**Power System Dynamics and Control**
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**Lecture No. # 38**
**Stability in Integrated**
**Power System: Large Systems**

As well as you know, a simulation, wherein we had given a three phase fault; and one of the key phenomena, which we observed was that in the especially that it was observed in the rotor speed and the angle. The phenomena, which was observed was the loss of synchronism, whenever there is a large, very large disturbance, I mean after for a certain large disturbance.

Also there is a center of inertia motion or you can say the common speed of the system changes, in case there is a load generation imbalance, which of course can be corrected by governors. In fact, there are two things which affect the motion of the center of inertia the in fact, the load generation imbalance is affected by the governor characteristics as well as the frequency dependence of loads of course, the frequency dependence of loads is generally weak; and it is not a good idea to rely completely on the load frequency dependence to get you to an equilibrium speed, the center of inertia speed which is in equilibrium, but if we depend on the load frequency characteristics to get you to an equilibrium that perhaps is not a very good idea, because for example, if there is a large load generation imbalance, which occurs, then you will find that the frequency settles down to a value which is very low; low or high of course, it is low in case there is a load is greater than the generation and vice versa.

Now, governors are should be you know, enabled governors are what is known as a primary response has to be enabled on all generators or at least the major generators in the system, so that each of them in some ways contributes to trying to maintain the load generation balance. So of course, there is an issue then of how to share the load amongst the various generators you know so for example, for a particular schedule there is a load generation balance and you are operating at the certain frequency. But if the there is suddenly a load change, then the frequency tends to deviate and all the governors which are enabled respond. So, various generators increase their mechanical input power and therefore, the electrical output power and the frequency tends to equilibrium. The sharing is dependent in fact, on the gains or you know gains or in fact, the inverse of the droop of the governor characteristics. So, the normally governors are proportional controllers in fact, the proportional gain in fact, determines the load sharing.

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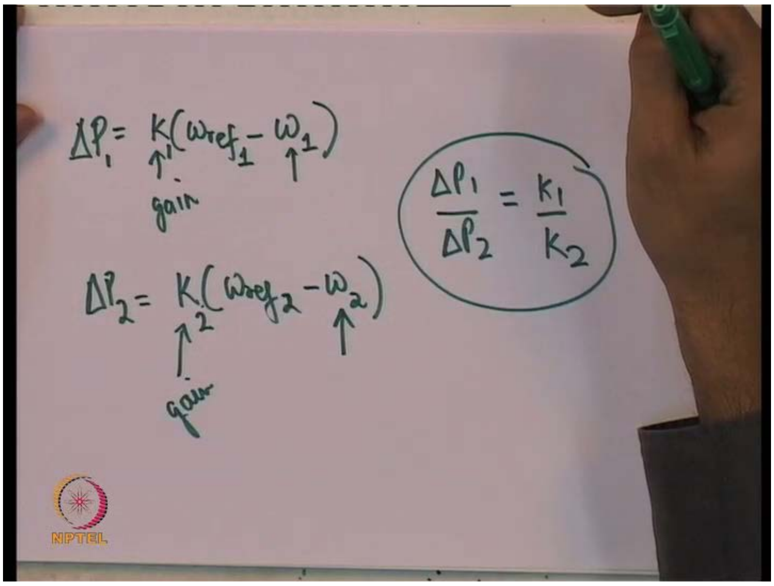

So, if you look at for example, suppose one of the governors it changes its mechanical power based on the difference between the reference value and omega 1, the actual speed measured at the generator, this is the gain. So, the change in the output of mechanical output of a generator will be basically given by this. Now, this is of course, true of other the governors as well. So, in another generator, the turbine changes its mechanical power as per this rule. Now if omega ref 1 and omega ref 2 are equal, it is obvious that this delta P 1 by delta P 2 is equal to K 1 by K 2. Why? I have first assumed here that omega ref 1 and omega ref 2 are equal. And another thing is that if your machines are still in synchronism after a low disturbance, normally to create a loss of synchronism scenario, you require large disturbance in principle even a low disturbance can cause relative angle motion and possibly in certain situations a loss of synchronism situation.

But we will assume that the system does the relative motion is stable and the system here will retain synchronism. In that case omega 1 and omega 2 in steady state are going to be equal therefore in steady state, your delta P 1 delta P 2 is equal to K 1 by K 2; so the gains of your governor in fact, determine how much heat generator shares this extra load. Remember that in an integrated system, what matters as far as the center of inertia frequency or the common frequency of the system is the total load generation imbalance. So, if once you have integrated all the synchronous generators that is connected them by ac lines, you cannot say that the load belongs to certain generator.

So, all the generators put together are cooling in their powers and meeting that load. So, any load change affects all generators, which have a governor; and you will find that this mechanical power change is proportional to K 1 by K 2. Of course, this is as I mentioned last time, a nice way to implement the load change I mean, you can for example, keep K 1 and K 2, so that generator share the load according to their ratings.

That is a reasonable thing to do. So, the proportional kind of scheme of maintaining you know kind of changing the mechanical output power of the turbines is quite a good idea. In fact, one consequence of having a proportional controller is of course, that in case there is a load generation imbalance if I want to change the mechanical power output of a machine then there has to be some steady state error between omega r f and omega.

So whenever you have these kinds of governors your frequency does not come back to the original value, before that is what existed before the disturbance load disturbance. It will have some frequency error, but this in spite of this you can choose your gains for example, large enough. So, if your gains are large enough your errors are smaller. But this proportional scheme is a nice way of sharing the load amongst various generators; and one of the important things is that it is completely local control all you require is the local speed of the machine. So, in this way, although generators may be interconnected in straight hundreds of kilometers apart or thousands perhaps, so still you can have a nice scheme to control the center of inertia motion.

The other phenomena which we discussed were of course, the loss of synchronism. So, in today’s lecture let us just recap this aspect also. So, today’s lecture in fact is well just think of what happens, when we have got even larger system of course, you consider two machine system in the previous class.

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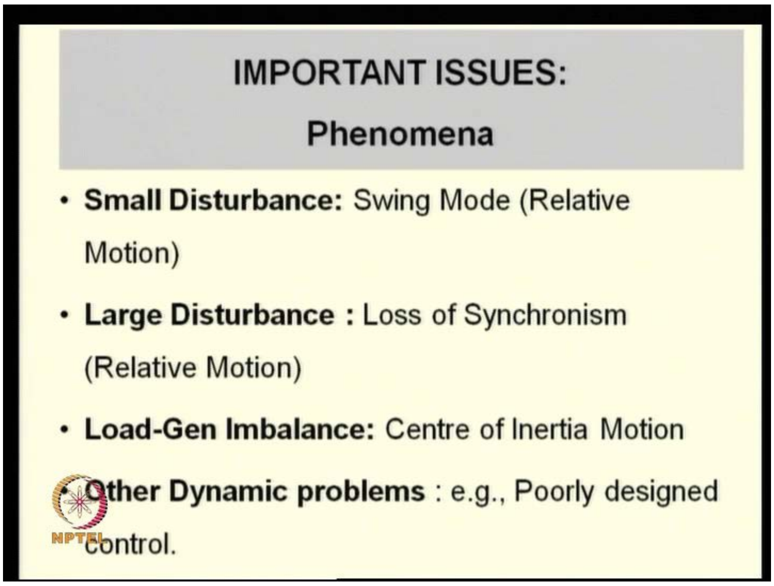


Well go for even larger systems, when you talk of relative motion there are two issues whenever you look at any small disturbance given to multi machine system, you will find that one of the prominent patterns there are of course, other patterns as I mentioned in the previous class, but one of the prominent patterns for small disturbance is a low frequency oscillation which occurs around one hertz.

