B. Bhattacharyya
S.K. Goswami
R.C. Bansal

J. Electrical Systems x-x (xxx): x-xx

Regular paper

Hybrid Fuzzy Particle Swarm Optimization Approach for Reactive Power Optimization

This paper presents a new approach to the optimal reactive power planning based on fuzzy logic and particle swarm optimization (PSO). The objectives are to minimize real power loss and to improve the voltage profile of a given interconnected power system. Transmission loss is expressed in terms of voltage increments by relating the control variables i.e. reactive var generations by the generators, tap positions of transformers and reactive power injections by the shunt capacitors. The objective function and the constraints are modeled by fuzzy sets. A term 'sensitivity' at each bus is defined which depends on variation of real power loss with respect to the voltage at that bus. Based on the Fuzzy membership values of the sensitivity, corrective action at a particular bus is taken i.e. shunt capacitors are installed at the candidate buses based on real power loss and sets of solution. Then, PSO is applied to get final solution. PSO is used for optimal setting of transformer tap positions and reactive generations of generators. The solutions obtained by this method is compared with the solutions obtained by other evolutionary algorithms like genetic algorithm (GA), differential evolution (DE) and particle swarm optimization (PSO).

Keywords: Fuzzy membership, sensitivity, reactive power optimization, particle swarm optimization.

1. INTRODUCTION

Reactive power control has become an important aspect for many reasons. First, the need for most efficient operation of power systems has increased with the price of fuel. For a given distribution of power, the losses in the system can be reduced by minimizing the flow of reactive power. Second, the extension of the transmission network has been curtailed in general by high interest rates, and in particular cases by right-of-way. In many cases power transmitted through older circuit has been increased, requiring the application of reactive power control measures to restore stability margins. Third, voltage is considered as one of the most important parameters of the quality of power supply. Its deviation from the normal value may be harmful and expensive. A large amount of research has appeared dealing with reactive power/voltage control in power systems.

In this paper, the main concerns are proper planning and co-ordination of control variables which are either transformer tap changers, shunt capacitors, generators reactive vars in an interconnected power system such that real power loss becomes minimum. The

Department of Electrical Engineering, Indian School of Mines, Dhanbad, India email: biplabrec@yahoo.com

Department of Electrical Engineering, Jadavpur University, Kolkata, India email: skgoswami_ju@yahoo.co.in

Electrical and Electronics Engineering Division, School of Engineering and Physics, The University of the South Pacific, Suva, Fiji email: rcbansal@hotmail.com

problem of reactive power planning in a power system can be shown to be a combinatorial optimization problem though a number of methods have been proposed to solve the problem using the classical optimization techniques [1-6]. Heuristics and approximate reasoning were tried to solve reactive power problem [7-8]. These methods however, require approximation to be applied to make the problem compatible to the classical optimization techniques. Fuzzy logic, as in many other field of the power system, has found its application in the reactive power problem [10-13]. Rahaman et al. [10] have proposed a Fuzzy based method to identify the location for placement of capacitors in a power system. Later on in [11] they have incorporated fuzzy logic to represent the variation of reactive power load while solving the reactive power optimization problem. Their methods however do not guarantee the optimality of the solution. Moreover, they did not consider the cost aspect of the problem. Only the sensitivity to voltage has been used for solving the problem. Thereafter use of SA [13-14] and GA [15-21] are found in the literature for solving reactive power problem. In recent times, evolutionary algorithms [22-37] have become very popular as optimization techniques. Differential evolution (DE) [28-29], Particle swarm optimization (PSO) [34-37] methods both under the category of Evolutionary Algorithms have been implemented individually as optimization techniques.

In the present paper, the authors propose a very new approach for the solution of the reactive power problem based on fuzzy reasoning approach and PSO. Fuzzy membership of loss sensitivity at each bus is defined and depending upon these membership values, shunt capacitors are installed at candidate buses. PSO is then applied for optimal setting of transformer tap positions and reactive vars generated by the generators. The optimality of the proposed approach has been tested by comparing the results obtained by other evolutionary algorithms.

2. PROBLEM FORMULATION

The objective of the reactive power problem is to minimize the transmission losses utilizing the available var sources in the system. Mathematically, the problem may be expressed as minimizing the power loss

$$P_{LOSS} = \sum_{k=1}^{L} g_{kj}(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}) \tag{1}$$

subject to the nodal active and reactive power balance

$$Pg_i - Pd_i - V_i\sum_j V_j(G_{ij}\cos\theta_{ij} + B_{ij}\cos\theta_{ij}) = 0 \tag{2}$$

$$Qg_i - Qd_i - V_i\sum_j V_j(G_{ij}\sin\theta_{ij} - B_{ij}\sin\theta_{ij}) = 0 \tag{3}$$

voltage magnitude constraints

$$V_i^{min} \le V_i \le V_i^{max} \tag{4}$$

on load tap change (OLTC) constraints

$$t_k^{min} \le t_k \le t_k^{max} \tag{5}$$

and the existing nodal reactive capacity constraints

$$\mathrm{Qg}_{\mathrm{i}}^{\min} \leq Qg_{\mathrm{i}} \leq Qg_{\mathrm{i}}^{\max} \tag{6}$$

