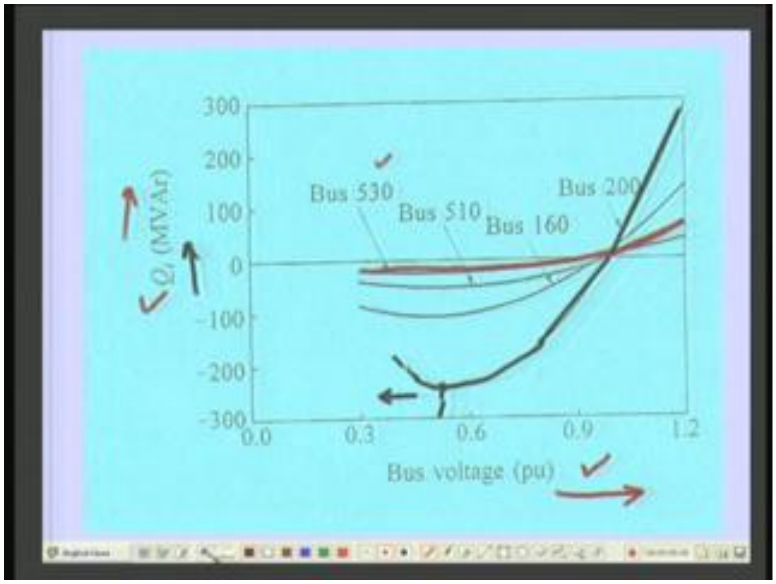

Now the voltage at this bus 530 is concerned, you can see here actually that you the variation of this voltage with the variation of reactive power which is injected is practically quite constant here and is the for different voltages you can see that this voltage is practically constant ah it is something like this. Now from this point onwards what happens is that the voltage start increasing right therefore you can see that from for something like this .6 and beyond if you if you increase the injected reactive power the voltage increases it means the if you take the ratio of ratio of voltage to delta V to delta q then this is a positive quantity if the voltage increases the reactive power increases.

Now if you see this one typical bus number 200 in the same area then the variation is very very sharp you can easily see that this is the type of variation like this. Now in this case at the point this is there is lowest point here in this on this graph that is if you are on this side of the graph, just wait if you are on the this side of the graph what we see here is that as the reactive power injected increases you can see the here actually the reactive power, the reactive power. We consider as a reactive power injected is considered as a positive and reactive power absorbed is considered as a negative right.

Therefore, if when the you can easily see that here when you increase the reactive power particularly you can just see here then the voltage decreases that because the graph is like this that is with the increase in the reactive power injected the voltage is dropped therefore this part of the graph is represents actually the unstable condition. Now from this lowest point onwards what we see that when you increase the reactive power which is injected at that particular bus the voltage also increases as a simple rule actually the rule is that at a particular bus when you injected the reactive power right the voltage when it increases that shows the stable condition, if the voltage decreases that shows that we are moving towards the voltage collapse situation.

The similar graphs are plotted actually for different loading condition. This is the graph which is plotted for the loading condition which is shown here A, because there are three different loading conditions which are identified in area one and for this loading condition the graphs are plotted for different buses in area one and these are the shows the variation it means you can easily see that except that most of the buses there exist actually a region where the voltage increases with the increase in the reactive power injection.

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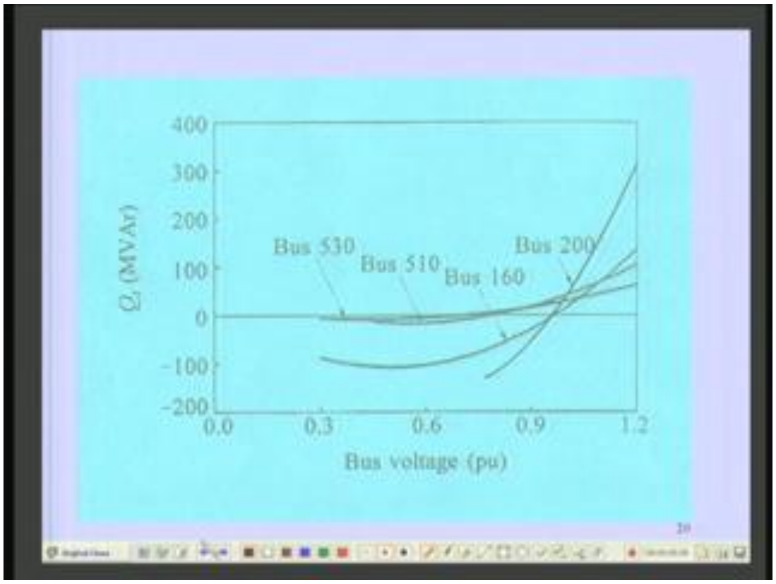

