Power System Dynamics And Control
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Lecture No. # 45
Stability Improvement (Large Disturbance Stability)

In this last lecture of this course, we will study the stability improvement of a power system in particular, we will focus on the possible instability which occurs in case of large disturbances, that is the relative angular instability which occurs due to large disturbances which causes loss of synchronism between synchronous machines.

So, when I say improving stability we shall look at measures in operation planning or design, which can actually allow us to operate the system more securely, that is for credible disturbances one can you know the system is stable for credible large disturbances. So, today's lecture is on stability improvement for large disturbance stability.

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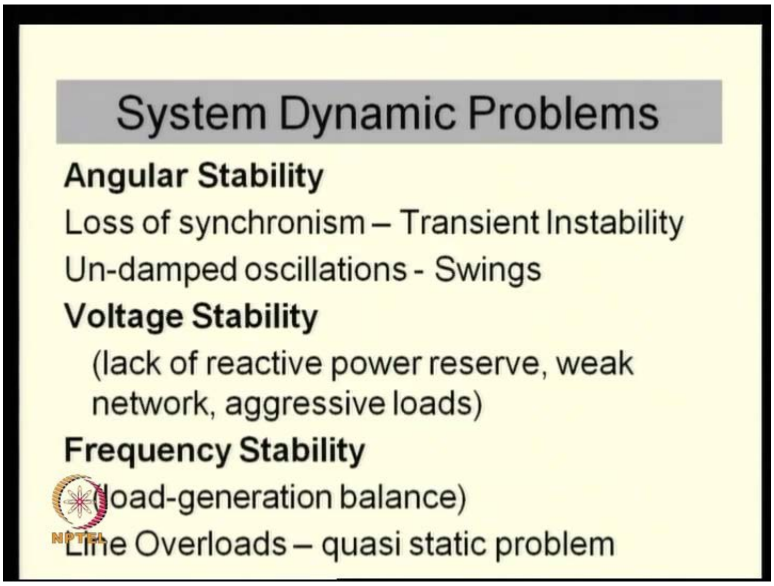

Now, as you know just to keep matters in perspective, angular instability is essentially consists of two phenomena loss of synchronism which is basically a large disturbance phenomena it is also called transient instability, we also saw in the last lecture that angular instability can also manifest in terms of small disturbances. And that is due to un damped oscillations or power swings, and the power swings could be you know the damping of power swings could be improved by making changes in controller; controllers are augmenting or having auxiliary controllers for controllable elements in a power in the power system like the excitation system in a generator or HPDC power flow control, we can actually ensure that these swings are actually stable.

We also saw the phenomenon of voltage stability. in which we could have a voltage collapse at certain buses due to lack of reactive power reserve because of for example, generators hitting the field current limits a weak network and loads which try to draw the same amount of power in spite of prevalent low voltage condition. So, and combination of the circumstances could in certain conditions cause a voltage collapse. in fact, if the loads maintain a constant power or you know kind of maintain constant power by the use of tap changing transformers one way to avoid voltage instabilities to recognize such a situation is developing and disable a transformer trap, so that your load is not aggressive load will fall if the voltage falls.

So, this is one way you can improve voltage stability. we also saw right in the beginning of the last 3 lectures, that we can have a better frequency stability that is a better load generation balance by using governors or emergency control in the form of under frequency relays or df by dt that is a rate of change of frequency relays.

Remember often when we are talking of stability problems or any problems in a power system. We also will encounter the phenomenon of line overloads transmission line overloads that is thermal heating overload this is not really stability problem it is a quasi static problem in the sense that heating could occur even if, there is no stability problem you can have a loading of transmission line above the thermal limits in that case you’re actually, having a steady state problem of heating. So, it is not exactly a stability problem, but the main stability problems which we do face of course, are angular instability voltage instability and frequency instability of course, if you design some of the feedback control systems in your you know in your controllers incorrectly you can actually, cause some pattern or mode to go unstable, so this is something which also which also can occur.

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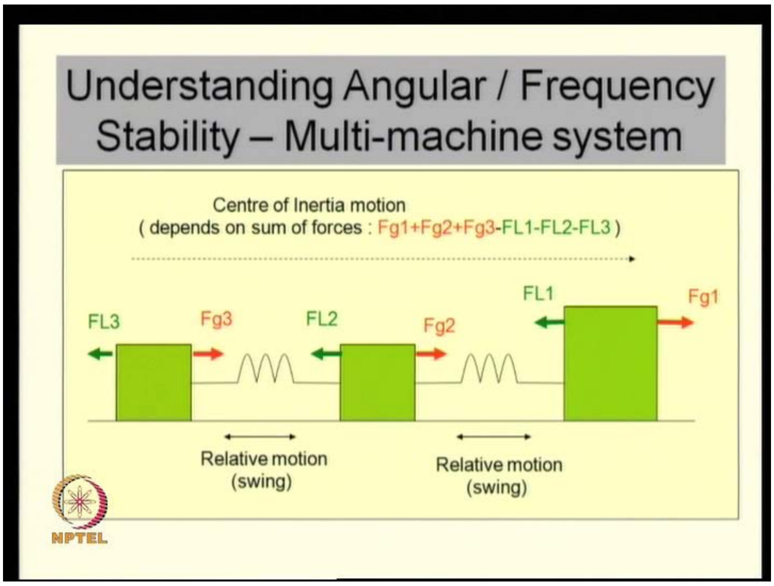

Now, there's one important thing when we are talking about angular or frequency instability we have I have shown you this kind of a crude analogy of a multi machine system you have 2 important things to worry about in a multi machine system one is frequency instability or in other words, the center of inertia motion of the system. which depends upon the sum of or rather the load generation cumulative load generation balance in the system in addition you have got relative motion which you have to worry about that is the problem of power swings and relative motion can also be large disturbance unstable and that is what we have called as transient instability, so these are the mainly the phenomenon associated with the electro mechanical system.

Of course, we have seen that power swings can you know be unstable small signal unstable or small disturbance unstable due to the effect of feedback controllers like high gain automatic voltage regulators in the system.

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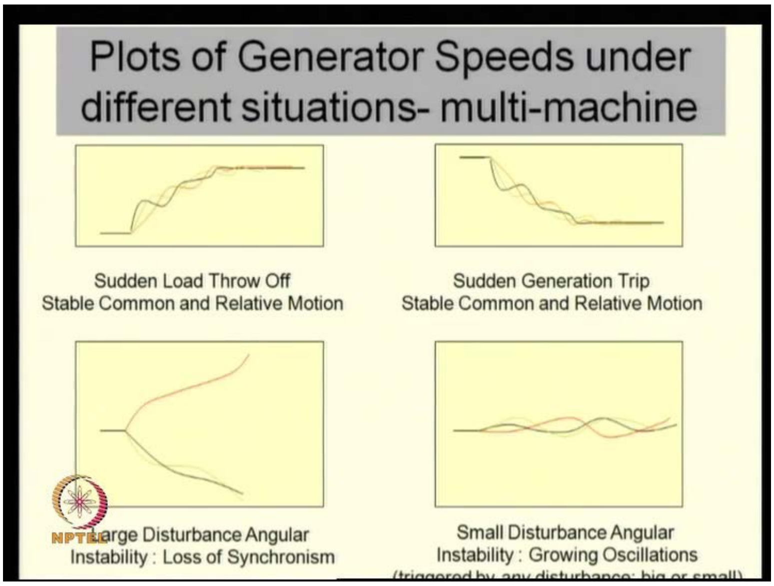

Again let us just try to understand it using these plots which I have shown you in previous lectures as well today's lecture actually, is worried about large disturbance angular instability, so we are really talking about the lower left hand system in which after a large disturbances the speeds of the generator deviate from one and other and you may have a situation where there may be large fluctuations in voltage and power in the system.

So, this of course phenomena occurs in synchronous grids only where that is in grids in which synchronous machines are inter connected by a c lines if machines lose synchronism that is they run at different speeds you will have unacceptable variations in power voltage and so on.

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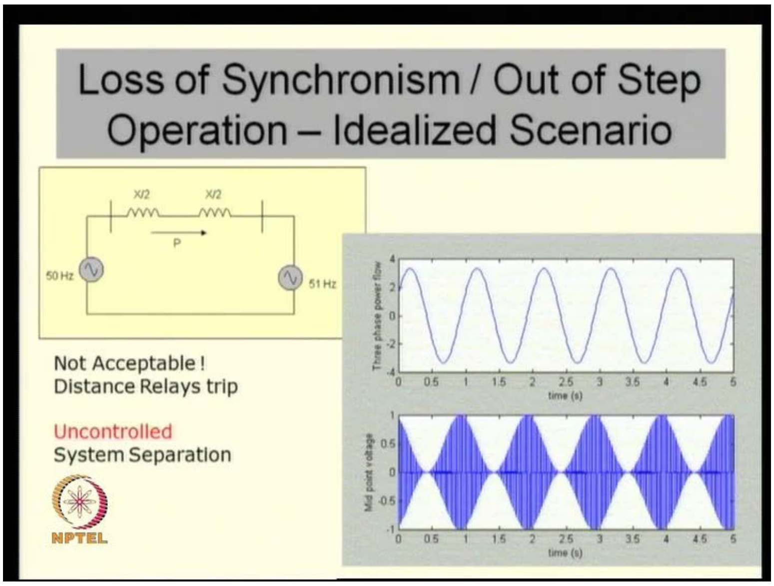

This can be of course, understood easily using this simple example which is showed in shown on the slide where you have got 2 it is a kind of a idealized scenario you have got 2 sources which are running at different frequencies and if you plot the 3 phase power the total 3 phase power you will find that if you have got 2 sources with different frequencies the power flow through the transmission line will kind of oscillate at a different frequency.

