Power System Analysis
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Lecture - 40
Power System Stability – VIII

Welcome to lesson 40 on Power System Analysis. This is the last lesson in the series on Power System Stability. As well as the last lecture for this course on power system analysis. In this lesson, we will be discussing about voltage stability of power systems.

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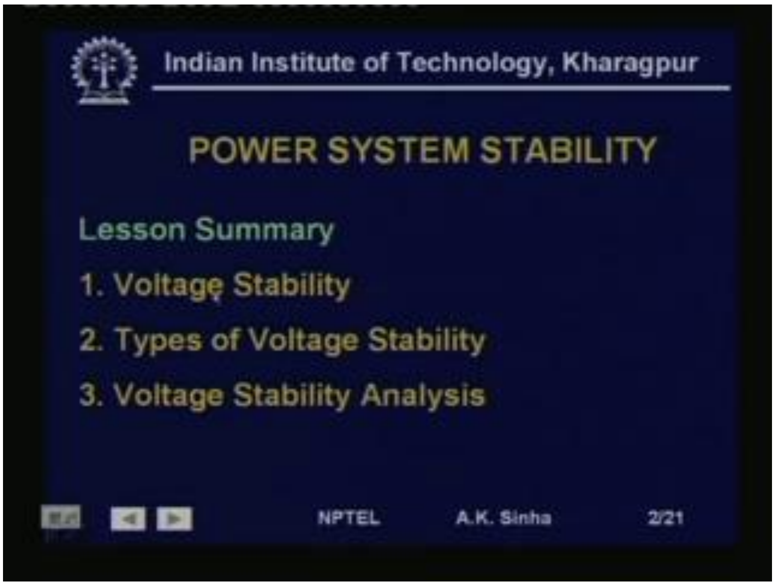

We will start with the, an introduction to voltage stability. That is we will discuss what how we define voltage stability, what voltage stability means. Then, we will talk about the different types of voltage stability. And after that we will discuss some aspects of voltage stability analysis. And we will see how we can try to contain instability in the system.

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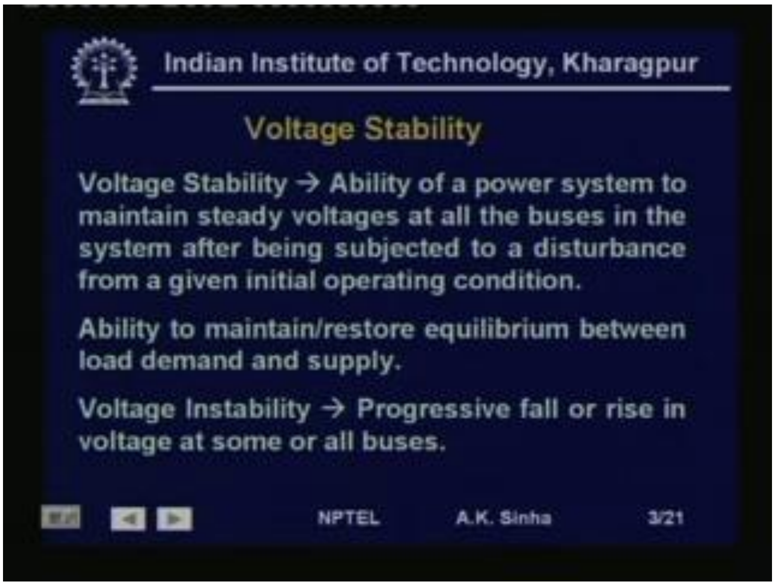

So, let us start with a voltage stability. What we really understand by this voltage stability is that... It is the ability of a power system to maintain steady voltages ability of a power system to maintain steady voltages at all the buses in the system, after being subjected to a disturbance from a given initial operating condition.

What this really means is, if a power system is operating in steady state. And some disturbance takes place. Then, whether the system is able to come back to another stable operating condition, where all the voltages are within the operating limits or not. So, it is disability of the system to come back to a stable operating condition, where the voltages at all the buses in the system comes back to the normal operating conditions that is within the limit.

Basically, what this means is that it is the ability to maintain or restore equilibrium between the load demand and the supply. That is, if we are able to maintain the equilibrium, that is we are able to provide or match the load demand with the supply. Then, the system will be stable; otherwise the system may become unstable.

Actually, what happens if this equilibrium is lost is that, there is going to be a progressive raise or fall in voltages at some or many of the buses. So, this is how we see voltage instability, that is when we are not able to match the system load demand with the supply. And when we are talking about matching the system load demand, we are talking about both real and reactive power demand.

So and in fact, the voltage stability problem stems more from the reactive power imbalance, than the real power imbalance. We have discussed the real power imbalance, when we discussed the rotor angle stability problem.

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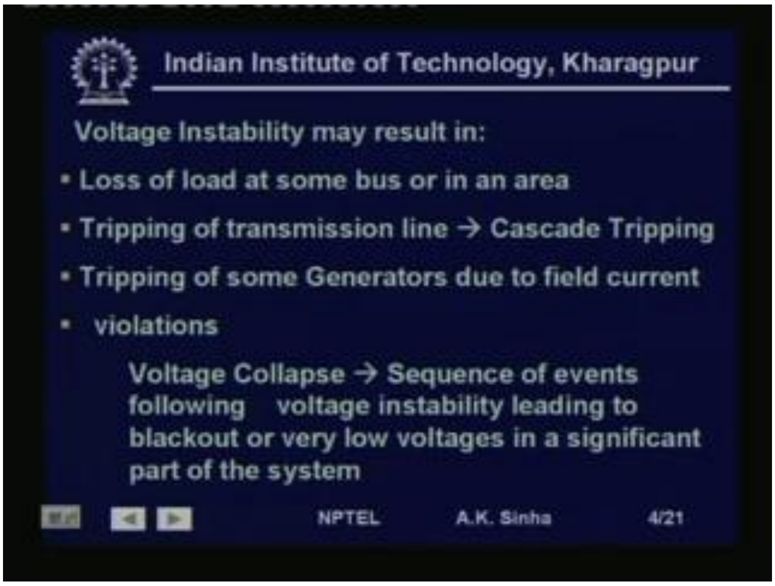

Now, what is going to happen, when there is going to be a voltage instability, that is the system is unable to match the reactive demand of the... That is, the supply side is unable to match the reactive demand of the system. What can happen under such situation is, that this will result in instability which will cause loss of load at some buses or in an area.

