NEW APPROACH OF OPTIMAL POWER FLOW WITH GENETIC ALGORITHMS

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ABSTRACT

The application of the genetic Algorithms (GAs) in the calculation of the optimal power flow (OPF) for active and reactive powers, simplifies more difficulties of the problem. In this case, the mathematical aspect is based on the analogy of the physical and biological processes. This new approach reduces the complexity, which is generally encountered, for the resolution of the optimisation problems. The combination of the decoupled method and GAs obtain a new calculation algorithm of the optimal power distribution. This new approach is more powerful and effective and will be described in this paper.

1. INTRODUCTION

The biologists used the genetic algorithms in the search for population of robust plants whose capacities of longevity and adaptation of the individuals are constantly improved [1], [3]. The same idea was planned to carry out algorithms of search for optimism that we could apply to other fields of research. In general, we manipulate a population whose individuals are represented by points of space. No condition is imposed with the function known as “objective function” which we seeks to optimise. If the traditional methods of optimisation recommend that the function is continuous and derivable, the GAs do not take into account the nature of the function [5], [6], [8]. Moreover, they are classified in the category of the algorithms of research by heuristic exploration of the space of solutions. To make this application more practical, we try to adapt it to the distribution of the powers in the electrical networks. As the requirements in electricity for the industrialized countries do not cease increasing, we can estimate that consumption in the power systems of a country doubles every ten years. The producer of electricity must be able to satisfy the requests of his customers, at the price of the Kilowatt-hour as low as possible. The transport and the distribution of the electrical energy are done according to purely technical criteria relating to an economic dispatch. The OPF will take much more importance when several power stations of production operate simultaneously. The essential goal is to satisfy all the loads and the losses caused by transport in the power systems. The OPF determines the optimal setting of generating units, bus voltage, transformer tap and shunt elements in Power Systems with an objective to minimize total production costs or losses while the system is operating within its security limit [2], [9]. In this paper, we will present, to begin with the method of the (GAs) [1], [4], then the decoupled method [9], [11], and finally combine these two methods.

2. GAS AND OPF

The OPF is a non-linear problem. It is used to determine the active and reactive powers which each power station must generate. The base of study will be limited to the cost function which must be minimized within limits of operation and safety [10], [11]. Since its appearance, in 1968, several methods were used to solve this problem (linear Programming, gradient, quadratic programming, sequential programming). However, all these methods do not produce exact solutions with a reassuring simplicity. The violations of one or several variables orient the optimal solution towards a best alternative, but are imposed for a given situation. In the best of cases, we can consider, within the limit, the degradation of the material within a short time. A second disadvantage appears when these methods are applied to functions supposed at the beginning continuous and derivable. That is not always the case in practice (discrete variables). To solve this problem, we use the GAs.

2.1. Conception and theory of GAs

The genetic conception showed that the appearance of the species in various forms was done by the natural selection of the individual variations of which the principal goal is to fight to live. Consequently, the most adapted individuals tend to survive a long time, reproduce and give other still better individuals. Mendel could explain thereafter why there were laws, known as of variation (crossing and mutation), which manage the species based on the probability of existence. Many theories were worked in this context to explain this base of study. The main is to justify the chance to give an explanation to the phenomena of evolution and adaptation without passing neither modification of heredity by the environment. Under these conditions, the evolution of the species is done in a harmonious way and allows them to better adapt to their medium. The GAs take as a starting point of this theory to extend its application in stochastic optimisation founded on the mechanisms of the natural selection and the genetics. They were developed by John Holland (1975) and presented very well by Goldberg (1989) [1], [7]. The simplicity and the effectiveness of GAs were distinguished by Lerman and Ngouet, in 1995, which clarified this difference compared to other methods. GAs differs from other optimisation and search procedures in four ways [6]:

(1) GAs work with a coding of the parameter set, not the parameters themselves. Therefore GAs can easily handle the integer or discrete variables.

(2) GAs search from a population of points, not a single point. Therefore GAs can provide globally optimal solutions.

