Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 75 (2015) 1153 – 1158

Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

New Sensitivity based Approach for Optimal Allocation of Shunt Capacitors in Distribution Networks using PSO

Neeraj Kanwar[a], Nikhil Gupta[a], Anil Swarnkar[a], K. R. Niazi[a], R.C. Bansal[b*]

[a]*Department of Electrical Engineering, Malaviya National Institute of Technology, Jaipur, 302017, India*
[b]*Department of Electrical, Electronics and Computer Engineering, University of Pretoria, South Africa*

Abstract

This paper proposes a new methodology for optimal allocation of shunt capacitors in distribution systems. The proposed method combines various objectives and constraints into a Comprehensive Constraint Multi-objective Function. The function has been optimized using a Particle Swarm Optimization (PSO) based method. Attempts have also been made to improve the performance of PSO. The search space of PSO is reduced by introducing a new reactive power flow sensitivity approach that determines the set of candidate nodes suitable for capacitor placement and also by employing a new constrained particle structure. The proposed method is tested on a 69-bus test distribution system and the application results are promising.

Peer-review under responsibility of Applied Energy Innovation Institute

Keywords: capacitor placement; distribution systems; sensitivity analysis; particle swarm optimization; reactive compensation.

1. Introduction

The present trend towards competitive business environment enforces electric utilities to enhance their annual profits while ensuring reliable and better quality of electric supply. Benefits such as reduction in annual energy loss, improvement in node voltage profiles, system capacity release, etc. depend greatly on how optimally shunt capacitors are installed. In the context of modern distribution, the aim of the capacitor placement problem is to maximize the profit on the investment of capacitor placement, subject to operational & power quality constraints.

* Corresponding author. Tel.: +27 12 4205446; fax: +27 12 3625000.
E-mail address: rcbansal@ieee.org.

Peer-review under responsibility of Applied Energy Innovation Institute
doi:10.1016/j.egypro.2015.07.546

In recent years population based meta-heuristic techniques such as Genetic Algorithm, Particle Swarm Optimization (PSO), Teaching Learning Based Optimization, Plant Growth Simulation Algorithm, Artificial Bee Colony, Micro-Genetic Algorithms, etc. [1-8] have been applied to solve this problem. PSO is modern swarm intelligence based search technique and has several advantages in term of simplicity, convergence speed, and robustness [9]. However, its performance is greatly depends on its parameters tuning and it often suffers from the problems such as being trapped in local optima due to premature convergence [10], lack of efficient mechanism to treat the constraints [11], loss of diversity and performance in optimization process [12], etc. In order to enhance its exploration and exploitation potentials, the problem search space should be intelligently selected.

In this paper, the search space of PSO is squeezed by proposing a new reactive power flow based sensitivity method and also by introducing a constrained particle structure. The capacitor placement problem is solved by suggesting a comprehensive constraint multi-objective function (CCMF) which considers loss reduction, voltage profile improvement, feeder overloading, kVA enhancement etc., in such a way that the annual savings is maximized. The proposed method is applied on a standard 69-bus test distribution system and the results are promising when compared with other existing methods.

2. Problem formulation

The proposed CCMF for the optimal allocation of shunt capacitor is as given below:

$$Max\ \ F(x) = k_1\left(K_e \sum_{j=1}^{N_L} T_j \Delta E_j + K_p \Delta P + K_S \Delta S_{CR}\right) \times \mathrm{PF} - \sum_{i=1}^{nc} K_{ci} Q_{ci} \tag{1}$$

Where, the first term within the bracket represents annual cost of energy loss reduction, second term represents the annual cost of peak power loss reduction and the third term represents the annual cost of the substation capacity release. The negative term represents annual charges on capacitor placement. The term penalty function (PF) is explained as under.