That is, if there is a progressive fall in the voltages at some buses or in an area. Then, under voltage relays in that area are going to trip the loads. So, we are going to lose some load at the some of the busses or in the area, where the voltage is progressively falling down. It can also lead to tripping of transmission lines. Mainly, because of heavy current flow, because of the large reactive power demand by the system loads, actually when we are having a large voltage drop across the transmission line. This really means, that the transmission line is carrying a large amount of reactive power, which results in large amount of current flow on the transmission line. So, the line can be tripped, because of over current relays acting in such a situation.

Now, once the one of the heavily loaded line gets tripped, the power which was flowing through this line. Now, gets rerouted through other lines. And these other lines will get overloaded and a similar situation will occur for them. And this leads to what we call cascade tripping. That is tripping of one line, then the another and then another and so on.

And this finally, results into a collapse of the system. That is a complete blackout in the system or at least in a part of the area. This can also lead to tripping of some generators due to field current violations. Now, as we said since voltage instability is basically stemming from the inability of the power system to supply the large reactive demand of the system.

What happens is this results in dropping voltage. And since, most of the generators have automatic voltage regulators with them. So, they will start acting and in trying to restore the terminal voltage of the generator. They, will increase the excitation current for the generators. And this will go on since the voltage keeps on falling. So, the increase in excitation voltage in trying to maintain the terminal voltage of the generator will also keep on going.

And this may result in over current in the excitation circuit, which will get tripped. Because of the over current relays in that part of the system, which will finally, result in tripping of the generator. So, some generators will get tripped due to high field current, which is caused by the progressive drop in voltage. We also come across one term, which is very much in use now a days. This term we call as voltage collapse, that is what we mean by voltage collapse.

See, as we have said that voltage instability can occur at some buses or may be in an area. What is this voltage collapse we are talking about. Well, this voltage collapse is seen as a sequence of events following voltage instability. That is, once a voltage instability occurs in any part of the system. This causes a sequence of events such as loss of load or tripping of transmission lines and etcetera.

So, sequence of events following voltage instability leading to blackout or very low voltages in a significant part of the system. So, if this sequence of events lead to a blackout or very low voltages in a significant part of the system. Then, we say voltage collapse has occurred in the system. That is, at least that part of the system has gone into a blackout situation. That is, there is no power in some part of the system.

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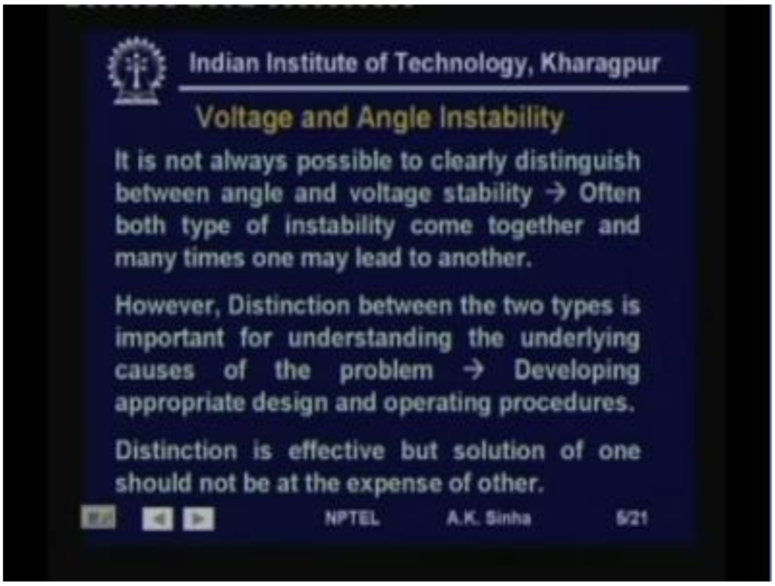

Now, let us see whether we can really differentiate this voltage instability problem from the rotor angle instability problem or not. That is are these two really distinct problems they are separate problems or are they a part of the same problem. When, we look at the stability of the system, basically both voltage stability, as well as rotor angle stability are basically a part of the stability of the system, because in both cases the system leads. That is, system leads into a situation, where some part of the system or major part of the system goes without power. That is, they become unstable. So, we say that it is not always possible to clearly distinguish between the angle and voltage instability. That is, it is not really very easy to say whether this has occurred. Because of voltage stability or this has occurred, because of angle stability.

In fact, in most of the cases we have both type of instability coming together. And many times basically what happens is one kind of instability leads to the another kind of instability. That is a voltage instability in one part of the system, which can cause tripping of transmission lines can lead to rotor angle instability of the system also.

So, we have, so it is not really very easy to distinguish these the two, though this distinction does help us very much. Because, the distinction between these two types is very helpful in understanding the underlying processes, the underlying causes which has created this instability. And if we can get to the causes of this instability, then we can certainly design and develop appropriate methods for arresting this instability of the system.

That is, we can design procedures and controls. So, that the instability is arrested and system is restored back to stable operating condition. Although the distinction is effective in terms of trying to understand, the causes as well as in trying to design the control actions for arresting instability for these two types of stability.

But, we should not think of the problem as isolated once. That is a voltage stability completely separate from the rotor angle stability, because many times as we have seen one leads to the other. Also if we are trying to design control actions we must take care of this aspect. That is, the solution for one should not be at the cost of the other.

That is, if we are trying to make or design control actions for voltage stability, which will be dealing mostly with the reactive power part. Then, we should not leave the rotor angle stability completely out of focus. Because, the tripping of lines, etcetera can lead to a rotor angle instability in many situations.

So, we must have a proper coordination to see. If one leads to another we have control actions to take care of that. Though, we can design control actions for both of them separately, these two needs to be coordinated for proper action on the system to arrest the stability. Whether, it starts with voltage instability or whether it starts with rotor angle instability.

