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Multiobjective Optimal Power Flow Using Particle Swarm Optimization

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ABSTRACT

Power system must be operated in such a way that both real and reactive powers are optimized simultaneously. Reactive powers should be optimized to provide better voltage profile as well as to reduce system losses. The four objectives of minimization of fuel cost, minimization of emission, minimization of losses and increasing stability by minimizing system stability index, these are conflicting and non commensurable. To solve this multi objective problem Particle Swarm Optimization (PSO) algorithm is proposed to solve this Optimal Power Flow (OPF) problem. The proposed algorithm is applied in MATLAB and tested with standard IEEE 57 bus system. The effectiveness of the proposed system is analyzed.

Keyterms: Optimal Power Flow, Real Power Loss, Fuel Cost, Emission cost, stability Index and Particle Swarm Optimization (PSO)

I. INTRODUCTION

Real power optimization problem is the traditional economic dispatch which minimizes the real power generation cost. Reactive power should be optimized to provide better voltage profile as well as to reduce total system transmission loss. Traditional Economic Dispatch [1] aims at scheduling committed generating unit's outputs to meet the load demand at minimum fuel cost while satisfying equality and inequality constraints. The operation and planning of a power system is characterized by having to maintain a high degree of economy and reliability [2]. Among the options available to the power system engineers to operate the generation system, the most significant is the economic dispatch. The characteristics of emissions of various pollutants are different and are usually non-linear. This increases the complexity of the Combined Economic and Emission Dispatch (CEED) problem.

Now a day, more number of optimization algorithms is proposed. In that list PSO (Particle swarm optimization) Algorithm is placed top of the position. Comparative study on PSO for optimal power flow in power systems are proposed [3]. In this paper we focused on the Particle optimization algorithm for optimal power flow. Derivative free optimization technique also incorporated with PSO and is explained in detail. Linear programming algorithms are having some disadvantages when we include this algorithm with piecewise linear cost approximation methods [4]. To integrate the other algorithms with PSO, It has been easily incorporate to form a hybrid tool. The environmental protection requirement does not meet with optimal power flow when generation cost minimization only considered [5]. (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling [6]. In past several years, PSO has been successfully

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applied in many research and application areas. It is demonstrated that PSO gets better results in a faster, cheaper way compared with other methods [7]. The damage caused by a pollutant depends on its type, meteorological conditions and on our exposure to it. This suggests that each pollutant should be treated on its own merit in assigning cost values usually referred to as valuing environmental externalities [8]. To solve the RPD (Reactive Power Dispatch) problem, a number of conventional optimization techniques have been proposed. These include the Gradient method, Non-linear Programming (NLP), Quadratic Programming (QP), Linear programming (LP) and Interior point method. Though these techniques have been successfully applied for solving the reactive power dispatch problem, still some difficulties are associated with them. One of the difficulties is the multimodal characteristic of the problems to be handled. Also, due to the non-differential, non-linearity and non-convex nature of the RPD problem, majority of the techniques converge to a local optimum. Recently, Evolutionary Computation techniques like Genetic Algorithm (GA) [9], Evolutionary Programming (EP) [10] and Evolutionary Strategy [11] have been applied to solve the optimal dispatch problem. Voltage stability is concerned with the ability of a power system to maintain acceptable voltages at all nodes in the system under normal condition and after being subject to a disturbance [12]. A power system is said to have a situation of voltage instability when a disturbance causes a progressive and uncontrollable decrease in voltage level. The purpose of a static voltage stability index is to, in some respect, quantify how 'close' a particular operating point is to the point of voltage collapse, i.e. to estimate the steady state voltage stability limit of the power system. One suggestion for a static voltage stability index is to use the minimum singular value of the power flow Jacobian matrix [13].

