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Short Paper

Economic Dispatch using a Genetic Algorithm: Application to Western Algeria's Electrical Power Network

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A genetic algorithm is used to solve an economic dispatch problem. The chromosome contains only the encoding of a normalized incremental cost system. Therefore, the total number of bits of a chromosome is entirely independent of the number of units. In the first case, the transmission line losses are calculated using the Newton-Raphson method and kept constant. In the second case, the transmission line losses are considered as a linear function of the real generated power. The coefficients are calculated using the Gauss-Seidel method. This method has been applied to the western part of the Algerian power network, and the results have been found to be satisfactory compared with other results obtained using classical methods.

Keywords: power transmission losses, economic dispatch, genetic algorithm, normalized incremental cost system, power systems, minimization, optimal load flow

1. INTRODUCTION

In an electrical power system, a continuous balance must be maintained between electrical generation and varying load demand, while the system frequency, voltage levels, and security also must be kept constant. Furthermore, it is desirable that the cost of such generation be minimal [1, 2]. In addition, the division of load in the generating plant becomes an important operation as well as an economic issue which could be solved at every load change (1%) or every 2-3 minutes. Research techniques have been successfully used to solve optimal load flow problems by using linear or non linear programming, but these algorithms are generally limited to convex regular functions. Many functions are multi-modal, discontinuous and not differentiable.

Stochastic sampling methods have been used to optimize these functions. Whereas traditional resolution techniques use the characteristics of the problem to determine the next sampling point (e.g., gradient, Hessians, linearity and continuity), stochastic resolution techniques make no such assumptions. Instead, the next sampled point is determined

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based on stochastic sampling or decision rules rather than on a set of deterministic decision rules. Genetic algorithms have been used to solve difficult problems with objective functions that do not possess properties such as continuity, differentiability and so forth [3-6]. These algorithms maintain and manipulate a set of solutions and implement a survival of the fittest strategy in their search for a better solution.

In our case, a genetic algorithm is used to solve the economic dispatch problem under some equality and inequality constraints. The equality constraint reflects a real power balance, and the inequality constraint reflects the limit of real generation. The voltage levels and security are assumed to be constant in both cases. The proposed approach has been applied to the western part of the Algerian power network, and the results have been judged satisfactory.

2. OBJECTIVE

The economic dispatch problem, which is used to minimize the cost of production of real power, can generally be stated as follows:

$$\text{Min}\left[\sum_{i=1}^{n} Fi(Pi)\right] \tag{1}$$

Subject to:

$$\sum_{i=1}^{n} Pi = D + P_L \tag{2}$$

$$P_i,^{\min} \le P_i \le P_i,^{\max}, \tag{3}$$

where, generally, $Fi(Pi)$ is a quadratic curve:

$$Fi(Pi) = c_i + b_iPi + a_iPi^2 \tag{4}$$

Here:

a_i, b_i and c_i are the known coefficients;
n : number of generators;
Pi: real power generation;
D: real power load;
P_L: real losses.

3. OVERVIEW OF THE GENETIC ALGORITHM

Genetic algorithms are resolution algorithms based on the mechanics of natural selection and natural genetics. They combine survival of the fittest among string structures with structured yet randomized information exchange to form a resolution algorithm with some of man's capacity for survival. In every generation, a new set of artificial creatures (strings) is created by using bits and pieces from the fittest of the old; an occasional new part is used for good measure. While randomized, genetic algorithms are no simple random walk, they efficiently exploit historical information to speculate on new research points with expected improved performance [3, 5].

Genetic algorithms are essentially derived from a simple model of population genetics. The three prime operators associated with the genetic algorithm are reproduction, crossover, and mutation.

Reproduction is a process by which individual strings are copied according to their fitness values. Copying strings according to their fitness values means that strings with higher values have a higher probability of contributing one or more offspring in the next generation.

Crossover is an important component of genetic algorithms, taking two individuals and producing two new individuals as shown in Fig. 1.

Parent A: 100 | 110
Parent B: 011 | 101

Child A: 100 | 101
Child B: 011 | 110

Fig. 1. Diagram of simple crossover.

Although reproduction and crossover search and recombine existing chromosomes, they do not create any new genetic material in the population. Mutation is capable of overcoming this shortcoming. It involves the alteration of one individual to produce a single new solution as shown in Fig. 2.

Child A: 100**1**10

New child A: 100**0**10

Fig. 2. Binary mutation.

Fig. 3 shows the genetic algorithm flow chart used in this study.

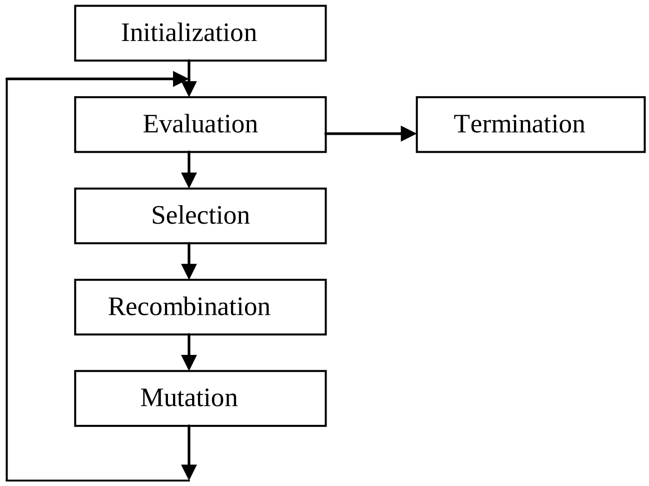

Fig. 3. General flow chart used in this study.