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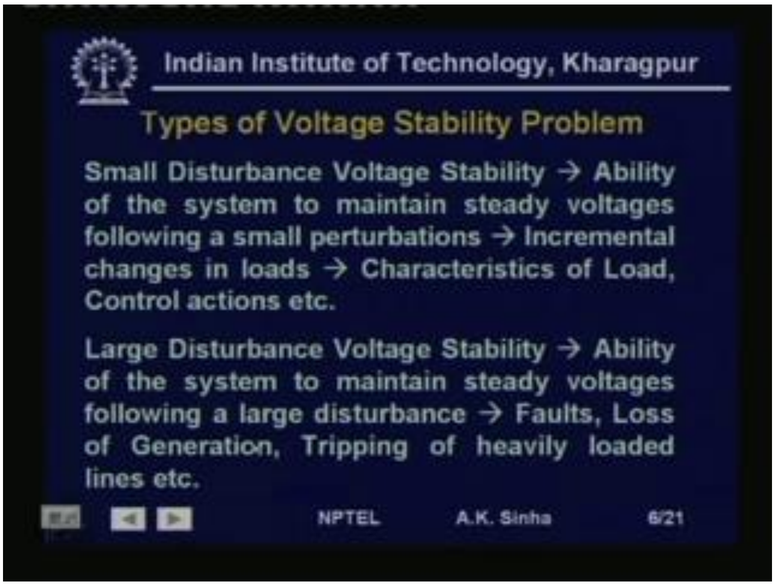

Now, let us look at if we have distinguished between these two. That is, if we are trying to look at the voltage stability problem. Then, we need to look at it from different angles. Whether, we are looking at small signal stability part. That is, small signal voltage stability part or whether we are talking about large signal voltage stability. That is, what is the quantum of disturbance, that is creating this problem.

So, if we are talking about small's disturbance voltage stability, which is basically stemming from gradual changes which occur in load. So, we say that small disturbance voltage stability is the ability of the system to maintain steady voltages followings small perturbations. That is, following small changes in the system or small disturbances if whatever they create the system after that becomes stable.

That is the voltages in the system gets maintained to the normal value. These, as we said small signals are basically coming in terms of small changes in load. Now, these disturbances which come, because of these incremental changes in load will depend on the characteristics of the load. Whether, it is a constant power load or it is a constant impedance load or it is a mixed kind of a load.

So, based on the characteristics the voltage is going to be different. And the fallen voltage is also going to be different. And this also will depend on what kind of control actions we are taking. Now, let us take the large disturbance voltage stability. Again this is the ability of the system to maintain steady voltages, ability of the system to maintain steady voltages following large disturbances.

Now, what is this large disturbance we are talking about. Well, we have already seen earlier. We talk of large disturbances; that is disturbances which create very large change in power flow pattern. So, these disturbances such as faults or tripping of transmission lines or tripping of generators. So, when these happen how the system is going to behave. That is, after the disturbance is the system able to come back to a steady operation with voltages, within the normal operating limits or not.

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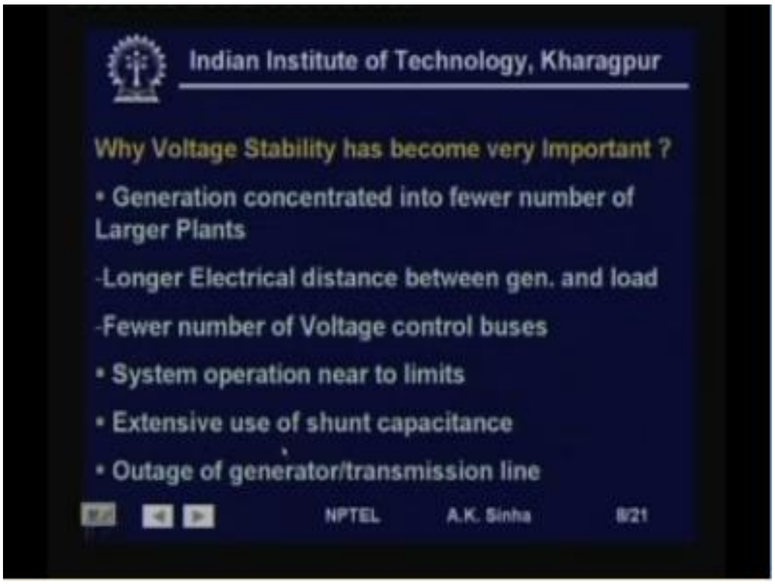

Next question comes, why are we talking about voltage stability so much these days? Well, the reason behind this is that now a days we are facing more blackouts, which are caused by voltage stability. That is many of the blackouts in recent times have been initiated by what we call as voltage instability in some part of the system.

What can be the reasons for this happening now? Whereas earlier as we have talked earlier was that a classical stability problem was the rotor angle stability problem. But, now we will also talk of voltage stability problem. The reason behind this is again mainly, because now we have very large generating stations, these large generating stations for environmental purposes. As well as for the purpose of fuel supply have to be sighted far away from the major cities, which are the major load centers. So, we have a large distance between the generating stations and the load. And this load that is this power is transferred from these generating stations to the load centre through the transmissions lines.

That is we have large power carrying high voltage transmission lines. Now, since the distance is large. So and the power being carried by these lines are also large. Therefore, we are going to get larger voltage drops in the transmission system. And that is why many times these long transmission lines have series compensation to compensate for the voltage drops, as well as to allow larger power flow on the transmission line.

This also results in another phenomena which we call that we because of this concentration of generators in a fewer number of larger plants. We have now fewer number of voltage controlled buses. That is, the generators as we know have automatic voltage regulators. So, they can control the voltage at their terminals by changing the excitation.

Now, since we have few large generating stations. So, we have very few buses where we have we this kind of a voltage control available. If we have large number of small generators dispersed all over the system. Then, we will have large number of voltage control buses. So, it will be easier to maintain voltage in all parts of the system, but unfortunately since we have these few large generating stations.

The situation is we have very few voltage control buses. And they are too remote from the load centers, where the voltage dips are going to take place. Another aspect which has created this problem more is the restructuring of power system. Now, because of the restructuring of the power systems, power systems are now running at in a much more competitive mode, which means in trying to be more competitive each equipment is now being used much more. That is, much more near to it is limits.

That is, the power system is now running in a much more stressed conditions and with most of the equipment running very near to the limits. That means, the margins available are not much. And therefore, large disturbances can create situations, where instability can occur. So, this is another reason, why the voltage instability is also coming into picture.

Because, the loads are now very high and the power which is flowing on these transmission lines are very near to their limits. And therefore, the voltage at the receiving end is also at a much lower value. And the margins available are very small and if the load increases further. Then, we may get into a situation that the system voltage is not possible to be sustained.

That is, there is a runaway situation where voltage keeps on reducing. And finally, it goes to 0. That means, that part of the system becomes a blackout. One more reason that has been there is the use of shunt capacitors. We have been using shunt capacitors extensively in trying to maintain the voltage under normal operating condition, as well as to reduce the maximum power demand and improve the power factor of the load.

So, most of the load points we have shunt capacitors available, but during heavy load conditions, when the voltages are low the reactive power supply by these capacitors drops. Because, the reactive power supplied by these capacitors will be proportional to V square Q is equal to V square into y c. Where, y c is the susceptance of the shunt capacitor.