(3) GAs use only objective function information, not derivatives or other auxiliary knowledge. Therefore GAs can deal with the non-smooth, non-continuous and non-differentiable functions which are actually existed in a practical optimisation problem.

(4) GAs use probabilistic transition rules, not deterministic rules

It is necessary to add to all, that the choice of the population size which is very determining, failing this, the solutions obtained by GAs will be near the total optimal solution.

2.2. Description of GAs

In GAs, it is always a question of making handling about the populations. For that, it is appropriate perfectly, to choose initially, their size which will remain constant. The number of individuals, whose populations are formed, represents each one coding of a potential solution of the function considered, and who is given in the form of character strings. Each one of these last corresponds to a chromosome, each character to a gene and each letter of the alphabet to an allele. Each chromosome is located at a suitable position called Locus. The population evolves of a generation to another by the production [1], [4]. Any physical system can be modelled by a selective function making it possible to associate at each individual population, a value image of the objective function to optimise. We can illustrate GAs by the following stages:

*Take a population of individuals, size given.

*Repeat same following operations until a robust individual remains:

*Selection and pairing of the individuals.

*Creation of two new individuals by recombining two paired individuals.

*Mutation of certain individuals.

*Creation of a new generation, by replacing the former individuals by the new ones.

We retain this description which the GAs exploit effectively information obtained previously to speculate in the position of new points to explore with in the hope to improve the performance. Then, they tend to offer a principal improvement of the robustness, balance between the performance and the cost necessary to survival in many and different environments. Like any algorithm, GAs from now on, will be described by a whole of operators who will be active along the exploration of a population to give individuals suited at each generation. If the selected choose is operated starting from a certain function known as fitness, then we will be sure to improve the population with each generation. In summarizing the algorithm can resemble one limps closed and which has inputs (variables e1,e2,…,ep) and outputs (the functions objectives f1,f2,..,fp) as the figure shows it after p modifications of variables of inputs fig.1 .

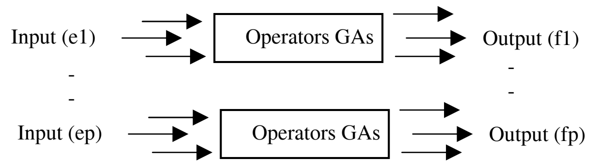

Fig. 1

2.3. Operators and algorithm of GAs

GAs are composed of three essential operators [1], [11], [12]:

Reproduction

It represents a process in which each chain is copied according to the values of the function to optimise fi (fitness). To copy chains according to the values of their fitness, amounts giving to the chains value whose is larger. The function to be optimised is the final parameter which decides life or death of each chain. The various called selection since calculation is made at the base of probability on each individual in the interval which is allocated to him in the population. The size of each interval correspond to the value of the fitness corresponding to him and could be calculated starting from the ratio (f_i / Σ fi) where (Σfi) is the sum of fitness functions in the population.

Crossover

A crossing makes it possible to create new chains by using a generator of random numbers, the copy of chains, and exchanges partial of chains.

Mutation

It is defined by the inversion of a bit in a chromosome. The mutation plays the role of noise and prevents the evolution from being appeared, thus it ensures a research as well global as local, according to the weight and the number of transferred bits. Moreover, it guarantees obtaining the global optimum. The mutation is also necessary because the reproduction and the crossover explore and recombine effectively the existing notations, but they can sometimes become too exaggerated and loses potentially useful genetic matter.

The steps of GAs are as follows:

Step1

Input of the data: vlb, vub, PC, Pm, the function of adaptation and size of the population.
Where:
Vlb, Vub : lower and upper bounds.
Pc, Pm : crossover & mutation probabilities

Step2

-To code the variables of the function into binary.
-To choose arbitrary the initial population.
-To decode the chains to calculate the value of the function to be optimised. For that, it is enough to inject the values of chains decoded in the function.

Step 3

To use the three following operators:
Reproduction .
Crossover.
Mutation.

