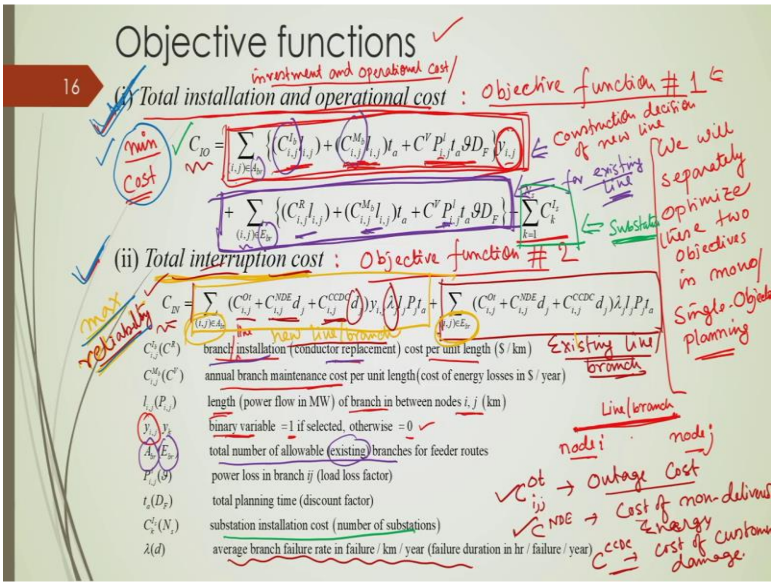
Operation and Planning of Power Distribution Systems
Dr. Sanjib Ganguly
Department of Electronics and Electrical Engineering
Indian Institute of Technology, Guwahati

Lecture - 26
Mono objective Power Distribution System Planning Approach

So, in my last lecture, I started module 6 that is Power Distribution System Planning different models and solution strategies ok. So, basically in my last lecture, I gave you an overview of different planning models available in the literature ok. And, in order to make you understand these different planning models, I gave a brief overview on basics of optimization. And, particularly what are the different types of optimization problems possible, those things I discuss in brief ok. So, also at the end of my last lecture, I discussed the formulation of a typical distribution system planning problem ok. And, that is basically single-objective optimization problem which means that we have one optimization objectives which we need to optimize under certain technical constraints ok.

(Refer Slide Time: 01:49)

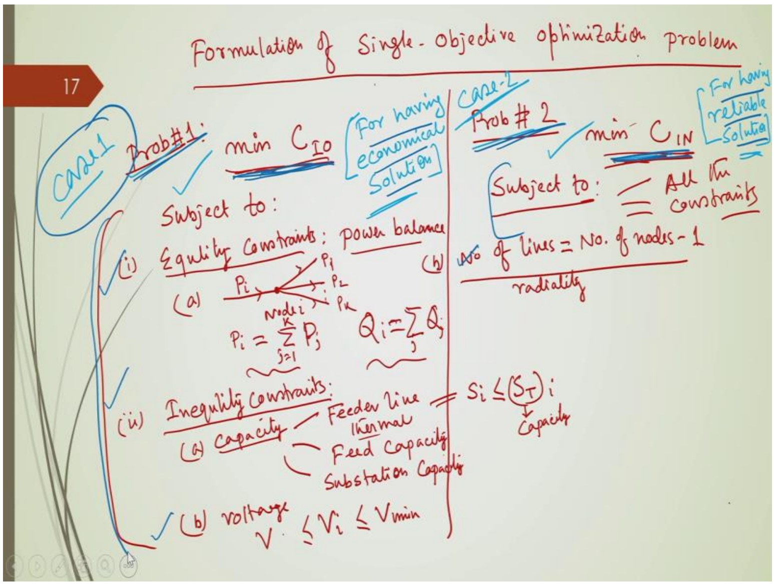


So, if I go to this my last lecture you can see you can see here we have shown that objective function formulation, objective function formulation. And, as I said although here we have formulated two objective functions, but actually we have one objective function which we will consider at a time; that means, we I have presented two different planning problems, two different planning models.

In one model, that is in problem 1, my objective function is total of installation and operational cost or total investment on operational cost or in fact, simply total cost which is basically sum total of all the cost components involved in a typical distribution network planning or design ok. So, this objective of course, we will minimize, this is a minimization problem. So, basically every time we know that we optimize the cost.

We minimize the cost in order to enhance the economy of the design network ok. So, this cost is optimized in order to improve the or in order to enhance the economic economy of the network or in order to have a economical solution; by optimizing this cost function we will get a economical solution ok, that I have mentioned. And, the 2nd problem and this of course, it is a constrained optimization problem. It means that we will optimize this cost function under certain constraints, those constraints I discussed in my next slide.

(Refer Slide Time: 03:34)

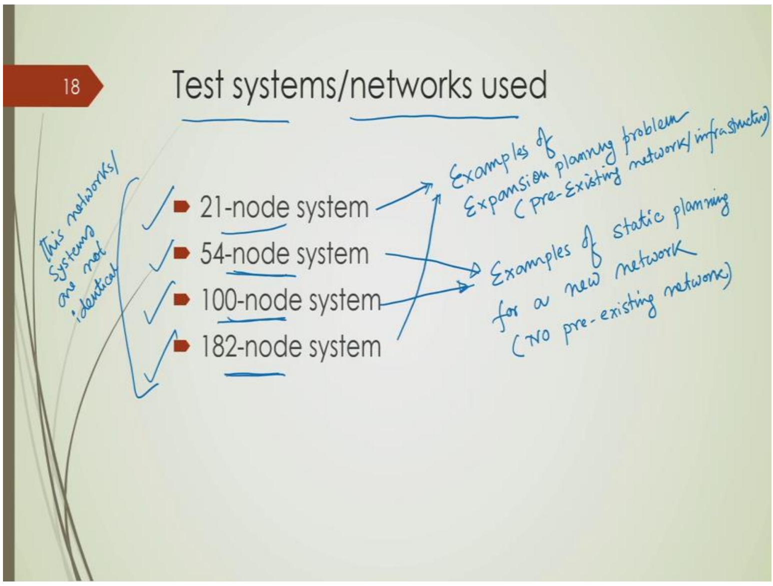


So, this problem 1 is minimization of this cost function under this constraints, we have 1, 2, 3 constraints and also in addition to that we have radiality constraints. So, this is radiality constraints ok, similarly this is what this problem 1 or case 1 ok.

Similarly, the 2nd planning problem is to minimize this other objective which is I mentioned next that is the total interruption cost by minimizing which we can maximize the reliability network or by minimizing that this objective function, we get a solution which would be reliable solution. So, our goal is to have reliable solution by solving that particular problem.

So, 2nd problem is to determine a reliable network and the 1st problem is to determine the economical network. So, this thing you have to clear. So in fact, the 2nd problem was to minimize this interruption cost or to maximize the reliability for under this constraint so, that we get reliable solution ok. And, in the 1st problem we minimize this total cost under this constraints, that is equality and inequality constraints, to have an economical solution. So, that is the thing that you should understand ok. In fact, all these technical constraints which I described in my last lecture are applicable for both the problems ok. Only objective functions will change, but constraints will be same for both this problem. Now, we have to verify these planning problems under certain systems ok.

(Refer Slide Time: 05:51)



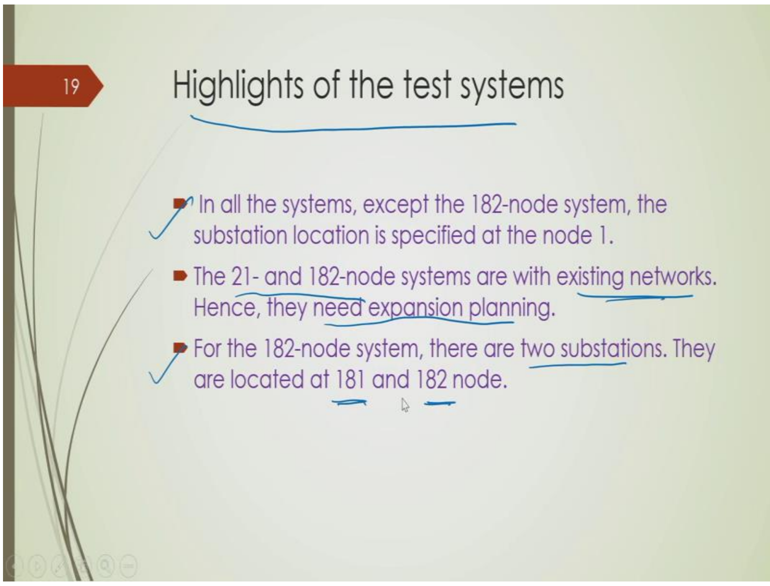
And here we have taken 4 test system or 4 test networks, one is a 21-node system; that means, that system or that network is having 21 load nodes or 21 number of nodes, not all are node load nodes, but we have total 20 number 21 numbers of loads or buses, 21 numbers of nodes or buses. The second problem is having 54-nodes, a network having 54 nodes. The third problem is a network of having 100 nodes or 100 buses and the fourth problem is a network with 182-node system ok, but we have many differences in this 4 system, they are not identical. So, these systems are not identical that you have to understand, this networks or systems are not identical that is one has to understand.

So, we have to understand that we have formulated this objective function in a generalized manner, but these problems are of different ok. How what are the differences? Now, 21-node system and 182-node system these two are examples of expansion planning problem; expansion planning problem, as I said there are two types of problem possible.

One is static planning; another is dynamic planning. In dynamic planning, we have a category where we need to expand the network. We have some pre-existing network which needs to be we have some pre-existing networks which need to be expanded with some additional nodes or additional load points ok. But, this 54-node and 100-node system, these are examples of static planning for a brand new network for a new network.

