ERJ
Engineering Research Journal
Faculty of Engineering
Minoufiya University

SECURITY CONSTRAINED OPTIMAL DISPATCH USING GENETIC ALGORITHMS FOR NORMAL AND EMERGENCY CONDITIONS

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ABSTRACT

This paper presents a proposed technique for security constrained optimal dispatch (SCOD) problem under normal and emergency conditions. In this technique a modified version of the genetic algorithm (GA) is used. The SCOD problem is formulated using non-linear unit cost functions and solved by the proposed technique. The results obtained using this technique are compared with those obtained using a conventional linear programming technique and with those obtained using fuzzy modeling technique.

The comparison studies are performed considering the changes in system constraints as: membership models in fuzzy technique and chromosomes in GA technique. Numerical studies of fuzzy modeling are based on the fuzzy linear programming (FLP) technique with fuzzy constraints of different shapes for their membership functions. Simulation results show that the proposed GA-based technique for SCOD is more accurate and efficient, especially with increasing the system size.

يقترح هذا البحث طريقة لحل مشكلة التوزيع الأمثل للقدرة الكهربية، والمقيدة بالحدود الآمنة، فى حالات التشغيل الطبيعية والطارئة. تعتمد هذه الطريقة على استخدام الخوارزميات المورثية (الجينية). تم صياغة المشكلة باستخدام مجموعة من الدوال غير الخطية لحساب تكاليف وحدات التوليد، وتم حل المشكلة باستخدام الطريقة المقترحة. كما تم مقارنة نتائج هذه الطريقة مع النتائج التى تم الحصول عليها باستخدام طريقة البرمجة الخطية التقليدية وكذلك مع النتائج التى تم الحصول عليها بطريقة المنطق الغيمى للبرمجة الخطية.

وقد أجريت دراسات المقارنة باعتبار التغير فى قيود النظام كنماذج لدالة العضوية وذلك فى حالة أسلوب المنطق الغيمى، بينما تم اعتبار هذا التغير فى القيود فى صورة كروموزومات وذلك فى حالة أسلوب الخوارزميات المورثية. اعتمد نموذج المنطق الغيمى على أشكال مختلفة لدالة العضوية للقيود المستخدمة فى المنطق الغيمى للبرمجة الخطية. وقد أوضحت النتائج أن أسلوب الخوارزميات المورثية أكثر دقة وكفاءة فى حل المشكلة خاصة مع زيادة حجم النظام.

Keywords: Optimal dispatch, Genetic algorithm, Fuzzy LP, Emergency conditions.

1. INTRODUCTION

The optimal dispatch (OD) represents one of the basic functions of energy management systems. In general, the task of OD is to optimally allocate loads among on-line generating units subject to power balance, system reserve requirements and other system constraints. The problem becomes more complicated due to the non-linear nature of the objective function and constraints of real life problems. When approximating the cost functions by piecewise linear curves, many segments may be required to achieve the desired accuracy, and a rather elaborate logic for traversing the segments has to be employed [1].

Literature survey shows that the SCOD problem has been studied extensively. In Ref. [2], an approach for solution of the security constrained economical dispatch (SCED) with piecewise linear cost and 2-segments spinning reserve curves was developed. This approach was based on what the author calls, the differential algorithm and the simplex method. The basic idea is to reduce the size of the underlying linear programming (LP) problem by searching and eliminating pinned units. Some results of an implementation of this approach are reported in [3]. An LP formulation of a multi-area system SCED is presented in [3]. While, the transmission constraints are defined with respect to the system as a whole, the reserve requirements are imposed on the levels of individual areas. Reference [4] presented preventive control actions using the fuzzy modeling of generation units, load demand and power flows in critical lines. Ref. [5] addresses different security regions that satisfy the condition of secure and economic solutions of power dispatch at different controller positions was presented. The authors in Ref. [6] proposed two types of fuzzy models, namely triangular and trapezoidal models to find the suitable model for each power system constraint. Reference [7] presented a hybrid method for the solution of the optimal allocation of reactive power sources based upon a modified genetic algorithm (GA) which is applied at an upper level stage and a successive linear program at a lower level stage. In Ref. [8], an improved GA was developed and applied to a least cost generation expansion planning (GEP) problem. Least cost GEP problem is concerned with a highly constrained non-linear dynamic optimization problem.

