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Optimal Compensation of Reactive Power in the Restructured Distribution Network

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Abstract**—**In this paper optimal capacitor placement problem has been formulated in a restructured distribution network. In this scenario the distribution network operator can consider reactive energy also as a service that can be sold to transmission system. Thus search for optimal location, size and number of capacitor banks with the objective of loss reduction, maximum income from selling reactive energy to transmission system and return on investment for capacitors, has been performed. Results is influenced with economic value of reactive energy, therefore problem has been solved for various amounts of it. The implemented optimization technique is genetic algorithm. For any value of reactive power economic value, when reverse of investment index increase and change from zero or negative values to positive values, the threshold value of selling reactive power has been obtained. This increasing price of economic parameter is reasonable until the network losses is less than loss before compensation.

Keywords**—** capacitor placement, deregulated electric market, distribution network optimization.

I. INTRODUCTION

SINCE most electric loads available in power networks consume reactive power, so the transferred power should consist reactive in addition to active power. According to available records of the ministry of power of Iran, about (2/3) of the total power networks losses is reported for distribution networks. One of the most significant methods to loss reduction is the optimal capacitor placement in distribution networks. It means the main task for optimization of the distribution networks is selecting optimal location and capacity of the capacitors [2]. The aim of this selection is loss reduction to increment saving considering investment, installation **&** maintenance cost of the capacitors. In general, because of discrete feature of compensating devices of reactive power, optimal design of the capacitors in distribution networks leads to non-linear programming problem with mixed variables (continuous or discrete). Moreover, in this paper optimal capacitor placement problem is reformulated in a restructured distribution network. In this network, the operator can receive or send reactive power to transmission network. So with this formulation the distribution network operator can determine arrangement of capacitor banks according to its economic profit. If the transmission network purchase the reactive power above a threshold cost, it is economically profitable for the operator of distribution network to install the capacitor banks; but if this cost is lower than the threshold value, there is no need to install additional compensation system other than what it is required for decreasing the loss of its own distribution network. This formulation is tested on a real radial 20kv distribution network in IRAN and average load diagram has been considered. The genetic algorithm is used as optimization technique.

A review on genetic algorithm, problem formulation and simulation results are presented in continuation.

II. PROBLEM DETAILS

A. Genetic Algorithm

The genetic algorithm uses Darwin natural selection theorem to find the optimal formula for adapt of the pattern. Generally the genetic algorithm consists of fitness function, selection and change. The most important operators of genetic change, are genetic mutation and cross-over, capable of copying the chromosomes because of their location change and also change of some of the bits of them (Actually they reproduce). At last the chromosome will be generated with maximum fitness amount of the function so the global optimal point is produced in this way [3] - [7]. Genetic algorithm or a composition of a genetic method and other ones for optimal designing of the capacitors could be used.

The GA based capacitor placement procedure is as following:

1. Generate the random population at load nodes.
2. Put R =0 (reactive energy unit price)
3. Perform load flow to determine various node voltage, active power losses
4. Determine the fitness function values
5. Select parents by tournament selection process
6. Perform crossover and mutation on the selection parents and produce next generation
7. Repeat step3 to 6 until the sum of fitness saturated

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8. R=R+ step of price of reactive energy
9. go to step3
10. Repeat until the network loss after compensation be less than loss before compensation.

B. Problem Formulation

In order to find the optimum solution of the problem, a numerical comparison must be drawn between the present position (before compensation) and new position (after compensation). The economic components of the present position include [2]:

1) The cost of power losses in the distribution network lines plus the cost of power losses in the HV/MV transformers. The annual energy losses before compensation can be obtained as:

$$E_{1loss} = 365 \times 24 \times (P_{1lossL} + P_{1lossTR}) \tag{1}$$

Where P_{lossL} is the lines losses and P_{lossTR} is the HV/MV transformer losses before compensation with average load diagram.