2.1. Penalty Function

The PF in (1) is incorporated to check node voltage and feeder current constraints and is defined by the geometric mean of node voltage deviation and feeder current deviation penalty functions as below

$$PF = \sqrt{(V_{pf} \times I_{pf})} \tag{2}$$

$$V_{pf} = 1/(1+k_2\ (Max\ (\Delta V_{ij\max}))) \tag{3}$$

2.2. Operating Constraints

- Power flow balance constraint

$$H(x,u)=0 \tag{4}$$

- Capacitor capacity and control setting constraint

$$Q_{ci} \le LQ_o;\ L = 0, 1, 2, \ldots, nc \tag{5}$$

$$Q_{ci} = k\Delta Q;\ k = 0, 1, 2, \ldots, Q_{ci}/\Delta Q \tag{6}$$

$$\sum Q_{ci} = Q_D \tag{7}$$

The CCMF defined by (1) is optimized using a proposed PSO based method. The above problem is solved in two steps. In the first step optimal installed capacity of shunt capacitors is determined on the basis of annual loading. In second step optimal control settings of installed capacitor, for each load level, is determined.

3. Proposed Particle Swarm Optimization

Particle swarm optimization is a robust stochastic evolutionary computation technique based on the movement and intelligence of swarms [13]. The conventional PSO is initialized with a population of random solutions and searches for optima by updating particle positions. The velocity of the particle is influenced by three components namely, initial, cognitive and social components. Each particle updates its previous velocity and position vectors according to the following model of [9].

$$v_p^{k+1} = W v_p^k + C_1 \times r_1() \times \frac{pbest_p - s_p^k}{\Delta t} + C_2 \times r_2() \times \frac{gbest - s_p^k}{\Delta t} \tag{8}$$

$$s_p^{k+1} = s_p^k + v_p^{k+1} \times \Delta t \tag{9}$$

$$W = W_{\min} + \frac{(W_{\max} \text{-} W_{\min}) \times (itr_{\max} \text{-} itr)}{itr_{\max}} \tag{10}$$

The optimal capacitor placement problem offers enormous search space and that results in poor convergence of PSO. Therefore, in the present work the search space is squeezed by proposing a reactive power flow sensitivity approach and also by employing constrained bound particle structure.

3.1. Proposed Reactive Power Flow Sensitivity Approach

Shunt capacitors should be placed at very few selected locations in distribution networks. Many researchers [1, 4, 7] used perturbations to determine these optimal locations by placing a small unit capacity and measuring the change in power losses. This provides ranking of nodes, and the high ranking nodes are selected for capacitor placement. However, the sensitivity based approaches select attractive buses in capacitor placement can lead to poor quality solutions [14]. Therefore, a new reactive power flow sensitivity based approach is proposed where the nodes in the identified prominent areas are considered possible candidate for capacitor placement.

3.2. Proposed Constrained Particle Structure

In this work, the site is taken randomly from the list of candidate nodes prepared through sensitivity analysis approach and the size represents randomly generated number of candidate capacitor banks between its minimum and maximum bounds. Therefore, the particle has been divided area-wise for candidate siting and sizing of shunt capacitors. This information is selected in accordance to the constraints defined by equations (7), (11) and (12).

$$TQ_{ci,n} \leq g_n(x) \tag{11}$$

$$TQ_{ct,n} \leq g_n(x) \tag{12}$$

These constraints are pertaining to maximum reactive power injection at a candidate node and area of the distribution network. The term $g_n(x)$ is taken proportional to total reactive power loading of respective area. Initially, such p numbers of particle are created to constitute the swarm.

4. Simulation results and discussions

The proposed method is tested on 69-bus radial distribution system which has been taken from [1]. The feeder current constraints are set at 300 A, except for the upstream branches 1-9, whose limits are set at 600A. The sensitivity test is applied on this system and the result obtained is presented in Fig.1. The figure shows a 3-dimensional view of the change in reactive power flow in the network when small capacity perturbations are employed. It can be observed from the figure that two areas of the network are prominent and are presented in Table 1. On this basis, $g_n(x)$ is obtained proportionately, as given in the table. Three cases for capacitor placement have been investigated for three, four and five optimal locations, respectively.