The planning problem solves an enlarged set of equations including the investment costs of the components. The objective function to be minimized is

$$\mathrm{CP} = \sum_{\mathrm{l=1}}^{\mathrm{N}} (\mathrm{Q_{nl}C}_n + \mathrm{C_{ol}}) + C_e \sum_{\mathrm{k=1}}^{\mathrm{L}} \mathrm{g_{ij}}(\mathrm{V_i^2} + \mathrm{V_j^2} - 2\mathrm{V_i V_j} \cos\theta_{\mathrm{ij}}) \tag{7}$$

The constraint set consists of those mentioned in (2)-(6) and the additional constraint due to the new var sources

$$\mathrm{Qn}_{\mathrm{i}}^{\min} \leq Qn_{\mathrm{i}} \leq Qn_{\mathrm{i}}^{\max} \tag{8}$$

In these equations
CP = Total Planning cost in \$
C_e = Cost due to transmission loss in \$
C_n = Cost of new reactive power sources i.e due to capacitors.
C_{o1} = Cost of existing capacitors.
Qn_i = Reactive power generation from ith capacitor.
L = total number of lines in the system.
ij = end buses of line k.
g_{ij} = conductance of branch i-j.
θ_{ij} = phase angle difference between buses i and j.
G_{ij} = real part of the mutual admittance between bus i and j.
B_{ij} = imaginary part of the mutual admittance between bus i and j.
t_k = tap setting of the kth transformer.
Pg_i = active power generation at bus i.
Pd_i = active power demand at bus i.
Qg_i = reactive Power generation at bus i.

superscripts min, max= minimum and maximum limits of the variables.

2.1 Fuzzy Approach in the Present Problem

Since the transmission loss is a function of the node voltages, the incremental transmission loss may be written as

$$\Delta P_L = \left[\frac{\partial P_L}{\partial V_1} \quad \frac{\partial P_L}{\partial V_2} \cdots\cdots \frac{\partial P_L}{\partial V_n} \right] \left[\Delta V_1 \quad \Delta V_2 \cdots\cdots \Delta V_n \right]^T \tag{9}$$

Again it is observed that transmission loss has inverse relationship with bus voltage profile. In the proposed method a term sensitivity is defined at each bus of the system, such that Si = Mi ΔVi, i=1,2,……..n, where n is the total bus number, Si is the sensitivity at the ith bus and Mi= $\frac{\partial P_{loss}}{\partial v_i}$. Minimization of loss will take place when Si is as negative as possible which indicates that if Mi is negative and ΔVi will attain its maximum positive value. Hence it implies that more the value of S at a bus more will be the voltage deviation at that bus. A fuzzy based reasoning approach is developed at this stage to vary the settings of the control variables depending upon the relative magnitudes of the sensitivities discussed above. A degree of membership is assigned to each value of sensitivity calculated for each bus. The membership values of each sensitivity is expressed as follows

$$\begin{aligned}&\text{if } S_i = D_i, \mu(S_i) = 1;\\&\text{or if } D_i \langle S_i \langle 0,\ \mu(S_i) = \frac{S_i}{D_i};\\&\text{or if } S_i \geq 0, \mu(S_i) = 0\end{aligned} \tag{10}$$

Now, fuzzy logic is used to determine membership values of these sensitivities and corrective action is taken according to the sensitivity observed at a particular bus. Here Di is the maximum negative value of Si . Furthermore, Fuzzy modeling discrimination between different values of variables by assigning higher membership values to the desired solution and lower values to less desirable ones. Hence we are able to control the solution by relating it closely to the desired values of variables.

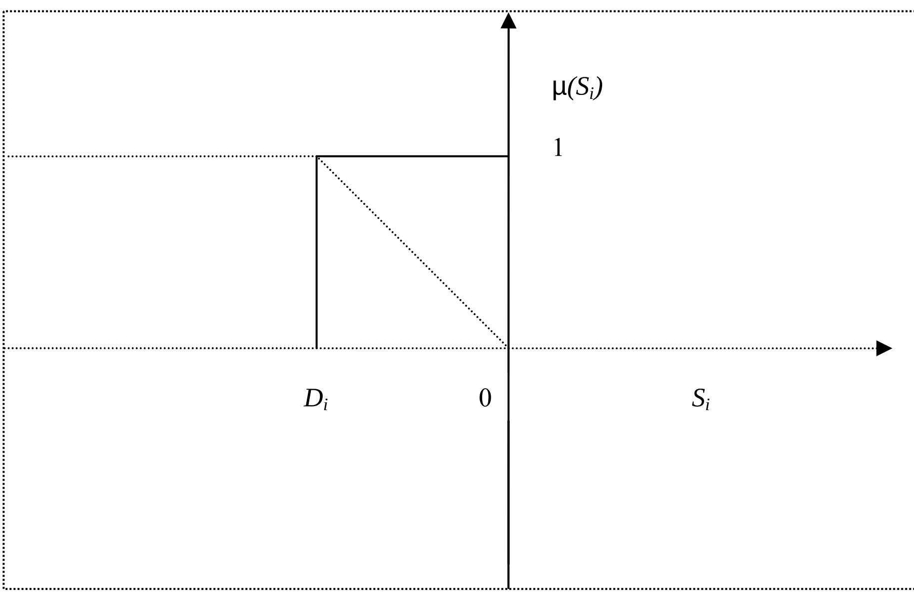

Figure. 1: Fuzzy membership function for the objectives

2.2 Application of PSO in the present problem

The formulae on which PSO works is given as

$$\upsilon_i^{k+1} = \omega_i \upsilon_i^k + C_1 \text{ rand } \times \left(P_{best_i} - S_i^k\right) + C_2 \text{ rand } \times \left(g_{best} - S_i^k\right) \tag{10}$$