So, that is essentially you know associated with the motion of the you know rather the states delta and omega of the machines and that is of course, a relative motion between the machines. So, what we call as power swings or low frequency oscillations etcetera are, in fact, are electro mechanical oscillations which involve relative motion between the machines, now this analysis says in an oscillation. So, you will find the you know, give a disturbance and you will find that the machines tend to a oscillate among themselves like a spring mass system.

And if your small disturbances if the machines are small disturbance stable the system is small disturbance stable. So, these oscillations die out and the machines kind of remain in synchronism. So, that is an important point about the relative motion; however, for large disturbances last time we saw, large fault, large duration fault. So, for large disturbances possibility of loss of synchronism of course, it depends on the disturbance itself and what operating point you are.

So, loss synchronism is also a phenomena associated with the relative motion of machines, suppose you have got the machines not coming back into synchronism but accelerating or decelerating with respect to each other; then you would say that the relative motion is unstable and loss synchronism has occurred, now loss of synchronism is not acceptable. It occurs for certain large disturbance it occurs for certain large disturbance its endeavor for an operator to ensure that the system has enough margins it is operated a bit conservatively. So, that you do not lose synchronies M 1 of the thing which we did not discuss much in detail, but something which you can do is try to increase the power flow on transmission lines for example, two machine system if we increase the initial power flow through the transmission line and then subject it to a particular disturbance because more susceptible to loss of synchronism.

So, one of the endeavors of the system operators is to operate system a bit conservatively, so that the system can withstand certain credible disturbance. In fact, even while planning the system planner will try out few credible contingencies and ensure that at least for loss of a credible kind of disturbance that is the fault with the loss of transmission line the system remains in synchronization.

What we discussed some time back of course, was this load generation imbalance which is associated with the center of inertia motion there is the overall movement of the system. So, that may or may not involve this center, but inertia motion can be thought somewhat as something distinct from the relative motion. So, of course, as I concluded in the previous lecture, it does not mean that there are other phenomena which can occur dynamical phenomena which can occur. We are focused on two particular phenomena which is relation motion stability as well as the center of inertia motion stability which is associated mainly with the electro mechanical states. But you can have other modes of in stability involving for example, poorly designed control etcetera.

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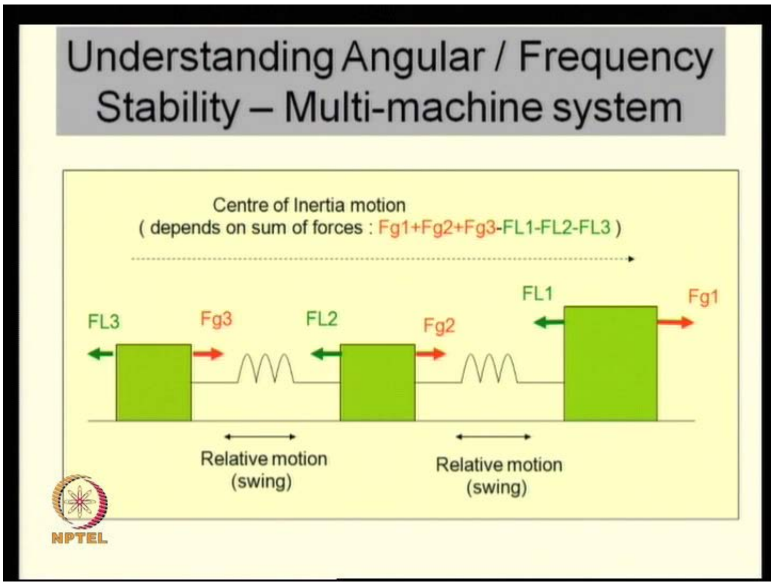


What happens when you go from one machine to three machines? So, to just kind of give a crude analogy again of a system, which is kind of a will give us at least some idea of how the electromechanical modes behave of you know whatever analogy am showing here for the spring mass system is actually, not completely does not completely reflect our system remember our system has many other modes as well.

In order of the system is quite high, it involves not only delta and omega as states, but several others too. So, whenever I am talking this analogy, it is only highlighting or kind of it is an analog of only the electromechanical pattern, which you see in a power system behavior. So if you look at this multi mass, multi spring system, what really holds true here is that the center of inertia motion that is the motion of that is you can talk of m 1, v 1 plus m 2 v 2 plus m 3 v 3 divided by m 1 plus m 2 plus m 3 this is the center of inertia speed. It is proportional to the sum of the external forces on the system that is the Fg1 plus Fg2 minus plus Fg3 minus FL1 minus FL2 minus FL3. So, this aspect of the motion in fact, remains the same.

We just add up all the torque equations or the what you call the spring equations of all the synchronous machines just add them up you will get this equation of the center of motion of inertia that is of course, something which what we saw in the two machine system will still be valid for a three machine system and so even a 500 Machines system the center of inertia is going to be the sum of the mechanical power input minus the electrical power output that is the sum of loads and the losses and the electrical losses, but maximum interesting point that you may consider at this point is what about the relative motion, in case of a single machine connected to infinite bus we considered of course, the relative motion consisted of the machine with respect to the voltage source

When you have got two machine systems, what we saw is the relative motion between the two machines delta 1 minus delta 2, what happens when you have got three or four or five machines connected to each other. Now looking at this analogy of course, gives you a picture of what is going to happen.

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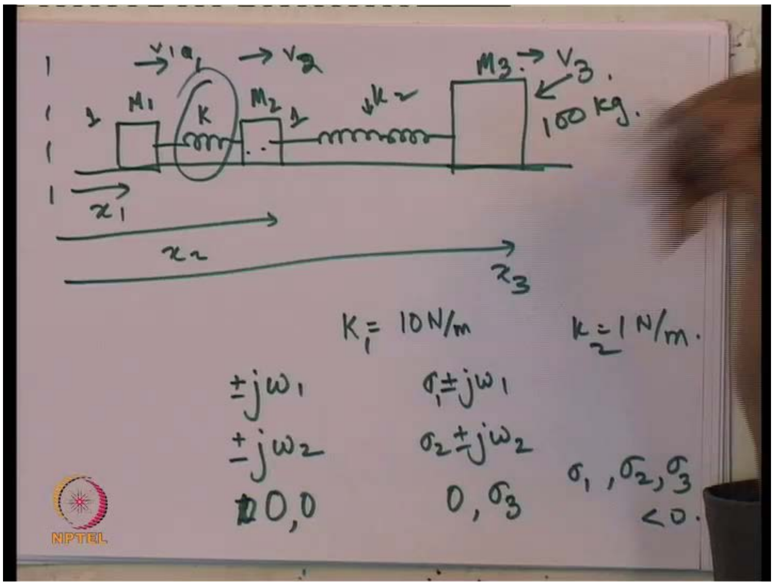


Now, what you have now is three machines; so one, two and three, so three machines are there. And suppose I give a disturbance to this system, the kinds of patterns you will see are going to be again quite interesting; one of course, is the motion of the center of inertia, but if you look at three machine system, just to highlight the simple kind of situation, suppose you have got 1 large mass connected to 2 other small masses and they connected by relatively a stiff spring. So, you have got a small mass these are M 1 and M 2 are small masses, and this is the mass three which is the large mass, and this is weak spring. Now if you look at the relative motion in this case forget the center of inertia motion we will talk only of the relative motion.

