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USING A PROPOSED PSO OPTIMIZATION WITH NON-DOMINATED SOLUTIONS FOR REACTIVE OPTIMIZATION AND VOLTAGE STABILITY

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Abstract- Reactive power distribution significantly affects the security and the economic performance of the power systems. Although the reactive power generation does not cause any cost in the operation phase, but it affects the whole cost by increasing the system losses. The reactive power optimum distribution is a sub-problem of the optimum power flow (OPF). Improving voltage quality and reducing power loss were the main goals of power system reactive optimization. Static voltage stability margin is an important index of power system safety. A new proposed optimization had been put forward in this paper. In order to put the variables in the allowable limits, had employed for this purpose the limit accept block, until controlled input variable on allowable Limits. The goal of this method was giving consideration to reducing power loss and increasing static voltage stability margin. The result of simulation showed this method is very effective.

Keywords: Optimal Reactive Power Dispatch, Power System Stability, Power System Loss, PSO.

I. INTRODUCTION

The optimal power flow (OPF) problem, which was proposed about 50 years ago by Carpentier, is one of the major issues in power-systems operation (ORPD) [1-3], which can be divided this problem into two sub problems, optimal real power dispatch and optimal reactive power dispatch [4-6]. Optimal reactive power dispatch in power systems is concerned with the security and economy of the power system operation.

The reactive power dispatch is used in order to keep all voltages within the limits and minimize real power transmission losses. Therefore, the optimal reactive power dispatch problem is a highly large-scale nonlinear constrained optimization problem.

The basic objective is to find proper adjustments of the control variables, such as generator voltages, shunt capacitors and inductors that would maintain acceptable voltage stability and minimize power losses.

Several mathematical models and conventional techniques such as gradient-based optimization algorithms, linear programming, interior point method and Newton method have been applied to solve the OPF problem [7, 8]. But the mentioned methods suffer from severe limitations in handling non-linear, discrete-continuous functions, and constraints [9]. Therefore, the conventional optimization methods are not suitable to solve the ORPD problem.

In order to overcome the limitations of classical optimization techniques, a wide variety of the heuristic methods have been proposed to solve the ORPD problem such as genetic algorithm (GA) [10, 11], simulated annealing (SA) [12, 13], Tabu search (TS) [14], differential evolution (DE) algorithm [15, 16], harmony search (HS) algorithm [17], biogeography based optimization (BBO) [18, 19] and particle swarm optimization (PSO) [20].

The reported results are promising and encouraging for further research in this field. In recent years, multi-objective optimization approaches for reactive power control have become popular. But, the attention has been focused upon power losses and voltage deviation.

In this paper, the OPF is formulated as a multi-objective optimization problem. The objectives consist of two important terms, i.e., the total real power loss, Power System Stability. The modified artificial MPSO algorithm is tested on the standard IEEE 30-bus test systems. Simulation results prove the effectiveness of the proposed method.

The rest of this paper is organized as follows: Section II presents the mathematical formulation of the multi-objective OPF problem. Section III introduces PSO and Non-dominating sorting strategy. In Section IV, the MPSO algorithm is described in detail. Simulation results are provided in Section V. Finally, the paper is concluded in Section VI.

II. MODEL

A. Problem Formulation

The purpose of the OPF problem is to determine the optimal control variables for minimizing one or more objective functions subject to the several equality and inequality constraints. The OPF problem can be formulated as

$$\min\{F(x,u)=\begin{matrix} f_1(x,u) \\ f_2(x,u) \\ \vdots \\ f_n(x,u) \end{matrix}\};n=1,2,...,N_{obj} \quad (1)$$

where f_1 is the ith objective function, N_{obj} is the number of objective functions. The vector of dependent and control variables are denoted by x and u, respectively. The slack bus active power P_G, load voltages V, reactive powers of generators Q_G and transmission line loadings S are the dependent variable vector.

$$u=(P_G,V_G,T,Q_{sh}) \quad (2)$$

$$x=(P_{G_{ref}},V,\delta,Q_G) \quad (3)$$

The control variable vector consists of real power outputs except at the slack bus, generator voltages V_G, transformer tap settings T, and reactive power injections Q_{sh}.

