

Comparative Study of Optimal Power Flow with Different Methods

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ABSTRACT: In this paper four different techniques conventional method, Sequential Quadratic Programming (SQP), Genetic Algorithm (GA), multiobjective Genetic Algorithm (MGA) are used to find optimal power flow solutions of an electrical power system. The power flow constraint of the power generators are included in optimal power flow problem in addition to the conventional constraint. Cost of power generated is minimized with objective function minimization and validity of their efficiency is checked with the help of different methods. Given methods are tested on IEEE standard 30 bus system.

KEYWORDS: SQP, GA, MGA, Optimal Power flow

I. INTRODUCTION

Moving towards the competitive environment pushes the power transmission systems closer to their stability limits. Thus there is a need to provide optimal power to improve the efficiency and reduce the operating costs. This trend results in several voltage collapse events which brought up the stability as a major concern in optimal power flow (OPF) problem. The overall stability limit can be modelled by voltage stability margin defining critical loading point but in reality the stability problem appears to be an OPF-like problem, in which stability can be viewed as a constraint in addition to the normal OPF voltage constraints, therefore first the study of OPF is important. Often trial and error used that can be costly and imprecise, hence new methodologies are used that eliminates the need for repeated simulation and saves time and effort. First we will see different popular methods used previously; Comparative study of GA and Particle Swarm Optimization (PSO) [10], Interline Power Flow Controller (IPFC) [11], Modified cataclysmic genetic algorithm [12], artificial bee colony algorithm [13]. Simulations results are obtained on standard IEEE 30-bus system for minimizing the operating cost of generation and optimal parameters are calculated.

The organization of the paper is as follows: Section II explains OPF problem objective function, equality and inequality constraints; Section III describes the detail of conventional method and algorithm to solve optimization problems, SQP is discussed in Section IV; Section V describes the Genetic Algorithm and Modified Genetic Algorithm procedure to solve optimization problems. A comparison of simulation results obtained using conventional method, SQP, GA and MGA for IEEE 30-bus system is presented in Section VI. Section VII describe conclusion.

II. PROBLEM FORMULATION

In general, the optimal power flow problem is formulated as an optimization problem in which a particular objective function is minimized while satisfying a number of equality and inequality constraints. The main objectives of the OPF problem are taken into consideration here is minimization of fuel cost in the normal state and the minimization of the fuel cost when generator limits are given. Objective function is given as.

$$F = \sum_{i=1}^{N_g} (C_i) = \sum_{i=1}^{N_g} (a_i + b_i P_{Gi} + c_i P_{Gi}^2) \text{ Rs/hr} \quad (1)$$

Equality constraints are power flow equations of the problem, while the inequality constraints include the limits on real power generation of each plant as follows

Equality constrains

$$\sum_{i=1}^{N_g} (P_{Gi}) - P_D \leq \varepsilon \quad (2)$$

Inequality constrains

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max}, \quad i = 1, 2, \dots, N_g \quad (3)$$

Where,

F is function to be minimize

C_i is cost function of i^{th} generator bus

P_{Gi} is active power generated by each generating plant

N_g is number of generator buses

P_D is total power demand

ε is tolerance limit (0.001 for programming purpose)

The equality constraints given by the above equations are satisfied by running the power flow program.

III. CONVENTIONAL METHOD

Hadi Saadat in his book [9] explains the conventional method for calculation of optimal power flow by iterative method using Lagrange multipliers. In this method objective function is modified by adding λ in product with equality constrains as follows

$$\mathcal{L} = F + \lambda \left(P_D - \sum_{i=1}^{N_g} P_{Gi} \right) \quad (4)$$

Where,

\mathcal{L} is modified objective function

λ incremental cost of generation (\$/MWh)

Minimum of this objective function is found by equating its partial derivative with respect to its variable i.e. P_i to zero

$$\frac{\partial \mathcal{L}}{\partial P_{Gi}} = 0$$

$$\frac{\partial F}{\partial P_{Gi}} + \lambda(0 - 1)$$

Since,

$$F = C_1 + C_2 + C_3 + \dots + C_{N_g}$$

Then,

$$\frac{\partial F}{\partial P_{Gi}} = \frac{dC_i}{dP_{Gi}} = \lambda$$

Hence condition for optimal dispatch becomes,

$$\frac{dC_i}{dP_{Gi}} = \lambda \quad i = 1, 2, \dots, N_g \quad (5)$$

And hence

$$b_i + 2c_i P_{Gi} = \lambda$$

therefore

$$P_{Gi} = \frac{\lambda - b_i}{2c_i} \quad (6)$$

But

$$\sum_{i=1}^{N_g} P_{Gi} = P_D \quad (7)$$

$$\lambda = \frac{P_D + \sum_{i=1}^{N_g} \frac{b_i}{2c_i}}{\sum_{i=1}^{N_g} \frac{1}{2c_i}} \quad (8)$$

$$\Delta P^k = P_D - \sum_{i=1}^{N_g} P_{Gi}^k \quad (9)$$

$$\lambda^{k+1} = \lambda^k + \Delta \lambda^k \quad (10)$$

Where,

$$\Delta \lambda^k = \frac{\Delta P^k}{\sum_{i=1}^{N_g} \frac{1}{2c_i}} \quad (11)$$