In this paper, another technique is proposed to solve SCOD problem using a GA. Simulation results demonstrate that the proposed technique is able to remove the overloads in the critical lines and to minimize the generation costs for both normal and emergency conditions.

2. MODELING OF SECURITY CONSTRAINT OPTIMAL DISPATCH

Let us define the procedure that enables minimization of the cost of the power injection shifts with respect to the initial economic dispatch of generating units while not losing any customer on the power grid. The costs are defined as:

$$\min F_t = \sum_{i=1}^{NG} f_i(PG_i) = \sum_{i=1}^{NG} a_i + b_i PG_i + c_i PG_i^2 \qquad (1)$$

where,

F_t : is the non-linear objective function defining the total power generation cost of the system.

a_i, b_i and c_i are the coefficients of power generation cost function.

NG : is the number of generation buses.

The objective function (1) is subject to the following constraints:

$$PG_i^{min} \leq PG_i \leq PG_i^{max} \qquad (2)$$

$$PF_k = |D_{k,i} PG_i| \leq PF_k^{max} \qquad (3)$$

$$\sum_{i=1}^{NG} PG_i = \sum_{j=1}^{NL} PD_j + P_{losses} \qquad (4)$$

where,

PG_i^{max} and PG_i^{min} are the maximum and minimum of power generation at bus i.

PF_k : is the power flow in line k.

PF_k^{max} : is the maximum power flow in line k.

$D_{k,i}$: is the sensitivity parameter of the power flow related to the power generation.

PD_j : is the load demand at load bus j.

NL : is the number of load buses.

P_{losses} : is the total power losses in the system.

3. PROPOSED MODIFIED GA FOR SCOD

Genetic Algorithms (GAs) are numerical optimization algorithm inspired by both natural selection and natural genetics. The algorithms are simple to understand and the required computer code is easy to write. Rather than starting from a single point within the search space, GAs are initialized with a population of guesses, which are usually random and will be spread throughout the search space. A typical algorithm then uses three operators; selection, crossover and mutation to direct the population towards convergence at the global optimum solution.

3.1. Representation of Modified GA

The binary code representation is used where each individual is usually encoded into a string of binary bits (chromosome). A chromosome is subdivided into genes, each gene represents a variable, consists of a binary string with length that depends on the boundary of the corresponding variable. The chromosome structure is illustrated as shown in Fig.1.

1000010111100	000111110111	100110011111
Gene of PG1	Gene of PG2	Gene of PG3

chromosome

Fig. 1 Chromosome and Genes structure

3.2. Selection

This operation attempts to apply pressure upon the population in a manner similar to that of natural selection found in biological systems. Poorer performing individuals are weeded out and better performing individuals have a greater than average chance of promoting the information they contain within the next generation. The commonly used methods for selection are roulette wheel method and tournament method. The roulette wheel method is represented as shown in Fig. 2, where infeasible solutions (poorer performing individuals) occupy a very small arc on the wheel, while feasible solutions (which satisfy system constraints) occupy a valuable length of arc.

3.3. Crossover

This operation allows solutions to exchange information in a way similar to that used by a natural organism undergoing sexual reproduction. The crossover occurs when two parents exchange parts of their corresponding chromosomes. The number of chromosomes that undergo the crossover operation is determined by the crossover probability. The crossover scheme used is two points crossover as shown in Fig. 3.a.

3.4. Mutation

It is used to randomly change (flip) the value of a single bit within individual strings. Mutating a binary bit means switching it from 0 to 1 or vice versa. The mutation operator is applied as shown in Fig. 3.b. This process of selection, crossover and mutation , is continued until a fixed number of generations are elapsed or some form of convergence criterion has been met.