And the power flow actually, undergoes variations which may be I mean the power flow you can go even negative I mean you can have both negative and positive variations. So, the variation is very significant, so in case you have got a loss of synchronism scenario where you have got 2 you know synchronous machines running at different frequencies while still being connected by an a c line this is unacceptable and typically it leads to voltage at some part of the grid you know under it makes the voltage undergo very large variations. in fact, if you look at the this lower graph here it shows that instantaneous voltage in the midpoint of the system and you see that in case the 2 systems lose synchronism that is the operated 2 different frequencies then your voltage in the midpoint the envelope of the a c voltages even touches 0 at certain points.

So, this is of course unacceptable and usually if you have got distance relays they mistake this variation in voltage in fact the voltage at some point becomes 0. So, they think it is a fault and if that happens they trip the line, so the system actually separates out.

In fact, you effectively have an uncontrolled system separation incase distance delays trip after the loss of synchronism, in fact if 2 machines are going out of synchronism due to a large disturbance this is a large disturbance phenomena in that case you have to separate out the 2 systems.

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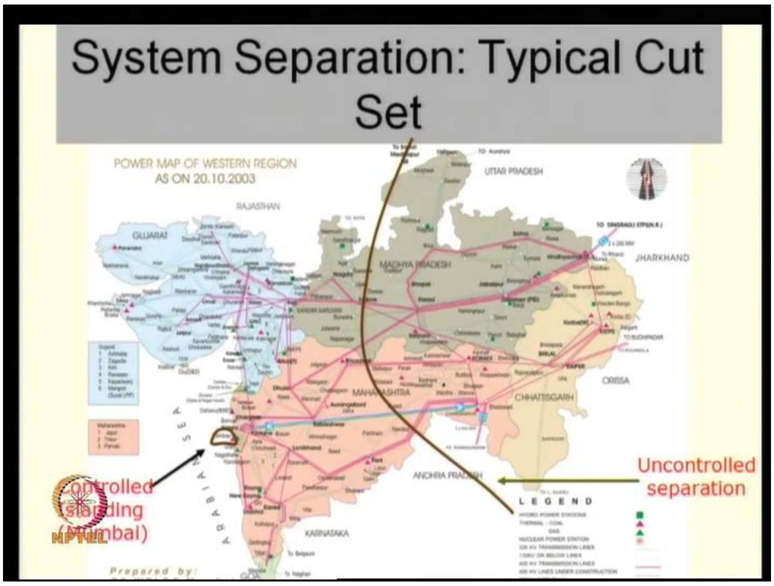

In fact, for the western grid of our country it was seen that typically whenever you had a loss of synchronism. you would have the western part and the eastern part of the systems splitting. So, this is typical cut set which is seen you have got the eastern part and the western part of the system splitting and thereafter of course, you have got 2 islands which are formed in the system or 2 separate synchronous grids which are formed in the system, so this kind of uncontrolled system separation can occur following loss of synchronism.

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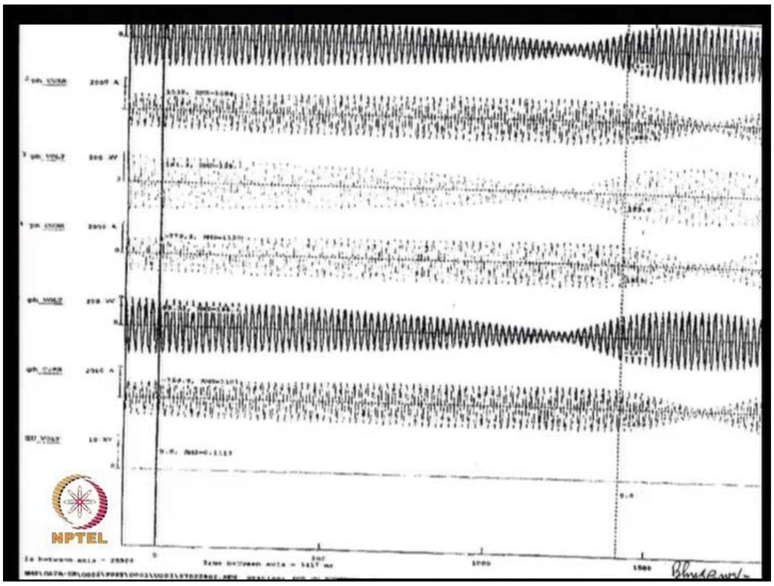

This is not although it the whole course has been kind of theoretical in the sense of telling you the theory modeling and there thereafter drawing inferences about the dynamic behavior. I have not really shown you a loss of synchronism after a following a large disturbance. We did see right in the first lecture situation where if we went on increasing the power output of a synchronous machine. which is connected to a voltage source, you come to a point where it loses synchronism, but loss of synchronism can also occur after a large disturbance and what you see here of course, is one such practical situation which did occur in our western grid several years ago.

And if you look at these graphs the first graph is the voltage in the a phase then the current in the a phase then the voltage in the b phase the current in the b phase voltage in the c phase and the current in the c phase, so what you notice very clearly is the signature of loss of synchronism this is a voltage which is measured at some at a location in the grid after the loss of synchronism.

You see this typical signature whether voltage dips down to 0 and again raises this is a scenario this is a typical signature which is seen this is. in fact, over a 400 k v line in the system, so this is a real life example of a loss of synchronism.

In fact, this idealized scenario which we saw using a 2 machine example is something what has happened in a bigger scale in the in a real grid whether groups of machines in the east part of the system have lost synchronism with the machines in the west part of the system. And this particular in fact, measurement was taken for a real life event real life response after a large disturbance and what was really being measured was the voltage on this particular line.

And this is what was really seen at one bus in this system, so this is a typical signature of a loss of synchronism it really occurs it really does happen in a real grid after a large disturbance of course, the loss of synchronism events occurring in grids happen very rarely in fact, I had to really dig out you know various disturbance records and you know consult my colleagues in the industry to get this particular situation where system actually, did not lose synchronism it does not normally lose synchronism, because you operate it or design it or plan it in such a way, so normally you loss of synchronism events are not seen.

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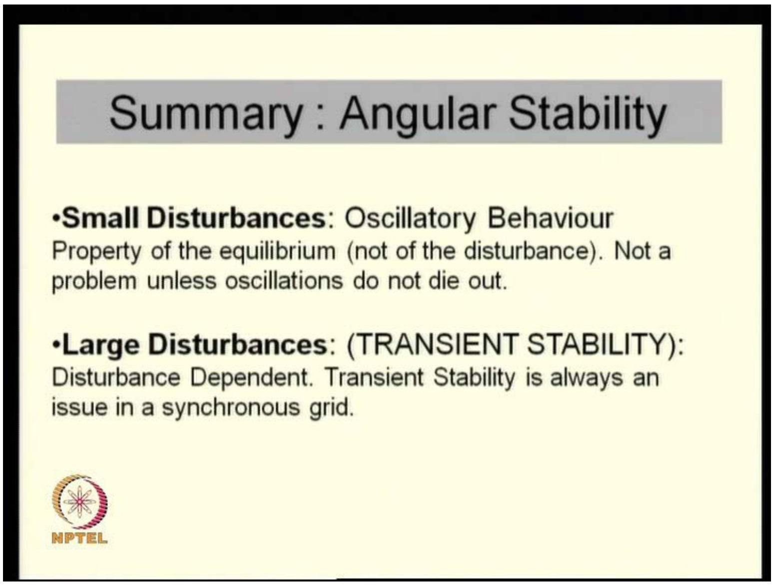

Now, we will just discuss what really I mean by this, but before that let us just summarize what we have learnt or what are the main aspects of angular instability one of the aspects of angular stability is the stability after small disturbances which can be actually, analyzed by linearized you know Eigen analysis of the system this is what we did in fact, in you know in the previous lecture we just discussed what happens for small disturbances how we can improve the small disturbance stability by improving the control systems or augmenting them with auxiliary controllers.

Now, remember that small disturbances relates to the relative angular oscillatory behavior and it is a property of the equilibrium in the sense that any disturbance small or large can excite these oscillations and under certain situations this may be unstable, but having power swings is not actually a problem as long as the oscillations die out.

In fact, any disturbances lead to you know these typical you know oscillations which you will see in the responses of the generator speed but these are not problem there is not a problem if, the oscillations we really are facing a small disturbance problem only if these oscillations die do not die out I mean the you have got sustained oscillations or growing oscillations this is something which may be of which may be a real worry.