So, it since the voltage at the receiving end or at the load point is low. So, the Q supplied by this capacitor becomes lower. And that is a 10 percent drop in voltage may result in almost a 20 percent drop in the reactive power supplied by the capacitor. That is, when we really need this reactive power support. The shunt capacitors are unable to deliver it, which creates further drop in voltages. And this is also one of the reasons for voltage instability in the system.

Outages of generators on heavily loaded transmission lines also lead to voltage instability, because an outage of a generator not only affects the real power output. But, also the reactive power output from the generator. In fact, for real power deficit that comes because of the outage of the generator. We always have spinning results available in the system.

But, there is no extra reactive power is available in the system. That means, the reactive power supply gets reduced and this causes further drop in the voltage in the at the receiving end of the system. That is, at the load points and this can again lead to voltage instability. Outage of heavily loaded transmission lines also creates the same problem. Because, if the line is heavily loaded. Then, the voltage drop because of the heavy current flowing through the line is going to reduce the receiving end voltage further and again this can lead to a runaway situation.

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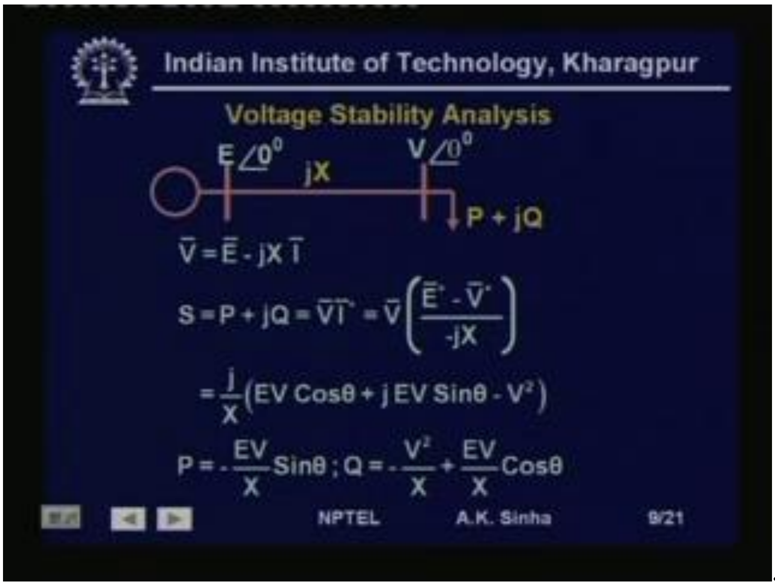

Now, let us try to see how this happens. And let us see, whether we can try and see what can be done in such a situation. So, let us start with a very simple system, we have a generator supplying a load. So, we have a generating bus, here we have taken the voltage at the generating bus as E angle 0 degrees. That is the reference this voltage, we can consider as the voltage behind the reactance of the machine.

And the reactance of the machine along with the reactance of the transmission line is put together here as j X. So, we have the reactance of the or the transfer reactance between the sending end and the receiving end as X, which includes the reactance of the generator as well as the transmission line. We have neglected the resistance of the transmission system.

The voltage at the receiving end is taken as V angle theta degrees. Where, this angle theta will depend on the load. The load on the system is P plus j Q, P is the real power load and Q is the reactive power load. Now, for this system we can write the voltage at the receiving end V is equal to E minus j X into I. That is, E minus the voltage drop in this line, where I is the current flowing in this line.

So, the voltage drop in this line is j X into I. So, the voltage at this point is this voltage minus the drop, that is what we have written here. Now, if we look at the power supplied to the load, this is P plus j Q which we can write as a complex power S. So, S is equal to P plus j Q and this is given by V I conjugate. Where, this bar on top is indicating that V and I both are phasar quantities.

So, V I conjugate is what we get as P plus j Q. And therefore, we can write this V into I conjugate we are writing as E conjugate minus V conjugate divided by minus j X. So, from here we can find that j X into I is equal to E minus V. And so j X conjugate I conjugate is equal to E conjugate minus V conjugate. And therefore, I conjugate is equal to E conjugate minus V conjugate divided by j X conjugate, which is equal to minus j X.

So, this is the term that we get for P plus j Q. That is the load complex load supplied at this end. This we can write in rectangular coordinate formulation or in polar coordinate formulation in trigonometric form as j by X into E V cos theta plus j E V sin theta minus V square. So, this is what we will get. Now, we separate the real and imaginary parts. Then, we will get P is equal to minus E V by X sin theta and Q is equal to minus V square by X plus E V by X cos theta.

This negative term that we are getting here is basically showing that this P and Q are load. That is, they are negative injections into the system. So, this is the real power and this is the reactive power that we have. Now, we can write this as Q minus V square by X is equal to E V by X cos theta and we can square both the equations.

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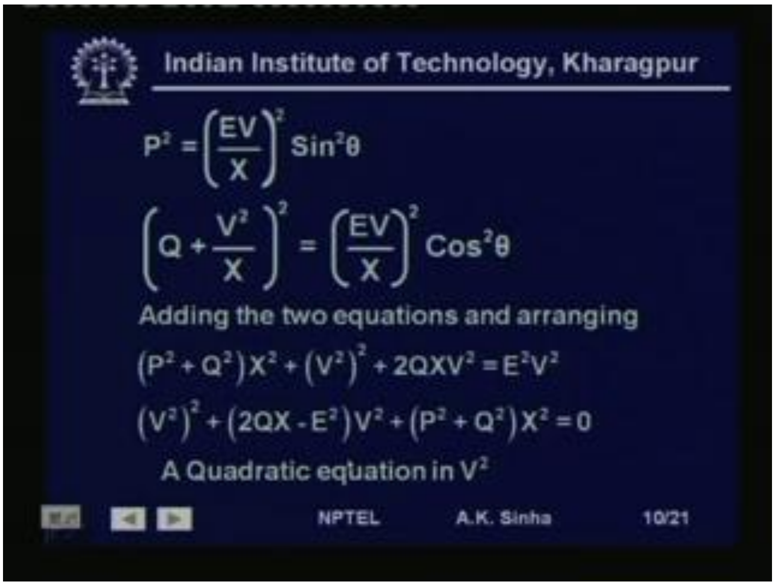

So, squaring both the equations we will get P square is equal to E V by X whole squared into sin square theta. Similarly, Q plus V square by X square of this is equal to E V by X square into cos square theta. If we add these two equations, then on this side we will get E V by X square into sin square theta plus cos square theta which is equal to 1. So, we will get P square plus Q plus V square by X whole square is equal to E V by X whole square.