The dynamic analysis implies the use of a model characterized by nonlinear differential and algebraic equations which include generators dynamics, tap changing transformers, etc, through transient stability simulations [14]. The emission dispatch sub problem minimizes total emission output from the fossil fuel plants by controlling the generator outputs. At this power output of generator, the cost, total system losses and stability index are high [15]. Similarly Stability index sub problem minimizes the index by controlling the PV bus voltages and thus improves the system stability limit. But the cost, emission and system losses are very high. Thus results of all the four sub problems are conflicting with one other. In order to meet all the four objectives, we need a compromised solution which minimizes fuel cost, emission release, total transmission and losses and improved stability limit. For the decision maker (DM) pareto solutions for individual objectives along with multi objective is presented and to aid decision making fuzzy logic min max methods are used in earlier literature. [16].

In the past decade, a global optimization technique known as genetic algorithms (GA) or simulated annealing (SA), which is a form of probabilistic heuristic algorithm, was adopted for EED (Emission Economic Dispatch) problems. The GA method is usually faster than the SA method because the GA has parallel search techniques, which emulate natural genetic operations. Due to its high potential for global optimization, GA has received great attention in solving ED problems. In some GA applications, many constraints including network losses, ramp rate limits, and valve-point zones were considered for the practicality of the proposed methods. In this research work Particle Swarm Optimization method is used to solve the non-convex, non-continuous and highly nonlinear solution space of the problem. This paper is divided into different chapter for better understanding they are, Chapter 2 presents the problem formulation, Chapter 3 presents proposed algorithm and Chapter 4 presents the Numerical results and Chapter 5 presents Conclusion.

II. PROBLEM FORMULATION

The OPF problem is a constrained optimization problem and it can be mathematically expressed as following equation 1,

Minimize
$$F_T = \sum_{i=1}^{n} F_i(P_i) = \sum_{i=1}^{n} a_i + b_i P_i + c_i P_i^2 \tag{1}$$

Where

F_T = Total cost of generation ($/hr)

n = Number of generators

P_i = Real power generation of ith generator

f_i = Fuel cost function of i^{th} generator

a_i, b_i and c_i are fuel cost coefficients

The objective of Real Power Loss (P_{loss}) of the system expressed in Equation 2.

$$P_{Loss} = \sum_{i=1}^{nbr} g_k [V_i^2 - V_j^2 - 2V_i\, V_j\, \cos(\theta_i - \theta_j)] MW \tag{2}$$

The evaluation function [3] from equation (3) – (5) adopted is

$$f = \frac{1}{1 + k\left(\dfrac{\sum_{i=1}^{n} P_i - P_D - P_{loss}}{P_D}\right)} \tag{3}$$

where, k is a scaling constant (k = 50 in this study).

The fitness function employed is

$$\text{Fit(ii)} = \frac{100}{100+\text{loss}} \tag{4}$$

where loss is the total transmission loss computed from Equation 2.

The fitness function employed is

$$\text{Fit(ii)} = \frac{100}{100+\text{index}} \tag{5}$$

where index is the stability index value.

The L index describes the stability of the complete system and is given by equation (6) - (10):

$$\text{Lindex(i)} = 1 - \left| \frac{\sum_{i \varepsilon n_L} \text{FLG(j-no\_units,i)*E(i)}}{\text{E(j)}} \right| \tag{6}$$

where

$$\text{FLG} = -[Y_{LL}]^{-1} * [Y_{LG}] \tag{7}$$

$$[Y_{LG}(i,j)] = \text{ybus(ng+i , j)} \quad \text{for } i=1 \text{ to } n-n_g, \quad j=1 \text{ to } n_g \tag{8}$$

$$[Y_{LL}(i,j)] = \text{ybus(ng+i,ng+j)} \quad \text{for } i,j=1 \text{ to } n-n_g \tag{9}$$

Here ng = number of generators; n = no of buses.

The L index value varies in a range between 0 (no load) and 1 (voltage collapse).

Stability Index of the system is computed as given in equation 10.

$$\text{index}=\sum_{i\varepsilon n_L} \text{Lindex}(i)^2 \tag{10}$$

The reactive power optimization problem is subjected to the following constraints.

