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Optimal Capacitor Placement in Radial Distribution System to minimize the loss using Fuzzy Logic Control and Hybrid Particle Swarm Optimization

[1]S.Joyal Isac, [2]K.Suresh Kumar
Department of EEE,
Saveetha Engineering College,Chennai, Tamil Nadu

[1]joyalisac25@gmail.com, [2]sureshbarath@gmail.com

***Abstract*— To increase the voltage profile and to reduce power loss in the distribution system shunt capacitors are to be installed at suitable locations in a large distribution system. Placing a capacitor in a Electrical distribution system involves various factors like maximizing energy and peak power loss reduction. The objective function includes cost of power loss, energy loss and capacitor banks. Constraints include voltage limits, number and location of installed capacitors. Location of nodes where the capacitor should be placed is decided by fuzzy expert system by incorporating a set of rules into it, Loss sensitivity factors are used to select the candidate location for capacitor placement. Optimal size of the capacitor is found using Particle Swarm Optimization and Hybrid Particle Swarm Optimization. The proposed method is applied to 15 bus and 34 bus radial distribution system. Comparative study was done for the system without capacitor and with optimally placed capacitors with and without voltage constraint. Results show robustness of proposed method in solving this difficult task.**

***Index Terms*— Radial Distribution Systems, Shunt Capacitors, Fuzzy Expert System, Hybrid particle swarm optimization, Savings.**

I.INTRODUCTION

Electrical power systems networks are typically composed of four main parts namely generation, transmission, distribution, and loads. In order to maintain voltage profile and to reduce the power loss in the distribution system, shunt capacitors are to be installed at suitable locations in a large distribution system. When we place the capacitors optimally we will get some benefits. Power grids are complex in nature due to widespread geographical coverage, various transactions, diversity in individual electrical power companies, size of an electrical equipments used. Some of this already existing tools are unit commitment, economic dispatch, automatic generation control (AGC), optimal power flow (OPF). Transmission and distribution system networks share energy at different levels and their characteristics are quite different.

Distribution systems have high R/X ratio, significant voltage drop that could cause power loss in the feeders. Totally 13%of the generated power is consumed as loss at the distribution level. Apart from that loss, voltage also will drop due to application of load, along with this power loss and voltage drop, demand also increases due to upgrading of total system and the structure. These losses are mainly due to flow of reactive currents in the network (RI^2).

Even though we can place capacitors anywhere in the system and reduce the loss which is the easiest way consideration of system security and economic issues we are in need to find out the apt location for placing the capacitor instead of placing it in all the buses. By placing capacitors optimally, we can thereby do power flow control, improve system stability, power factor correction, voltage profile management and thereby reduction in active energy losses.

All 11 KV radial distribution feeders are too long, Eventhough we have many voltage regulation systems the voltage at far end from the utility are very low. Many methods are there to solve optimal capacitor placement problem such as Genetic algorithm, Ant colony algorithm, and Simulated annealing based on fuzzy logic and other intelligence techniques.

In this paper fuzzy logic control is used to solve the problem. This problem is suited only for fundamental frequency signal. The sizing of capacitors is modeled by the objective function to obtain maximum savings using Particle Swarm Optimization and Hybrid Particle Swarm Optimization. To illustrate the applicability of the algorithm, this method is applied to IEEE 15 bus and 34 bus radial distribution system.

II.FRAMEWORK OF APPROACH

This complete framework of this approach is to solve for optimal capacitor allocation problem. It includes use of some computational procedures, to find out the total power loss and voltage level in the radial distribution system and then the coupling of fuzzy expert system to find out the candidate sensitivity index. A modified newton raphson program is used to calculate power loss reduction in the test system.

There are some simplifies approach for the load flow program in the radial system, Ref [6].

An efficient method for load flow solution in radial distribution system is also there, Ref [10].

Per unit voltage is also calculated using the same load flow at all nodes in the system. Incorporating both the power loss index (PLI) and per unit voltage in fuzzy expert system which will determine sensitivity index and thereby the most sensitive nodes for placing capacitors.

Particle Swarm Optimization and Hybrid Particle Swarm Optimization is used to find the optimal capacitor sizing to reduce the cost [1].

