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HEURISTIC METHODS TO SOLVE OPTIMAL POWER FLOW PROBLEM

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Abstract: *Optimal Power Flow (OPF) is one of the most effective tools for both analysis of current and planning of new power systems. The Manuscript is about an Artificial Intellicence (AI) application based on Heuristic methods can solve OPF problems with an more extreme accuracy compared to conventional methods. In this paper, the total hourly generation cost of generator units are minimized as an objective function to meet the load demand and system losses. Real Coded Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) methods developed using MATLAB are applied to IEEE 14 and IEEE 30 standart test systems to solve OPF problem. In consequence of the OPF carried with the use of PSO and GA, the optimum solutions were compared to similar studies in the literature. It was determined that the PSO algorithm developed within the scope of this paper provides lower-cost results than GA developed for this study and the GA studies that are present in the literature.*
Keywords: *Optimal power flow, heuristic methods, particle swarm optimization, real coded genetic algorithm, total generation cost minimization.*

1. Introduction

Optimal Power Flow (OPF) that was initially developed by Carpentier in 1962 is used to find minimum generation cost of generator units in case of normal operation conditions holding traditional power flow results within operation limits [1]-[2].

The conventional methods used in the literature for solving the OPF problem are i) lambda iteration method, ii) gradient method, iii) Newton method, iv) linear programming and v) interior point algorithm [3]. Moreover, the heuristic methods have recently been used for OPF solution. Genetic Algorithm (GA) [4], Artificial Bee Evolutionary Programming (EP) [5] and Particle Swarm Optimization (PSO) [6]-[9] can be listed as the examples of the heuristic methods used to solve OPF problem in literature.

In this paper, Real Coded Genetic Algorithm and PSO are proposed to solve OPF problem. The proposed algorithms developed by MATLAB are applied to IEEE 14 and IEEE 30 bus standart test systems. After optimization process, the results are compared with similar studies using same methods in the literature to show which algorithm performs best in case of finding minimum generation cost with consideration of system losses in large scale power systems.

2. Optimal Power Flow

The optimal power flow problem is to optimize the steady state performance of a power system in terms of one or more objective functions while satisfying several equality and inequality constraints [10]. The objective function of OPF problem can be to minimize the system losses and hold voltage profile within acceptable limits in addition to minimizing total generation cost of generation units [11]. Generally the problem can be formulated as a nonlinear and constrained optimization problem, as shown below [12]:

Minimize:	$f(x,u)$
Subject to:	$g(x,u) = 0$
	$h(x,u) \leq 0$

where f(x,u) is the objective function, g(x,u) is the function of equality constraints, h(x,u) is the function of inequality constraints, x is the vector of the state variables consisting of load bus voltage V_L, slack bus power P_{G_1}, generator reactive powers Q_G and transmission line loading S_L. x can be demonstrated in Eqn.1

u is the vector of control variables consisting of generator voltages V_G, generator real power outputs P_G except slack bus P_{G_1}, and transformar tap settings T, in Eqn.2 [13].

The generation cost function is calculated in Eqn.3 where a_i, b_i and ci are the generation cost coefficients of the ith unit.

g(x) is the function of equality constraints and depends on load flow equations which are formulated in Eqn.4 and Eqn.5 where P_{Li} and Q_{Li} are the active and reactive powers of i-th line, respectively.

Generation constraints: Generator voltages V_{Gi}, real power outputs P_{Gi}, and reactive power outputs Q_{Gi} are restricted

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by their lower and upper limits and N_G indicates the number of generators. Generation constraints are shown in Eqn.6-8.

Transformer constraints: Tap setting limits of transformers are shown in Eqn.9

$$x^T=[V_{L1}\dots V_{LNG},P_{G1},Q_{G1}\dots Q_{GNG},S_{L1}\dots S_{LNG}] \quad (1)$$

$$u^T=[V_{G1}\dots V_{GNG},P_{G2}\dots P_{GNG},T_1\dots T_{NT}] \quad (2)$$

$$F_{cost} = \sum_{i=1}^{N_G} a_i P_{Gi}^2 + b_i P_{Gi} + ci \quad \$/h \quad (3)$$

$$P_{Gi} - P_{Li} - V_i \sum_{j=1}^{N} V_j \left(G_{ij}cos\theta_{ij} + B_{ij}sin\theta_{ij} \right) = 0 \quad (4)$$

$$Q_{Gi} - Q_{Li} - V_i \sum_{j=1}^{N} V_j \left(G_{ij}sin\theta_{ij} - B_{ij}cos\theta_{ij} \right) = 0 \quad (5)$$