Equality Constraints

The Equality constraints are given in equation (11) & (12) represent load flow equation such as

$$\sum_{i=1}^{NG} P_{Gi} = P_D + P_L \tag{11}$$

$$\sum_{i=1}^{NG} Q_{Gi} = Q_D + Q_L \tag{12}$$

Inequality Constraints

These constraints represent the system operating constraints. Generator bus voltages (V_{gi}), reactive power generated by the capacitor (Q_{ci}), transformer tap setting (t_k), are control variables and they are self restricted. Load bus voltages (V_{load}) reactive power generation of generator (Q_{gi}), line flow limit (S_l) and reactive power flow limits (MVA_i)are state variables, whose limits are satisfied by adding a penalty terms in the objective function. These constraints are formulated as from equation (13) – (19).

(i) Voltage limits

$$V_i^{\min} \le V_i \le V_i^{\max} ; i \in N_B \tag{13}$$

(ii) Real Power Limits

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad \text{for i = 1 to NG} \tag{14}$$

(iii) Generator reactive power capability limit

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} ; i \in N_g \tag{15}$$

(iv) Capacitor reactive power generation limit

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max} ; i \in N_c \tag{16}$$

(v) Transformer tap setting limit

$$t_i^{\min} \le t_i \le t_i^{\max} ; i \in N_T \tag{17}$$

(vi) Transmission line flow limit

$$S_l \le S_l^{\max} ; l \in N_l \tag{18}$$

(vii) Reactive Power Flow Limit

$$MVA_i \le MVA_i^{\max} \quad \text{for i = 1 to Nbr} \tag{19}$$

III. PARTICLE SWARM OPTIMIZATION ALGORITHM (PSO)

PSO is inspired by social system, more specifically, the collective behaviors of simple individuals interacting with their environment and each other. PSO simulates the behaviors of bird flocking. Suppose the following scenario: a group of birds are randomly searching food in an area. There is only one piece of food in the area being searched. All the birds do not know where the food is.

PSO, simulation of bird flocking in two-dimension space can be explained as follows. The position of each agent is represented by XY-axis position and the velocity is expressed by V_x (the velocity of X-axis) and V_y (the velocity of Y-axis). Modification of the agent position is realized by the position and velocity information. PSO procedures based on the above concept can be described as follows. Namely, bird flocking optimizes a certain objective function. Each agent knows its best value so far (*pbest*) and its XY position. Moreover, each agent knows the best value in the group (*gbest*) among *pbest*. Each agent tries to modify its position using the current velocity and the distance from *pbest* and *gbest*. The modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation.

$$V_i^{k+1} = V_i^k + C_1 \times rand()_1 \times (pbest_i - S_i^k) + C_2 \times rand()_2 \times (gbest - S_i^k) \tag{20}$$

$$S_i^{k+1} = S_i^k + V_i^{k+1} \tag{21}$$

Where

V_i^{k+1}: Velocity of particle *i* at iteration *k*+1

V_i^k : Velocity of particle *i* at iteration *k*

S_i^{k+1} : Position of particle *i* at iteration *k*+1

S_i^k : Velocity of particle *i* at iteration *k*

C_1 : Constant weighing factor related to *pbest*

C_2 : Constant weighing factor related to *gbest*

$rand()_1$: Random number between 0 and 1

$rand()_2$: Random number between 0 and 1

$pbest_i : pbest$ Position of particle i

$gbest : gbest$ Position of the swarm

Expressions (20) and (21) describe the velocity and position update, respectively. Expression (20) calculates a new velocity for each particle based on the particle's previous velocity, the particle's location at which the best fitness has been achieved so far, and the population global location at which the best fitness has been achieved so far.

