Operation and Planning of Power Distribution Systems
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Lecture - 25
Power Distribution System Planning: Different Models and Solution Strategies

Ok, So, in today's lecture I will start with the discussion of electrical power distribution system planning. So, what is power distribution system planning? If you could see that course name is operation and planning of power distribution systems, so far whatever I discussed except this last lecture all are focused on this operation of a distribution network ok; different issues, different aspects, different features of power distribution networks etc., ok.

In today's lecture, I will start with this planning of power distribution networks planning ok. Now, what is power distribution system planning? What is the formal definition or informal definition?

And then, I will also show you what are the different mathematical models we have for this power distribution system planning and different solution strategies and some of my own research works on this power distribution system planning to illustrate you, what is that research problem and also how did we solve this thing ok.

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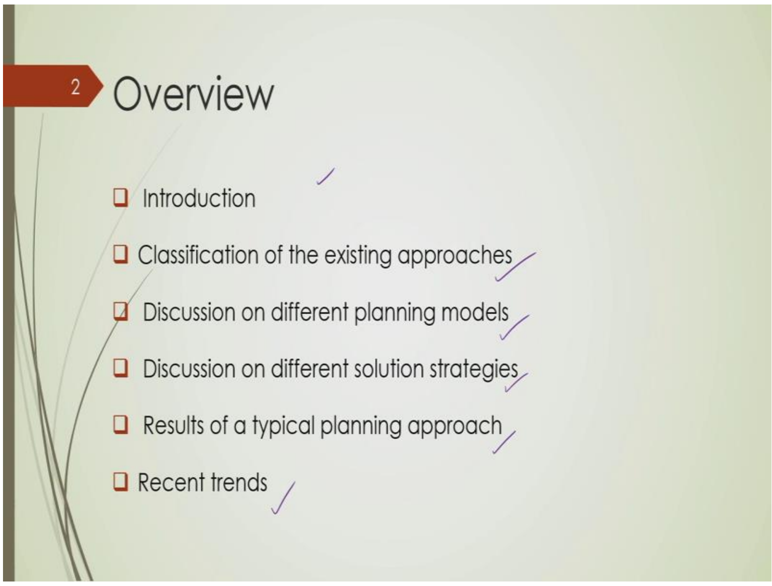

So, this is my presentation outline, first brief introduction on power distribution system planning, some informal definitions, and that some categorization of existing literature which I will discuss in the next part. And different planning models at least some few planning models I will discuss in this particular module which is the next, I will discuss and then different solution strategies and also I will show you some results and research, recent trends in research ok.

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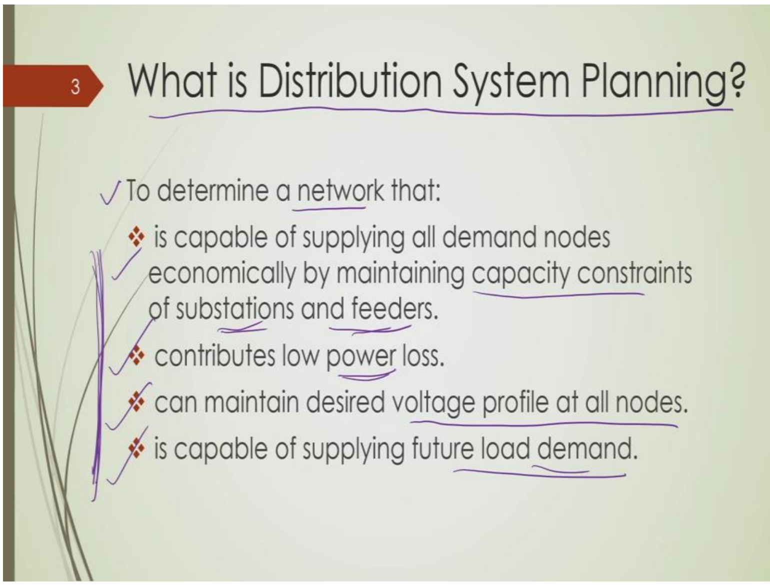

So, first is the question what is distribution system planning or what is power distribution system planning? Ok. There is no formal definition available which we I can readily show you, but based upon my experience in doing research upon several years in this particular field, I can make an informal definition ok.

So, this power distribution system planning is basically an approach by which we can determine a power distribution network which is capable of supplying all the demand nodes economically, by maintaining the capacity constraints of substation and other and feeders ok.

So, basically it is a kind of design, it is a kind of design of a network which would be able to supply all the demand nodes under its service area and this will work with this will this design would be economical and the network will work reliably ok to supplying all the demand nodes, under the constraints of the substation and feeder capacities ok. I will talk about what are those things. Second is; obviously, that network should contribute, should incur as lower power loss as possible ok.

So, power loss minimization you have seen is one of the goals, for distribution network for people who are doing research in distribution networks as well as the distribution network owners and operators.

Also this network should maintain desired voltage profile at all these nodes, who are getting supply through these networks and also it is capable of supplying future load demand as well. Keeping all these features in mind we should formulate an approach which provides a network structure or network topology which will have these properties ok. So, that is what the planning process and that approach by which we will determine this network, network topology or network structure which is having this properties we call it distribution system planning ok.

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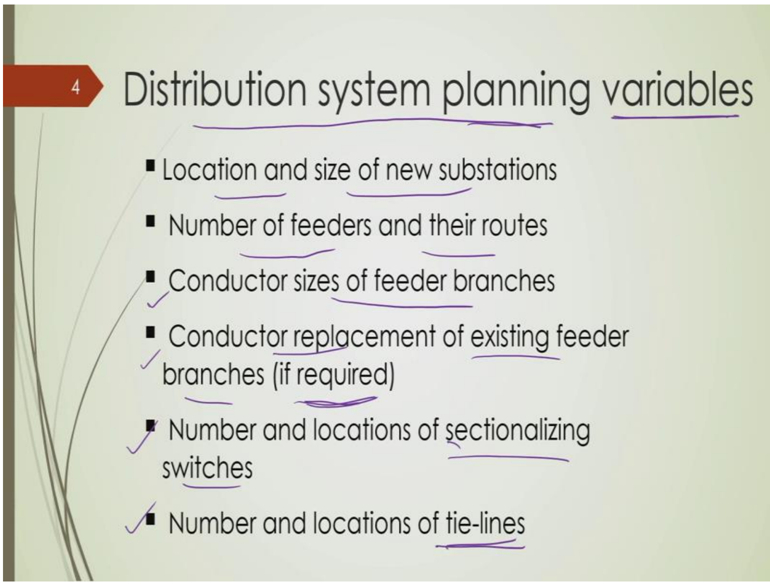

Now, we have some planning variables or we have some decision variables which we need to determine through an approach ok. And what are the planning variables we have? We have to decide about this location and size of the new substation, as well as the capacity addition of the existing substation.

So, these are the decision variables. Similarly, we need to determine the number of feeders and their routes. So, determination of number of feeders and their routing are planning variables ok. Similarly, determination of conductor size of feeder lines or feeder routes at each and every distribution line you need to decide that what should be the ideal conductor size. So, that is also one of the decision variables, also, conductor replacement of existing feeder lines or feeder branches if required ok.

So, this is another decision which we need to determine through this distribution planning approach that what are the distribution line sections, which need this conductor replacement ok; also, number and locations of sectionalizing switches and number and location of tie lines. Sectionalizing switches and tie lines are already discussed in module 2; so I hope that you can remember. Now where do we locate this sectionalizing? Where do we allocate this sectionalizing and tie lines those are also part of the decision variables?