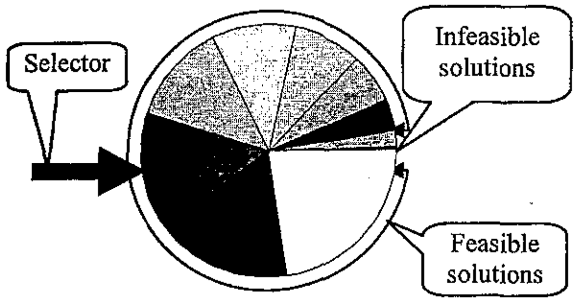
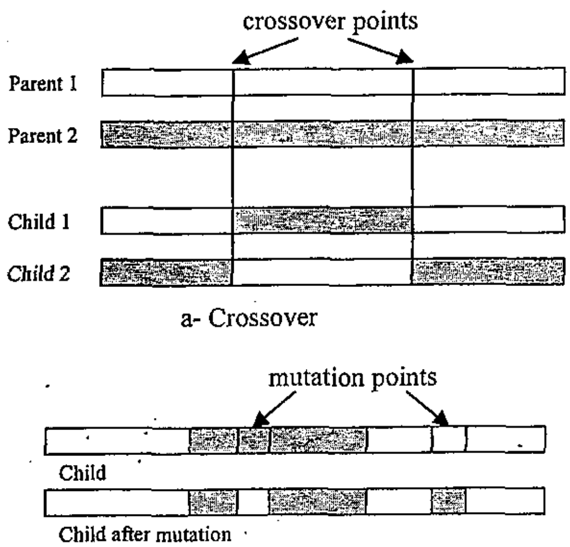


Fig. 2 The roulette wheel method



a- Crossover

b- Mutation

Fig. 3 The crossover and mutation operations

4. PROPOSED FLP MEMBERSHIP MODELS

The changes in membership models have an effect in the optimization problem [6]. The shape of the membership function is constructed according to the nature of variable variations.

4.1. Modeling of Objective Function

The objective is to minimize a certain function (*Min* Z). The proposed shape of fuzzy modeling is shown in Fig. 4, where the membership function $\mu(Z)$ of the generation cost can be written in the following form:

$$\mu(z) = \begin{cases} 1 & z < z_0 \\ (z_1 - z)/(z_1 - z_0), & z_0 < z < z_1 \\ 0 & z > z_1 \end{cases} \qquad (5)$$

where Z is a point between Z_0 and Z_1.

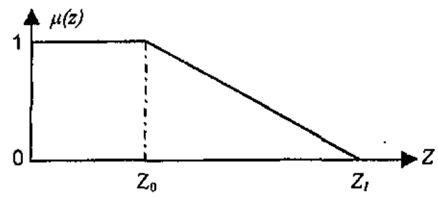


Fig. 4. Objective membership function

4.2. Modeling of Power Generation

The proposed shape of the power generation fuzzy membership function is shown in Fig. 5, which can be written in the following form:

$$\mu(Pg) = \begin{cases} (Pg - Pg^{min})/(Pg^{max} - Pg^{min}), & Pg^{min} < Pg < Pg^{max} \\ 0 & , \text{otherwise} \end{cases} \qquad (6)$$

where Pg is a point between Pg^{min} and Pg^{max}

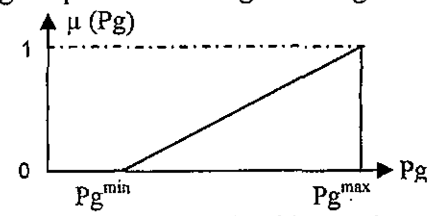


Fig. 5 Power generation membership function

4.3. Modeling of Power Flow Constraints

The proposed shape of the power flow fuzzy membership function is shown in Fig. 6, which can be written in the following form:

$$\mu(PF) = \begin{cases} (PF - PF^{min})/(PF^{max} - PF^{min}), & PF^{min} < PF < PF^{max} \\ 0 & , \text{otherwise} \end{cases} \qquad (7)$$

