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Reactive Power Control in Distribution Network by Optimal Location and Sizing of Capacitor using Fuzzy and SFLA

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ABSTRACT : This paper presents a hybrid method for the Optimal Capacitor placement in radial distribution networks by using Fuzzy and Shuffled Frog Leaping Algorithm (SLFA). The main objective of this thesis is to reduce power losses & to improve voltage profile of distribution networks. Here the fuzzy approach is used to find the optimal capacitor locations and Shuffled Frog Leaping Algorithm is used to find the optimal sizes of capacitor which are used to reduce the power losses and improve the voltage profile. The SFLA is a meta-heuristic search method inspired from the memetic evolution of group of frogs when seeking for food. The SFLA consists of frog leaping rule for local search and a memetic shuffling rule for global information exchange. The proposed method is tested on IEEE 15-bus IEEE 33-bus, and IEEE 69-bus test systems and the results are discussed.

KEYWORDS: SLFA, memetic.

I. INTRODUCTION

A Power system is an interconnected system composed of generating stations, which convert fuel energy in to electrical energy, and transmission lines that tie the generating station and distribution substations, substation that distribute electric power to loads (consumers). According to the voltage levels power system consists of three major components.

1. Generation
2. Transmission
3. Distribution

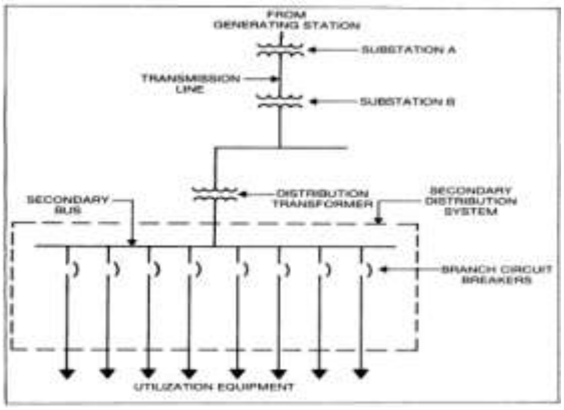

Fig: Typical Electrical Power System.

In generating phase the fuel energy is converted in to electrical energy. Some of the generating plants are thermal plants, hydro, nuclear power plants and some plants are renewable energy resources. The Transmission system is to deliver the bulk power from station to the load centers and large industrial consumers beyond the economical services range of regular primary distribution lines whereas distribution system is to deliver power from power stations or substations to various consumers. Although electric power can be transmitted or distributed in AC or DC but in practice 3-phase 3-wire ac system is universally adopted for transmission of large blocks of power.

Generating voltages are in between 3.3 kV and 33 kV most usual values adopted is around 13.2 kV most usual value adopted is around 13.2 kV. Depending upon the voltage of transmission, the transmission system is classified in to

1. Primary transmission (110 kV and above)

2. Secondary transmission (33 or 66 kV)

II. RELATED WORK

With these different types of objectives in mind, optimal capacitor placement aims to determine the location of a capacitor and its size. Optimal placement of capacitor has been investigated over decades.

Optimal capacitor setting has been investigated since the 60's, J.V.Schmill [1] & Duran H [2] proposed a dynamic programming approach to find the optimum number, location and size of shunt capacitors. These methods are suitable for efficient solution in a digital computer.

In the 80's, Baran. M.E and Wu F.F [3,4] proposed a capacitor sizing problem for capacitors placed on a radial distribution system is formulated as a nonlinear programming problem, and a solution algorithm by Benders decomposition is developed for the capacitor sizing problem is based on a phase I phase II feasible directions approach.

In the 90's Sundharajan and A.Pahwa [5] proposed a dynamic approach of genetic algorithm for optimal selection of capacitors for radial distribution systems.

[6-8] presents optimal capacitor placement by reducing the power losses in the distribution systems by using heuristic search strategies.