If you can guess of course, this is something I do not prove here nor I do the mathematical analysis of it, but you can just guess that in case this spring is very stiff that is difficult to stretch it whereas, this spring is a bit loose I mean you can stretch it quite easily.

This mass is large these 2 masses are small then you will find if you do a Eigen value analysis you can actually write down the equations of the states you know of the differential equation corresponding to x 1, x 2, x 3 and V 1, V 2, V 3 which are the velocities, in that case if you look at the Eigen values the modes of the system there is something we can do the typical you can choose some simple small values of M 1, M 2.

Large values of K small value of K large value of M 3 in this particular system in this particular system what you can expect are two actually two oscillatory modes corresponding to relative motion of the machine. So, if you take a three machine three mass spring system we have got you will have two oscillatory modes which actually if you lose at the Eigenvectors corresponding to these oscillatory modes.

That is the complex pair of Eigen value s if you come about when you do the Eigen value s of this system, two oscillatory modes one would be of high frequency mode; one would be a low frequency mode. So, I encourage it to do the Eigen value analysis for this system suppose this is 1 kilogram, this is 1 kilogram, this is 100 kilograms or 10 kilogram you can take something extreme.

. So, that you know what I am trying to it will you will come out very clearly. Let us say this is K you know 10 newtons per meter and this is K is equal to 1 Newton this is just fictitious values, which I have asked you to just consider do the Eigen value analysis, now if you do the Eigen value s of this system as I told you can find.

If there is no friction the Eigen value s will come out to be this. In fact, plus or minus is relevant here there will be two Eigen value zero Eigen value s these two zeroes Eigen value s of course, are associated with the motion of center of inertia of the motion the motion and actual x 1, x 2 x 3; values corresponding to the center of inertia of motion or common pattern of the system. If you have got friction then you will have an Eigen value of this kind and you have 1 zero Eigen value and one sigma 1 sigma, 2 and sigma 3 are lesser. So, this is in case you have got friction; friction is provided that is if you make the external forces a function of speed this of course, in a in multi machine system or in the actual path system is provided by the governors and load frequency characteristics of the system.

Now, the two frequencies are. In fact, these are corresponding to the relative motion and if you look at the relative motion it is easy to guess this is only a guess I am not really proving anything to you can actually do an Eigen value analysis and show it if there in this particular system not there in this first for all systems is that, the low frequency oscillation you will find that these masses look at Eigen vectors. The information they give you is that masses M 1 and M 2 whenever only the low frequency mode is excited the masses M 1 and M 2 move together against the big mass M 3. So, these these are the two masses M 1 and M 2 and this is M 3, so you find that there is a low frequency oscillation associated with these two masses moving against the large mass there is hardly any relative motion between the smaller masses whenever the other another pattern of motion is when this M 3 mass does not move much, but there is some relative motion between M 1 and M 2 of relatively high frequency.

So you have got these three patterns which will rather three patterns one is the center which corresponds to the center of inertia and the relative motion there are two patterns two oscillatory patterns one is the high frequency one involving masses M 1 and M 2 low frequency one involving masses M 3 moving against M 1 and M 2 which move together. This is the pattern which you can infer by doing an Eigen value analysis, now the important point which of course, I wish to make here is that whenever you have got a three machine three mass system you have got two relative modes of oscillation.

Now, in general, whenever you give a disturbance if it is a general disturbance you will find that all the modes are excited. So, a general disturbance no special initial condition you will find that the masses move together there is a this high frequency mode and a low frequency mode also you can have all this. So, this kind of behavior you can expect. So, if you take a 500 machine system you will find that there are you know 499 relative modes for oscillations, yes that is true not all of them are excited for all, if we give a disturbance or a initial condition which this not the equilibrium condition you will find that certain modes are excited others are not.

So remember that in a machine system n minus one relative mode of electro mechanical oscillations. Now one more issue which you should remember is that whenever you should go from a you know the relative motion although in the spring mass system is a linear system a power system is non-linear system. So, for large disturbances again you may have relative motion going you know is you can have a losses synchronism phenomena in which machines separate out from each other that is you have got machines one of the machines accelerating and other machine decelerating this is a non-linear phenomena which cannot be predicted by Eigen value analysis.

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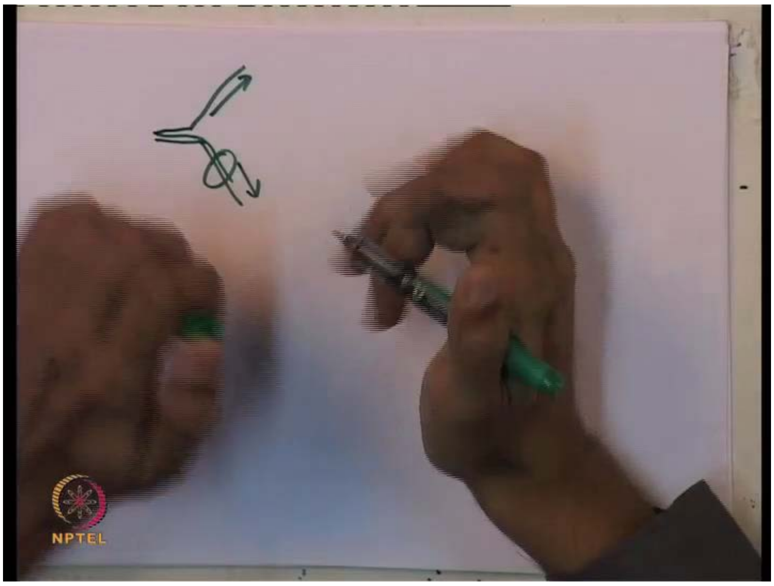

So you can have a situation where the machines you know M 1, M 2 for example, move together and they go out of synchronism with M 3 that is the springs break you can look at it that way he the springs are non-linear then the springs can break. So, you can have losses synchronism phenomena even in multi machine systems larger systems also have these phenomena of loss of synchronism.

So, what you have seen is single machine infinite buy system is all seen in two machine system it is also seen in a multi machine system when you go from graduate form single machine connected to a voltage source to a two machine system the additional phenomena, which you have to consider is the motion of the center of inertia when you go to the center of two machine system to n machine system.

The center of inertia motion of course, remains there, but you have got n minus one swing modes or patterns, but again the loss of synchronism corresponding to relative motion is still there you can have loss of synchronism for large disturbance only of course, there is an important point which you should remember is that in multi machine systems groups of machines may lose synchronism with respect to other groups of machines. So that is the major difference which you should know.