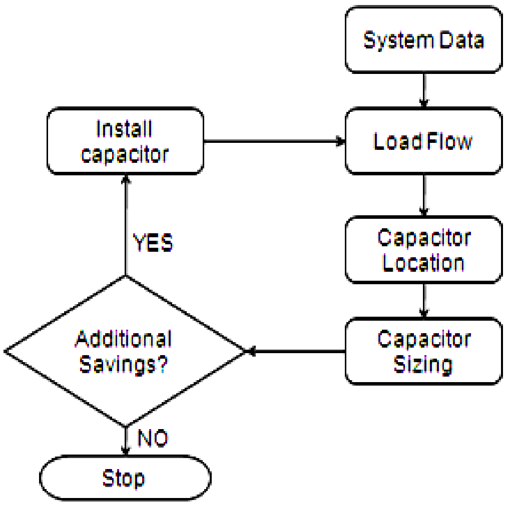


Fig 1. Framework of approach

FLOW CHART

1. Read the given data for the radial distribution system.
2. Perform load flow and base case total active power loss
3. By means of reactive power injection each node (expect source node), run load flow and calculate active power loss.
4. Calculate power loss reduction and power loss index using this equation,

PLI(t)=[{X(t)- Y} / {Z-Y}] ¥ t=2,3,4….,n

X=Loss reduction
Y=Minimum reduction
Z=Maximum reduction

5. Select candidate nodes where PLI > tolerance.
6. Calculate the optimal size of the capacitor by PSO and HPSO.
7. Find the additional savings by placing the optimal size of the capacitor.
8. Install the capacitor.
9. Stop

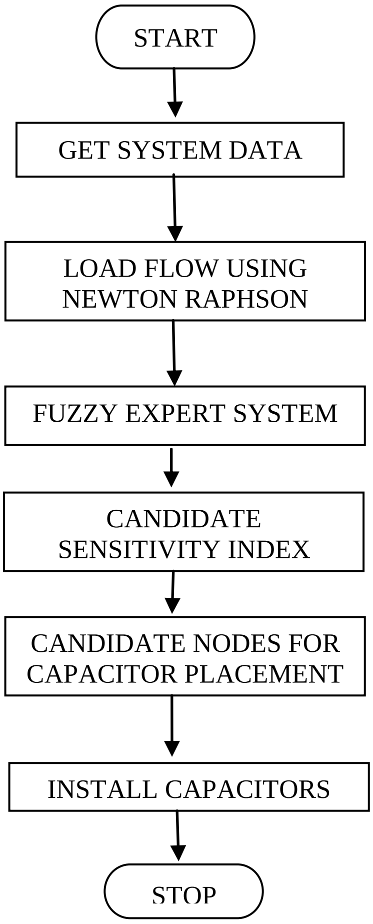


Fig 2. Flow chart for finding candidate nodes and installing capacitors.

III. PROBLEM FORMULATION AND IMPLEMENTATION

i. Radial Distribution System(15 bus)

Feeder test specification:

Radial Feeder	: 11 KV, 15 bus system
Load	: 1.0 P.U
Number of Load level	: 1
Load duration	: 8760 hours

Number of capacitor location: 5(15 bus system)
Number of capacitor location: 7(34 bus system)

Consider a IEEE 15 bus distribution system and IEEE 34 bus distribution system.

The single line diagram of such a feeder comprising a branches and node is shown in the figure 3.

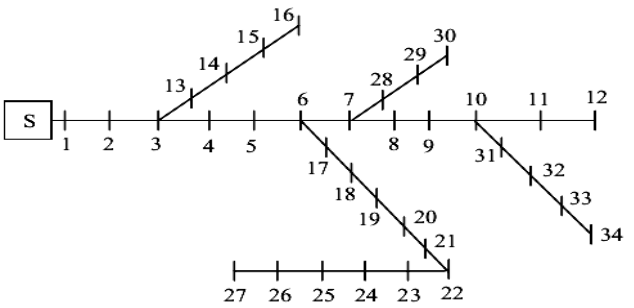


Fig 3. 34 Bus Distribution Network

Load flow is a requisite one for solving problem for capacitor location. Various methods like Newton Raphson, Gauss Seidal, Fast Decoupled are there in which Newton Raphson is a root finding method that uses first few terms of Taylor series function in the vicinity of suspected root. It is a powerful technique for solving equations numerically. It is based on simple idea of linear approximation.

IV. Distribution System

Radial Distribution System provide link between the high voltage transmission system and the consumers. The circuit starts from a substation and it passes through the major load centres. There will be laterals and sub-laterals in this distribution system . Lateral feeder connects all the load points with main feeder connected with many lateral and sublaterals are called Radial Distribution System. Since the design in simple and they are generally low cost they are popular.

