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Optimal Distribution of the Reactive Power and Voltages Control in Algerian Network Using the Genetic Algorithm Method

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Abstract: This study presents a Genetic Algorithm (GA) approach for solving the reactive power flow problem including the line flow constraint. Minimizations of real power loss with FACTS and without FACTS devices are the objectives of this reactive power optimization problem. The proposed method has been successfully applied in the case of the western Algerian transmission system. The FACTS placement problem considers the upper and lower bound constraints of the voltage at different load levels by minimizing the system loss. The simulation results are promising and show the effectiveness and robustness of the proposed approach.

Key words: Reactive power control, genetic algorithm, FACTS devices, voltage violation

INTRODUCTION

Purpose of 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), 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 *et al.* (1985) and 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 (Leung and Chung, 2000).

In this study, GA based 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.

Genetic algorithm (Laouer *et al.*, 2006; Golderg, 1989) is a general-purpose optimization algorithm based on the mechanics of natural selection and genetics. GA maintains a population of individuals that represent candidate solutions. Each individual is evaluated to give some measure of its fitness to the problem from the objective function. In each generation, a new population is formed by selecting the more fit individuals based on a particular selection strategy.

The introduction of Flexible AC Transmission System (FACTS) devices in a power system improves the stability (Benzargua *et al.*, 2006, 2007), reduces cost of generation and also improves the load ability of the system. Optimal placement of multiple FACTS devices will naturally control the overall reactive power requirements (Zhao *et al.*, 2005). Due to high cost of FACTS devices, it is important to decide their optimal placement to meet the desired objective. GA based approach is suggested for optimal placement of the FACTS devices.

List of symbols

G_{ij}, B_{ij} = Mutual conductance and susceptance between bus i and j
Q^g_i = Reactive power generation at bus i

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Q^{sh}_i = Reactive power generated by ith capacitor bank
P^l_i Q^l_i = Active and reactive load power at bus i
a = Tap setting of transformer
V_i = Voltage magnitude at bus i
V_i^g = Voltage magnitude at generator i
θ_{ij} = Voltage angle difference between bus i and j
n = Total number of buses
n_g = No. of generator buses
n_{sh} = No. of capacitor banks
n_T = No. of tap-setting transformer branches

MATHEMATICAL FORMULATION OF (ORPF) PROBLEM

The objective of ORPF is to identify the reactive power control variables, which minimizes the real power loss (P_{loss}) of the system (Laouer *et al*., 2006; Benzargua *et al*., 2006). This is mathematically stated as follows:

Minimize F = [f_1]

$$f_1 = P_L = \sum_i^n \sum_j^n -G_{ij}(V_i^2 + V_j^2 - 2V_iV_j\cos\theta_{ij}) \quad (1)$$

The reactive power optimization problem is subjected to the following constraints:

Equality constraints: These constraints represent load flow equation such as:

$$\Delta P_J = \sum_{j=2}^{n} V_iV_j(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) - P_i^g + P_i^l = 0 \quad (2)$$

$$\Delta Q_J = \sum_{j=2}^{n} V_iV_j(G_{ij}\cos\theta_{ij} - B_{ij}\sin\theta_{ij}) - Q_i^g + Q_i^l - Q_i^{sh} = 0 \quad (3)$$

Inequality constraints: These constraints represent the system operating constraints. Generator bus voltages (V^g_i), reactive power generated by the capacitor (Q^{sh}_i), transformer tap setting (a_i), are control variables and they are self restricted. Load bus voltages (V_i) and reactive power generation of generator (Q^g_i), whose limits are satisfied by adding a penalty terms in the objective function. These constraints are formulated as:
Voltage limits

$$V^g_{i,min} \le V^g_i \le V^g_{i,max} \quad i = 1.....,n_g \quad (4)$$

Generator reactive power capability limit:

$$Q^g_{i,min} \le Q^g_i \le Q^g_{i,max} \quad i = 1.....,n_g \quad (5)$$

Shunt reactive power generation limit:

$$Q^{sh}_{i,min} \le Q^{sh}_i \le Q^{sh}_{i,max} \quad i = 1.....,n_{sh} \quad (6)$$

Transformer tap setting limit

$$a_{i,min} \le a_i \le a_{i,max} \quad i = 1.....,n_T \quad (7)$$

FACTS DEVICES

As power transfer grows, the power system can become increasingly more difficult to operate and the system becomes more insecure with unscheduled power flows and higher losses. The rapid development of self-commutated semiconductor devices, have made it possible to design power electronic equipments. These equipments are well known as Flexible AC Transmission Systems (FACTS) devices (Berizzi *et al*., 1999; Gerbex *et al*., 2001; Sing and David, 2001).