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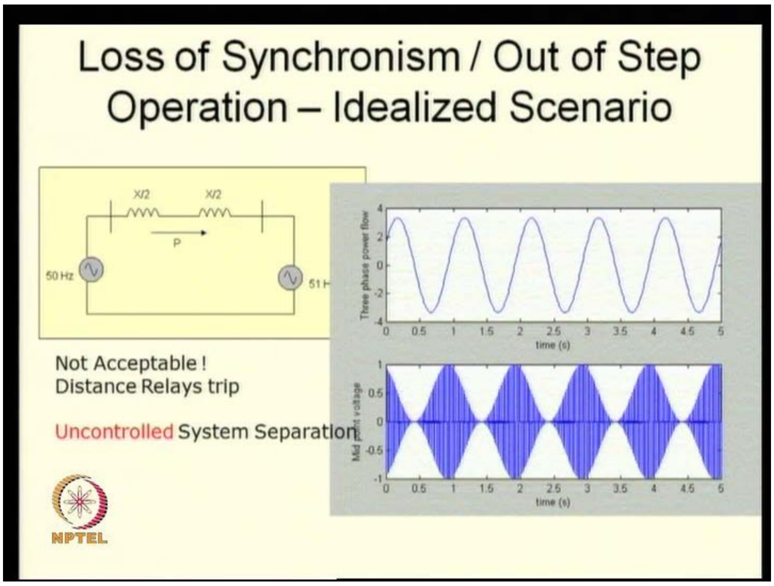


And as I mentioned sometime in case you lose synchronism that time is one set of machines has a frequency, which is tends to be different from other set of machines, then you will have oscillations, which is something we saw in the previous class, you have got oscillations in the electrical power as well as several at several places for example, in this example the midpoint voltage tends to oscillate this is a fifty hertz waveform, but you see the magnitude goes on going up and down.

So, in case two machines which are inter connected lose synchronism in that case you have got wild oscillations in voltage and other quantities and usually distance relays will think this is a fault. Whenever you have got voltage zero any distance relays which observe this kind of voltage and current will tend to trip and then you have got the separation of the two systems and as I mentioned sometime back whenever you have got loss of synchronism phenomena you have to separate inadvertently or untold fashion you separate and once you separate you are left with the other problem that is maintaining load generation balance in the separated system. If we remain connected you will have to see a very large these kinds of oscillations a hand variations which cannot be tolerated because they can lead to equipment damage. So, loss synchronism is never tolerated for more than you do not allow the you know machines to slip poles.

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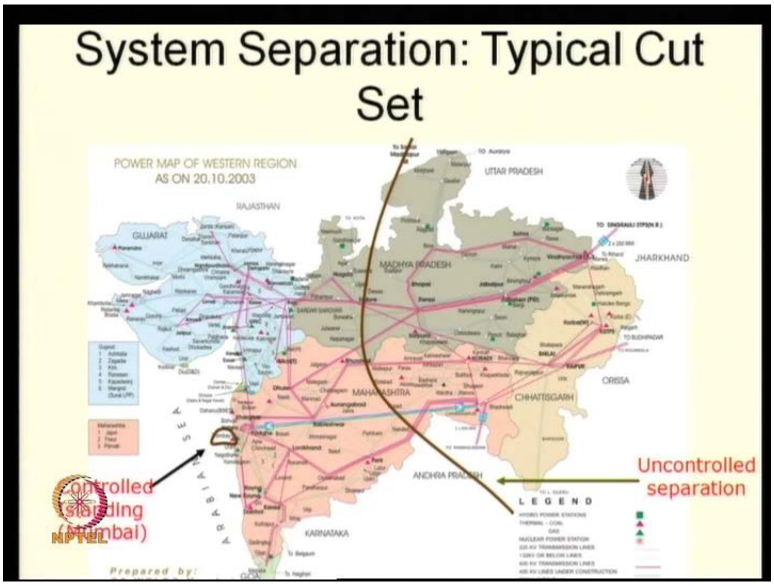


Several years ago, the western part of our country was a synchronous grid. In fact, now it has got integrated to several other grids in the country, but this is a scenario which was prevalent about four or five to six years back, when western region was a kind of an independent system which was consisting of the states which are shown here it was seen that for large disturbances groups of machines on the eastern parts of the western grid.

There are large machines here you know vindhyachalkorba and so on there are a large number of coal based generating plants here, they separated they normally used to separate out if the system was subjected to large disturbances. So, there are several instances where there were fairly large disturbances and the system used to separate out in the sense. These machines used to accelerate with respect to these machines, while still remaining connected to the center of inertia machine motion would have not really prominent, but the machines would be separating out with respect to each other and because of this the distance relays on these lines is to trip and cause islanding of the western part in the eastern part of the western region.

And once this used to happen, this used to be a load deficient rather a generation deficient area. So, the frequency in this islanded system would suddenly drop and often the system used to collapse. Interestingly in Mumbai we had a controlled islanding we have. In fact, a control islanding system which kind a kind of isolates itself from the rest of the system in case a situation several there are certain checks if this happens they separate out Mumbai form the rest of the western grid. This is the example of a controlled islanding, but you can have uncontrolled system separation as well.

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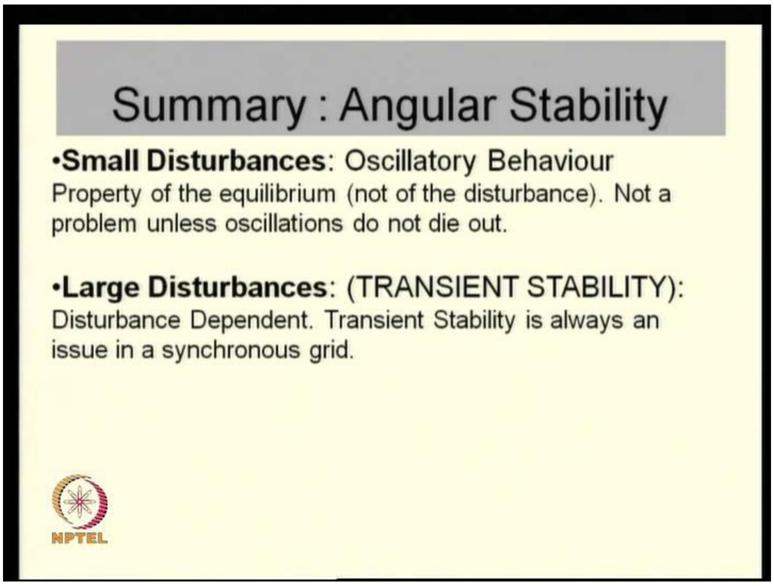


So, if you look at relative angular stability I should use the word relative angular stability because there is also corresponding phenomena of the center of inertia motion is also an electro mechanical phenomena. So, we will talk here in these two points which here are related to angular stability remember as I mentioned some time back small disturbances you generally say an electro mechanical behavior which is oscillatory which is a mixture of n minus one mode, remember that you can analyze small disturbance stability by Eigen value analysis of the linearized system around an equilibrium point remember the power system is a non-linear system. So, if you want to do small signal analysis you have to linearism around an equilibrium you have done this for the study of a v r some lectures back you can show of course, that for certain operating points the linearized system has got Eigen value s which have positive real parts sometimes you can have in fact, small disturbance behavior unstable too. So, this is something you should remember.

Large disturbances on the other hand are disturbance dependent they are also operating point dependent and quite in appropriately power system engineers refer to the phenomena of large disturbances as transient stability. Transient instability or transient stability refers to large disturbance. So, if the power system confronts you with the word transient stability what he really means is large disturbance instability which results in loss of synchronism. So, transient instability means that.

It is disturbance dependence and remember that in a synchronous grid that is synchronous machines connected by a c lines it is always found to be an issue there will always be some large disturbance for which a system loses synchronism. So, you take any multi machine system connected by a c line synchronous machine connected by a c line there will always be a large enough disturbance from which a machines lose synchronism. So, just to make this now absolutely clear I hope you will not have to recap this again.