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \quad i = 1 \dots . N_G \quad (6)$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \quad i = 1 \dots . N_G \quad (7)$$

$$V_{Gi}^{min} \le V_{Gi} \le V_{Gi}^{max} \quad i = 1 \dots . N_G \quad (8)$$

$$T_{Ti}^{min} \le T_{Ti} \le T_{Ti}^{max} \quad i = 1 \dots . N_T \quad (9)$$

3. Genetic Algorithm

The Genetic Algorithm (GA) was developed by the evolutionary theory of Darwin. GA was initially used by Holland in 1975, for solving the optimization problem [14].

First of all, a series of initial solutions that meet all conditions are created randomly and then the control parameters are encoded to solve OPF problem. Fitness function is developed to generate more resistant generations using operators of crossovers and mutations in each iteration step. The iteration process keeps going until the optimal solutions are obtained for OPF problem in Fig.2.

Binary encoding system is generally used in basic GA concept. However, if binary encoding is used to seek the optimal solution, it needs long chromosome indexes and larger search space. Therefore, the calculation (convergence) time increases and system performance decreases. In order to overcome these difficulties, in this study the variables were used directly in their natural forms [15]. Furthermore, the applied crossover and mutation operators have floating-point forms. Application of GA to OPF is shown in Fig. 4.

4. Particle Swarm Optimization

Kennedy and Eberhart developed a PSO algorithm based on the behavior of individuals of a swarm [16]-[17]. In PSO process, each particle adjusts its position according to its own and the experience of neighbour particles such as in Fig.2. Each particle in a swarm corresponds to a specific solution to the problem. Individuals in the swarm approach to the optimum through its present velocity, previous experience, and the experience of its neighbours [18].

The velocity and position vectors of particle i_{th} are respectively are shown in Eqn.10 and Eqn.11.

$$X_i = (x_{i1}, \dots, x_{in}) \quad (10)$$

$$V_i = (v_{i1}, \dots, v_{in}) \quad (11)$$

The parameters of Individual Best and Global Best are shown in Eqn.12 and Eqn.13.

$$Pbest_i = ({x_{i1}}^{best}, \dots, {x_{in}}^{best}) \quad (12)$$

$$Gbest_i = ({x_{i1}}^{best}, \dots, {x_{in}}^{best}) \quad (13)$$

The updated velocity and position of particle i_{th} at (k+1) iteration is found by using Eqn. (14).

$$X_i^{(k+1)} = X_i^{k} + V_i^{(k+1)} \quad (14)$$

In general, the velocity updating procedure is set according to both Eqn. (15) and Eqn. (16) where initial and final weights ω_{max} and ω_{min} , maximum number of iterations $Max.Iter$, current iteration number *Iter.(k)*, number of iterations *k*, velocity of particle i_{th} at iteration *k* V_i^k, positision of particle i_{th} at iteration *k* X_i^k, acceleration coefficients are c_1 and c_2 , inertia weight *w* and parameters of $rand_1$ and $rand_2$ which are random numbers between [0,1] .

$$\omega(k) = \omega_{max} - \frac{\omega_{max}-\omega_{min}}{Max.Iter.} \, xIter. \quad (15)$$

$$\omega V_i^k + c_1 rand_1 \left(Pbest_i^k - X_i^k \right) + c_2 rand_2 \left(Gbest_i^k - X_i^k \right) \quad (16)$$