So, here in this case this expansion planning problem in for 21-node and 182-node systems, we have some pre-existing infrastructure pre-existing network or infrastructure ok. But, here for this 54-node and 100-node system, we do not have no pre exist we do not have any pre-existing network and we are supposed to build a brand new network. So, no pre-existing network ok. So, there are some differences. So, let me discuss this problem one by one.

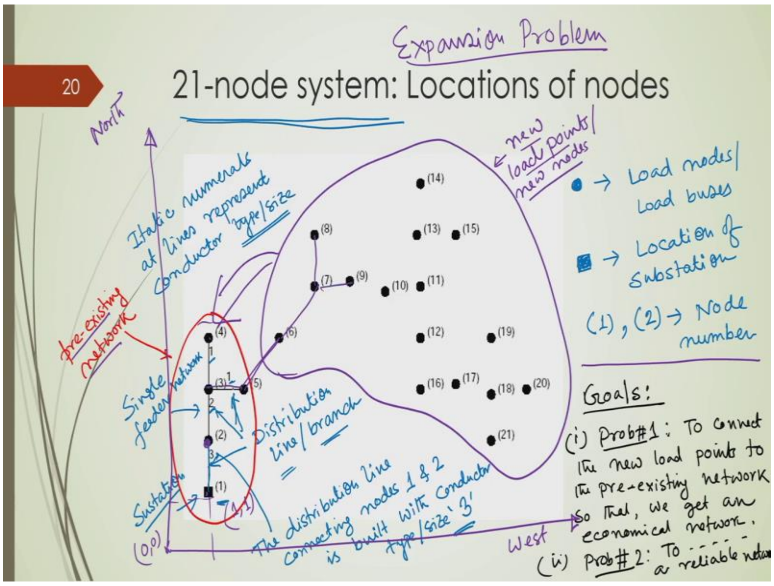
(Refer Slide Time: 10:04)



Let us start with; so, here you can find some highlights of this test system as I mentioned, 182-node system basically we have two substations, other than that we have only one substation for all other network ok. And, also for 21- and 182-node systems, we have some existing networks as I was talking about in the last slide.

So, hence they need expansion planning. But, for 182-node system, we have two substations. They are located at node number 181 and 182 and we have also some pre-existing networks which we need to expand with some additional node points ok.

(Refer Slide Time: 10:59)



So, let us start with this 21-node system. This 21-node system is having these black dots. So, these dots represent load nodes where we have some load demand or load nodes or load buses ok. So, here we have some load demand and this symbol is representing the location of substation; location of substation. So, here you can see here we have at bus number 1 bus number 1, we have substation located ok and this is a single feeder network.

So, this is a single feeder network which is pre-existing which is pre-existing. So, this node numbers are shown within bracket. So, this 1 or this 2 this represents node number alright and this line represents this distribution line; thin line, this represents distribution line or branch whatever you can call. In some paper they have considered I mean they have mentioned this as a branch and in some paper they have written as line.

So, what do you mean by line? Again it is the connection of the two neighboring nodes or two neighboring buses. So, we have a one line between node number 1 to node number 2, we have another line between node number 2 to node number 3 and similarly we have another two lines, one is node number 3 to 4 and one is node number 3 to 5 ok.

So, in between these two nodes we have one line each and in every line there is an italic numeral. You can see 1, 2, 3, 1; this basically represents this italic numerals at lines represent conductor size, conductor type or conductor size. I will show you that at conductor table where there are a sets of a set of conductors which are in fact, differentiated with conductor type 1, type 2, type 3, type 4 or size 1, size 2, size 3, size 4 and so on ok.

So, this 3 represents that this line which is connecting node number 1 and node number 2 is built with a conductor type 3 ok. So, we can write it again. So, this 3 represents the distribution line connecting nodes 1 and 2 is built with is built with conductor type or conductor size whatever you can call 3, conductor type or conductor size 3 ok.

So, now we have you can see we have this pre-existing network. So, this is pre-existing network ok and we also have this new load points or new nodes ok. So, we have a pre-existing network which consists of this bus 1, bus 2, bus 3 or node 1, node 2, node 3, node 4, node 5. And, we have some new nodal points, some new load points starting from node number 6 to node number 21.

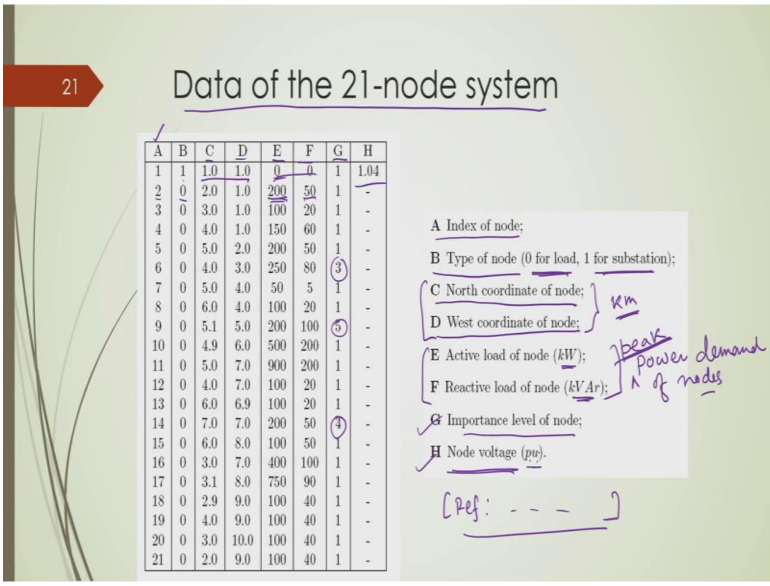
Now, our goal is to connect all these new load points with this pre-existing network with an optimal way ok, with an optimal way. Now of course, you can understand this needs an optimization problem to be formulated and we have formulated two optimization problems here, which I have shown you in by last lecture. One is we should connect this new load points to this pre-existing network, such that we get an economical network; we get an economical network ok.

And, the second and the second problem we have seen that we will connect this new load points or new loading points to this pre-existing network in such a way that we will get a reliable network. So, I can write it here. So now so, our goals are number i that is problem 1.

Problem 1 to connect the new load points to the pre-existing network; so, that we get an economical network, economical network ok. And, in problem 2, everything is same here also our goal is to connect all this new node or new load points to the pre-existing network, but here our goal is to find a reliable network. So, instead of economical network, here we are intending to have a reliable network ok.

So, this is that is what the difference between this problem 1 and problem 2 ok alright. So, I hope that this is understood and that is why, since we are intending to connect this new load points to this pre-existing network that is why we call this planning problem as expansion problem. So, this is an example of expansion problem because, ultimately we are expanding a pre-existing network by connecting with so many new node points ok. So, that is something one needs to understand.

(Refer Slide Time: 20:20)



A	B	C	D	E	F	G	H
1	1	1.0	1.0	0	0	1	1.04
2	0	2.0	1.0	200	50	1	-
3	0	3.0	1.0	100	20	1	-
4	0	4.0	1.0	150	60	1	-
5	0	5.0	2.0	200	50	1	-
6	0	4.0	3.0	250	80	3	-
7	0	5.0	4.0	50	5	1	-
8	0	6.0	4.0	100	20	1	-
9	0	5.1	5.0	200	100	5	-
10	0	4.9	6.0	500	200	1	-
11	0	5.0	7.0	900	200	1	-
12	0	4.0	7.0	100	20	1	-
13	0	6.0	6.9	100	20	1	-
14	0	7.0	7.0	200	50	4	-
15	0	6.0	8.0	100	50	1	-
16	0	3.0	7.0	400	100	1	-
17	0	3.1	8.0	750	90	1	-
18	0	2.9	9.0	100	40	1	-
19	0	4.0	9.0	100	40	1	-
20	0	3.0	10.0	100	40	1	-
21	0	2.0	9.0	100	40	1	-

Now, these are the data of this 21-node system; I will give the reference from where we get this data ok. In my list of the references you can find from where we get this data. So, here you can see we have in this table we have some columns. So, column A is basically representing this index of nodes: node 1, node 2, node 3 up to node 21.

Column B is representing this type of the node ok. So, node 1 is of one type; that means, it is for substation and other all nodes starting from node 2 to node 21; all entries as 0 means that they are load nodes; that means, that we have some loads connected to this node ok and column C and D represent this North coordinate and West coordinate of the node. So, this is basically shown over in my last slide.

So, suppose this is your coordinate system. So, basically all these nodes are located within this coordinate system and this is North and this is probably West coordinate ok. So, each of this starting from the substation all these nodes all these nodes are physically located in this coordinate system ok, in this coordinate system. So, it means that for node 1 this node is located one this is of course, I think it is in kilometre.

It is in kilometre so; that means, this is located 1 kilometre North, West starting from the reference point. So, this is, suppose, reference point 0, 0. So, this is basically the location of 1 comma 1 ok. So, with this physical coordinate system you can find out the distance between these two nodes. So, you can easily find out this, what is the distance between these two nodes, what is the distance between these two nodes and so on so.

So, what is the distance between these two nodes? So, this you can find out with this coordinate system that is from C and D ok and E and F represent this power demand. So, this represents power demand of nodes. So, you can see that since you know that node 1 is at it is substation so, or it is slack bus or slack node. So, power demand is written over 0 and, but all other nodes having some finite power demand.

For example: node 2 is having 200 kilowatt of active power demand and 50 kVAr of reactive power demand, but remember this is a planning problem and this kilowatt and kVAr basically representing peak load demand. So, we always, as I mentioned at the module 2, that we design a network by considering peak load demand; by considering peak load demand ok.