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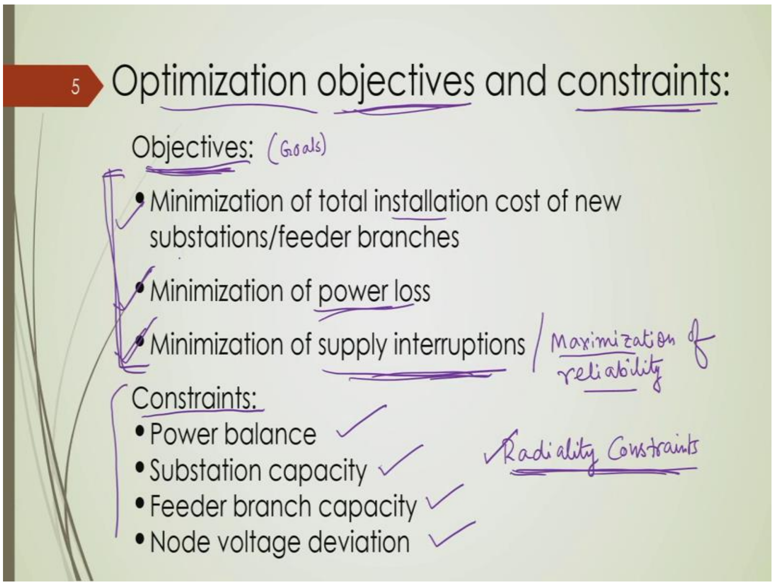

And you have to remember that I was talking about an approach by using which we are supposed to determine this distribution network structure or topology ok. And that approach is essentially an optimization approach ok.

So, distribution system planning is essentially an optimization problem ok and that is why you know, that if you do literature review on distribution system planning you will get a voluminous researchers. You will get a voluminous research in which a number of researchers, thousands of researchers are working on in this particular field irrespective of the fact that they are electrical engineering or not ok.

So, in fact, many people who are working in computer science also work in this distribution system planning because it is an example of a fantastic optimization problem ok. And it has many challenges, so many people who works in optimization, whether they belong to computer science or they belong to mathematics or they belong to some others areas, they also take this particular optimization problem as a challenge to solve ok.

So, you may develop an optimization algorithm that algorithm can be tested on this particular real time optimization problem ok. So, that is why distribution system planning it is a very well known of optimization problem and it is a kind of interdisciplinary research people are doing ok, alright.

Now, as I said, it is an essentially optimization problem. So, in optimization problem, we have certain objectives and certain constraints ok. So, in fact, in my next few minutes, I will basically give you some brief idea about optimization, because when I go for teaching this course and this particular part of this course. I found that many of the students they do not have a fair idea on optimization ok.

So, in order to at least guide them, because this discussion on optimization problem or different optimization techniques is not part of this course ok, but, I will give you a brief idea through which people should understand different terminologies which I am going to use in next few lectures ok, in the next few minutes ok. Now, I will talk about what do you mean by optimization objectives, what are the constraints, how do we mathematically represent those objectives all these things I am going to discuss ok.

Now, in this particular problem that is distribution system planning problem, we have a number of objectives or number of goals or number of goals which include minimization of total cost, minimization of total cost. I am not talking about this installation cost and all this thing; so minimization of total cost.

Now, what do you mean by total cost? This cost function consists of several cost components, which I am going to discuss ok. Also, one of the objectives for this optimization approach or distribution system planning approach is to minimize the power loss ok. Because power loss minimization, as I have discussed, in fact, in the last module as well is one of the goals for power distribution engineers, because distribution networks incur higher amount of power loss for the obvious reason I discussed many times ok.

Now, also another objective is to minimize the supply interruptions ok. And that is what basically the reliability part or this is similar to maximization of reliability. So, if you can minimize these interruptions, then you can maximize the reliability which is another objective for power distribution system planners. So, that the customers can enjoy uninterrupted power or customer can enjoy electrical supply from a reliable network ok.

Now, these are the typical objectives of distribution network/distribution system planning, but these are not the exhaustive list; this is not an exhaustive list; there are many other objectives people use in different works, different research works. I am going to discuss later on.

And these objectives are optimized under certain constraints, under certain constraints and these are the constraints. One is called power balance constraint; what is that constraint I will basically discuss today. What is substation capacity constraint? This is another constraint which constraints the optimization process and what is this I am going to discuss today.

Similarly, what is feeder branch capacity constraint or distribution line capacity constraint, I am going to discuss. And also what is node voltage deviation constraint, this is another constraint I am going to discuss, but apart from that there is another constraint which is called radiality constraint; radiality constraint; radiality constraint. So, what is radiality constraint also I am going to discuss.

This is another constraint; this distribution network planning planners they used to keep so that they will get a radial network as a outcome of their planning process ok. And what is radiality constraint?

So, as I have discussed many times, even though we have different distribution networks which might be weakly meshed or meshed, but they are operated, their operation is done keeping in mind of radial of network ok. So, even though network is weakly meshed or meshed its operation is radial so far, for passive distribution networks ok.

So, before I go to the detail mathematical description for those objectives and these constraints, I will discuss about different solution strategies which we use for solving this problem. Let me give you a brief idea, a brief overview about optimization ok. I will not spend much time on it, much time in it, but I will give you a basic idea, so that you should have a fair idea about the different terminologies which we will I will be using in discussing this planning problem ok.

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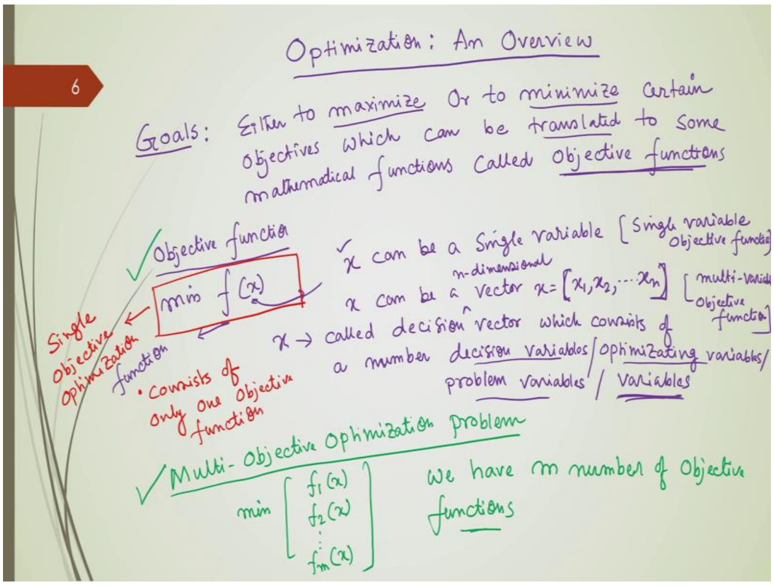

So, here I am going to discuss optimization and overview optimization and overview ok. Now, in optimization, we have certain goals, we have certain goals. In fact, optimization is such a process that every minute an individual used to do unknowingly ok. In fact, if I say that you go to market to purchase some essential commodities, having a fixed amount of money with you ok.

So, there what you will do? You will try to optimize your spending so that the whole spending should be within that money you have ok. And thereby you will optimize the commodities that you are getting; as much as commodities as possible, and as far as their quality is concerned and quantity is concerned.

So, that is what an optimization process we every day exercise. Similarly, suppose if I ask you to move from one place to another place in a city. So, what we used to do? We use to identify the shortest possible path or the shortest route, by which I can reach one destination to another destination.

This is another kind of optimization. In fact, optimization of shortest path is another very very well known research in computer science ok. So, every day we do optimization unknowingly ok. So, in optimization our goal is to maximize or minimize certain objectives and if we represent this, if we translate these objectives into a mathematical function, then we call them as objective function.

So, in optimization, our goals are either to maximize or to minimize certain objectives ok, which are which can be translated to some mathematical function, some mathematical functions called objective functions, called objective functions ok.

So, in optimization our goal is to either maximize or minimize certain objectives which if you translate to some mathematical function then we call this function as objective function ok. So, this should be clear to you. And in fact, in my last slide, I said that these are typical objectives or for a power distribution network planner; one is to minimize the total cost; another to minimize the power loss and another to minimize the interruptions or maximize the reliability.