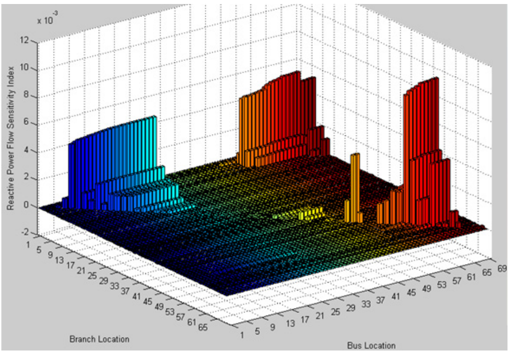

Fig. 1. 3-dimensional view for change in reactive power flow

Table 1. Results of proposed sensitivity method

Particulars	Area 1	Area 2
Buses	16- 27	53- 65
Area reactive power demand (kVAr)	225.1	1226.7
System reactive power demand (kVAr)	2694.6	
$g_n(x)$ (kVAr)	414	2280

The system constraints and PSO parameters considered for simulations are shown in Table II. Three different load levels and corresponding load durations considered are taken from [1]. The cost of annual energy loss for the bare system is US $135905.

Table 2. System constraints and PSO parameters

Parameter	Value	Parameter	Value
V_{minS} (p.u.)	0.95	V_{min} (p.u.)	0.90
V_{maxS} (p.u.)	1.05	I_{maxS} (p.u.)	1.1
K_s (US $/kVA)	19.8	I_{max} (p.u.)	1.0
K_e (US $/kWh)	0.06	Q_0 (kVAr)	300
K_{ci} (US $/kVAr)	3.0	ΔQ (kVAr)	100
K_p (US $/kW)	42.6		

Table 3 Optimal solution for different cases

cases	Case 1	Case 2	Case 3
Optimal solution Node(capacitor in kVAr)	18(300),61(1200) 64(600)	18(300),59(300),61(1200), 64(600)	18(300),59(300), 61(1200),64(300), 65(300)

Table 4. Network performance after optimal capacitor placement

Load level	Particulars	Proposed PSO		
		Case 1	Case 2	Case 3
Light	Power Loss (kW)	34.32	34.33	34.33
	*V*min (p.u.)	0.9666	0.9664	0.9664
Nominal	Power Loss (kW)	146.17	145.99	145.95
	*V*min (p.u.)	0.9320	0.9317	0.9315
Peak	Power Loss (kW)	417.21	411.72	412.25
	*V*min (p.u.)	0.8814	0.8854	0.8863

Table 5. Comparison result for proposed PSO

Method	Load levels	Power loss (kW)	Minimum Voltage (p.u.)
DSA [1]	Light	35.52	0.9683
	Nominal	147.0	0.9318
	Peak	427.3	0.8936
GA [2]	Light	40.48	0.9622
	Nominal	156.52	0.9369
	Peak	460.45	0.9001
Dedicated GA [3]	Light	34.95	0.9668
	Nominal	146.88	0.9302
	Peak	-	-
TLBO [5]	Light	34.43	0.9662
	Nominal	146.80	0.9321
	Peak	417.28	0.8795
Proposed PSO	Light	16.29	0.9810
	Nominal	66.57	0.9680
	Peak	179.11	0.9413

Table 6. Comparison result of cost benefit appraisal

Particulars (US $)	Case 1	Case 2	Case 3
Annual Investment on shunt capacitors	6300	7200	7200
Annual cost of energy loss reduction	48106	48656	48621
Annual cost of peak power loss reduction	10019	10253	10230
Annual cost of sub-station capacity release	24077	26350	26350
Annual Savings	75902	78059	78001
Benefit/Cost Ratio	12.05	10.84	10.83

The optimal solutions obtained are summarized in Table 3 and the performance of the network after this optimal compensation is presented in Table 4. It can be observed from the table that all cases provide almost similar results. The application results are compared with other existing methods in Table 5 shows that proposed PSO provides least power losses and better minimum node voltages at all load levels than other established methods. Finally, the impact of optimal capacitor placement on the benefits and cost involved is presented in Table 6. The table reveals that all cases generate comparable results.

