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Multi-objective Genetic Algorithm for Optimal Power Flow Including Voltage Stability

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ABSTRACT

A MOGA for solving the multi-objective optimal power flow (OPF) problem is proposed in this paper. In this method, in the genetic population, the optimization variables are represented in their natural form. The algorithm ensures non-dominated solutions and simultaneously maintains diversity among the non-dominated solutions. The new algorithm applied to an IEEE 30 bus system. The Pareto-optimal front obtained from MOGA is compared with reference Pareto front which is obtained with multiple runs. This paper shows the effectiveness of the proposed algorithm.

Keywords: Genetic Algorithms, MOGA, OPF.

1. INTRODUCTION

The optimal power flow problem aims to achieve an objective function. Various mathematical techniques are proposed for solving the OPF problem. They are linear [1] and nonlinear programming [13], [20], [24]. Quadratic programming [5], Newton method [26], Interior point method [28] etc. In [15] linear programming with bounded variables is used for the optimal shift in power dispatch related to contingency states. Recently, techniques such as genetic algorithms [10], evolutionary programming [29] and particle swarm optimization [2] are proposed to solve the OPF problem. In this paper, the OPF problem is treated as a multi-objective optimization problem. L-index [11] is used as the indicator of the stability of voltage.

2. PROBLEM FORMULATION

2.1. Objective functions

$$Minimize \quad F_C = \sum_{i=1}^{N_g} (a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad \$/hr \tag{1}$$

and

$$Minimize \quad L_{\max} \tag{2}$$

These constraints represent the typical load flow equations

2.2. Inequality constraints

Voltage limits

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$$V_i^{\min} \le V_i \le V_i^{\max} \quad ; i \in N_B \tag{3}$$

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \quad ; \; i \in N_B \tag{4}$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \quad ; i \in N_g \tag{5}$$

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max} \quad ; i \in N_c \tag{6}$$

$$t_k^{\min} \le t_k \le t_k^{\max} \quad ; k \in N_T \tag{7}$$

$$S_l \le S_l^{\max} \quad ; l \in N_l \tag{8}$$

$$Minimize \quad F_T = [\; F_C \;, L^{\max} \;] \tag{9}$$

constraints (3) – (8).

3. MULTI-OBJECTIVE GENETIC ALGORITHM (MOGA)

$$r_i = \eta_i + 1 \tag{10}$$

The niche count is

$$nc_i = \sum_{j=1}^{\mu(r_i)} Sh(d_{ij}) \tag{11}$$

$$d_{ij} = \left[\sum_{k=1}^{M} \left(\frac{f_k^{(i)} - f_k^{(j)}}{f_k^{\max} - f_k^{\min}} \right)^2 \right]^{1/2} \tag{12}$$

4. IMPLEMENTATION OF THE OPF PROBLEM

4.1. Representation of the decision variables

$$\underbrace{97.5}_{P_{g2}} \;\; \underbrace{100.8}_{P_{g3}} \;\; \ldots \;\; \underbrace{250.70}_{P_{gn}} \;\; \underbrace{0.981}_{V_{g1}} \;\; \underbrace{0.970}_{V_{g2}} \cdots \underbrace{1}_{V_{gn}} \;\; \underbrace{4}_{Q_{c1}} \;\; \underbrace{3}_{Q_{c2}} \cdots \underbrace{4}_{Q_{cn}} \;\; \underbrace{-2}_{t_1} \;\; \underbrace{+1}_{t_2} \cdots \underbrace{+3}_{t_k}$$

4.2. Fitness Evaluation

$$PS^K = \begin{cases} K_S \left(PS^K - PS^{\max} \right)^2 & , \; if \quad PS^K > PS^{\max} \\ K_S \left(PS^K - PS^{\min} \right)^2 & , \; if \quad PS^K < PS^{\min} \\ 0 & , \; otherwise \end{cases} \tag{13}$$

$$PV_i^K = \begin{cases} K_V \left(V_i^K - V_i^{\max} \right)^2 & , \; if \quad V_i^k > V_i^{\max} \\ K_V \left(V_i^K - V_i^{\min} \right)^2 & , \; if \quad V_i^k < V_i^{\min} \\ 0 & , \; otherwise \end{cases} \tag{14}$$

$$PQ_g^K = \begin{cases} K_q\left(Q_g^K - Q_g^{\max}\right)^2 & , \ if \quad Q_g^k > Q_g^{\max} \\ K_q\left(Q_g^K - Q_g^{\min}\right)^2 & , \ if \quad Q_g^k < Q_g^{\min} \\ 0 & , \ otherwise \end{cases} \tag{15}$$