So, these are different objectives ok. When when we will represent them into different mathematical functions then we call them as objective functions ok. Now, this translation of these different objectives into mathematical functions is called formulation of what objective functions, formulation of an objective function.

So, in objective function so typical one objective function I can show you here is minimize f x, f of x where f is a function and x is called a variable ok. So, f is basically a function which maps n dimensional variable into a real variable and x is basically call, x is x can be a single variable. So, x can be a single variable or x can be a vector, n dimensional vector. So, where x can be written as x 1 x 2 dot dot n.

So, here n x is basically n dimensional vector, x is a n dimensional vector ok. So, if x is a single variable, it is called, it is called single variable objectives ok or single variable objective function. So, it is called single variable objective function ok, and f is if it is a multi-dimensional and then it is called multivariable objective function, it is called multivariable objective function ok.

So, depending upon that what is that x? We have two different kinds of optimization problem, either it is a single variable problem or multivariable problem, but practically means most of the practical engineering problems are of multivariable optimization problem ok. And this x is called; x is called decision variables or decision vector which consists of a number of decision variables which consists of a number of decision variables, often we call them only variables or optimizing variables or problem variables; optimizing variables or problem variables or simply variables. So, if you go through different papers on this optimization problem, they represent in different name, but all represent with the same meaning, they are decision variables x 1, x 2, x n they are decision variables or optimizing variables or problem variables or simply variables, only variables ok.

So, x is basically this decision variable ok. Now, this problem whatever I have shown over here is basically having a one-objective function this is an example of a single objective function optimization, single objective optimization ok. So, if we have only one objective function which we need to maximize or minimize we call that problem as single objective optimization or mono-objective optimization.

So, single objective optimization consists of only one objective function. So, this consists of only one objective function ok, only one objective function. Now, it is also possible that we have multiple objectives in an optimization problem and those problems which are having multiple objectives, which conflict with each other, we call them as multi-objective optimization problem.

So, for multi objective optimization problem; multi objective optimization problem a typical representation of multi objective optimization problem is something like that. Minimize a number of objectives f 1 x, f 2 x dot dot f m x ok. So, here you can see we have m number of objective functions ok.

So, we call this type you know optimization problem as m objective optimization problem, where we have m number of objective functions. And this multi-objective optimization problem is a complex problem and I will discuss I am going to discuss in the next lecture ok. Today, I let us focus on this single objective optimization problem ok.

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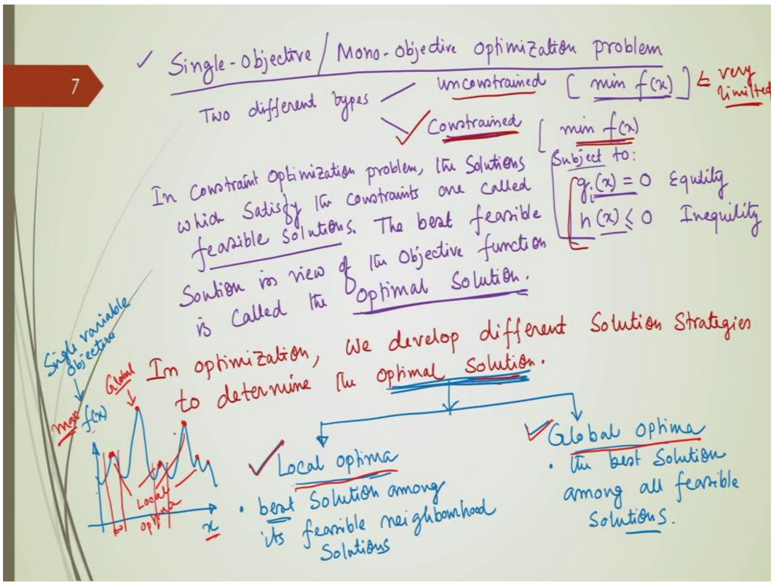

So, let us consider single objective or sometimes we name it as mono-objective optimization problem. So, today, I am going to discuss this single objective or mono-objective optimization problem, which consists of only one objective function, only one objective. Now, this objective function may have 2-3 components, but it is essentially representing one function ok. So, that is why it is a mono objective a single objective optimization problem alright.

Now, we also have two different types of single objective or mono-objective optimization problem. So, we have two different types ok, one is called constrained unconstrained optimization problem, another is called constrained optimization problem ok. So, in unconstrained optimization problem the only problem is to minimize an objective function. So, here the problem is only minimization of a function f x, which might be having single variable or multi variables ok.

So, we do not have any other constraint on this ok, but this constrained optimization problem is an example is minimization of f x, subject to some constraints.

Now, these constraints can be equality constraint or can be inequality constraints. So, one of this equality constraint is g x is equal to 0. So, this is called equality constraint, equality constraint another constraint can be h x less than equal to 0.

So, this is called inequality constraint, inequality constraint ok. So, when we have this constraint you know in an optimization problem having one or multiple number of constraints. So, in fact, this g, I mean there might be a number of equality or number of inequality constraint in an optimization problem, but even though if we have at least one constraint then our goal is not only to minimize this f x, but also to check whether this the solution that we are getting is satisfying this equations or constraints or not ok.

So, here whatever solution we will be getting should satisfy this constraints, equality and inequality constraint. So, there might be a number of you know equality constraint and number of inequality constraints ok. So, in a typical optimization problem, in constraint optimization problem, so constraint optimization problem, in constraint optimization problem the solution solutions which satisfy the constraints are called feasible solution, are called feasible solutions.

So, we may have a number of feasible solutions, we do have number of feasible solutions in a typical constraint optimization problem. And the best feasible solution in view of the objective function is called the optimal solution. So, the best feasible solution in view of the objective function is called the optimal solution ok. So, you can understand here is that in unconstraint optimization problem, the best solution in view of the objective function is the optimal solution ok.

But for constraint optimization problem among the feasible solution, among the feasible solutions; now what is feasible solution? Those solution which satisfy the constraint ok. Now, among this feasible solution the best solution in view of the objective function is called optimal solution ok.

So, in optimization; so in optimization, we develop different solution strategies to determine the optimal solution. So, in order to solve this the optimization problem traditionally there are different solution strategies and the main goal or main I do not I will not call objective because objective is another objective functions we already mentioned.

So, the main feature of these solution strategies is to determine the optimal solution for an optimization problem. And most of the engineering problems are of constrained optimization problem. So, unconstrained optimization problem are very limited very limited ok.

So, most of the engineering optimization problem so as our distribution system planning problem is the constraint optimization problem, where we have some objective function minimization of some f x subject to a number of constraints. Some of the constraints might be equality constraint some of the constraints might be inequality constraints ok.

So, this is what this constraint optimization problem all about. Now, apart from that there is another thing that what how do you define this optimal solution? How do you define this optimal solution? There are basically two types of optimal solution, one is called local optima another is called global optima ok.

Now, there are two types of optimal solution. So, optimal solutions are of two types; one is called local optima; another is called global optima. Now, which one is local optima? Local optima are those solutions which are best solution, within neighbourhood ok. Now, how do you define this best solution? In view of the objective function; in view of the function f ok; so, best solution among its feasible neighbourhood solutions ok. So, local optima or local optimal solution or local simple local optima are those solutions which are best solution within its neighbourhood, within its neighbourhood ok. And global solution or global optima is the best solution, the best solution among all feasible solutions, among all feasible solutions ok.

So, global optima is the best solution among all feasible solutions; there are some mathematical conditions to represent this what is local optima, what is global optima, I am not going into detail on this. If you are interested you can go through the different books or you can follow some lectures available on optimization theory ok. Now, I can give an example for a single variable optimization problem. Let us consider unconstrained optimization problem.

So, suppose this is f x and this is x ok. So, this is an example of single variable objective ok. Now, if we plot this single variable objective with respect to this variable x and this plot is something like this, ok alright. Now, I want to maximize this, our goal is to maximize this f x. So, whichever solutions this is unconstrained, so there is no constraint on this. So, whichever is having the maximum value of f will be of course, an optimal solution.

