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Combination of Fuzzy and Second Order PSO based Capacitor Placement in Radial Distribution Feeder

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ABSTRACT

A new method of Second order PSO for a more effective capacitor sizing in radial distribution feeders to reduce the real power loss and to improve the voltage profile is proposed. The location of the nodes where the capacitors should be placed is decided by a set of rules given by the fuzzy expert system and the sizing of the capacitors is modeled by the objective function to obtain maximum savings using Particle Swarm Optimization(PSO). The newer upgrade to PSO enables the problem to use the knowledge of past solutions into present sizing and hence a second level of optimization procedure to provide better results. A case study with an IEEE 34-bus radial distribution feeder is presented to illustrate the applicability of the newer algorithm.

Index terms: Fuzzy expert system(FES), Second Order Particle swarm optimization, Radial distribution feeders (RDF)

1.INTRODUCTION

The $\mathbf{I^2R}$ losses is the major problem in Power system at the distribution level causing unnecessary power consumption of almost 13% of generated power and raising the power demand. Also reactive currents account for a portion of these losses. Installing shunt capacitor banks at suitable locations in such large distribution system improves the voltage profile and reduces both real power losses and losses produced by reactive currents. This requires finding the optimal location and size of capacitors required to maintain good voltage profile and to reduce feeder losses, which tends to a reduced billing charge.

Reference [1] suggests different techniques devised to solve the problem of capacitor allocation in distribution systems providing insight into the choices of available capacitor allocation techniques and the respective merits and short comings. A novel approach using approximate reasoning to determine suitable candidate nodes in a distribution system for a capacitor placement is presented in reference [2]. A simple optimisation technique to solve the VAR control problem in a distribution system with lateral branches, taking into account the time varying characteristics of load was presented in reference [3]. IEEE standard of 34-bus RDF test system is referred from reference [4]. A new and robust Newton Raphson method in complex form which gives the solutions in whole phasor format is presented in reference [5]. Reference [6] presents the reactive power compensation using Genetic algorithm technique wherein the basic framework of capacitor allocation problem is detailed. The PSO objective function used in this paper is taken from a Fuzzy and PSO based capacitor placement method proposed in reference [7]. Reference [8] provides algorithm for Hybrid PSO (HPSO) used in this paper. Reference [9] presents a detailed overview of the basic concepts of PSO and its variants. It provides a comprehensive survey on the power system applications that got benefited from the powerful nature of PSO as an optimization technique.

In this paper, a newer procedure of 2^{nd} level of optimisation with PSO is proposed. Particle Swarm optimization is among the popular meta-heuristic methods in all the engineering fields and it has been used to find the size of the capacitors designed with the objective function, which minimises the power loss [7]. While the solution is primarily optimized by PSO, the 2^{nd} level optimization deals with better initialization of suitable random set of capacitors within a narrow range of KVAR based on previous best results for the next trial of primary PSO, hence improving the degree of optimization further. The results with that of using PSO, HPSO and 2nd order PSO are compared and presented. Results of proposed 2^{nd} order PSO method is found to be improved than other PSO methods.