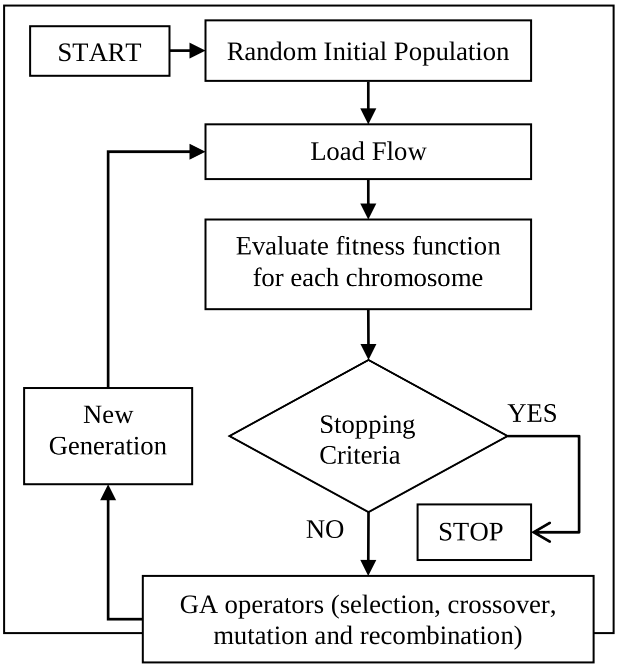

Figure 1. Application of GA to OPF Problem

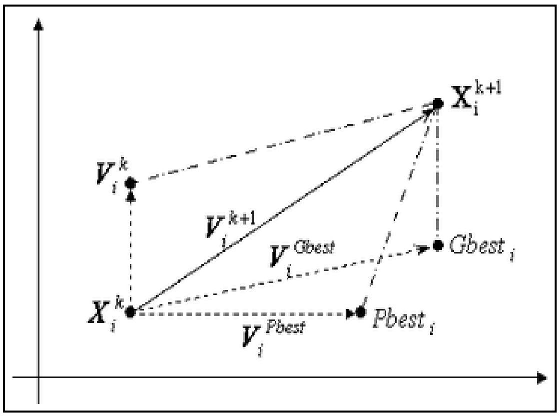

Figure 2. Concept of modification of a searching point by PSO

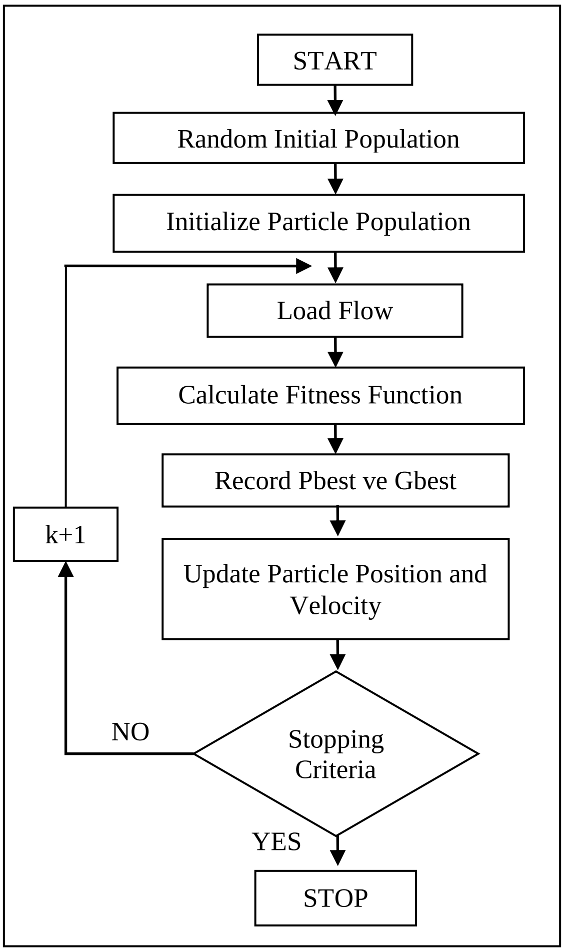

Figure 3. Application of PSO to OPF Problem

Table 1. Requiered Parameters for GA

Test System	14	30
Population Size	100	100
Iterations	50	50
Best Chromosome	5	5
Crossover Rate	0.6	0.6
Mutation Rate	0.05	0.05

Table.2. Requiered Parameters for PSO

Test System	14	30
Number of Particles	100	100
Iterations	50	50
w_{min} **and** w_{max}	0.1-0.9	0.1-0.9
Number of Intervals	15	15
c_1 **and** c_2	2	2

Table.3. Cost Coefficients of Generator Units for IEEE 14 and 30 Bus Standart Test Systems

	Bus	a	b	c	e	f
IEEE 14	1	0.0016	2.00	150	50	0.0630
	2	0.0100	2.50	25.0	40	0.0980
	3	0.0625	1.00	0	0	0
	6	0.00834	3.25	0	0	0
	8	0.025	3.00	0	0	0
IEEE 30	1	0.00375	2	0	50	0.063
	2	0.0175	1.75	0	40	0.098
	5	0.0625	1	0	0	0
	8	0.00834	3.25	0	0	0
	11	0.025	3	0	0	0
	13	0.025	3	0	0	0