So, you can see this function is having several peaks. So, this is one peak, this is another peak, this is another peak, this is another peak, this is another peak, and this is another peak. Now, if you just consider that some range of x; that means, if within this range of x or within this neighbourhood this is one of the optimal solutions, and this is of course, the local optima.

Similarly, this is another local optima, within its range and this is another local optima this is another and so on. And among all whoever is the, suppose the all are feasible solution because there is no constraint on it, we are not construct even making a constraint of the range of this x. Then the best solution among all this optima local optima is called global optima. So, this one will be a global optima.

So, these are all local optima local optima and this is called global optima ok. So, you should understand that the difference between local optima and global optima, in if you want to higher than that you should follow some optimization theory book ok.

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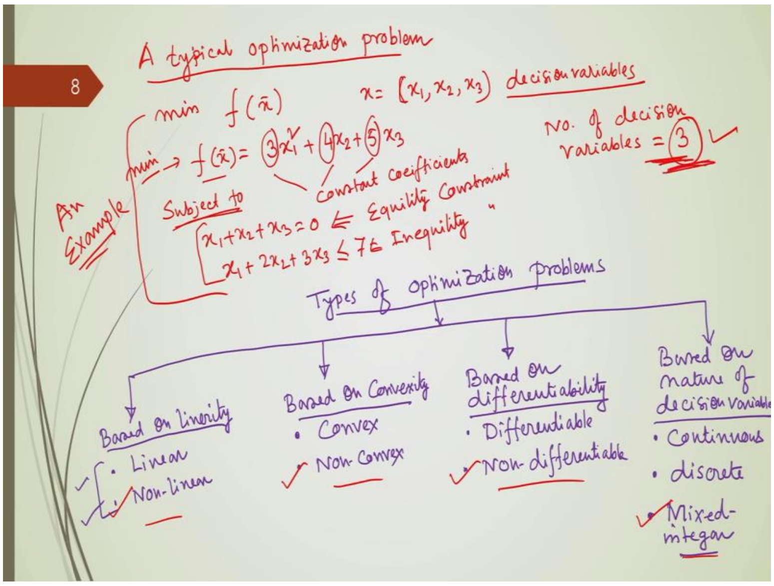

Now, I will also give some example; I will give some example of optima of a typical optimization problem. So, a typical optimization problem, a typical optimization problem, it is a single objective because as I said this here we will focus on only single objective optimization.

So, our goal is minimization of f x and x is having 3-dimensional minimization of x or x is having 3 variables, it is a decision vectors of 3 decision variables one is x 1, another is x 2, another is x 3 ok. So, let us consider that f x is basically 3 x 1 plus 4 x 2 plus let us say 5 x 3 ok. So, this is a typical objective function. So, typical objective function which we will need to minimize ok which we will need to minimize.

So, where x 1 and x 2 x 3, these are decision variable ok or only problem variables. And this apart from this x 1 x 2 x 3 we have some constraint, like 3, 4 and 5 these are coefficients or some constants, constant coefficient ok alright.

And this optimization problem may be subject to some constraint like x 1 plus x 2 plus x 3 is equal to 0. So, this is an example of equality constraint and it can be let us say x 1 plus 2 x 2 plus 3 x 3 less than equal to 7. So, this is an example of inequality constraint. So, this is a typical example of an optimization problem having 3 variables. So, this is a 3 dimensional optimization problem.

So, number of decision variables is equal to 3. So, number of decision variables is equal to 3, so it is a 3 dimensional optimization problem having this optimization objective is minimization of f x is equal to that 3 x 1 plus 4 x 2 plus 5 x 3.

Where this 3, 4, 5 they are constant coefficients ok. And also this objective is to be optimized or is to be minimized under these two constraints, one is equality constraint another is inequality constraint. So, this is an example of a typical optimization problem an example.

Now, instead of that optimization problem can be 3 x’s x 1 square, then there will be some you know non-linearity involved into that and those things will come into picture. So, here you can understand how can we represent a optimization problem into a mathematical problem ok. So, that is what my goal is.

Now, we have depending upon different nature of optimization problem we have we can categorize into a different types ok. So, types of optimization problems ok. So, this is not an exhaustive list, but whatever I think that I have found particularly in the literature of distribution system planning I will basically mention over here ok. So, so the different, we have different types of optimization problems. So, we can categorize them based on linearity.

So, based on linearity, we have linear optimization problem or non-linear optimization problem. As you know linear is a special quest other than that all practical problems are of non-linear ok. So, we can categorize different optimization as you know linear is a special case other than that all practical problems are of non-linear ok.

So, we can categorize different optimization problem based upon linearity, and we can categorize them into two types one is linear optimization problem another is non-linear optimization problem. Now, second categorization is based upon the convexity; based on convexity.

So, based on convexity we can categorize into two different types, one is called convex optimization problem another is non convex or concave optimization problem ok. So, based on convexity we get convex optimization problem or non-convex. Also we can categorize the optimization problem based on differentiability, based on differentiability ok.

So, based on differentiability, we have we can categorize optimization problems which can be differentiable or non-differentiable ok alright. Now, there is another you know categorization is possible that is based on nature of decision variable. So, based upon this nature of decision variables, we have continuous problem where all these decision variables x 1 x 2 x 3 to x n are of continuous. Or, we can categorize as discrete optimization problem where all these decision variables are of discrete in nature ok, or we can categorized as mixed integer.

In mixed integer some of the decision variables are of discrete, even it can be binary and some of the decision variables are of continuous, some of the decision variables are of continuous. So, these are broad classification of different optimization problem ok so. In fact, in distribution system planning problem, our problem is typically a very complex problem and this problem belongs to it is having non-linearity, it is having non convexity, it is having non differentiability, it is also having mixed integer type ok.

Where some of the decision variables like number of feeders, where or what should be the feeder routes these are all discrete decision variables ok. And some of the decision variables are continuous, like power flow; how much power will flow from one through one particular line and based upon that power loss would be decided. So, that is one an example of continuous decision variable ok.

So, we have non-linearity in the problem, we have non convexity we have non differentiability and we have mixed integer type. And that is why this distribution system planning problem is a complex optimization problem, complex optimization problem ok.

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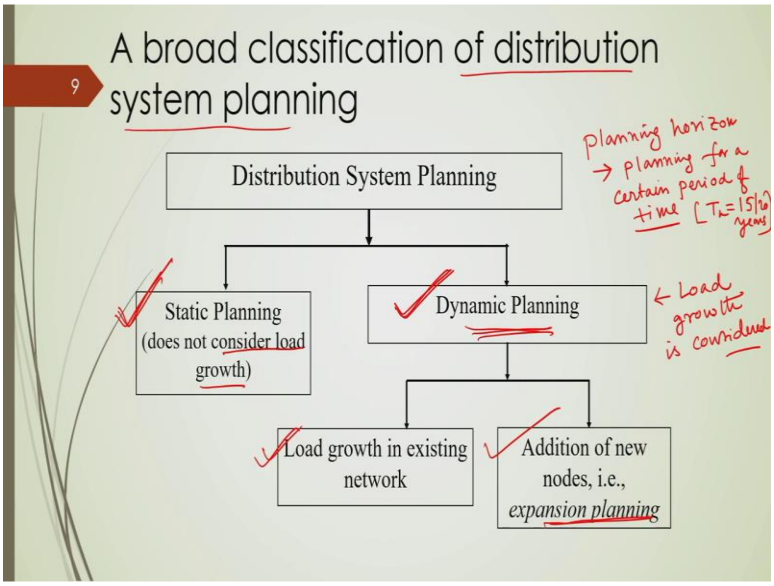

Now, here I have categorized the literature of this distribution system planning problem into two broad categories. One is called static planning; another is called dynamic planning ok.

