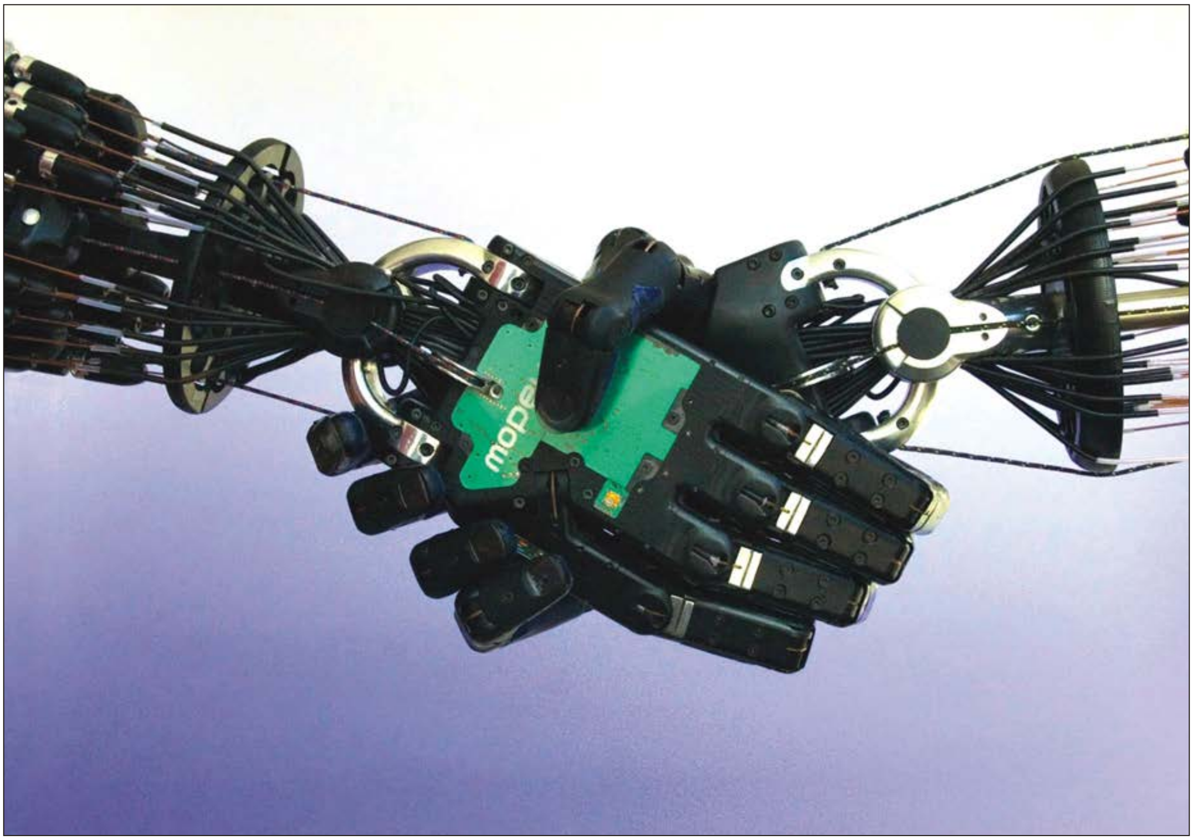

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Voltage Control and Reactive Power Optimisation using the Meta Heuristics Method: Application in the Western Algerian Transmission System

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ABSTRACT

This study reported on a meta heuristics method for solving the optimal reactive power flow problem we proposed an application of particle Swarm Optimization Method (PSO), compared to the GA method. The methods incorporate natural ideas to give load flow solution. To demonstrate the global reactive power optimisation of those methods it is applied to the Western Algerian Transmission System 68 bus 220/60 kV. To show the contribution of new techniques, the simulation results are compared with work history using a hybrid approach.