4.3.1. Selection Scheme

$$P_i = \frac{f_i}{\sum_{j=1}^{N} f_j} \tag{16}$$

4.3.2. Crossover Scheme

$$y = \begin{cases} e_1 + r \times (e_2 - e_1) \ ; \ if \quad u^{\min} \leq y \leq u^{\max} \\ repeat \quad sampling; \quad otherwise \end{cases} \tag{17}$$

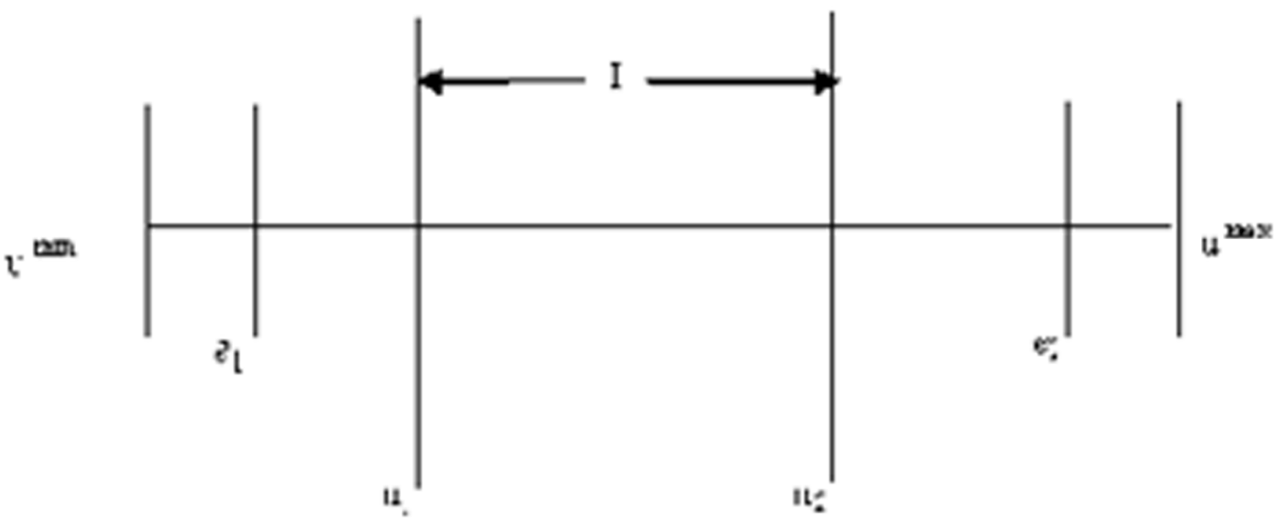

Figure 1:

4.3.3. Mutation Scheme

$$u_k^1 = \begin{cases} u_k + \left(u_{\max}^k - u_k\right). \left(1 - r_1^{\left(\frac{1-p}{M}\right)^q}\right) & if \quad r_1 \leq 0.5 \\ u_k - \left(u_k - u_{\min}^k\right). \left(1 - r_1^{\left(\frac{1-p}{M}\right)^q}\right) & if \quad r_1 > 0.5 \end{cases} \tag{18}$$

5. SIMULATION RESULTS

$$Minimize \quad F_T = \omega_1 \left(L_{\max}\right) + \omega_2 \left(F_C\right) \tag{19}$$