Now, what is static planning? Static planning is where in static planning this load growth is not considered. It is a one step planning process and based upon a certain amount of load demand, for a certain amount of nodes it plans for a design of a network which could supply of all these nodal point and this load demand. So, there is no load growth considered.

In dynamic planning, load growth is considered; load growth is considered. And typically, this in dynamic planning, in fact, all these planning are done considering a certain amount of planning period and we call it as a planning horizon. So, planning horizon stands for the planning for a certain period of time, planning for a certain period of time.

And normally we do plan distribution network considering this planning horizon T h, T h is the representation of planning horizons for example, for 15 years or 20 years; 15 years or 20 years ok. So, if we plan a distribution network considering a planning horizon of 15 years, without considering a load growth in between. Then it will belong to the category of static planning. But within this planning horizon, if we consider this load growth time to time up and we can split the whole planning or horizon into small planning period 5 years each.

And we do plan this network for this 5 year, then it is a type of dynamic planning ok. So, there are two types of learning dynamic planning as well, one is load growth in existing network and addition of new nodes which is called expansion planning. So, as already I have discussed, under a distributions station service area, there are two ways that load will grow. One is existing nodes having higher amount of load and that is the first category, load growth in the existing network.

So, in those cases, we do not need to install or any additional distribution feeder or additional distribution line, but as long as the capacities of this all stakeholders of a distribution network is under this the new loading ok. But, this is one case, another case we have a distribution network existing distribution network and under the service area of the substation there are new nodes, which are coming in ok. These nodes might be the new residential complex, new commercial complex or new industries.

Now, we are supposed to connect these nodes to the existing distribution network and this process is called expansion planning. So, in expansion planning, we have a existing network, which we will plan for this connection of new nodal points or new loads, but for this other category we do not need any expansion of the network ok.

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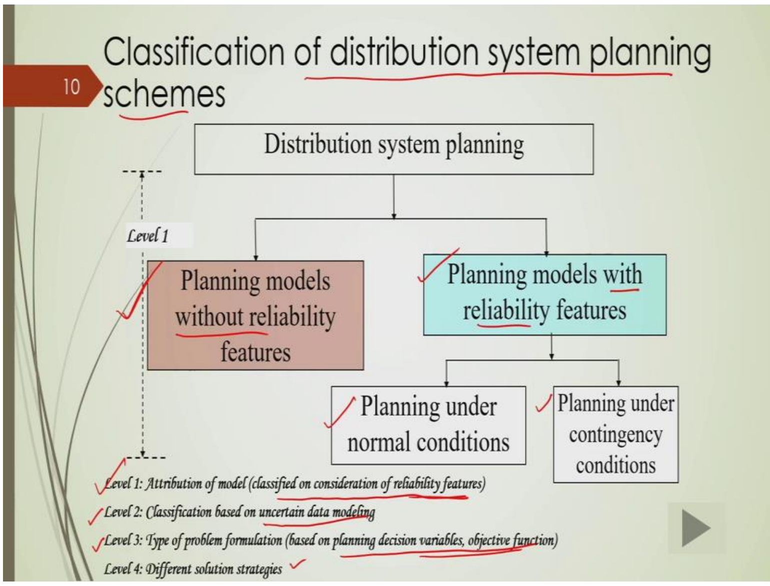

Now, this is the tree you know, I have classified this whole literature. This literature of distribution system planning consists of 100s of paper available, in the recent year should be also number of papers are reported ok. So, this categorization of this/classification, I made bit time ago ok few years ago.

And we made a four-level tree structure based upon different attributes of this planning and level one is based upon the attribute that consideration of reliability features ok. So, if you do this literature review on distribution system planning problem, you will see there are some papers some research articles in which reliability is modelled. And some research articles reliability does not model at all. So, based upon that, we have this level-one categorization.

The first case planning models are without reliability features and second case planning models are with reliability features; with reliability and without reliability ok. And under this category that planning models with reliability features we have two sub-areas, one is planning under normal condition; another is planning under contingency condition ok.

So, this is our level one categorization or categorization of different planning models based upon level 1, based upon the attributes of reliability features. Subsequently we have another 3 levels of classification; level 2 is based upon this uncertainty data modelling or the uncertainty modelling or those approach we in which uncertainty of the data is properly appropriately modelled.

And level 3 is depending upon the types of the objective function and types of the decision variables as I was talking about. And the final you know level is based upon different types of solution strategies used typically ok.

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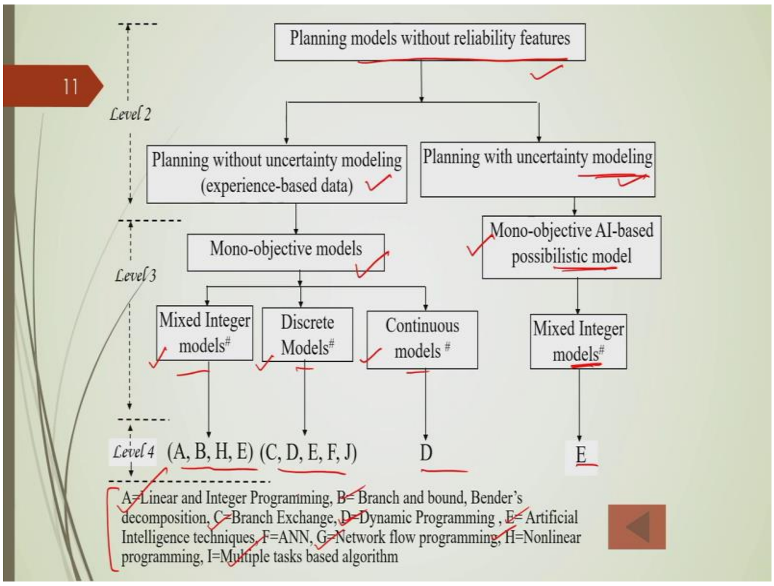

Now, you can see level 2 classification based upon, this is for only for these planning models without reliability features. It has also subs category by which uncertainty modeling is done, one is experience based data, another is uncertainty modelling. And then level 3 we have whether single objective optimization is carried out or multi objective optimization carried out.

And what types of decision variables we have, you can see it is these are the mono objective models, means we have only single objective on these models. And there are 3 categories as already I mentioned based upon this types of the decision variables; one is mixed integer, discrete, another is continuous ok.

And planning without uncertainty modeling also, planning with uncertainty modeling is an example of possibilistic model, where a possibilistic approach is used, a fuzzy set theory-based approach is used to model the uncertainty of different data ok.

And only one types of one type of model is used that is mixed integer model ok. And this represents basically types of solution strategies used, which include linear integer programming branch and bound bender decomposition. These are the names of different solution strategies of solving this typical distribution system planning problem, which include Branch Exchange, Dynamic Programming, Artificial Intelligence techniques, ANN that is Artificial Neural Network, Network flow programming, non-linear programming, multiple task based algorithm. There are different meta-heuristic algorithms as well.

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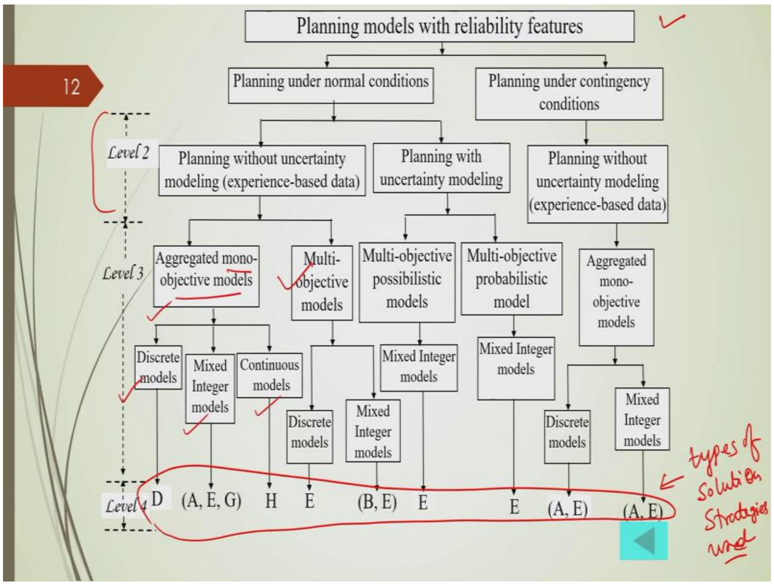

Similarly, this is another you know category already I mentioned what that is planning models with reliability features, under which we have level-2 classification based upon this how this uncertainties model in the data ok. And also, level-3 classification based upon mono-objective and multi-objective optimization used and the nature based upon the nature of decision variables, whether these are discrete variables or continuous variable or mixed integer variables.