Key words: Electrical network analysis, optimal reactive power flow, meta heuristic method particle swarm optimization, genetic algorithm, transmission loss

INTRODUCTION

Purpose of optimal reactive power flow is mainly to improve the voltage profile in the system and to minimize the real power transmission loss while satisfying the unit and system constraints. This goal is achieved by proper adjustment of reactive power control variables like Generator bus voltage magnitudes (V^g_i) and their reactive power (Q^g_i), transformer tap settings (a_i), reactive power generation of the capacitor bank (Q^{sh}_i). To solve the ORPF problem, a number of conventional optimization techniques (Lee and Yang, 1998; Granville, 1994) have been proposed. These include the Gradient method, non-linear programming, quadratic programming, linear programming and Interior point method. Though these techniques have been successfully applied for solving the reactive power flow problem, still some difficulties are associated with them. One of the difficulties is the multimodal characteristic of the problems to be handled. Also, due to the non-differential, non-linearity and non-convex nature of the RPF problem, majority of the techniques converge to a local optimum. Recently, Evolutionary Computation techniques like Genetic Algorithm (GA) (Iba, 1994), Evolutionary Programming (Wu and Ma, 1995) and Evolutionary Strategy (Bhagwan and Patvardhan, 2003) have been applied to solve the optimal dispatch problem.

In this study, particle swarm optimization approach has been proposed to solve the ORPF problem, in order to remediate the specific structure of the Algerian Western network 220/60 kV. Because of its serious problems of tension and shortage of the reactive power, especially for the network 60 kv which is characterized by a great number of loading nodes which are connected radially to the principal nodes and sometimes located far from the generators.

This approach is inspired from the behaviour of birds assembling into clouds, fish benches under water or displaced swarms of bees. It is a stochastic optimization technique based on a population, developed by Kennedy and Eberhart (1995, 2001) and then Lee and El-Sharkawi (2008). In the PSO method, the system is initialized with a population of random solutions and it therefore seeks optima by providing generations all like (AG). Unlike the genetic algorithms, we opted for the PSO which does not include an operator of evolution such as crossing or mutation. The potential solutions, called particles, move in the definite space of the studied problem while following the existing optimal particles.

In the present study, we devote ourselves to dealing with the problem of optimal distribution of reactive power by applying a method called Particles Swarm Optimization (PSO), in order to remediate the specific structure of the 220/60 kV Algerian Western network. This network has serious problems of tension and reactive power shortage, especially for the 60 kV network, which is characterized by a great number of loading nodes that are connected radially to the principal nodes, sometimes located far from the generators.

PROBLEM FORMULATION

Basic concept of the PSO: According to the guiding principle of the PSO and the simulation of the clouds of birds (Kennedy and Eberhart, 1995, 2001; Lee and El-Sharkawi, 2008; IEEE Committee Report, 2002), the simulation is a two-dimensional process. The position of each particle is represented by its coordinates along the XY axes as well as by the speed, which is expressed by Vx (the speed along the X axis) and Vy (the speed along the Y axis).

The modified position of each particle is carried out by the information of its position and speed.

The assembly of the birds is optimized by using a certain objective function. Each agent or particle maintains its coordinates in the space of research where the coordinates correspond to the best-reached solution (position) at the present. This value is called pbest. If another best value found by the PSO is the best value, obtained up to the present by any of the nearest neighbours, this place is called ibest. When a particle takes the entire population as its topological neighbours, the best value is a better total and is called gbest.

This information is thus obtained from the personal experiments of each particle. Moreover, each particle knows the best total value of the (gbest) group among the (pbest) ones. This information is obtained from the knowledge of the way in which the other agents are carried out Each agent tries to modify its place based on the following information:

- The current positions: (x, y)
- The current velocities (vx, vy)
- The distance between the current position and pbest
- The distance between the current position and gbest

The concept of a particle swarm optimization changes each time the particles take a step to change their speed (accelerating) towards the best positions ibest of pbest.

