Digital Protection of Power System
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Lecture 23
Coordination of Overcurrent Relays for Distribution Network - III

Hello friends. So, in the previous lecture, we have discussed regarding the features of digital overcurrent relay. And then we have discussed that coordination between the relays in distribution network is carried out and when we carry out this coordination among the relays, then we need to determine the three important parameters.

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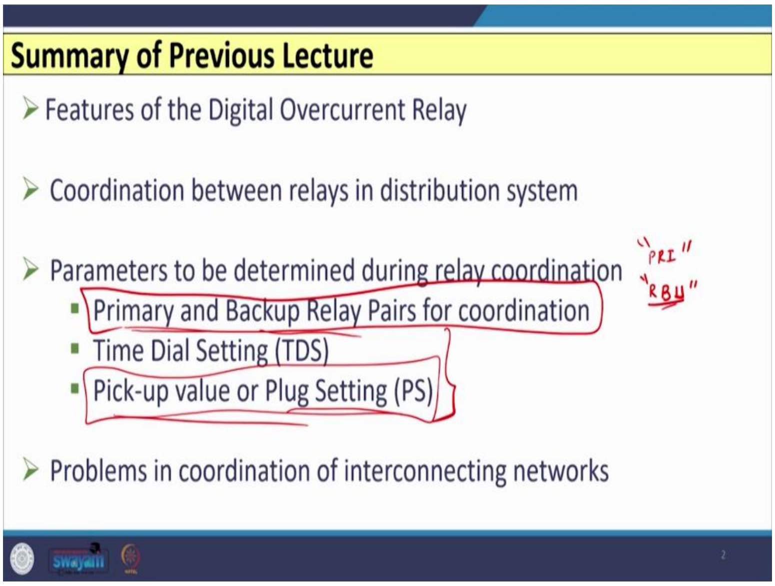

The first is the primary relay and backup relay pairs. So, primary relays are known as PRI, whereas, the backup relays are known as the relay backup, so RBU. So, this one we need to determine, then we need to determine the time dial setting of the relay and third thing we need to determine that is the plug setting of the overcurrent relay.

After determination of this thing, we have discussed that if we need to determine these three settings, then manual calculation is not possible. The reason behind this is that whatever network we are considering that network may be radial distribution network fed from maybe multiple ends or two ends, it can be multi-network system it can be multi-network multi-source system or it can be ring main system.

So, when such type of different structure of the distribution networks are available, then and when the number of relays in these structures or networks are also large along with the number of distribution feeders, then manual calculations are not possible. And in that case, we have to go for some algorithm for which we have to write the code in the some language and output of that code will give you these three settings. The first is the primary and backup relay pairs that is PRI and RBU.

Second is the time dial setting and the third is the pickup or plug setting of the relay. So, whatever LINKNET structure we will see that will give you the first part only that is the primary and backup relay pairs, the remaining two settings that is time dial settings and the pickup value and plug setting that will be calculated based on some other parameter also like we need to carry out load flow studies or short circuit studies.

Because load flow studies are used to establish initial condition in a particular network and second, the short circuit studies are utilized for the calculation of time dial settings, whereas plug settings are calculated based on the full load current of the feeder with some percentage of overload.

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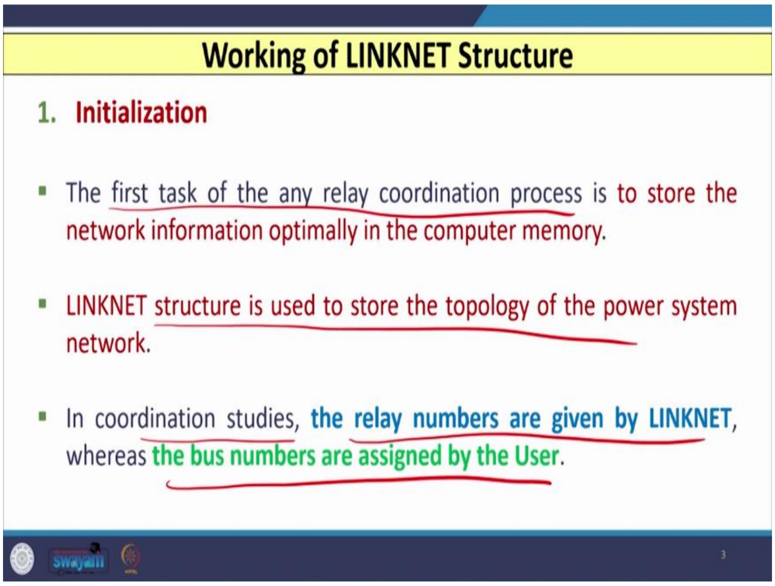

So, with this background, let us see how the LINKNET structure works. So, the first task of any relay coordination process is to store the network information optimally in computer memory. So, LINKNET structure is used to store the topology of a particular distribution network such that we can store that values optimally in the computer.