Power loss in the distribution system is high because of low voltage and high current compared to high voltage transmission system. If we decrease the power loss at the utility then overall efficiency will be increases.

The part of a distribution system consisting of circuit conductors, between the final overcurrent protection and the outlet or load attached

A. Features of Radial Distribution System

a. Many nodes and branches.
b. Wide range of resistance and reactance values.
c. Unbalanced load and unbalanced operations.
d. Radial network structure.

If we run these using conventional power flow methods, the result will not converge. So new data buses have to be built and maintained to run these systems which also depend upon data format. These are due to high R/X ratio, nature of the distribution system. So we go for modified newton raphson methods to do load flow and to find total loss in the system.

B. Some advantages and benefits

1. Line loss reduction.
2. Reduced envirionmental impacts.
3. Improved system stability.
4. Improved feed voltage conditions.

Bus data and Line data are given as inputs to the load flow program by Newton-Raphson method. This gives power loss and voltage of each of the bus which is used for further analysis.

V.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 inferencing, whereas, in a conventional expert system, a rule is either fired or not fired. 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 rules are summarized in the fuzzy decision matrix. These fuzzy variables described by linguistic terms are represented by membership functions. The membership functions are graphically shown in Figs.5,6,7.

A. Fuzzy expert system- output-15 and 34 bus system

In the fuzzy expert system two inputs and one output type is selected in mamdani type fuzzy interference system, Power loss index and per unit voltage are selected as input and the output obtained is candidate sensitivity index. The two inputs are given to the fuzzy interference system to obtain the candidate sensitivity index. Only triangular membership function is selected for power loss index considering that the loss will increase to the peak and then It will be reduced to the lower value. Five functions are selected for power loss index. All the membership functions are tried and found that triangular function shows best result and it is shown here.

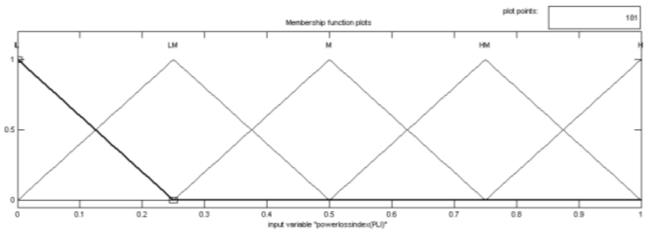


Fig 5. Membership function for the 1st input-Power loss index-15 and 34 bus system

The membership function for voltage is shown in the below diagram. Both triangular and trapezoidal membership function are tried and found it to be best. Here also five membership functions are selected and it is enough to explain the concept. The result is shown below.

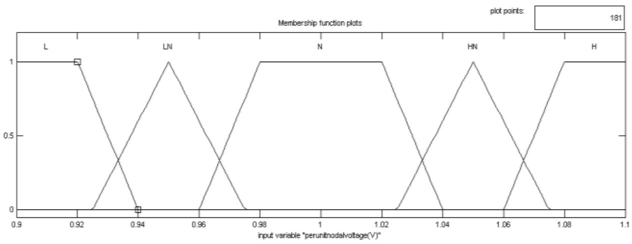


Fig 6. Membership function for the 2nd input- Per unit voltage-15 and 34 bus system

The output membership function is shown here. Only triangular membership functions are obtained. The sensitivity should be there or it shouldn't be there. So only triangular function is selected. The output obtained is found to be perfect and checked for different functions.

The values are then obtained using program written in Matlab M-file .

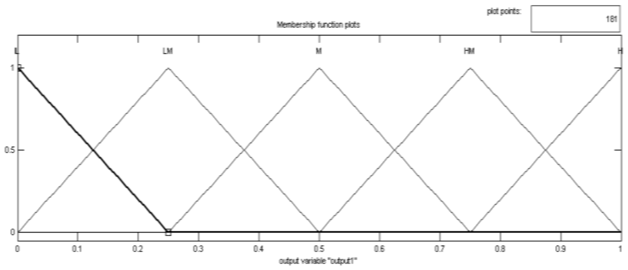


Fig 7 Membership function for the output – Candidate sensitivity index-15 and 34 bus system

For obtaining the output as desired some set of rules have to be incorporated in the fuzzy interference system. It is found that only 25 rules are framed and they are incorporated in the system. The decision matrix is framed and it is incorporated in the system, The pop-up menus that is used in this project is AND method.

The rules are framed between the power loss index and voltage for the candidate sensitivity index.

Table 1. Decision matrix for determining the optimal Capacitor locations.

