COMPARISON BETWEEN DIFFERENT MULTI-OBJECTIVE APPROACHES TO DISTRIBUTION NETWORK PLANNING

Alireza Haji	Bahman Jamshidi Eini	Morteza Mirvazand	Mohamadali Safari
Sharif university of technology – Iran	Sharif university of technology, Alborz PPDC – Iran	Alborz PPDC– Iran	Alborz PPDC– Iran
ahaji@sharif.edu	b_jamshidieini@ie.sharif.edu	Mirzavand_morteza@yahoo.com	safari@wtppdc.ir

ABSTRACT

Distribution companies try to meet different goals such as increasing profitability, reducing investment and improving reliability indices. Therefore, distribution network planning has converted into complex multi-objective optimization problems. Mathematicians and operation research experts have developed many methods which can be used for solving these problems. Despite all efforts to develop applicable approaches for these problems, there is still no general consensus on project selection policy. Evaluating the strengths and weaknesses of each network optimization strategy selection in pragmatic manner is the objective of current research. In this paper, many methods used in network planning and reconstruction were categorised into few groups such as weighed sum, pre-emptive and Chebyshev. After that, the results of using each method were compared. The result of this research corroborates the claim that the approach used for combining multi-objective distribution network problem objectives has great effect on its optimal result.

INTRODUCTION

Distribution companies have focused on gaining customers' confidence and increasing their profitability by reducing their investment and running cost while improving reliability and power quality indices. Thus distribution network planning is converting into complex and conflicting multi-objective optimization problem. Growth of operation research and evolutionary algorithms stimulate engineers to develop numerous innovative methods for finding optimum solution. These methods can be categorized into a few approaches.

The level of complicity is an important issue in modelling. Although oversimplified methods help engineers to understand the fundamental concepts of distribution network planning, relevant models are idealistic and optimum solution of these models is not achievable in reality. In contrast, some distribution network design methods are too complicated for practical usage. Funding is another subject which should be considered in network planning. Financial Issues can be embedded in optimization model as a constraint, objective function or mixture of them. In addition, interest rate, Inflation rate and capital recovery have an impact on optimization result. Therefore, distribution network planning engineers should be aware of models weaknesses and strengths in decision making, otherwise optimization may cause resource or time wasting, ineffective budget allocation and profitability reduction.

DISTRIBUTION NETWORK PLANNING APPROACHES

Network planning problems have been formulated by many researchers and numerous methods have been used in these formulation. Although each researcher has tried to develop an original approach for formulating or solving optimization problems, there are some similarities between their methods. Thus, their methods can be categorized into a few strategies. It is not possible to list all articles which were used in categorization, but some of them were listed in reference section of this paper [1] … [10].

Decision making based on Pareto frontier

When the optimization objectives conflict with each other, such a complete optimal solution that simultaneously optimizes all objectives could not exist. Therefore, concept of Pareto-optimal solution has been introduced. A solution is weakly Pareto optimal if there is no other point that improves all of the objective functions simultaneously and a point is Pareto optimal if there is no other point that improves at least one objective function without detriment of another function. It is obvious that each Pareto optimal point is weakly Pareto optimal, but weakly Pareto optimal point is not always Pareto optimal point. In many references Pareto optimal point has been named: non-dominated solution or non-inferior solution.

This approach of distribution network planning is based on finding a set of feasible solutions along a Pareto frontier and selecting non-dominated set of solutions that moving away from them to any other solution leads to sacrificing in at least one criterion. There are many tools like genetic algorithm for finding Pareto frontier. Decision makers can select satisfactory solution among the Pareto points by various multi criteria decision making tools.

Weighted-sum approaches

The weighted-sum model is the simplest and the most famous method used for multi-objective optimization. This approach is based on achievement of conflicting goals by converting a multi-objective optimization problem into a

single-objective one. In this method weighted-sum of all the objectives is used instead of all the objective functions.
These weights are assigned to goals according to their importance. Weight assignment is the most challenging part of the optimization and solving the optimization problem with weighted-sum approach generates an optimal solution which is highly sensitive to weight selection. Weighted-sum method is reliable only when all the data are expressed in exactly the same unit or numerical weights can be precisely assigned to the achievement of each goal.
In many articles, researchers have used multi criteria decision making (MCDM) tools like analytic hierarchy process (AHP) for weight assignment. Although expert opinion is the key of weight assignment, there is not a general consensus on how their expertise can be used in modeling, especially when some goals are not measurable or the number of conflicting objective is considerable. In addition, the objectives can be numerous in reality, but a person capability of pair-wise comparison is limited.