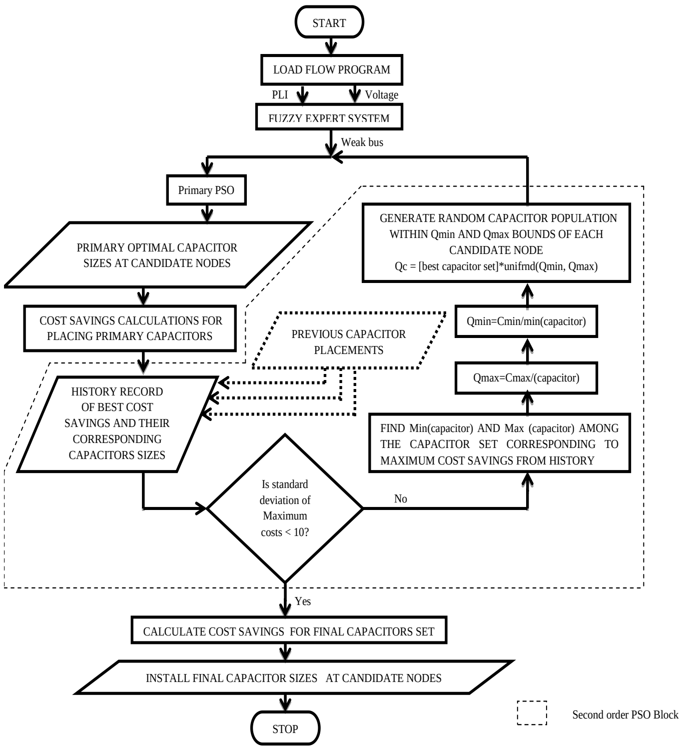

Figure 1. Framework of the approach

2. FRAMEWORK OF THE APPROACH

The complete framework of this approach to solve the optimal capacitor allocation problem includes the use of numerical and computational procedures coupled to the FES, PSO and 2nd order optimization of primary PSO. A complex form of Newton-Raphson load flow program initially calculates the power loss reduction by compensating the total reactive load currents at every node of the distribution system. Reference [5] presents a simplified approach for the load flow program. The loss reductions are then linearly normalized as Power Loss Index into

[0, 1] range with the largest loss reduction having a value of "1" and the smallest one having a value of "0". These power loss reduction indices along with the per-unit node voltages are evaluated with FES, which determines the most sensitive nodes for capacitor installation by fuzzy inference. Then a practical mathematical-computational procedure of Particle swarm optimization is used to determine the optimal size of capacitor to be placed at the chosen node for its most economic savings. The savings function NS (7) computes the cost savings of the primary optimized set of capacitor sizes.

This savings in $ along with their capacitor set is recorded on a data log file which stores all such previous optimal solutions of sizes of capacitors and their corresponding cost savings data. The second level PSO identifies the best cost savings among the records and obtains the capacitor size set of that best cost. Based on the maximum and minimum KVARs among the capacitor sizes obtained, a suitable random set of capacitors within a narrow range of KVAR is generated for the next trial of primary PSO. Thus, further iterations of PSO generates a better optimized result.

The above procedure is repeated for iterations until the best of maximum of costs among the data log come under a standard deviation of less than 10. The solution of capacitor sizes corresponding to maximum of the costs in record is installed in the system. The capacitor sizing procedure also takes into account of the discrete nature of the capacitor sizes and the piecewise cost function for capacitors. The Figure 1 illustrates the flow of data through the individual components of this system.

3. PROBLEM FORMULATION AND IMPLEMENTATION

3.1 Radial main feeder test system

An IEEE 34-bus radial distribution system [4] and the single line diagram of the feeder comprising branches / node are considered from reference [2] [4] & [6] and shown in Figure 2 & Table 1 .

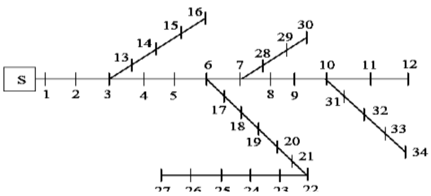

Figure 2. IEEE 34-Bus Test System

Table 1. Test System Specification

Radial feeder type	IEEE 34-BusSystem
Base KV	11 KV
Base MVA	100 MVA
No. of Load level	1 (constant load)
Load Duration	8760hours

3.2 Load flow solution – Newton Raphson method

Newton-Raphson method is an iterative method which approximates the set of non-linear simultaneous equations to a set of linear simultaneous equations using Taylor's series expansion and the terms are limited to first approximation. A new and robust Newton Raphson Method in Complex form, an extension of Newton-Raphson method and its Jacobian in complex form that gives the solutions in whole phasor format is used here as from reference [5]. 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.

3.3 Fuzzy Expert System (FES) Implementation

A set of rules are defined in FES to determine the suitability of a node for capacitor installation, which are developed from qualitative descriptions. The decision variables and their ranges for determining suitable capacitor location are considered from references [2] & [6-8]. The inputs to the rules are the voltage and power loss indices (PLI), where PLI are the loss reductions, linearly normalized into [0, 1] range with the largest loss reduction having a value of 1 and the smallest one having a value of 0.

$$PLI_{(n)} = \frac{(Lossreduction_{(n)} - Lossreduction_{(min)})}{(Lossreduction_{(max)} - Lossreduction_{(min)})} \quad (1)$$

The rules and membership functions are summarized in the fuzzy decision matrix in Table 2. The output is the suitability of capacitor placement based on the decision matrix for determining suitable capacitor locations (PLI Vs Voltage) on Table 3.