5. Conclusions

This paper presents a PSO-based method for optimal capacitor allocation in radial distribution systems. The search space of PSO is reduced by introducing a new reactive power flow sensitivity-based approach and also by suggesting a new constrained bound particle structure. The proposed CCMF maximizes net annual savings by reducing annual energy and peak power losses and enhancing substation capacity release while simultaneously improving system node voltage profile with optimal investments on shunt compensation. The proposed method first determines the optimal siting and sizing of installed capacities of shunt capacitors and then the optimal control settings are determined under variable load scenarios. The proposed method is tested on 69-bus test distribution system and the application results are promising when compared with other established techniques.

References

[1] Das D. Optimal placement of capacitors in radial distribution system using a Fuzzy-GA method. *Int J Electr Power and Energy Syst* 2008; **30**:361–367.
[2] Levitin G, Kalyuzhny A, Shenkman A, Chertkov M. optimal capacitor allocation in distribution systems using a genetic algorithm and a fast energy loss computation technique. *IEEE Trans Power Syst*. 2000; **15** (2): 623–628.
[3] Guimaraes M A N, Castro C A, Romero R. Distribution systems operation optimization through reconfiguration and capacitor allocation by a dedicated genetic algorithm. *IET Gener. Transm. Distrib.* 2010; **4** (11): 1213 –1222.
[4] Singh S P, Rao A R. Optimal allocation of capacitors in distribution systems using particle swarm optimization. *Int. J. Electrical Power and Energy Syst*. 2012, **43**(1): 1267–1275.
[5] Sultana S, Roy P K. Optimal capacitor placement in radial distribution systems using teaching learning based optimization. *Int. J. Electrical Power and Energy Syst.* 2014; **54**: 387–398.
[6] Rao R S, Narasimham S V L, Ramalingaraju M. Optimal capacitor placement in a radial distribution system using Plant Growth Simulation Algorithm. *Int. J. Electrical Power and Energy Syst.* 2011; **33**: 1133 –1139.
[7] El-Fergany A A., Abdelaziz A Y. Capacitor placement for net saving maximization and system stability enhancement in distribution networks using artificial bee colony-based approach. *Int. J. Electrical Power and Energy Syst* 2014; **54:** 235–243.
[8] de Souza B A, Alves H. do N, Ferreira H A. Microgenetic algorithms and fuzzy logic applied to the optimal placement of capacitor banks in distribution networks. *IEEE Trans. Power Syst.* 2004; **19**(2): 942–947.
[9] Kennedy J, Eberhart R. Swarm Intelligence. *Morgan Kaufmann Publishers* 2001.
[10] Safari A, Shayeghi H. Iteration particle swarm optimization procedure for economic load dispatch with generator constraints. *Expert Syst. with Appl.* 2011; **38**: 6043–6048.
[11] Park J B, Jeong Y W, Shin J R, Lee K Y. An improved particle swarm optimization for non-convex economic dispatch problems. *IEEE Trans. Power Syst.* 2010; **25**(1): 156 –166.
[12] Niknam T, Mojarrad H D, Meymand H Z. Non-smooth economic dispatch computation by fuzzy and self-adaptive particle swarm optimization. *Appl. Soft Comput.* 2011; **11**: 2805–2817.
[13] Kennedy J. The particle swarm: social adaptation of knowledge. *Proc. IEEE Int. conf. on Evolut. Comput.* 1997: 303–308.
[14] Gallego R A, Monticelli A J, Romero R. Optimal Capacitor Placement in Radial Distribution Networks. *IEEE Trans. Power Syst.* 2001; **16**(4):630-637.