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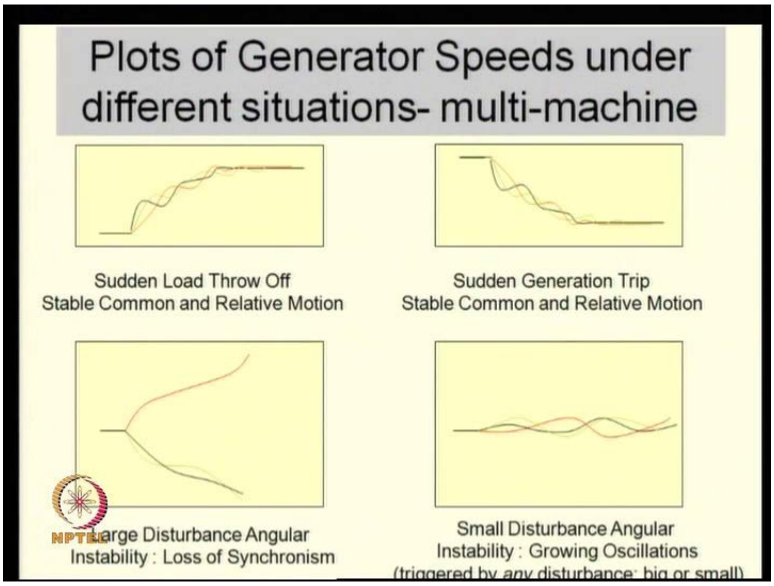


Suppose you have got this is a plot of generator speeds under various situations in a multi machine systemic of course, it is a multi machine system, but I have plotted only three machines, three speeds here this is a typical situations if there is a sudden load through off in the system the generator speeds tend to accelerate.

So, if there is a general load off you will find the swing you will see these power swings corresponding to the oscillatory motion, but more prominently you will feel the center of inertia speed is increasing and of course, if you have got governors or load frequency dependence or loads are frequency dependent eventually the system settles down to an equilibrium somewhere at a higher speed. Of course, if you have got one machine with an integer type of governing system or also called as isochronous governor you may find even that the frequency goes down back to the original speed, but most governing systems in a multi machine set up rather all you know multi machine set up you cannot have you know many machines having a proportional controller, I mean integral controller utmost one can have an integral controller.

Why that is something you try to think over, but typically all machines have proportional type of droop characteristics that is you will have some steady state error in frequency the governor will not get the frequency back to the previous speed you may have to do some extra work in order to get the frequency back to the original frequency that is called the secondary control.

So, that something we will not do right now in this course, but we can look at any undergraduate text book will take of governor action coupled with slower secondary control, if there is a generator trip on the other hand you will find that the frequency drops and although relative motion is also excited, the most important here you see is of course, the frequency tends to the center of inertia frequency will tend to drop and settle down. So, this is situation, where the common that is the center of inertia motion as well as the relative motion is stable if this occurs and this frequency deviation is not too much nobody will be worried too much everybody people will finally, say fine we have settled down to a frequency, which is slightly different from the original frequency usually power system you know, cannot tolerate anything more than half a hertz or so that is the absolute maximum of frequency of course, our normally this the amount of deviation you can allow depends on what the turbine blades in a steam turbine can you know tolerate.

Looking at the figures at the bottom what I see here the plot which I have shown here is two machines, the speed of two machines is kind of tending to deviate from the machine, which is shown in red generator speed which is shown in red this is an example of a large disturbance angular instability or what I termed as transient instability, this is a loss of synchronism phenomena. And you will find that it is relating to the relative motion between the machines. You also can have we have seen this in the single machine in the finite bus with an avr you can also under certain circumstances have the machine the synchronous machines having small disturbance instability this can happen if for example, you have control systems like an avr we have very high gains and they adversely affect the oscillatory modes.

This is electro mechanical mode it can happen we have seen that happen in the single machine infinite bus system. You find that you have got this motion which does not die down usually it is manifested as growing oscillation and is triggered by anything big or small. So, what you find is that we do have situations in which system operator is operating the system and he finds that after sometime. He notices that the oscillations which simply do not seem to be dying down, this is occurred in the past and what is effectively seeing here is situation of small disturbance instability whether no large disturbance occurred in the system, but you have entered an operating point or a new equilibrium point of a system is such that the system is small disturbance unstable.

So, you may actually have these electro mechanical modes going unstable small disturbance going unstable under certain situations you cannot operate this way you will have to do some corrective measures. So, that would involve at least and the planning and non real time operating stage tuning of controllers. So, that this does not occur.

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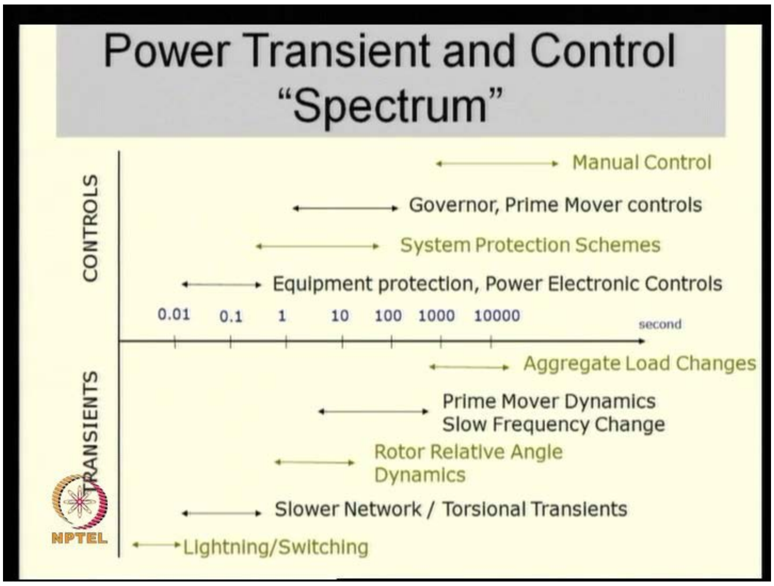


Of course, remember that something which should always keep in mind is what I have told you right now is a specific aspect the electro mechanical oscillations are a specific and an important phenomena which occur in synchronous grid, but there are other you know kind of phenomena and we should have some idea of the time scales, which are involved when studying them. Luckily there is a clear separation of you know, the time scales which are associated various transient phenomena for example, if you look at the this scale at the bottom the fastest transients are those associated with lightning and switching.

Then you have got the slower network transient associated with the electrical network as well as what we call as tensional transients associated with the shaft of the rather the shaft and mass system corresponding to turbines and generators these are also phenomena which are manifest, but these are faster phenomena relative rotor angle dynamics are. In fact, what we are studying now. They are occurring in the time scale or frequency range of one hertz, half a hertz, one hertz, two hertz half hertz you know that range you know these are relative rotor.

You have got slower frequency dynamics associated with the center of inertia motion that of course, depends on the overall inertia of the system the sum of inertia constants of the system So, it is a bit slower. In fact, prime mover dynamics those associated with the boiler are every very slow compared to for example, rotor relative angle dynamics and of course, very at a very slow level we have got aggregate load changes load there is a kind of pattern to how load changes over the day. So, that is a very slow change. So, luckily for us all these phenomena well separated out in time. So, actually that in that sense, we can analyze each phenomena separately; so you know that is an advantage I could take of relative angular motion without worrying too much about for example, some of the real Eigen values or from the patterns associated with the damper windings of a synchronous machine. So, you could actually look at electro mechanical variables in a focused way because one of the reasons it is a good time separation between various transients you need not worry about lightning switching transients whenever you are talking studying about you know relative motion dynamics.