And using that we can process it and we can calculate the primary and backup relay pairs and those primary backup relay pairs can be further used for the calculation of plug setting and time dial settings. Now, when we consider the coordination among the relays, the relay numbers are given by LINKNET structure.

So, when we use the LINKNET structure, relay numbers are given by LINKNET structure, whereas bus number are assigned by the user. So, we have to enter or we have to give the bus number and based on that the relay numbers are assigned by the LINKNET structure itself.

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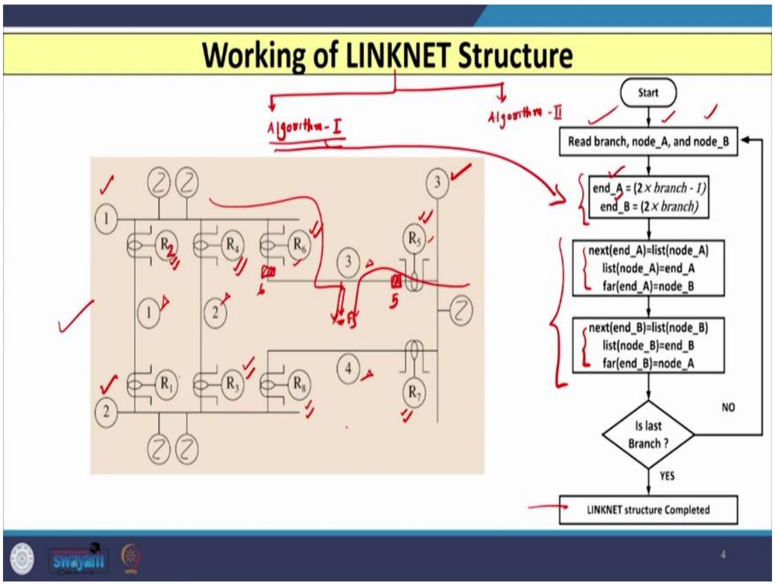

So, let us see how the LINKNET structure works. So, LINKNET structure contains two flowchart, two algorithms. The first algorithm is related to the calculation of few variables or parameters and second algorithm that is related to the determination of primary relays and calculation of backup relay pairs. So which relay will provide backup and which is the primary relay that will be taken care by second algorithm.

So let us see these two algorithms step by step. So, if we consider let us say one network so you can see here (as shown in above slide), I have shown you a network which contains 3 buses, bus number 1, bus number 2 and bus number 3 are there. And here you can see between bus 1 and 2, two branches or two distribution feeders are connected, which is number as let us say this as a one branch and this as a second branch (as shown in above slide).

So, branch 1 and branch 2 are connected between bus 1 and bus 2. So, basically this branch 1 and 2 are parallel feeders, then between bus 1 and bus 3, the another branch that is denoted by 3 that is also connected and the 4th branch that is also connected between bus 2 and bus 3. So, you can see (as shown in above slide) that in each branch I have connected or I have shown two relays, one is the relay R_1 and another is the relay R_2, this is R_2.

So, similarly, you can see that you have relay R_3 and relay R_4 for 2nd branch, you have relay R_5 and relay R_6 for the 3rd branch and you have relay R_7 and relay R_8 for the 4th branch. So, for each branch we have assigned two relays obviously and this is true. Why we require two relays? Because if there is a fault let us say in branch number 3 at let us say F_3. So obviously in that case, the fault current is feed like this one path and the second path is like this.

So, obviously this fault at F_3 should be detected by relay R_6 as well as relay R_5, R R_6 6 will give signal to the circuit breaker 6 that is available in substation 1 and R_5 will give signal to the circuit breaker 5 which is available in substation 3. So, both the circuit breaker will become open and hence this fault gets disconnected. So that is why for each branch we need two relays and hence here you can see for 4 branches 8 relays are shown. Now, let us see how the algorithm works.

So, as I told you LINKNET structure that is categorized by two algorithms, the first is we can call it as algorithm 1 and second, we call it as the algorithm 2. So, the first algorithm here I have shown in terms of flowchart (as shown in above slide). Here, in the first algorithm, you need to acquire or enter some data like you need to enter the data of branches, how many branches are there, you need to enter the data of nodes that is bus.

So, as I told you that relay numbers are calculated by LINKNET structure, whereas the bus number should be given by the user. So, node means here the bus, so bus number you have to enter and branch also you need to enter. After entering this you need to carry out some calculations in these two portions. So, you need to calculate few things like end A and end B, you need to also calculate these three things, that is next, list and far variables.