where $\upsilon_i^k =$ current velocity of agent i at iteration k,

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \times iter \tag{11}$$

Eq. 11 is the modified velocity of the ith agent

rand =is the random number between 0 and 1,

$S_i^k =$ current position of agent i at iteration k,

Ci = weight coefficient for each term,

$P_{best_i} =$ Pbest of agent i,

gbest = gbest of the group,

$\omega_i =$ weight function for velocity of agent i.

where ω is updated by eq. 11 at each iteration

Here $\omega_{\max}$ =0.9, $\omega_{\min}$ = 0.4, $iter_{\max}$ = 500 and $iter$ = current iteration, C1 and C2 are set to 2.0. PSO is used immediately after the correction due to sensitivity and the combined technique is allowed to run for the specified number of iterations. Initially strings are generated randomly and each string may be a potential solution. In PSO, each potential solution, called particles is assigned a velocity. The particles of the population always adjust their velocity depending upon their position with respect to the position of the pbest (the particle having the best fitness in the current generation) and the gbest (the particle having the best fitness up to the present generation). While adjusting their velocities and positions, particles adjust their fitness value as well. The particle having the best fitness among all is selected as the pbest for the current generation, and if this pbest has better fitness than the gbest, it takes the position of the gbest as well. In PSO, therefore, the gbest particle always improves its position and finds the optimum solution and the rest of the populations follow it. The string length depends upon test system and in the proposed technique; string length is reduced because of the exclusion of shunt var sources from the control variables as compared to other optimization techniques discussed later. Initially strings are generated randomly.

3. OTHER EVOLUTIONARY ALGORITHMS

3.1 Simple Genetic Algorithm (SGA)

In this method Genetic Algorithm works entirely for the reactive power-planning problem and string length as shown in Fig. 2 is larger because it includes shunt capacitors besides transformer tap positions, generator's reactive vars. Initially strings are generated randomly. The string numbers are equal to the population size.. The cross over between two strings take place in such a manner that the particular type of elements (say transformer tap changers or shunt capacitors) of one string crossover with the same type of elements of other string. New sets of strings are produced. Then mutation operation takes place. After completion of all genetic operations, first generation is completed and the second generation is about to start. In this way genetic algorithm is continued in order to reduce the cost of operation in each generation until the optimum solution is obtained.

Q_{g1}	Q_{g2}	……	Q_{gn}	t_1	t_2	……	t_n	S_{h1}	S_{h2}	……	S_{hn}

Generators reactive vars   Transformer tap positions   Shunt capacitors

Figure. 2: String of reactive power generations of the generators, transformer tap positions and shunt capacitors

3.2 Differential Evolution (DE) Method

The performance of a DE algorithm depends on three variables – the population size, mutation scaling factor and the cross over rate. DE starts by generating a population of Np real valued n-dimensional vectors whose initial parameter values being chosen at random from within bounds set by the user. In this problem number of strings (vectors) equal to the population size is generated. This population then undergoes evolution in the form of a natural selection. In every generation, each vector in the population becomes a target vector. Each target vector crossovers with a donor vector, which is generated by mutating a randomly selected population vector with the difference between two randomly selected population vectors, in order to produce a trial vector. If the cost of the trial vector is less then that of the target, the target is replaced by the trial vector in the next generation.

3.3 Simple Particle Swarm Optimization (PSO) Technique

PSO algorithm works entirely for the solution of the above mentioned reactive power problem. The string length is larger than that of the hybrid fuzzy PSO technique and is same as that in case of GA and DE approach.

4. TEST RESULTS

The hybrid fuzzy PSO approach optimization technique and other above discussed such as GA PSO and DE optimization techniques are applied to the IEEE 14, IEEE 30 and IEEE 57 bus system. GA, DE, PSO each techniques are used for 500 iterations for controlling of tap positions, reactive generations, shunt capacitor placements and string length is obviously higher than that of fuzzy-PSO approach since fuzzy membership is used for shunt capacitor placement and the PSO technique is used for handling the string containing only transformer tap position and reactive generation of the generators. But PSO still runs for 500 Generations in the hybrid (Fuzzy PSO) approach. As the result of all the Evolutionary algorithms (GA,DE,PSO) vary with the number of populations, here in each case populations are varied from 6 to 20 and the corresponding results are shown in Table 2. Fig. 3 to 5 show the convergence characteristics for planning for IEEE 14, 30 & 57 Bus system with PSO, GA and DE techniques. Fig. 6 to Fig. 8 show the convergence characteristics for planning for IEEE 14, IEEE 30 & IEEE 57 Bus respectively with fuzzy PSO, GA and DE methods. In Fig 9 the convergence characteristics for each technique are not easily defined. That is why the convergence characteristics for the same techniques are shown for lesser number of iterations (Generations). Table 1 shows the optimum cost of planning with different techniques; Table 2 shows the variation of cost of operation with generation for different techniques. Various cost data taken from [13] are as follows: energy cost = 0.06$/kwh, fixed installment cost = 1000$, and capacitor cost/kvar = 3$.