Pre-emptive or lexicographical approaches

In some of distribution network planning, the importance of goals may not be quantifiable, so other forms of the optimization are more realistic. When Engineers are unwilling or unable to assign weights to each goal, it is possible to assign priority levels to objectives and to rank them lexicographically based on their importance. This method, which is called pre-emptive approach, is based on the assumption that in the criterion ranking. Each attribute is more important than all the other attributes, which follow it in the ranking. [11]
Selecting the best alternative by rank ordering of criteria upon importance can be performed by following procedure: firstly, alternatives with the best possible level upon the most important criterion are selected. Then, Alternatives with the best possible level upon the next important criterion are chosen from the resulting subset of pervious step. This step will be repeated until all alternatives are sorted. In this approach, the optimization in a higher priority level is infinitely more important than lower priority levels and there are no finite trade-offs among objectives in different priority levels. [12] Therefore, the effects of low priority objectives may be neglected.

Minimax and Chebyshev approaches

The other approach of network planning has originated from Chebyshev goal programming, which is based on minimization of the maximum deviation from each single goal. In this approach, the first step is defining ideal solution which can satisfy all objectives simultaneously. This solution is not feasible and reflects utopian idea of decision making. There are deviations between ideal solution and feasible alternatives. In next step, the solution which its maximum deviation is less than other alternatives is selected as optimum solution.
The effectiveness of this approach depends on selecting of utopian solution. If there is an unrealistic gap between ideal solution and reality, the result of optimization may not be Pareto-optimal. on the other hand, if attainable alternative is selected as utopian one, the optimization algorithms never search for better solutions.

Non-deterministic approaches

Even though mathematical programming models are generally assumed to be deterministic, in real world modeling, we encounter a lot of uncertainty sources. Consequently, it is sensible to consider uncertainty in modeling.
There are three main non-deterministic approaches:
1- Fuzzy programming
2- Stochastic programming
3- Robust optimization
Fuzzy programming has been developed for treating vagueness and ambiguity in optimization by using fuzzy set in problem objectives and constraints defining. [13] The use of fuzzy models reduces not only the need of costly and accurate information, but also the chance of unrealistic modeling.
Stochastic programming deals with a class of optimization problems which some of its data are random variables. Stochastic optimization methods are based on the calculation of probability associated with multi-dimensional random variables and conditional expectation. There are computational challenges related to multi-dimensional integration for calculating expectation or probability, even if random variables are discrete. In addition, it is hard to estimate probabilistic behavior of model parameters.
Robust optimization is methodology which considers the random character of problem parameters without making any assumptions on their probability distribution functions. This approach guarantees the feasibility and optimality of the solution for the almost worst conditions. Because robust optimization is based on worst case approach, feasibility often comes at the cost of performance and generally leads to over conservative solutions. Controlling the level of cumulative conservativeness of uncertain problem parameters is a challenging topic in robust optimization.

Financial issues

There is a growing trend toward more realistic financial study in distribution network planning like microeconomics and macroeconomics considering, energy market and investment risk evaluation.
Generally, reasonable investment is profitable and can improve network reliability, but over investment have not considerable effect on reliability and therefore unnecessary projects reduce company profitability. The relation between investment and profitability of distribution network was shown in figure 1.

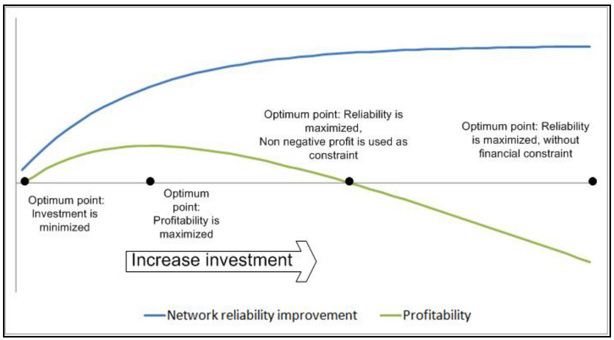

Figure 1: relation between investment and profitability

Mixed approaches

The strategies which have been introduced in previous sections can be mixed for more effective methods. Nowadays, numerous researchers have used metaheuristic algorithms including particle swarm optimization (PSO), Taboo search (TS), genetic algorithm, simulated annealing (SA) and ant colony optimization (ACO) for finding optimal solution in deterministic and stochastic conditions.

METHODOLOGY

For evaluation of effectiveness of various planning approaches, eight objectives have been selected and the level of achieving them has been estimated by computer simulation. These objectives are:

1- EENS reduction
(Expected energy not served)
2- SAIFI reduction
(System Average Interruption Frequency Index)
3- SAIDI reduction
(System Average Interruption Duration Index)
4- MICIF reduction
(Maximum Individual Customer Interruption Frequency)
5- MICID reduction
(Maximum Individual Customer Interruption Duration)
6- Power loss reduction
7- Profitability
8- Investment reduction

Objectives one, two and three are general reliability indices which reflect average reliability of distribution network. Objectives four and five are related to reliability of the worst-case customers. Objective six is the reduction of power loss and Objective seven is the long-term profitability of project. The last objective is investment minimization.