So, same variables are given here just by considering the node change. And after this you have to see that whether you have covered or consider all the branches available in a particular network or not. So here when I say, Is last branch? That means for this network shown here, whether I have considered or covered all the four branches or not, if all the four branches are covered or completed their LINKNET structure is completed, if it is first branch or second branch you have to go again, you have to read the branch data bus data and again you need to calculate these things. So, this will be cleared when we consider one example.

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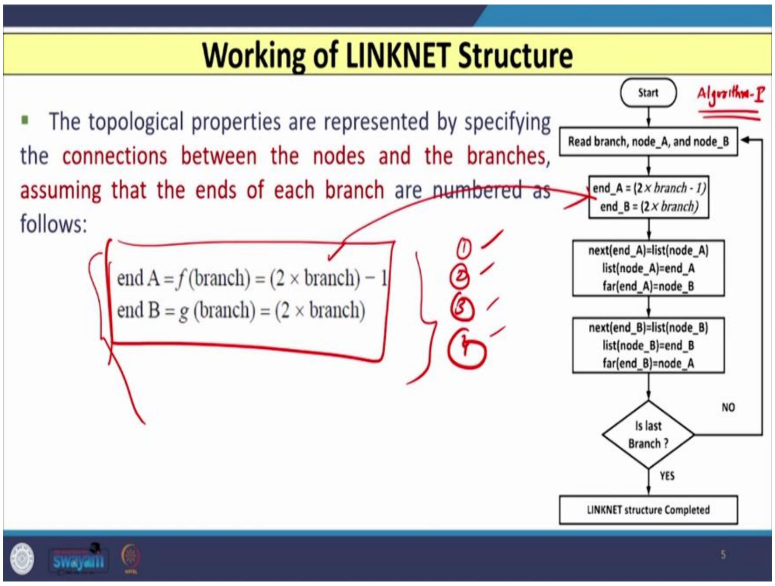

Now, when we consider this algorithm 1, this is my algorithm 1 (as shown in above slide). So, when I consider this algorithm 1, the topological properties that in this algorithm are represented by specifying the connection between the nodes and the branches. So whatever connection you are going to do between the node that is bus and the branches, because we know that a particular branch is connected between two nodes or two bus.

So whatever connections you will give between the nodes and the branches, assuming that ends of each branch are numbered by this way, using these two equations,

$$\text{end A} = f(\text{branch}) = (2 \times \text{branch}) - 1$$
$$\text{end B} = g(\text{branch}) = (2 \times \text{branch})$$

then that is represented by this algorithm 1. So, when you consider the ends of a particular branch, let us say I consider branch 1, branch 2, branch 3, branch 4. So, when I consider branch 1, then for each branch let us say 1, 2, 3, 4, the numbering is given considering these two equations.

So, these two equations you can see I have shown here in the algorithm, one is end of A and end of B both are functions of the branch. And that is calculated based on which branch you are considering, whether you are considering first branch, whether you are considering second branch like that. So, based on that you need to calculate these two parameters that is end A and end B.

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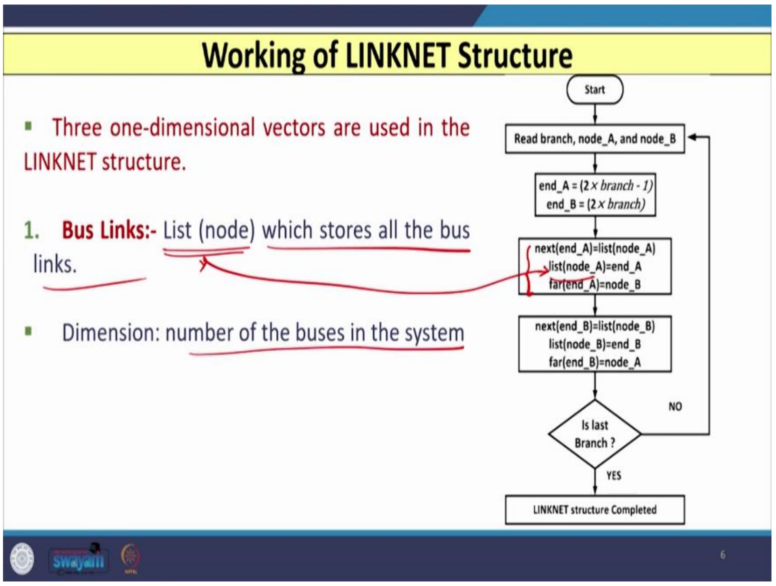

Once you have these two parameters end A and end B, you need to calculate three one-dimensional vectors and these vectors are shown here as next, list and far. So, this next, list and far are the three one-dimensional vectors, which you need to calculate in LINKNET structure particularly, when you are dealing with algorithm 1 of the LINKNET structure. So, let us see what is the significance of these three one-dimensional vectors.

