Global Advanced Research Journal of Engineering, Technology and Innovation (ISSN: 2315-5124) Vol. 2(6) pp. 173-180, July, 2013
Available online http://garj.org/garjeti/index.htm

Full Length Research Paper

Capacitor Allocation and Sizing for Distribution System via Fuzzy Technique

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Accepted 07 June 2013

This paper presents a new approach for capacitor placement in the modified IEEE 16 bus distribution system that determines the optimal locations and size of capacitor with an objective of improving the voltage profile and reduction of power loss. The location of the buses where the capacitors should be placed is decided by a set of rules given by the Fuzzy Expert System (FES) and the sizing of the capacitors determined by Q-V analysis in these buses. A comparison is made between the proposed Fuzzy approach and the Particle Swarm Optimization (PSO) algorithm in terms of improve voltages with reduce losses and economic savings achieved to study the performance of both Techniques. The proposed Fuzzy Technique is proven to give better results.

Keywords: Distribution Systems, Capacitive compensation, Loss minimization, Fuzzy.

INTRODUCTION

The problem of reactive power compensation has become one of the most problems that face the electric utilities in the last few decades. Recently, the electrical distribution networks become more complex due to the fast change in the load's dynamic behavior. The use of Artificial Intelligent (AI) techniques for adapting with the network changes becomes more important to overcome these problems from reactive power leakage point of view. Shunt capacitors are used in order to reduce the line and transformers power losses and to improve the system's voltage profile (Elabasiri, 2006).

Various approaches, compiled in reference (M.A. A.El Ata, 2008), have been suggested to solve this problem that has received considerable attention from researchers and utilities (M.A. A.El Ata, 2008).

There are many several techniques developed to solve the optimization problem for capacitor placement in distribution system, these techniques can be classified into four categories. Analytical methods, Numerical programming approaches, Heuristic methods

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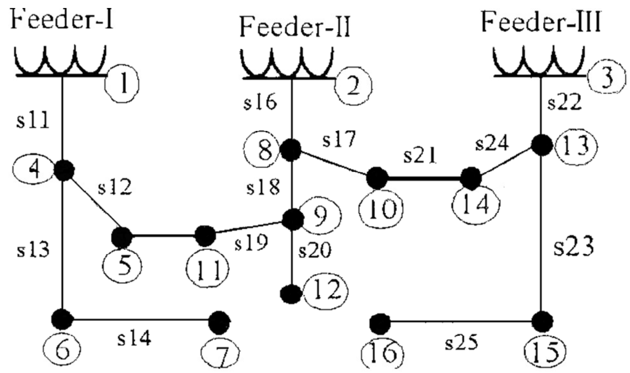

Fig. 1. Modified IEEE 16 bus, three feeder system

Table I. Three feeder system data (base 100 mva, 23 kv)

Line From- To	Resistance (p.u.)	Reactance (p.u.)	P(MW) (End bus)	Q(MVAR) (End bus)
1-4	0.075	0.10	7.5	6
4-5	0.08	0.11	12	6
4-6	0.09	0.18	15	4
6-7	0.04	0.04	6.25	5
2-8	0.11	0.11	12	8.1
8-9	0.08	0.11	10.5	6
8-10	0.11	0.11	4.44	4
9-11	0.11	0.11	3	5
9-12	0.08	0.11	12	4
3-13	0.11	0.11	4.44	4
13-14	0.09	0.12	5.7	4
13-15	0.08	0.11	4.44	4
15-16	0.04	0.04	10	5
10-14	0.04	0.04	-	-
5-11	0.04	0.04	-	-

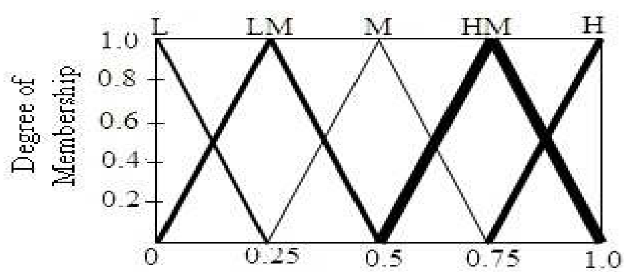

Figure 2. Membership Function for Power Loss Index

and AI-based techniques which include Expert Systems (M.A. A.El Ata, 2008), (Abdel-Ghany, 2008).

In this paper, we have developed a Fuzzy Expert System (FES) to identify the suitable locations for capacitor placement. In the sense, capacitor location at a particular bus depends on the values of power loss and voltage magnitude. The power loss and bus voltage exhibits a nonlinear relation. Owing to these facts, FES method is used in this work to address the capacitor allocation problem required to improve the performance of the modified IEEE 16 bus, three feeder systems. Q-V analysis is used for sizing of required level of shunt capacitive compensation to improve the voltage profile of the system.