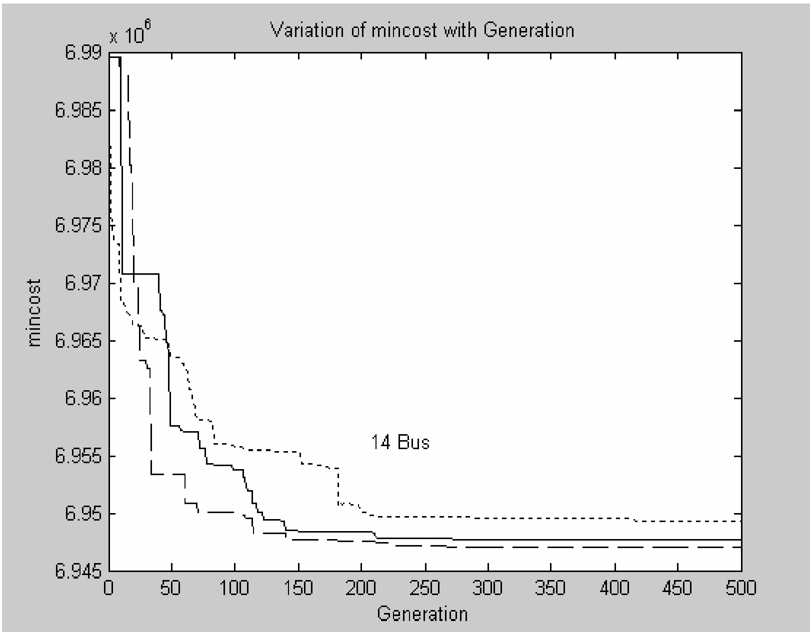

Figure. 3: Convergence characteristics for planning :GA, PSO, DE techniques

IEEE 14 Bus, ….. GA , PSO, -.-.-.-.- DE

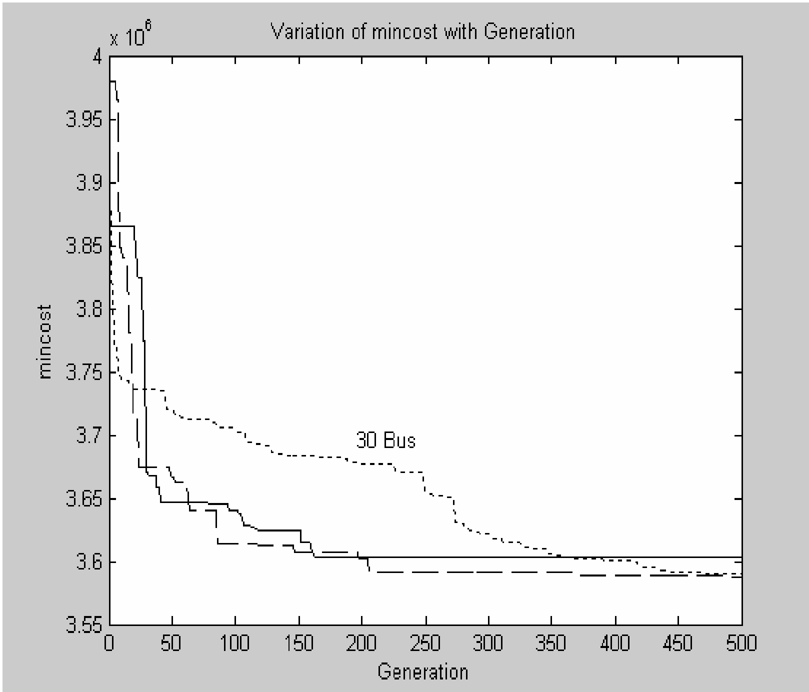

Figure. 4: Convergence characteristics for planning : GA, PSO, DE techniques

IEEE 30 Bus, ….. GA, PSO, ...DE

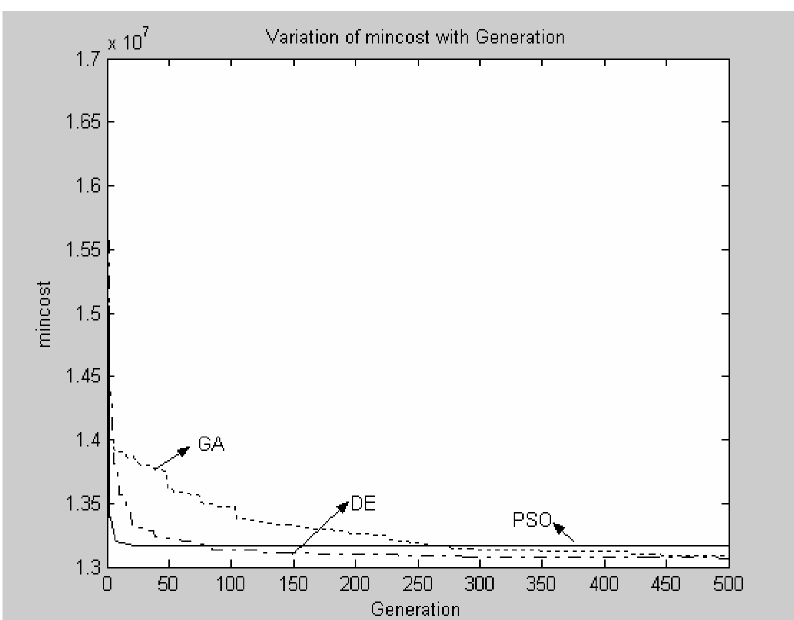