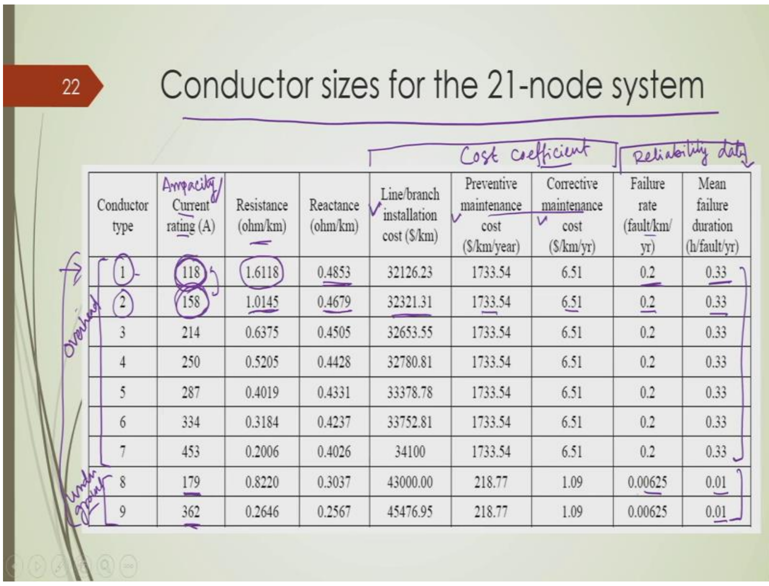
So, whatever network we will be getting after executing this optimization problem, this network should be capable of supplying this peak load demand. So, that is what the goal and all this planning process subsequently all these test systems the planning or to design a network, we consider the peak load demands ok.

And that peak load demand may be a projected peak load demand for next 10 years or maybe next 15 years depending upon what type of planning horizon you have chosen. So, it is of course, not the peak load demand at this present time because we build a network, we design a network considering a certain planning horizon. Already, I mentioned in my last lecture that we build a network by considering a planning horizon.

So, if planning horizon is let us say 10 years or 15 years; so, we build a network so that it can capable of supplying all its demand nodes up to next 10 years or up to next planning horizon years ok and this column G is basically representing importance level of the node. So, this is something that it is used to specify that some nodes are of different types of nodes, but eventually you can assume that we will not consider it at the moment this importance level.

But of course, if you have some different types of loads like this hospitals where we have some dedicated equipment connected, we need some special attention for that; if we have some air traffic control system in a network we need some special attention. So, though based upon that this importance is decided and column H specifies this substation voltage, voltage magnitude which is in per unit which is in per unit ok.

(Refer Slide Time: 26:27)



Conductor type	Current rating (A)	Resistance (ohm/km)	Reactance (ohm/km)	Line/branch installation cost ($/km)	Preventive maintenance cost ($/km/year)	Corrective maintenance cost ($/km/yr)	Failure rate (fault/km/yr)	Mean failure duration (h/fault/yr)
1	118	1.6118	0.4853	32126.23	1733.54	6.51	0.2	0.33
2	158	1.0145	0.4679	32321.31	1733.54	6.51	0.2	0.33
3	214	0.6375	0.4505	32653.55	1733.54	6.51	0.2	0.33
4	250	0.5205	0.4428	32780.81	1733.54	6.51	0.2	0.33
5	287	0.4019	0.4331	33378.78	1733.54	6.51	0.2	0.33
6	334	0.3184	0.4237	33752.81	1733.54	6.51	0.2	0.33
7	453	0.2006	0.4026	34100	1733.54	6.51	0.2	0.33
8	179	0.8220	0.3037	43000.00	218.77	1.09	0.00625	0.01
9	362	0.2646	0.2567	45476.95	218.77	1.09	0.00625	0.01

Now, this table gives you the different types of conductor sizes, different types of conductor sizes. As I said this, in normal planning what usually planners do we have a set of conductor, types or set of conductor sizes from which we need to select one specific type of the conductor or one specific size of the conductor for constructing a distribution line ok.

And, here we have 9 different types of the conductor, 9 different types of the conductor; Out of which one can be used to construct a particular line; that means, if I want to construct a distribution line between node 2 to node 3, I need to take the decision that what type of conductor I should use ok and you can see here we have a set of 9 different types of conductors.

So, I can use either 1 or 2 or 3 or whatever, that basically depends upon different things that what should be the tentative power flow through this particular line and also that depends upon the economy of the solution that depends upon how much reliability do we need to construct this line. Now, corresponding each of this conductor type, you can see this row is basically representing all the specification of this conductor type 1 ok.

So, here, you know second column is basically representing this current rating or ampacity rating or ampacity limit. This is ampere capacity limit or thermal limit you can say or thermal limit ok; that means, if you build a line with this conductor type 1, maximum current that should flow through this line should be limited to 118 ampere ok.

Similarly, corresponding to this conductor type 1, the resistance of the conductor is given to be 1.6118 ohm per kilometer ok and reactance is also given 0.4853 ohm per kilometer. And, next three columns give the cost component, cost coefficient because as I have said that we need some cost coefficient in order to estimate the cost of installation of a particular line.

And these three are the cost coefficients; so, this one is installation cost, branch or line installation cost, this one is preventive maintenance cost and this one is corrective maintenance cost. So, these two are maintenance cost and this is installation cost. In fact, you can see in the problem formulation we have this cost coefficient C; C is basically cost coefficient for installation cost.

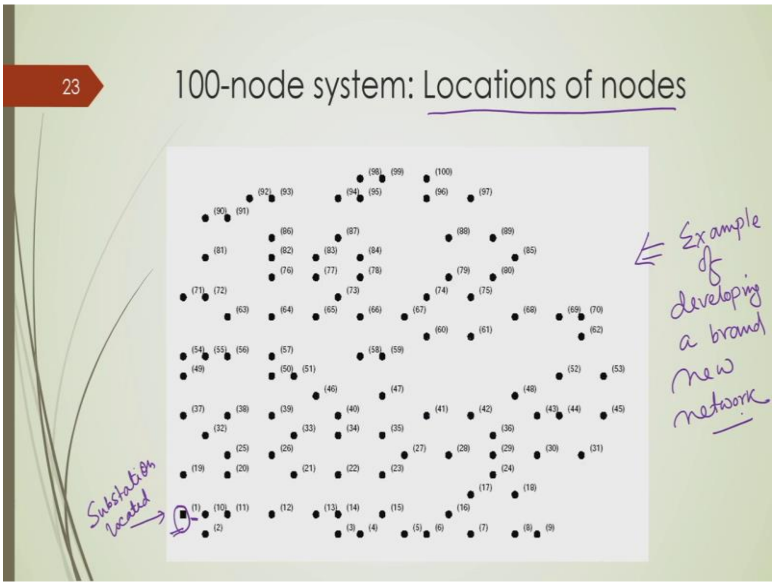
And C, i is basically representing the cost coefficient for installation cost and C M is basically representing the cost coefficient for maintenance cost. So, this we can obtain from this conductor table ok and this last two are basically representing reliability data, reliability data. As you know in my 3rd module, I explained that in order to assess, in order to estimate the reliability of a particular component we need two data. One is called a failure rate; another is mean failure duration ok. These data are provided over here one is 0.2 faults per kilometer per year, one is 0.33 alright. Now, similarly for all other conductor types this is specified; these all information is specified. Now, you can see the difference from one type of the conductor to the other type.

So, conductor 1 is having ampacity of 118 ampere, but conductor 2 is having ampacity of 158 ampere ok. Now, what is the difference of this these two? It means that conductor 2 can withstand higher amount of current. Why how it is possible? Because, its conductor cross sectional area is higher ok and that is why its resistance is lower, reactance depends upon this line construction.

And, since this conductor cross sectional area is higher its cost is also higher, both the installation cost, only installation cost, but maintenance cost is almost same. And, failure rate and repair duration are also not dependent upon this cross sectional size of the conductor ok. Now, for you can look at from conductor type 1 to 7, we have specific types of the conductors or conductors built with specific materials.

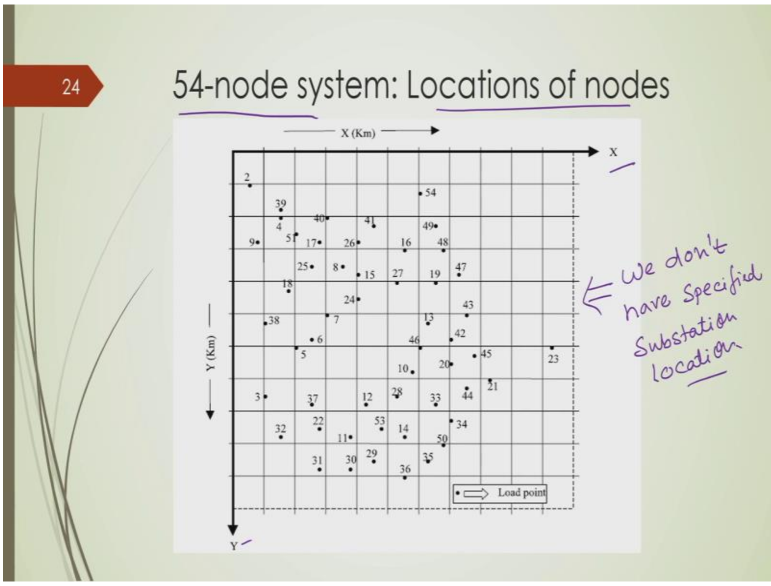
And that is why their failure rate and repair duration are similar or same, but conductor type 8 and 9 are different. So, conductor 8 is having ampacity of this and 9 is having higher ampacity, but there you know failure rate and repair duration are significantly small ok. So, for example, you can understand that it might be that conductor types 1 to 7 are all overhead conductor and conductor 8 to 9 may be underground cable which is having lower value of failure rate, but you know failure duration is also higher, it might be underground cable or might be built a conductor is having superior reliability parameter ok.