Large disturbance instability on the other hand which is also called transient instability is disturbance dependent it depends on the magnitude of the disturbance and one important point which is which has to appreciated that in any synchronous grade that is a grade in which you have got large number of synchronous machines connected by transmission lines transient in stability will always be an issue in the sense that you never get rid of this problem in the true sense you will always find in a synchronous grade a large enough disturbance which leads to instability.

Now, the key problem is for credible disturbances credible I mean a disturbance which seems realistic does the system remain stable or not so when I say large disturbance stable it is of course, disturbance dependent on the magnitude of the disturbance for typical or credible magnitude of disturbances is the system stable or not would be a more engineering like question, but remember that this large disturbance stability phenomena as such will always be there in a system a power system.

Remember when I say large disturbance instability it also means that this arises due to the non-linear nature of a power system otherwise small disturbance stability and large disturbance stability would be equivalent in a linear system there is no such distinction, but in a non-linear system large disturbance behavior may be significantly different from small disturbance behavior, so for small disturbances the system may be stable the oscillations may be dying out, but for large disturbances you can always co up a large enough disturbance in a synchronous grade which will make your system unstable.

So, this is what I mean by the large disturbance instability being disturbance dependent, but it always being an issue in a synchronous grade.

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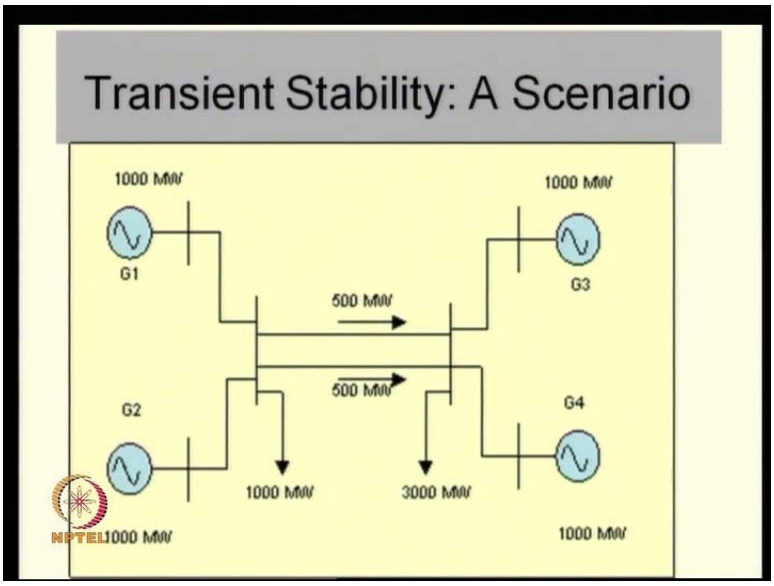

So, just to lo at just to reemphasis what I am trying to say transient stability if you lo at this particular figure suppose you have got a multi machine system transient instability in a 2 machine system was in fact, simulated if you look at the lecture number 38 or 39 you will find that we have actually, simulated a 2 machine system in which you can have transient instability following of fault.

So, let us just see a typical situation another typical situation where you could have transient instability, so you have got a system in which there are 4 generators each of them say generating 1000 megawatt and you know you have got 2 loads or 2 buses in which loads are actually, you know accumulated that is 1000 mega watt and 3000 mega watt they are here at this bus and at this bus.

And since there is of course, load generation balance is generating 4,000 megawatts there is a load of 4,000 megawatts. So, center of inertial frequency will be stable, but here of course, we are assuming no losses are there the total load generation is balanced, but you need to transfer 1000 megawatt from this system to that system because, there is more load here than the generation here.

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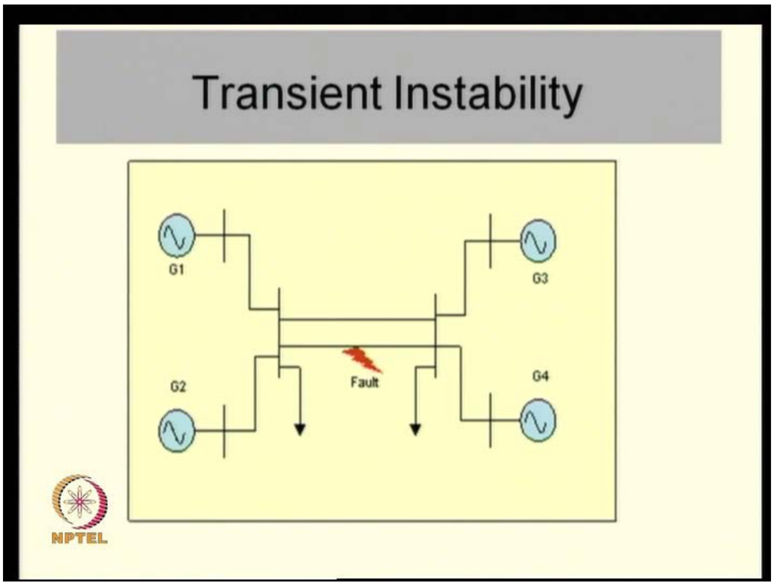

Now, suppose this is a typical situation you know there is a fault on one of these transmission lines now if there is a fault on one of these transmission lines typically if your protection system is well designed and is operating well.

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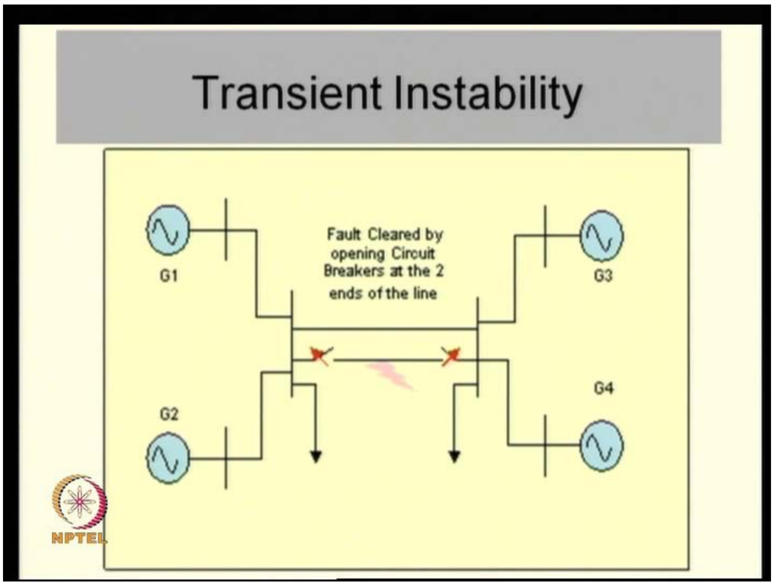

It will be detected quite soon enough and there will be circuit breakers will be opened at both ends of this transmission line and this fault gets cleared or de energized now, once you trip open this lines this particular line on which is faulted you have to the load generation scenario of course, is not changed in the mean time. So, what you will have effectively is that the power which is flowing to 2 lines will have to now flow through one line.

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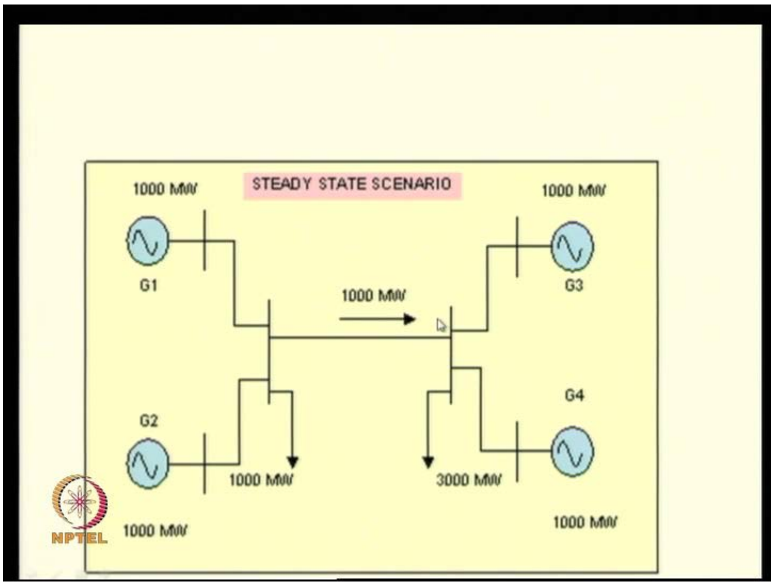

And what would be a steady state scenario would be this that 1000 megawatts flows through the remaining line, but the key issue here is this is the steady state scenario because, the system is undergone a fault and a line tripping thereafter some transients will be the you know created and the basic point is that the system moves from one equilibrium to another or rather there is a fault and the system deviates substantially from the original equilibrium the equilibrium itself changes now the question is whether the system will settle down to this new equilibrium.