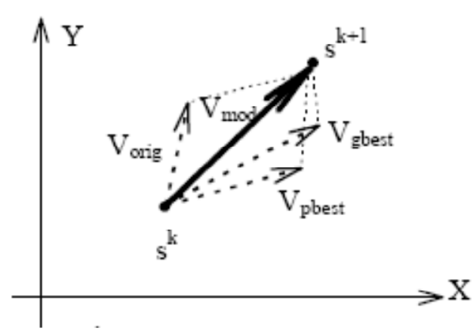

Figure 1: Concept of modification of a searching point

S^k Current Position

S^{k+1} Modified Position

V_{orig} Current Velocity

V_{mod} Modified Velocity

V_{pbest} Velocity base on *pbest*

V_{gbest} Velocity based on *gbest*

3.1. Proposed Algorithm

1. Read the system data.
2. Form Ybus matrix and FLG matrix for Lindex calculation.
3. Form B1 sub matrix. Decompose B1 by Cholesky decomposition.
4. Randomly initialize population and velocities of particles.
5. Set Pbest=0 and iteration count=1.
6. Set particle count=1
7. Decode the particle. Decoded particle gives the values of voltage magnitudes, tap values and shunts.
8. Form the Ybus and B2 sub matrix from Ybus computed in step8.Decompose B2 by Cholesky decomposition
9. Run FDC (Fast Decouple) load flow. From converged voltages compute total system transmission Loss, stability index from equation (6 - 10), emission cost, fuel cost.
10. Calculate the evaluation value of each individual in the population using Equation (3) - (5). Compare each individual's evaluation value with its P_{best}. If the evaluation value of each individual is better than the previous P_{best}, the current value is set to be P_{best}.
11. Increment individual count by 1. If count < population size go to step (7).
12. The best evaluation value among the P_{bests} is denoted as g_{best}.
13. Modify the member velocity V of each individual according to $v_i^{k+1} = k*(w* v_i^k + c_1*rand_1*(pbest_i - x_i) + c_2*rand_2*(gbest_i - x_i))$ $x_i^{k+1} = x_i + v_i^{k+1}$
14. Modify the member position of each individual Pi according to $Pi^{(k+1)}=Pi^{(k)}+Vi^{(k+1)}$

    $Pi^{(k+1)}$ must satisfy the constraints.
15. Increment iteration count by 1.If the number of iterations reaches the maximum, then go to Step 16, Otherwise, go to Step 6
16. The individual that generates the latest g_{best}, is the required control vector for the index optimization sub problem.
17. Run FDC load flow to determine Fuel cost, Emission Cost, System losses and stability index. Print the results.

IV. NUMERICAL RESULTS

The IEEE 57 bus system is considered to validate this developed algorithm; the parameters considered to evaluate the performance are fuel cost, emission cost real power loss and stability index. The proposed system also analyzes the voltage stability of the system, which is given in the following. The proposed IEEE 57 system structure is given in the following figure 2. The proposed algorithm is applied in MATLAB and tested with standard IEEE 57 bus system. The PSO parameters used in this case study are: No of particles 60, learning factors c_1=2.05, c_2=2.05, weight factor w = 1.2, constriction factor K = 0.7925. Maximum number of iterations = 100. Figure 3 shows that Fuel cost Vs iterations; Figure 4 shows that Emission cost Vs iterations; Figure 5 shows that Real Power loss Vs iterations; Figure 6 shows that Stability index Vs iterations.