Figure. 5: Convergence characteristics for planning :GA, PSO, DE techniques

IEEE 57 Bus, ….. GA , PSO, -.-.-.-.- DE

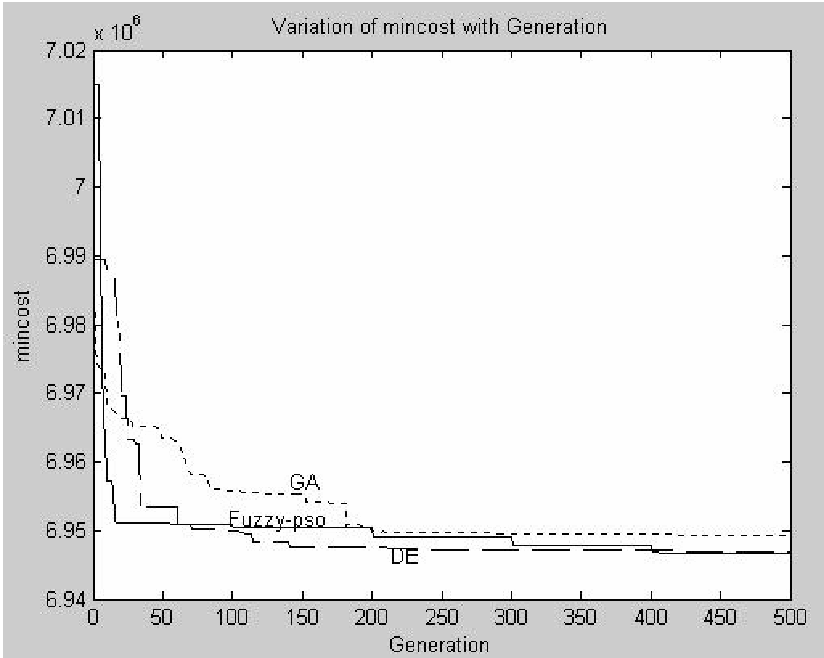

Figure. 6: Convergence characteristics for planning: GA, Fuzzy-PSO, DE techniques:

IEEE 14 Bus, ….. GA, Fuzzy-PSO, -.-.-.-.-.DE

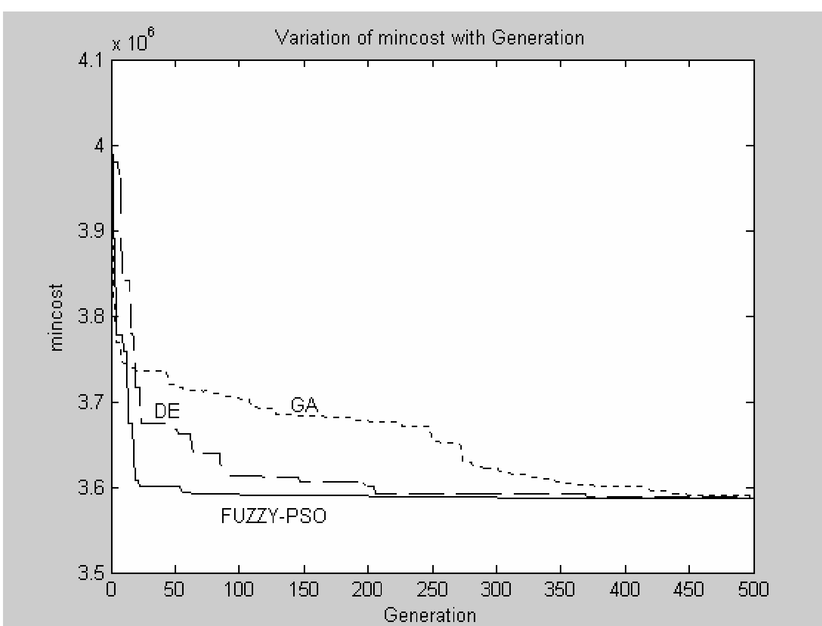

Figure. 7: Convergence characteristics for planning: GA, Fuzzy-PSO, DE techniques