Step 4
If the convergence of GAs is reached we print the optimal values and stop;
else go to the second step

3. FORMULATION OF THE OPF PROBLEM

The OPF is the essential component of a good management and a better exploitation of the electrical networks [8]. The factor determining of the market of electricity is the cost of the electrical energy. Knowing as a preliminary that the electrical energy is not storable at the long-time. The producer must always think of giving a keen price to kWh in order to emphasize his product. The respect of the technical and economic constraints allows a exercise reassuring in the reliability of the electrical supply network. The problem of optimisation arises generally in the following way [5], [6}:

$$\begin{aligned} &\text{Min} \quad f(x) \\ \text{Under} \quad & h(x) = 0 \\ & g(x) \geq 0 \end{aligned} \tag{1}$$

Where:
f(x) : Objective function
h(x) , g(x): equality and inequality constraints

If we want to extend this definition in order to apply it to the calculation of the OPF, we will have the following representation:

Min F(x)

where F(x) is the objective function adapted to the problem studied. We can formulate the OPF problem with all constraints by:

$$\begin{aligned} &\Phi_P = \sum_{i=1}^{G} P_{Gi} - \sum_{j=1}^{N} P_{Dj} - P_L = 0; \\ &\Phi_Q = \sum_{i=1}^{G} Q_{Gi} - \sum_{j=1}^{N} Q_{Dj} - Q_L = 0; \\ &P_{Gi}^{Min} \leq P_{Gi} \leq P_{Gi}^{Max} \\ &Q_{Gi}^{Min} \leq Q_{Gi} \leq Q_{Gi}^{Max} \\ &V_i^{Min} \leq V_i \leq V_i^{Max} \\ &P_{ij} \leq P_{ij}^{Max} \\ &Q_{ij} \leq Q_{ij}^{Max} \end{aligned} \tag{2}$$

Where:

Φ_P,Φ_Q :active & reactive power equality constraints
N,G : all Bus & all Generators of power system.
P_{Gi} , Q_{Gi}: active & reactive power generated at bus i.
P_{Dj} , Q_{Dj} : active & reactive power load at bus i.
P_L,Q_L : Total active & reactive power losses.
P_{ij},Q_{ij} : active & reactive power flow from bus i to j.
V_i : magnitude of bus voltage at bus i.
P_{Gi}^{Min} , P_{Gi}^{Max} :min & max active generation at bus i.
Q_{Gi}^{Min} , Q_{Gi}^{Max} :min & max reactive generation at bus i.
P_{ij}^{Max} , Q_{ij}^{Max} :min & max reactive power flow from bus i to bus j.
V_i^{Min} , V_i^{Max} : min & max bus voltage magnitude at bus i

To solve this problem with these all constraints is not easily realizable for a complex network generally comprising a significant number of nodes and branches. To be done, we will have to simplify the problem by an adaptation of suitable mathematical model. Our paper presents an aspect of interactive and decoupled calculation. Interactive, by integrating AGs for the minimization of the objective functions and decoupled by the call from two sub-algorithms; one for the optimal active power and the other for the optimal reactive power.

4. DECOUPLED METHOD

The decoupled method consists in separating the study from the general problem of the OPF in two sub-problems active and reactive.

The study of each sub problems will be made at the base of the following objective functions: For the active power, the objective function is represented by the total production cost of the power stations in the network. But for the reactive power, we take the objective function equal to the total losses of active powers caused by the lines of transport. It is more convenient to present the method in the form of flow charts.

4.1. Active sub problem

To carry out this first part, we must define the corresponding objective function as well as the constraints. The objective function is represented by the total cost of the whole of the manufacturing units. For the generator (i) the function cost is given in quadratic form[9], [10] by :

$$F_i(P_{Gi}) = a_i + b_i P_{Gi} + c_i P_{Gi}^2 \tag{3}$$

Where:
F_i (P_{Gi}) : cost function
a_i ,b_i ,c_i : coefficients of cost function
The formulation of active sub-problem gives:

$$Min \quad : f(P_G) = \sum_{i=1}^{G} F_i(P_{Gi}) \tag{4}$$

Under constraints :

$$\begin{aligned} &\sum_{i=1}^{G} P_{gi} - \sum_{j=1}^{N} P_{Dj} + P_L = 0 = \Phi_P \\ &P_G^{Min} \leq P_G \leq P_G^{Max} \end{aligned} \tag{5}$$

In order to apply GAs, we must choose the fitness function for this type of problem. It is advisable to take the Lagrangian function such as:

$$L_P(P_G, \lambda) = f(P_G) + \lambda_P \Phi_P \tag{6}$$

Where:
λ_P : Multiplying vector of Lagrange for the active Power
L_P: Lagrangian function of the active power.