(Refer Slide Time: 33:11)



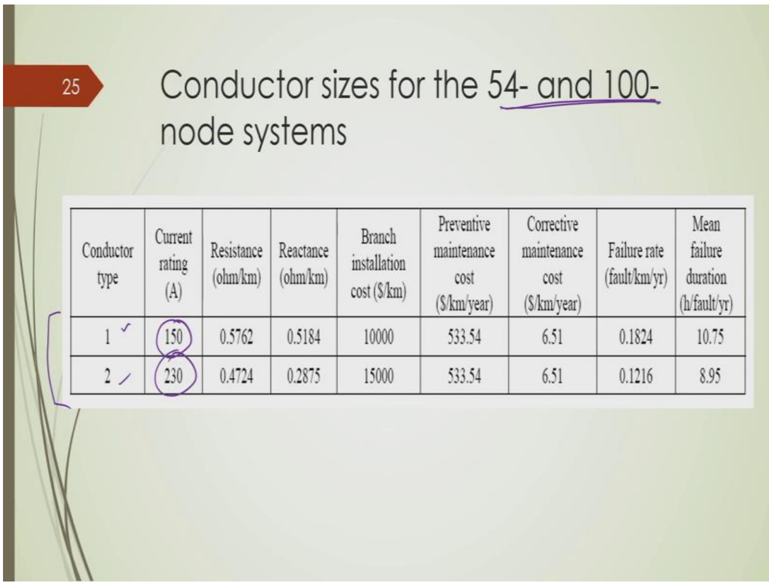
Now, this was all about 21-node system, for-100 node system it is an example of a static planning and it is an example of building or designing a brand new network. And, that is why you can see substation is specified at this node 1. So, here we have substation located and you can see apart from this location of the substation which is already mentioned which is already specified at node 1, there is no pre-existing network; there is no pre-existing network. So, we have to connect all these different nodes or loading points to this substation in order to build one brand new network. And, that is to be done by using this optimization approach ok or by using this planning approach. So, it is an example of developing a brand new network ok; it is an example of developing a brand new network.

(Refer Slide Time: 34:43)



So, this is 54-node system, it is also similar to 100-node system; here we do not have any pre-existing network. So, similar to the previous one, it is also a system to develop a brand new network where substation location is not even specified. So, the characteristic of this 54-node system or the difference of this 54-node system with the 100-node system, although both of them are same type like both of them are the example of planning a brand new network, but here we do not have specified substation location. So, we do not have specified substation location ok. And, these are the coordinate systems; this information related to their respective position of all these nodes are specified from which you can eventually find out the distance from one node to other ok.

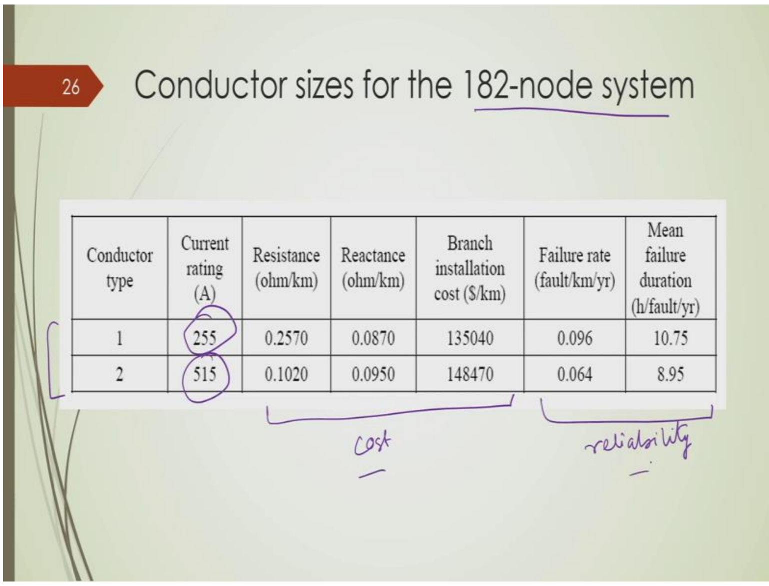
(Refer Slide Time: 36:14)



Conductor type	Current rating (A)	Resistance (ohm/km)	Reactance (ohm/km)	Branch installation cost ($/km)	Preventive maintenance cost ($/km/year)	Corrective maintenance cost ($/km/year)	Failure rate (fault/km/yr)	Mean failure duration (h/fault/yr)
1	150	0.5762	0.5184	10000	533.54	6.51	0.1824	10.75
2	230	0.4724	0.2875	15000	533.54	6.51	0.1216	8.95

But, for this 54- and 100-node system, we have used only two conductor types, one is conductor type 1 and type 2 ok. So, type 1 is having ampacity of 150 ampere and type 2 is having ampacity of 230 ampere ok. This is purposefully done in order to reduce the problem dimension ok. I will explain later on, because compared to this 21-node system here we have more number of nodes. So, more number of decision variables involved and this increases the problem dimension ok.

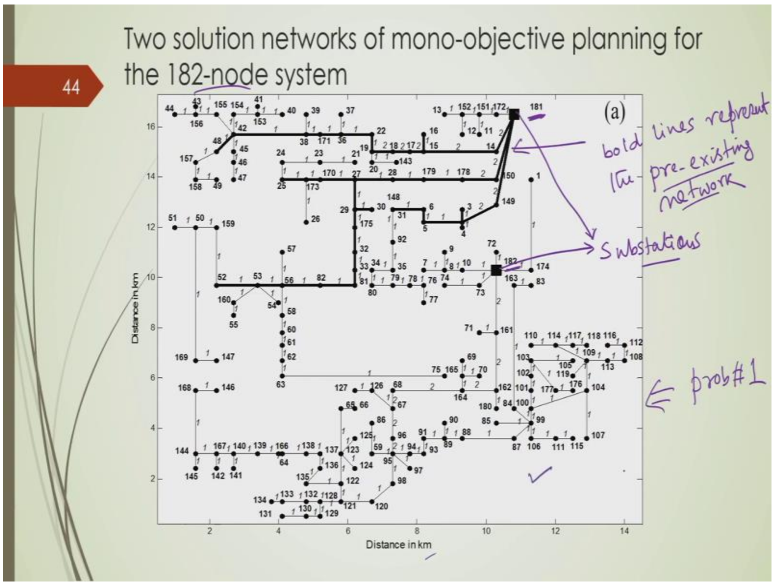
(Refer Slide Time: 36:56)



Conductor type	Current rating (A)	Resistance (ohm/km)	Reactance (ohm/km)	Branch installation cost ($/km)	Failure rate (fault/km/yr)	Mean failure duration (h/fault/yr)
1	255	0.2570	0.0870	135040	0.096	10.75
2	515	0.1020	0.0950	148470	0.064	8.95

For 182-node system, we use these two conductor size, one is having ampacity of 255 ampere, another is ampacity of 515 ampere and their respective cost and reliability data are specified. This is cost data, this is reliability data are specified and we need to build a network by with these two conductor sizes. Now, 182-node system, it is not shown over here; I can show you, I have some illustration here.

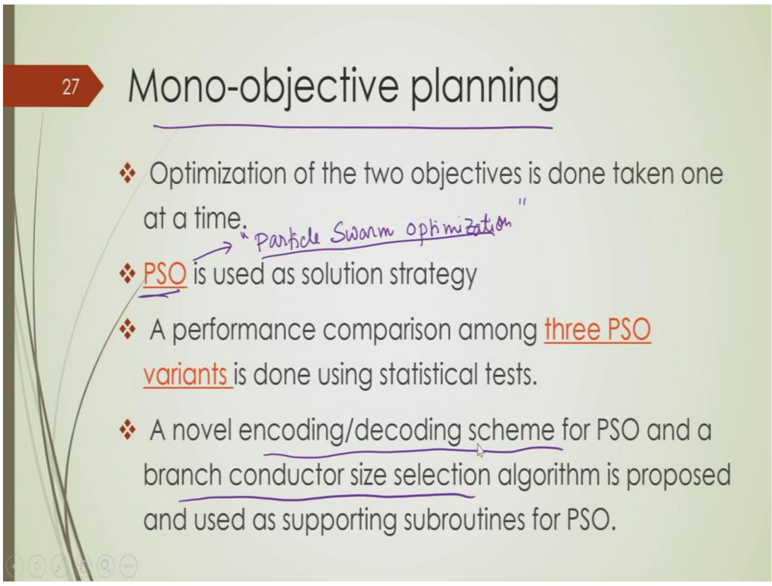
(Refer Slide Time: 37:33)



So, this is 182-node system, where you can see these bold lines. So, bold lines represent the pre-existing networks ok. So, here at 182-node at node number 181 and at node number 182 we have substation. So, these two are substations ok and substations locations are specified at node number 181 at node number 182.

And, in node number 181, we have some pre-existing network pre-existing network, but node number 182, we do not have any pre-existing network. So, our goal is to connect all these node points either to connect this pre-existing network where substation is located at 181 or to connect this substation 182 ok. So, that is what we have done through this optimization.

