OPTIMAL CAPACITOR PLACEMENT IN RADIAL DISTRIBUTION NETWORKS CONSIDERING UNCERTAINTY IN LOAD USING PSO ALGORITHM

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ABSTRACT: *In this paper we try to find the place and capacity of the considered capacitor in the distribution network through modeling the uncertainty of consuming loads in distribution networks by interval analysis and using the PSO evolutional algorithm. Also by studying the economical aspect, we determine the expense of installing the capacitor in the network. The proposed objective function in this research is on the basis of losses amounts reduction in the network and capacitor installation. Regarding the available and present uncertainties, the proposed approach has better compatibility with the real systems and as a result it shows better operation*.

Key words: Capacitor placement , active losses , voltage profile , PSO algorithm , uncertainty.

1-INTRODUCTION:

Flow of reactive power in the distribution network causes increase of power losses and decreases the lines capacity. Appropriate installation of capacitors, can include releasing the installed equipments capacity in the distribution system, and adjusting the power factor and improving the voltage profile, in addition to decrease energy losses, by compensating a part of consumed reactive current. So finding the optimal size and place of capacitor in the distribution system is so important. So far, several optimization methods are applied to find the place of capacitors. Reference [1] has studied this issue using the integer programming method that considers the load and voltage distribution constraints too. Reference [2] proposes some innovative methods to recognize the critical buses using the amount of their influence on losses of the proposed system. Reference [3] presents a new method using the fuzzy innovative combined method and considered the membership functions for voltage and active losses. The objective function of this reference is a combination of capacitor installation expense and active losses expense.

In reference [4] the multi-objective algorithms of safety system are used to solve the problem of capacitors locating. In reference [5] the fuzzy method is used for this purpose. Locating the capacitor using the fuzzy logic on the real networks is presented in reference [6]. Reference [7] proposes some methods on the basis of metal plating algorithm and considered it on the 69 buses networks. Reference [8] used genetic algorithm to gain the optimum solution for the problem of location capacitor and its objective function is just a combination of the capacitor expense and power losses without considering the operation constraints. Reference [9], at first, obtained the losses of primary approximate places using the sensitivity coefficients and then determines the exact place and capacity of capacitors using the bee colony algorithm. Reference [10] presents the particle swarm optimization method for optimum capacity and place of capacitor. The proposed algorithm obtained the place and location of capacitors regarding the daily load curve (load level) and dynamic sensitivity analysis.

In this article the capacitor locating problem is optimized using the particle swarm optimization algorithm (PSO) through considering the load uncertainty and with an objective function that consists of the installed capacitors expenses and the power loses expenses. In the following after expressing the problem analysis tools (the load distribution method), explaining the procedures of PSO method and presenting the objective function, the results of implementing this method on the 10 buses network will be compared in the form of some tables.

2-Uncertainty in the consumed loads of distribution network

Uncertainty is a concept that determiner is always faced it during the process of decision making. Because of uncertainty, some uncertain details are expressed in the affair or problem that for this reason it's not possible to determine the system parameters exactly. Several mathematical methods are presented for studying the uncertainty of systems and procedures and in them it is tried to decrease the uncertainty as much as possible and the qualitative and quantitative information about a specific case is controlled by them and the model outputs become evaluable and controllable. In the distribution network for the purpose of modeling the uncertainty in consuming loads some different methods can be used that include fuzzy logic and interval mathematics. In this article we will use the interval theory to model the uncertainty. Since the real issues faced or associated with doubt and uncertainty, the interval arithmetic is known as a suitable method for modeling such issues and cases. The interval linear programming model is a method for decision making under the condition of uncertainty.

In fact by interval definition of parameters and consuming loads of the network we cannot determine a specific and particular amount for consuming load of each feeder with certainty and conclusively. The uncertainty will be modeled using the interval theory. Therefore this case causes to distinguish the size of calculated optimal capacitor by PSO algorithm in two high and low intervals.