IEEE 30 Bus, ….. GA, Fuzzy-PSO, -.-.-.-.-.DE

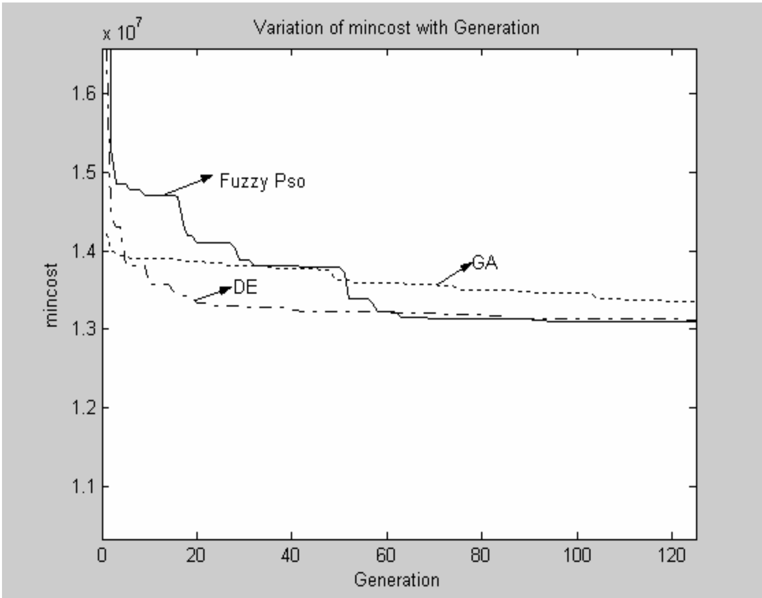

Figure. 8: Convergence characteristics for planning: GA, Fuzzy-PSO, DE techniques

IEEE 57 Bus, ….. GA, Fuzzy-PSO, -.-.-.-.-.DE

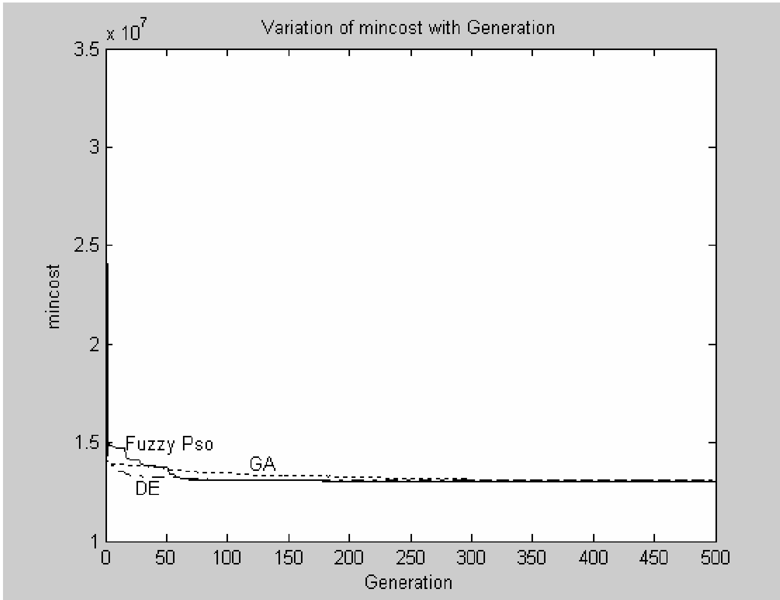

Figure. 9: Convergence characteristics for planning: GA, Fuzzy-PSO, DE techniques

IEEE 57 Bus, ….. GA, Fuzzy-PSO, -.-.-.-.-. DE with 500 Generation

Table 1: Optimum costs of the evolutionary algorithms planning

Algorithms	Planning cost ($)		
	IEEE 14 Bus	IEEE 30 Bus	IEEE 57 Bus
GA	6.9493×10^{6}	3.5899×10^{6}	1.3086×10^{7}
DE	6.9470×10^{6}	3.5877×10^{6}	1.3070×10^{7}
PSO	6.9477×10^{6}	3.6029×10^{6}	1.3164×10^{7}
Fuzzy-PSO	6.9468×10^{6}	3.5861×10^{6}	1.3033×10^{7}

Table 2: Effect of the Variation of number of population: planning problem

Population size	Test system	GA	DE	PSO	Fuzzy-PSO
		cost ($)	cost ($)	cost ($)	cost ($)
6	IEEE 14 Bus	6.9830×10^6	6.9879×10^6	7.0834×10^6	7.303×10^6
	IEEE 30 Bus	3.6621×10^6	3.6659×10^6	3.6029×10^6	3.5861×10^6
	IEEE 57 Bus	1.3331×10^7	1.3337×10^7	1.3164×10^7	1.3033×10^7
8	IEEE 14 Bus	6.9657×10^6	6.9472×10^6	6.9560×10^6	6.9977×10^6
	IEEE 30 Bus	3.6335×10^6	3.5970×10^6	3.6147×10^6	3.6312×10^6
	IEEE 57 Bus	1.3262×10^7	1.3216×10^7	1.3428×10^7	1.3222×10^7
10	IEEE 14 Bus	6.9510×10^6	6.9475×10^6	6.9681×10^6	6.9730×10^6
	IEEE 30 Bus	3.6314×10^6	3.5984×10^6	3.6113×10^6	3.5868×10^6
	IEEE 57 Bus	1.3120×10^7	1.3167×10^7	1.3524×10^7	1.3380×10^7
20	IEEE 14 Bus	6.9493×10^6	6.9470×10^6	6.9477×10^6	6.9468×10^6
	IEEE 30 Bus	3.5899×10^6	3.5877×10^6	3.6432×10^6	3.5867×10^6
	IEEE 57 Bus	1.3086×10^7	1.3070×10^7	1.3691×10^7	1.3437×10^7