Among the devices facts (shunt, series and combined series - shunt) one was interested in the controllers shunts (Statcom, Svc, Svs, etc.), (Benzargua *et al*., 2007) and with the model of injection.

Static VAR Compensators (SVC) are devices that control the reactive power injection at a bus using power electronics switching components. It is for what one them selected to inject them into present network.

OVERVIEW OF GENETIC ALGORITHM

Some members of new population undergo genetic operations to form new solutions. The three commonly used operations are reproduction, crossover and mutation. This section briefly describes the various components of GA.

Reproduction: The reproduction operator is a probabilistic selection in which strings are selected so as to produce offspring based on their fitness value. There are number of selection methods such as fitness proportionate selection, ranking and tournament selection. Tournament selection is used in this study. In tournament selection, n individuals are selected randomly from the population and the best of the n is inserted into the new population for further genetic processing. This procedure is repeated until the mating pool is filled.

Crossover operation: Crossover operator is mainly responsible for the global search property of the GA. The operator basically combines substructures of two parent chromosomes to produce new structures, with the chosen probability (Pc). Crossover can occur at single position.

(single crossover) or at a number of different positions (multiple crossover). In ORPD problem, two point crossover is used in which two crossover sites are randomly chosen and offspring's are produced by swapping the bits after the chosen crossover sites.

Mutation: The final genetic operator in the algorithm is mutation. The mutation operator is used to inject new genetic materials into the population. Bitwise mutation is performed here which switches a few randomly chosen bits from 1 to 0 (or) 0 to 1 with a small probability (Pm). After mutation, the new generation is complete and the procedure begins again with the fitness evaluation of the population.

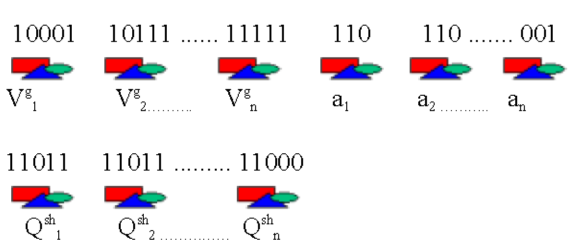
Population representation: To obtain an optimal reactive power flow, the elements of the solution consist of the control variables namely, generator bus voltage, reactive power generated by the capacitor and transformer tap settings. These variables are represented as binary strings in the GA population.

Genetic algorithm implementation for ORPD problem: When applying GA's to solve a particular optimization problem, two main issues must be addressed.

- Representation of the decision variables
- Formation of the fitness function

These issues are explained in the subsequent section.

Population representation: In the ORPD problem, the elements of the solution consist of the control variables namely, Generator bus voltage (V^g_i), reactive power generated by the capacitor (Q^{sh}_i) and transformer tap settings (a_i). These variables are represented as binary strings in the GA population. The length of the binary strings is based on their actual value to obtain accurate solution. The binary strings are randomly generated as shown below:



Fitness function: In the ORPD problem, the objective is to minimize the total real power loss while satisfying the constraints (2) to (7). For each individual, the equality constraints are satisfied by running Fast Decoupled algorithm and the constraints on the state variables are taken into consideration by adding penalty function to the objective function. With the inclusion of the penalty factors, the new objective function then becomes.

