Computer Aided Power System Analysis
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Lecture – 49
Fault Analysis

Hello friends. Welcome to this lecture on computer aided power system analysis. From this lecture onwards, we will be discussing the topic of fault analysis of our system. But before that we have already said in the last lecture that we need to discuss the issue of measurements for power system state estimation. So today, we will first discuss that issue briefly and then after that we would be actually start discussing the issue of fault analysis of power system. So in the case of power system state estimation, so we are now talking about power system state estimation.

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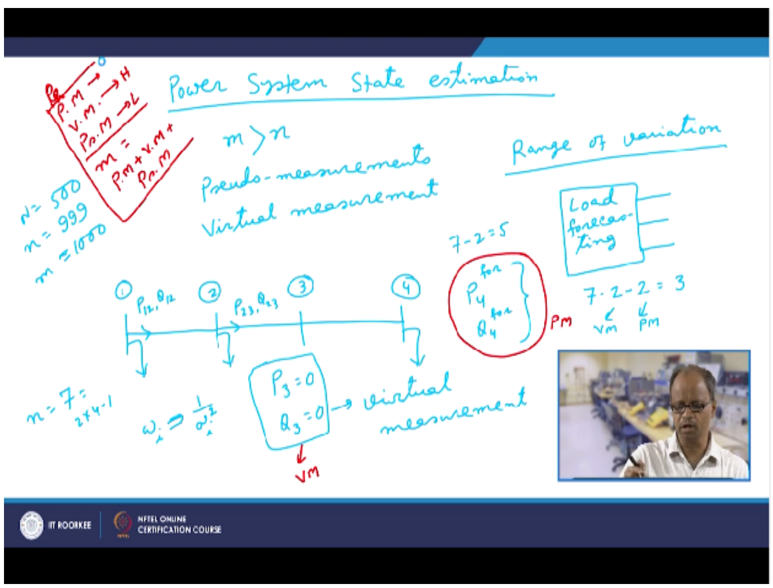

So power system state estimation, it will just take 5 to 10 minutes. After that we will start fault analysis. So we know that the number of measurements aim always has to be greater than number of states. And this is due to the fact that we need to take into account the presence of bad data and in case there is any bad data detected, so then we need to remove it and so then therefore our effective number of measurement gets reduced.

So to take into account that possibility, we need to ensure that always our number of measurement should be greater than the number of states to be estimated. Now suppose for an example that we do have, let us say, 500 bus system. N=500. So then in that case n would be 999, so then obviously my aim should be at least 1000. In fact, it should be much more than 1000.

So now the point is that if I have to put all this meters into the system, it may not be always possible, neither it may not be always very much feasible, neither it may not be always very much cost effective. So then instead of using our physical measurements, we also use 2 other types of measurements. And basically these 2 types of measurements are called pseudo-measurements and virtual measurements.

Now please note that these particular pseudo-measurements and this virtual measurements are not the physically metered quantities. That means we are not really putting any kind of physical meter to get these values but we will get this values from some other information. Let us see. First let us come to this aspect of virtual measurement because it is easy to understand. Suppose that I do have a system like this, bus 1, bus 2, bus 3, bus 4, 1, 2, 3, 4; 1, 2, 3, 4.

And let us say, at all these buses except at bus 3, there are loads. There are loads and these loads can always change. So then I really do not know that what this values are. But I know that there is no load at bus 3. So then therefore, I can always say for sure either $P3=0$ and $Q3=0$, for surety. Because there is no physical load, so then therefore, these values of injected powers would be always equal to 0 come what may, right.

So then therefore, these information are very accurate information, right and which are already known. So then therefore, these kind of information which are already known very accurately, these are called virtual measurements. Virtual measurements means that we are as if that we are virtually measuring this without putting any physical meter there because we already know what their value would be from the other sources.

And these values would be quite accurate. Now what happens in the case of pseudo-measurements? Suppose for example if we look at, let us say, a load at any bus and this load, all these loads at bus 1, 2, or 4, they can also vary. But now if I know that their range of variation by some historical data, let us say that we do measure these loads for, let us say, for past 10 years and then we have got all these data and then we do something called, let us say, load forecasting technique.

Suppose we do employ something called load forecasting techniques, suppose called a load forecasting, where and these particular load forecasting model will simply give us the forecasted values of loads at bus 1, 2 and 4. Obviously these forecasted values may or may not be equal to the actual load present but then these values would be probably somewhat closer to the actual loads, right.