AND		Voltage				
		L	LN	N	HN	HH
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

The rule view for the radial distribution system in the fis file of Matlab is shown here. This view shows the rule view for the rules that are incorporated in the system. The functions selected for the rules are classified as low, lowmedium, medium, highmedium, high.

B .Inference-15 bus system

From the above result it is found that the sensitivity index is more in 4,6,7 ,11,15 buses. But placing the capacitors in all the 5 buses will increase the total cost to a higher level. So the bus where the sensitivity is peak is selected as the node for placing the capacitor. They are 11,15 buses.

C. Inference-34 bus system

From the above result it is found that the sensitivity index is more in, 8,9,11,18,19,20,21,22,23,24,25,26 buses. But placing the capacitors in all the 5 buses will increase the total cost to a higher level. So the bus where the sensitivity is peak is selected as the node for placing the capacitor. They are 19,20,21,22,23,24,25 buses.

VI. CAPACITOR SIZING – PSO

PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity. Particle swarm optimization is originally attributed to Kennedy, Eberhart.

Step 1 Initialize a population of particles (pp) with random positions.

Step 2 Calculate the fitness value for the given objective function for each particle.

Step 3 Set present particles as "Pbest".

Step 4 Initialize velocity (V_{old}) for initial particles

Step 5 Find fitness value for each new set of particles.

Step 6 Compare each particle's fitness value to find new "Pbest" between the two set of particles.

Bus No.	*FES Inputs*		*FES Output*
	Power loss Index (p.u)	*Voltage (p.u)*	*Candidate Sensitivity Index*
1	0	1	0.08
2	0.1779	0.9713	0.2373
3	0.4294	0.9567	0.4203
4	0.954	0.9509	0.75
5	0.3158	0.9499	0.3254
6	0.8365	0.9582	0.75
7	0.8773	0.956	0.75
8	0.4422	0.957	0.4307
9	0.3141	0.968	0.3483
10	0.2063	0.9669	0.2423
11	0.9862	0.95	0.75
12	0.551	0.9458	0.5613
13	0.3602	0.9445	0.3631
14	0.5094	0.9486	0.5135
15	1	0.9484	0.75

Step 7 Find minimum fitness value by comparing two set of particles and corresponding particle is "Gbest".

Step 8 Update velocity and position for next iteration using the below formula,

$$V_{new} = w * V_{old} + [a (P_{best} - pp) + b (G_{best} - pp)]$$

$$pp_{new} = pp_{old} + V_{new}$$

Step 9 The iteration is repeated until the convergence is made.

A. Objective function

$$MinS = k_e \sum_{j=1}^{L} T_j P_j + \sum_{i=1}^{ncap} (K_{cf} + K_c Q_{ci}) + \lambda (V^l_{min} - V^s_{min})^2$$

P_j = Power loss at j^{th} load level.
Q_{ci} = Reactive power injection from capacitor to node i.
S = Savings in '$'
T_j = Load Duration (8760 hrs)
N_{cap} = Number of Capacitor locations
L = Number of Load level
K_e = Capacitor Energy Cost of Losses (0.06$/kWh)
K_{cf} = Capacitor Installation Cost (1000$)
K_c = Capacitor Marginal Cost (3$/kVAr)
V^l_{min} = Minimum voltage limit
V^s_{min} = Voltage of the system
λ = Constant multiplier

B.Capacitor Sizing – HPSO

For the positions of children:
$Child_1(x_i) = p_i \times parent_1(x_i) + (1-p_i) \times parent_2(x_i)$
$Child_2(x_i) = p_i \times parent_2(x_i) + (1-p_i) \times parent_1(x_i)$

For the velocity of the children:

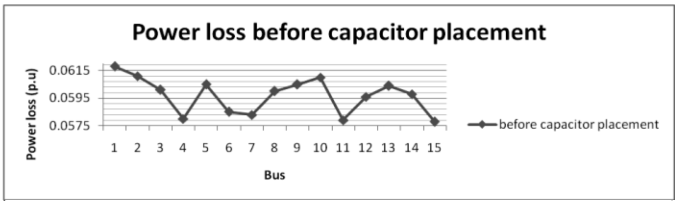
$$Child_1(v) = \frac{(parent_1(v) + parent_2(v)) \times |parent_1(v)|}{|Parent_1(v) + parent_2(v)|}$$