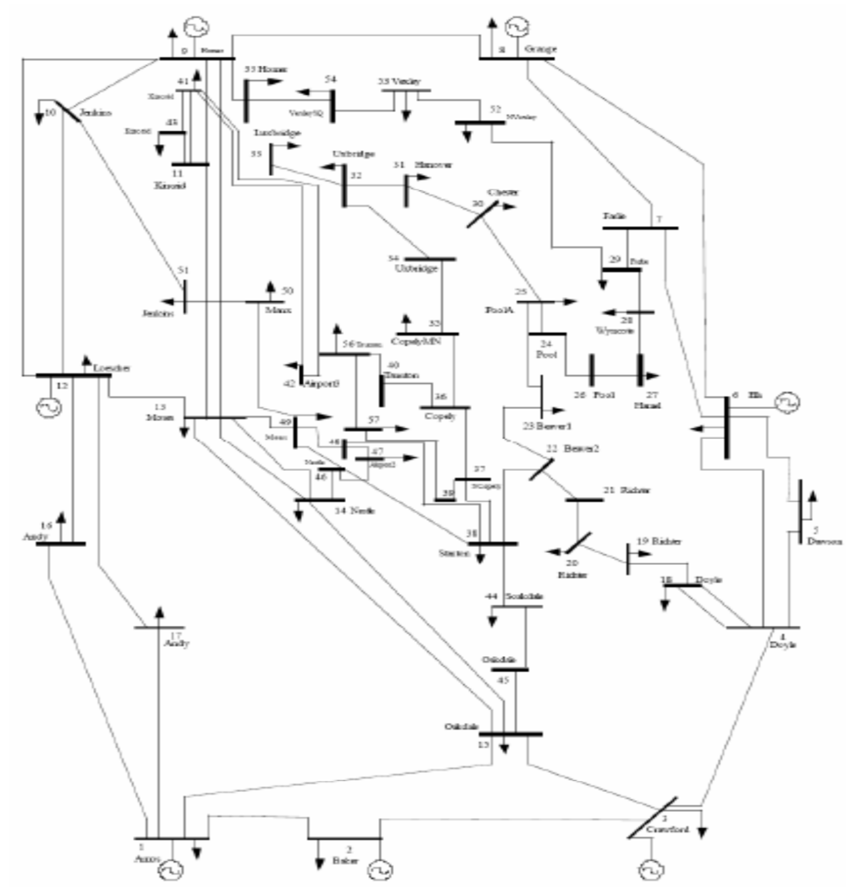

Figure 2: Single Line Diagram of IEEE-57 bus system

Table 1
Multi objective Solution of Optimal Power Flow

Optimization Problem	*Fuel Cost ($/hr)*	*Emission (kg/hr)*	*Losses (MW)*	*Stability Index*	*Multi Objective Solution*
Fuel cost minimization	**752.445076**	148.67573	36.141642	6.188327	**752.445076**
Emission minimization	767.669895	**144.904969**	23.525670	6.67085	**144.904969**
Losses minimization	754.82509	149.425212	**22.679544**	2.191044	**22.679544**
Stability Index minimization	754.825092	149.425212	30.361109	**0.580994**	**0.580994**

*System generation =1273.47MW, total load 1250.8MW

V. CONCLUSION

We have successfully implemented Particle Swarm Optimization solution for multi objective optimal power flow. The PSO algorithm has been tested on IEEE 57 bus system. An attempt has been made to determine the optimum dispatch of generators, when emission release is taken as objective. Optimal Power Flow is taken as another objective and the algorithm has been developed for minimizing the total system losses using PSO. Improving stability index of the system is taken as another independent objective and this improvement is done using PSO. Thus all the four objectives are solved individually and the results from