5. CONCLUSIONS

A new approach is presented in this paper for optimal reactive power planning of interconnected power system. From Table 1, it is observed that the optimum cost is minimum in with hybrid fuzzy PSO technique for IEEE 14, 30 & 57 Bus system. From Fig. 3 to 5 it is observed that a DE characteristic is best among GA, PSO and DE characteristics. But as simple PSO is replaced by fuzzy PSO method, Fuzzy PSO out perform DE for all the IEEE standard Bus system discussed here which is clearly viewed from Fig. 6 to 9. This technique is termed as fuzzy based PSO as fuzzy memberships are used for capacitor placements and the control of reactive generations, transformer tap positions are solely handled by PSO technique. As GA and DE are known as global optimization techniques and they yield result with the increased number of iterations. DE gives better result than GA when compared with specified number of generations which is also proved here. PSO has never been able to catch up DE. It follows closely DE in small system (as in IEEE 14 Bus, here), even better than GA (only for IEEE 14 Bus, here). But as the size of the system increases it gives sub optimal result. Among DE, GA and PSO, DE is found best followed by GA, then PSO in general. But when fuzzy decision making approach is incorporated with PSO, it gives excellent result in all cases as shown and becomes the best optimization method compared to simple DE, GA and PSO techniques. So after comparison of the results obtained by this hybrid fuzzy PSO technique with that obtained by other optimization techniques, it is clearly observed that this Fuzzy based PSO optimization method is far more superior and can be a new tool for reactive power planning.

Refferences

[1] K. Aoki, W. Fan, and A. Nishikori, “Optimal var planning by approximation method for recursive mixed- integer programming”, IEEE Trans. Power Systems, Vol. 3, No. 4, pp. 1741-1747, Nov. 1988.

[2] N. Deeb and S.M. Shadidepur, “An efficient technique for reactive power dispatch using a revised linear programming approach”, Electric Power Systems Research, Vol. 15, No. 2, pp. 121-134, 1988.

[3] S.M. Shaidehpour and N. Deeb, “An overview of the reactive power allocation in electric power systems”, Electric Machines and Power Systems, Vol. 18, pp. 495-518, 1990.

[4] R. Yokoyama, T. Niimura, and Y. Nakanishi, “A coordinated control of voltage and reactive power by heuristic modelling and approximate reasoning”, IEEE Trans. Power Systems, Vol. 8, No. 2, pp. 636-670, May 1993.

[5] K. Iba, H. Suzuki, K. Suzuki, and K. Suzuki, “Practical reactive power allocation/operation planning using successive linear programming”, IEEE Trans. Power Systems, Vol. 3, No. 2, pp. 558-566, May 1998.

[6] R.C. Bansal, “Optimization methods for electric power systems: an overview”, Int. Journal of Emerging Electric Power Systems, Vol. 2, No. 1, article No. 1021, 2005.

[7] R. Yokoyama, T. Niimura, and Y. Nakanishi, “A coordinated control of voltage and reactive power by heuristic modelling and approximate reasoning”, Paper # 92 WM 114-9 PWRS, EEE/PES Winter Meeting, New York, USA, Jan. 1992.

[8] S.K. Goswami, T. Ghose, and S.K. Basu, “An approximate method for capacitor placement in distribution system using heuristics and greedy search technique”, Electric Power Systems Research, Vol. 51, No. 3, pp. 143-151, Sept. 1999.

[9] R.C. Bansal, T.S. Bhatti, and D.P. Kothari, “Artificial intelligence techniques for reactive power/voltage control in power systems: a review”, Int. J. Power and Energy Systems, Vol. 23, No. 2, pp. 81-89, 2003.

[10] K.H.A. Rahaman and S.M. Shahidehpur, “A fuzzy based optimal reactive power control”, IEEE Trans. Power Systems, Vol. 8, No. 2, pp. 662-669, May 1993.

[11] K.H.A. Rahaman and S.M. Shaidehpur, “Reactive power optimization using fuzzy load representation”, IEEE Trans. Power Systems, Vol. 9, No. 2, pp. 898-905, May 1994.

[12] R.C. Bansal, “Bibliography on the fuzzy set theory applications to power systems (1994-2001)”, IEEE Trans. Power Systems, Vol. 18, No. 4, pp. 1291-1299, Nov. 2003.

[13] H.D. Chiang, J.C. Wang, O. Cockings, and H.D. Shin, “Optimal capacitor placements in distribution systems: part 2: solution algorithms and numerical results”, IEEE Trans. Power Delivery, Vol. 5, No. 2, pp. 634-641, April 1990.

[14] H.D. Chiang, J.C. Wang, O. Cockings, and H.D. Shin, “Optimal capacitor placements in distribution systems: part 1: a new formulation and the overall problem”, IEEE Trans. Power Delivery, Vol. 5, No. 2, pp. 643-649, April 1990.