3-Modeling the problem

In a distribution network, the active power losses of the network are related to the reactive component of the branch current and will be introduced as equation (1):

$$P_{Lr} = \sum_{i=1}^{n} I^2{}_{ri} * R_i \quad (1)$$

Where

I_{ri} is the reactive component of the branch current in the branch ith according to [A]

R_i = resistance of the i^{th} branch of the network on the basis of [Ω]

P_{Lr} = the network active power losses on the basis of [kw]

But in fact the reactive component of the current of i^{th} branch is not a constant amount because the changes of consuming load in each power system can't be shown correctly with a load curve. Usually, using the mean (average) curve of the consuming load changes is a common and ordinary way to show the curve of consuming load changes. The load changes during the hours of night and day occur because of the change in the kind of use and during the year they occur on the basis of different seasons changes. So for exact modeling of the load, using the time-varying model is proposed. Regarding the fact that the load time-changes model, increase the size of calculations and therefore, the required time for performing simulation, so to decrease the complexities of problem these changes can be classified into some specified levels that are known as the load duration curve.

According to the mentioned matters, so its better that the reactive component of i^{th} branch current from the constant situation is considered as equations (2-4):

$$I_{ri} = \left[I_{ri}\_lower \quad I_{ri}\_upper \right] \quad (2)$$

Where I_{ri}_lower is the lower limit of the reactive component of i^{th} branch current and I_{ri}_upper is the upper limit of reactive component of the i^{th} branch current, these changes in the load consuming model cause the active power losses of the network changes from the constant situation and the losses amounts are defined as interval form. Therefore in the case of locating the capacitor in the distribution network each constant amount must be considered as the interval amount.

3-1- equal constraints of problem

The power balance is an equal constraint that must be observed. In fact, the real power ob buses must be limited as equation (3) that expresses the power conservation law.

$$P_{Loss} + \sum P_{Dj} = \sum P_{DGj} \quad (3)$$

The real power that is produced in bus j^{th} by DG must be equal to the total of consumed power in bus j^{th} and the real power losses in that bus.

3-2- unequal constraints of problem

The compensated reactive power must be limited as equation (4):

$$Q_j^c \le \sum_{j=1}^{n} Q_{Lj} \quad (4)$$

Where Q_j^c and Q_{Lj} are the compensated reactive power in bus j^{th} and the consumed reactive power in bus j^{th}. In fact to preserve the power quality, Q_j^c must be equal to or lower than Q_{Lj}. Also the voltage range in each group and the current range in each branch must be defined and determined in an allowed limit in equations (5) and (6):

$$\left|V_{j\min}\right| \le \left|V_j\right| \le \left|V_{j\max}\right| \quad (5)$$

$$\left|I_j\right| \le \left|I_{j\max}\right| \quad (6)$$

Where, P_{Loss} is the real power loss and P_{DGj} is the amount of the real power that is produced by DG in bus j^{th}, P_{Dj} is the amount of consumed power in bus j^{th}. $V_{j\min}$ and $V_{j\max}$ are the minimum and maximum amounts of voltage in bus j^{th} respectively and also $I_{j\max}$ is the maximum amount of current that passes from branches.

4-Applying PSO algorithm in finding the optimum location and size of capacitor

At first , we enter the network information including the network line and bus information (active and reactive consuming load)and constant parameters of particle swarm optimization algorithm as the input of optimization program. The backward–forward load distribution program is performed in the network to accomplish the load distribution, and according to the objective function of the problem that is decrease the losses, we will form the initial population. In this situation there is the particle fitness function and the problem of optimizing the losses decrease. In fact a particle of considered population that has the most losses decrease is known as the superior bus and dominant bus. For this purpose in the next step all the constraints and limitations which are mentioned in modeling must be observed to obtain an optimized response.So after performing the load distribution to for optimization, the problem constraints must be considered. In the case of violating these constraints, the initial population must be formed again and if these constraints were observed we will pass to the next step of algorithm. According to the structure of PSO algorithm, the P-best and g-best of it should appear so that the best public experience and the best personal experience is obtained from the possible answers and this cycle is repeated until attaining the optimum answer of the problem that is finding the optimum location and size of capacitor in the distribution network.