(Refer Slide Time: 39:00)



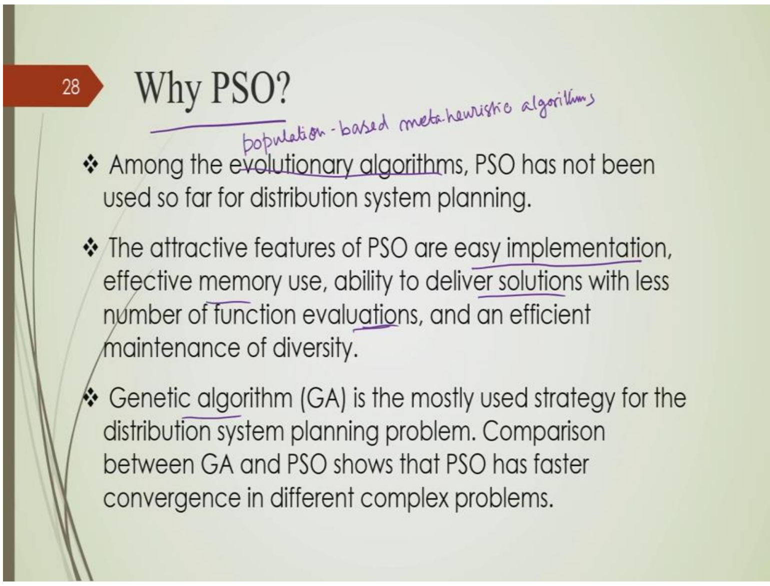
Now, we have mentioned that we have formulated two planning problems, two single objective planning problems where the difference between these two problem is that in one problem we have objective function as total cost. And, another problem we have objective function is of total interruption cost or it is related to maximization of reliability ok.

And, with both the optimization problem we will solve separately, separately and in order to solve this optimization problem we need to have one solution strategy and here we will use PSO. PSO stands for Particle Swarm Optimization. So, this is a metaheuristic optimization algorithm which we will use as the solution strategy for this two planning problems ok.

Also, I will talk about particle swarm optimization after a little while and you will see that it is a kind of metaheuristic algorithm, which can solve any type of optimization problem whether it is linear or non-linear, does not matter to it. It can solve convex or non-convex problem or differentiable, non-differentiable problem. So, it can solve many problems, but the drawback is that the convergence that the solution at the end we are getting which we are thinking that it is an optimal solution, that optimality is not guaranteed. And, since it is a metaheuristic algorithm, it will provide you different solution if you make different simulation runs. And, that is why whoever will be using this particular algorithm, metaheuristic algorithm needs to work with some more statistics; to statistically show the performance ok.

And, that is what exactly is done in this particular case, I will be discussing. And, apart from that we will be using a noble encoding decoding scheme for PSO which I will be explaining after a while and also we will be using a branch conductor or line conductor size selection algorithm as a support subroutine of the main solution algorithm so that we can decide or we can take the decision that what should be the conductor size for each of the line that we are we are going to construct ok.

(Refer Slide Time: 42:11)

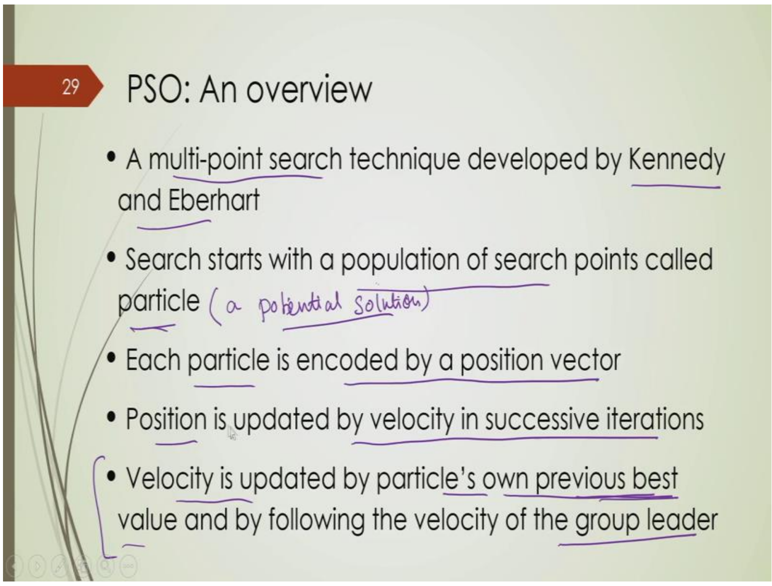


Now, why we have taken PSO? PSO, many people will not agree that this is an evolutionary algorithm, but this is a population based metaheuristic algorithm. So, I can rename as population based metaheuristic algorithms. So, the idea was that motivation for selecting PSO was that time, whenever I worked on this, that PSO was not used for distribution system planning problem.

But, PSO has one attractive feature that it can be easily implemented. Although easy is something a vague word means something which I can tell you as easy, but cannot be easy to someone else. But, eventually if you implement many of such kind of metaheuristic algorithms by yourself, you can realize that PSO needs a few line of coding to implement ok. So, that is indeed easy to implement and also effective memory use, less memory use and ability to deliver solution with less number of function evaluation. So, those things you can identify, if you go through the literature of different types of metaheuristic algorithms.

And, that time when I worked on this genetic algorithm, this is again one metaheuristic population based metaheuristic algorithm under this category of evolutionary algorithm, was more popular and it was extensively used to solve this distribution system planning problem. So, idea was that if we implement PSO, we can make a performance comparison ok. Now, how PSO works?

(Refer Slide Time: 44:12)



So, PSO is a population based algorithm; that means, it is a multi point search technique. Now, what is that basically? The iterative algorithms can be classified into two types: one is point-to-point search technique, it means that you start with any initial guess and then you update it in the next iteration. But, this PSO or genetic algorithm, these are population based search technique and that is why they are multi-point search techniques.

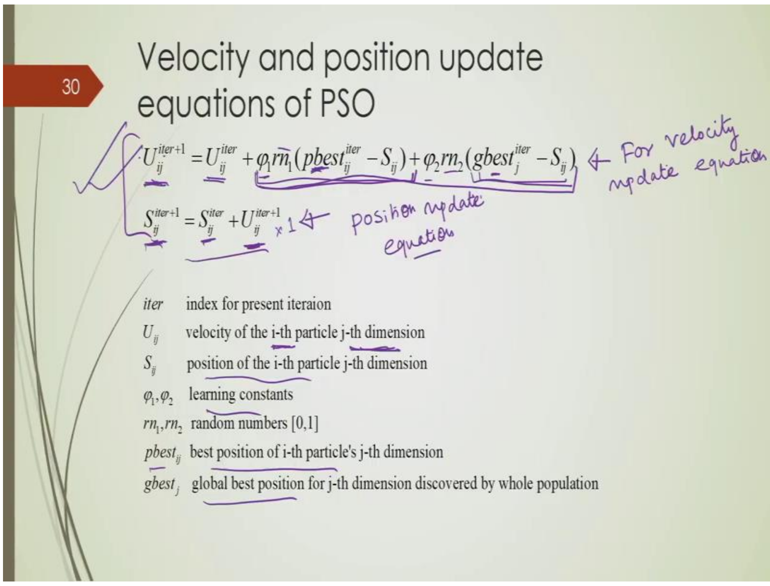
So, they will start with multiple initial solutions, all the solutions will be randomly generated and these solutions will be iteratively updated to have a best solution at the end. At the end also, we will get a set of solutions, among them we have to select the best solution and that is what we consider to be the optimal solution. So, we have a population based search technique; you know potential solution is called as particle.

So, each particle is basically in particle search optimization represents a potential solution, which may be a decoded solution or which may represent direct solution; that depends upon how you are encoding decoding the problem variables ok. If you are encoding/decoding direct then you get whatever particle you get that represents a direct solution.

Otherwise, you have to decode the information from this particle to have this final solution and each particle is encoded by a position vector. Then, this position vector will be updated by the velocity in the successive iteration and this velocity is finally updated with you know two equations, that I am going to show you in the next slide. One is called velocity updating equation, another is called particle updating equation. A Velocity updating equation is done by considering this particle previous best value and a group leader based value or the global or the group based value ok. So, the idea behind this velocity updating is that when we have some you know athletic competition ok. For example, we have some 100 meter race, now how a competitor can win?

If that competitor exceeds its his or her previous best as well as if he can perform better than all other competitors ok, So, that is what the motivation and this particle swarm optimization was developed in 1995 I think, by Kennedy and Eberhart ok and that paper was cited many times ok.

(Refer Slide Time: 47:28)



And, these are the two equations this equation is basically for velocity updating equation, velocity update equation and this equation is basically position update equation. And, as I said this are basically the basic PSO variant which was proposed by Kennedy Eberhart and subsequently this basic update equation was modified or revised by different authors.

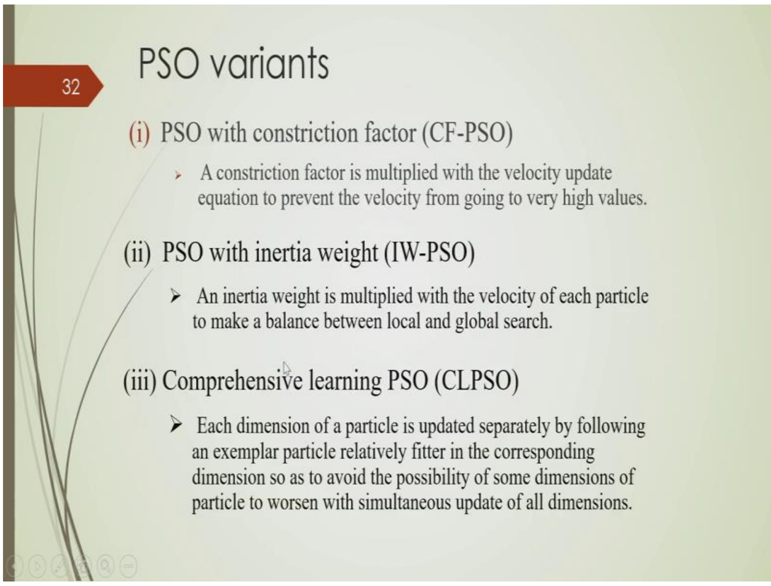
And, we have different PSO variants as well depending upon this you know change in this updating equation or by incorporating different features in it we have different PSO variants. And, till today people are working on it to have a better PSO variant ok. So, here you can look at this equation this U, capital U ij iter plus 1 stands for this is the velocity for ith particle jth dimension ok.

