APPLICATION OF MIXED-INTEGER HYBRID DIFFERENTIAL EVOLUTION TO OPTIMAL REACTIVE POWER DISPATCH

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This paper presents the application of an evolutionary algorithm: Mixed Integer Hybrid Differential Evolution (MIHDE) to the solution of reducing the system losses and improving the system voltage profile by obtaining an efficient distribution of the reactive power in an electric network. This can be achieved by varying the excitation of generators or the on-load tap changer positions of transformers. The feasibility, effectiveness and generic nature of MIHDE approach investigated are exemplarily demonstrated on the IEEE 30 bus system.

Keywords: Optimal Reactive Power Dispatch, Reduction of the System Losses, Mixed Integer Hybrid Differential Evolution

1. Introduction

The objective of optimal reactive power dispatch (ORDP) is to minimize the real power losses and keep the voltages and reactive power generations in their operating limits. In this matter the control variables are generator bus voltages and transformer tap position. Many methods based on linear and non-linear programming have been proposed to solve this problem. These optimization methods are based on successive linearization and use the first and second derivatives of objective function and its constraint equations as the search directions. Such treatments quite often lead to a local minimum point and sometimes result in divergence.

This paper presents an application of Mixed Integer Hybrid Differential Evolution (MIHDE), instead of the conventional methods, to solve an optimization reactive power dispatch problem with the purpose of minimizing the active power losses and improving the voltage level in a large scale power system.

MIHDE algorithm is technically simple; population based evolutionary algorithm (EA), which is highly efficient in constrained parameter optimization problems [1]. MIHDE employs a *greedy* selection process. It has demonstrated its

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robustness and effectiveness in a variety of applications, such as neural network learning and infinite impulse response filter design.

The algorithm for reactive power and voltage control of power system has been developed using MATLAB Version 7.0 R13. The technique applied here presents no difficulty in solving *mixed integer* problems and hence highly suitable for reactive power optimization where the generator voltage is a real valued parameter while tap position and the number of shunt devices to be switched are integer parameters [2].

2. Problem formulating

The mathematical model for optimal reactive power dispatch problem is formulated as follows.

The objective function:

$$MIN\left[P_{LOSS}\right]=\sum_{(i,k)\in L\cup T}\Delta P_{i,k} \tag{1}$$

with equality constraints:

$$\begin{aligned} P_i^{sch} &= U_i\sum_{k=1}^{n}U_k\left(G_{ik}\cos\left(\theta_i-\theta_k\right)+B_{ik}\sin\left(\theta_i-\theta_k\right)\right)\\ Q_i^{sch} &= U_i\sum_{k=1}^{n}U_k\left(G_{ik}\sin\left(\theta_i-\theta_k\right)-B_{ik}\cos\left(\theta_i-\theta_k\right)\right)\end{aligned} \tag{2}$$

and inequality constrains:

$$\begin{aligned} &Q_{gi}^{\min}\le Q_{gi}\le Q_{gi}^{\max} \quad i\in N_{PU}\\ &t_{ik}^{\min}<t_{ik}<t_{ik}^{\max}\ i\in T\\ &U_i^{\min}\le U_i\le U_i^{\max} \quad i\in N_B\end{aligned} \tag{3}$$

In this context the tap position of the transformer ***i-k*** and the voltage at generator bus, U_i, represents the control variable of our problem. For implementing the evolutionary techniques the inequality constrains are added as a quadric penalty terms to the objective function and the active power losses are expressed from the equation of active power balance. Thus the optimization problem can be reformulated as follows:

$$MIN\left[f_q\right]=P_{LOSS}+\sum_{i\in N_{U\lim}}\lambda_{U_i}\left(U_i-U_i^{\lim}\right)^2+\sum_{i\in N_{Qg\lim}}\lambda_{Q_{gi}}\left(Q_{gi}-Q_{gi}^{\lim}\right)^2+\sum_{i\in T}\lambda_t\left(t_{ik}-t_{ik}^{\lim}\right)^2 \tag{4}$$

where λ_{U_i}, λ_t and $\lambda_{Q_{gi}}$ are the penalty factors that can be increased in the optimization procedure and $U_i^{\lim}$, respectively $Q_{gi}^{\lim}$ are defined in the following equations:

$$U_i^{\lim} = \begin{cases} U_i^{\min} & if \quad U_i < U_i^{\min} \\ U_i^{\max} & if \quad U_i > U_i^{\max} \end{cases}; \quad Q_{gi}^{\lim} = \begin{cases} Q_{gi}^{\min} & if \quad Q_{gi} < Q_{gi}^{\min} \\ Q_{gi}^{\max} & if \quad Q_{gi} > Q_{gi}^{\max} \end{cases}$$

$$t_{ik}^{\lim} = \begin{cases} t_{ik}^{\min} & if \quad t_{ik} < t_{ik}^{\min} \\ t_{ik}^{\max} & if \quad t_{ik} > t_{ik}^{\max} \end{cases} \tag{5}$$

It can be seen that the generalized objective function f_q is a non-linear and non-continuous function. Gradient based conventional methods are not good enough to solve this problem.