So then in that case, if I do use them so then in that case I really do not have to put a meter for measuring these loads. Now here in this case, here, here, here for example in this case, a total number of states to be measured is 7, that is equal to 2*4-1, so that is equal to 7. So then therefore, I need at least 7 measurements. Now if I have to put meters here, so then probably I need to, let us say, measure P12, Q12, let us say, I also probably have to measure P23, Q23 and etc.

So then therefore, I need to put at least 7 meters. But now if I use these 2 virtual measurements, so then therefore, my physical number of meter needed is 7-2=5. So then therefore, my actual requirement of the meters have got reduced. On top of that, if I perform say a load forecasting technique to forecast the loads at this particular bus, so then I would be having the values of P4 and Q4, we would say that it is estimated, we should not say estimated, we should say that these are forecasted.

Now obviously, probably with all probability, these forecasted values would not be exactly equal to this values had we put a meter at this particular location. But then with all probability, these values would not be either too far away from these loads values. So then therefore, if we also use these forecasted values, so in that case my requirement of total number of meters would be 7-2-2, that is equal to 3.

So this is for virtual measurement and this is for pseudo-measurement. So you see, so then therefore, I am able to reduce my requirement of total number of physical meters by more than 50% if I use virtual measurement as well as the pseudo-measurements. So as a result probably my installation cost of installing the meters as well as the installation cost of establishing the combination link from those meters to our central control center would be all reduced by half.

Now there is one small point to be understood. Now we have already said that for any measured values, we do use something called Wits, Wi. And we said that for any physical meter, this Wits are nothing but 1/sigma square, that we have already said that is already equal to 1/sigma square. But what would be the Wits for these meters as well as these meters or sorry, what would be the Wits for these measurements, that is these measurements, that is these pseudo-measurements, that is these pseudo-measurements which are nothing but the pseudo-measurements and what would be the Wits for these virtual measurements.

Now these virtual measurements are already known values and which values are very accurately known, right. So then therefore, we give these virtual measurements much more Wit as compared to the Wits we will give in even for these physical meters. So then therefore, the Wits of these virtual measurements we give very high. On the other hand, for the pseudo-measurements, these values are not very accurate but we hope that these values are also not too bad.

But because these values cannot be very accurate, so then therefore, we do keep their Wits to be relatively low as compared to the Wits given to the measurements obtained by physical meters. So then therefore, what is the final conclusion? That for power systems state estimation, we do use 3 different types of measurements. One is the physical measurement which we call physical measurement and then we use virtual measurement and then we use also pseudo-measurement, right.

Their Wits are very accurate, very high Wits. Their Wits are normal Wits and these you already know, and their Wits are low. And the total number of measurements aim is nothing but total number of physical measurement + total number of virtual measurements + total number of pseudo-measurements.

So then by using this philosophy, we do indeed reduce the requirement of our total number of measurements or rather we do indeed reduce the number of required physical meters, thereby reducing the cost of the meters as well as the cost of the communication links. So this closes the discussion on power system state estimation. Now let us come back to our discussion of this particular topic which we would be doing for the next couple of lectures or rather the next lecture.

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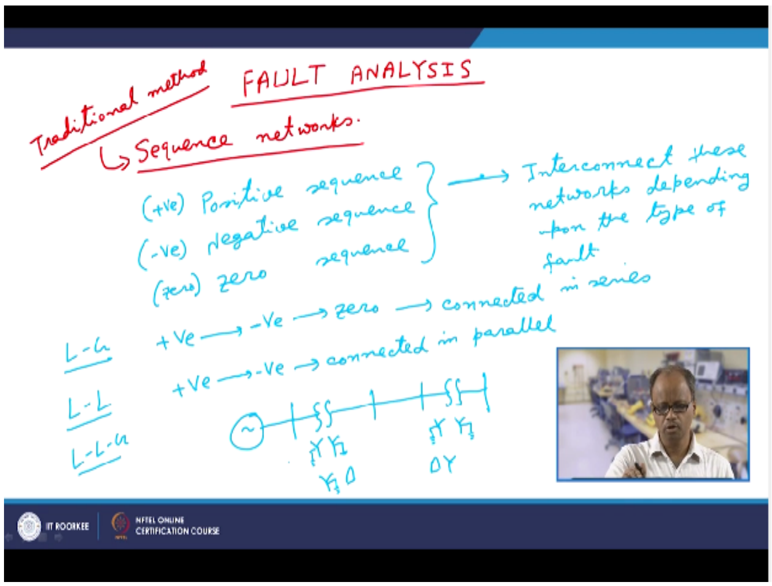