4. GENETIC ALGORITHM SOLUTION

The encoding and decoding techniques, constrained generation output calculation, and the fitness function are described in more detail below.

4.1 Encoding and Decoding

In this paper, the proposed approach uses the λ equal system (equal incremental cost system) criterion as its basis. λ^{nm} is the normalized incremental cost system, where $0 \leq \lambda^{nm} \leq 1$. The advantage of using the λ system is that the number of bits of a chromosome will be entirely independent of the number of units. Ten bits, however, represent λ^{nm}. Fig. 4 shows the encoding diagram of λ^{nm} [1, 6].

d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}
x	x	x	x	x	x	x	x	x	x
2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	2^{-8}	2^{-9}	2^{-10}

where $d_i \in \{0, 1\}$, $i = 1, 2, \ldots, 10$

Fig. 4. Encoding diagram of λ^{nm}.

The decoding of λ^{nm} can be expressed as follows:

$$\lambda^{nm} = \sum (d_i x 2^{-i}), \tag{5}$$

where $d_i \in \{0, 1\}$, $i = 1, 2, \ldots, 10$.

The relationship between the incremental cost value λ and the normalized incremental cost system λ^{nm} is

$$\lambda = \lambda_{\min} + \lambda^{nm}(\lambda_{\max} - \lambda_{\min}), \tag{6}$$

where $\lambda_{\min}$ and $\lambda_{\max}$ represent the initially computed minimum and maximum values:

$$\lambda_{\min} = \min\left\{\frac{dFi(Pi, \min)}{dPi}\right\}$$

and (7)

$$\lambda_{\max} = \max\left\{\frac{dFi(Pi, \max)}{dPi}\right\}$$

4.2 Generation Output

If the Lagrange function methods and the Kuhn-Tucker [6] conditions are applied to the constrained optimization, the economic dispatch problem can be reformulated as follows:

$$L(P, \lambda) = \sum_{i=1}^{n} Fi(Pi) + \lambda(D + P_L - \sum_{i=1}^{n} Pi), \tag{8}$$

which, after some rearrangement of terms, becomes

$$L(P, \lambda) = \sum_{i=1}^{n} Fi(Pi) - \lambda(\sum_{i=1}^{n} Pi - P_L) + \lambda(D), \tag{9}$$

$$\begin{aligned} &PF_i(2a_iP_i + b_i) = \lambda \text{ for } P_{i,}{}^{\min} \le P_i \le P_{i,}{}^{\max} \\ &PF_i(2a_iP_i + b_i) \le \lambda \text{ for } P_i = P_{i,}{}^{\max} \\ &PF_i(2a_iP_i + b_i) \ge \lambda \text{ for } P_i = P_{i,}{}^{\min} \end{aligned} \tag{10}$$

where PF_i is the penalty factor of unit i, given by

$$PFi = \frac{1}{1 - \frac{\partial P_L}{\partial Pi}}. \tag{11}$$

4.3 Fitness Function

The fitness function for the minimization problem is generally given as the inverse of the objective function. In this paper, the fitness function is given by the relation

$$Fit = \frac{1}{1 + \frac{1}{\sum Fi}}. \tag{12}$$

4.4. Parameter Selection

The genetic algorithm has a number of parameters that must be selected. These include population size, crossover, and mutation probability:

population size = 10,
crossover probability = 0.85,
mutation probability = 0.1.

5. TEST SYSTEM AND RESULTS

The proposed method was applied to the electrical network in western Algeria (Fig. 5) to assess the suitability of the algorithm. The fuel cost (in Nm^3/hr) equations for the two generators are

$$F_1(P_1) = 2000 + 150P_1 + 0.85P_1^2,$$
$$F_2(P_2) = 3000 + 250P_2 + 1.7P_2^2,$$

subject to

$$30 \le P_1 \le 510 \text{ (MW)},$$
$$10 \le P_2 \le 70 \text{ (MW)},$$
$$D = 505 \text{ MW}.$$

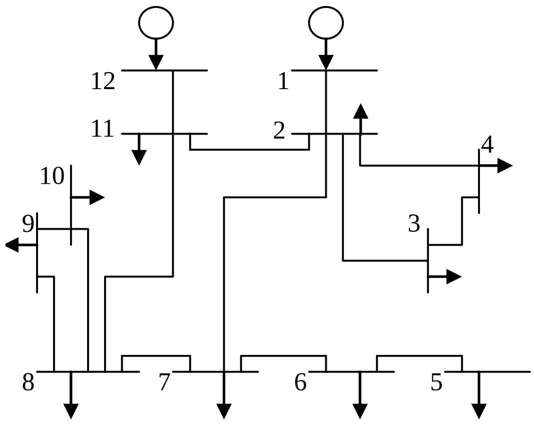

Fig. 5. Electrical network in western Algeria.