5-NUMERICAL RESULTS

The test network that is considered in this article is a 10 buses radial distribution network from IEEE standard networks. The information about the line and buses of network (the amount of consuming active and reactive power) and the network structure for the 10 buses test network is taken from reference [11]. Figure (1) shows the single-line diagram of this network. This network includes 9 lines, 10 buses, and total of the active and reactive consumed load in the network in the case of base load is 12368 kW and 4186 kVar respectively. The amount of losses in the base condition in this network is equal to 742.61 kW and the number 10 bus voltage, is the weakest point of the network from the view point of voltage level that is 0.86323 per unit. The apparent base power of this network is 100 MW and its base voltage is 23 kV.

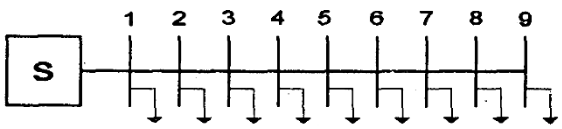

Figure (1) single-line diagram of 10-bus radial network in distribution network

The limitation for voltage amount of each bus in the 10-buses network is considered between $0.9 \le |V_j| \le 1.1$ per unit.

Regarding the fact that the size of existed and available capacitors in the market is standard and the standard size of capacitor together with their prices (kvar/$) are obtained from reference [11], we round up these numbers in order to standard selection. The expense of losses (kvar/$) are considered 168. Table (1) shows the results of optimization in conditions of the load certainty. According to the table it is observed seen that installing two capacitors in this network is an optimum choice because by installing two capacitors the total losses of network and its annual expenses will decrease significantly in comparison with the first condition. The reason of not choosing the state of installing three capacitors in a network is the little decrease of losses and annual expense because this work naturally increases the annual expense of repair and maintenance but the losses and annual expenses have very little decrease. So according to table and attained results for all conditions and cases, the second case (installing two capacitors in the network) is known as the optimum answer.

By installing two capacitors in buses number 5 and 10 respectively in to 345 and 1050 kVar capacities, the voltage profile has more improvement in comparison with conditions that there isn't any capacitor or one capacitor is used. In the next step by installing three capacitors in the network on buses number 5, 10 and 3 with 3000, 1050 and 3750 kVar capacities respectively, the voltage profile has little and insignificant improvement and increase in comparison with conditions that two capacitors are used in the network. In fact installing three capacitors in the network will be cancelled regarding the economical observations and their maintenance and repair expenses.

Table (1) - the optimum answers of PSO algorithm in the case of having certainty in the consuming load

Amount of installed capacitors	One capacitor	Two capacitors		Three capacitors		
Installation place	6	5	10	5	10	3
capacity (Kvar)	3033.9	3305	939.9	2888	930.6	3667
Standard capacity (Kvar)	3150	3450	1050	3000	1050	3750
Capacitor Cost (Kvar)	0.195	0.188	0.228	0.18	0.228	0.183
Total losses of network (Kw)	671.45	647.18		641.888		
Annual expense ($)	113418	109615.36		109302.83		

shown in table (2).

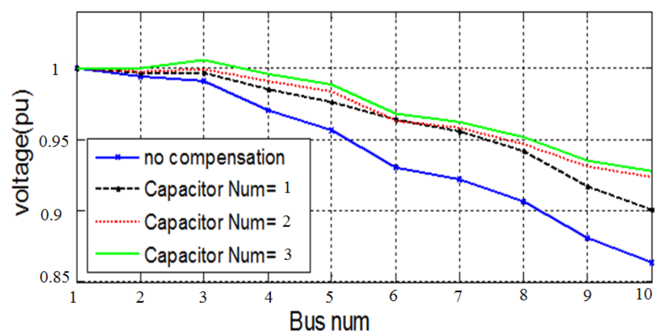

Figure (2) diagram of voltage profile in different conditions of installed capacitors

5-1-Results of PSO algorithm in finding the optimum location and size of capacitors in the case of uncertainty in consuming load

In order to model the certainty in consuming load, we will use the interval mathematics. In fact, by interval definition of upper limit and lower limit numbers, the 5% load will be considered as the base load. In this condition it not possible to consider a certain capacity for the optimum capacitor and the capacity of optimum capacitor is determined between two upper limit and lower limit. Table (3) shows the optimum amounts considering the uncertainty by PSO algorithm.