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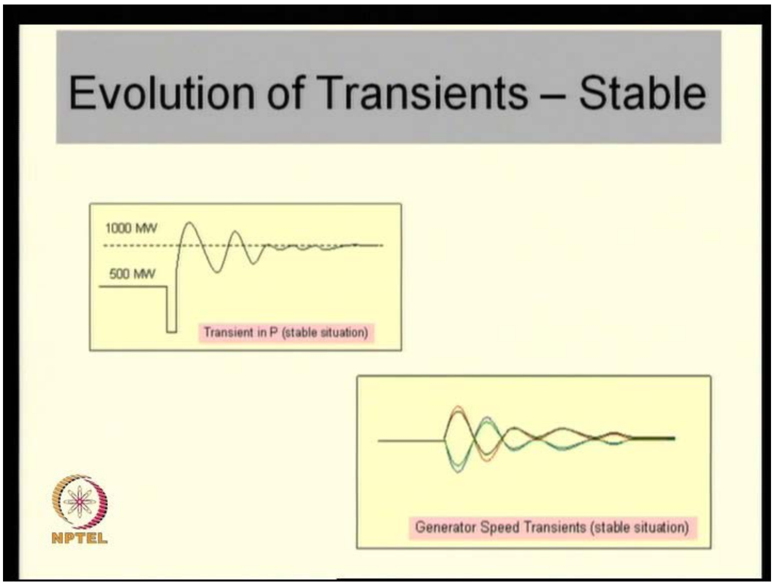

So, this is the equilibrium condition after the large disturbance, but the point is that you may either be stable and the power flow may go from the remaining in the remaining line from 500 megawatts to 1000 megawatts, so the transient in this particular line earlier the power was 500 mega watts now it is 1000 megawatts under steady state the question is that you will of course, have a transient initially 500 megawatts was flowing through the line then there was a fault, so the power dips because, the voltage would dip in the system the power flow dips in the line then the fault is cleared by tripping the line and the system tries to go to this new equilibrium and this is the response if the system is stable, so you would say that the system is large disturbance stable for this particular disturbance.

And if you lo at the generator speeds you will find that the generator speeds also the relative motion stabilizes after sometime that is the speeds of all generators remains in synchronism.

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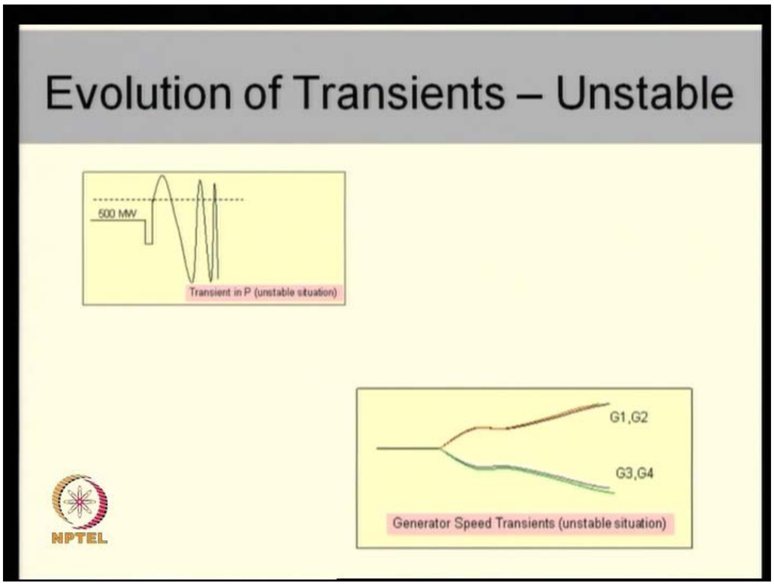

What would happen if the system was not stable this is what would happen you would find that the generators speeds would deviate from each other one set would accelerate one set would decelerate and if you look at the power transients in the transmission line you will find this very large variations what we had discussed sometime back the power will start pulsating at a very with a very large magnitude and this is an unstable situation this is a large disturbance unstable situation.

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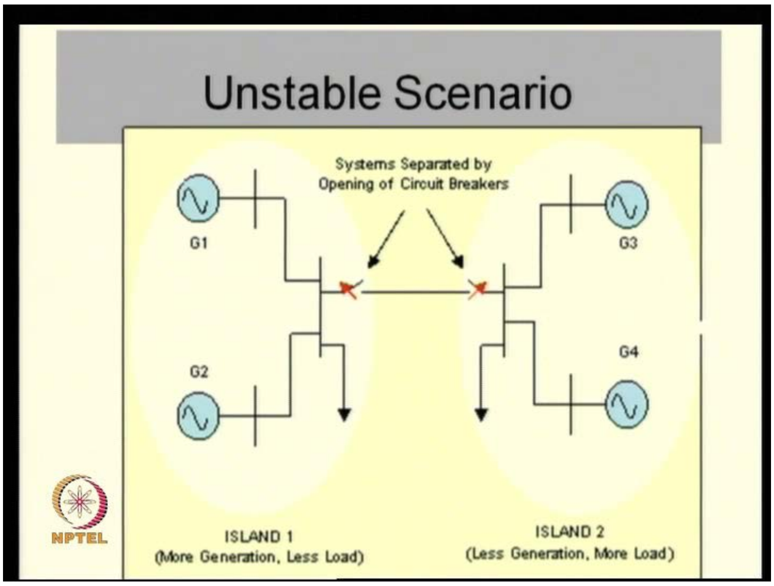

So, of course, if you are unstable there is nothing you can do you have to disconnect the 2 systems remember the system are still connected, so you need to disconnect the 2 systems otherwise a transient variations can be large enough to damage equipment.

So, once you have tripped out or separated out the 2 systems you have formed 2 islands and you have the island one has more generation, but less load, but island 2 has less generation and more load, so there will be a dual problem which you need to solve that is whether the system you know this system islanding is taken place whether the individual 2 individual island whether the center of center of inertial frequency within those island is are going to stabilize or not.

So, we get a frequency stability problem after islanding has occurred of course, the frequency can stabilize provided you have got mechanism to ensure this load generation balance that is you have governing systems or under frequency load shedding schemes which ensure that there is generation load balance.

For example in island 2 you need to do quick load shedding in order to ensure that the island is stable otherwise you will in no time the frequency will drop down to such an extent in island 2 that you will have to trip out the steam turbine turbines and therefore, you will have a complete black out in that region so, you need to take quick actions after this if the system is unstable.

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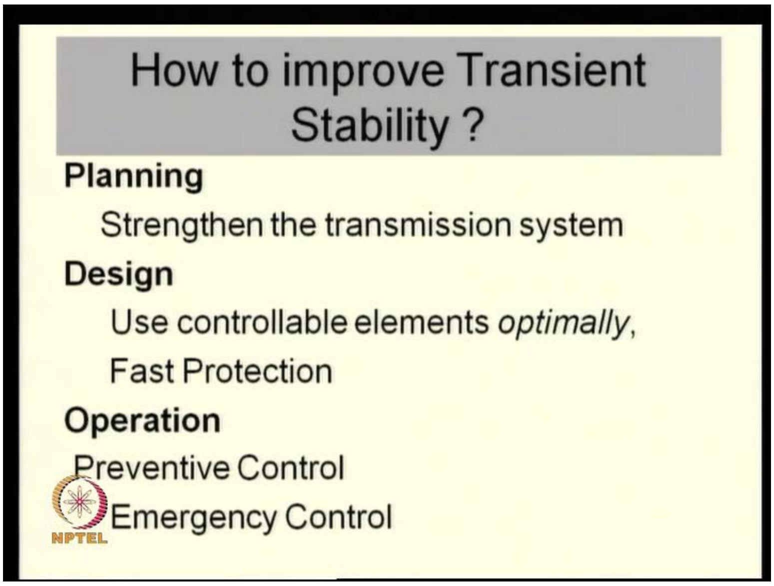

So, how do we improve transient stability or large disturbance stability unlike you know the problem which we discussed in the previous class this is a large disturbance instability problems in fact, by tweaking controls a little bit you know or having auxiliary controllers which modulate you know some voltage reference say of an automatic voltage regulator etcetera you may not be able to got you know improve upon this transient stability.

Of course you can make large changes in controllers you can have controllers you know kind of you can make controllers act in such a way that they actually, improve transient stability as well.

What do you mean by improving transient stability for a given credible disturbance if the system is unstable you make changes in the system, so that the system becomes stable.

So of course, when I say how do you improve transient stability it can mean 3 things how do you improve transient stability in a system during planning so what do you do when you plan a system, so that your system is transient stable see a planner knows that transient stability is always going to be an issue in a synchronous grade, so when the system is being planned say for you know you know if you are doing short term or long term let us say talk about long term planning you are sure that you know some new generation is going to come up some new load loads are going to come up and you know you are going to have power different kind of power flow scenarios in the system.

A system planner what he does is he kind of predicts a forecast the kind of load and generation scenario and the he carries out what is known as transient stability studies what are transient stability studies they are essentially simulation studies on how the system behaves following credible disturbances, so there are set of disturbances a continuances with which a planner will consider like a loss of a major generating plant or a fault you know a 3 phase fault at a particular bus which is cleared by primary protection or a single line to ground fault at certain important buses which is cleared not by the primary protection, but back up protection or the loss of an h v d c pole.