***Table 2. Fuzzy Membership Functions**

Membership function for power loss index.					
Variable	*L*	*LM*	*M*	*HM*	*H*
PLI	<0.25	0.00–0.50	0.25–0.75	0.50–1.00	>0.75
Membership function for bus voltage.					
Variable	L	LM	M	HM	H
Voltage	<0.94	0.92–0.98	0.96–1.04	1.02–1.08	>1.1
Membership function for sensitivity index.					
Variable	*L*	*LM*	*M*	*HM*	*H*
CSI	<0.25	0.00–0.50	0.25–0.75	0.50–1.00	>0.75

***Table 3. Decision Matrix for Determining Suitable Capacitor Location (PLI Vs Voltage)**

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

*Symbols L,M & H used in Tables II & III are **L**ow, **M**edium & **H**igh

3.4 Primary Capacitor Sizing – Particle Swarm Optimization

Particle swarm optimization is a population based stochastic optimization to treat problems with discrete variables. This feature enables the application of PSO in evaluating the capacitor sizing based on objective function.

3.4.1 PSO Parameters Used

C_1=1, C_2=1; W_{min}=0.2, W_{max}=0.9; Q_{min}=150, Q_{max}=1000;
Population Size = 50; Number of iterations = 100,
Number of Capacitor locations =7.

3.4.2 Steps in basic PSO algorithm

Step 1: Initialize a population of particles 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: Add velocity to initial particles in order to obtain new set of 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.
Step 7: Find minimum fitness value by comparing two set of particles and corresponding particle is "Gbest".
Step 8: Update velocity for next iteration using the below formula,

*v = w * [a (Pbest - pp) + b (Gbest- pp)];*

pp = pp + v;

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

3.4.3 Objective Function for capacitor Sizing

PSO estimates the size of the capacitor to be installed by minimizing the following objective function [7],

$$S = k_e * 365 * 24 * P_j + \sum_{i=1}^{ncap} (K_{ef} + K_c Q_{ci}) \quad (2)$$

where,

P_j = Total Power loss ;	K_c = Capacitor Installation Cost (1000$) ;
V_i = Bus voltage magnitude at node i ;	K= Capacitor Marginal Cost; (3$/KVAR) ;
S = Savings in '$' ;	Q_{ci}= Reactive power injection from capacitor to node i ;
P_{Loss}= Real Power loss ;	P_i,Q_i = Real and Reactive power flows into the sending end of branch i+1 connecting nodes i and i+1.
K_e = Capacitor Energy Cost of Losses (0.06$/kWh) ;	
ncap = Number of Capacitor locations ;	

3.5 Savings – Mathematical Formulation

Table 4. Equations of Mathematical Formulation

Criteria	*Equation*	*Elements of the Equatio*
Benefits due to released demand ($)	KP = ΔKP * CKP * IKP ----(3)	*ΔKP*= Reduced demand (kW) *IKP*= Annual rate of generation (taken as 0.2) *CKP*= Cost of generation (taken as $200/kW)
Benefits due to released feeder capacity ($)	KF = ΔKF * CKF *IKF ----(4)	*ΔKF*= Annual rate of cost of fee (taken as 0.2) *IKF*= Released feeder capacity *CKP*= Cost of feeder (taken as $3.43/KVA)
Benefits due to savings in energy ($)	KE = ΔKE * r -----(5)	*ΔKE*= Savings in Energy *r*= Rate of energy (taken as $0.06/kWh)
Cost of Installation of Capacitor ($)	KC = Q_c * ICKC * IKC -----(6)	Q_c= Total KVAR *ICKC*= Cost of capacitor (taken as $4/KVAR) *IKC*= Annual rate of cost of capacitor (taken as 0.2)
Net Savings ($)	NS=KP+KF+KE-KC ----(7)	

The degree of optimum in capacitor allocation and sizing problem solving methods can be identified by maximizing the objective function stated as Net Savings (7) in the Table 4. Difference in annual energy loss before installing capacitor and annual energy losses after installing capacitor gives the savings in Energy.

3.6 Final Capacitor Sizing - Second Order Particle Swarm Optimization

The performance of the PSO technique is strongly dependant on the initial range of random parameters assigned to it at every iteration. The proposed Second order PSO optimizes initiation of every primary PSO trial. The secondary optimization identifies a best set of solution ever recorded from the history of previous solutions and generates a random set of parameters varying randomly within a short range such that the parameters are restricted to maximum and minimum boundaries.

Thus, 2^{nd} order Optimization carries the merits of:

a) Improved optimization to generate a higher quality result than the conventional techniques.
b) More Determined solution as obtained from deterministic methods.
c) The use of knowledge of past best solutions makes the procedure close towards human intelligence.
d) Opens the door to an extensive research on improvement of present day optimization techniques.