The total load was 505 MW, and the transmission line losses were 15.94 MW after calculation using the Newton-Raphson method [2, 7]. Two cases were considered. In the first case, the transmission line losses were calculated and kept constant, and in the second, the transmission line losses were considered as a linear function of real generated power.

Table 1. Transmission line data in p.u.

k – *m*	Impedance	Line charging
1 – 2	0.000239 + *j*0.00115	*j*0.0075
2 – 3	0.017760 + *j*0.08657	*j*0.0645
2 – 4	0.025900 + *j*0.12890	*j*0.0959
2 – 7	0.013800 + *j*0.06700	*j*0.0498
2 – 11	0.003180 + *j*0.01544	*j*0.0464
3 – 4	0.012570 + *j*0.06100	*j*0.0455
5 – 6	0.022000 + *j*0.10710	*j*0.0597
6 – 7	0.014500 + *j*0.07052	*j*0.0797
7 – 8	0.015000 + *j*0.07347	*j*0.0525
8 – 9	0.011170 + *j*0.05400	*j*0.0403
8 – 10	0.014000 + *j*0.04828	*j*0.0342
8 – 11	0.029000 + *j*0.10117	*j*0.0712
9 – 10	0.011700 + *j*0.04095	*j*0.0290
11 – 12	0.008000 + *j*0.02770	*j*0.0196

Table 2. Bus data in p.u.

N°	Bus type	Real power	Reactive power
1	Reference	–	–
2	Load	– 0.70	– 0.52
3	Load	– 0.32	– 0.20
4	Load	– 0.33	– 0.30
5	Load	– 0.35	– 0.26
6	Load	– 0.30	– 0.22
7	Load	– 0.35	– 0.26
8	Load	– 0.54	– 0.31
9	Load	– 1.38	– 0.60
10	Load	– 0.08	– 0.06
11	Load	– 0.70	– 0.52
12	Production	0.55	0.18

Table 3. Results for case 1.

	GA	Fletcher-Reeves [8]	Fletcher [8]	Sonelgaz* [8]
$P_1^{optimal}$ (MW)	450.95	466.64	469.93	465.94
$P_2^{optimal}$ (MW)	69.00	54.25	49.98	55
P_L (MW)	15.94	15.94	15.94	15.94
Fuel cost (Nm^3/h)	271764	278649	279940	278319
Computing time(s)	0.05	0.01	0.01	/
Generation number	304	8	3	/

* Sonelgaz: Algerian Electricity and Gas Board.

5.1 Case 1

The transmission line losses were calculated and kept constant (P_L = 15.94 MW). The power balance equation then became: $P_1 + P_2 = 520.94$ MW. The results for the real generated optimal power, minimum fuel cost, and computing time are given in Table 3.

5.2 Case 2

The transmission line losses were considered as a linear function of real generated power. The coefficients were calculated using the Gauss-Seidel method [8, 9]:

$$P_L = 0.0189P_1 + 0.0924P_2.$$

The power balance equation was, therefore,

$$0.9811P_1 + 0.9076P_2 = 505 \text{ MW}.$$

The results for the real generated optimal power, minimum fuel cost, and computing time are given in Table 4.

Table 4. Results for case 2.

	GA	Fletcher-Reeves [9]	Fletcher [9]	Sonelgaz* [9]
$P_1^{optimal}$ (MW)	449.98	465.37	468.92	465.94
$P_2^{optimal}$ (MW)	70.00	53.36	49.50	55
P_L (MW)	14.97	13.72	13.43	15.94
Fuel cost (Nm^3/h)	270444	277067	278779	278319
Computing time(s)	0.1	0.05	0.01	/
Generation number	76	25	3	/

6. INTERPRETATIONS

In the first case, the losses as determined using Newton-Raphson method are kept constant (15.94 MW) for the three methods, and they are equal to the losses recorded by Sonelgaz. A better cost has been obtained using the genetic algorithm method as compared with the Fletcher and Fletcher-Reeves methods. A gain of 57 378 000 Nm^3/year of gas has been obtained. If the Sonelgaz costs were considered, this would be the equivalent to a 2.35% profit.

In the second case, the losses are linearly formulated, which makes it possible to reduce them by a significant degree. Although the Fletcher and Fletcher-Reeves methods give losses that are lower than those obtained using the genetic algorithm, the latter gives a better production cost and a profit evaluated at 68985000 Nm^3/year of gas, which would be the equivalent of 2.82% of the production cost of Sonelgaz.

7. CONCLUSIONS

The determination of the steady-state operating condition of the optimal power system is a non-linear problem. A genetic algorithm solution has been developed in this paper, based on the Lagrange method. The numerical results in both cases indicate that the proposed method can be used to determine the optimum control for the generation of power with the minimum fuel cost and lower transmission line losses, and with accurate results obtained in a short enough period of time to be compatible with on-line applications.

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