In the 2000's Ng H.N.Salama M.M.A and Chikani A.Y [9] presents a novel approach using approximate fuzzy reasoning to determine the suitable candidate nodes in a distribution system for capacitor placement. A fuzzy expert system [FES] containing a set of heuristic rules is then used to determine the capacitor placement suitability of each node in the distribution system.

Prakash K. and Sydulu M. [10] presents a novel approach that determines the optimal location and size of capacitors on radial distribution system to improve the voltage profile and reduce the active power loss. Capacitor placement and sizing are done by loss sensitivity factors and particle swarm optimization respectively.

M.Damodar Reddy and V.C. Veera Reddy [11] presents a paper for optimal capacitor placement using fuzzy and real coded genetic algorithm for maximum savings.

M.Damodar Reddy and V.C Veera Reddy [12] presents a fuzzy and particle swarm optimization (PSO) method for the placement of capacitors on the primary feeders of the radial distribution systems to reduce the power losses and to improve the voltage profile. Capacitor placement using fuzzy and particle swarm optimization method.

M.M. Eusuff and K.E Lansey [13,14] proposed a new algorithm shuffled frog leaping algorithm for optimization of water distribution network and discrete optimization. The effectiveness and suitability of this method have been demonstrated by applying it to a ground model calibration problem and water distribution system design problem. Compare to the other methods the experimental results in terms of likelihood of convergence to global optimal solution and the solution speed suggest that SFLA can be effective tool for solving combinational optimization problems.

Q.Li [15] presents an algorithm i.e. shuffled frog leaping algorithm for based optimal reactive power flow in the distribution networks for reducing the power losses and improvement of voltage profile.

III. IMPLEMENTATION OF FUZZYAND SFLA FOR OPTIMAL PLACEMENT & SIZING OF CAPACITOR

Fuzzy Approach:

A fuzzy approach is proposed to finding the suitable locations for placement of a capacitor. Two objectives are considered while designing a fuzzy logic for identifying the optimal capacitor locations. The objectives are:

1. To maintain the real power loss and
2. To maintain the voltage within the permissible limits.

Voltages and power loss indices of distribution network nodes are modeled by fuzzy membership functions. A fuzzy inference system (FIS) containing a set of rules is then used to find the capacitor placement. Capacitors are placed on the nodes with the highest suitability.

For the capacitor placement problem approximate reasoning is employed in the following manner when losses and voltage levels of a distribution system are studied, an experienced planning engineer can choose locations for capacitor installations, which are probably highly suitable. For example, it is intuitive that a section in a distribution system with high losses and low voltage is highly ideal for placement of capacitors. Whereas low section with good voltage is not ideal for capacitor placement. A set of fuzzy rules has been used to load flow solution for the original system is required to obtain the real and reactive power losses. Again, load flow solutions are required to obtain the power loss reduction by compensating the total reactive load at every node of the distribution system. The loss reduction having a value of 1 and the smallest one having a value of 0. Power loss

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index value for nth node can be obtained using below equation.

PL(n) = [$LR(n)-LR$(min)] / [LR(max)$-LR$(min)]

These power loss reduction indices along with the p.u. nodal voltages are the inputs to the Fuzzy Inference System (FIS), which determines the node more suitable for capacitor installation. In this present work, Fuzzy Logic toolbox in MATLAB7 is used for finding the capacitor suitability index.

In this thesis, two input and one output variables are selected. Input variable-1 is the power loss index (PLI) and input variable-2 is the per unit nodal voltage (V). Output variable is capacitor suitability index (CSI).

IDENTIFICATION OF SENSITIVE BUS FOR CAPACITOR PLACEMENT:

The fuzzy logic is used to identify the optimal location to place the capacitor in a radial distribution system so as to minimize the losses while keeping the voltage at buses within the limit and also by taking the cost of the capacitors in to account.