3.6.1 Steps in Second order Optimization technique

Step 1: Identify the best of maximum cost savings.
Step 2: Obtain the capacitor set for best of maximum cost.
Step 3: Calculate the minimum capacitor change limit (Minlimit) and maximum capacitor change limit (Maxlimit) using:

$$\text{Minlimit} = \frac{(\text{Min Capacitor Size})}{(\text{Min(best capacitors set)})} \quad (8)$$

$$\text{Maxlimit} = \frac{(\text{Max Capacitor Size})}{(\text{Max(best capacitors set)})} \quad (9)$$

Step 4: Generate random capacitor population for next Primary PSO iteration using:

Qc[i,j]=Bestcapacitor[i,j]*rand(Minlimit,Maxlimit) (10)

Step 5: Run next Primary PSO and repeat iterations of 2^{nd} order PSO until a standard deviation of less than 10 in Maximum costs is reached.

4. RESULTS AND DISCUSSION

Algorithms of PSO and HPSO are taken from reference [8] and their results were obtained for comparison with Second order PSO.

Table 5 shows the output results from FES for the Bus Nos. 20 to 27 of the test system, which are considered as weak buses as the CSI are very high compared to other buses. Table 6 shows the comparison of results on the loss reductions in the test system by using PSO, HPSO and by using the proposed method. A much reduction is evident from the 2^{nd} order PSO.

Table 7 shows the summary of the results obtained from normal PSO, HPSO and the proposed 2^{nd} order PSO methods for the test system. An efficient capacitor sizing by second order optimization compared to normal PSO and HPSO that improves the benefits due to saving in energy, thus generating a maximum cost saving can be inferred from the summary.

Table 5. Candidate Nodes From Output Of FES Of IEEE 34-Bus System

Bus No.	PLI	Voltage (p.u)	CSI
20	0.7579	0.9548	0.7500
21	0.8102	0.9519	0.7500
22	0.8719	0.9487	0.7500
23	0.9225	0.9460	0.7500
24	0.9698	0.9434	0.7500
25	0.9920	0.9422	0.7500
26	1	0.9418	0.7500

Table 6. System Parameters Before And After Placing Capacitors

Report			Average Voltage (p.u)	Total Real Power loss (KW)	Total Reactive Power Loss (KVAR)
Before Capacitor Placement		34-bus	0.9657	7475.7	2219.8
After Capacitor Placement	PSO	34-bus	0.9730	7108.7	1997.1
	HPSO	34-bus	0.97219	6557.1	1856.2
	2^{nd} Order PSO	34-bus	0.97005	5700.5	1679.1

Table 7. Summary Of Results For 34-Bus System

Parameter	PSO	HPSO	2nd order PSO
FES Inputs	PLI vs. Voltage	PLI vs. Voltage	PLI vs. Voltage
Weak Buses	20,21,22,23, 24,25,26	20,21,22,23, 24,25,26	20,21,22,23, 24,25,26
Capacitor sizes in respective weak buses (KVAR)	609,313,670,290, 788,356,285	660,172,220, 240, 702,290,581	898,159,151,151, 162,159,203
Capacitor Size in total (KVAR)	3311	2863	1891
Benefits due to released demand ($)	7044	7044	7100
Benefits due to released feeder capacity ($)	4137	4137	4137
Benefits due to saving in Energy ($)	92559	92559	93300
Cost of capacitor installation ($)	2648	2290	1510
Net Savings ($)	**101092 $**	**101450 $**	**103027 $**

5. CONCLUSION

This paper has discussed the combined method of FES & 2^{nd} order PSO to determine optimal capacitor placement in radial distribution system for energy loss minimization and annual cost savings maximization. The results of three methods such as PSO, HPSO and Second order PSO used for determining the size of capacitor in this capacitor placement problem are compared. The use of FES determines the nodes for capacitor allocation by finding a compromise between the loss reduction from capacitor installation and voltage level improvement. In addition, the FES can easily be adapted for capacitor allocation in distribution system planning, expansion and operation. A newer upgrade to PSO is proposed in this paper. Primary optimal size of capacitor is obtained by PSO and the improved optimal size of capacitors is obtained by the 2^{nd} order PSO. By considering maximum savings in cost, this upgraded PSO method is found to give a better performance than normal PSO and HPSO. However, capacitor sizing using normal PSO also has unique merit like improved voltage profile. Still compared results show the more advantages of Second order PSO approach over the PSO and HPSO capacitor sizing in distribution system feeders. Future work will focus on the combined objective of capacitor placement and sizing on other bigger distribution systems considering their imbalance and dynamics in load nature and harmonics in the system for a better practical approach.

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7.AOTHURS PROFILE

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