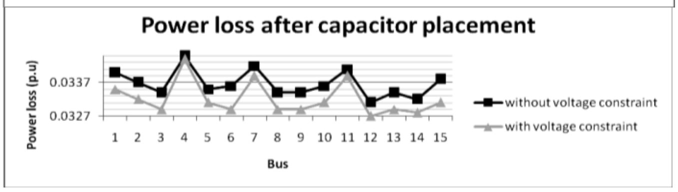
$$Child_2(v) = \frac{(parent_1(v) + parent_2(v)) \times |parent_2(v)|}{|Parent_1(v) + parent_2(v)|}$$

C.FES output-15 bus system

λ value should be taken as high as possible so that convergence will be attained easily and in advance. Result can be found only by means of trial and error method satisfying the constraint limit.

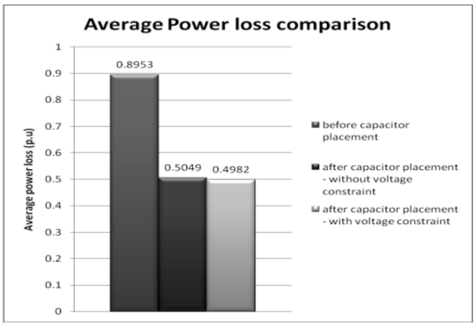
D. Power loss comparision-15 bus system

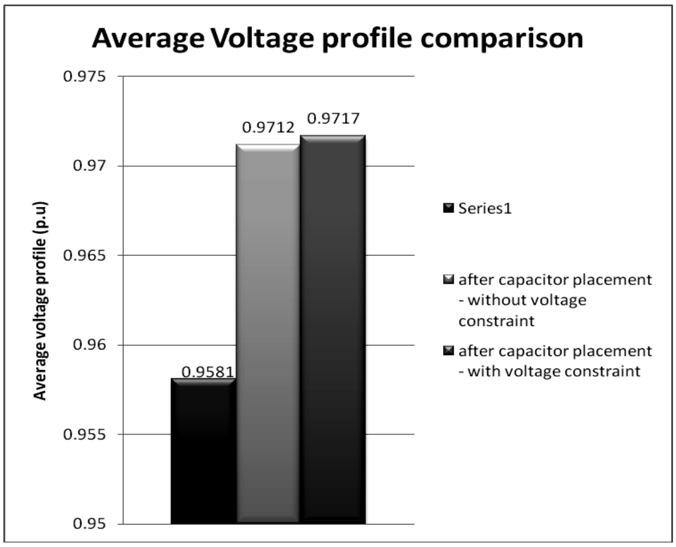




E.Average voltage comparision

F. Average power loss and voltage comparison





G.Savings

$$Max.S = KP + KF + KE - KC$$

a. Released demand:
   i. KP = ΔKP * CKP * IKP

b. Released feeder capacity:
   i. KF = ΔKF*CKF * IKF

c. Savings in Energy:
   i. KE = ΔKE * r

d. Cost of Installation of Capacitor:
   i. KC = Qc * ICKC * IKC

- ΔKP-Reduced Demand.
- CKP-Cost of Generation($200/KW)
- IKP-Annual rate of Generation cost(0.2).
- CKF-Cost of feeder($3.43/kVA)
- ΔKE-Savings in energy.
- r-Rate of energy($0.06/kWh)
- Qc-Total KVar
- ICKC-Cost of Generator($4/KVar)
- IKC-Annual rate of cost of capacitor(0.2)

VII. CONCLUSION

Algorithm based on fuzzy logic is developed for capacitor placement in radial distribution system to minimize the line loss. Fuzzy expert system determines the candidate nodes for capacitor placement by striking a compromise between the possible loss reduction from capacitor installation and voltage levels. Simulation study was carried out on sample 15 bus and 34 bus systems, comparative study was done for the system without capacitor and with optimally placed capacitors and the following inferences were made.

1. Locations for optimal capacitor placement were identified.
2. Significant loss reduction is observed.
3. Considerable voltage improvement is achieved.

The voltage constraint is taken into account in this paper which distinguishes this present work, when compared to previous published work.

VIII. PROBLEMS ASSOCATED WITH ABOVE TECHNIQUE

- Capacitor siting and sizing is performed under sinusoidal conditions only. Improvement in stability constraints is not guaranteed at each iteration.
- Applied method is not practical for the analysis of real networks due to their great number of calculations. Over voltage and under voltage once capacitor bank is installed.
- Actual power loss being differ from the calculated value.
- Optimal placement may not be practically feasible for capacitor placement.

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