So, these kind of scenarios are worse you know kind of worse case but credible scenarios you know they should not be incredible scenarios what do mean by incredible scenarios you should not consider scenarios of disturbance scenario which are very unlikely to occur, but the loss of a transmission line following a fault is a very common occurrence you know in a given day you may find that you know at least 3 or 4 such events may take place in a large synchronous grade like in India.

So, if you look at the disturbance reports which are you know put out by many of these utilities you will find that they have given you will find very not infrequently there will be faults you know single line to ground faults and, so on which is result in transmission line tripping and. so on.

These are large disturbances because, when you have a fault for some duration the voltages everywhere come voltages go down there may be sudden changes, so you can consider a fault is a very large disturbance.

So, these things continually occur, so for a credible disturbance is something which we which we think has got some reasonable probability that will occur, so a planner system planner will try out many probable such probable contingencies and ensure that the system is stable even under stress condition that is unusual load and generation patterns again credible patterns in which certain lines are loaded more or less, so this kind of exercise is done in planning though sometime you may planner may find that for credible disturbances which he may simulate using a transient stability program that the system is not stable in such a situation he will think of augmenting the transmission system.

So, he may think of for example, you know building a new transmission line he may. In fact, think of that that is the way of going forward now how does you know of course, I have told you that you know whenever a system is not transiently stable I mean it is not stable for credible large disturbances one of the ways of improving stability is to strengthen the transmission system what is the basis of saying that.

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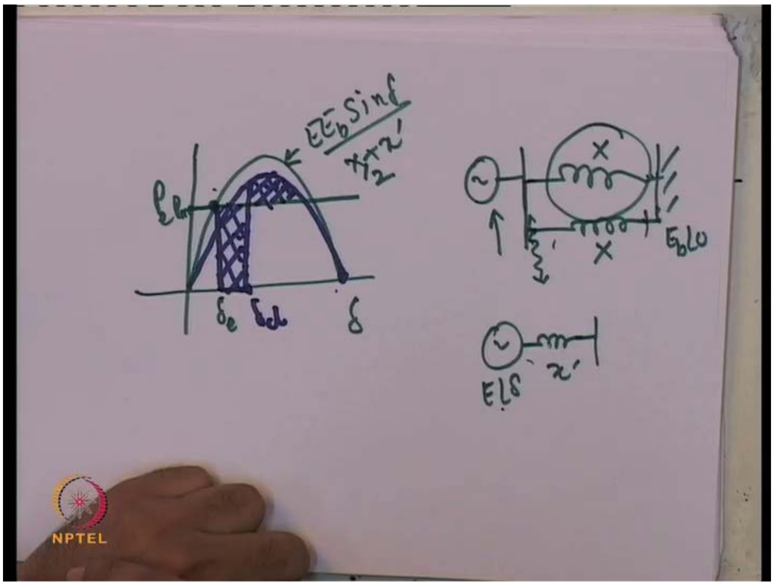

Now, if you look at to understand that we will consider a simple single machine connected to an infinite bus through a say a reactance X this is a representation of a transmission line you know that the power flow for an idealized or very simple model of a generator as a voltage source behind a reactance the power flow versus delta that is the phase angular difference between this generator this you know which is a representative of in some ways of the rotor position and this infinite bus is given by this power angle characteristics.

That is EE b sin delta by X plus X dash this is of course, the simplest model assuming that the generator is represented by classical model a transmission line by simple X network transients stator transients everything is neglected in that case you come to this power angle characteristic.

And if you recall what you have done in your undergraduate years if you have got a system which has got say 2 transmission lines X and X in that case the power angle E will be sin delta divided by X by 2 plus X dash because there are 2 transmission lines in parallel.

Now, if there is fault here this is a typical kind of a study which we did when we were undergraduates and studying power systems you give a fault on one of the transmission lines at one end the fault is detected and then cleared out.

So, this is a typical fault or large disturbance scenario which we considered while time: trying to study transient stability, so under normal operating conditions we will be having this equilibrium condition here if there is a fault the this is of course, the mechanical power the intersection of the electrical power and the mechanical power defines the operating delta.

Now, if there is a fault electrical power suddenly becomes equal to 0, so the machine accelerates then the fault is cleared and you are having you are now left with only one transmission line because this transmission faulted transmission line is tripped out.

So, your post fault power angle characteristic will be like this will be somewhere lower like this and one of the things we studied in our undergraduate years when we when we when we were attacking this problem was for such a scenario and for such simple single machine infinite bus system with a very simplified generator model one could show that if at the point of fault clearing your rotor angle had deviated due to the disturbance to this point delta then the system is stable if this area is more than this area.

So, the system is stable if this area is more than this area this was called equal area criterion, so although in this particular course in some sense we never use this criterion the emphasis of this course was you know trying to model a synchronous machine in more realistic kind of detail, so we did not use such simple models to show loss of synchronism. we in fact, we did a 2 machine system simulation in which we gave a fault and then we showed that for a large enough fault the system is unstable we did not actually, use equal area criterion to show that the system is unstable we did a simulation for large very large system to get quantitatively accurate results simulation may be the only way which can assess stability quantitatively accurately that is what I mean.

But from a conceptual or a roughly you know if you want to get a rough or approximate answer then one may use equal area criteria like analytical tools for simplified system models and get approximate you can approximately assess transient instability as done in this example.

So, if you have got a single machine infinite for this fault and a very simplified model the equal area criterion which is derived not in this course, but in the first course of power systems tells that this area if it is greater than this then the system is stable and this can be said without stimulating the system because this is a very simple system now this equal area criterion although we have not used it for getting quantitatively accurate results it can easily tell you what needs to be done in case you want to improve stability.

So, we will use equal area criterion not to get exact quantitative results, but to suggest what can be done to improve stability.

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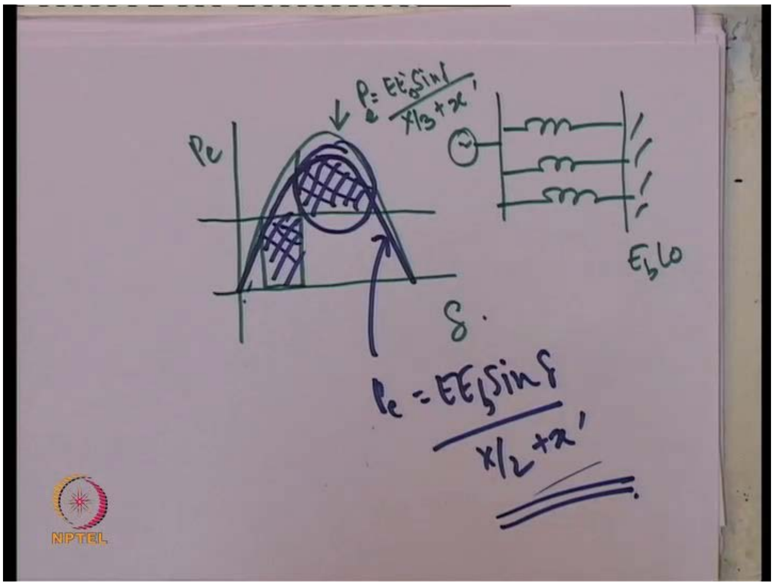

So, let us just talk of the planning option a planning option says is strengthen the transmission system what do I mean by that suppose my system had 3 lines instead of 2 in that case the power angel curve is enhanced because, now you have got p is equal to electrical power is given by EE b sin delta X by 3 plus X dash this is really got enhanced.

This is electrical power versus delta so, for the same power flow if I give the same disturbance it is more likely that if there is of course, one line trip after a fault equal area criterion would say after one line trip this becomes p e is equals EE b sin delta by X by 2 plus X dash, so now what you have got is a much more enhanced area because this is slightly enhanced compared to the earlier case.

In the earlier case the post fault post fault power angle curve was EE b sin delta X plus X dash which is much lower, so if I may say. So, the decelerating area in this case is much larger than the earlier case, so it appears that if you strengthen the transmission line say be decreasing the reactance effective reactance of interconnection then it appears that you can improve transient stability.

So, this is what I meant when I said you strengthen the transmission system you make another transmission line or alternatively you can do another thing.

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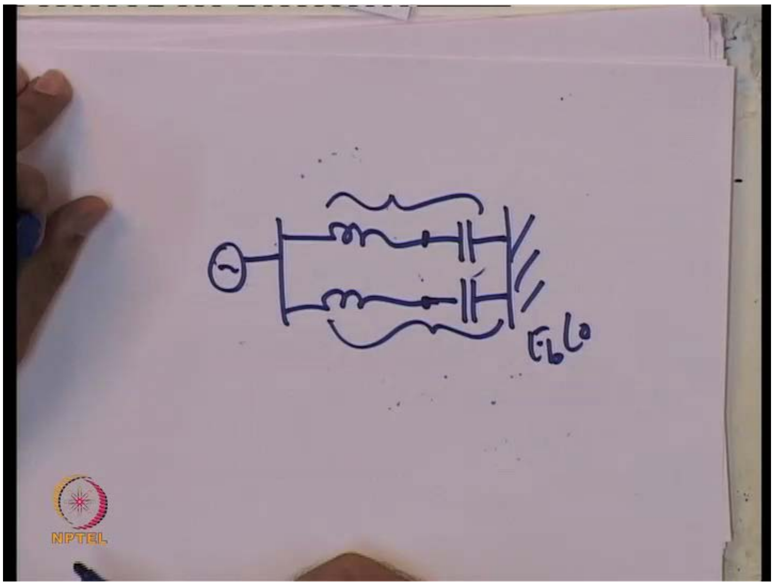

You can take the same transmission system as before and compensate it by using series capacitor this will reduce the X, so using series capacitors is another way in which you can enhance transient stability.