So that means, this is for ith particle jth a dimension, but means this is for jth decision variables. In fact, one particle consists of many decision variables. So, this is basically the ith particle jth decision variable ok. And, this is updated with this information of previous iteration velocity value and plus by adding these two terms.

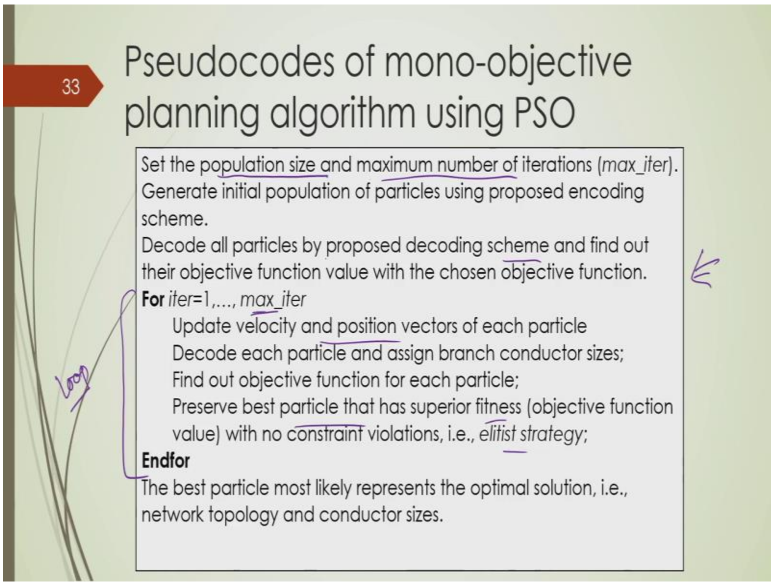
One is this term, this term is basically to update its own previous best value which is representing this by pbest; you can see the best position of that same particle same dimension previously and this gbest is basically representing the global best or the leader best information ok.

So, this is basically how this velocity of one particle is updated with its own previous best and with a global previous best ok. And, how we know these pbest and gbest? This is basically done with the evolution of one function by comparing two particles by one function that is called fitness function ok. Those who have a fair idea on such kind of population materialistic algorithm they can understand. And, this fitness function is eventually derived from our objective function, it can directly represent objective function or it can be some modified form of the objective function ok. And, there are many other parameters which I am not going into detail like this phi 1, phi 2 represent learning constraints. These are random numbers r n 1, r n 2 and this S is basically representing this position of this ith particle, jth dimension means jth decision variable. So, the second equation you can see that one particle position to next iteration is updated with the previous iteration position value by adding this new iterations velocity ok. And, since you know position is updated with previous position plus velocity multiplied by this time, here you can see the difference between the one velocity and other velocity, the time difference is iter plus 1 minus iter that is equal to 1 ok. So, that multiplied by 1 which basically the position update equation.

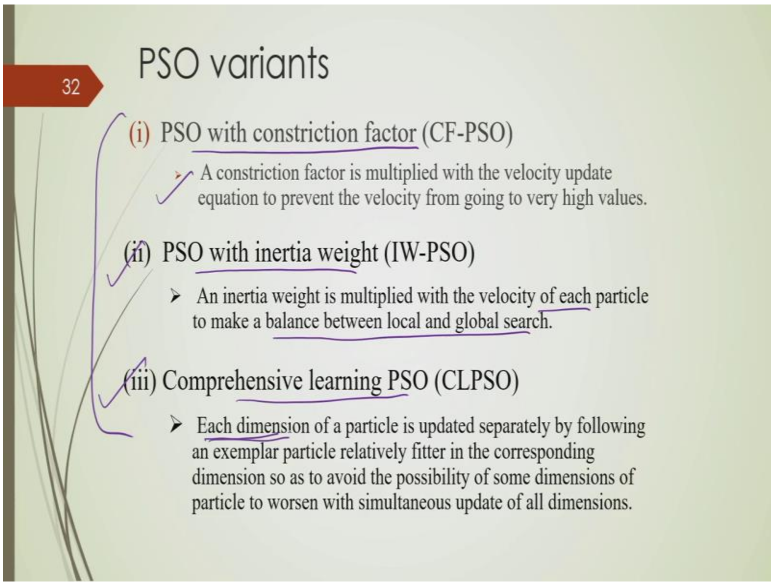
(Refer Slide Time: 51:38)



(Refer Slide Time: 51:48)

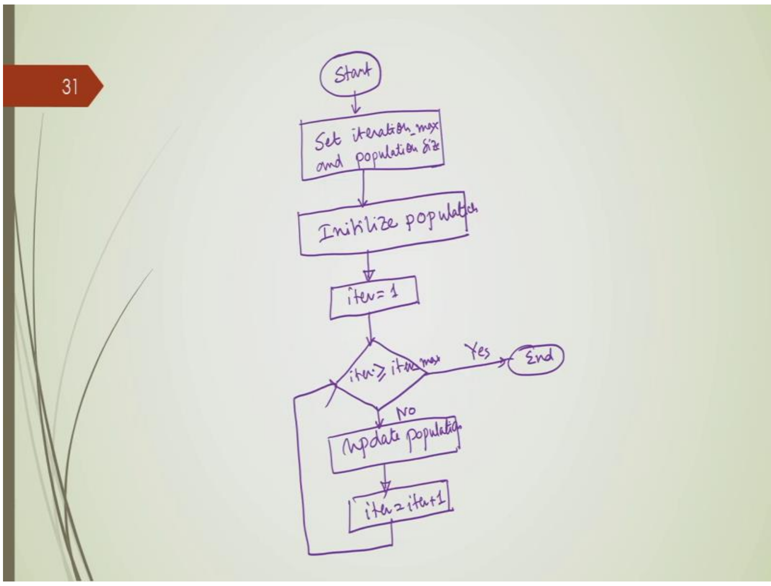


(Refer Slide Time: 51:48)



Now, we have different PSO variants. So, what I can tell you that how this PSO works, although we have this equation you know pseudo codes for this PSO.

(Refer Slide Time: 51:49)



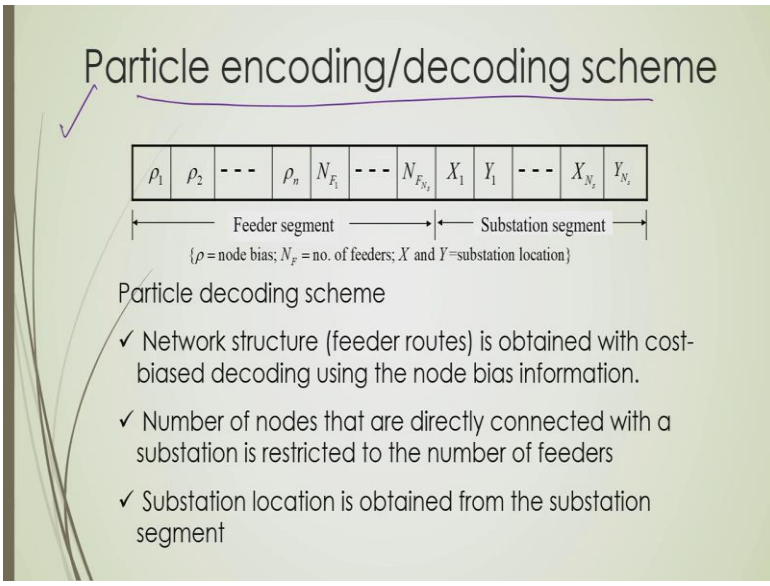
But I can tell you that in general this PSO algorithm flowchart is something like that, first you start this algorithm, then you initialize. Before that, you set this iteration count or maximum iteration, iteration max and population size ok. So, these are the two parameters like there are several parameters in forward backwards sweep load flow. So, similar to that to these two parameters, we have to set at the very beginning ok. Then we have to initialize the solution; initialize this particle population ok. So, once you have done it, then you start with iteration 1 and then you have some conditions that whether it is exceeding this maximum iteration or not, this iteration is higher than equal to that maximum iteration for example, it iteration max, eps then you terminate, end, if no, what you can do you update population. How do you update? This update equations already I have shown you, this is how we can update ok and after updating you make this iteration count iter plus 1 ok. Once you get that you again go back to this main loop. Now, here if it yes then it ends, if no it will keep updating. In fact, this is the basic equation, but one can; obviously, change this algorithm by suitably revising some of the things ok.

Now, we have used three PSO variants. We have, as I mentioned in, one is PSO with constriction factor, where one factor is multiplied with this velocity update equation ok. And, that factor may have some constraint value or some time I mean iteratively changing value. Similarly, second variant is one inertia weight which is multiplied with this velocity and that inertia weight; the idea is to make the balance between local and global search ok.

Too many considerations of you know, too many preference of this previous best will make entrapment into local optima. So, in order to come out from that, we need to have some balancing of this local exploration with global exploration ok. Similarly, we have another variant which is called comprehensive learning PSO in which each dimension or each decision is updated separately.