Table.4. Generation Limits on Active and Reactive Powers of Generator Units for IEEE 14 and 30 Bus Standart Test Systems

	Bus	Pmin	Pmax	Qmin	Qmax
IEEE 14	1	50	200	−40	100
	2	20	80	-40	50
	3	15	50	0	40
	6	10	35	-6	24
	8	10	30	-6	24
IEEE 30	1	50	200	-40	200
	2	20	80	-20	100
	5	15	50	-15	80
	8	10	35	-15	60
	11	10	30	-10	50
	13	12	40	-15	60

The application of Particle Swarm Optimization to Optimal Power Flow Problem is shown in Fig.3.

5. Simulation Results

Required parameters for GA and PSO to carry out OPF process on standard IEEE 14 and 30 bus test systems are shown in Table 1 and Table 2, respectively. Furthermore, cost coefficients and generation limits on active and reactive powers of generator units for IEEE 14 and 30 bus test systems are shown in Table 3 and Table 4, separately.

IEEE 14 bus test system shown in Fig.4 has a total load demand (P_D) of 259 MW. Additionally, IEEE 30 bus test system which has a total load demand of 283.4 MW is also shown in Fig.5.

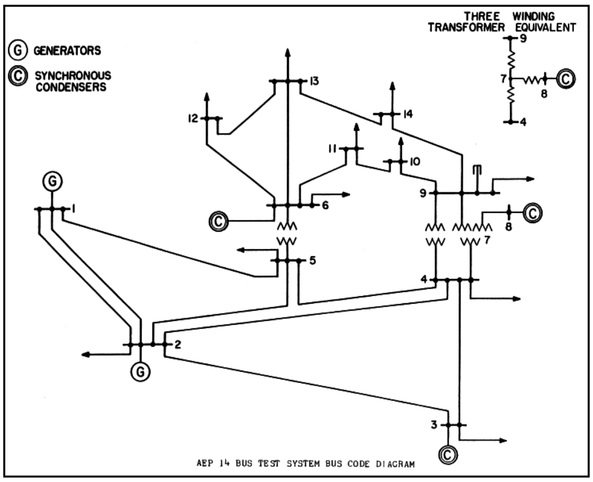

Figure 4. IEEE 14 Bus Standard Test System

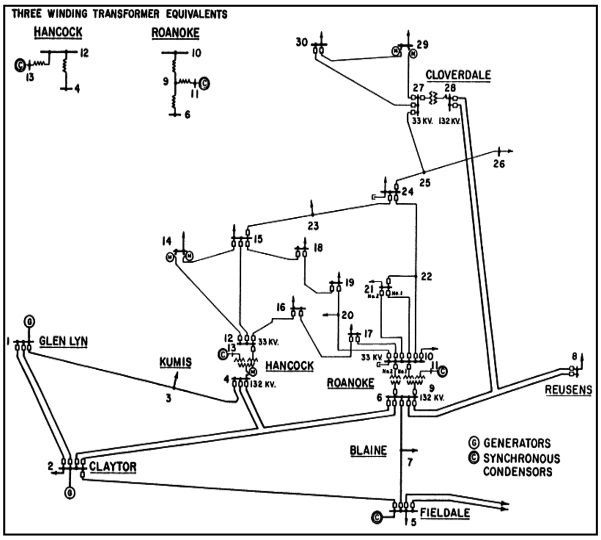

Figure 5. IEEE 30 Bus Standard Test System

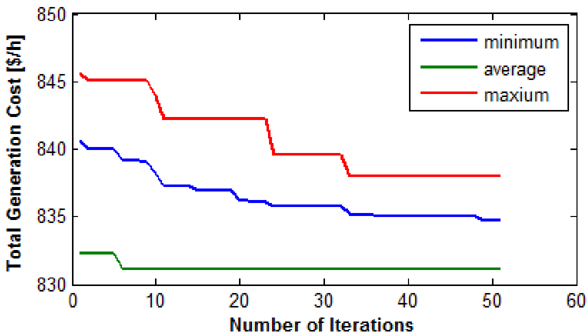

Figure 6. Solution of OPF with GA on IEEE 14 Bus Standard Test System

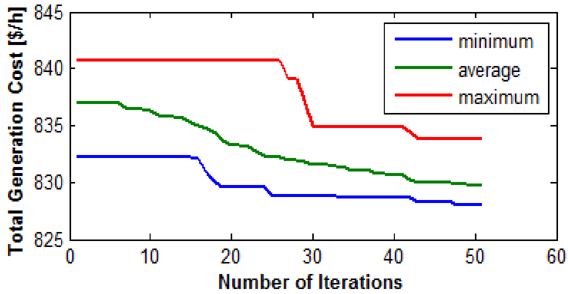

Figure 7. Solution of OPF with PSO on IEEE 14 Bus Standard Test System

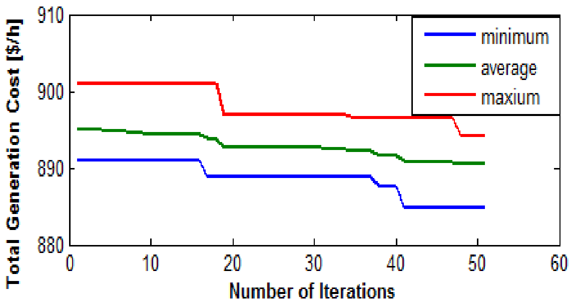

Figure 8. Solution of OPF with GA on IEEE 30 Bus Standard Test System

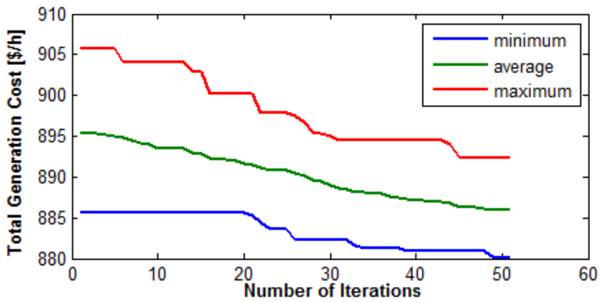

Figure 9. Solution of OPF with PSO on IEEE 30 bus standard test system

Table 5. IEEE 14 Bus Test System Simulation Results for Minimum Values after 25 Running

	Active Power Outputs of Generation Units [MW]			
IEEE 14 Bus	**GA [19]**	**PSO [20]**	**GA**	**PSO**
P_1	181.13	197.47	191.53	200
P_2	46.75	20	34.92	29.27
P_3	19.15	21.34	16.50	15