So, when we consider the first one let us say list, then list is nothing but it is related to the bus link. So, list node which stores all the bus links and dimension of this is the number of buses of a particular network or this system. So, list node here you can see (as shown in above slide) second, I have shown that is nothing but your list node one-dimensional vector which stores all the bus links. And the dimension of this list node is again equivalent to the number of buses in the network or in this system.

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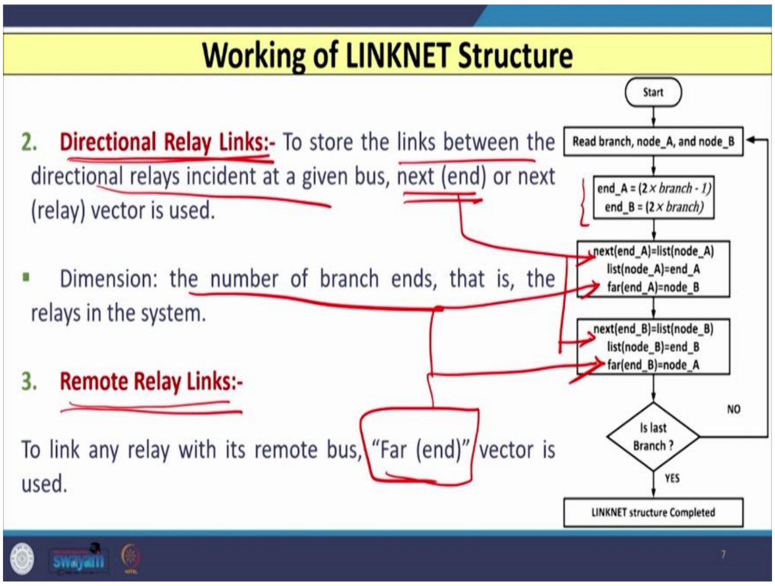

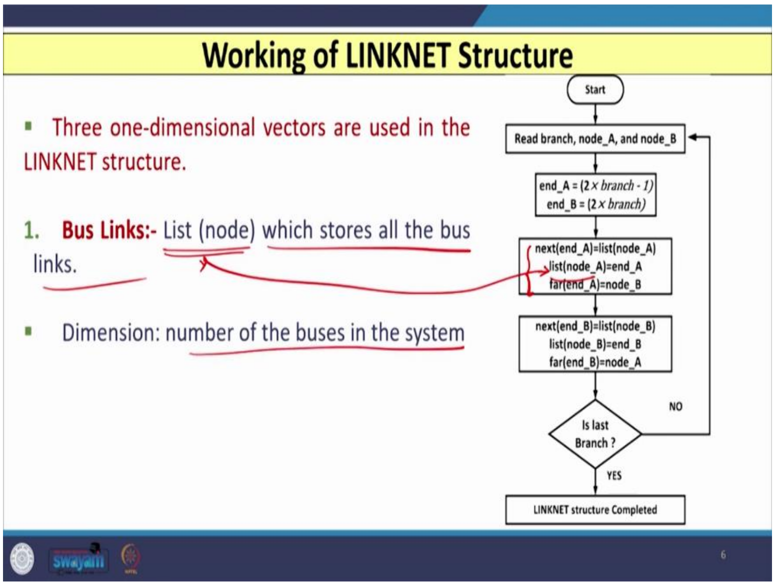

The second one-dimensional vector is nothing but that indicates or that is related to directional relay links. So, to store the links between the directional relays incident at a particular given bus, we have to define the one-dimensional vector that is shown as next. So, here I have given this in both the stages, next one-dimensional vector is given, next end or next end A and next end B, end A and end B we have already calculated here, so based on that, you can have the value of next (as shown in above slide).

And this one-dimensional vector indicates the directional link related to a particular or a given bus. And the dimension of this next one-dimensional vector is nothing but equivalent to the number of branch ends that is the number of relays available in a network or in a given system.

The third one-dimensional parameter is related to the remote relay links and this is defined as the Far vector.

So, Far that is also defined here. So, this Far vector is nothing but it is going to link any relay with its remotes bus that is defined as a Far vector. So, with this definition of these three one-dimensional vectors, one is the directional relay link, one is the remote relay link, and another is the bus link.