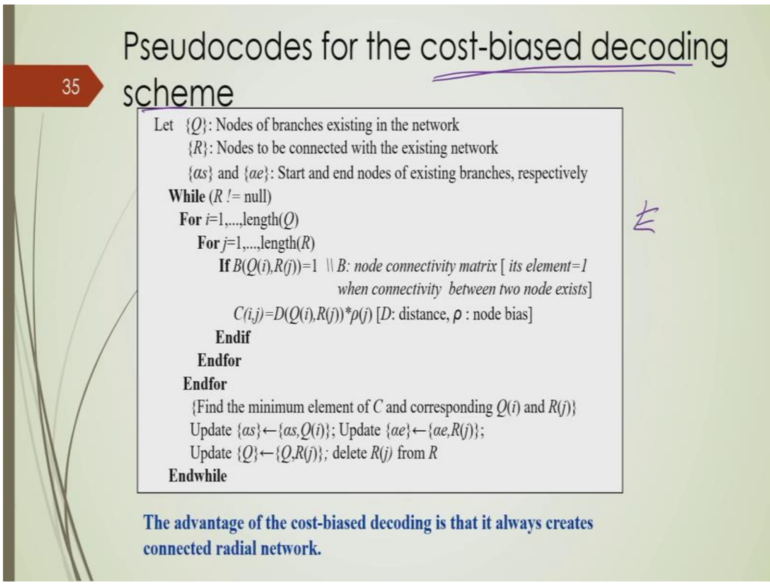
This will not follow this in general velocity update equation which I have shown over this slide, but this is use the separate velocity update equation for different decisions variable or different dimensions of the problem ok. So, this is the pseudo code of this mono-objective planning problem; initially we set this population size that means, how many number of particles we should utilize in the search process and, also maximum number of iterations. Then, if you have some encoding technique that we use to encode the solution and to get the direct information with the decoding value, then, we have this loop, this is the main loop by which we will update this velocity and position vectors ok and we update them, we preserve this previous best velocity. We preserve this the best solution among all the particle, all this will come under elitist strategy and this will continue till we get this maximum iteration arrived ok. So, this is here the termination criteria is maximum iteration, but again one can change the termination criteria as well.

(Refer Slide Time: 56:36)



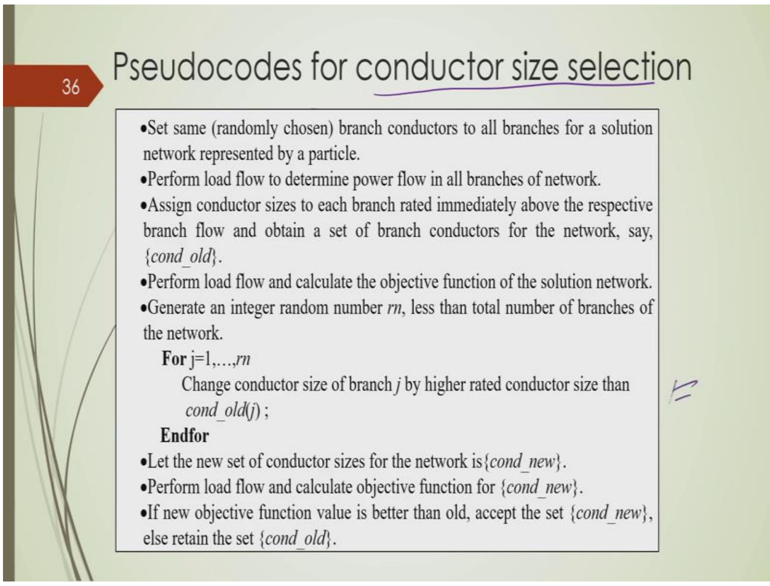
This is a special type of encoding decoding technique, encoding decoding scheme. We have used instead of designing direct information, we have some indirect encoding technique where we have some it is called cost biased encode encoding techniques. So, each of the nodes which are which need to be connected with the new network will have some bias value and this bias value will be updated iteratively.

(Refer Slide Time: 57:09)



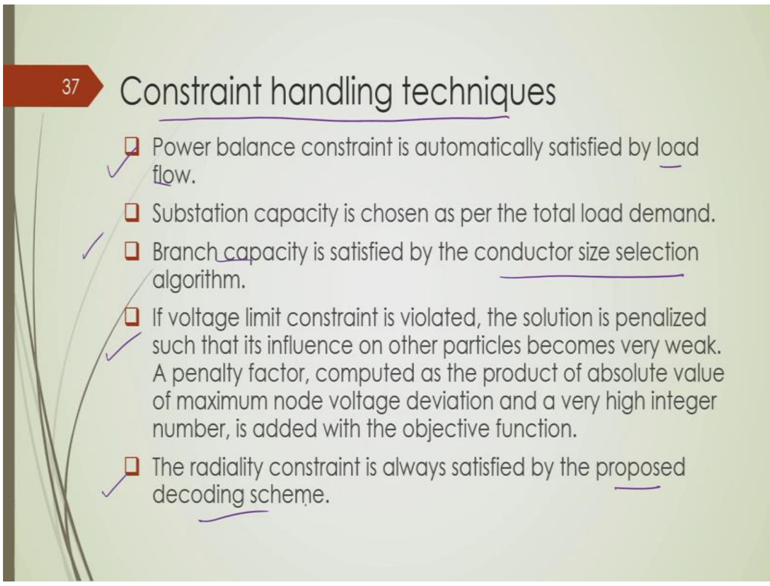
And, from this bias value with the suitable decoding scheme which is mentioned over here which is called cost biased decoding scheme, we get the a total network topology or total network structure of a network and that will make your radiality constraint satisfied ok. It always gives a radial network. So, I will not discuss this in detail, if you have further interest you can go through this algorithm ok.

(Refer Slide Time: 57:39)



Also, this is how we can select the conductor size, we for each of the branch we assign some set of conductors then we also make some heuristic idea. So, that for each branch or line this line capacity constraint would be would not be violated ok.

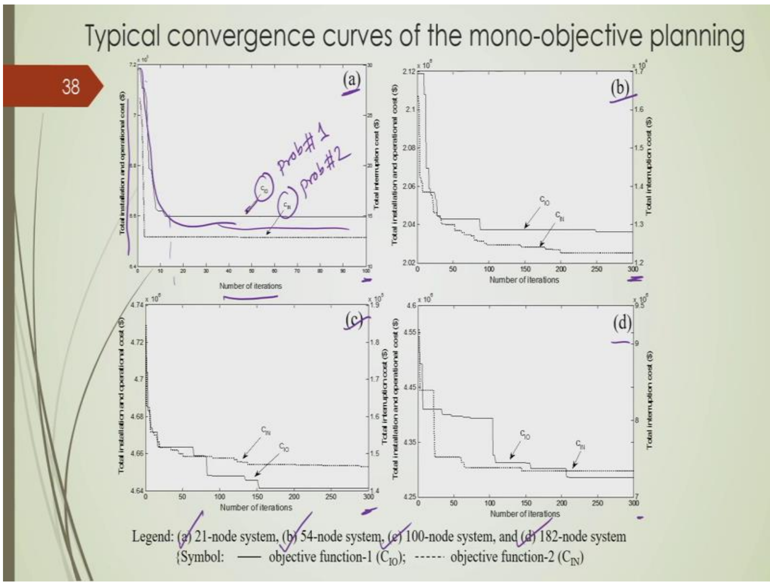
(Refer Slide Time: 58:05)



So, this is how it is formulated. So, you can go through this algorithm and this is how this other constraint are handled in this particular problem, we have many constraints. So, power balance constraint is automatically handled by forward backward sweep load flow. Capacity constraint is substation capacity is chosen as per the load demand.

Similarly, branch capacity is satisfied with this conductor size selection algorithm or conductor size selection subroutine. If voltage limit is violated then we have some penalty factor which needs to be added to penalize the solution and radiality constraint is always satisfied by the proposed decoding scheme which I was talking about.

(Refer Slide Time: 58:45)

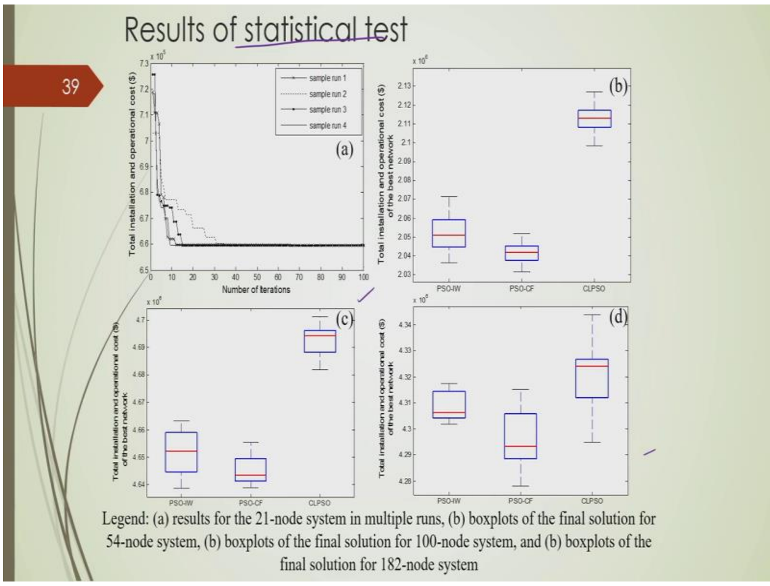


Now, these are the solutions we got before we got the solution, you can see both the problems or solutions of both the problems are shown in the same graph. This is for 21-node system, b figure b is for 54-node system, c is for 100-node system and d is for 182-node system ok. And, here this is basically representing this solution that we will get in problem 1 and this is for problem 2. So, all these graphs you can see ok.

And, this is basically representing, this graph is basically representing how this cost function, how this objective function varies with this number of iterations. So, here we have set 100 number of max iterations as maximum iteration, for 54-node systems if problem dimension is higher. So, we set higher number of maximum iteration that is 300, for 100-node system also we consider 300, 180-node system we consider 300. Again how do you choose this population size and maximum number of iteration?