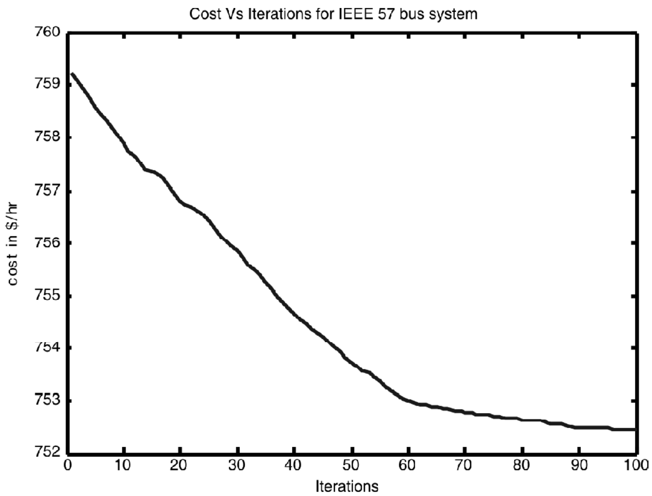

Figure 3: Fuel Cost Vs Iterations

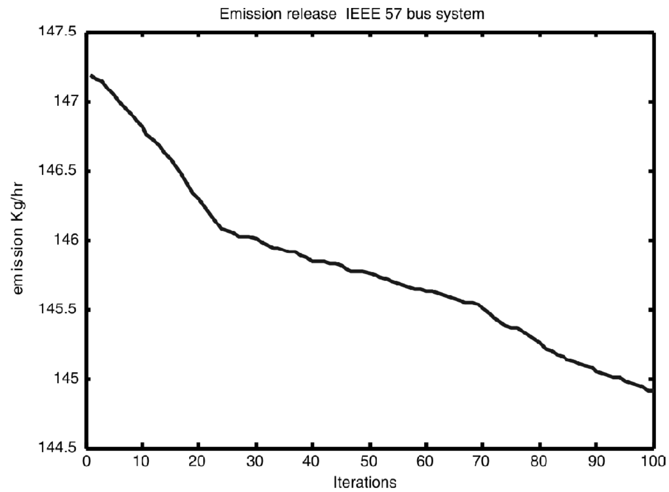

Figure 4: Emission Cost Vs Iterations

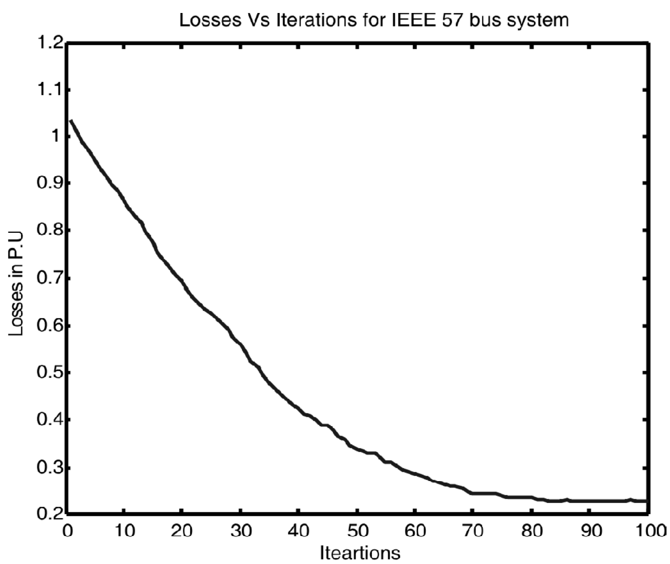

Figure 5: Real power Loss Vs Iterations

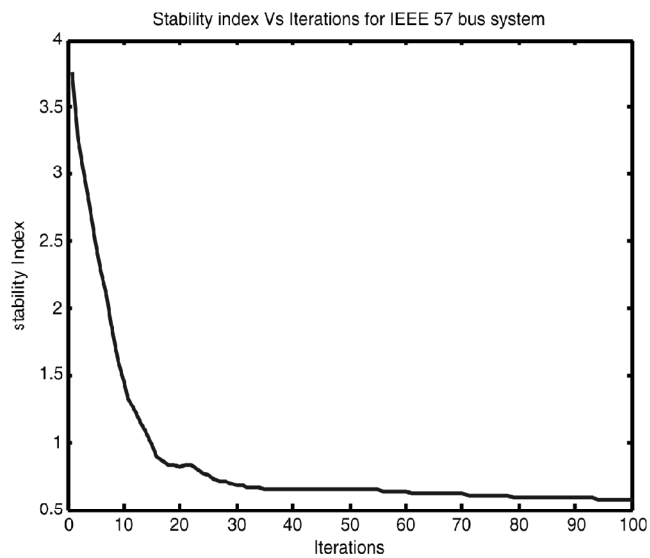

Figure 6: Stability Index Vs Iterations

these individual optimization solutions are obtained. Our proposed approach satisfactorily finds global optimal solution within a small number of iterations. The algorithm is fast and can be applied online. The multiobjective problem is handled using PSO and best solutions has arrived and proved.

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