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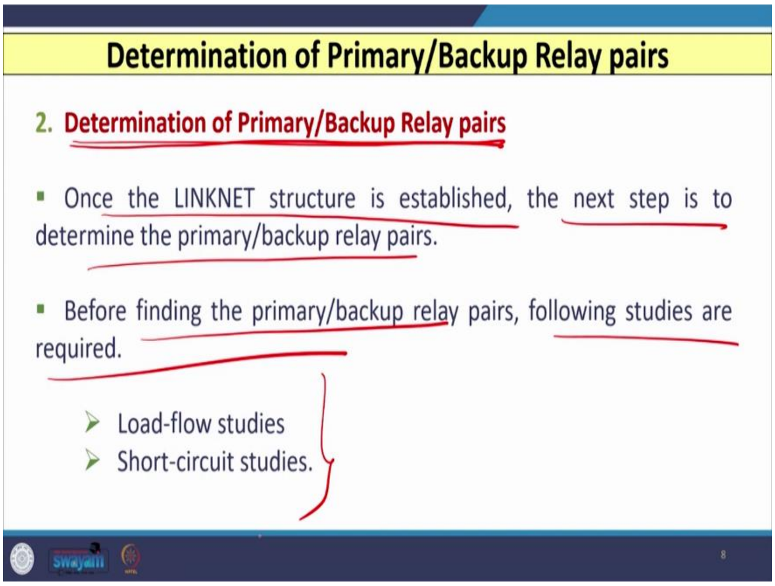

These one-dimensional vectors you need to calculate based on the equation or availability of end A and end B parameters, once you have all these things, the second step you need to follow that is nothing but the determination of primary and backup relay pairs. So, once you have the values of all these three one-dimensional vectors and end A and end B two parameters, you can have or you can calculate the primary and backup relay pairs and for that you have to use algorithm 2 for the LINKNET structure which is given. So, we will discuss this also.

So, once the LINKNET structure is established, that means once you have determined the three one-dimensional vectors along with the end A and end B parameters, the next step you need to follow is the determination of primary relays and determination of backup relays for a particular primary relay. If you want to find out primary and backup relays, you need to carry out these two studies.

As I told you earlier load flow studies you need to carry out to establish the initial condition for a particular or given network and short circuit studies are also required to calculate the fault MVA at a particular bus. So, for each bus you need to know fault MVA, so that you can calculate the plug setting multiplier or multiple of pickup current and based on that you can calculate the time of operation of relay and based on that you can calculate the time dial setting of the relay.

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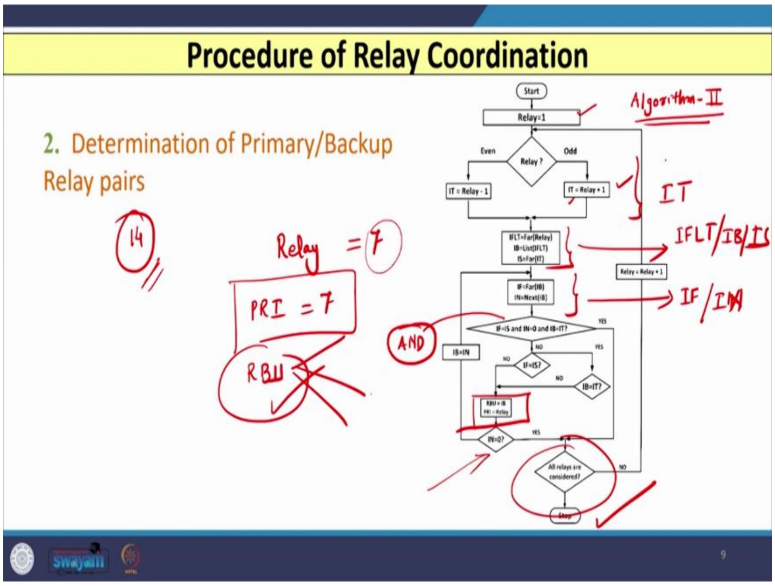

Now, let us see what is the procedure to calculate the primary and backup relay pairs. So, for that, we need to use the algorithm that is known as algorithm II or 2 for the LINKNET structure. So, whenever we wish to calculate the primary and backup relay pairs, in this situation, we have to use this algorithm 2.

And the flowchart of this algorithm 2 is given here (as shown in above slide). You can see, initially, you have to start in this algorithm or in this flowchart with the relay number. Let us say I want to find out the primary relay and backup relay, let us say I want to find out relay is equal to 7 suppose, so in this case, my primary relay PRI that is equal to 7 and now I need to find out the backup relay for this 7 number primary relay.

So, when I consider relay a particular number, then you have to decide whether that relay is even or odd. So, based on that, whether you are considering this 7 which is an odd quantity, you can have the value of IT which is nothing but relay plus 1, so 7 plus 1 that is 8. So, IT value you can calculate it based on the relay number that is what relay you are considering. Once you have this value of it, that is you can obtain here then you can have the values of these three things one is IFLT, which is based on Far.