So, if we recall it is important to correlate what we have done before in this course and what we are doing now whenever you are studying slow transients you can assume that the network and some parts of the system are in fact, in quasi steady state. So, for example, if you are studying electro mechanical transients you could afford to neglect the network transients and the state transients, because they are relatively fast this is something which we have beaten to theirs, when we were standing in the first five to ten lectures.

On the other hand when we are studying lightning and switching transient ship for all practical purposes we assumed that the speed of the generators etcetera is constant. In fact, most of the times while studying such transients you can safely assume that the machine has a constant speed running at a constant speed you may even model machine as a voltage source. So, remember that our modeling has to be consistent with the kind of a phenomena we wish to study. Now correspondingly you can also see what are the controls you know when we are talking about transient you can also talk in terms of control.

If you look at electronic protection and power controls they occur at a very they are quick acting. So, for example, the primary protection can act within a few cycles you know for example, there is a three phase part on a transmission line, you can the state of the art is you can switch it off you can trip out the transmission line and isolate the fault in just two or three cycles. You can have differential protection which acts even faster. So, this equipment protection acts as a very fast scale. So, does power electronic control. So, if we recall for most electro mechanical you know studies we could assume that a excitation system is the converter is modeled simply as a kind of a gain you give a control system and it implements the order.

Because power electronics controls in a system are also extremely fast. So, if you have got h v d c systems or the static excitation systems we need not model name extract excessive detail if we are studying for example, relative rotor angle dynamics or prime mover dynamics. So, just remember that modeling and analysis. In fact, the tools which you use for certain phenomena are kind of designed for that phenomena.

Of course you may take an approach that I will model all the whole system in full detail. In fact, you can model network transient safe transit everything and use a variable time step implicit method to integrate or simulate this system this is also a viable approach. In fact, now a day’s there is less of a distinction between fast and slow you do not have different programs to study fast dynamics slow, dynamics, long term dynamics you can in principle make a program in which you use an implicit numerical integration method and have variable time step so. In fact, you can capture not only the fast transient as well as slow transient as well, but at least whenever as the first step or to keep a good distinction between all the phenomena. In fact, people have written different programs with different modeling assumptions for a different phenomena, one class of course, I am not you know we will be talking of system rather methods for improving stability a boot alter in the course I mean the we are almost at the far end of the course, but we will still spend about a lecture discussing various ways to improve stability you can actually think of also implementing what are known as system protection scheme.

For example let me give you an example suppose there is a big load through off. So, you see what you can do is there is a big load through off and the frequency falls down precipitously rather it should rise precipitously suppose for example, let there is a generation trip and therefore, the frequency drops precipitously and your governors are not able to act well in time then you may think of deploying schemes like rate of change of frequency protection; that is the rate of frequency drop is higher in certain value trip out some loads. So, you can have these kind of local schemes which try to insure that the system remains you know the frequency of the system remains within a certain value, these are also known as emergency control schemes or rapid action schemes and. So on.

So, these are kind of what are known as system protection scheme which operate at a slightly slower level they are not what you call equipment protection schemes. So, they are typically act in the range of half a second and one second and so on. In fact, with the availability of synchronized non local measurements under what are known as wide area measurement system, one can device non local you know when I say non local means you are using signals which are time synchronized and obtained from various locations in the grid.

You can use these signals to fine tune some of your system schemes. So, this is some interesting research in this area which some of you can think about taking up. Governor prime mover controls are somewhat slower than system protection or equipment protection schemes typical equipment protection and system protection schemes and of course, manual control is the lowest amongst them all. So, this is a good giving you idea for various transient which you can encounter and what are their what is their bandwidth.

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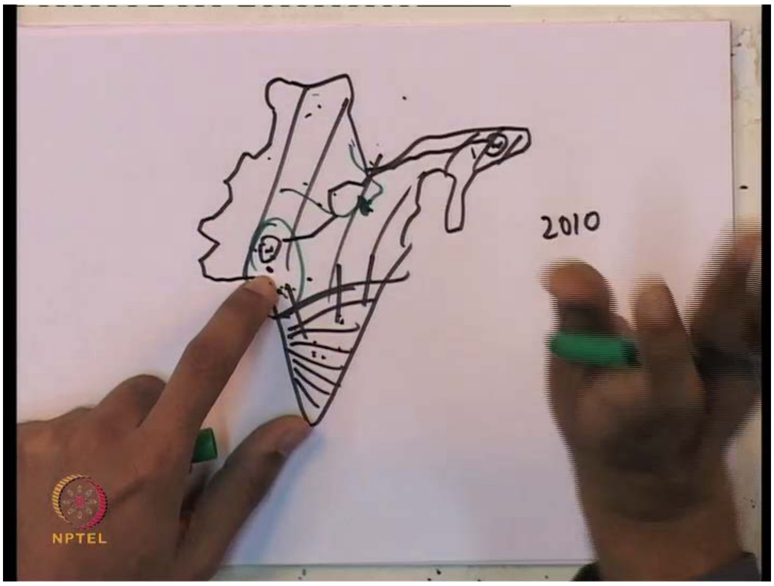


Let us just look at some actual system see this is a what I am going to show you next is the kind of measurements which we have observed in our grid for example at the present time in India you have got if you look at our country this is the approximate map. This portion of the grid is one synchronous grid that is they are synchronous machines connected together by a c lines, if you have a synchronous generator here you will find as a c line patch right up to any generator here as well. So, this is basically asynchronies grid you have another synchronized grid this is the southern grid these two grids are not connected to each other right now.

As of 2010, by ac lines they are connected by d c lines. So, actually to rectify the voltage invert it again. So, these two systems need not be of the same frequency but generators here they have to have a stable relative motion then all of them have to be running in synchronism in steady state, now what we did us we have measured frequency at fairly distant locations in the grid.

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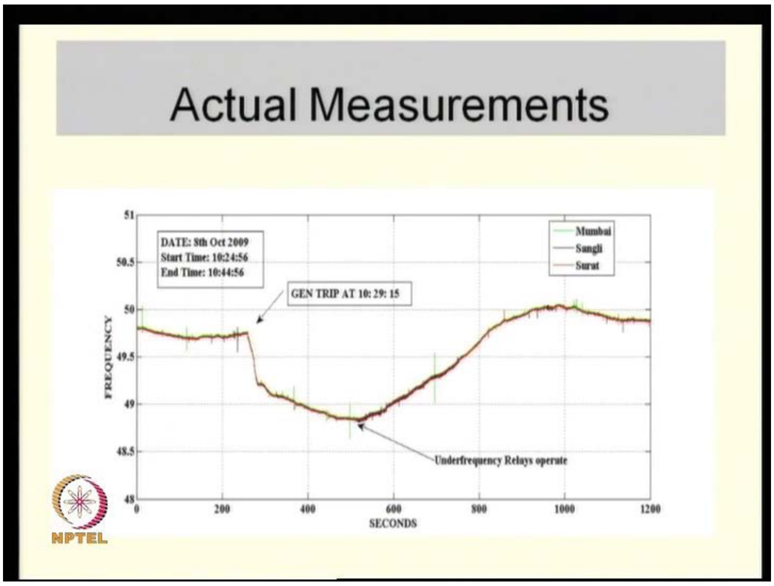


In fact, the ones I am going to show you are approximately 300 to 400 kilo meters apart this disturbance which I am showing you is a generation trip. So, generation trip has occurred and what you notice here of course that the frequency drops.