So, based upon that we have discrete models, mixed integer continuous model, we also have mono-objective optimization model, we have multi-objective optimization problem so on and so forth ok.

Similarly, at the end you can see different types of solution strategy; this level-4 is based upon different types of solution strategies; different types of solution strategies used ok. So, as I already mentioned that what you mean by A B C D and so on ok. So, this is a typical 4-level classification of available literature on distribution system planning ok.

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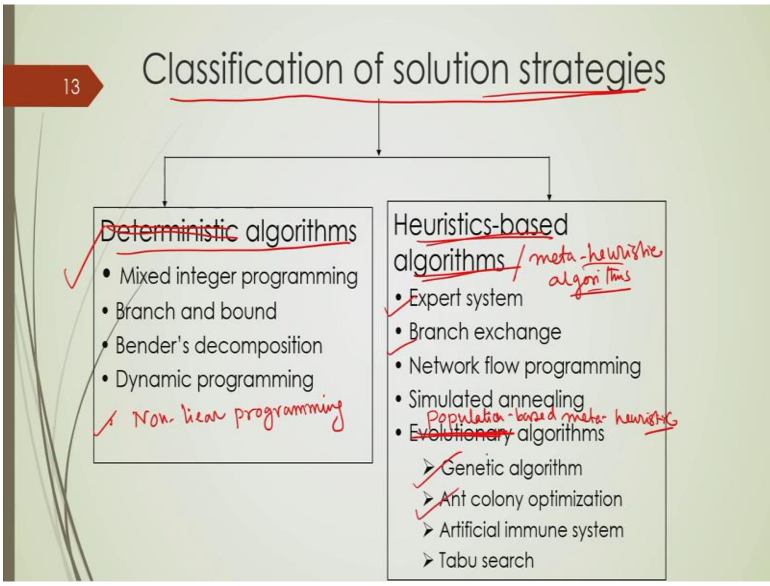

Now furthermore, if you classify this different solution strategies used in this distribution system planning problem, we can categorize as mathematical algorithm not, this is deterministic algorithm may not be suitable word, you can make mathematical logic based algorithm, another is heuristic or meta-heuristic based algorithm; heuristic or meta-heuristic based algorithm, meta heuristic based algorithm ok. So, in this category different mathematical optimization algorithms used which include linear programming, non-linear programming. In fact, non-linear programming is there and there are several other ok and in heuristics or meta-heuristic based algorithms there are expert system, branch exchange and some of the population based algorithms. You should not categorize that evolutionary algorithm; we should categorize that population based meta-heuristic algorithm based meta-heuristic algorithm.

Population based meta-heuristic algorithms which include genetic algorithm and colony optimization particles from differential evolution and there are many to name a few ok.

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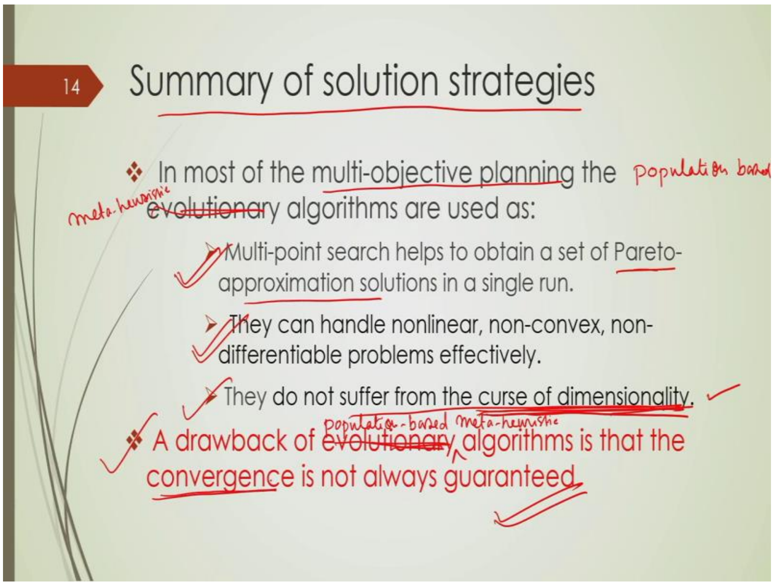

Now, let us make a summary of this different solution strategies used for solving this optimization problem. In fact, this particular course, I am not focusing on different solution strategies, rather I am trying to make you understand about the different optimization problem, different optimization problem ok.

You need to understand the problem the solution strategy; you need not to understand in detail ok. If you can understand this optimization problem the solution strategy you can choose as per your own and you can solve it ok. Now, what we have found by doing this literature review particularly for multi-objective optimization problem or multi-objective planning?

We have seen that multi-point search technique for this meta-heuristic population based meta-heuristic algorithms, they can find out a set of solution which you call Pareto solutions. What do you mean by Pareto solution? This again I will discuss in my next lecture in more detail, because in next lecture I will focus on this multi-objective optimization. So, if you understand this multi-objective optimization only then you can able to understand what is Pareto solution ok, this I am going to discuss.

And also, this meta-heuristic population based meta-heuristic algorithm. This is not only evolutionary algorithm, basically these are population based meta-heuristic algorithm, meta-heuristic algorithm meta-heuristic algorithm. These are having this features like multi point search technique, this they can handle any type of problem, basically linear non-linear programming, these are limited to application to certain problems ok.

But here this is this meta-heuristic algorithm, since they are not based on this mathematical logic or mathematical hard rules, rather they are basically inspired from different attributes of the nature or you can call them as nature inspired optimization approaches.

So, they can be used for any type of optimization problem, irrespective of linear problem, non-linear problem, irrespective of differentiable problem, non-differentiable problem; irrespective from you know that discrete or continuous problems or mixed integer problems ok.

And they do not suffer from curse-of-dimensionality. What do you mean by this curse-of-dimensionality? So, basically this optimization solution strategies they suffer when this dimension of the problem, when the value of n or when the number of decision variables we have in an optimization problem significantly higher ok.

So, as I have shown you in this typical example, we have this number of decision variables equal to 3, here we have 3 numbers of decision variables. But it may so happen in a typical problem, we may have 300 numbers of decision variables or even if it is 30 number of decision variables, then many of the solution strategies will not work ok. And that process is called curse-of-dimensionality.

And these solution strategies they will take excessive time, maybe several years to provide you solution because of the increase of this dimension of the problem, and this property is called curse-of-dimensionality ok. And this population based algorithm, I am not advocating any algorithm over here, but you know these are the facts that I am trying to show you, which you can even verify with this your literature review as per your own idea. And you will see that you know this solution strategy will suffer from this dimensionality problem ok, but there is a drawback which is very significant for this population-based meta-heuristic algorithm, for population based meta-heuristic algorithm; meta-heuristic algorithm, is that the convergence is not guaranteed. What do you mean by convergence? Convergence means ultimately whether we come, whatever solutions that we are getting that solution is of global optima or not, that is not known to us even after execution of several times in a simulation process ok. And that is the major drawback. We do not have any idea that whatever solution we are getting at the end after execution of this solution strategy, whether that is a local optima or global optima or even neither local optima nor global optimum, that is not known to us ok, that is a significant drawback ok.