The principle resolution of the active sub problem is defined by the comparison of the two values of active powers generated. The two values follow one another of two consecutive calculations of optimisation.

We can more clarify the method in the following flow chart.

With:

K : number of iterations
N,G : all Bus & all Generators of power system.
ε1 : tolerance

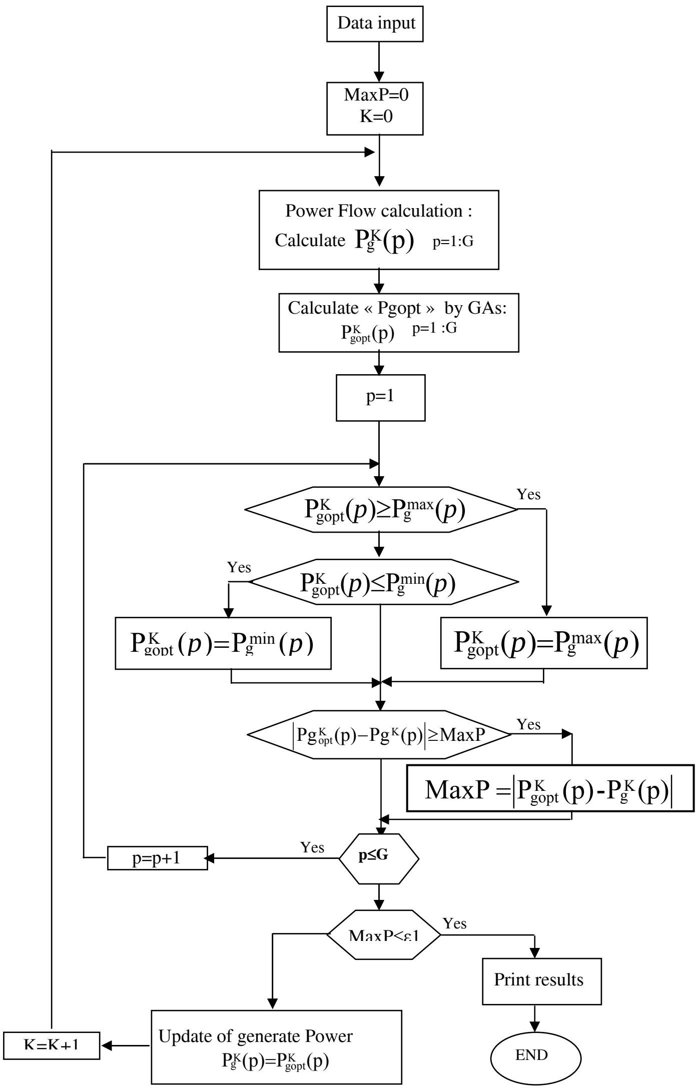

Fig. 2 Flow chart of active sub problem

4.2. Reactive sub problem

In this module, the objective function is represented by the total losses of active power. It is expressed according to the complex nodal voltages

$$P_L = \sum_{i}^{n}\sum_{j}^{n} -G_{ij}(V_{ij}^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)) \quad (7)$$

Where:

V_i, δ_i : magnitude & angle bus voltage at bus i.
G_{ij} : real part of element in row i, column j of bus admittance matrix.