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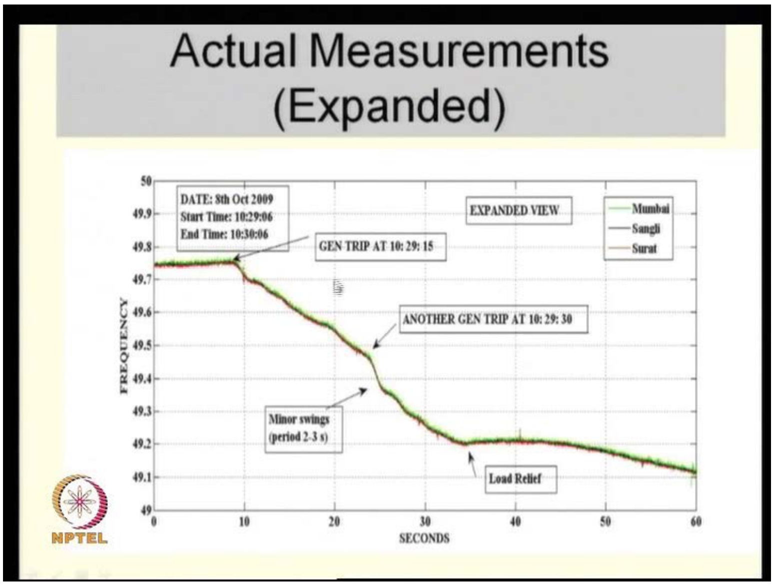


So, the center of inertia motion is suddenly excited whenever there is a load generation imbalance and this is a relatively large generation trip this icon expanded view actually which occurred somewhere the interesting thing is that is generation trip occurred somewhere in eastern trip occurred somewhere in eastern UP. Eastern UP is a state here.

So, it occurred somewhere here and what you notice is the frequency change which measured in the western region, since this is a synchronous grid and relative motion was stable for this disturbance the frequency here, here, here, here would have been the same.

But since the there is a sudden load generation imbalance caused by generation trip.The frequency dropped here, it infect it dropped everywhere in the grid because for this particular disturbance the system did not lose synchronism, relative motion was stable, but the measurement was done here and interestingly for load trip here for the generation trip here the effects are seen more than 1500 kilometers away in the western region.

And this is because they are all interconnected by ac lines, synchronous machines connected by ac lines. So, you see that the frequency drops down at a certain rate and there is another frequency there is another probably generation trip here then again the slope becomes normal. So, probably there was a load tripping here.

In fact, if you look at this slightly compressed graph what you notice is that the frequency drops kind of has a lower slope here and at 48.8 roughly you have under frequency release which are system protection schemes which tend to get that get back the center of inertia frequency back to normal, remember that the machines or frequency at Mumbai, Sangli and Sutra; which are all in the western region are practically the same forget all this noise which appears here this is measured here this is measured at a distribution point, so you have got all to of noise, but you noticed that all the frequencies are moving together you can hardly distinguish between the three locations. So, there is no loss of synchronism occurring.

The machines all move together, but because here is a load generation imbalance is a very prominent motion of the center of inertia of the system. This trip remembers occurred 1500 kilometers roughly away from the points where these measurements were taken.

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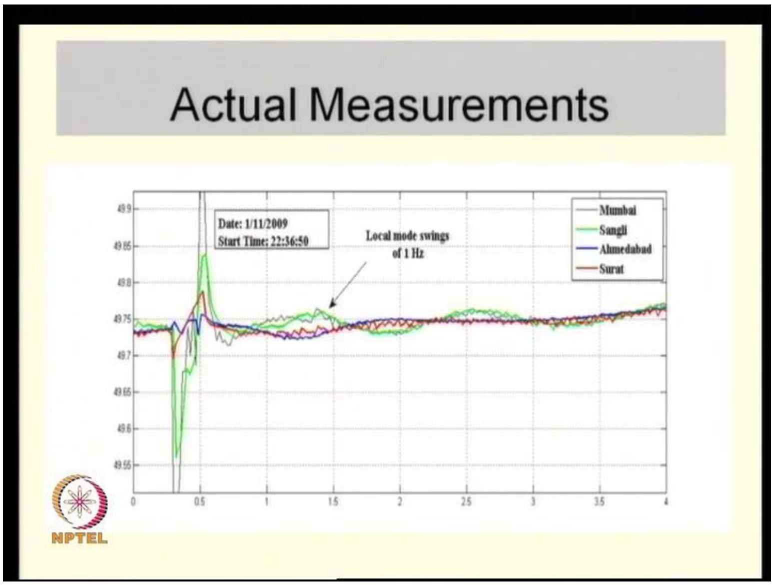


This is the another disturbance, but this is the fault situation. This is the frequency measured at four locations in the western grid, for a fault which occurred in the western grade. So, what you noticed of course, if you look at it carefully is that there is a very, you can see relative motion oscillatory motion of one hertz. So, you will find machines in the north part of the western grid, western part of the country that is at Ahmadabad and Sutra are swinging together against machines in Mumbai and Sangli. This is the approximately one hertz motion, they are moving out of phase is you actually see this relative motion. This relative motion is of course, stable because these oscillations remain eventually die out with time.

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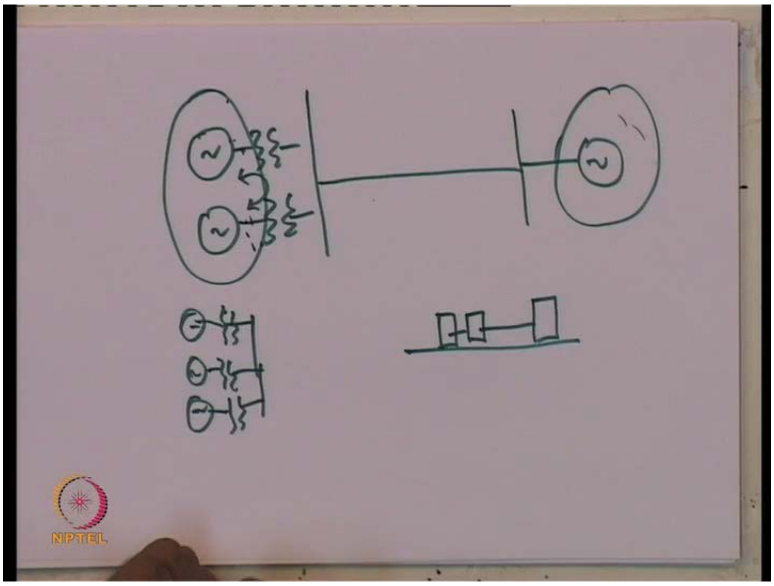

So, I would say, I really interesting phenomena which you are seeing here, which of course, is consistent with what we have understood. Remember that in case you have got synchronous machines say connected like this, two synchronous in close proximity connected to each other via say a long transmission line to another machine you will find that there is a relatively high frequency local mode and in which these two machines swing against each other and there is a low frequency oscillation, in which the two machines swing together against this machine. So, you can have a mixture of local and what you call inter area modes.