This modification can be represented by the concept of velocity (Kennedy and Eberhart, 2001; Lee and El-Sharkawi, 2008). Velocity of each agent can be modified by following equation:

$$v_i^{k+1} = wv_i^k + c_1 rand_1 \times (pbest_i - S_i^k) + c_2 rand_2 \times (gbest - S_i^k) \quad (1)$$

Where:

v_i^{k+1} : Velocity of particle i at iteration k+1
w : Weighting function
v_i^{k+1} : Weighting factor
rand : Random number between 1 and 0
s_i^k : Current position of particle i at iteration k
$pbest_i$: Pbest of the particle i
gbest : gbest of the group

The weight function, which is usually used in Eq. 2, is written as follows (Kennedy and Eberhart, 2001; Lee and El-Sharkawi, 2008):

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} - iter \quad (2)$$

Where:

w_{max} : Initial weight
w_{min} : Final weight
$iter_{max}$: Maximum number of iteration
iter : Current number of iteration

While referring to Eq. 2, a certain speed, gradually approaching pbest and gbest, can be calculated. The current position S_i^k, which represents the research of the point within solution space, can be modified by the following equation:

$$S_i^{k+1} = S_i^k + v_i^{k+1} \quad (3)$$

General algorithm of the PSO: General Algorithm of PSO can be described as follows (IEEE Committee Report, 2002; Shi and Eberhart, 1998):

Step 1: Generation of initial condition of each agent. Initial searching points (S_i^0) and velocities (v_i^0) of each agent are usually generated randomly within the allowable range. The current searching point is set to pbest for each agent. The best evaluated value of pbest is set to gbest and the agent number with the best value is stored
Step 2: Evaluation of searching point of each agent. The objective function value is calculated for each agent. If the value is better than the current pbest of the agent, the pbest value is replaced by the current value. If the best value of pbest is better than the current gbest, gbest is replaced by the best value and the agent number with the best value is stored
Step 3: Modification of each searching point. The current searching point of each agent is changed using Eq. 1, 2 and 3
Step 4: Checking the exit condition

The current iteration number reaches the predetermined maximum iteration number, then exit. Otherwise, go to step 2.

Application for active power loss minimisation: The principal objective of the problem of the optimal flow of the reactive power is to minimize the actives losses in the electrical supply network and to maintain the tension within their allowed limits while satisfying constraints as a whole: equalities and inequalities (Arif *et al.*, 2007).

The equality constraints represent the equations of the flow of power. The limits, applied to the tension, of the generators or the shunt of compensations and on the ratios of the regulators in load, which constitute the constraint inequalities. In our case, the objective function represents the active losses in the electrical supply network and the general formulation of this problem is then written as:

$$\text{Min} : P_L(V_i, \theta_i) \tag{4}$$

Under the constraints:

$$\Delta P_J = \sum_{j=2}^{n} V_i V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) - P_i^g + P_i^i = 0 \tag{5}$$

$$\Delta Q_J = \sum_{j=2}^{n} V_i V_j (G_{ij} \cos\theta_{ij} - B_{ij} \sin\theta_{ij}) - Q_i^g + Q_i^l - Q_i^{sh} = 0 \tag{6}$$

$$Q_{i,min}^g \leq Q_i^g \leq Q_{i,max}^g \quad i = 1....n_g \tag{7}$$

$$Q_{i,min}^{sh} \leq Q_i^{sh} \leq Q_{i,max}^{sh} \quad i = 1....n_{sh} \tag{8}$$

$$a_{i,min}^g \leq a_i^g \leq a_{i,max}^g \quad i = 1....n_T \tag{9}$$

$$V_{i,min}^g \leq V_i^g \leq V_{i,max}^g \quad i = 1....n_g \tag{10}$$

With:

$$P_L = \sum_{i}^{n} \sum_{j}^{m} -G_{ij}(V_i^2 + V_j^2 - 2 V_i V_j \cos\theta_{ij}) \tag{11}$$