Thus, the formulation of reactive sub problem becomes:

$$Min : f(V,\delta) = P_L \quad (8)$$

Under the constraints:

$$\sum_{i=1}^{G} Q_{Gi} - \sum_{j=1}^{N} Q_{Dj} + Q_L = 0 = \Phi_Q$$
$$Q_G^{Min} \le Q_G \le Q_G^{Max} \quad (9)$$
$$V_i^{Min} \le V_i \le V_i^{Max}$$

In the same case, the fitness function is given by the following Lagrangian function:

$$L_Q(V,\delta,\lambda_Q) = f(V,\delta) + \lambda_Q \Phi_Q \quad (10)$$

λ_Q: Multiplying vector of Lagrange for the reactive Power
L_Q: Lagrangian function of the reactive Power.

The algorithm of the reactive sub problem is identical to that of the active power in substitution active powers P_G by reactive powers Q_G.

4.3. Final Algorithm

The final algorithm is summarized as follows:

1/ the optimal active powers found in the active sub problem will be used like values planned for the reactive module to deduce the power Pg1 of slack bus.

2/ the optimal reactive powers given by the reactive sub problem will be used for the calculation of the power flow to deduce the new value of the power slack bus P'g1.

3/The two found values of Pg1 will be compared to end the programme: This method converge when:

$$\left| P'_{G1} - P_{G1} \right| \leq \varepsilon 3 \qquad (11)$$

Where ε3 is the tolerance Else go to the first stage.

5. SIMULATION AND RESULTS

The present method was applied to a network IEEE test five Bus including three bus of production [9], [12].

Data of power system is given by following tables with :

Sb = 100 MVA (Base Power)
Vb= 220 KV (Base voltage)

Table 1 Line data of power system

Bus : i to m	Line Impedance $Z_{im}=(r_{im}+jx_{im}$ [pu]	shunt Conductance: $ysh_{im}/2$[pu]
1-2	0.02+j0.06	0.0+j0.03
1-3	0.08+j0.24	0.0+j0.025
2-3	0.06+j0.18	0.0+j0.02
2-4	0.06+j0.18	0.0+j0.02
2-5	0.04+j0.12	0.0+j0.015
3-4	0.01+j0.03	0.0+j0.01
4-5	0.08+j0.24	0.0+j0.025

Table 2 Bus data of power system

Bus	Voltage [pu]	Loads		Genrators	
		P_D [pu]	Q_D [pu]	P_{Gen} [pu]	Q_{Gen} [pu]
1	1.06∠0°	0	0	?	?
2	?	0,20	0,10	0,40	0,30
3	?	0,45	0,15	0,30	0,10
4	?	0,40	0,05	0	0
5	?	0,60	0,10	0	0

With:

P_{Gen}: Scheduled active power contributed by the generator
Q_{Gen}: Scheduled reactive power contributed by the generator

Tab. 3 Coefficients of cost function

Bus i	a(i)	b(i)	c(i)
1	0,0060	2,00	140
2	0,0075	1,50	120
3	0,0070	1,80	80

Under constraints:

For active and reactive power generators

$0,30 \leq P_{G1} \leq 1,20$; $-0,20 \leq Q_{G1} \leq 0,20$
$0,20 \leq P_{G2} \leq 0,80$; $-0,20 \leq Q_{G2} \leq 0,80$
$0,10 \leq P_{G3} \leq 0,60$; $-0,20 \leq Q_{G3} \leq 0,60$

For Voltage magnitude for all bus

$0,9 \leq V_p \leq 1,10$ p=1,..5

For all tolerances
ε1=0,00001;
ε2=0,00001;
ε3=0,00001

The program written in Matlab language was carried to find optimal active and reactive power flow.

The important part of this program is centred on GAs. Then, it is essential to make a preliminary choice of data to be introduced:

Size of the population Si = 30
Probability of Mutation Pm = 0.01
Probability of crossover Pc = 0.9
The number of bits to code the generated powers: 16
The number of bits to code the nodal tensions: 6
The number of bits to code the ratios of transformers: 4

In the case of the absence of one or several data, a flexible handling can be considered for the correct running of the program. Such as for example for the transformers: All the ratios will be equal to 1 in order to express their absence, else we will allot the value corresponding to the ratio of transformer and an additional function is added to Lagrangian definite by: $\lambda_r\ \Sigma(r_i - r_{ilimit})$ where r_i is the ratio of the transformer connected to the bus i, under the following conditions:

$r_{i\,limit} = r_{i\,min}$ if $r_i < r_{i\,min}$

$r_{i\,limit} = 0$ if $r_{i\,min} \leq r_i \leq r_{i\,max}$

$r_{i\,limit} = r_{i\,max}$ if $r_i > r_{i\,max}$

Where:

λ_r: Multiplying Vector of Lagrange for ratio r.
$r_{i\,min}$, $r_{i\,max}$: min and max of the ratio of transformer.