3. Evolutionary Techniques

Evolutionary techniques are artificial intelligence methods used mainly for optimization, based on the principle of natural selection, such as mutation, recombination, and reproduction. Starting from an initial generation of candidate solutions, this evolutionary process produces advanced generations with candidates that are successively better suited to their environment.

Mixed Integer Hybrid Differential Evolution

In the past decade, there has been an increased interest in solving optimization problems consisting of real and integer (or discrete) variables. Such problems are called mixed-integer nonlinear programming (MINLP) problems. This paper introduces a Mixed Integer Hybrid Differential Evolution (MIHDE) algorithm, an extension of the classical Differential Evolution Algorithms (DEA), for solving the MILP problem of optimal reactive power dispatch.

The algorithm proposed in this paper presents no difficulty in solving mixed integer problems [5] and hence is highly suitable for reactive power optimization where the generator voltage is a real valued parameter while tap position and the number of shunt devices to be switched are integer parameters.

MIHDE use mutation process which randomly perturbs a candidate solution, recombination which randomly mixes their parts to form a novel solution, and reproduction who replicates the most successful solutions found in a population.

Treatment of control variables

In its basic form, differential evolutionary algorithm can handle only continuous variables. However, reactive power source installation and tap position of tap changing transformers are discrete variable or integer variable and generator terminal voltages are continuous variables in the reactive power dispatch problem. Here, differential evolutionary algorithm has been extended to handle mixed integer variables [4]. For integer variables the value is rounded off to the nearest integer value of the variable.

$$x_i = \begin{cases} x_i & \text{for continuous variables} \\ \lfloor x_i \rfloor & \text{for integer variables} \end{cases}$$

where $\lfloor x_i \rfloor$ function gives the nearest integer less than or equal to x.

1). Representation and Initialization

MIHDE algorithm is a parallel direct search algorithm that uses N_P (number of individuals) vectors of decision variables (*U*, *t*) real – integer [5]. The population at a G generation is defined as being: $P_i^G = \left(U, t_{ik}\right)_i^G$, $i = 1, ..., N_P$. Decision variables (genes), U_{ik} and t_{ik} are directly used as values of real and integer numbers. The initialization process generates N_P individuals (*U*, *t*) randomly and should try to cover the entire search space uniformly.

The value of the *fitness* function of each individual, P_i^G, is obtained by running load-flow with Newton-Raphson method.

2). Mutation

MIHDE does not use a predefined probability density function to generate perturbing fluctuations. It relies upon the population itself to perturb the vector parameter [5]. According to the mutation operator, for each individual $P_i^G, i = 1, ..., N_p$ at G generation, a mutant individual is determined P_i^{G+1} using the following equation:

$$P_{i,mut}^G = P_{r_1}^G + s\left(P_{r_2}^G - P_{r_3}^G\right) \tag{6}$$

where $s \in [0,1]$, which controls the amplification of the difference between two individuals to avoid search stagnation and r_1, r_2 and r_3 are randomly selected.

3). Crossover

The mutation factor in MIHDE is heuristic using the random choice. In essence, the mutant individual in (6) is a noisy replica of $\left(U, t_{ik}\right)_i$. While the population diversity is small, the candidate individuals will rapidly cluster together so that the individuals cannot be further improved. This fact may result in a premature convergence. In order to increase the local diversity of the mutant individuals, a *crossover* is introduced. In the crossover operation each gene of the individual *i* is reproduced from the mutant individual, $P_{i,mut}^G$ and the current individual (parent):

$$P_{i,cross}^{G} = \begin{cases} P_i^G & ,\text{if a random number} > \rho_c, \\ P_{i,mut}^{G} & ,\text{else.} \end{cases} \tag{7}$$

where the crossover factor $\rho_c \in [0,1]$ is a constant and has to be set by the user.

4). Evaluation and Selection

In MIHDE the evaluation process is based on one to one competition between the parent and his offspring. The actual individual competes with his parent based on their fitness function. All individuals in the population have the same chance of being selected as parents independent of their fitness value. If the parent is still better, it is retained in the population. The best individual of the two is going to participate at reconstruction the new generation.

5). Termination criteria

The iterative procedure can be terminated when any of the following criteria is met, i.e., an acceptable solution has been reached, a state with no further improvement of the solution is reached, the control variables has converged to a stable state or a predefined number of iterations, set by user, have been completed.

4. Case Study

In this section the IEEE 30 bus system [6] is used to show the effectiveness of MIHDE by doing a comparative study between MIHDE and Particle Swarm Optimization (PSO) [7], [8]. The results are obtained by implementing the two algorithms in Matlab 7.8 [9], [10]. The branch parameters and loads are given in [11].

Initial conditions

Generator bus voltages are set to 1.0 p.u. and tap position is set to 0 (nominal), totals active and reactive loads, generated active and reactive power and network power losses are presented in Table 1. After running the power flow, for the initial conditions, we observe that there are buses with voltages violating their limits (Fig.1).