Now, rearranging this equation we will get this as P square plus Q square into X square plus V square to square of that plus twice Q X into V square is equal to E square V square. Now, taking this term on the left hand side and arranging the equation in terms of V square. Then we will get V square square is equal to twice Q X minus E square into V square.

So, this is this term and this term taken together plus P square plus Q square into X square, this is this term is equal to 0. This as we see is a quadratic equation in V square. From solving this quadratic equation, we can get the relationship for V.

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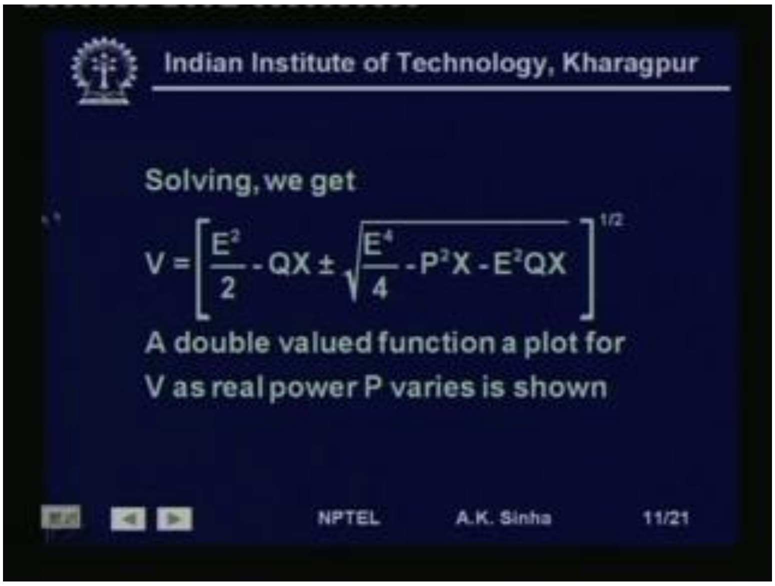

If we write that, then we have this V is equal to E square by 2 minus Q X plus minus square root of E to the power 4 by 4 minus P square X minus E square Q X this whole to the power half. That is square root of this whole term, because V square is equal to this term in the bracket. This is a double valued function, that is because of this plus and minus we will get two values of V for any value of P and Q.

So, if we say that the power factor of the load is constant. That is P by Q is equal to... That is cos theta is constant, then we have this relationship. That is for any value of P we will get two values of voltage, one with this plus sign, one with this minus sign. We can plot V as the real power P changes.

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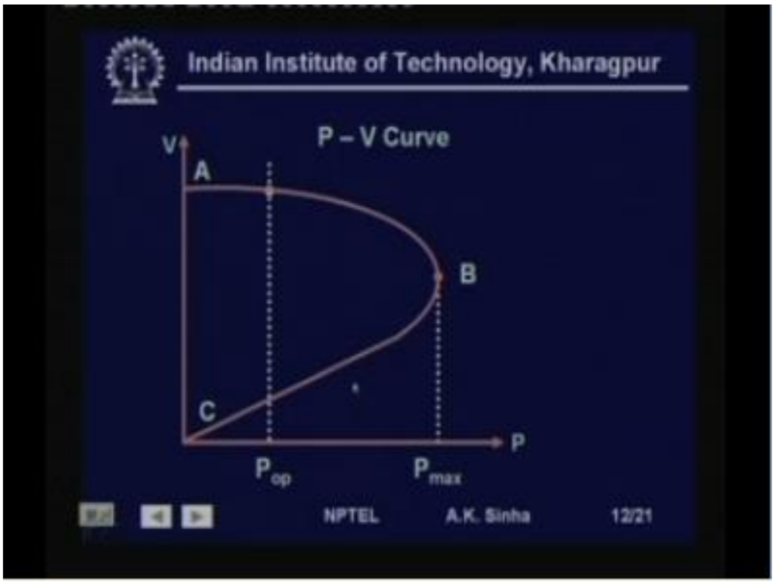

If we do that, then we will get what we call the P V curve for the load. So, this is the P V curve, this is also called the nose curve. Now, this P V curve tells us that for every operating point. That is, every value of P we have two points, two voltages which are available one here and another here.

Normally, the system is will work in this region only, because this is the stable region, whereas this region is a stable region. That is here if we increase the load a little we are going to get a decrease in voltage. And that is going to cause some increase in current. And that is what will feed this increased power.

Whereas, in this part of the curve. That is this B C part of the curve, if we increase the power. Then, the voltage also increases or if we reduce the power the voltage also reduces. And if that happens; that means, if we reduce the power a little bit, the voltage reduces. That will again further reduce the current; that means, it will reduce the power, again which will again reduce the voltage and so it will reduce the current and power.

So, this will be a runaway situation. And finally, system will go to 0 voltage with 0 current. That is the load will be thrown off, that is there is load will become 0. This is occurred for a constant impedance load. But, if we have a constant power load which is there in most of the cases. Then, this curve will have a further larger dip taking place.

Here, what we see is as we reach near this maximum point. The slope of the curve becomes larger and larger and at this point it is highest. The slope is very large at this point. And this point B is the maximum power of the load that we can have, this basically for a constant impedance load, when this is going to occur.

This is going to occur when the load impedance is a complex conjugate of the line impedance or the transfer impedance between the source and the receiving end. Normally, we will be working near this point. And that is a voltage which is very close to the low load voltage. That is regulation will be of a few percentage only.

But, if we keep on increasing this load, the regulation will keep on increasing. That means, the receiving end voltage will keep on dropping. And this process will be accelerated as we come closer to the maximum load. That is, possible that is what we call this point as a this voltage also has the critical voltage.

That is, voltage below this cannot be sustained by the load. After this voltage, that is if any drop takes place, then it is a runaway situation and the load is completely lost.