where PF is a point between PF^{min} and PF^{max}

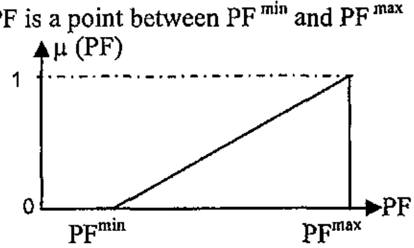


Fig. 6 Power flow membership function

Hence, the SCOD problem, as Equations (1)-(4), can be considered as a multi-objective optimization problem because the aim is to find the values of Pg and the degrees of membership of Pg and PF which maximize the degree of membership for objective function $\mu(z)$.

This multi-objective optimization problem can be solved by *MAX_MIN* [μ(z)], which can be written as:

$$\text{Max} [\text{Min} (\mu(z), \mu(pg), \mu(pf), \ldots\ldots)] \quad (8)$$

Or $\quad \text{Max}\ \alpha$

Subject to : $\mu(Z) \geq \alpha$

$$\mu(Pg) \geq \alpha \quad (9)$$

$$\mu(PF) \geq \alpha$$

where α ∈[0,1], α is the degree of the problem optimality.

5. APPLICATIONS

5.1. Test Systems

Three standard test systems are used to study the proposed technique for SCOD using a modified GA. The first test system contains 5 buses and 7 transmission lines (modified 5-bus test system [4]). The second system is IEEE 14-bus test system [9], while the third is IEEE 30-bus test system [9]. Tables 1 and 2 illustrate the generation and lines data for the modified 5-bus system. The critical lines are number 1 in all test systems. The maximum power flow ratings of these critical lines are equal to 45, 150 and 65 MW for the three systems, respectively. However the ratings of the other lines in the three systems are below their security limits.

Table 1 Generation bus data for 5-bus test system

Bus No.	Pg^{min} (MW)	Pg^{max} (MW)	$Pg^{initial}$ (MW)	Cost Function ($/hr)
1	10	120	100	$1.7P_1+0.0001 P_1^2$
2	10	90	45	$2.3P_2+0.002 P_2^2$
5	10	60	40	$2.2P_5+0.0015 P_5^2$

Table 2 Line data for 5-bus test system

Line No.	From bus	To bus	r + j x (p.u.)	y/2 (p.u.)	$PF^{initial}$ (MW)
1	1	2	0.02+j 0.06	0.06	52.29*
2	1	3	0.08+j 0.24	0.05	33.34
3	2	3	0.06+j 0.18	0.04	27.75
4	4	2	0.06+j 0.18	0.04	30.09
5	2	5	0.04+j 0.12	0.03	38.86
6	3	4	0.01+j 0.03	0.02	13.12
7	4	5	0.08+j 0.24	0.05	-3.85

* denotes overflow in line.

Two different operation conditions are considered to obtain the SCOD, which are normal and emergency conditions.

The emergency conditions that may occur in the three test systems are:

a) sudden increase in load demand.
b) unexpected outage of one line.
c) unexpected outage of units inside the generation plant.

5.2. Results and Comments

5.2.1 Normal Conditions

Tables 3, 4 and 5 show the comparison between the results obtained using four different techniques; namely the conventional linear programming technique, the FLP technique [4], the proposed FLP technique and the proposed technique using GA. In these tables, the SCOD which is computed using the proposed modified GA has most reduction in the generation cost compared with other techniques.

Table 3 Comparison between different optimization techniques for 5-bus system (load=185 MW)

	LP	Triangle FLP [4]	Proposed FLP	Modified GA
P1	90.2	76.1	78.9	90.2
P2	34.8	60	61.7	35.8
P5	60	48.9	44.4	59
PF1	45	32.48	34.6	44.98
Cost ($/hr)	380.7	393.1	391.7	374.1
Time (sec)	0.55	0.66	0.66	0.99

Table 4 Comparison between different optimization techniques for 14-bus system (load =260 MW)