Where:

P^g_i, Q^g_i : Active and reactive power generated in node i
P^l_i, Q^l_i : Active and reactive power of load in node i
Q^{sh}_i : Reactive power of shunt capacitors or facts devices shunt in node i
V_i, V_j : Modules of the tensions to the node i and j
$\theta_{ij} = \theta_i - \theta_j$: Angles of the tensions to the node i and j
G_{ij} : Conductance between the nodes i and j
B_{ij} : Susceptance between the nodes i and j
n_g : Generator number
n_T : Transformer number
n_{sh} : Shunt condenser number

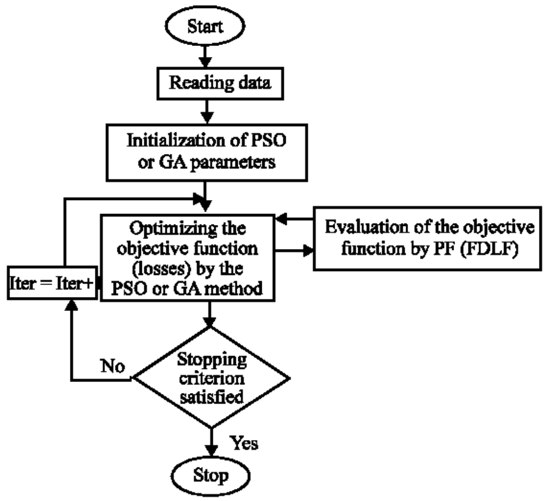

Fig. 1: A general flowchart of power losses minimization by meta heuristic method

In this study, the means of compensation considered are the groups of production, the shunt capacities and the transformers with the regulator in load. The latter are regarded as variables of control. The state variables are: $x= [V_i,\theta_i]$.

The application of the particle swarm method in optimizing the power of an electrical supply network requires following the stages of the flow chart by mentioning that the variables of control represent the particles or the agents of the method and their value is found in a random way in the allowed range that will be represented first by pbest then by gbest in another stage. The flowchart of our method to minimize power losses by both methods used is show in Fig. 1.

It should be noted that with the help of these values (gbest), we can calculate the active power losses of the system studied by PF for each iteration.

Step 1: For each variable of control X_i, we make a random choice of a population within limit of function. Each item fits into a certain position S_i^0 and to an initialised velocity V_i^0.

Step 2: Calculate loss P_L for all of the elements of each population. If there is a value $x_j \epsilon X_i$ that gives $P'_L < P_L$, x_j takes the pbest value. The best value of the population will take the gbest value. If it is better than the previous step, so it will be stored

Step 3: The moving or changing of the value of the items by Eq. 1, 2 and 3

Step 4: Check stop criteria

ILLUSTRATION

The 220/60 kV Algerian western test network studied is represented by Fig. 2. The network is made up as follows:

This system described in Table 1 and 2, is structurally particular Fig. 2 (many load buses radially connected to the main grid) . However, serious problems could be faced dealing with the voltage and the reactive power shortages, especially with the 60 kV systems.

Control parameters of the Meta heuristics methods applied: The particle swarm optimization method contains several parameters whose values can be adjusted so that the algorithm manages to find the optimal solution.

Table 1: Main data of the Western Algerian system

Load buses	64
Generator buses	4
Lines	78
Transformers	12
Shunt capacitors	5
Load demand	871 MW, 541 MVAR
Losses	28,7 MW

Table 2: The control variables limits, of and bus voltages

Magnitude	Lower	Upper
220 kV voltage	0.99	1.11
60 kV voltage	0.95	1.10
Taps	0.9	1.10
Q_{shunt}	0	10 MVAR
Q^g_1	-250 MVAR	500 MVAR
Q^g_9	90 MVAR	180 MVAR
Q^g_{23}	15 MVAR	35 MVAR
Q^g_{36}	20 MVAR	36 MVAR