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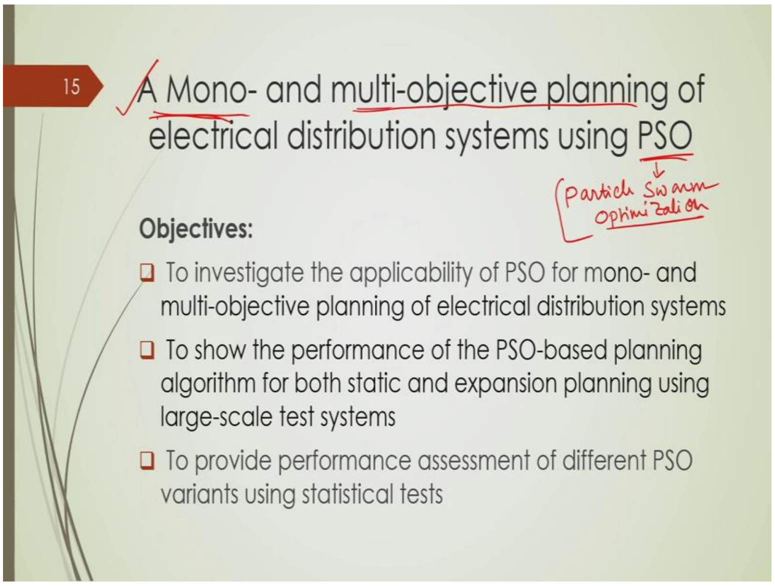

Now here in this particular you know part of the lectur,e I will basically discuss about a mono-objective and a multi-objective optimization problem for designing this distribution networks. And we will talk about one meta-heuristic algorithm, that is called particle swarm optimization. Already it is I hope it is declared somewhere or if no, you can I can write it as its full form that is.

So, as I said so the solution strategy how it is how it is solving that that is not important for this part, in view of this theme of this particular course. But we learn what is particle swarm optimization and why we use it for solving this typical problem. And most importantly one needs to learn from this part of the lecture is how do we formulate this optimization problem ok.

So, first we will talk about mono-objective or single objective optimization problem for designing a distribution network and then we will switch over to multi-objective optimization problem ok. So, here we will talk about mono-objective problem. So, in mono-objective problem what we will do? First we will formulate the problem and then we will this problem formulation is something which is very essential to know. Once you have a fair idea on that you can eventually formulate a new problem for a existing distribution network or expanding a distribution network.

And then accordingly you can devise your own solution strategy ok and that is how you can initiate the research in this particular field ok.

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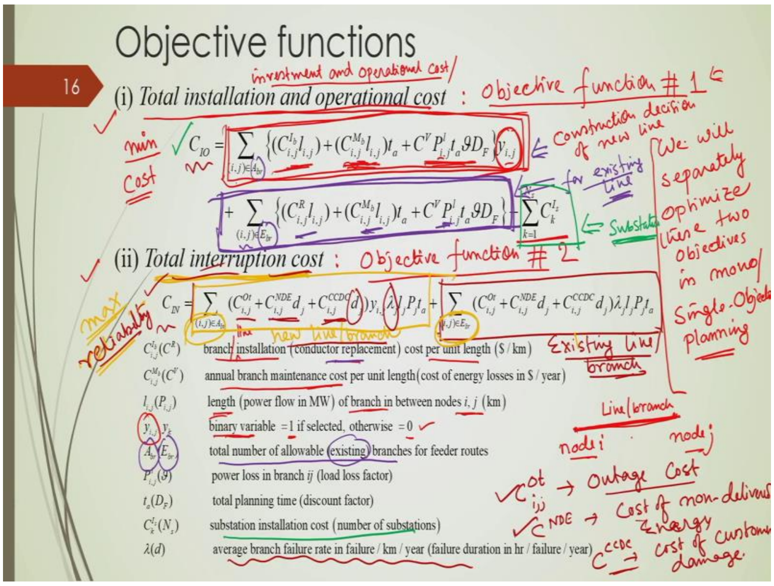

So, here I will show you how we will basically formulate, this mono-objective optimization problem for designing a distribution network ok. Now, although it is a mono-objective optimization problem, but I have shown you two different objective functions, one is called objective function 1, another is objective function 2 ok.

Now, we will separately optimize these two objectives. So, we will separately, we will separately optimize these two objectives in mono or single objective planning ok. So, that is something that I should tell you at the very beginning because looking at two objective functions, but still we are calling it as a single objective optimization is somewhat confusing ok.

So, here, we have formulated two objective functions, but we will consider them separately. When you will optimize this objective function 1, I will not consider objective function 2 and vice-versa. When you will consider objective function 2, I will not consider objective function 1 as objective at all ok, and we will optimize them ok.

Now, let us understand what is this objective function 1 and what is objective function 2 ok. So, in objective function 1 basically the goal is to optimize or to minimize the cost, minimize the cost. Now, what is that cost? Cost is basically total installation or operational cost or total investment or operational cost, this can be also called as investment and operational cost ok.

So, this is this can be also called as investment and operational cost, because it indeed needs an investment. Now, what is that cost all about? These costs have 3 components, one is this, one this is one cost component, this is another cost component and that is another cost component ok. This cost component this cost component basically, this cost component is basically having again three different components, one is this; another is that, another is that.

And this what is that C I b i j multiplied by l i j, so this is basically the branch or line installation or line branch or line installation or conductor replacement cost per unit length multiplied by this length of the branch, between the nodes i and j.

For example, if this is node i and suppose this is node j ok, now I need to construct a line this is line or branch which connects this node i to node j ok, and this line constructing this line, constructing this line whatever cost is involved this is basically kept in this particular first cost component ok.

This is basically included in the first cost component. So, this involves this line construction cost or line replacement cost and also the cost of the you know energy or power losses ok and this is multiplied by this variable y i j, y i j where this y i j is basically a binary variable, that if it is it can be either 1 or it can be 0. When it can be 1? If you decide to construct a line. When it can be 0? If we do not consider to construct a line at all between this node i to node j, that is something one needs to understand very clearly ok.

So, between this node i to node j, if I construct a line then how much will be the cost of this construction of this line involve, that attributes to this, but first cost component ok. But that will be added to the objective function, if we decide to construct this line. Now, if we have an existing line then we may go for this you know construction, we may go for this conductor replacement, is not conductor replacement this C M b is basically this in maintenance cost.

So, this is in investment cost, this is maintenance cost and this is cost due to this energy losses. So, if we go for this constructional construction of this line, if we decide to construct this line then only we will add this installation and maintenance cost, as well as cost due to energy loss of this particular line to this objective function. That is something one needs to understand ok.

Now, what is that second cost component? The second cost component that is this cost component has having the 3 components, one is this; another is this; another is this. The first component you can see it is related to conductor replacement ok and this is maintenance and this is you know that energy loss ok. And here i j belong to a set E b r, previously i j's belong to set A b r, where is A b r and E b r mentioned, here you can see the set A b r, this is a set which consist of number of allowable branches. And E b r stands for number of existing branches.

So, this is for new line construction of new line, I can write it in the same; construction decision of new line a new branch and this is for existing line ok. If there is no existing line or if you want to plan or if one needs to design for a brand new network, then this whole part would have been 0. This whole part, this whole part would have been 0.

So, this is only applicable if we have some existing pre-existing line or pre-existing network, which we need to expand ok. So, this is applicable for expansion planning and the third cost component that is this cost component, this cost component is basically this cost to the C I s k its stand for this substation installation cost. So, this is applicable for substation.

As you know this you know a typical design of distribution network consist of design of substation, design of different feeder branches or feeder lines. So, first two cost components they consider, there we considered the construction of new line or new feeder branches and existing for new, existing feeder branch or existing lines.