In fact of course, one interesting point is that having series capacitors can under certain circumstances destabilize torsional oscillations in a synchronous turbine generator system this was what we called sub synchronous resonance not always sometimes it could happen.

But anyway here we are talking about distinct application where we are using series capacitors the rather I the series the use of the series capacitors is essentially to improve the transient stability of the system because the X is reduced, so we are actually enhancing the power angle electrical power versus delta and therefore, having a larger decelerating area and as per equal area criterion which can give the stability behavior of a simple system by increasing this decelerating area where effectively ensuring that this area is greater than this area and therefore, for this disturbance the system will be stable.

Let us look at the other you know way you can improve stability that is more obvious you reduce the you extent of the disturbance itself.

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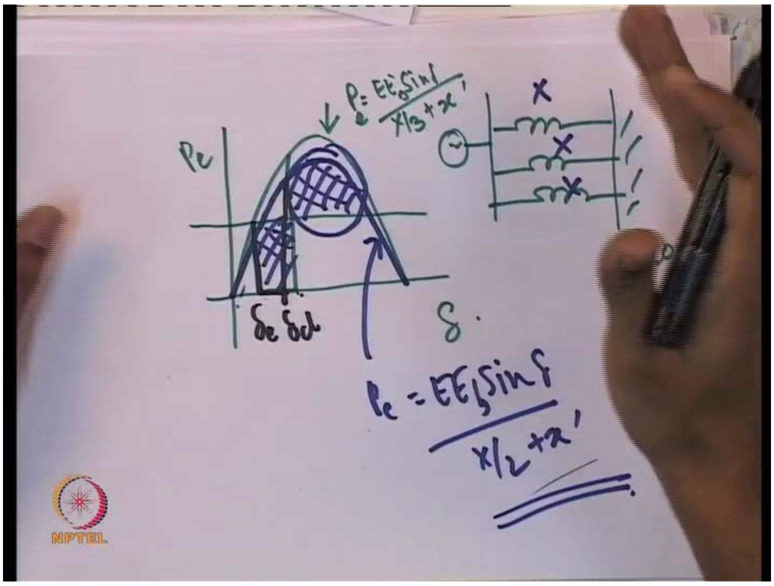

So, if you are disturbance is cleared very fast, then you will find that instead of being cleared here, you are clearing it out here, so this area reduces. So, you are clearing it earlier clearing I mean the fault is detected and the faulted element is removed before the variables deviate too much from the original equilibrium.

So, if I am able to clear this fault a bit earlier I ensure that this area is smaller, and this area is larger, so the system becomes more stable. So, improving the protection system that is you know detecting the fault fast enough, and tripping out the opening the circuit breaker at 2 ends after faulted element would really if you do it fast enough, one can improve stability.

But of course, they are limitations to how fast you can do a detection of a fault, actually the problem is not so much about how fast you can detect the fault how, but fast you detect it reliably. So, usually a relay will take about half a cycle to one cycle to reliably, you know it reliably it you know detect that there is actually, a fault taking. You know you for example, a relay should not trigger on noise a noisy input.

So, typically a relay would a good relay would take a little bit of time, and ensure that it does not trip out something on a false alarm, so typically you know you can say the state of the art would be that at fault you know fault on say an extra high voltage system would be detected in roughly you know between it will take approximately a cycle to detect reliably, you can you can be sure that there is a fault.

So, relay detects that there is a fault and not it is not a false alarm in about you know slightly less than one cycle to one cycle and then it gives a tripping command to a circuit breaker the circuit breaker opening time also you know may be a cycle or 2, so the state of this of you know the kind of best case situation, so in 3 or 4 cycles you can expect that the fault will be cleared under the best case scenario.

So, they are limitations to how fast you can do equipment protection it is already if you look at the state of the art in a HV systems you can clear out faults in 3 or 4 cycles, so that is that is possible. So, there is there is a limitation on how much faster you can go than this. in fact, if you try to make it faster you may compromise in the sense that the you may have trippings due to false alarms you know due to noisy input or you know that kind of things can occur.

So, you need to have a dependable kind of relaying system which do not trip on a false alarm it does not give a false alarm in trip out elements, so there is a limitation to how much you can design fast protection schemes, so this is essentially a design issue means you know you cannot make protection faster than a certain know a certain time scale.

The other way you can actually, improve stability which is of course, not apparent directly apparent using equal area criterion is try to make proper use of your equipment in the sense see for example, every synchronous machine has an excitation system the excitation system can you know usually design to have fairly large transient limits.

I mean you actually, have very high ceiling voltages or limiting voltages in a static excitation system you can actually, just for a few you know just for a short time you can actually, inject you now fairly large field voltage you can have a large voltage at the field applied at the field.

All though typically under steady state conditions under say full load conditions you know say round rotor machine you may have a field voltage typically operating at around 2.5 to 3 per unit, but during transients you can actually, boost up the field voltage to around 6 or 7 per unit plus or minus 6 per 7 per unit this kind of range is given, so that you can actually, ensure a quick response time of the excitation system.

Remember the field winding is a relatively slow sub system. so, if you want to get fast response you have to really push it hard and that is why you have got rather large ceiling voltages for short duration you cannot of course, apply very large field voltages like 6 or 7 per unit for a long time, but for a short while you can boost up the field voltage and boosting up the field voltage is to some extent like boosting the internal voltage of a synchronous machine.

And that is seen to improve the transient stability of the system, so a very prudent use of the transient you know transient limits or the transient rating of the power system equipment seems to be a good idea.

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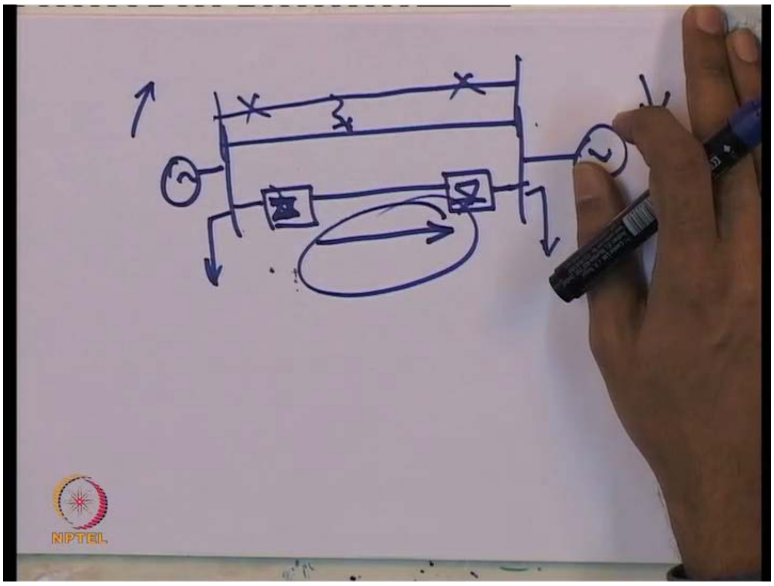

Another example of this is when you have got a synchronous grade which also has got an h v d c link embedded in it, so if you have got an h v d c link embedded in a synchronous grade it is a still a synchronous grade because, you have got a parallel a c line connecting the generators and the tool at the 2 sides of the system the point is that in case for example, you have got a disturbance say these are 2 a c lines you have got a fault on this line and this line gets cleared.

Now, there may be an issue of loss of synchronism. so, what normally is one of the good ways of ensuring transient stability is to temporarily boost up the power in the dc link. so, you boost up the power in the dc link and that can decelerate the 2 you know the angular deviation or the angular speed deviation between the 2 machines.

So, if these this machine is accelerating and this machine is decelerating you transiently boost up the power in the h v d c link typically an h v d c link also allows you a transient over heating for a very short while say half a second or one second you can boost up the power to a fairly large value I mean for example, even 1000 mega watt h v d c link you may be able to go for just a second or, so to one 1000 500 or. so, mega watts.

That really could help in this transient instability you could transiently boost up the power and ensure that the deviation between the machines is not too large. So, most h v d c link would have this feature of boosting power transiently during disturbances.

So, these are 2 examples in which you can prudently use the transient capabilities of equipment controllable equipment to improve transient stability the third way you can improve transient stability is through preventive control and emergency control preventive what do you mean by preventive control? Look at this.