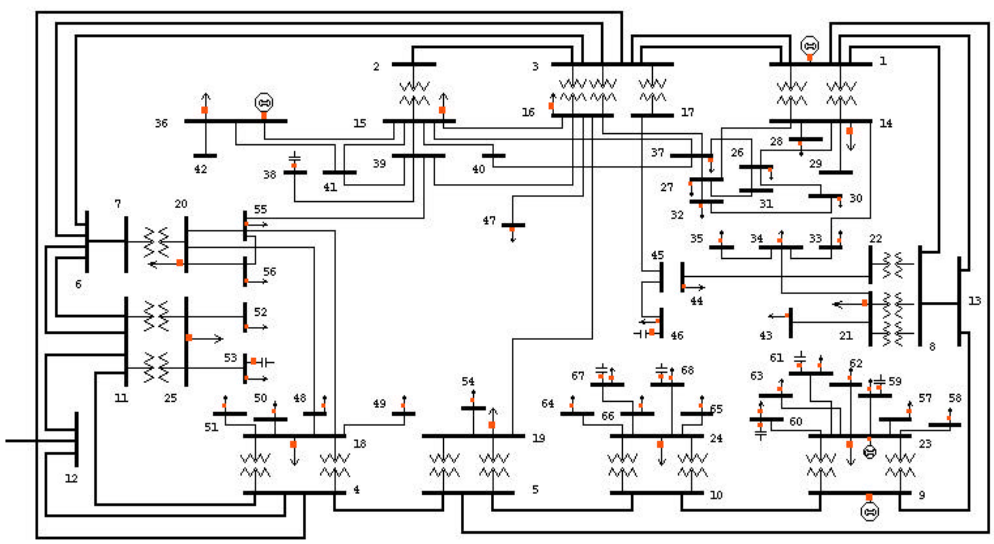

Fig. 2: Algerian 220/60 KV transmission/sub-transmission system

The same with the GA parameters, we can adjusted the values to locate the optimal solution. After several tests are carried out, values of the parameters adapted.

These parameters were mentioned in several references (Kennedy and Eberhart, 2001; Lee and El-Sharkawi, 2008) and Shi and Eberhart (1998), adding that our simulation was made with a population of N = 150 and a maximum iteration equal to 150.

RESULTS AND DISCUSSION

We have applied this method to the studied network by using one variant u, the represent case: u=[Q_i^g , a_i , Q_i^{sh}].

The simulation results of this technique are illustrated in the tables following before and after optimization, compared with an optimization by the algorithms genetics (Chettih *et al.*, 2008a, b) and the corrections achieved with an hybrid approach by Khiat *et al.* (2003a, b).

We can clearly notice that the objective function power losses is effectively minimized by the Meta heuristics method. An analysis of the results can clearly show that Efficiency of meta heuristics techniques to resolve the problem of ORPF, towards the minimization of the active losses (Table 5) as well as numbers of compensators shunt (Table 3), because in the methods (GA, or, PSO) witch we have used so far, we note that we have considered tow news compensators in the node 17 and 35 (Table 4). This one has proven to be successful in GA and better yet in a PSO method (Fig. 2), controlling several variables simultaneously and it helps improve the optimization to progress over a short period of time.

Table 3: The control parameters of the Meta heuristics methods applied

Meta heuristics	Control parameters
AG	N_{gen} = 150; P_c = 0.9; P_m = 0.0O5; T_{pop} = 20; croisement: double
PSO	T_{pop} = 20; W_{max} = 0.9; W_{min} = 0.4; C1=C2=2.0; $iter_{max}$=150