And last one this cost component is basically component of the substation ok, or substation cost. So overall, this you know objectives provide you this total cost required to install a new line, a new installed all new lines and capacity addition or conductor replacement required for existing lines ok. Now, this is one objectives and the second objective is that is total installation, total interruption cost; here our goal is maximize reliability.

So, it also has two component, one is this; another is that ok. Now, again you can see here for this component, for this component this feeder lines belong to this new branches or lines that we are going to construct. And this here i j belong to the existing branch or existing line. So, this is for existing line, this is for new line or new feeder branch new line or new feeder branch and this is for existing line or existing branch ok.

Now, how do we basically optimize this reliability? Or by minimizing this total interruption cost. Now, how do we determine this interruption cost? It has three components, one is called outage cost that is C Ot another is called cost of non-delivered energy, cos C ND, another is called cost of customer damage cost. So, this C Ot i j is basically outage cost.

So, here again we translate this reliability, we translate this reliability into a cost function ok, by considering this outage cost or C NDE stands for cost of non-delivered energy.

In fact, similar cost similar index you have already seen when I teach this reliability ok, and this third component that is CCDC; CCDC is cost of customer damage.

So, that means, the first you know cost components is the cost associated with one interruption, the second component stands for cost associated with this non deliver energy. Because non deliver energy is something that the utility cannot provide that much of energy to the customers, because of that interruption or because of that falls. And thereby the utility is suffering from that less revenue from the customer ok.

And also this CCDC is another cost component, which is not associated with this utility directly, but it is the customer damage cost, that cost due to the particular interruption which makes some damage of the customer ok.

So, this component is for new line or branch and the fault of new line of the branch and these are called existing line of the branch. Now, for existing line of the branch you can see that how do we have defined this thing, this all depend upon this lambda, that is failure rate and also depends upon this d; this small d stands for this failure duration.

So, here you can see lambda and d these two are this reliability parameters, which we have already discussed in the reliability module ok. So, they are function of this lambda and d. Here, instead of r, small r we represent this repair rate by small d and this you know interruption cost is function of this lambda and that is failure rate and repair duration for a particular new line or feeder. So, we have two objectives one is C IO and other is C IN.

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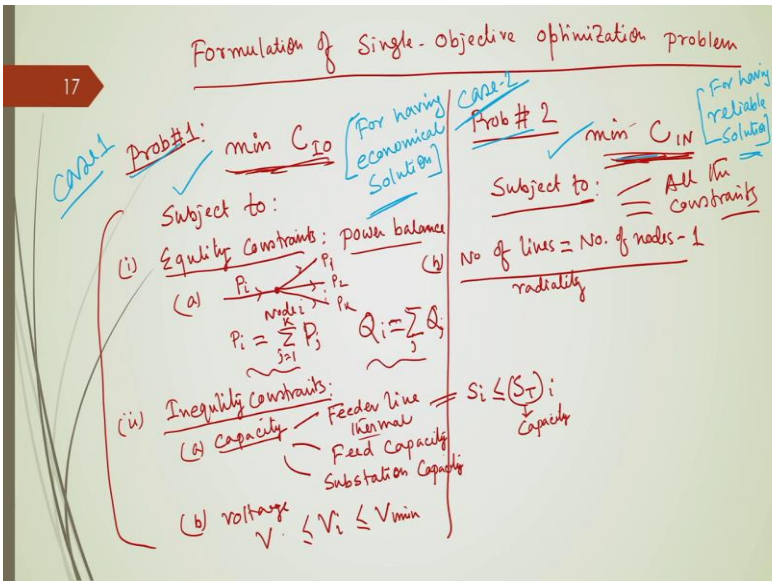

So, what we will do? We will formulate. So, we will formulate two problem, one is problem 1, one is problem 2. So, in problem 1 our objective function is minimization of C IO, that is minimization of this interruption in installation and operational cost, C IO. And in problem 2 our optimization problem is minimization of C IN, IN stands for interruption C IN ok. So, this is one problem and this is another problem. Both are constraint problem ok, both are constraint problem subject to some you know constants, here it is also subject to some constant.

Now, what are this constant? First constant is equality constraint. This equality constraint is power balance constant, power balance constant ok. Now, what is power balance? You know that any particular node suppose, here we have this node I and these are the active power which is entering this node and these are the some of the reactive power, some of the active power which is going out. So, this is P 1, P 2 dot dot P k.

So, here as you know this P i should be equal to the summation of P j, where j varying from 1 to k. So, this is how we can make this power balance. So, this is for active power as well as reactive power. So, since; it involves this equal equality so that is why it is inequality constraint. And how do we fulfil this equality constraint for a feasible solution? By performing this load flow or forward backward sweep load flow ok.

But apart from that we have a number of inequality constraint; number of inequality constraints. What are those inequality constraints? First is voltage constant or capacity constants, first is capacity constants; that means, this any feeder this capacity constants are of two types, one is called feeder line thermal constant, another is called feeder capacity constant, another is also there that is called substation capacity constant, substation capacity constant.

You can easily represent this any particular feeder line constant is something like its line flow, it is represented by let us say this apparent power S i, should be lower than s let us say T i where S T i is basically capacity, this is the capacity ok. Now, apart from that we have another constant that is, called voltage constant. That at any of this node voltage V i, it should lie in between some given maximum and minimum limits ok.

And apart from that we also incorporate radiality constant ok; you incorporate radiality constant. In radiality constant, how do you represent this radiality constant? By this number of you know line, this is this will come to this actually here in equality constants. So, that is I can write over here number of lines is equal to number of nodes minus 1.

So, this is one constant which is called radiality constant ok. So, what we will do in this single objective optimization problem? We will basically optimize this objective function under these constraints. Similarly, we will optimize this objective function under all the constants, all these constraints ok.

So, constants will remain same in both the problems, but objective function will change, in one case our objective is total installation and operational cost, another case our objective function is total interruption cost and both are minimization problem. Here by minimizing this you know total investment and operational cost, we will be getting as a solution that solution would be economical solution.

So, this is for having economical solution economical solution, but this problem where we optimize this total interruption cost.

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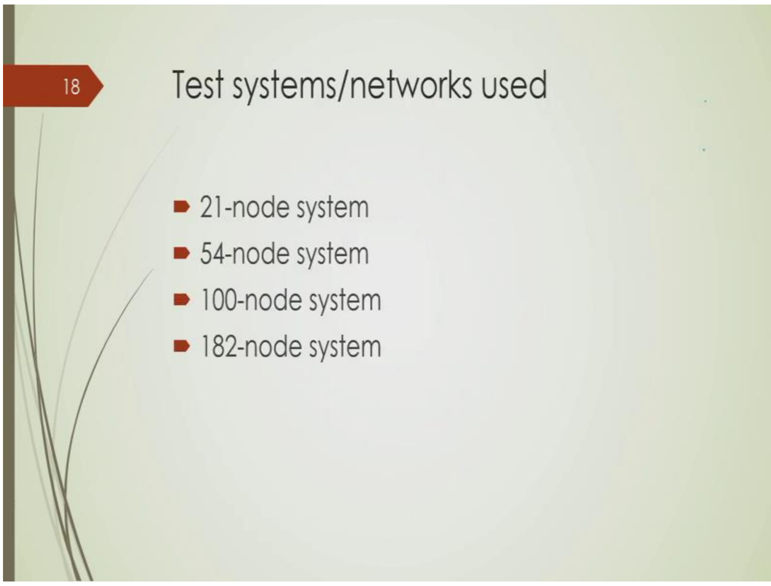

So, here whatever we will be getting that is for having reliable solution ok. So, by optimizing this we will get an economical solution and by optimizing this we will get a reliable solution. So, we will consider two problems separately and one time we will optimize this, another time we will optimize that. But both the cases we have same constants ok, both the cases we have same constants ok. So, this is problem 1 or case 1; case 1 and this is problem 2 or case 2.

So, these two case studies, I will show you the result for these two case studies in my next lecture ok. And I will stop at this point today.