[15] K. Iba, “Reactive power optimization by genetic algorithm”, IEEE Trans. Power Systems, Vol. 9, No. 2, pp. 685-692, May 1994.

[16] K.Y. Lee, X. Bai, and Y.M. Park, “Optimization method for reactive power planning by using a modified simple genetic algorithm”, IEEE Trans. Power Systems, Vol. 10, No. 4, pp. 1843-1850, Nov. 1995.

[17] T. Ghose, S.K. Goswami, and S.K. Basu, "Solving capacitor placement problems in distribution systems using genetic algorithms", Electric Machines and Power Systems, Vol. 27, No. 4, pp. 429-441, April 1999.

[18] J.R.S. Mantovani, S.A.G. Modesto, and A.V. Garcia, "Var planning using genetic algorithm and linear programming", IEE Proc.- Gener. Transm. Distrib, Vol. 148, No. 3, pp. 257-262, May 2001.

[19] A.G. Bakirtzis, P.N. Biskas, C.E. Zoumas, and V. Petridis, "Optimal power flow by enhanced genetic algorithm", IEEE Trans. Power Systems, Vol. 17, No. 2, pp. 229-236, May 2002.

[20] W. Yan, S. Lu, and D.C. Yu, "A novel optimal reactive power dispatch method based on improved hybrid evolutionary programming technique", IEEE Trans. Power Systems, Vol. 19, No. 2, pp. 913-918, May 2004.

[21] B. Bhattacharyya and S.K. Goswami, "SA based genetic algorithm for reactive power optimization", The Journal of CPRI, Vol. 3, No. 1, pp. 59-64, Sept. 2006.

[22] J.T. Ma and L.L. Lai, "Evolutionary programming approach to reactive power planning", IEE Proc.- Gener. Transm. Distrib., Vol. 143, No. 4, pp. 365-370, July 1996.

[23] K.Y. Lee and F.F. Yang "Optimal reactive power planning using evolutionary algorithms: a comparative study for evolutionary programming, evolutionary strategy, genetic algorithm and linear programming", IEEE Trans. Power Systems, Vol. 13, No. 1, pp. 101-108, Feb. 1998.

[24] L.L. Lai and J.T. Ma "Practical application of evolutionary computing to reactive power planning", IEE Proc.- Gener. Transm. Distrib., Vol. 145, No. 6, pp. 753-758, Nov. 1996.

[25] L.L. Lai and J.T. Ma, "Application of evolutionary programming to reactive power planning- comparison with nonlinear approach", IEEE Trans. Power Systems, Vol. 12, No. 1, pp. 198-206, Feb. 1997.

[26] Q. H. Wu and J.T. Ma " Power system reactive power dispatch using evolutionary programming", IEEE Trans. Power Systems, Vol. 10, No. 3, pp.1243-1248, Aug. 1995.

[27] J.R. Gomes and O.R. Saavedra, "Optimal reactive power dispatch using evolutionary computation: extended algorithms", IEE Proc.- Gener. Transm. Distrib., Vol. 146, No. 6, pp. 586-592, Nov. 1999.

[28] R. Storn and K. Price "Minimizing the real functions of the ICEC'96 contest by differential evolution", Proc. Int. Conf. Evolutionary Computation, ISBN: 0-7803-2902-3, Nagoya, Japan, pp. 842-844, 1996.

[29] J.P. Chion, C.F. Chang, and C.T. Zong, "Ant direction hybrid differential evolution for solving large capacitor problems", IEEE Trans. Power Systems, Vol. 19, No. 4, pp. 1794-1800, Nov. 2004.

[30] M.A. Abido and J.M. Bahashwain, "Optimal var dispatch using a multi objective evolutionary algorithm", Int. Journal of Electrical Power & Energy Systems, Vol. 27, No. 1, pp. 251-259, Jan. 2005.

[31] L.L. Lai, "Intelligent system applications in power engineering", John Wiley and Sons, New York, USA, 1998.

[32] K. Wardwick, A. Ekwue, and R. Aggarwal, "Artificial intelligence techniques in power systems", IEE, London, UK, 1997.

[33] R.C. Bansal, "A bibliographical survey of evolutionary computation applications in power systems (1994-2003)", Int. Journal of Power and Energy Systems, vol. 26, no. 3, pp. 216-225, 2006.

[34] J. Kennedy and R.C. Eberhart, “Particle swarm optimization”, IEEE Int. Conf. Neural Networks, Perth, Australia, 1995.

[35] H. Yoshida, K. Kawata, Y. Fukuyama, S. Takayama, and Y. Nakanishi, “A particle swarm optimization for reactive power and voltage control considering voltage security assessment”, IEEE Trans. Power Systems, Vol. 15, No. 4, pp. 1232-1239, Nov. 2000.

[36] C.Yang and D. Simon, “A new particle Swarm Optimization technique”, Proc. of the 18th Int. Conf. on Systems Engineering, pp. 164-169,2005, ICSENG Archive.

[37] A. I.Selvakumar and K. Thanuskodi,“Anti predatory particle swarm optimization solution to non convex economic dispatch problems”, Electric Power System Research, Vol. 78, No. 1, Jan. 2008, pp. 2 -10.