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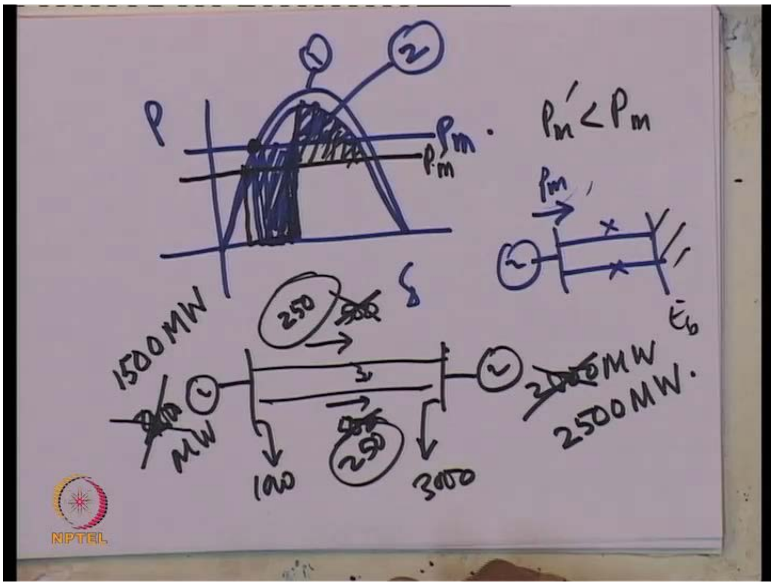

So, if you have got a system we will again use equal area criterion this is a pre fault system this is the power angle curve for the post fault system this is pre fault this is post fault, so a typical equal area analysis suppose yields you these areas and you find that this area is less than this area you may be unstable.

So, this is an approximate equal area kind of analysis now. so, this is the system reactance X p is the p m is equal, so electrical power output is equal to mechanical power output in steady state so p m is the steady state electrical power output of the generator.

Now, if p m is large you see for the given fault and clearing time this area is more than this area suppose this is the typical or particular scenario which is there now if p m is not. So, large, but I operate the generator at not at this p m, but at p m dash which is less than p m I can actually, come to a situation where this area is more than this area.

So, if I am during actual system operation if the operator senses or you know by doing simulation studies realizes that is current operating condition is such or the mechanical power output of the generators the load patterns etcetera are such the system is transiently unstable for credible disturbances.

Then one of the ways you can actually, improve it in this particular situation single machine infinite bus situation you can reduce p m, so instead of operating at this operating point initially you operate at this operating point.

If you operate at this operating point it is likely that the decelerating area will be more than the accelerating area and therefore, you can have for the same disturbance better stability in fact, you may not lose stability or you may not lose synchronism for large disturbances if your initial operating power is lesser.

Now, in a multi machine system you know suppose there is a initial power flow of 500 mega watt on both lines this is 1000 this is 3000 and this is the generation here is 4000 mega watts 2000 mega watts here and 2000 mega watts here suppose.

There is a fault there is a line clearing for this clearing time suppose you see that the system is unstable then one way of improving stability is to decrease the initial power flow through this system what it would mean of course, is to do some generation scheduling rescheduling what you can do is instead of this being 2000 this being 2000 you can have this as 1500.

Reduce this power output of this generator increase the power output of this generator now you will have 250 mega watts flowing here and 250 mega watts flowing here and for this power flow scenario it is possible that you may be transiently stable for this particular disturbance.

For a single machine infinite bus this can be easily understood from this you know these accelerating and decelerating areas for a multi machine system it would mean that the power flow through an interface can be reduced if it is seen that this system tends to separate across this interface.

So, one of the ways of reducing transient instability is of course, trying to reduce power flow through interfaces of course, remember that whenever a system in a multi machine system a system loses transient instability it can lose it in many ways in the sense that you can have different combinations of machines forming groups and separating out against other groups of machines.

And which group separates against which other group or which machines constitute a group depends on the disturbance, so that is one interesting and complicated challenge in the assessing the transient instability, but suppose I know that the system separates in such a way that this machine separates out from this machine.

In a 2 machine system there is no other way you can separate out in that case I know the interface you know between the you know the cut set you can say and you try to reduce the initial flow through the cut set you may improve stability .

So, this is called preventive control where in a system operator realizes that the system may not be stable for this particular disturbance and therefore, he uses the interface flow at interfaces which characterize the accelerating and decelerating machines for that particular disturbance.

So, this is called preventive control, but remember like the augmentation of a transmission system or adding a series capacitor in a transmission system this will have an economic you know will have a economic penalty in some sense in the sense that you are you can reduce or improve the transient stability in this case by rescheduling generation.

Now, it may, so occur that this may be a cheap generator and this may be a costly generator, so by doing this you are incurring an economic penalty, so improving transient stability is really going to require some amount of you know you know it will require has to spend a bit of money. So, if you want to be more secure you know you have to pay a bit money that is the whole problem with a transient stability in case you are unstable.

The other way you know, so you know actually, when I say an operator does this he actually, does it in the sense that he while a system is operating he actually, gets the data from various remote measurements.

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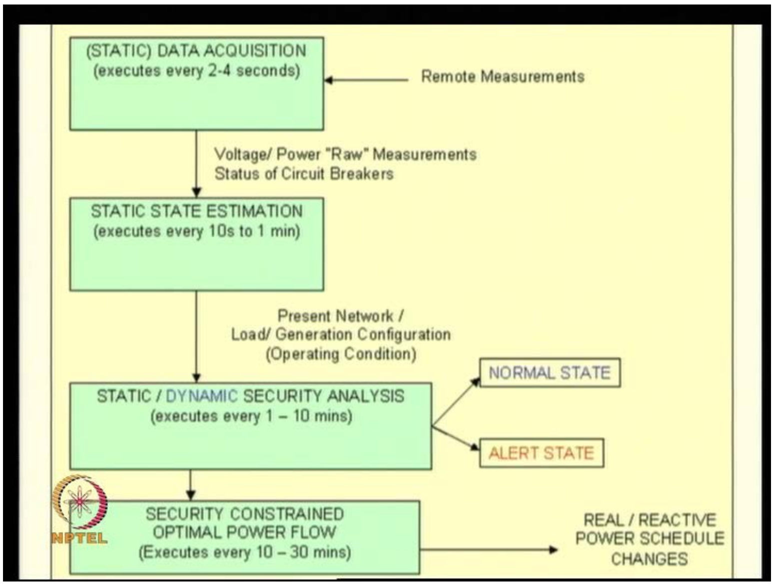

And he tries to evaluate the system state or the system operating condition every ten seconds to one minute once he knows what the system the you know the operating condition of the system is after all he is sitting at a control center he is getting remote measurements from that he is inferring what is the operating condition what are the flows what are the phase angular differences for a particular operating condition.

Now, once he gets this information what he does is runs transients stability simulation programs or variations of equal area kind of analysis to find out whether the system will be stable or not for credible disturbances and if he finds that the system is stable for credible disturbances according to the simulated response he will flag the system state as being normal.

But in case the system could go unstable if a credible disturbance were to occur then he will flag the state as alert in the sense that the system is operating in a alert state and the system may lose instability if a credible disturbance were to occur at that operating condition in such a case he will flag the system as an alert system condition and there after he will try to reschedule a power flow. so, as to reduce the interface power flows

Along certain interfaces which really characterize the separation of machines for example, in a 2 machine system the interface the tie lines which connects the 2 machines really define the interface.

So, he will try to reduce the power flow through the interface, but he will try to do it in such a way. so, that there is a minimum economic penalty in the sense that you lose money by rescheduling or reducing cheaper power and increasing you know generation from costlier sources.

Remember that the interface across which machines accelerate or decelerate depends on the disturbance itself. so, you know it would not be correct to say that he reduces the system operator he or she would reduce the power flow through the interface there are many possible interfaces and depending on the disturbance for which the system goes unstable.

A particular interface power flow may be more critical and a system may system operator may tweak around the loads in load or even the mainly the generation schedule. so, that the system interface power through those interfaces reduces and there by transient stability improves for that particular disturbance possible disturbance.

this is called preventive control he may do it an optimal way in the sense there may be many machines in one group many other machines in the other group and he may tweak around the power flows or the power schedule in such a way that there is minimum economic penalty.

That’s called security constraint optimal power flow and he may be doing it every half an hour or. so, and this is the way a system is operated securely and as a result of which it is quite rare in a synchronous grade that you have got this transient a large disturbance instability problem.

All though disturbances are continually occurring in a day there may be one or 2 major faults in a transmission system as in our country in a big power system as in our country, but you rarely the lights are always on; that means, the system is operating stably

So, one of the a beauties or one of the important things about the system operation power system operation is that it needs continuous monitoring and evaluation and assessment of stability and system operating changes will have to be made online in case the system operators senses that the system may go unstable for some credible disturbances.

He senses it of course, not by actual sensing, but by simulating the system. so, there in he uses some numerical integration program which integrates numerically integrates the power system dynamically equations.