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$$F_{obj} = P_L + \lambda_V \sum \left(V_i - V_i^{lim}\right)^2 + \lambda_Q \sum \left(Q_i^g - Q_i^{glim}\right)^2 \tag{8}$$

Where:

$X_i^{lim} = X_i^{max}$; if $X_i > X_i^{max}$
$X_i^{lim} = X_i^{min}$, if $X_i < X_i^{min}$
λ_i = Penalisation factors

SIMULATION RESULTS

In order to demonstrate the effectiveness and robustness of the proposed technique, minimization of real power loss under two conditions, without and with FACTS devices were considered. The validity of the proposed Genetic Algorithm technique is demonstrated on Western Algerian Transmission System 220/60 kV. Figure 1 its main data and operational limits are summarized in Table 1 and 2.

Table 1: Main data of the Western Algerian system

Magnitude	Lower	Upper
220 kV voltage	0.99	1.11
60 kV voltage	0.95	1.10
Taps	0.9	1.10
Q^{sh}	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

Table 2: The control variables limit of and bus voltages

Magnitude	Lower	Upper
220 kV voltage	0.99	1.11
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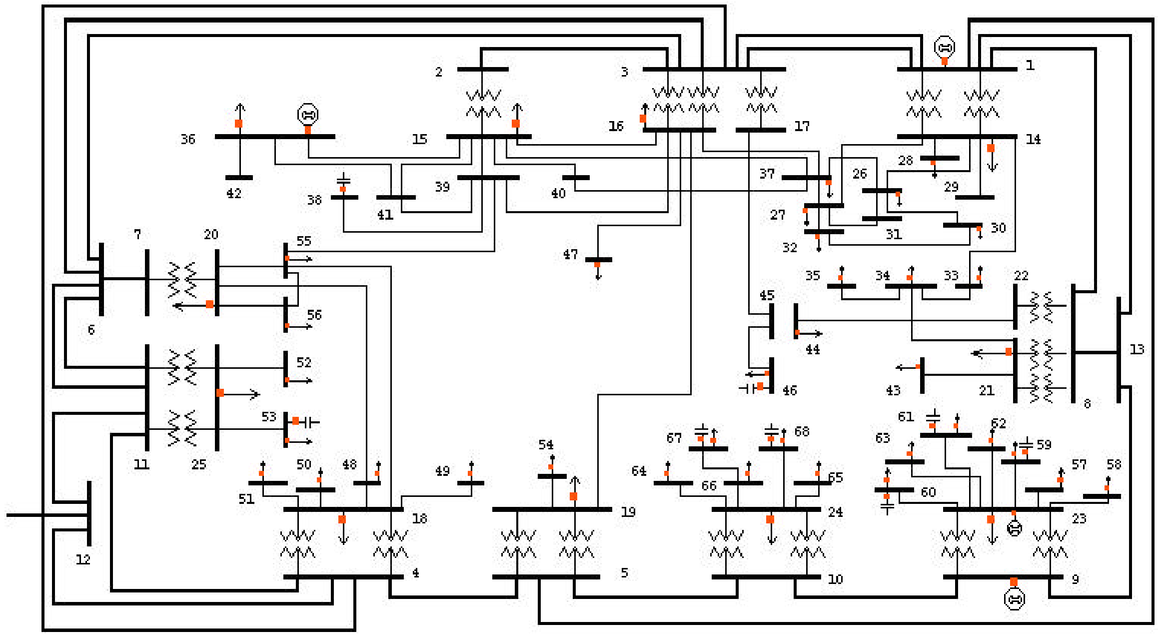

Fig. 1: Western Algerian transmission system 220/60 kV

From this considered power system, the optimal settings of GA control parameters are given below:

Maximum generation	: 50
Population size	: 30
Crossover Probability (Pc)	: 0.9
A number of points to crossing	: 2
Mutation Probability (Pm)	: 0.01

The proposed algorithm is applied for loss minimization in the base condition, without considering FACTS devices and with the inclusion of FACTS devices. Without FACTS devices, the algorithm reaches a minimum loss of 29.22 MW. The optimal values of the control variables obtained are given in the second column of Table 3-5 and it was found that all the state variables corresponding to these control variables satisfy their limits. The loss obtained is less than the value reported by Khiat *et al*. (2003) and Benzargua *et al*. (2007). The location of SVC was found out using Genetic Algorithm. The placement of SVC in five lines gives the optimum loss as 22.87 MW as shown in Table 6.