Now these graphs are plotted for the second operating point which is shown here. This is the operating point the heavy loading condition. For this loading condition, for this loading condition you consider that loading condition and see the sensitivity of the voltage at a particular bus by by injecting the reactive power right. These graphs show the variation of the uh voltage bus voltages of the buses 200, 160, 500,10 ,530 as different buses in the same area right. You can easily see here actually that yes we have some minimum point and from the lowest point there exist a region where the voltage is going to increase with the increase in the injected power.

Now these are the graphs which are plotted you can see here they are the graphs which are plotted for the third operating condition that is the critical point. At this critical point you can easily see here actually that can you see here that there is a large region or that the minimum point is occurring at at these points you can see this this is the minimum here this is the minimum point here while earlier the minimum points were occurring on this side see this. Suppose this is the this this minimum points are below .6.

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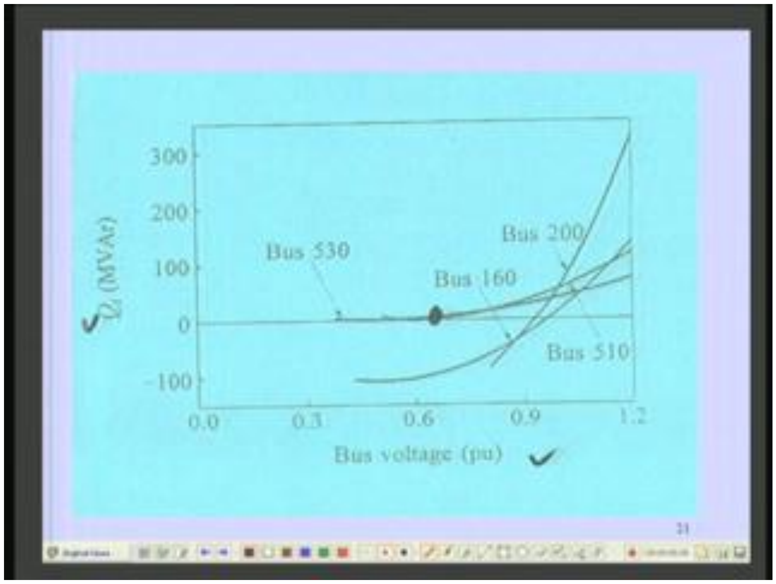

Similarly, you can see the minimum point here again on this side but if you see the minimum point here, they are occurring somewhere actually around .6, this minimum point is somewhere here. Therefore at this critical point you will find actually that the voltage sensitivity or actually the the relationship between the Q_i and the bus voltage there is a large portion where the system will become unstable.

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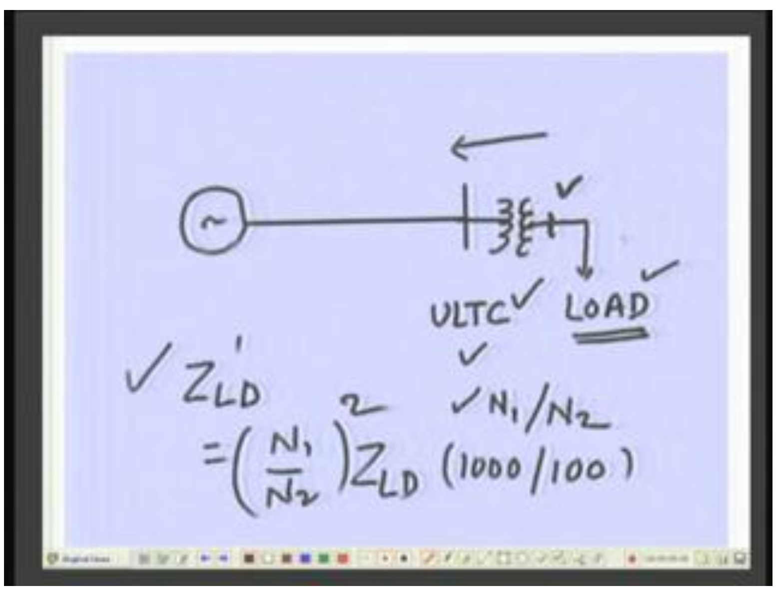