1. Algorithm

Step 1: assume initial value of λ equal to or more than largest value of b_i

Step 2: calculate value of P_{Gi}^k from equation (6)

Step 3: calculate ΔP^k and equate it to ε ,

if $\Delta P^k \leq \varepsilon$, then check generator limits

$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max}$, then optimal solution obtained, goto step 6

$P_{Gi}^{min} \leq P_{Gi}$, then $P_{Gi}^{min} = P_{Gi}$ for rest of iteration, continue

$P_{Gi} \leq P_{Gi}^{max}$, then $P_{Gi} = P_{Gi}^{max}$ for rest of iteration, continue

If $\Delta P^k > \varepsilon$, then continue to next step

Step 4: calculate $\Delta \lambda^k$ and λ^{k+1} from equation (10) and (11).

Step 5: repeat from step 2.

Step 6: exit.

IV. SEQUENTIAL QUADRATIC PROGRAMMING

1. General information

SQP stands for Sequential Quadratic Programming, this method invented in the mid-seventies, SQP can be viewed as the Newton approach applied to the optimality conditions of the optimization problem. Each iteration of the SQP algorithm needs finding a solution to a quadratic program (QP). This is a simpler optimization problem, which has a quadratic objective and linear constraints. QP is still difficult to solve however, it is hard when the quadratic objective is nonconvex. On the other hand, as a Newton method, the SQP algorithm converges very rapidly, means it requires few iterations (hence QP solves) to find an approximate solution with a good precision (this is particularly true when second derivatives are used). Therefore, one can say that the SQP algorithm is an appropriate approach when the evaluation of the functions defining the nonlinear optimization problem, and their derivatives, is time consuming.

2. Algorithm accessing toolbox

Step 1: make a function file in MATLAB with objective function.

Step 2: make script file with constrained.

Step 3: open optimization toolbox and enter objective function, limits, constraints.

Step 4: run

V. GENETIC ALGORITHM AND MULTI OBJECTIVE GENETIC ALGORITHM

1. History and working principle

Rechenberg suggested the earliest instance of an evolution-based technique related to modern GA in the 1960's [10]. John Holland is generally credited with the invention of GAs. Holland's 1975 monograph [11] describes the basic approach to the population-based search characteristics of today's GAs. A second major milestone in the history of GAs

came up with the publication of David Goldberg’s 1989 book [10]. The publication of Goldberg’s text accelerated the application of GA. Since then, search algorithms from GA have been applied in a diverse array of disciplines, and the benefits resulting from these efforts have been numerous.

The GA Algorithm works by creating an initial population of N possible solutions in the form of candidate chromosomes. Each of these individuals is a representation of the target system. Initial population could be generated at random, or as genetic material from some previous procedure. A population consists of a collection of chromosomes. Every chromosome represents a possible solution. Each chromosome consists of one or more genomes. A particular feature in the chromosome is represented by a genome. The nature of a genome depends on the underlying data representation. For binary representations, the genome is a series of bits. For a real number representation, the genome is an integer or floating-point number.

Multi-objective optimization has been applied in many fields of science, including engineering, economics and logistics (see the section on applications for detailed examples) where optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives. ‘gamultiobj’ can be used to solve multi objective optimization problem in several variables. Here we want to minimize two objectives, each having one decision variable.

$$\min F(x) = [objective1(x); objective2(x)]$$

2. Algorithm accessing toolbox

Step 1: make a function file in MATLAB with objective function.