The Fuzzy Expert System (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, where as in a conventional Expert System, a rule is either fired or not fired. For the capacitor placement problem, rules are defined to determine the suitability of a bus for capacitor placement. Such rules are expressed in the following general form:

IF premise (antecedent), THEN conclusion (Consequent)

For determining the suitability of a particular bus for capacitor placement at a particular bus, sets of multiple-antecedent fuzzy rules have been established. The inputs to the rules are the bus voltages in p.u., power loss indices, and the output consequent is the suitability of a bus for capacitor placement.

POWER LOSS INDEX PROCEDURE TO CALCULATE

The power loss index at ith bus, PLI(i) is the variable which is given to fuzzy expert system to identify suitable location for the capacitor.

Step 1 : Read radial distribution system data

Step 2 : Perform the load flows and calculate the base case
active power loss

Step 3 : By compensating the reactive power injections (Q) at each bus (except source bus) and run the load flows, and calculate the active power loss in each case.

Step 4 : Calculate the power loss reduction and power loss
indices using the following equation

PL(i)= [$X(i)-Y$]/[$Z-Y$]

Where X(i)= loss reduction at ith bus

Y= minimum loss reduction

Z= maximum loss reduction

Step 5 : Stop.

Five membership functions are selected for PLI. They are L, LM, M, HM and H. all the five membership functions are triangular as shown in fig- 4.1. Five membership functions are selected for voltage. They are L, LN, N, HN, and H. these membership functions are trapezoidal and triangular as shown in fig- 4.2. Five membership functions are selected for CSI. They are L, LM, M, HM, and H. these five membership functions are also triangular as shown in fig.

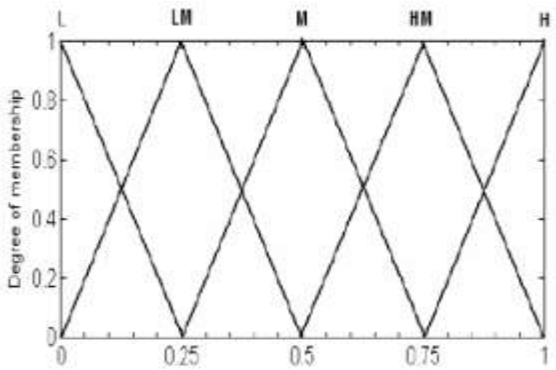

Fig: Membership function plot for power loss index

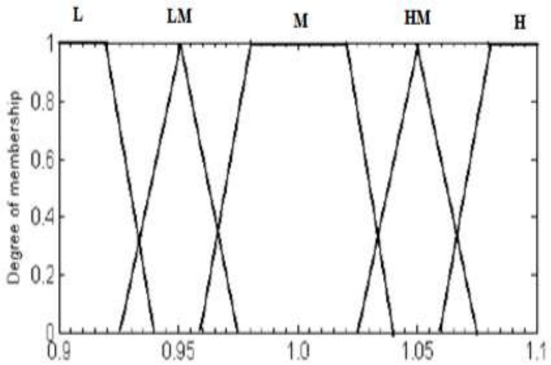

Fig: Membership function plot for p.u nodal voltage

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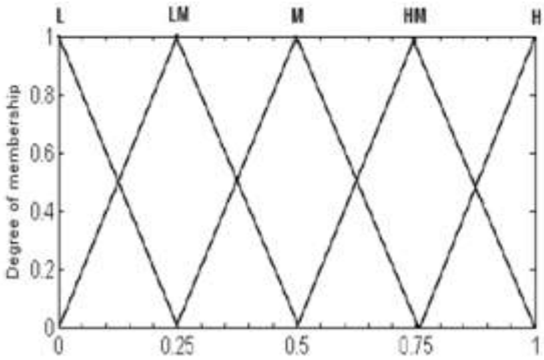

Fig: Membership function plot for Capacitor Suitability index.

The Rule Editor is for editing the list of rules that defines the behavior of the system. Constructing rules using the graphical Rule Editor interface is fairly self-evident. Based on the descriptions of the input and output variables defined with the FIS Editor, the rule Editor allows us to construct the rule statements automatically, by clicking on and selecting one item in each input variable box, one item in each output box and one connection item. Choosing none as one of the variable qualities will exclude that variable from a given rule.