So what we start is actually fault analysis of power system. So what we do is fault analysis of Now you may be wondering that when we are saying that fault analysis of power system, what we are trying to do? After all in our standard course on power system analysis, we already do fault analysis of our system by utilizing sequence networks. Now what do we do in the case of sequence networks, with this approach?

This is already done. This is the traditional method. I should say that this is the traditional method and this traditional method is utilization of sequence network. So what we do in the case of this particular method? What we do is simply find out for actually any given power system network, we do find out positive sequence network, we do find out negative sequence network and we also do find out the 0 sequence networks.

So we first do find out the positive sequence, negative sequence and a 0 sequence networks and then depending upon the fault, then we interconnect this networks in a particular fashion. After that what we do? We interconnect this networks, interconnect these networks depending upon the type of fault. For example, if it is an LG networks then I know that this positive sequence, we call it positive sequence, we call it negative sequence, we call it a 0 sequence.

We know that this positive sequence and negative sequence and 0 sequence, this is negative, positive sequence, negative sequence and 0 sequence and they are connected in series that we know. These we have already learnt, connected in series. Similarly, if it is for LL fault, then positive sequence and negative sequence, they are connected in parallel and if it is LLLG fault, then these 3 sequence networks are also connected in parallel, something like this.

Now this is basically the traditional method. Now this method works well but there is only one simple problem of this method is that for a large power system network, we have to find out essentially 3 networks. Positive sequence, negative sequence and 0 sequence. Usually this particular positive sequence as well as the negative sequence networks are essentially the same. So when therefore, if we do find out the positive sequence network, then we also find out the negative sequence network.

But finding out the 0 sequence network is little tricky because this 0 sequence network depends on the transformer connection. As an example if I have in a system, for example if I have something like this, suppose something like this that I do have a transformer and then something like this, so then if both these transformers are star-star ground so then essentially finding the 0 sequence network is very trivial but then on the other hand if these 2 transformers are, let us say, star grounded delta and let us say, delta star ungrounded, so then therefore, for the same network, these 0 sequence network becomes completely different.

And in any large power network, there will be at least 100s of transformers and these 100s of transformers may have any connection. So then therefore, for any given large power system network, finding out, finding the 0 sequence network is always a tricky issue. So to avoid that, what we should develop is essentially a technique to analyze the behaviour of a system, upon occurrence of a fault, in the phased domain.

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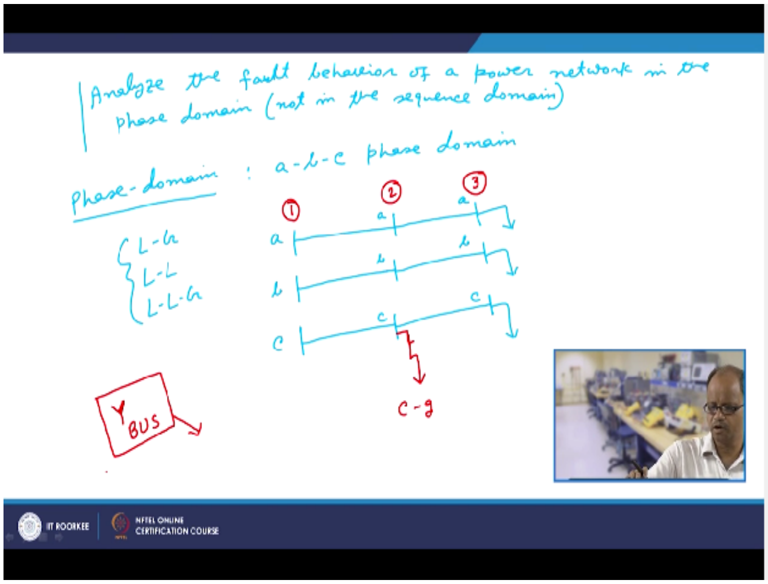

So our goal is, so then therefore, we should have, essentially we should analyze the fault behaviour of a power network in the phase domain that is not in the sequence domain. So this is our goal. So with this course or in this lecture as well as the ensuing lectures, we would be trying to find out or rather we would be actually discussing the method of analyzing the fault behaviour of a system not in the sequence domain but in the phase domain such that we do not have to find out 3 different networks of any given power network but, not 3, it is 2.