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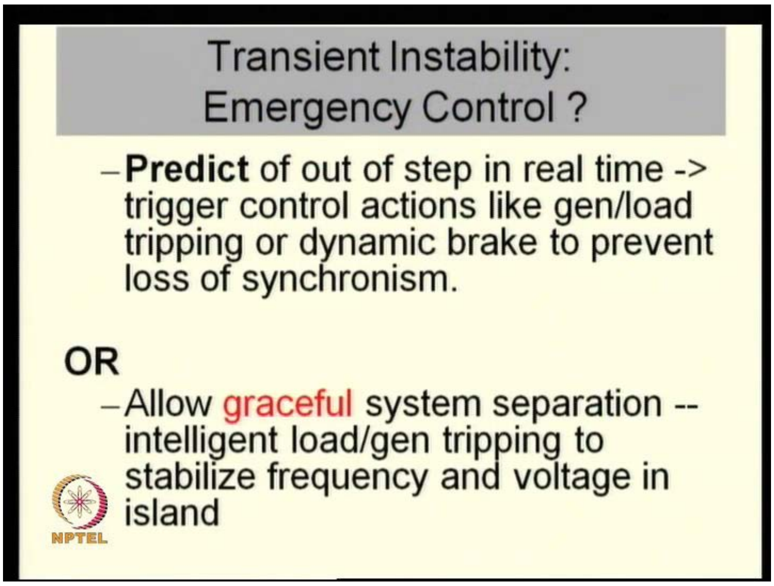

Another way of course, this is of course, we can try to do improve stabilities through emergency control that is you the emergency control also is called heroic action your you kind of predict or sense that an actual disturbances occur and the system is going out of step in spite of preventive control.

See of course, because, of preventive control one does not expect that the system will go transiently unstable for a credible disturbance, but sometimes if there is a mistake or error in our assessment because, we have not a disturbance much more you know much larger in magnitude then has been anticipated in our simulations occurs.

In that case preventive control may not be adequate the system operator would have sensed that the system could be go unstable for a certain disturbance and it does some preventive control, but that preventive control is not adequate it is not adequately implemented say.

Or the system as I said the system disturbance magnitude may be much more than what was considered in our simulation in that case a system may actually, go unstable in spite of all these precautions which were taken.

In such a situation as the system is going unstable can we trigger a certain control actions and get back the system and ensure that it does not go unstable this kind of thing is conceivable, but not easy. so, they are 2 possibilities that because, of inadequate preventive control or inability to anticipate a very large disturbance which actually, occurs eventually you may actually, go out of step in that case you are going out of step as the system is evolving you have to predict that you are going out of synchronism.

And if you are going out of synchronism you trigger control actions like generation load tripping or use specialized devices like dynamic breaks I will not describe to you today what a dynamic break is you can do a search a literature survey on this and see what a dynamic break is it is a device to improve stability.

So, you see that the system is going out of synchronism, so you quickly take some actions and prevent the system going out of synchronism or allow graceful system separation you know allow islanding, but the thing is you allow you do not allow uncontrolled system separation.

What you do is you try to form islands you know which are controlled island formation you trip out certain lines and form island, so that there is good load generation balance in that area the island. so, that there is a greater possibility that the island survives, so both these possibilities exist.

In this in the latter possibility you are allowing loss of synchronism, but you are separating out the areas and you are forming the areas based on some previous study which you have done that there is better load generation balance in this area, so let us form an island consisting of these generators and these loads with the knowledge that the system is going out of synchronism.

But of course, you would be nice if the system did not go out of synchronism at all because, that would involve no generation on load trippings, but the problem is how do you predict out of step operation in real time and how do you determine the quantum of control actions.

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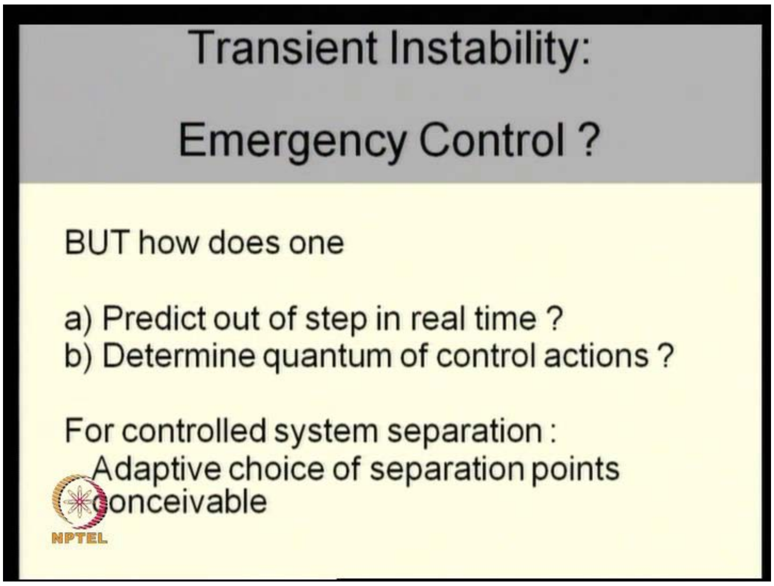

In case you are going for separation of the system then how do you do the have an good adaptive choice of separation points, so these are the kind of problems which may come up in the emergency control remember that the time window in which you have in order to act is quite small just a few seconds.

You know 1 or 2 seconds you have to act and do this thing otherwise you may not be left with you may be having unviable islands where in which frequency collapses or rises beyond 51 or 52 hertz and that causes a complete black out, so we have do not have much of time to really do this, but one can conceive and one can try to do the best under the circumstances.

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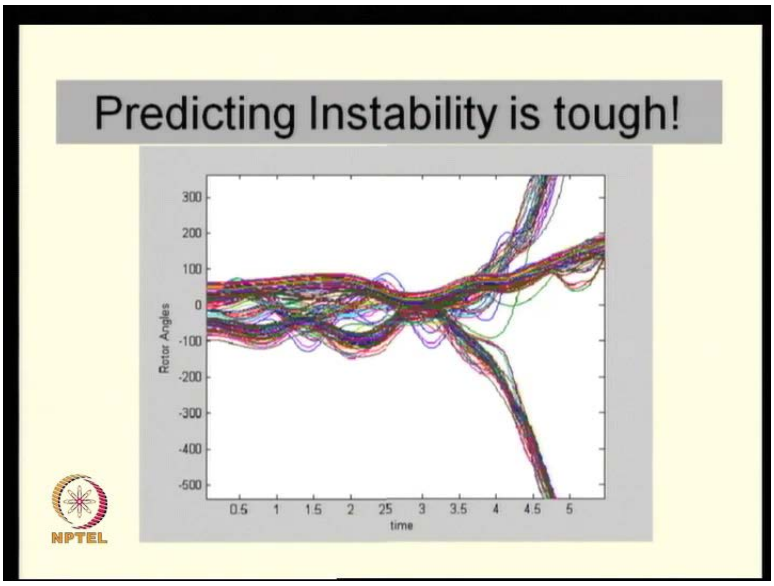

And people have in fact, if you look at this particular example just to show you that just by looking at the rotor angles for a short while you may not be able to tell what happens after sometime, so prediction is a very difficult problem.

This particular this particular example shows a system simulation in which the system breaks in to 3 groups of machines this can occur also so it really shows you that predicting instability is quite a tough problem.

Just from available measurements to predict whether this how the system is going to behave in real time is really going to be tough. in fact, faster than real time you have to make prediction and then take some control action.

So, this kind of problem is a very very tough problem and robustness of emergency controls will always be a very big issue, but none the less such kind of emergency control schemes have been conceived in fact, you have got you know several in the world in such kind of heroic actions in which you determine some kind of signatures of transient instability and then take some control actions to prevent instability.

So that kind of thing is conceivable, but robustness will always be an issue under such circumstances, so with this we kind of close our course we have really discussed in this particular lecture ways of improving stability.

If you just recap what we have done in this course we started off with the analysis general analysis techniques and then we spent quite a bit of time in modeling of synchronous machines and some other elements.

There after we did using simple systems small signal analysis numerical simulation and tried to I tried to show you some of the phenomena stability phenomena which can be analyzed in fact, one of the quotes of Einstein which which I did mention in the first lecture was that the most in comprehensible thing about this universe is that it is comprehensible.

In some ways you can even apply this to a power system of course, the power system is a part of the universe, so obviously, this code applies to it also, but what I mean to say is that by systematic analysis and use of analytical tools all these phenomena can actually, be predicted.

All using synchronous machine modules all the systematic modeling techniques and analysis techniques can allow you to analyze these kind of phenomena and of course, if you can analyze the phenomena you can often find out or predict or design ways of improving stability.

So in fact, I did show you some real life disturbance plots etcetera in this course and all the stability most of the stability phenomena which you know which we discussed in this course in fact, all of them have actually, been observed in practice and analyzed also and replicated using this analysis tools, so this is what it would like to tell to take back with you after doing this course.

There a lot of things which we could not cover like you know we could not cover in detail how to make large scale power system analysis programs or large scale Eigen analysis programs small signal stability programs.

But with the tools which you have learnt in this particular course and the models which you have learnt and the case studies which you have done in this course I hope it will give you a good starting point to actually, take on the studies all though we could not cover it in this particular course, so with that we end this course and I hope you enjoyed it.