Choosing not under any variable name will negate the associated quality. Rules may be changed, deleted or added, by clicking on the appropriate button.

For the capacitor allocation problem, rules are defined to determine the suitability of a node for capacitor installation. Such rules are expressed in the below:

IF premise, THEN conclusion. For determining the suitability of capacitor placement at a particular node, a set of multiple-antecedent fuzzy rules has been established. The inputs to the rules are voltage and power loss indices and the output is the suitability of capacitor placement. The rules are summarized in the fuzzy decision matrix in table 4.1

AND		Voltage				
		L	LM	M	HM	H
PLI	L	LM	LM	L	L	L
	LM	M	LM	LM	L	L
	M	HM	M	LM	L	L
	HM	HM	HM	M	LM	L
	H	H	HM	M	LM	LM

Table- 4.1 Decision matrix for determining the optimal capacitor locations.

In the present work 25 rules are constructed. For example:
If PLI is H and voltage is L then CSI is H.
If PLI is M and voltage is M then CSI is LM.
If PLI is H and voltage is H then CSI is LM.

The rule viewer is a MATLAB-based display of the fuzzy inference diagram. Used as a diagnostic, it can show which rules are active, or how individual membership function shapes are influencing the results.

Surface viewer can display how one of the outputs depends on any one or two of the inputs –that is, it generates and plots an output surface map of the system.

And finally to save the current file uses the commands Export to workspace and Export to disk. By calling this file in the main program, the CSI values corresponding to each bus can be obtained. Thereby, we can find the nodes suitable for capacitor installation.

IV. RESULTS

Optimal Capacitor Sizes for 15-Bus System:

The proposed algorithm is applied to 15 bus test system. Optimal capacitor locations are identified based on the C.S.I values. For this 15-bus system, the optimum locations are identified. Capacitor sizes in optimal locations, total real power losses before and after capacitor compensation are shown in table .

Optimal capacitor locations: 5

- Base kV= 11 kV
- Base MVA= 100 MVA

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Results of 15-bus system:

Bus number	Capacitor size in kVAr
4	344.6547
6	264.9500
7	142.8415
11	300.3639
15	142.9217
Total kVAr	1195.7318
Total real power loss in kW(before capacitor placement)	61.7944
Total real power loss in kW (after capacitor placement)	29.9079
loss reduction	51.6009

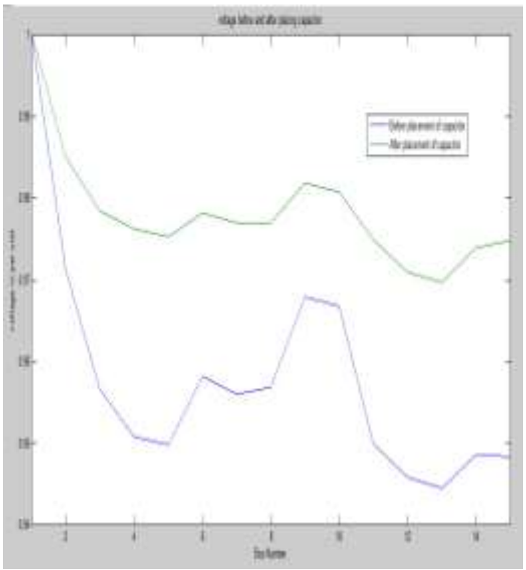

Fig: voltage profile(before and after placement of capacitor) for 15-bus system

2 Optimal capacitor sizes for 33-bus system:

The proposed algorithm is applied to 33 bus test system. Optimal capacitor locations are identified based on the C.S.I values. For this 33-bus system, the optimum locations are identified. Capacitor sizes in optimal locations, total real power losses before and after capacitor compensation are shown in table .