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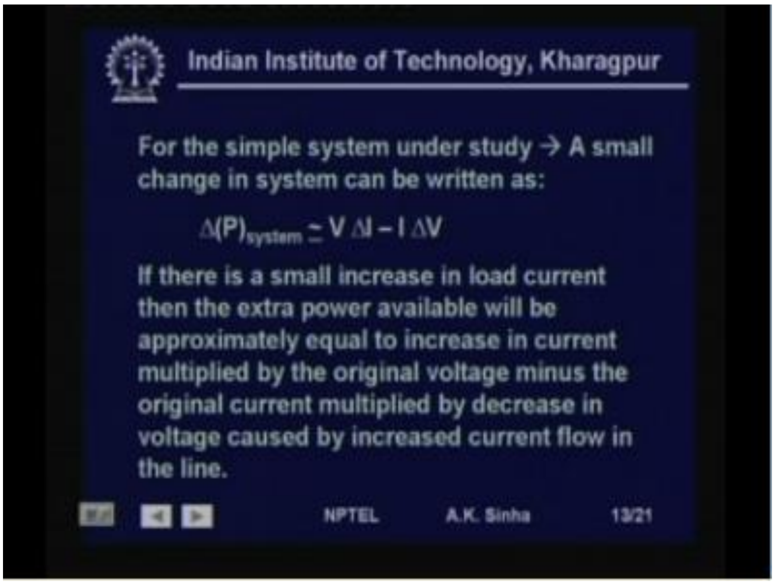

This can be explained also from another point of view. That is for this small system, that simple system under study. A small change in system can be written as, that is a small change in the real power for the system can be looked as V into delta I. That is the original voltage multiplied by the change in current minus the original current multiplied by the drop of voltage because of the increased current.

So, this is if there is a small increase in load current. Then, the extra power available will be approximately equal to the increase in current multiplied by the original voltage. That is, if the current changes by delta I, then extra power available will be V into delta I which will be there. But, the actually the power which is available is not going to be equal to this.

But, because of this change in current there is going to be drop in voltage. So, this will be minus the original current multiplied by the decreasing voltage caused by the increased current, because more current is flowing through the transfer reactance. So, there is going to be a voltage drop. And therefore, this term is coming into picture, this is the term this is the power which is subtracted from this power, because the voltage is not remaining constant. Because of this increase in current, the receiving end voltage drops because of the line drop increases. And therefore, we have the change in system power given by this relationship.

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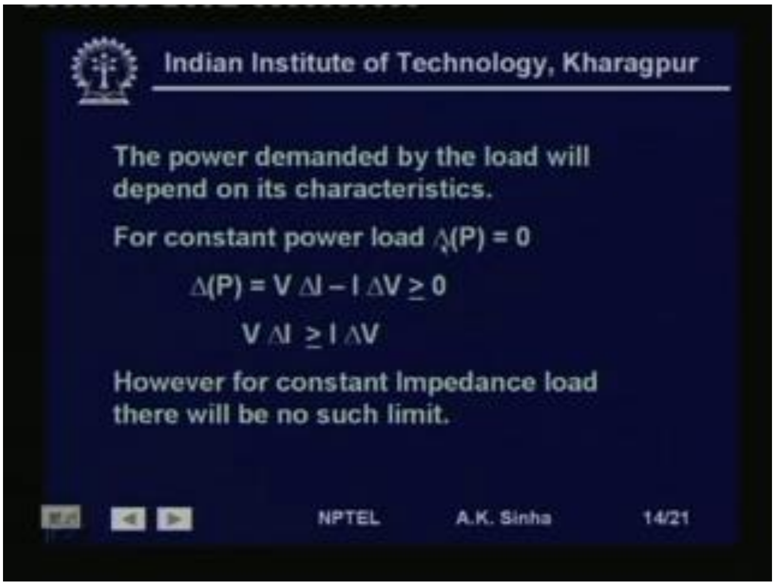

So, power demanded by the load generally depends on it is characteristics. For a constant power load delta P will be equal to 0. And therefore, we get delta P is equal to V delta I minus I delta V, which is the this relationship and this must be greater than or equal to 0.

That is, this is greater for a constant impedance load for a constant power load delta P is equal to 0. So, this term will be equal to 0 or this term must be greater than 0 ((Refer Time: 41:03)). That is, if this will be greater than 0 in this part A B. If this term becomes less than 0, then we are in this part V C and the system becomes unstable.

So, we have delta P is equal to V delta I minus I delta V must be greater than or equal to 0 for the system to be in stable operation, which simply means V delta I must be greater than I or greater than or equal to I delta V. This will be equal if the load characteristic is constant power load. And this will be greater if the load is a constant impedance kind of a load. So, this greater term comes in case of a constant impedance load.

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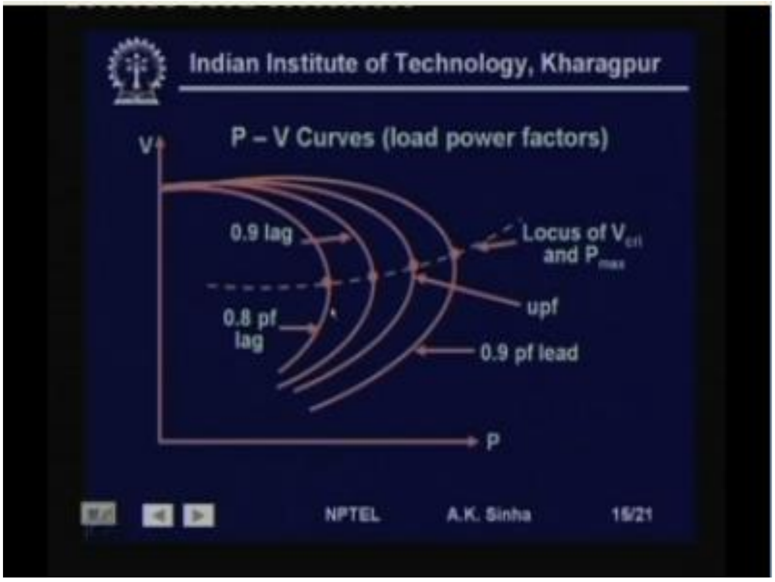

Here, we have shown the same nose curves for different power factor of the load constant impedance load, we are looking at which has different power factor. We see that if this is the curve for unity power factor. Then, 0.9 power factor lead we can go for much larger power or much larger loading or for the same operating point, we have much larger margin. But, if the power factor of the load is lagging, then our margin reduces considerably. So, this is what shows that if the load is demanding more reactive power. Then, the margin is smaller. That is, we are going to get instability much at a much lower real power demand.