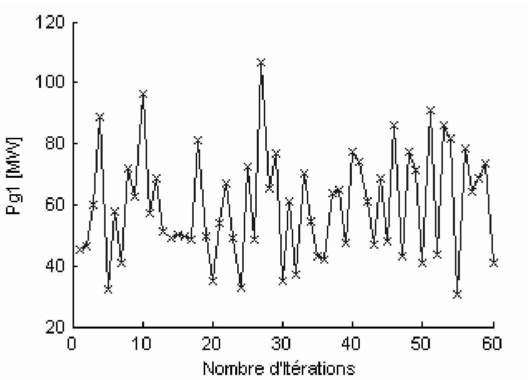

Fig. 3 Active power generated by the slack bus

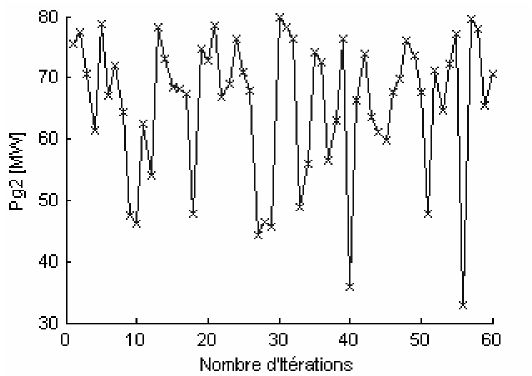

Fig. 4 Active power generated at the bus N°2

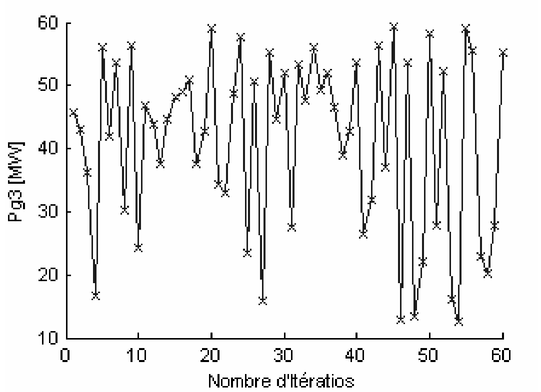

Fig. 5 Active power generated at the bus N°3

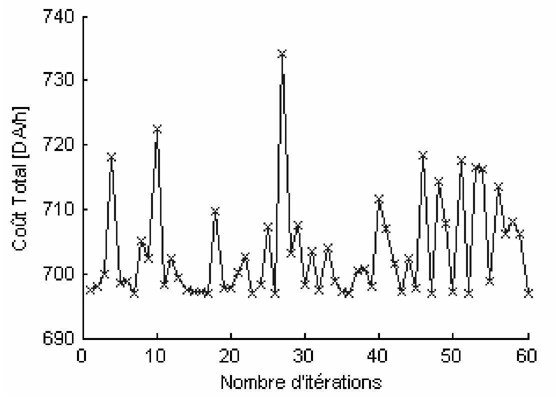

Fig. 6 Total Cost of production.