So earlier one-dimensional vector IB, that is also based on list earlier one-dimensional vector. And IS that is also based on Far one-dimensional vector. So, here you can have the value of

IFLT, value of IB and value of IS. So, you have four values IT, IFLT, IB and IS. Once you have these four values, the next step is to calculate the another two values that is IF and IN. So, then after calculation of IT, IFLT, IB, IS, IF and IN, you have the logic whether IF is equal to IS and IN is equal to 0 and IB is equal to IT.

So, this is end logic. So, when all the three values are satisfied, maybe whether it is true or not, based on that again, you have one more logic IF is equal to IS or IB is equal to IT. Once you have this, you will have this box that is nothing but you are RBU is equal to IB, so whatever is the value of IB that is your backup relay for a particular primary relay.

So, if here I have considered primary relay as 7 and I want to find out for this relay number 7 which relays will provide backup then in that case RBU is equal to IB whatever value of IB comes out, number comes out that is my relay backup or backup relay. And this value of RBU can be more than let us say 1 or more, maybe more than 2, sometimes these values are 3 also.

And once you have this finally cross check with the value of IN, whether IN is 0 or not, if it is not 0 and again you have to assign the value of IN to the value of IB. So, value of IB changes and accordingly again you need to calculate IF, IN and then you have to compare and you can obtain the value of RBU and you have to stop particularly at this point where all the relays are coordinated.

So, once you have considered all the relays, let us say for example 14 relays are available. Then you have to cover all the 14 relays, you have all the primary relays as 14 relays, you have the backup relays of all these 14 relays which you have considered, once you have that then this algorithm will stop, if it is not and again you have to increase the relay number and you have to go up to maximum let us say 14. Because we have 14 relays and a particular network. If you have more relays, accordingly, you have to go and you have to calculate the primary relays and backup relays.

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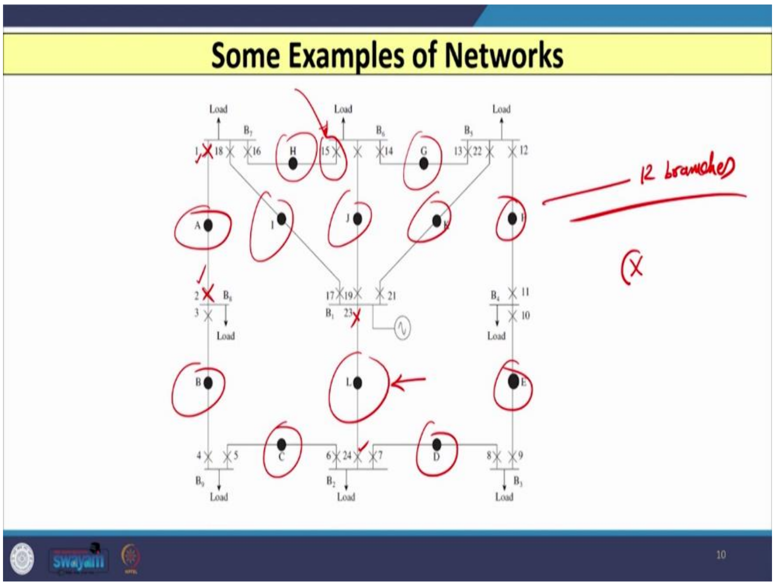

Now, with this background, let us see some of the networks available. So, that you can have an idea that how many relays are available, how many branches or link or distribution feeders are available. So, here you can see that (as shown in above slide) this relay has number of branches, you can see (as shown in above slide) I have shown the branches like A, B, then you have C, D, E, F up to you have let us say G, H, I, J, K, L, so this many branches are there.

So, if you calculate this, then you have 12 branches are there and as these are the 12 branches, and as I told you, for each branch we have to use two relays. So, total 24 relays are available in this network and you can see relays are shown by symbol cross. So, you can see that if I consider branch A, then two relays relay 1 and relay 2 are shown by cross like this you can see (as shown in above slide).

Similarly, you have 12^{th} branches, where that is L you can see (as shown in above slide) that here you have relay number 23 and relay number 24. So, these two relays are there. So total 24 relays are there. And for these 24 relays, you need to calculate primary relays, let us say if I consider relay number, let us say 15. Then for this 15 relay number, let us say this is the relay I am considering. So, if I consider relay 15 then I have to calculate which relays will provide backup to this primary relay 15.