Although there are numerous distribution network enhancement or reconstruction methods which can help distribution companies to achieve these objectives such as installing capacitors, constructing new networks and replacing outdated or damaged components, we confined current research to installing recloser, replacing old disconnector with load break switch, changing bare conductors to cover wire and increasing conductors diameters in medium voltage network.

Pre-emptive, weighed sum and Chebyshev optimization were selected for evaluation in current research. Three different weight set were selected for simulation. Weight set one was selected by try and error seeking balanced goal achievement. Weight set two and three were chosen by analytic hierarchy process. Weight set two was economy focused and weight set three was biased in favor of reliability indices. Similarly, three different lexicographic orders were used in pre-emptive method. Power loss reduction is the highest level of priority in orders one. This position was assigned to profitability in order two and maximum individual customer interruption frequency in order three.

For comparing the effect of each optimization approach on objective achievement, we left out unnecessary data. Therefore, network detailed information was neglected and the average result of optimization in different network was estimated by rough simulation.

RESULT AND DISCUSSION

The simulation result was displayed in figure 2 and 3. The impractical utopian solution was plotted in blue (outer symmetric octagon). The red asymmetric octagon was result of Chebyshev optimization. Chebyshev optimal solution was rather balanced and the results of other methods were compared with it.

The results of weighted-sum based optimization were displayed in figure 2 showed the effect of weight variation. Figure 3 showed the result of different priority order in pre-emptive optimization. The result of simulations showed that in pre-emptive optimization, the results of different orders were under the influence of only most important criterion. Thus, our try to balance the goal achievement in pre-emptive method was not successful.

There is considerable positive correlation between some objectives, especially between EENS and SAIDI reduction, so when a project has positive effect on SAIDI, the EENS will be reduced too. In contrast, some objectives are negative correlated, for example power loss reduction needs a lot of investment and this matter increases the level of conflict between these two objectives.

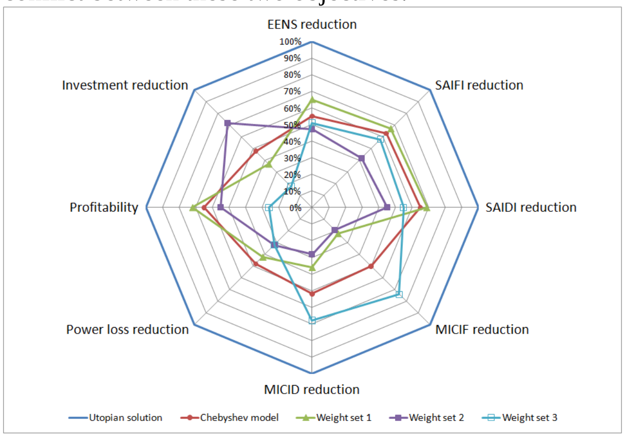

Figure 2: The result of weighted-sum optimization

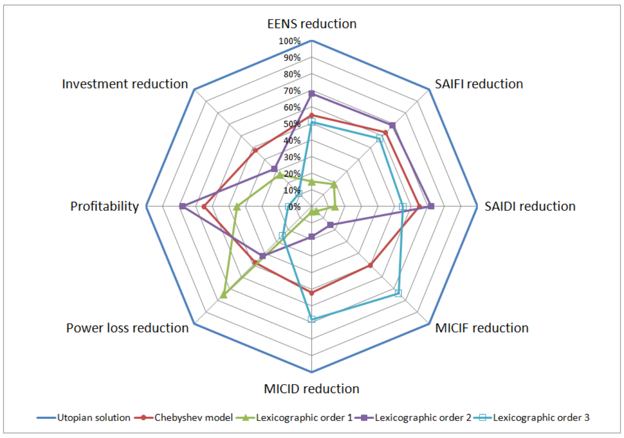

Figure 3: The result of pre-emptive optimization

CONCLUSION

Although numerous methods have been developed for distribution network planning, there are some similarities between developed methods. In current research we compared approaches which are foundations of these methods. Finally, the effects of selecting each approach on goal achievement were estimated by simulation.

The results of simulation showed that Chebyshev based models are capable of balancing conflicting objectives. In contrast, pre-emptive methods are powerful tools for focusing on the most important objectives. The results of weighted-sum methods are between these two extremes.

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