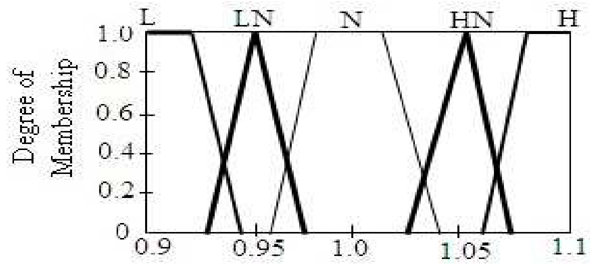

Figure 3. Membership Function for Bus Voltage

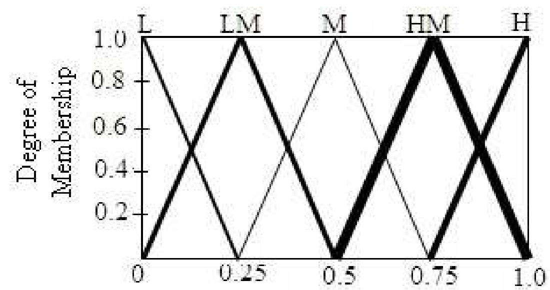

Figure 4. Membership Function for Sensitivity Index

Table II. Fuzzy Decision Matrix For Capacitor Location

AND		**Voltage**				
		L	***L N***	***N***	***H N***	***H***
Power Loss Index	***L***	L M	L M	L	L	L
	L M	M	L M	L M	L	L
	M	H M	M	L M	L	L
	H M	H M	H M	M	L M	L
	H	H	H M	M	L M	L M

In the other hand, the objective function, employed by PSO, includes the annual net saving and the cost of power losses resulting from the reduction of peak power losses while taking into account the total cost of the capacitor (Birge, 2003 : Raja et al., 2011) : (Karimian, 2011) : (Sattianadan, 2011) : (Matlab Online Help, http://www.MathWorks.com) .

The paper is organized as follow: First, in Section II, the IEEE modified system under study is presented. In Section III, an overview of the problem formulation, Fuzzy Expert System (FES) Implementation and PSO with the construction of the fitness function as well as the constraints are illustrated. Simulation results are given in Section IV for exhibiting the FES technique performance and its effectiveness compared to the PSO and the base case (before using fuzzy). Finally, conclusions are drawn in Section V.

SYSTEM UNDER STUDY

This modified network consists of 16 buses, three feeder distribution system connected to conventional generators as shown in Fig. (1). the system's data are given in Table (1) (Whei - Min Lin Hong and Chan Chin, 1998).

Bus data and Line data are given as inputs to the load flow program by Gauss-Seidel method. This gives power loss and voltage of each bus which is used as the inputs into the FES.

For PSO technique, the cost fitness function, which has to be minimized or maximized, is considered while developing the network taking into account the plant's constraints. Therefore, the performance of this network for different proposed capacitor locations and rating are analyzed (Khattab, 2005).

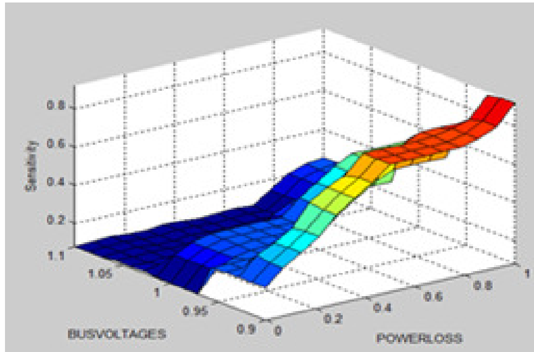

Figure 5. Surface viewer

Table III. Base Case Data

Bus no.	Voltage (p.u)	Cost*
1	1.000	
2	1.000	
3	1.000	
4	0.936	
5	0.907	
6	0.907	
7	0.904	
8	0.932	1.3775(Million
9	0.901	$ per year)
10	0.926	
11	0.903	
12	0.885	
13	0.942	
14	0.927	
15	0.915	
16	0.907	

* Power Losses cost (Million $ per year)

Using MATLAB program, the network data is applied. The main objective of the overall model is to evaluate the voltage and capacitor rating at the specified location besides the total power losses cost.

PROBLEM FORMULATION

A. Fuzzy Expert System (FES) Implementation

The FES contains a set of rules, which are developed from qualitative descriptions. In a FES, rules may be fired with some degree using fuzzy inference system; whereas, in conventional expert system, a rule is either fired or not fired. Defuzzification is the process of producing quantifiable result in the form of a crisp value in a fuzzy logic system. The defuzzification method used in the FES implemented in this work is the 'Center of Area (COA)' method, one of the widely used techniques for defuzzification.