This is again you need some statistical and you need to do some statistical analysis by changing them and by suitably doing the sensitivity analysis. Now, you can see all these characteristics are in general same. So, initially cost was higher then it becomes lower after certain iteration and then it gets saturated. When it gets saturated, we can as understand that the solutions are not getting updated which means that no better solutions we are getting.

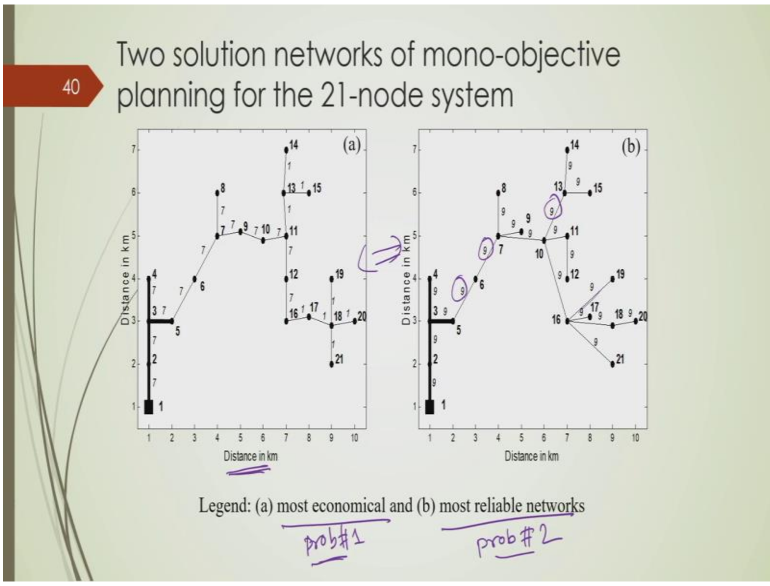
(Refer Slide Time: 60:33)



But, again as I said these are all involve some randomness. So, we need to do some statistical test. So, here we need we did many statistical test which are not shown over here, here we have used box plots to represent how the variability that we get in the final solution ok.

So, this box plot is used basically to compare the performances of these three different PSO variants that we have studied. And, out of which you can identify by yourself which one is better ok, which one will have less variability as well as less median value.

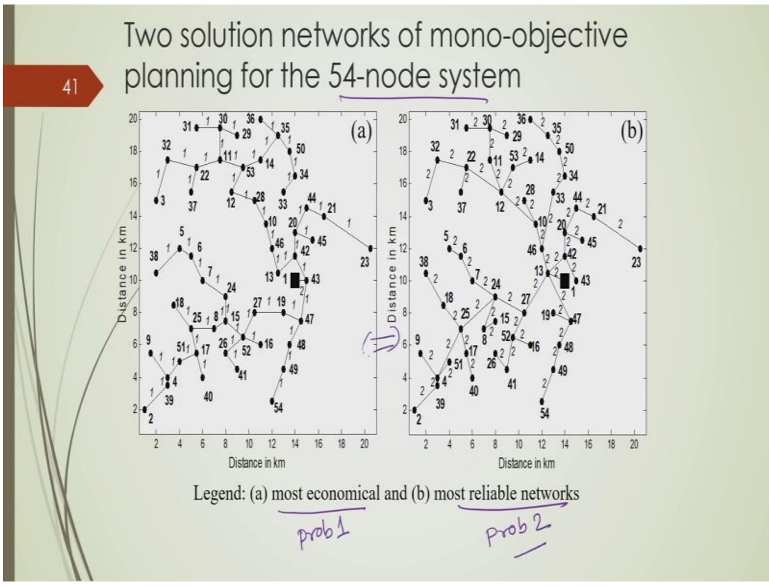
(Refer Slide Time: 61:21)



And, these are the final solutions; we get here; we have shown this here most economical solution which we get from problem 1 and this is most reliable network which we get from this problem 2, by solving this problem 2. So, problem 1 objective was minimizing cost and problem 2 objective was maximizing the reliability.

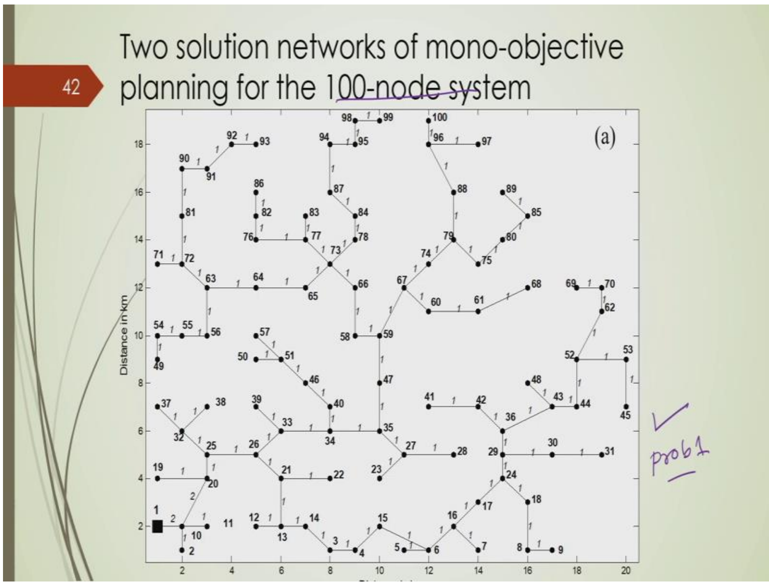
So, here you can see the difference between these two; here you have more number of branching which requires that dependency of one node to other which reduce the dependency, also the conductor sizes are different. Here conductor type 9 is used so that we have better reliable network. Whereas, in this most economical system we have almost shortest path, almost shortest path network meaning that the total cost that it will incur will be less.

(Refer Slide Time: 62:18)



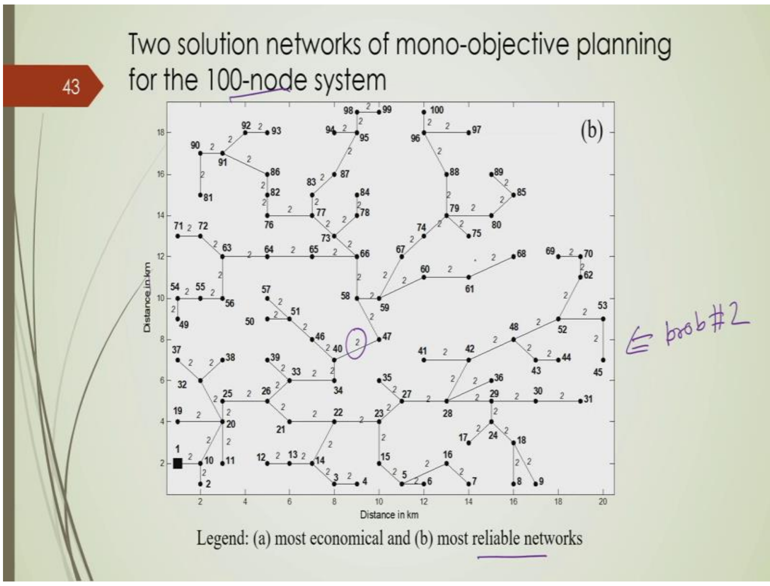
So, similar things, we observe for you know 54 node system, we got most economical network; we got by solving this problem 1 and most reliable network, we got by solving problem 2 ok. So, similar observations you can get with what we get in previous.

(Refer Slide Time: 62:28)



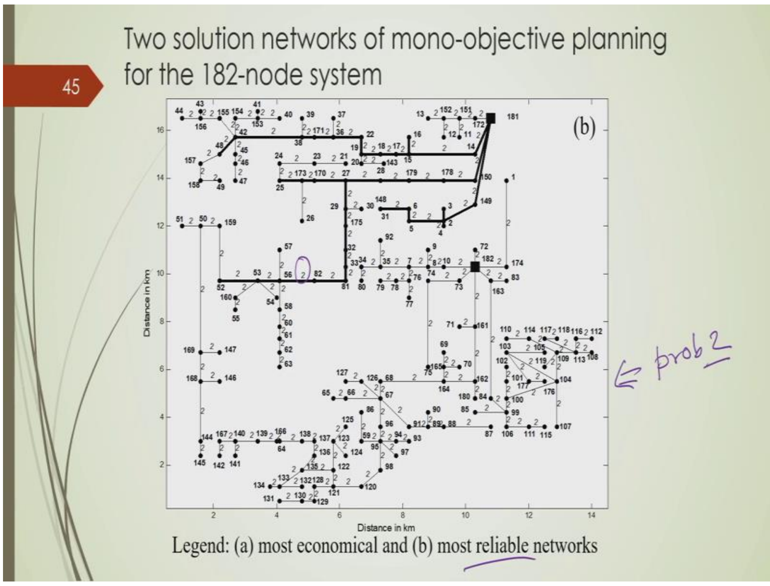
Similarly, this is for most economical network by solving this problem 1 for 100 node system, this is a kind of shortest path problem, shortest path network.

(Refer Slide Time: 62:50)



But, here this is what we get from 100-node system by solving this problem 2 ok, here different conductor sizes are used, also more number of branching is there. Similarly, this is you know we got from 182-node system by solving this problem 1, that represents this economical network.

(Refer Slide Time: 63:18)



And, this is what we get by solving this problem 2, that is the reliable network ok and the observations are also similar. Previously, it is a kind of shortest path network whereas, you can see there this is not ok, and also this conductor sizes are of different. Now, with this I will stop in this lecture, we will proceed further in the next lecture.

Thank you.