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Step 4: run

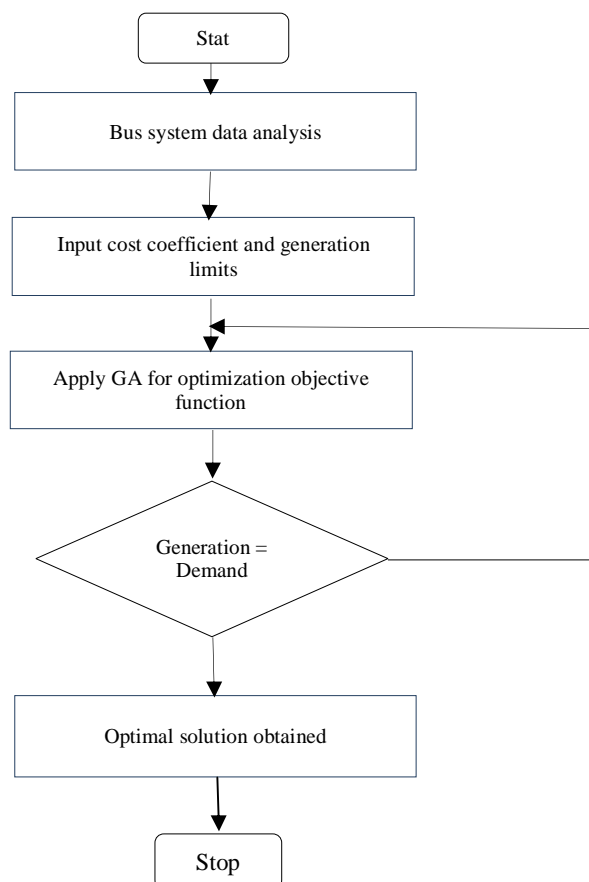


Fig. 2 Flow chart of execution of GA

VI. RESULT

The proposed solution techniques were applied in several test cases yielding good results. The program was written in Matlab R2015a. To illustrate the efficiency of the algorithm performance of the conventional method, SQP, GA, MGA tested on IEEE 30 bus and results were obtained. In given bus system there are 6 generator bus, 25 load buses, 41 transmission line. Cost coefficients and generator limits are given Table 1, total load demand of system is 283.4 MW

Table 1
Generator data for 30 bus IEEE test system

Bus no	P_G^{min} MW	P_G^{max} MW	Cost coefficient		
			a	B	c
1	50	200	0	2.0	0.00375
2	20	80	0	1.75	0.01750
5	15	50	0	1.0	0.06250
8	10	35	0	3.25	0.00864
11	10	30	0	3.0	0.02500
13	12	40	0	3.0	0.02500

1. Results with conventional method

Table 2 shows the optimization results for conventional method, it gives optimized active power generation by each generator and optimal cost of generation. For initial value of λ is should be chosen equal to or greater than largest value among coefficient b. Iterations are taken until absolute value of $\Delta P^k > \epsilon$. For this above example 18 iterations were needed.

Table 2
Conventional method

Control Variables	Optimized value
P_{G1}	185.4036
P_{G2}	46.8722
P_{G5}	19.1242
P_{G8}	10.0000
P_{G11}	10.0000
P_{G13}	12.0000
Minimum fuel cost, F \$/h	767.60

2. SQP result

Fig. 1 shows final optimal cost of power generated by each generating plant and cost obtained at each iteration with the use of SQP toolbox. It has been observed that frequency of reduction of cost is more at starting iterations and becomes zero at later stage. SQP uses 23 iterations for final optimal result. Table 2 and Table 3 shows conventional method and SQP has same results.

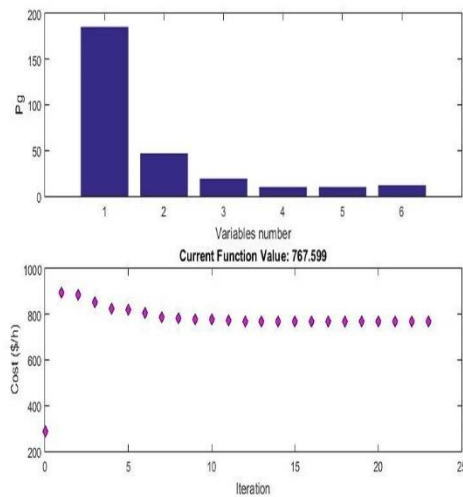


Fig. 1 Shows optimized power generation values and cost at each iteration

Table 3
SQP method

Control Variables	Optimized value
P_{G1}	185.403
P_{G2}	46.872
P_{G5}	19.124
P_{G8}	10
P_{G11}	10
P_{G13}	12
Minimum fuel cost, F \$/h	767.599

3. Genetic algorithm result

Genetic algorithm gives different results if executed multiple times, table 4 shows simulation result for optimized problem with genetic algorithm. Genetic algorithm consumes lot more time as compared with other methods and it needs 5 iterations before it reaches final value.

Table 4
Genetic algorithm method

Control Variables	Optimized value
P_{G1}	185.942
P_{G2}	46.228
P_{G5}	19.045
P_{G8}	10.063
P_{G11}	10.120
P_{G13}	12.000
Minimum fuel cost, F \$/h	767.6196

4. Multi objective genetic algorithm

Table 5 gives results for optimization with the help of multiobjective genetic algorithm. It gives different results comparing to other method.

Table 5
Multiobjective genetic algorithm method

Control Variables	Optimized value
P_{G1}	172.564
P_{G2}	40.892
P_{G5}	21.194
P_{G8}	18.749
P_{G11}	15.208
P_{G13}	14.79
Minimum fuel cost, F \$/h	772.0032

Finally results of all methods are combined and presented in Table no. 6.

Table 6
Comparative analysis of all method

Control Variables	Optimized value			
	Conventional method	SQP	GA	MGA
P_{G1}	185.4036	185.403	185.942	172.564
P_{G2}	46.8722	46.872	46.228	40.892
P_{G5}	19.1242	19.124	19.045	21.194
P_{G8}	10.0000	10	10.063	18.749

P_{G11}	10.0000	10	10.120	15.208
P_{G13}	12.0000	12	12.000	14.79
Minimum fuel cost, F \$/h	767.60	767.599	767.6196	772.0032

VII. CONCLUSION

In this paper three methods for determining optimal power flow and result are compared with conventional method of finding optimal power flow. It has found that results obtained from these methods have approximately same results as compared to conventional method. It is observed that SQP method consumes less time compared to GA method and MGA gave worse cost compared to other method.

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