B. Objective

B.1. Voltage Stability

Among the different indexes for voltage stability and voltage collapse prediction, a fast indicator of voltage stability, L-index, presented by Kessel and Glavitsch [21], is chosen as the objective for the voltage stability index.

Besides the fast calculation time needed to evaluate each load bus steady state voltage stability level, the chosen index can also take into account generator buses reaching reactive power limits. The L-index value ranges from 0 (no load of system) to 1 (voltage collapse). The bus with the highest L-index value will be the most vulnerable bus and hence this method helps identifying the weak areas needing critical reactive power support in the system. The general theory and algorithm of the index is summarized as following [22, 23].

$$L_j=\left|1-\sum_{i=1}^{N_g}F_{ij}\frac{V_i}{V_j}\right| \ , \ j=N_g+1,...,n \quad (4)$$

The matrix F is computed as follows:

$$\left[F_{ij}\right]=-\left[Y_{LL}\right]^{-1}\left[Y_{LG}\right] \quad (5)$$

where $\left[Y_{LL}\right]$ and $\left[Y_{LG}\right]$ are submatrices of the Y bus matrix. The L indices for the given load condition are computed for all load buses and the maximum of L-indices gives the proximity of the system to voltage collapse.

A global indicator (L) describes the stability of the whole system which is calculated by the following equation:

$$L=\max(L_j) \ , \ j\in\alpha_j \quad (6)$$

In practice, L must be lower than a given threshold value. The predetermined threshold value is specified depending on the system configuration and on the utility policy regarding service quality and allowable margin [22]. Therefore, the minimization of the L value is considered as an objective function.

B.2. Minimization of Transmission Loss

The active power losses in a transmission network can be described as follows [21, 24]:

$$P_{Loss}=\sum_{k=1}^{N_L}g_k[V_i^2+V_j^2-2V_iV_jCos(\delta_i-\delta_j)] \quad (7)$$

where g_k is the conductance of kth branch, V_i, V_j, δ_i and δ_j are the voltage magnitudes and phase angles of terminal buses of branch k.

C. Constraints

Power balance is equality constraint. In other word, the total power generation must cover the total demand and total real power loss in transmission lines (P_{Loss}). The proposed problem has some equality and inequality constraints. Equality constraints reflect the physics of the power system, expressed as [23]:

$$P_{G_i}-P_{D_i}=\sum_{j=1}^{N_{Buses}}V_iV_jY_{ij}Cos(\theta_i-\delta_i+\delta_j) \quad (8)$$

$$Q_{G_i}-Q_{D_i}=\sum_{j=1}^{N_{Buses}}V_iV_jY_{ij}Sin(\theta_i-\delta_i+\delta_j) \quad (9)$$

Inequality constraints reflect the limits of physical devices in the power system as well as the limits created to ensure system security, expressed as

$$V_{G_i}^{\min}\le V_{G_i}\le V_{G_i}^{\max}, i=1,2,...,N_G \quad (10)$$

$$P_{G_i}^{\min}\le P_{G_i}\le P_{G_i}^{\max}, i=1,2,...,N_G \quad (11)$$

$$Q_{G_i}^{\min}\le Q_{G_i}\le Q_{G_i}^{\max}, i=1,2,...,N_G \quad (12)$$

$$Q_{sh_i}^{\min}\le Q_{sh_i}\le Q_{sh_i}^{\max}, i=1,2,...,N_G \quad (13)$$

$$V_i^{\min}\le V_i\le V_i^{\max}, i=1,2,...,N_G \quad (14)$$

III. OPTIMIZATION

A. Particle Swarm Optimization

PSO [25] is one of the methods among the many smart methods for solving the optimization problems that was first introduced as an optimization method by Kennedy and Eberhart and it is inspired by the birds wings. In the PSO algorithm, each particle has a value that is called fitness and it is calculated by the fitness function. This fitness is measured by the amount of the closeness to the target. Basically the beginning of the PSO is in a way that a group of particles are randomly created and in each level, each particle is optimized by the use of two optimum values.