So at least if I am able to develop this technique so then in that case our advantage would be that we do not have to find out the positive sequence network as well as the 0 sequence network of any system. So then our work would be much less and it will be much more convenient. So essentially the goal of this module of this lecture is to discuss about the techniques of analyzing the fault behaviour of a power network in the phase domain but not in the sequence domain.

So then therefore, we will not be talking about development of the sequence networks but rather we will be talking about how to analyze the effect of a fault in the phase domain. Now when we talk about phase domain, phase domain means, that means we are talking about in the a, b, c phase domain. So essentially we are talking about a, b, c phase domain. It is not because our faults can be asymmetrical that is we can have faults LG, LL, LLLG.

So then these are nothing but the asymmetrical faults. Because our faults can be asymmetrical, so then therefore, we now need to consider the power system as a 3 phase network. So then therefore, whenever we are trying to discuss the fault behaviour of a power system in the phase domain and because we are going to analyze the fault behaviour for all these types of asymmetrical as well as the symmetrical types of faults, so then therefore, we now need to represent our power network in its totality that has an unbalanced power network.

That is we should not assume that our network is then completely balanced network. Please do remember that so far whenever we have discussed the techniques of load flow, contingency analysis, state estimation, etc., we have assumed that our system is a balanced network because we have simply represented the system as an 1-line diagram. We have only represented the system, only let us say as phase a or phase b or phase c, right.

We have simply represented the system as a 1-line diagram. And we have, essentially we have only represented only one phase of the system assuming that the system is entirely balanced. So then therefore, if we are able to calculate all the values corresponding to one phase, we should be, we would be able to calculate all the values at the other phases because for a balanced system, the voltage magnitudes at all the phases would be equal and their angles would be just 120 degree phase shifted.

But because here, we are talking about asymmetrical fault, so then therefore, even if we have a totally balanced network, now suppose I do have a totally balanced network. For example, now we just take a very simple example. Let us say, this is bus 1, this is phase a, this is phase b, this is phase c. And from this, there is one line is going. Then it is phase a, phase b, again phase c. And from there also another line is going phase a, phase b, phase c.

This is also phase a, phase b, phase c. This is also phase a, phase b, phase c. And let us say, there are also loads connected here, there are also loads connected here and there are also loads connected here. Now here, this is bus 1, this is bus 2, this is bus 3 and these loads are all balanced. So now let us assume that all these 3 lines are identical in nature. All these 3 lines are also identical in nature.

And these loads are also equal to each other. So then therefore, this entire network is completely balanced. But now if there is a fault at this bus, just an LG fault. So this is just a cg fault, so the moment there is an asymmetrical fault, right, this operation of the system becomes totally unbalanced. Because the same fault is not occurring here, so then therefore, this entire system operation becomes unbalanced.

So then therefore, even if we have a perfectly balanced system, all generation are perfectly balanced that is all generated voltages are perfectly balanced, all lines are perfectly balanced lines, all loads are equal to each other in all the phases. But even then if there is an asymmetrical fault, then the behaviour of the system becomes totally unbalanced. So then therefore, we have to first develop some technique for representing an unbalanced network through some proper appropriate matrix.

Now if we recall our discussion on load flow, we found or we have noted that for load flow analysis in which we do consider our system to be perfectly balanced and basically that is why we have represented the system as a 1-line diagram. We do capture this particular network, topology and everything, etc. in the Ybus matrix.

So for representing a system or rather for capturing the topology of the network, etc., we do represent, we have utilized Ybus matrix and this Ybus matrix is a very powerful matrix because the bus capture the entire topology of the network in a matrix and this matrix elements give us a lot of information.

But this Ybus matrix, we have only developed for a single phase system. Single phase system means that although our system was perfectly unbalanced but then we have considered to be a single phase system assuming that the system is absolutely balanced. So then therefore, analogous to the case of a balance system, here also we should first develop some method to find out the Ybus matrix of any given unbalanced network.