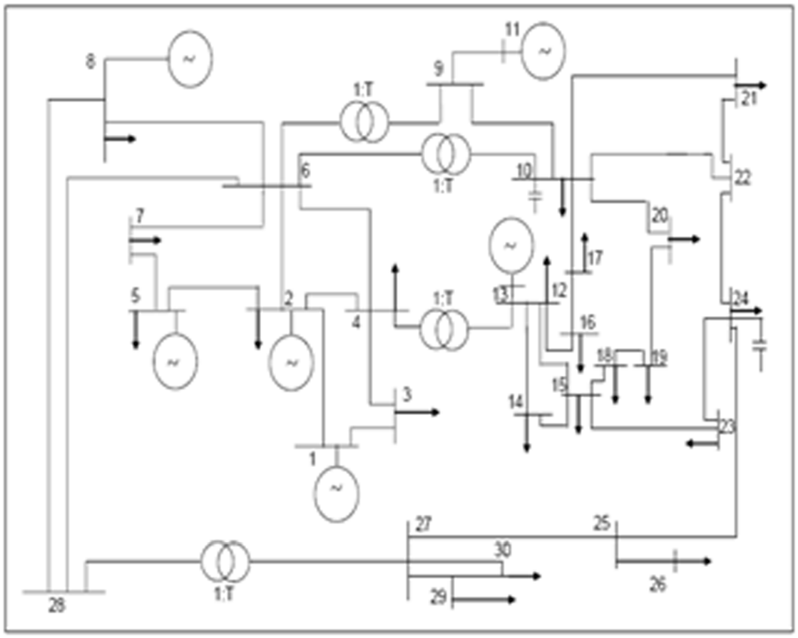

Figure: 2

Table 1
The extreme Solutions

Control Variable	*cost solution*	*Voltage Stability*
P_1	175.8663	143.9107
P_2	40.0139	48.8388
P_5	20.9582	21.1655
P_8	22.3892	22.5546
P_{11}	11.9904	16.5910
P_{13}	12.5718	37.9159
T_{11}	0.9750	0.9750
T_{12}	0.9250	0.9250
T_{15}	0.9750	0.9750
T_{36}	0.9750	1
Q_{C10}	2	2
Q_{C12}	2	2
Q_{C15}	5	5
Q_{C17}	5	5
Q_{C20}	5	6
Q_{C21}	5	5
Q_{C23}	0	0
Q_{C24}	0	0
Q_{C29}	5	5
Cost	802.1208	825.7458
VSM	0.1117	0.876

Table 2
minimum cost

Methods	*Minimum Cost ($/hr)*
Gradient Approaches	802.43
Hybrid Evolutionary Programming	802.62
Refined Genetic Algorithm	804.019
Improved Evolutionary Programming	802.465
Proposed Method	802.1208

Table 3
Comparison of L-index

Methods	*L-index value*
Least Square Optimization Algorithm	0.258
Improved Genetic Algorithm	0.1807
Differential Evolution Algorithm	0.1248
Proposed Method	0.113

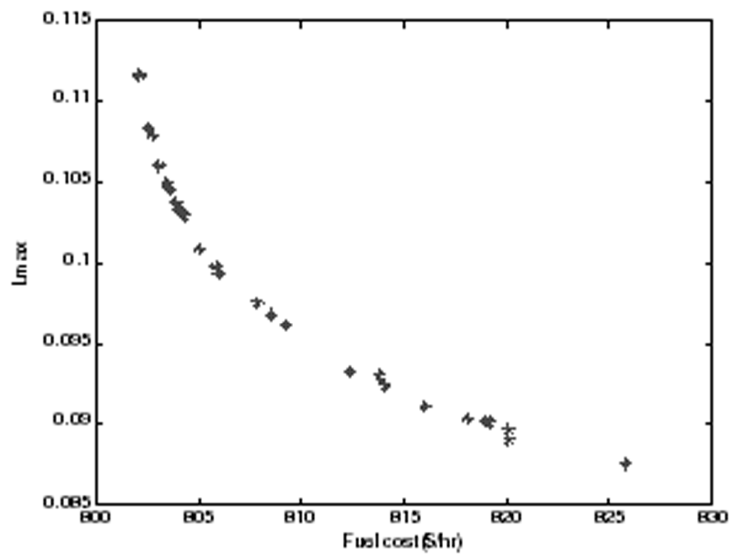

Figure: 3

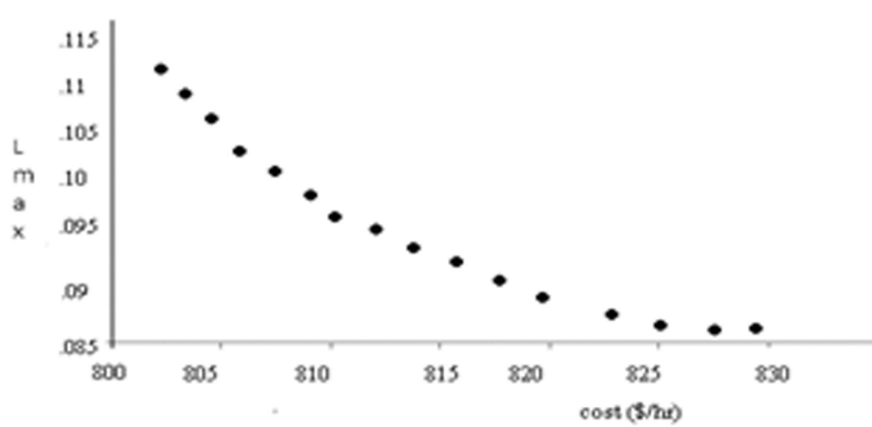

Figure 4: Reference Pareto Optimal Front

6. CONCLUSIONS

The paper has proposed a MOGA for solving the multi-objective OPF problem including stability of voltage. The system stability is assessed with L-index method. The simulation result shows that theproposed algorithm is perfect in solving the multi-objective optimization problems. The new method is found to produce good quality solutions with more stable convergence characteristics. The proposed MOGA has well performed to obtain the Pareto optimal front of the multi-objective OPF problem.

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