The first value is called the best personal experience or the "*pbest*". The other best result which is used is the best position that is gained by a group of particles and it is called the "*gbest*". The equation of the velocity updating [25]:

$$V_i^{k+1} = V_i^k + C_1 rand_1 + (pbest_i - s_i^k) + C_2 rand_2 + (gbest_i - s_i^k) \quad (15)$$

The role of the weigh parameter in converging the algorithm is so important, because it is used for affecting the velocity at the present moment by the velocity of the previous moment. The equation of the position updating:

$$s_i^{k+1} = s_i^k + v_i^{k+1} \quad (16)$$

Step 1) Assuming primary values for parameters like: congestion, the weigh function, the accelerator function and etc. The primary search (s_i^0) and v_i^0 are randomly selected for the N generating units. These primary particles are to create the possible solutions according to the possible operational limitations.
Step 2) Calculating the value of P_{Gi} core in the global particle
Step 3) Comparing the value of fitness for each particle, using its "*pbest*". The best "*pbest*" is used as the "*gbest*".
Step 4) V, the velocity of each particle according to the updating.
Step 5) The value of the position "*s*" is used as the changed position of each particle.
Step 6) If the value of the fitness is better than the value of "*pbest*", the value of "*pbest*" is replaced by the present value of the function. Also, if the value of the "*pbest*" is better than the value of the present "*gbest*", then it is replaced by its best amount and this best amount is stored.
Step 7) If the number of repetitions has reached to the preserved value, it goes to the step 8, otherwise it goes to the step 2.
Step 8) The particle that has generated the last "*gbest*", is the most optimum generated power of each unit with the less total generation cost.

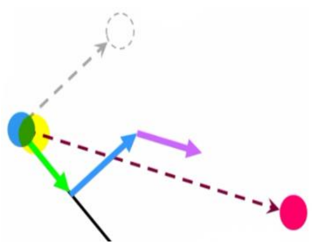

Figure 1. Behavior of PSO Algorithm

The steps mentioned above are shown briefly in the flowchart below:

B. Multi-Objective Optimization

Multi-objective optimization refers to the simultaneous optimization of multiple conflicting objectives, which produce a set of alternative solutions called the Pareto optimal solutions. The Pareto method determines a set of solution for multi objective problems using the dominance concept.

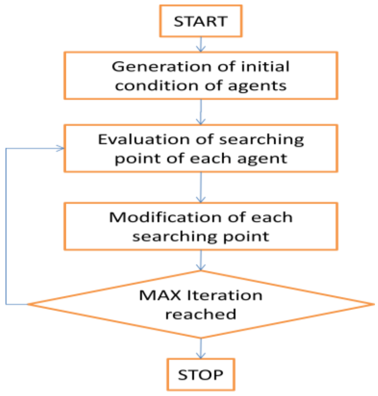

Figure 2. The steps of PSO

The population is initialized as PSO. Once the population in initialized the population is sorted based on non-domination solutions into each front.

$$X \le Y (XdomY) \leftrightarrow \forall i : X_i \le Y_i \cap \exists i_0 : X_{i_0} \prec Y_{i_0} \quad (17)$$

The first front being completely non-dominant set in the common population and the second front being dominated by the individuals in the first front only and the front goes so on. Each individual in the each front are given rank (fitness) values. Individuals in first front are given a rank value of 1 and individuals in second are assigned rank value as 2 and so on.

In addition to the fitness value, a new parameter called crowding distance is calculated for each individual. The crowding distance is a measure of how close an individual is to its neighbors. In the other word, the crowding distance *di* of point *i* is a measure of the objective space around *i* which is not occupied by any other solution in the population. Here, we simply calculate this quantity *di* by estimating the perimeter of the cuboid (Figure 3) formed by using the nearest neighbors in the objective space as the vertices (18).