Table 4: The compensation of optimized device performances using the PSO method

Compensation means control	N1	N2	Before optimization	GA optimization	PSO optimization
Q^g_1(Mvar)	1	-	383.00	3200	260.23
Q^g_2 (Mvar)	9	-	103.10	72926	22.37
Q^g_3 (Mvar)	23	-	28.20	351	34.48
Q^g_4 (Mvar)	36	-	27.20	2158	25.75
Q^{sh}_1 (Mvar)	17	-	0.00	-8	0.00
Q^{sh}_2 (Mvar)	35	-	0.00	2	0.00
Q^{sh}_3 (Mvar)	38	-	5.00	5	5.00
Q^{sh}_4 (Mvar)	46	-	0.00	10	10.00
Q^{sh}_5 (Mvar)	53	-	10.00	10	8.00
Q^{sh}_6 (Mvar)	59	-	10.00	2	2.00
Q^{sh}_7 (Mvar)	60	-	10.00	10	10.00
Q^{sh}_8 (Mvar)	61	-	10.00	5	3.00
Q^{sh}_9 (Mvar)	67	-	0.00	2	2.00
Q^{sh}_{10} (Mvar)	68	-	0.00	2	5.00
T_1 (p.u)	1	14	0.98	95	0.93
T_2 (p.u)	2	15	0.99	99	0.99
T_3 (p.u)	3	16	0.98	100	0.99
T_4 (p.u)	3	17	0.95	95	0.98
T_5 (p.u)	4	18	0.98	100	0.99
T_6 (p.u)	5	19	0.98	98	1.01
T_7 (p.u)	7	20	0.99	99	0.97
T_8 (p.u)	8	21	0.96	100	0.98
T_9 (p.u)	8	22	0.99	99	0.98
T_{10} (p.u)	9	23	1.07	100	1.02
T_{11} (p.u)	10	24	0.95	96	0.97
T_{12} (p.u)	11	25	0.98	98	0.94

Table 5: Total losses for all of cases

	Before optimization	Hybrid approach and optimisation	GA optimization	PSO optimization
Losses (MW)	28.70	22.98	22.87	21.25
Reduction (%)	-	9.52	9.96	16.33

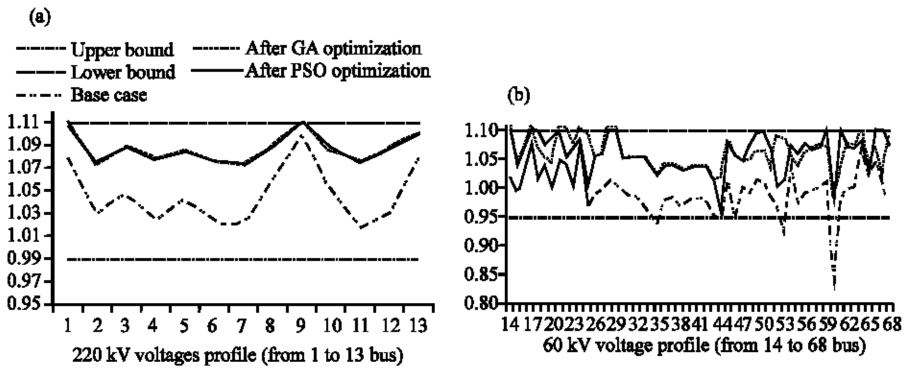

Fig. 3: Voltages profiles in the western Algerian transmission systems 220/60 kV

We also notice that the behaviour of the system 60 kV voltages is improving from the GA optimization to the case where the PSO optimization method is applied; this improvement is followed by a reduction of power losses, which can reach 16% (Table 5) with a steady control of the voltage level (Fig. 3a, b).

CONCLUSION

The Meta heuristics techniques was studied and applied to resolve the problem of optimal reactive power flow. The model of electrical supply networks that we test in simulations is the 220/60 kV Algerian western network. The analysis of our results showed that this technique (meta-heuristic) gave results quantitatively better than (Khiat *et al.*, 2003a, b), in terms of minimization of the loss of active power. We also noted that the particle swarm technique is simple to implement and its execution leads quickly and effectively to a good convergence with few parameters to be adjusted.

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