After optimal placing capacitor banks in the load nodes of medium voltage distribution network and HV/MV bus bar, the economic effect of new positioned capacitors are also included:

2) Considering cost of new values of the line losses and HV/MV transformer loss, the annual energy losses after compensation is:

$$E_{2loss} = 365 \times 24 \times (P_{2lossL} + P_{2lossTR}) \tag{2}$$

The economic profit arising from reduction in network lines losses can be obtained as follows,

$$R_E == (E_{1loss} - E_{2loss})C_{Et} \tag{3}$$

Where C_{Et} represents the cost of energy unit [*Rial*[1]*/kwh*] which will amount to 773 *Rials*, according to 1387 IRAN price list.

3) Income arising from the sale of reactive power to the transmission system during a year.

$$R_i = 365 \times 24 \times R \sum_{i=1}^{n} Q_{ci} \tag{4}$$

Where, n is the total number of network buses and Q_{ci} is the capacitance of capacitor bank at bus i **.**

4) Cost for investment, installing and maintenance of capacitor banks is:

$$R_c = C_{ins} \times Q_c \tag{5}$$

This cost is obtained from multiplying of a KVAR of capacitor bank price with the total capacitance of installed capacitor banks Q_c. Here, C_{ins} is considered to be equal to 506100 *Rials(*present price*)*.

All of economic components must be considered during a year.

The next step for determining the optimal capacitance of the capacitor banks is determining an effective objective (fitness) function.

The fitness function should be capable of reflecting the objective and directing the search towards optimal solution. For each population the calculated capacitors are placed at the load nodes and the load flow method is conducted, then the profits due to loss reduction, sell reactive power to transmission system and cost for capacitor banks instrumentation are calculated. Hence, the following fitness or objective function is used in this paper:

$$\max\{\mathrm{F}\} = \max\left\{\frac{R_E + R_i - R_c}{R_c}\right\} \tag{6}$$

This optimization should consider following constraints:

$$V_{i\,\min} < V_i < V_{i\,\max} \ , 0 \le n_i \le n_{i\,\max} \ , \quad Q_{c(\min)} \le Q_c \le Q_{c(\max)} \tag{7}$$

Where, V_i is voltage at bus bar i; n_i represents the number of capacitor banks at bus bar i; and Q_c is the reactive power to be sent to or received from the transmission network.

III. APPLICATION

A practical area power system has been tested in MATLAB7.0.4 software area, in which a Newton-Raphson load flow program is employed to calculate fitness function. Some results are described as following.

There are 103 buses, 79 load buses in the borujerd2 power system in Lorestan Province, IRAN. The capacitor banks (in this paper) are of fixed type and the step of capacitance change of them is 25 Kvar. The average load diagram is used in the simulation. The single point crossover and mutation probabilities in GA are 0.8 and 0.01 respectively. Simulation study is done for different prices of reactive power. Table I shows the results of application this method for each value of 'R' parameter (prices of one Kvarh of reactive energy).

TABLE I
SIMULATION RESULTS

R (Rial/kvarh)	**Q_c (kvar)**	**F**	**$Q_{loss+load}$ (kvar)**	**$Q_{surplus}$ (kvar)**
0	2125	-0.87668	2695	-570
5	2200	-0.81876	2694	-494
10	2375	-0.71448	2694	-319
15	2475	-0.64335	2694	-219
20	2500	-0.55944	2694	-194
25	2525	-0.4705	2694	-169
30	2550	-0.38653	2694	-144
35	2600	-0.27769	2693	-93
40	2650	-0.20243	2694	-44
45	2650	-0.12281	2693	-43
50	2675	-0.03147	2694	-19
51	2750	0.001351	2693	57
55	2900	0.063688	2693	207
60	4775	0.14754	2695	2080
65	5575	0.21009	2699	2876
70	6025	0.3254	2699	3326
75	6950	0.42086	2953	3997

Considering Table I, it is seen that for low R values the capacitance of installed capacitors is often constant and the F

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[1] Rial - the basic unit of money in Iran (10000 Rials = 1$)

(fitness of objective function) is negative. With gradually increasing in R, fitness and capacitance of capacitors get increased simultaneously. The threshold price is 51 Rial/kvarh. With fewer prices than threshold price the increasing rate of Q_c is done with a slow rate but after reaching threshold price, it continues to increase with a higher rate. If distribution network operator sells one Kvarh of reactive energy for 51 Rials or more, it would be profitable for it to invest on installation of capacitor banks more than the amount required for decreasing power loss of its own distribution network.