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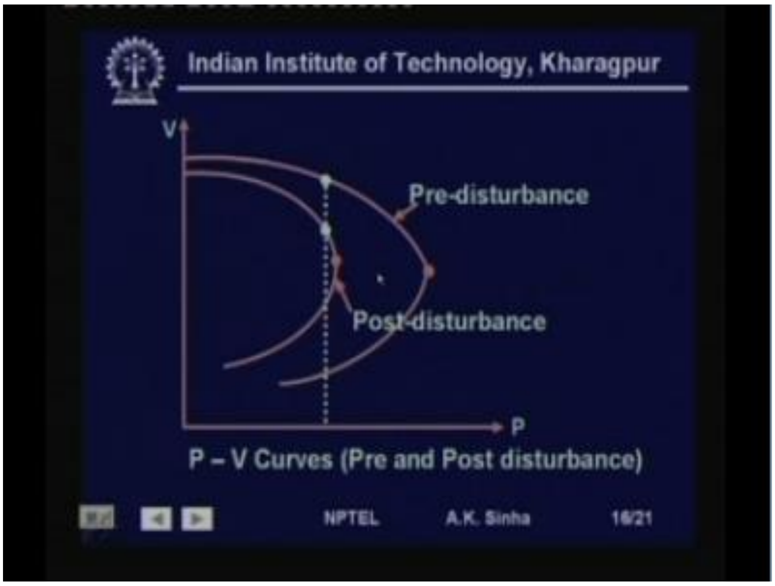

Now, the same thing can also occur, when a disturbance takes place or a contingency takes place. That is, if a transmission line was carrying power and it is tripped. Then, initial P V curve is like this. But, after the tripping of the transmission line, the voltage is going to go down for the simple reason, that the same amount of power is now being carried by other lines. So, the voltage drops on those lines are going to increase.

So, the receiving end voltage is going to go down. And the P V curve well it looks something like this. That is, from this pre disturbance condition we come down to this post disturbance condition. And here, what we see if we were operating at this point, then after the disturbance we are operating at this point, which means our margin is very, very small here.

In fact if we would have been working a little lower on this curve, then this disturbance would have meant a voltage instability in the system or at least at that particular bus.

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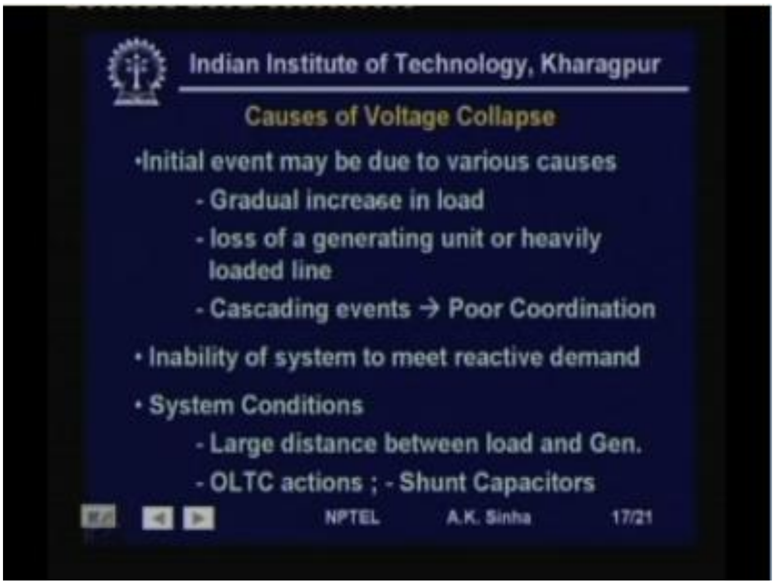

Now, let us see what are the causes of this voltage instability and voltage collapse. Well, as we have seen voltage collapse is basically a sequence of events. So, initial event may be due to various causes. What are these various causes? Gradual increase in load ((Refer Time: 44:51)). As we have seen here that, if we keep on increasing this load beyond this point we will have instability coming.

So, gradual increase in load, loss of a generating unit or heavily loaded line ((Refer Time: 45:08)). As we have seen, because after the disturbance the P V curves, they shift like this. And this reduces our stability margin. And therefore, this can lead to instability, if we are working around this region. That is, beyond this maximum P max point under the post contingency or the post disturbance condition.

Loss of generating unit, this mainly also as we have seen results in loss of reactive power supply. And therefore, the voltage drop is somewhat high. Cascading events, that is a tripping of a line as we said will overload another line. Because, the another lines, because the same power will now have to be transmitted through the other lines.

That is, these other lines which were already carrying some power will have to now also share the power which were slowing on the line which got tripped. And therefore, there is going to be further drop in voltages. Now, we can take control actions to restore the system. But, if the control actions are not properly taken, then we may take actions which will further aggravate the situation.

Like, we know that the voltage has dropped. And in trying to restore voltage, if we try to use the on load tap changing transformers. That is, we try to raise the voltage by using the tap on the transformer. Then, what is going to happen is that the load voltage will get restored to some extent,. And because of this restoration of the lower voltage, the load is also going to increase.

So, load demand will increase which will mean further increase in the reactive power demand, and thereby reducing the voltage further. And this kind of a situation can lead to a runaway condition, where the system looses stability or the load will be lost. So, a poor coordination of control events can lead to further cascading events. Other reasons can be inability of the system to meet the reactive demand.

That is, if a generator goes out which was supplying large amount of reactive power and there are not many reactive sources available in the system, which have margins. That is most of the generators are already working at their reactive power limits. Then, in such a situation again we can have a voltage gradual decrease in voltage, which will keep on going and we will lose stability.

As we have seen system conditions. That is, large distance between load and generation can create this. Because, larger drops in heavily loaded transmission lines. OLTC actions, as we have seen that on load tap changing transformers can create or aggravate the situation further.

Use of shunt capacitors can also as we have seen, can create problems, because the reactive power supplied by the capacitors reduces, when the voltage reduces. And thereby the capacitors cannot supply the reactive power, when it is most needed. That is under low voltage conditions.

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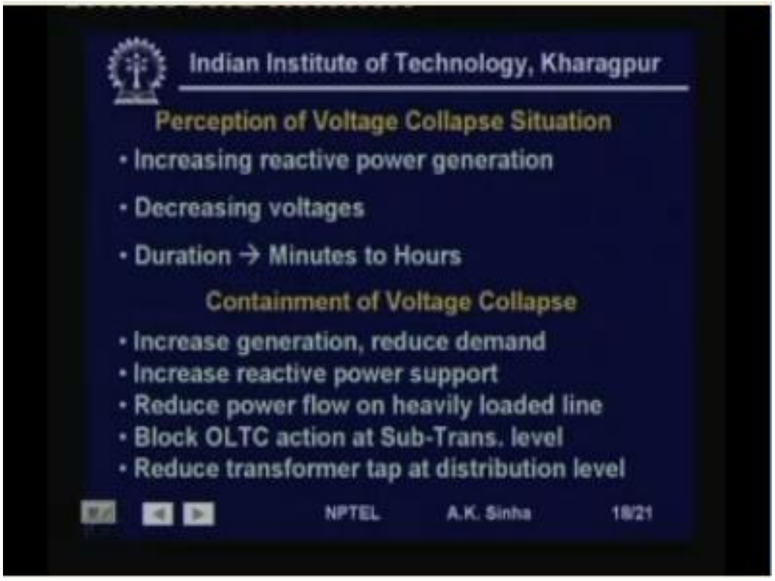

How one can understand that a voltage collapse is taking place. How do we perceive that a voltage collapse situation is coming? Well, an operator can see that the reactive power generation is increasing in the system. That is, all generators have increased their reactive power supply, which means basically that the reactive power demand in the system is increasing. And this is being supplied by the generators.