Installing two optimal capacitors which have upper and lower limits the annual expenses will decrease and also the network losses will have significant decrease in comparison with situation that no capacitor is used.

Table (2) – the upper and lower limit of consuming loads before locating capacitor

Load level	Lower limit	Base load	Upper limit
Consuming active power (kw)	11750	12368	12986
Consuming reactive power (kvar)	39767	41860	43953

According to table (3) it is observed that by

Table(3)optimum amounts considering uncertainty by PSO

	Lower limit		Upper limit	
Installation location	5	10	5	10
Capacitor capacity (kvar)	3128.8	857.5	3840.5	1026
Standard capacity of capacitor (kvar)	3150	900	3600	1050
Capacitor expense ($/kvar)	0.195	0.183	0.17	0.228
Total losses of network (kw)	582.2821		715.3956	
Annual expense ($)	98602.34		121037.85	

Table (4) shows comparison between the network losses and the annual expenses before and after using capacitor in network.

	Before installing capacitor in the network		After installing capacitor in the network	
	Lower limit	Upper limit	Lower limit	Upper limit
Total losses of network (kw)	663089	826032	582.28	715.39
Annual expense (kVar)	111530	138820	98602	121037

In figure (3), diagram of voltage profile in lower limit, before and after installing capacitor in 10-buses network is shown. It is observed that in this condition the voltage profile is placed among the allowed range that is defined for solving the optimization problem. In figure (4) the diagram of voltage profile in upper limit, before and after installing capacitor is shown.

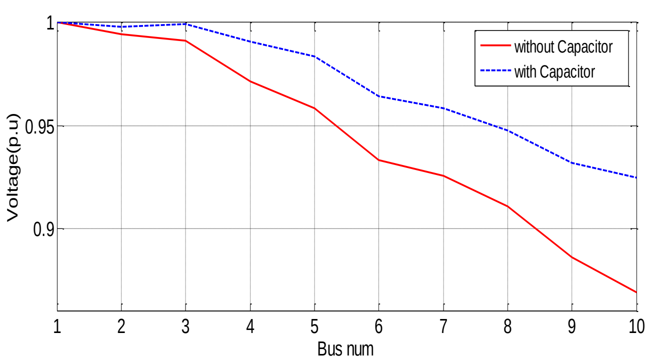

Figure (3) diagram of voltage profile in lower limit, before and after installing capacitor

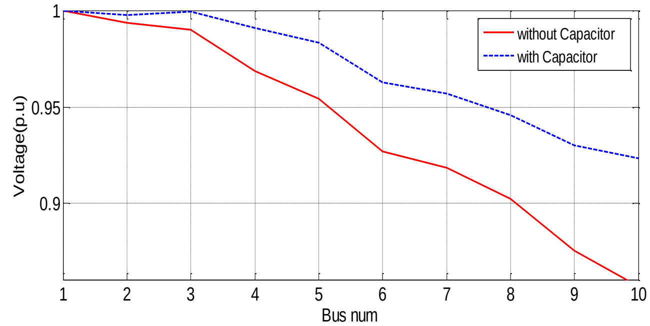

Figure (4) diagram of voltage profile in upper limit, before and after installing capacitor

6- CONCLUSION

In this paper, place and size of installed capacitor is considered as one of the approaches in energy management that should be studied in programming procedures of distribution networks. So as two main principles of energy management principles applying new technologies and also necessity of measuring and evaluating the results of capacitor placement plans are emphasized and results indicate that in using the real conditions (load uncertainty) in comparison with ideal conditions, the results are closer to the reality. Meanwhile, the sizes of capacitors are chosen in a way that they are available in the markets of planed capacities.

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