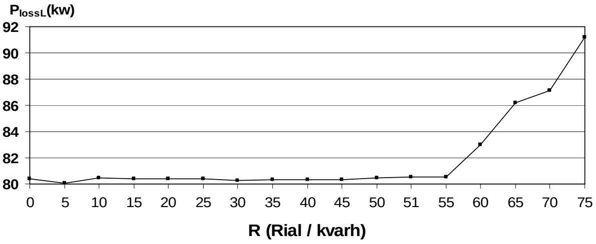

Fig. 1 Active line losses against the unity reactive service price

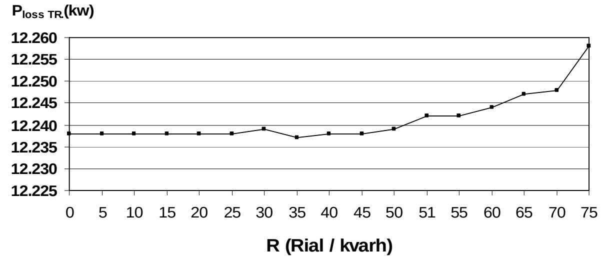

Fig. 2 Active loss in 63/20 kv transformer against the unity reactive service price

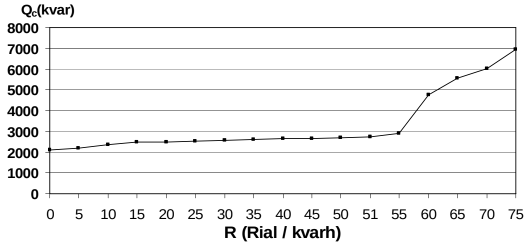

Fig. 3 Total installed capacitance in network against the unity reactive service price

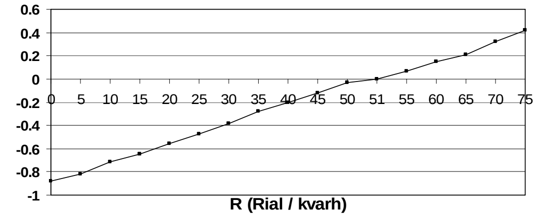

Fig. 4 Fitness variation against the unity reactive service price

As it is expected, as the unity reactive price increases the transferred reactive power to transmission system is also get increased. Fig. 1 shows that, with increasing the transferred reactive power to transmission system, the line loss is also increased. Hence, if the price of reactive energy increases without constraints, there is the possibility that the resulted line losses overcome economic profit. Comparing Fig. 1 and Fig. 4 the maximum sale price (75 Rial/kvarh) is specified in the obtained solutions as upper limit of reactive power. At this point profit is switched to cost.

IV. CONCLUSION

In this paper an advanced method is used for designing reactive power compensator in a distribution network. Simulation of market conditions shows that in the restructured distribution networks, the number of the installed capacitors which are intended to decrease the loss and increase the economic profit arising from the reactive energy sale to the transmisssion network, depends on the price of reactive energy at the electric market.

If the transmission system purchase the reactive power with the costs above the threshold cost, it is economically profitable for the operator of distribution network to install the capacitor banks and utilize them. But, if this cost for transmission system be lower than the threshold value, there is no need to install additional compensation system other than what it is required for decreasing the loss of its own distribution network. This occurs when the price of production and transfer of reactive power is lower than the price of purchasing from transmission network.

It is obvious that in order to decrease the line losses, the great part of the reactive power to be sold to transmission system, produced by capacitors installed at the 63/20kv station. However, there are limitations for permissible number of installed capacitor banks at the distribution load nodes, the allowed maximum sending Mvar to transmission system and voltage limit of each load node.

If unity value of reactive price(R) gets increased up to the threshold value, the capacitance of installed capacitor will get increased with the reverse on investment index. If the economic profit arising from investment on installing capacitor banks increases more than the network requirement, it will simultaneously lead to network and transformer loss.

Reactive power compensation with new formulation and Fixed capacitors, showed very good results. However, since loads of a distribution system are not fixed in 24 hours a day and the curve of load cycle can be approximated by a piecewise linear function, use of switchable capacitors is proposed. Authors will consider its advantages and disadvantages in the next research, investigating the problem of capacitor placement.

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