Optimal capacitor locations: 2

- Base kV= 12.66 kV
- Base MVA= 100 MVA

Table:Results of 33 bus system

Bus number	Capacitor size in kVAr
30	826.2841
32	505.2361
Total kVAr	1331.52
Total real power loss in kW (before capacitor placement)	369.2558
Total real power loss in kW (after capacitor placement)	298.6698
% Loss reduction	19.1157

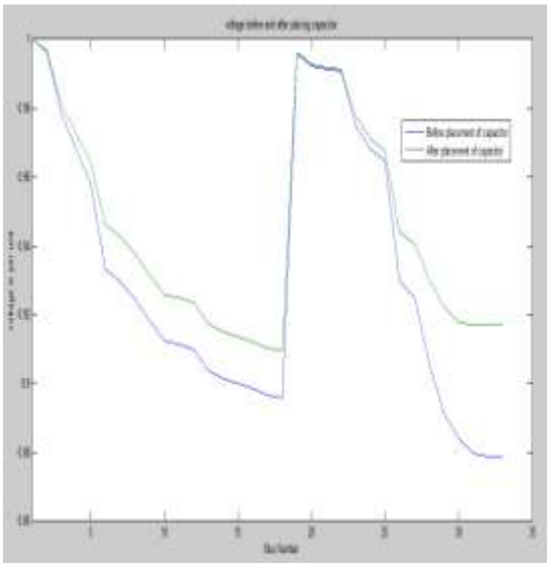

Fig :Voltage profile (before and after placement of capacitor) for 33-bus system

Optimal Capacitor sizes for 69-bus system:

The proposed algorithm is applied to 69 bus test system. Optimal capacitor locations are identified based on the C.S.I values. For this 69-bus system, the optimum locations are identified. Capacitor sizes in optimal locations, total real power losses before and after capacitor compensation are shown in table

Optimal capacitor locations: 2

- Base kV= 12.66 kV
- Base MVA= 100 MVA

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Table:Results of 69 bus system

Bus number	Capacitor size in kVAr
61	829.8772
64	502.1646
Total kVAr	1332.04
Total real power loss in kW (before capacitor placement)	225.0041
Total real power loss in kW (after capacitor placement)	152.3945
% Loss reduction	32.2703

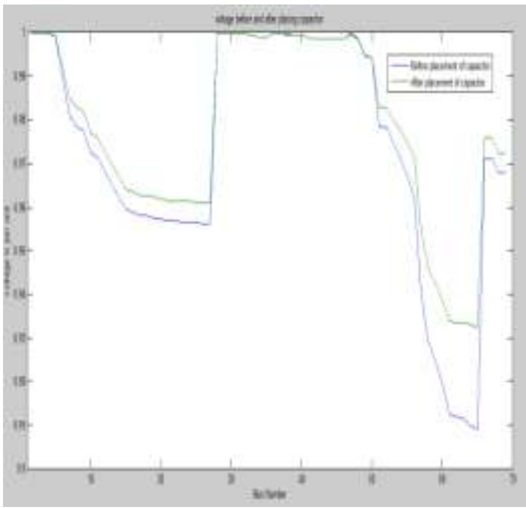

Fig :Voltage profile (before and after placement of capacitor) for 69-bus system

V. CONCLUSION:

By placing the capacitors at all the optimal locations, the total reactive power loss of the system has been reduced significantly and bus voltages are improved simultaneously. The fuzzy approach is capable of finding the optimal location based on the CSI values. The proposed shuffle frog leaping algorithm iteratively searches the optimal capacitor sizes corresponding to minimum loss. Also it is worthy or mentions that the time of performing of this algorithm is faster.

When the proposed method was tested on 15 bus system. For 15 bus system it was found that by placing a total of 1195.9 kVAr at different locations (buses 4, 6, 7, 11, 15) the real power losses were reduced by 51.60%.

For 33 bus system it was found that by placing a total of 745.84 kVAr at buses 30, 32 the real power losses were reduced by 19.11%.

For 69 bus system it was found that by placing a total of 1329.6 kVAr at buses 61, 64 the real power losses were reduced by 32.27%.

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