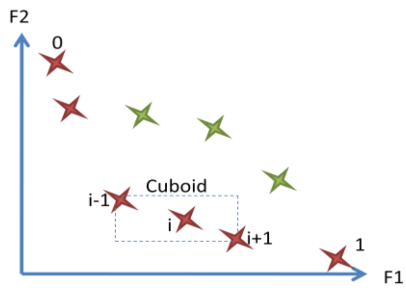

Figure 3. Behavior of crowding distance

$$\begin{cases} d_i^1 = \dfrac{\left| f_1^{back} - f_1^{next} \right|}{f_1^{\min} - f_1^{\max}} \\ d_i^2 = \dfrac{\left| f_2^{back} - f_2^{next} \right|}{f_2^{\min} - f_2^{\max}} \\ \vdots \\ d_i^j = \dfrac{\left| f_j^{back} - f_j^{next} \right|}{f_j^{\min} - f_j^{\max}} \end{cases} \Rightarrow D = d_i^1 + d_i^2 + \ldots + d_i^j \quad (18)$$

Parents are selected from the population by using tournament selection based on the rank and crowding distance. An individual is selected in the rank is lesser than the other or if crowding distance is greater than the other. The selected population generates child from kind of crossover and mutation operators.

The population with the common population (P_t) and current child (Q_t) is sorted again first crowding distance then based on non-domination (rank) and only the best N individuals are selected. The selection is based on rank and then on crowding distance on the last front (Figure 4).

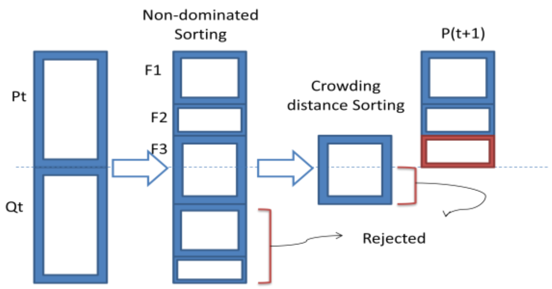

Figure 4. The selection

IV. PROPOSED MPSO ALGORITHM FOR SOLVING PROBLEM

In this study, an innovative approach based on PSO was chosen for solving the ORPD problem. For maintaining the variables in allowable limits, a limit accept block had been employed for this purpose (Figure 5).

We do according to the following method:

Step 1) at first, all the units should give their minimum amount and after that a unite is chosen.

Step 2) According to the random function one of them is selected. Then the utilized value, is added in to the primary value that was set it first step. If this action does not violate condition "11" and that the amount of $\sum_{i=1}^{N_g} F_i(P_i)$ is less than P_D, then adding the constant value is accepted and proceeding to the Step 3 is approved, otherwise the constant value is reject and repeated.

Step 3) If the is not violated, then proceeding to the next level is approved, otherwise going to the Step 2 is mandatory.

Step 4) The primary amounting is done.

Step 5) Chose another unite, i.e. Go to Step 1.

We should do the same guess algorithm in a decreasing way, in which we give the maximum amount of units to them and we do the same steps in the decreasing route.

V. SIMULATION RESULTS AND CONCLUSION

The Proposed PSO algorithm was coded in the MATLAB, and executed on Intel core i5 2.5 GHz PC, with 6 GB of RAM. The test was performed on the IEEE 30-bus system which has 41 transmission lines and the system demand is 283.4 MW in all simulations. The simple line diagram of IEEE 30-bus test system is shown in Figure 6.