The different results obtained are as follows:

Figure 2a indicates different values of voltage, for network 220 kV (buses 1-13), we notes that voltages are in limits for the tow cases.

Desired voltage in the 60 kV network is 0.95 to 1.1 p.u. after optimization all voltages are in the limits. Results are shown in Fig. 2b-c.

Table 3: Reactive power (MVAR) of generators.

Bus	Without FACTS	With FACTS
1	383.8	320.000
9	103.1	72.926
23	28.2	35.100
36	27.2	21.580

Table 4: Shunt controller

Bus	Without FACTS	With FACTS
17	0	-8
35	0	2
38	5	5
46	0	10
53	10	10
59	10	2
60	10	10
61	10	5
67	0	2
68	0	2

Table 5: Transformer tap changer ratios

Buses	Without FACTS	With FACTS
1-14	0.98	0.95
2-15	0.99	0.99
2-16	0.98	1.00
3-17	0.95	0.95
4-18	0.98	1.00
5-19	0.98	0.98
7-20	0.99	0.99
8-21	0.96	1.00
8-22	0.99	0.99
9-23	1.07	1.00
10-24	0.95	0.96
11-25	0.98	0.98

Table 6: Active power losses reduction

	Without FACTS	With FACTS
Losses (MW)	29.22	22.87
Reduction (%)	-	21.73

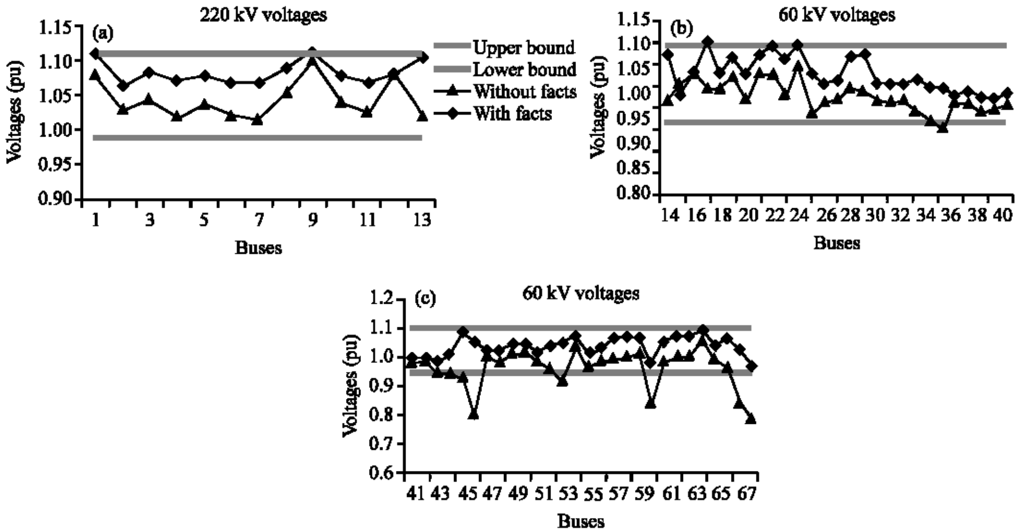

Fig. 2: (a) Bus voltages for buses 1-13, 220 kV, (b) Bus voltages for buses 14-40, 60 kV and (c) Bus voltages for buses 41-68, 60 kV

There are 5 buses whose voltages is initially below the lower limit. We can notice that after optimization by GAs there was a new seedling of tension which satisfies the limits of operation, a new repair of the compensators and some corrections on the ratios of the transformers taps.

The active power losses are decreased from 29.22 to 22.87 MW that is to say 21.73% (Table 6).

CONCLUSION

In this study, Genetic Algorithm technique has been presented and applied to solve ORPF problem with a voltage control where minimization of real power loss is taken as the objectives. The feasibility of the proposed method is demonstrated on Western Algerian Transmission System 220/60 kV with promising results.

Simulation results show that GA based reactive power flow algorithm is able to minimize the power loss in the system. Also, it is found that the results of GA technique are better than that obtained using other conventional methods.

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