	LP	Triangle FLP[4]	Proposed FLP	Modified GA
P1	208.1	188.7	196.8	208.1
P2	51.86	71.3	63.2	51.9
PF1	150	133.6	140.4	149.96
Cost ($/hr)	958.1	963.7	961.4	767.5
Time (sec)	0.5	0.66	0.72	1.1

Table 5 Comparison between different optimization techniques for 30-bus system(load =220 MW)

	LP	Triangle FLP [4]	Proposed FLP	Modified GA
P1	10	52	53.7	49.1
P2	80	62.3	63.3	65.6
P3	39.4	28.9	31	21
P4	10	16	17	23.7
P5	30	25.5	24	16.5
P6	50.6	35.3	31	44.1
PF1	-0.251	30.94	31.89	28.07
Cost ($/hr)	871.93	879.22	879.72	685.13
Time (sec)	0.6	1.1	0.66	1.75

Table 6 shows the comparison of the computational times for different optimization techniques applied on three test systems. In this table, it can be noticed that, the computation time for the proposed modified GA are around 2.3 % of the time in the linear programming technique, while the computation time consumed for the proposed shape of the fuzzy membership technique is in the order of 1.2 % of the time in the linear programming technique.

Table 6 Comparison between the computational time for the different optimization technique for three test systems.

	Computation time (sec)			
	L.P	Triangle FLP [4]	Proposed FLP	Modified GA
5-bus	0.55	0.66	0.66	0.99
14-bus	0.5	0.66	0.72	1.1
30-bus	0.6	1.1	0.66	1.75

Table 7 shows the comparison of the total generation costs for different techniques applied on three test systems. In this table, it can be noticed that the generation costs determined by the proposed modified GA have considerably lower values compared with that obtained by the linear programming technique and the fuzzy membership technique. On the other hand, the proposed FLP has a little reduction in the generation cost, in some cases, compared with the FLP using triangular membership functions [4].

Table 7 Comparison between generation cost for different systems

	Generation Cost ($/hr)			
	L.P	Triangle FLP [4]	Proposed FLP	Modified GA
5-bus	380.7	393.1	391.7	374.1
14-bus	958.1	963.7	961.4	767.5
30-bus	871.93	879.22	879.72	685.13

5.2.2 Emergency conditions

- ***Sudden increase in load demand***

Tables 8 and 9 show the SCOD using the proposed modified GA for different loading states for the 5-bus and 14-bus test systems.

In these Tables, the power flows in the critical lines are kept within their limits, and the generation costs are increased according to increasing the load demand.

Table 8 SCOD using the proposed modified GA for different loading states for 5-bus test system

Load (MW)	150	170	185	200	220	230
P1	83.02	87.17	90.2	92.48	92.5	92.48
P2	17.09	29.04	35.8	50.41	70.15	80.02
P3	49.89	53.79	59	57.11	57.35	57.50
PF1	44.31	44.47	44.98	44	40.72	39.1
Cost ($/hr)	295.21	340.1	374.07	409.63	460.4	486.38

- ***Unexpected outage of transmission line***

Tables 10 and 11 show the SCOD computed using the proposed modified GA technique for different lines outage compared with the load flow (LF) using the Newton-Raphson method for 5-bus and 14-bus test systems. In these tables, overflows in the critical lines are removed using the proposed modified GA technique.

Table 9 SCOD using the proposed modified GA for different loading states for 14-bus test system

Load (MW)	220	240	260	270	280	285
P1	203.4	205.8	208.1	209.3	210.5	211
P2	16.6	34.2	51.9	60.7	69.5	74
PF1	148.93	149.17	149.43	149.65	149.89	149.94
Cost ($/hr)	616.1	689.2	767.5	808.55	850.9	872.7

Table 10 SCOD for different line outage for 5-bus test system (load=185 MW)

Line Outage	1		2		6	
Technique	LF	GA	LF	GA	LF	GA
P1	90.2	58.1	90.2	58.1	90.2	85.6
P2	35.8	70	35.8	70	35.8	40
P3	59	56.9	59	56.9	59	59.4
PF1	----	----	76.89*	44.46	48.26*	44.16
PF2	78.41*	44.64	----	----	26.96	26.37
Where, the maximum power flow in line 2 is 45 MW						