In most fuzzy systems, for the capacitor allocation problem, rules are defined to determine the suitability of a node for capacitor installation. For determining the suitability of capacitor placement at a particular node, a set of fuzzy rules has been established. The inputs to the rules are the voltage and power loss indices, and the output is the suitability of capacitor placement. The power loss index in each ith node is calculated as active power loss in (MW) in that node. The rules are summarized in the fuzzy decision matrix. These fuzzy variables described by linguistic terms are represented by membership functions. The membership functions for all the input and output variables are graphically shown in Figure 2 to Figure 4. The decision matrices for

Table IV. Output From Fuzzy Expert System

BUS NO	FES INPUTS		FES OUTPUT
	POWER LOSS (MW)	***VOLTAGE (P.U)***	***SENSITIVITY INDEX***
1	2.269	1.000	0.500
2	2.121	1.000	0.500
3	1.654	1.000	0.500
4	3.125	0.936	0.500
5	0.438	0.908	0.678
6	0.459	0.907	0.699
7	0.027	0.903	0.286
8	2.649	0.932	0.500
9	0.681	0.901	0.750
10	0.029	0.926	0.288
11	0.039	0.903	0.299
12	0.163	0.885	0.406
13	2.142	0.941	0.500
14	0.111	0.927	0.364
15	0.479	0.915	0.722
16	0.109	0.907	0.362

Table V. Results of Capacitor Sizing

Bus No	**5**	**6**	**9**	**15**	**Total MVAR**	**Average Bus Voltage (p.u)**
Qcap (MVAR)	11.06	15.03	25.30	11.63	63.03	0.966

Table VI. Q (MVAR) Generated By Slack Bus

Bus No	**1**	**2**	**3**	**Total MVAR**
Qcap (MVAR)	0.538	1.477	3.026	5.04

determining suitable capacitor location are shown in Table 2 (Srinivasa, 2011).

Upon opening the Surface Viewer of proposed FIS, you see a three-dimensional curve that represents the mapping from Active power loss and voltage value to Sensitivity Index. The Surface Viewer is equipped with drop-down menus X (input): Y (input): and Z (output) shown in Figure 5

The higher value of Sensitive Index for a bus gives more probability of capacitor allocation at the same bus. Then the Q-V analysis in each buses which chosen by fuzzy for capacitor sizing.

B. Particle swarm technique

Analytical optimization algorithms have been used in optimal capacitor placement. These algorithms were recommended when powerful computing resources were available especially for complex networks (Salama and Chikhani, 2000). In these methods, the use of calculus to determine the maximum saving cost function, which relates to the minimum cost of power losses, is involved. The following constraints are considered during the constructing of the fitness function:

Table VII. Results of Capacitor Sizing Using PSO

Bus No	**4**	**5**	**8**	**10**	**11**
Qcap (MVAR)	12.2	6.3	12.4	6.8	6.8
Bus No	**12**	**13**	**15**	**Total MVAR**	**Average Bus Voltage (p.u)**
Qcap (MVAR)	6.5	6.6	12.8	70.7	0.960

Table VIII. Q (MVAR) Generated by Slack Bus

Bus No	**1**	**2**	**3**	**Total MVAR**
Qcap (MVAR)	0.514	-1.509	-1.020	-2.015

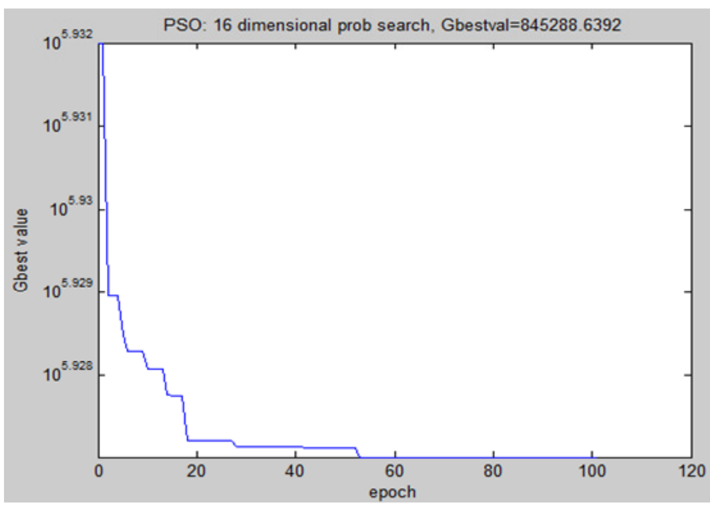

Figure 6. Variation of fitness function with number of generation

Voltage constraint

The voltage magnitude at each bus must be maintained within a specified limit expressed as follow:

$V_{min} \leq |V_i| \leq V_{max}$ $\quad i:1,2,3,\ldots..,n$

where V_i is the voltage magnitude of the bus i, V_{min} and V_{max} are bus minimum and maximum voltage limits respectively.