Optimal solution using evolutionary techniques

In order to use MIHDE and PSO in reactive power planning problem [12], the control variables of the transmission network (voltages at *PU* buses and tap position) are arranged as elements of an individual in populations used during evolutionary search:

$$p_i = \begin{bmatrix} U_{g2} & U_{g5} & U_{g8} & U_{g11} & U_{g13} & U_{g30} & t_{6,9} & t_{6,10} & t_{4,12} & t_{28,27} \end{bmatrix}$$

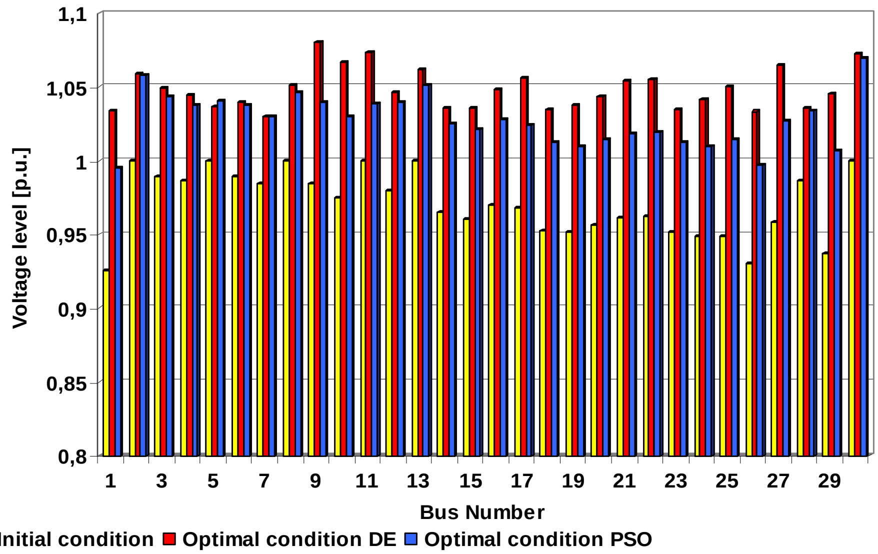

Fig. 1. Voltage level – Initial condition / Optimal condition

After computation of power flow with the optimal values obtained with MIHDE and PSO, we notice an improvement of the voltage level at the system buses (Fig. 1) and new total active and reactive generated power and active power losses (Table 2 for the implementation of MIHDE algorithm and Table 3 for the implementation of PSO algorithm) .

Table 2

Active and Reactive Generated Power and Power Losses with MIHDE

P_G [p.u.]	Q_G[p.u.]	P_{LOSS}[p.u.]
2.8865	1.2398	0.0520

Table 3

Active and Reactive Generated Power and Power Losses with PSO

P_G [p.u.]	Q_G[p.u.]	P_{LOSS}[p.u.]
2.8865	1.2517	0.0516

To be noted that after the optimization process [13] we obtain a better reactive power dispatch in the system (Fig.2) and a considerable power saving of 14.1914% in MIHDE case and 14.94% in PSO case [14].

The stochastic methods studied here, leave room for uncertainties. For this reason ten simulations where carried out in order to evaluate the deviation of the final results, in particular, the reductions of the active power losses under the assumed constraints [14].

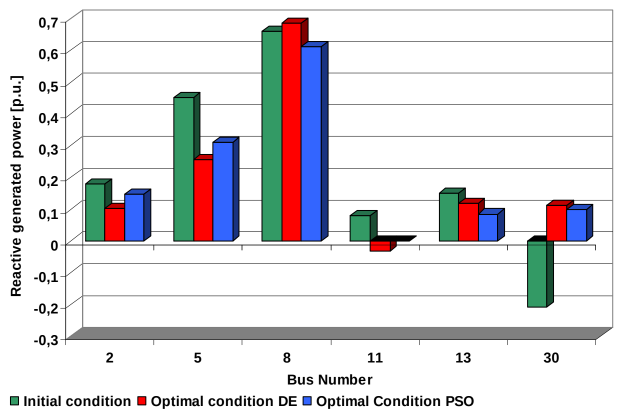

Fig. 2. Reactive power generation – Initial condition / Optimal condition

5. Conclusions

Results show that both approaches succeeded in achieving the goals of reactive power planning and power loss reduction. In the implementation phase few preparative calculations sufficed to find appropriate parameter settings for both approaches; MIHDE generally requires fewer settings than PSO. PSO procured little better power loss reduction compared with MIHDE. Regarding the performance, both approaches used here are based on stochastic search; thus, definite statements concerning the computational efficiency would require systematic investigation based on a multitude of test runs.

The simulation results revealed that both approaches were able to remove the voltage limit violations, but PSO procured in some instances slightly higher power loss reduction as compared with MIHDE. On the other hand, in the observed test cases MIHDE required a considerably lower number of function evaluations as compared with PSO.

The simulation results shows that the application of MIHDE to reactive power planning could achieve very attractive power savings and better operating conditions, cheeping the voltages and reactive generated powers into their limits.

Acknowledgements

This work has been funded by the sectorial operational program human resources development 2007-2013 of the Romanian Ministry of Labor, Family and Social Protection through the financial **Agreement Posdru/88/1.5/s/60203**

R E F E R E N C E S

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