There is a certain portion actually we are operating beyond this particular point then yes, you will be in a position to operate stability but if you are operating below that particular voltage condition then you will find actually the voltage will voltage will decrease when you are injecting the reactive power. Now here I will actually like to mention one very important point what is the effect of on load tap changer on the h voltage stability phenomena. Now suppose the, we consider a system a very simple system, a system right, I am drawing only the one line diagram. Now if this system is supplying a load load and let us say it is a constant impedance load right and this is supplied through a transformer, here is a transformer connected, here is a here is a transformer which is connected okay that we show this transformer here and the load is connected here. At this point we are connecting the load and we are assuming here that the load is a constant impedance load. This transformer is provided with with under load tap changer right.

Now when you increase the load here, let us say they are increasing the load impedance, I am sorry not load impedance the you are actually reducing the load impedance to increase the power or other way we can say that you are increasing the load admittance. Now if the if the voltage drops here the action of the ULTC is, what is the action of this ULTC? It will try to maintain the voltage at this point and how does it maintain the voltage by changing the transformation ratio suppose the the transformation ratio is determined by this quantity N_1 by N_2, N_1 is the primary turns N_2 is the secondary turns.

Now to boost the voltage at on the secondary of this transformer the ULTC will work so as to reduce N_1. So when you reduce N_1then what will happen is that voltage at the other end will increase, the applied voltage is same right such that it is stepping down by a different ratio. Suppose you take a ratio let us say the N_1 is 1000 and $N_2$is say 100 right then input voltage is step down by a factor of 10. Now suppose instead of 1000 I make it say 950 therefore it will be step down by a factor of 9.5 it means this through this effect that the this transformer is trying to maintain the voltage but now this load impedance when it is reflected to primary side that is the load impedance when it is reflected to primary side what happens, the Z_{LD} prime will be equal to N_1 upon N_2 square into Z_{LD} that is when you refer actually the secondary impedance to the primary side, this is the impedance which is referred.

Therefore here what has happened is that Z_{LD} decreased so that power consumed was to increase the power Z_{LD} was decreased but now happens that system will see that the Z_{LD} is further decreased because N_1 has been decreased. Now when Z there therefore the impedance which is which is seen by the system system is now decreasing when the impedance decreases the voltage will further decrease when voltage further decreases ULTC will again try to increase the voltage by reducing this ratio. When it reduces this ratio again this Z_{LD} is going to be decreased.

Therefore, this becomes a cumulative phenomenon and therefore in this particular situation where you have a constant impedance load the operation of under load tap changer is is adversely affecting the voltage stability phenomena. Normally one should always think actually that yes the uh the ULTC should be in a position to stabilize the voltage right but here in this particular case incidentally when the you are operating operating on the other part of the curve that is we have the curve by the volt when you increase this decrease this impedance the power is increasing but after certain maximum value the power decreases and voltage decreases, power increases but voltage decreases right. If it is a constant impedance load and you do not have this ULTC the you will operate at a stable point but the movement you a ULTC which is trying to trying to boost the voltage at the load point. You will find that in a sequence that a ULTC tries to increase the voltage the impedance in further decreases and so on is it understood like that therefore ULTC's affect or the under load tap changer operation it plays a very significant role actually in the stability of the power system.

Now let me sum up what we have discussed today I have introduced the the basic concepts of voltage stability and I have also introduced that what is all what about we are going to discuss in the voltage stability problem. Then I have given the given the basic characteristic of a transmission line. We have plotted the variation of voltage current and power as a function of variation in load impedance then we generated the nose curves for a multi-machine system and also a technique how to generate the nose curves for the multi-machine system and I have introduced the basic concept of the voltage reactive power sensitivity.