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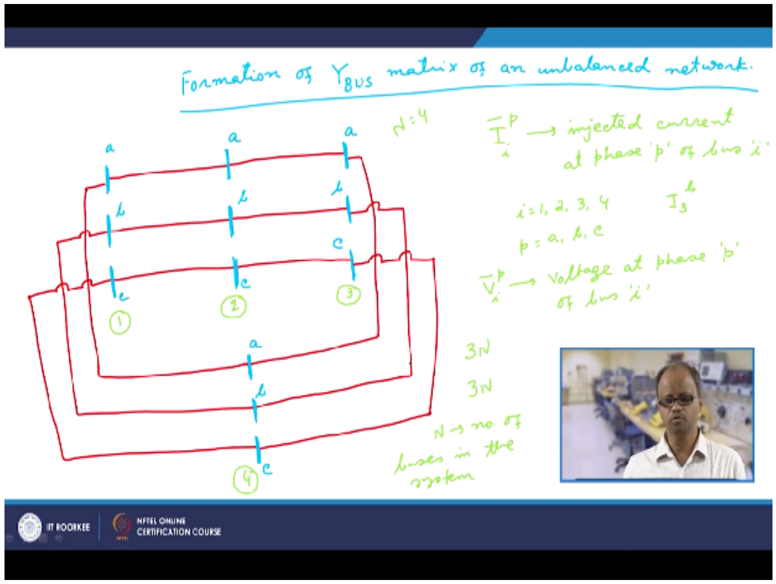

So our first task is to formation of YBUS matrix of a unbalanced network. Of course, when we are talking about unbalanced network, we are talking about unbalanced power system network. Suppose I do have, let us say, a 4 bus system. So now because we have to talk about unbalanced system, so now let us say, I do have a 4 bus system, bus 1, bus 2, bus 3; bus 1, bus 2, bus 3; bus. And let us say I do have something like this, let us say, 1, 2, 3.

So what I have is that these are the lines, these are the lines, these are the lines, these red lines are the lines and these blue lines are the buses. And I have connection between, and then we have. So this is the case. So what we have is now let us again, so these are bus. And this is phase a, this is phase b, this is phase c; this is phase a, this is phase b, this is phase c; this is phase a, this is phase b, this is phase c.

This is phase a, this is phase b, this is phase c. And let us say that this is bus 1, this is bus 2, this is bus 3, this is bus 4. So we are considering only a very simple 4 bus system and then we will try to understand that how to develop this Ybus matrix. Now please note that here what we have done? We have simply represented the entire system by its 3-phase entirety. Now at each phase of the system, now essentially at each phase of all these buses, there may be some load connected or there may be some generator connected or there may be nothing connected.

So then therefore, if there is some generator connected at this, at any of these bus in phase a, phase b and phase c, so then therefore, these generators will give some injected current or some injected power. Similarly, if there is some load connected at some phase of some bus, so then therefore, these loads will actually draw current obviously. So then therefore, according to our earlier discussion in those buses also we can think of some injected current which are nothing but the negative of the load current.

And on the other hand, if there is nothing connected at this particular bus, so then therefore, at those buses we can say that this injected current would be 0. So then therefore, analogous to the case, we have discussed for the single phase analysis, we can also have I, we can also have the injected current Ii and p.

What is Iip? It is the injected current at phase p of bus i. Now here in this example, I is 1, 2, 3, 4 and p is a, b, c, right. So then therefore, I can have something like I3b. So I3b means, will simply denote that the injected current at phase b of bus 3. Similarly, I can also define Vip. Of course these all are complex quantities.

So Vip, what is Vip? Voltage, of course, these are all complex voltage. Voltage at phase p of bus i. So in this case also, I is 1, 2, 3, 4 and p=a, b, c. Suppose for example in the case of a balance system, I would have simply I1, I2, I3, I4. So then therefore, there would be only 4 injected currents. But now corresponding to each bus, I have got 3 injected currents corresponding to 3 phases.

So then therefore, all together I have got 4*3, that is 12 injected current. So then therefore, for any n bus unbalanced systems, the total number of injected current would be 3N total number of injected current and the total number of voltages would also be 3N. Where N is the number of buses in the system. In this case, N=4. So this short introduction, we do stop. We will continue to discuss this important issue in the next lecture. Thank you.