Accordingly, I have to consider all the relays and I have to provide the backup or I have to calculate the backup for all the primary relays because those things are required, because it may be possible that sometimes if there is an issue of sympathetic tripping, there it may possible that one relay may give nuisance trip and your feeder may unnecessarily disconnected.

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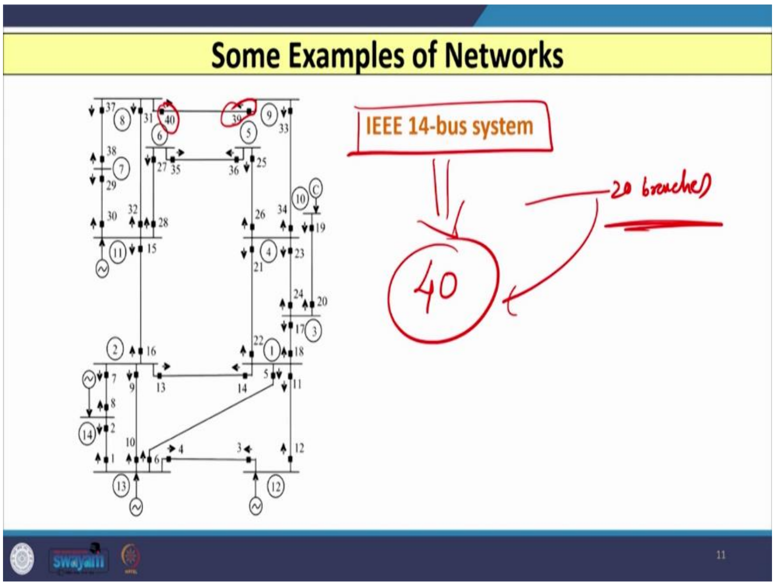

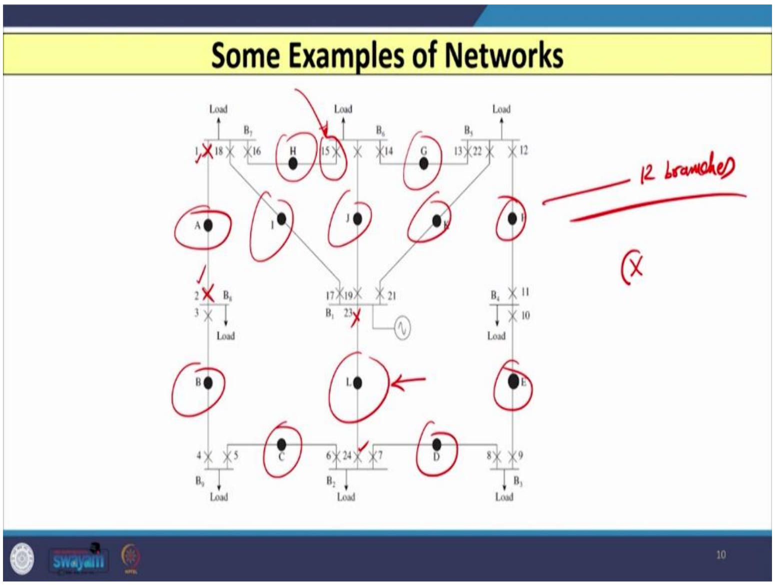

Similarly, if you consider, these systems are not standard systems, but if you consider some IEEE systems like IEEE 14 bus systems, then here you can say in IEEE 14 bus system, the total relays available are 40, you can see the last relay, (as shown in above slide) here that is number 40 and number 39. So, total 20 branches are available and for each branch I have the two relays, so total 40 relays are available in IEEE 40 bus system or network.

And here, manual calculation of primary backup relay pairs, plug setting and time dial settings are not possible. And hence we have to go for LINKNET structure which consists of two algorithms algorithm 1 for calculation of 5 parameters that is three one-dimensional vectors and 2 end A and end B two parameters and then we have to go for algorithm 2 which can be used for calculation of primary and backup relay pairs.

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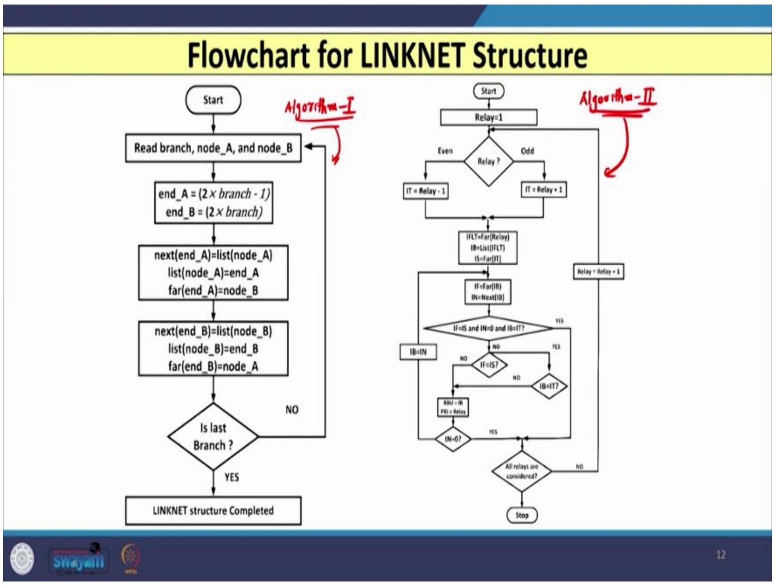