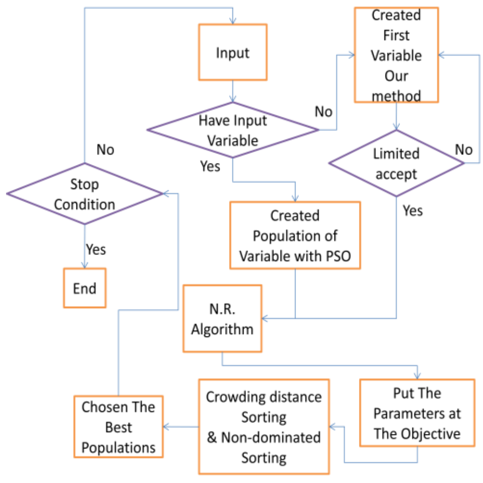

Figure 5. The brief of Method

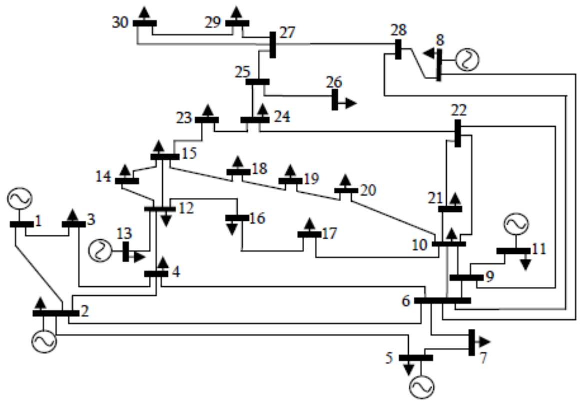

Figure 6. Topology of the IEEE 30-bus

Table 1. Variables for best solution

Control Variables	Optimal control variable settings	
	Best P_L (MW)	Best Voltage Stability
P_1	26.2441	53.6908
P_2	27.1431	29.6772
P_5	95.9255	56.9856
P_8	40.1907	34.4360
P_{11}	60.5662	41.9253
P_{13}	35.3028	70.5632
V_1	1.0479	1.0131
V_2	1.0415	1.0171
V_5	1.0355	1.0342
V_8	1.0439	1.0514
V_{11}	1.0195	1.0135
V_{13}	1.0877	1.0596
t_{11}	0.9559	1.0194
t_{12}	0.9576	0.9561
t_5	1.0012	1.0097
t_{36}	0.9631	1.0173
Qc_{10}	12.6308	10.9464
Qc_{12}	15.8400	12.1170
Qc_{15}	23.1463	17.8243
Qc_{17}	15.0704	20.9365
Qc_{20}	12.9537	8.5345
Qc_{21}	8.7276	21.4836
Qc_{23}	15.2271	9.0910
Qc_{24}	13.5628	6.4339
Qc_{29}	11.3905	8.9282
P_L (MW)	**1.9753**	3.881269
Voltage Stability	0.0758	**0.023055**

MATPOWER4.1 is a package of MATLAB m-files for solving power flow and optimal power flow problems. It is intended as a simulation tool for researchers and educators which will be easy to use and modify. Best Simulation results for each of Objective are reported in Table 1.

VI. CONCLUSIONS

From the result seen in Table 2, it is obvious that, the MPSO method obtains lower power loss and Voltage stability than the EA [24], PSO [25], CA [25], EGA-DQLF [26], FAPSO [27], OSAMGSA [28], GSA [29], CLPSO [30], PSO [30], BBO [31], SARGA [32], etc. method, thus resulting in the higher quality solution method.

One of the goals of the reactive power programming is to reach the increase in the power system stability margin. This studying is accomplished in a way that the voltage stability margin is being set to an appropriate amount by using the least new reactive power resources corresponding to the probable disturbances.

A MPSO is presented in this paper to solve the multi objective problems The main goal is to determine the optimal combination of power outputs for all generating units that minimizes the total Power loss and in other side give the upper voltage stability while satisfying load demand(active and reactive) and operating constraints. This problem has been formulated as multi objective optimization problem.

In this paper, MPSO multi objective Optimization with Pareto optimal non-dominated solutions, a stochastic optimization technique was employed to obtain the optimum values of the reactive power variables applied to standard IEEE systems to show advantages of proposed algorithm.

The results show that the proposed algorithm provide a accurate algorithm to tackle efficiently the difficult problem. It is observed that obtaining the global optimal solution is possible by using the proposed algorithm. Numerical experiments demonstrate that the proposed algorithm is more practical and valid than many existing techniques for the solution of the problem.

Table 2. Convergence results

Method	Objective	
	P_{loss} (MW)	Voltage Stability
EA [24]	5.1065	-
PSO [25]	5.0938	-
CA [25]	5.0933	-
EGA-DQLF [26]	-	0.10402
FAPSO [27]	-	0.1238
OSAMGSA [28]	5.0713	0.1036
[23]	4.6501	0.1828
[23]	20.8074	0.2027
GSA [29]	4.514310	0.141090
CLPSO [30]	4.5615	0.1230
PSO [30]	4.6282	0.1423
BBO [31]	4.5511	-
SARGA [32]	4.57401	-
C-PSO [33]	2.6629	-
B-DE [33]	2.1070	-
MABC [33]	2.0673	-
MNSAGA-II (Best P_{loss})	**1.9753**	0.075796
MNSAGA-II (Voltage Stability)	3.881269	**0.02305**

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BIOGRAPHIES

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