Constraints of capacitor placement

The distribution of different bank locations and ratings depend upon the network configuration and actual load values, the capacitor sizes and location are placed with the following constraints (Ponnavaikko and Rao, 1983), (Kaplan, 1984):

- Capacitors are inserted on those circuits with heavy

Table IX. Results of Capacitor Sizing and* Slack Gen.

Bus No	1*	2*	3*	4	5	6	8	9
FES	0.538	1.477	3.026		11.06	15.03		25.3
PSO	0.514	-1.509	-1.020	12.2	6.3		12.4	

Bus No	10	11	12	13	15	Total MVAR
FES					11.63	68
PSO	6.8	6.8	6.5	6.6	12.8	68.7

Table X. Total P Loss (MW) & Average Bus Voltage (P.U)

Total Real Power Loss (MW)			Average Bus Voltage (p.u)		
Before Capacitor Placement	*After Capacitor Placement*		*Before Capacitor Placement*	*After Capacitor Placement*	
	With FES	*With PSO*		*With FES*	*With PSO*
8.251	6.1	5.6	0.931	0.951	0.961
% Decrease	26	32.1	% Increase	2.1	3.2

kVAR load.

- Capacitor sizes do not exceed than the record kVAR of each feeder.

Finally the fitness function can be described as follows:

min F = min (cost)

Cost = H_{Loss}* P_{loss} + H_{cap} + V_{pen} + C_{pen}

Where:

- H_{Loss} is the annual cost of real power loss = 168 $/kW (Ching Tzong Su and Chu Sheng Lee, 2002).
- P_{loss} is the total power loss.
- H_{cap} is the capacitor cost price where $H_{cap} = K_c * Q_c(i)$, Kc is the cost of kVAR, for i=1,2,3,…16 and Q_c is the available standard capacitor
- Vpen is the Voltage constraints penalty.
- C_{pen} is Capacitor constraints penalty (if the required capacitor is outside the standard specified range).

The annual saving is calculated using PSO technique.

SIMULATION RESULTS

To validate the established model and the proposed FES comparing with optimization technique, simulation studies of the system shown in Fig. 1 have been executed by MATLAB with the operating conditions, also the following three cases will be presented:

C. Base case

The base case (i.e without capacitor insertion) includes the voltage profile at all buses of the network, the values of the voltage at many buses are outside of the permissible level.

The cost of the losses is shown in Table (3).

* Power Losses cost (Million $ per year)

D. Proposed Technique using FES with Q-V analysis

Table 4 shows the output results from FES for the test system studied as shown in Figure 1. The inputs of FES are obtained as an output from Load flow solution. The higher value of Sensitive Index for a bus gives more probability of capacitor allocation at the same bus. From the results of FES, we find that bus number (4, 5, 6, 8, 9, 13, and 15) have the highest Candidate Sensitive Index of greater than 0.4. Hence these buses are chosen as suitable locations for capacitor placement.

After chosen a suitable locations or buses for capacitor placement, Q-V analysis in these buses will done by uses a fictitious synchronous generator with

active power generated equal zero and open range of generated reactive power to give the size of Mvar required .
Table (5) shows the result of Q-V analysis as capacitor sizing in buses which need compensation

E. Proposed Technique using PSO

In this section, PSO algorithm is proposed for the optimization of the base case study, the objective function includes the voltage and capacitor constraints for capacitor allocation implementation in the pre specified network. Table (6) shows the result of PSO as capacitor sizing, Figure.(6) Shows the variation of fitness function with number of generation. It demonstrates how the technique success in forcing the Fitness function value to decrease by increasing the number of epoch.

Finally, the voltage profile enhancement when using Fuzzy or PSO techniques is depicted compared with the base case.

After comparing result from each technique it’s appear that the fuzzy –QV method reduce cost of compensation than PSO method and improve voltage in permissible limit with reduce losses as shown in tables (7, 8)

CONCLUSIONS

A new and efficient approach that employs sensitivity factors and Q-V analysis for capacitor placement and sizing in the distribution system has been proposed. The FES is used to determine the optimal locations of the buses required for compensation. The Q-V analysis is used to size the required level of shunt capacitive compensation at the optimal candidate locations to enhance the voltage profile the system and reduce the active power loss. The simulation results based on the modified IEEE 16 bus systems using FES technique have produced the best solutions that have been found using a number of approaches available in the literature. The advantages of the proposed method are: 1) it handles the capacitor placement and sizing separately; 2) the proposed approach more accurate and give better result; 3) the proposed approach take very short time; 4) the proposed approach does not require any objective functions; 5) the proposed approach has a guiding search direction that continuously changes as the change of the set of rules. This method places the capacitors at less number of locations with optimum size and offers much net annual saving in initial investment.

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