Even within a power plant if there are many units you can have what are known as the inter plant modes. So, I refer you to our discussion of the two mass three mass spring system where you have got two masses connected to a large mass the kind of behavior you have there so. In fact, you can break up the motion into several modes and in some cases you can very easily distinguish between oscillations within a plant or between generators in close proximity or machines moving together against other machines which hare far away these are called inter area modes.

So, you can have this kind of mixture of several modes remember I told you that for n machine system you can have n minus one modes. So, you have got all these mixture of modes in certain situations you can actually distinguish them you have got a high frequency inter plant modes relatively higher lower frequency local modes and much lower frequency inter area modes also. So, you can have all these modes of electro mechanical modes of relative motion. Interestingly for large disturbances you may lose synchronism because it is something which you have discussed some time back.

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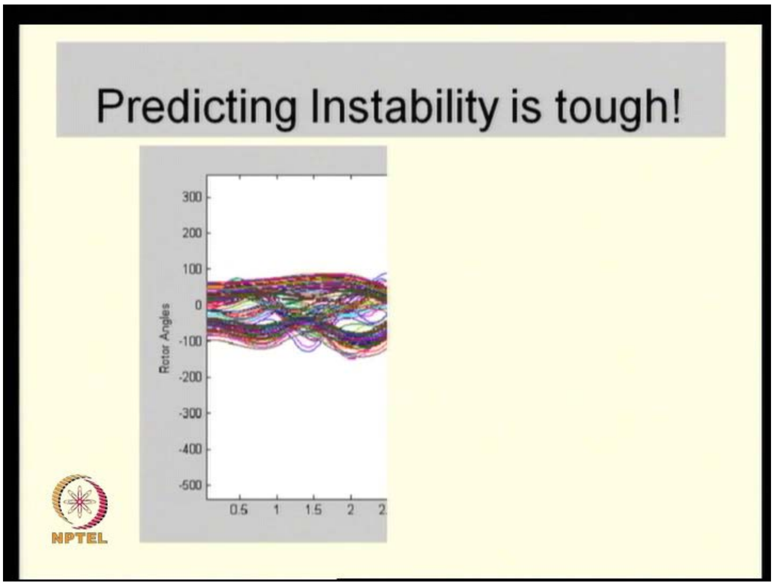


But it is difficult to sometimes predict instability for example, which group of machines will lose synchronism with respect to other group of machines it is a bit difficult to predict. In fact, if you look at the movement of the machines following a large disturbance sometimes just by looking at the mirror a short while it may not be possible for you to tell whether the system is going to go unstable a few seconds later or not.

And if it goes unstable what are the groups of machines how will the system separate out, that is something which you cannot easily tell without actually doing simulation on the system; with a two machine system there is only one mode of separation the two machines fall apart, single machine infinite bus system, single machine loses synchronism with the infinite bus.

In a multi machine system that may be much more tough because you can have many modes of separation just like you can have many modes of oscillation for small disturbances for large disturbances for certain large disturbances you can have many modes of separation and that may be not easy to tell which machine is going to fall within which group an accelerating group or decelerating group.

So relative motion, so large disturbance relative motion leading to loss of synchronism, may be difficult to may be difficult to predict unless you do a simulation actually see there is no you have to do it the brute force way sometimes to get an answer to this question.

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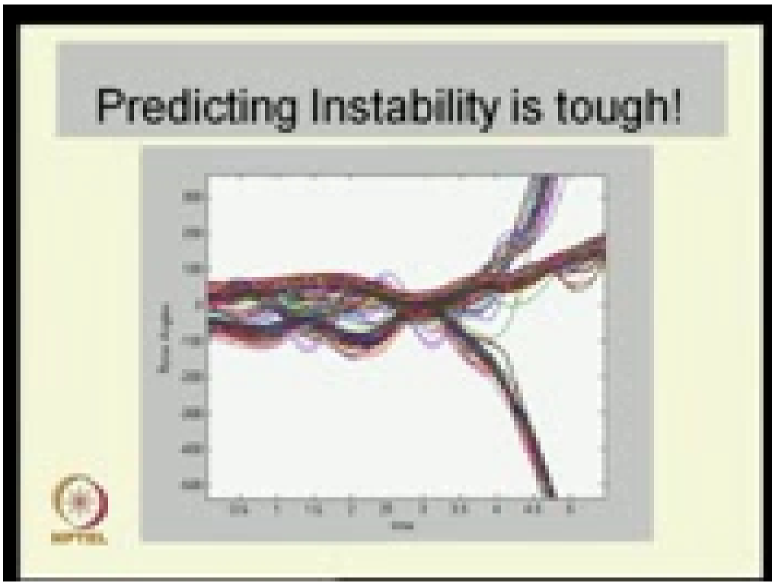


So, just look at this graph, which I am showing here. These are the relative angle plots for the motion of around 300 generators of western region, this is a kind of an academic, academic, but realistic study not a real study, but a realistic study of 300 machine system and this is a evolution of angles up to two seconds for a fault which occurred at 0.5 seconds which have cleared after sometime.

Cleared in the sense the line which the fault was there was tripped out. So, the rest of the system was fault free after that, but because of the disturbance the system was disturbed from the equilibrium and starts evolving the transient starts evolving and you see actually several modes you see a low frequency kind of mode and some high frequency oscillations also so you have got a mixture of several alternative modes which are seen after this disturbance. Now, the question is will this system lose synchronism or not something is difficult to say just from what you have seen here. So, let see how the system eventually evolved actually did a numerical integration of this system. And what I see here is the system breaks into three groups. So, groups of machines and losing synchronism with another group of machines.

So, this kind of thing can cause a complete you know this is a system wide kind of breakup of the system and you know well the system is still interconnected, but as I mentioned some time back you may outer step relays or distant relays actually causing a system separation and now if each of the islands which have formed after the is system separation the load generation balance is now quickly maintained using under frequency relays or by governor action or prime mover action or sometimes even generated trips you may find that each of these islands may collapse and that will cause system wide blackout. These kinds of things does occur though rarely it is a nightmare for a system operator if the system a disturbance leads to a system collapse of this kind

So, that starts off with a losses synchronism then the system separation cause islands is do not survive and you will have a blackout. So, you will have now started a restore the system from scratch you have to re synchronize all the machines. So, that is an extremely intensive and difficult process and sometimes it may take hours if not days to get back the system. Back to normal let us re synchronize and reintegrate the grid. So, this occurs rarely, but it can occur it is a nightmare really for a system operator, but for our academicians and students it is a very interesting outcome of the physical equations which govern the system. So, in that sense, it is very exciting.

We do not have time in this course to now look at the power system tools which are used to understand these electro mechanical transients we have actually done a two machine example and I told you how the equations are, but I really did not tell you the intricate detail is about how you solve these equations of course, you have to apply some numerical integration method or in case you are doing eigen analysis you have to do form the linearized system matrices, but we will spend a bit more time on the topics, which are shown on your screen in the next lecture, this is more to do with the power system tools which are used to understand transient stability or even the small signal stability, remember that simulation as a tool is very general. You can use it to understand fast rather small disturbance rather larger disturbance problems. So, this is what we will do in the next class; see you then.