The another aspect which the operator sees is in some part of the system, the voltages are decreasing to abnormally low levels. That is, they are going below the normal limits. The duration of this gradual changes, that is increase in reactive power generation. Till hitting the limits or decrease in voltage, which keeps on going can be a few seconds to few minutes. And may be sometimes even it takes hours, there is a very gradual change in voltage which keeps taking place.

And therefore, manier times we say that, if we really want to analyze the voltage stability conditions. Then, we must do a long term stability analysis. That means, we must take into account all the control actions, like OLTC, like generator reactive power, like any other reactive sources. Even, the load characteristics like the characteristics of thermally controlled load. That is, basically the heating load or the cooling load, which are controlled by thermostats, they have very large time constants.

So, these loads will also change. So, these slow acting loads also their characteristics must be modeled. Of course, fast acting loads as well as controls must be modeled. Because, these will act initially and we will get into a situation, where in the very beginning the voltage collapse may be averted. If that does not happen, then slowly these other load characteristics, as well as other controls will start acting.

And we will have to see how the system behaves and what control actions we need to take. Now, how do we contain the voltage collapse situation. Well, increase the generation reduce the demand that, so as to match the supply and demand. Basically, this means some load shedding to improve the voltage in the system. And increase reactive power generation from various sources.

That is, increase the reactive power support. Reduce power flow on heavily loaded lines by trying to route it through other lines. Of course, this is not very simple, but now it is the flexible AC transmission system devices. That is the fax devices, this is possible to do and people are looking at controls using these fax devices.

Block OLTC action at sub transmission levels, that is we are saying that we as we discussed just a little earlier. That, we need to block the OLTC, that is On Line Tap Changing transformer action. When, voltage collapse situation is being perceived, because as we have seen in trying to restore the voltage if taps are raised, this in effect increases the load demand. And thereby further drop in the voltage in the line.

And that means, further decline in the voltage at the receiving end, causing a runaway situation. We should reduce transformer taps at distribution levels. In fact, sometimes it is advisable to reduce the voltage at the load ends. So, that it reduces the load demand, that is both the real and reactive power load demand. And thereby, the loading on the transmission line is reduced to some extent.

This kind of an action many times is called as a brownout situation. That is, reduction in voltage is going to reduce the load. And that restores the voltage drop on the line to a lower value, because now the line loading has reduced. So, this is not a blackout, but since the voltage has got reduced.

So, if you have incandescent bulbs, they will not be glowing at their full they will be glowing at a that is providing much less illumination. And that is why we call that situation as a brownout situation. So, we sometimes take help of brownouts to avert blackouts in the system.

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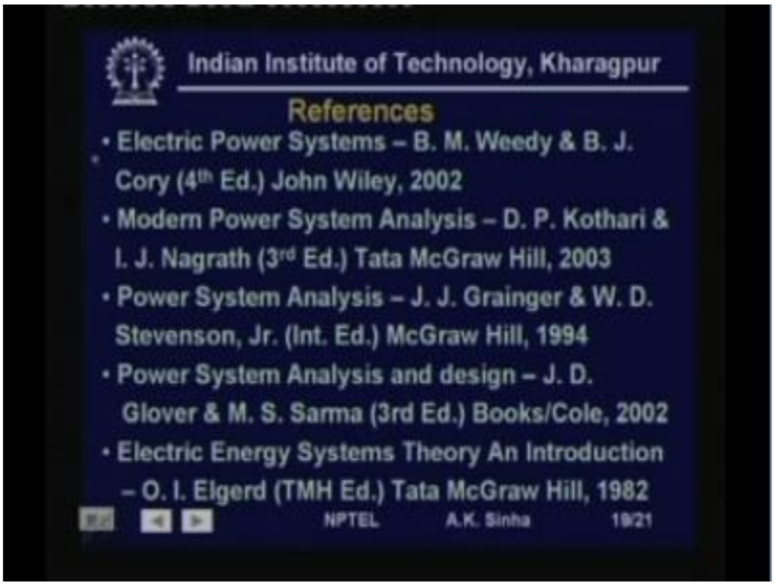

Well, this is all that we wanted to discuss about voltage stability there are many other things. That can be discussed, but it is a very complex problem. As we have seen just for a very simple system, the situation that we get is a quite a complex situation. So, if we talk about the other controls and all that the analysis is very, very complex. So, this is all we are going to do instability, as well as in this course on power system analysis.

Now, I will just give you some of the references, that we used mostly the text books that we use for this course they are. Electric Power Systems by B.M. Weedy and B. J. Cory 4th edition, published by John Wiley two in 2002 that is the 4th edition. Modern Power System Analysis by D.P. Kothari and I. J. Nagrath 3rd edition. This is published by Tata McGraw Hill 2003.

Power System Analysis by J. J. Grainger and W. D. Stevenson junior, this is a international edition published by McGraw Hill in 1994. Power System Analysis and Design by J. D. Glover and M. S. Sharma 3rd edition, this published by Books and Cole 2002. Electric Energy Systems Theory an Introduction by Olle. I. Elgerd, it is a Tata McGraw Hill edition and published in 1982.

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Power System Analysis by A. R. Bergen and V. Vittal 2nd edition published by Prentice Hall published in 2002. Advanced Power System Analysis and Dynamics by L. P. Singh 3rd edition published by New Age 1996. Power System Analysis by H. Saadat 3rd reprint Tata McGraw Hill published in 2003.

Power System Dynamics and Stability by P.W. Sauer and M. A. Pai, this is a low price edition it is available in low price edition by Pearson Education Asia published in 2002. So, these are some of the text books that we followed, of course you will get most of the things that we discussed in majority of these text books. What I would say is, I would very much appreciate your comments about all these lessons, So, that we can improve these lessons finally.

Thank you very much for listening to this course.

Thank you.