P_6	10.18	11.67	13.53	12.87
P_8	10.77	17.77	10.94	10.72
P_{Loss}	8.99	9.26	8,42	8.86
Cost (R/h)	905.54	836.45	831.11	828.04
CPU (s)	100.08 [21]	-*	82.67	89.67

Table 6. IEEE 30 Bus Test System Simulation Results for Minimum Values after 25 Running

	Active Power Outputs of Generation Units [MW]			
P_1	182.47	199.63	188.16	200
P_2	48.35	20	48.90	43.64
P_5	19.85	22.27	16.97	15.21
P_8	17.13	29.79	12.88	12.97
P_{11}	13.67	10	11.06	10.09
P_{13}	12.34	12	15.59	12
P_{Loss}	10.43	10.10	10.16	10.51
Cost ($/h)	984.94	920.97	884.80	880.05
CPU (s)	315[24]	926[24]	82.67	89.67

6. Conclusions

PSO and GA were used in the OPF problem solution on standard IEEE 14 and 30 bus test systems, and the following conclusions were obtained after 25 running:

- The PSO method developed particularly for this study exhibited a better performance than the OPF solution used by PSO in the similar studies in the literature.
- GA carried out in the literature to solve the OPF problem provided more costly objective function values than the real coded GA method developed for this study.
- The PSO method developed for this study reached smaller cost values in a shorter period of time than the both real coded GA developed for this study and GA in the literature, as well.
- It can be said that, the transmission losses found through the optimization process are acceptable limits compared to similar studies in the literature.

In this paper, results show that use of PSO as a heuristic method to solve OPF on standard IEEE 14 and 30 bus test systems provided significant benefits such as smaller objective function values in a shorter convergence time by enabling power generation within acceptable transmission losses. To sum up, these features make PSO method more advantageous than the others for solving OPF problems.

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