So, this two flowchart as I told you, this is my algorithm 1 and this is my algorithm 2 (as shown in above slide) which I need to use for the calculation of primary backup relay pairs for any given interconnected network which contains let us say a large number of relays and branches.

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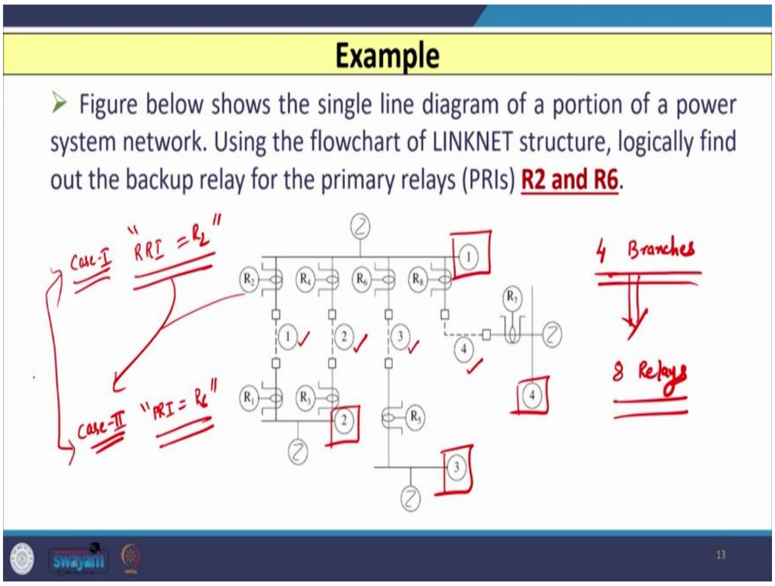

So, with this background, we will discuss one example. And in this example, I will just give you the highlights of this example. So, you can see (as shown in above slide) that here, the figure below shows the single line diagram of a portion of power system network. So here, you can see that four branches are there, this is my branch number 1, branch number 2, branch number 3 and branch number 4, four branches are there.

So, four distribution feeders are available in this network. The sources are connected at each bus. You can see (as shown in above slide) this is bus number 1, this is bus number 2, this is bus number 3, and this is bus number 4. So, four buses shown by square boxes. These are the four buses. And as I told you four branches are there. So, for each branch we need two relays. So, eight relays are available for this network.

And using the flowchart of LINKNET structure that is algorithm 1 and algorithm 2, we need to find out the primary backup relay pairs for the given relay, let us say case 1, in which I am going to assume that my primary relay PRI, that is relay R_2, okay. And for this relay, I want to find out which relays out of 8 relays will provide backup to relay R_2, if relay R_2 fails, because of some reason.

And similarly, in case 2, we need to calculate let us say by considering primary relay, as relay R_6, then out of 8 relays, which relays will provide backup to this relay R_6. So that we need to determine. And we will consider two separate cases case 1 and case 2. In case 1, we will consider relay R_2. And in case 2, we will consider relay R_6 and then we will determine using two algorithms which we have discussed in case of LINKNET structure, we will calculate the backup delays for R_2 and R_6.

So, in this lecture, we started our discussion with what is the LINKNET structure and why the coordination of the overcurrent relays are required. We have discussed that if we wish to carry out coordination of overcurrent relays for a large network which contains large number of relays and distribution feeders or branches, then we have to go for or we have to use LINKNET structure.

And if we want to use LINKNET structure, then two algorithms are there in LINKNET structure. In first algorithm we need to determine the three one-dimensional vectors along with two parameters end A and end B. And in algorithm 2, we need to calculate 7 different parameters and based on that we can have the value of a remote relays or backup relays for a particular primary relay.

And we have discussed just the outline of one example that if we consider the 4-bus network, which contains 4 branches and 8 relays, and if I want to consider primary relay as relay R_2 then which relays will provide backup. So, this we have discussed in this class. More related to this example how to calculate backup relays for R_2 and R_6 that we will discuss in the next class. Thank you.