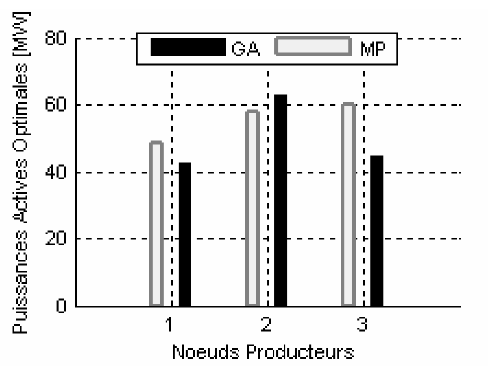

Fig. 7 Optimal active powers

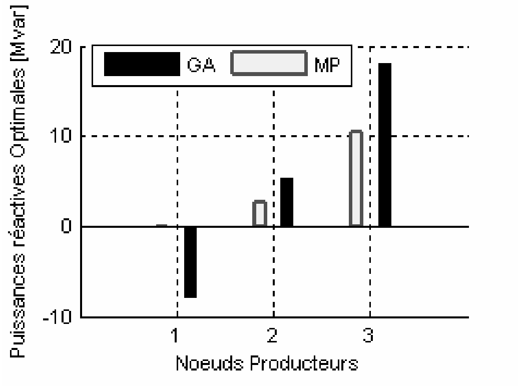

Fig. 8 Optimal reactive powers.

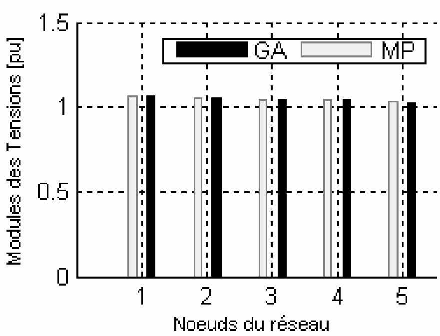

Fig. 9 Magnitude of the bus voltages

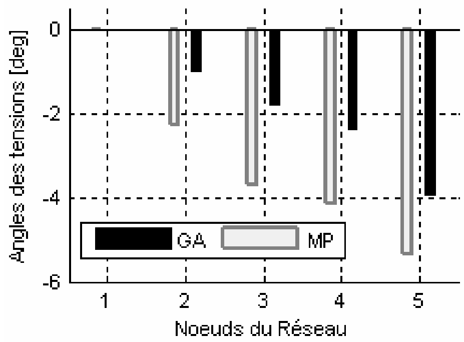

Fig. 10 Angle of the bus voltages

The sequence of the curves obtained makes it possible to visualize the difference in values between the results of this method and those which are obtained starting from the reference [11]. The curves given by figures 4, 5, 6 and 7, enable us to observe, as example the respective evolution of the active powers produced by the generators G1, G2, G3 and the total function cost, on wide of 60 iterations.

The curves given by figures 8,9,10 and 11 make it possible to obviously put the approach of the method of GAs and that used in Mat Power. The differences in values which are not important make it possible to give an insurance of the use of GAs for a choice of initial values to the iterative calculation of the direct methods. What advances the advantage of accelerating the speed of their convergence.

The values of active and reactive powers optimal reserves correspond at a minimal total cost. They are gathered in a summary table Table.1 compared with those of MatPower.

Table 4. Table of comparison

Methods	GAs	MP
Pg1 (opt.) [MW]	42,2840	48.72
Pg2 (opt.) [MW]	62,9680	57.81
Pg3 (opt.) [MW]	44,8436	60.11
Qg1 (opt.) [Mvar]	- 7,8956	0
Qg2 (opt.) [Mvar]	5,2460	2.70
Qg3 (opt.) [Mvar]	18,1450	10.43
Losses [MW]	1,2268	1.639
Costs [DA/H]	696,2889	711.4

GAs : Genetic algorithms
MP : Mat Power

6. CONCLUSION

In this paper, we have presented a method of calculation which can be added to others to be useful like computational tool of the optimal distribution of the active and reactive powers. All the constraints were taken into account. The results obtained were compared with those which are given by the reference [11]. Its application on a network test 5 bus enabled us to make a comparative study to develop this new method and to give him a considerable dimension when the network is very large. We can notice that the losses of active powers (1.2268 MW) are quite lower. The handling of GAs is flexible but slow and even slower when the size of the population is important, the local optimum is guaranteed.

The major disadvantage of GAs is the choice of the probabilities of mutation and crossover what explains the results different from two successive executions. The robustness and the effectiveness of the method depend mainly on the choice of the function on adaptation or fitness

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BIOGRAPHIES

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