Table. 11 SCOD for different line outage for 14-bus test system (load=260 MW)

Line Outage	7		6		10	
Technique	L.F	GA	L.F	GA	L.F	GA
P1	208.1	185.4	208.1	202.7	208.1	203.5
P2	51.9	74.6	51.9	57.3	51.9	56.5
PF1	169.68*	150	154.5*	149.9	153.84*	149.9
PF7	----	----	46.1	27.7	94.71	94.3
Where, the maximum power flow in line 7 is 100 MW						

- ***Unexpected outage of some units inside the generation plant***

Figures 7 and 8 show the SCOD using the proposed modified GA for different percentage outage of generation plants 1 and 3 for the 5-bus test system, respectively. From these figures, the power generation at bus 2 (PG2) is increased according to an increase in the percentage outage of power generations, while the generation costs are increased.

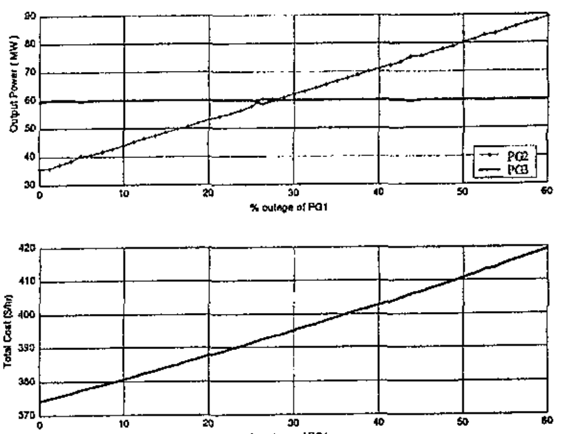


Fig. 7 *The SCOD using the proposed modified GA* for different percentages outage of plant 1

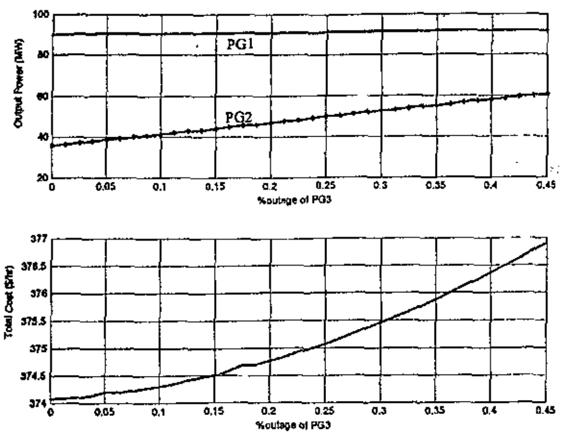


Fig. 8 The SCOD using the proposed modified GA for different percentages outage of plant 3 .

Notes

- Simulation is carried on P3-1.2 GHz processor, by MATLAB 6.5 software package.
- Parameters for GA are selected through experiments as following:

Population size	*80*
Probability of Crossover	*50 %*
Probability of Mutation	*5 %*
Number of Crossover Points	*2*
Termination Precision *0.01* for *10* population	
Roulette Wheel Selection with Elitism Strategy.	

6. CONCLUSIONS

This paper presents two efficient, accurate and optimum proposed techniques to remove the overflows in the critical lines for both normal and emergency conditions. The first proposed modified GA leads to a lower generation costs for normal condition, while all the power flows in the critical lines are kept within their permissible limits. The other proposed shape of the fuzzy membership function results in a little reduction in generation cost compared with the triangle shape of the fuzzy membership [4], while the power flow in all transmission lines are within the security limits. In the emergency condition, the proposed modified GA is efficiently applied to remove the insecure operation for different emergency conditions.

These proposed techniques fulfill the practical requirements of the electricity utility companies, which prefer faster and accurate methods to remedy, as quickly as possible, many potentially dangerous operating conditions. Therefore, the proposed techniques represent a potential tool to aid the power system operators in the on-line environment.

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