Research of Dynamic Economic Emission Dispatch Based on Parallel Molecular Differential Evolution Algorithm

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Abstract. Power system dynamic economic emission dispatch plays an important role in energy saving and emission reduction. The model is set up with generation cost and pollution emission minimum as the optimization objectives. The energy cost caused by the valve point effect of the conventional thermal power unit is included in the generation cost. The network loss is considered in the equality constraint, and the solution equation is used to deal with the complex constraint relation. In view of the premature diversity caused by the low diversity of differential evolution algorithm, the molecular differential evolution algorithm is adopted to solve the model. Under the premise of ensuring the accuracy of the original calculation, using the ability of Matlab multi-core parallel computing to improve the molecular differential evolution algorithm, the computational efficiency of the algorithm is improved. The simulation results of the classical 10-unit test system show that, compared with the traditional differential evolution algorithm, the parallel molecular differential evolution algorithm is improved, not only has better global search ability, but also can provide a faster and better choice for decision maker.

1. Introduction

With the continuous development of social economy and the rapid increase of power system, Static Economic Dispatch only considering the generation unit output constraints cannot meet the requirements of power system security and stability. Based on ED and the interaction of each time, Dynamic economic dispatch (DED) is produced. DED considers the ramp / landslide rate of the unit, and its scheduling strategy is more practical but more difficult. In recent years, with the further increase of environmental pollution and air pollution, many countries have formulated relevant laws and regulations about energy saving and emission reduction, taking into account the conventional gas pollution from thermal power plant, Dynamic Economic Emission Dispatch (DEED) came into being [1].

DEED considers not only the economy but also the environment, and it is a multi-objective optimization problem with nonlinear and strong constraints. At present, the research on solving DEED mainly focus on multi-objective functions and have made great achievements on algorithms[2-3], but overall the following problems exit: the objective function and constraint conditions are not complete; the cost caused by the valve point effect in the objective function and optimal network loss are not considered; in the optimal solution concentration, the individuals are dense and unevenly distributed,
the computational speed is slow[4-5]. In this paper, a Parallel Molecular Differential Evolution (PMDE) algorithm is proposed to solve the DEED problem quickly and efficiently.

2. DEED Modelling

DEED choose the minimum generation cost and pollution emission as two competing objective function, the mathematical model is as follows:

\[
\begin{cases}
\min \{ f(x), f_2(x) \} \\
\text{s.t. } g(x) = 0 \quad h(x) \leq 0
\end{cases}
\]

Where \( f(x) \) the objective function, \( g(x) \) is equality constraint, \( h(x) \) is inequality constraint.

2.1. Objective Function

**Generation Cost.** When the valve point effect of the turbine is taken into account, the objective function is expressed as follows:

\[
f_1 = \sum_{i=1}^{T} \sum_{t=1}^{H} \left[ F_i(P_{it}) + E_i(P_{it}) \right] \\
F_i(P_{it}) = a_i + b_iP_{it} + c_iP_{it}^2 \\
E_i(P_{it}) = d_i \sin \left[ e_i \left( P_{it}^{\text{min}} - P_{it} \right) \right]
\]

Where \( F_i(P_{it}) \) and \( E_i(P_{it}) \) is the total fuel cost and energy cost caused by valve point effect of the \( i \)th conventional thermal power unit in the \( t \)th period; \( T \) is the total period number of dispatch; \( H \) is the number of conventional thermal power units; \( P_{it} \) is the active power output of the \( i \)th generator in the \( t \)th period; \( P_{it}^{\text{min}} \) is the minimum output of the \( i \)th generator; \( a_i, b_i \) and \( c_i \) are the cost coefficient of the \( i \)th generator; \( d_i \) and \( e_i \) are the valve point effect coefficient of the \( i \)th generator.

**Pollution Emission.** Comprehensive emission characteristics can be expressed as:

\[
f_2 = \sum_{i=1}^{T} \sum_{t=1}^{H} \left[ a_i + \beta_i P_{it} + \gamma_i P_{it}^2 + \eta_i \exp(\delta_i P_{it}) \right]
\]

Where \( \alpha_i, \beta_i, \gamma_i, \eta_i \) and \( \delta_i \) are the emission coefficients of the \( i \)th generator.

2.2. System Constraints

**Equality Constraint.** The total power of thermal generations must cover the total load demand and system network loss:

\[
\begin{align*}
\sum_{i=1}^{H} P_{it} &= P_{dt} + P_{lt} \\
P_{lt} &= \sum_{i=1}^{H} \sum_{j=1}^{H} P_{ij} B_{ij} P_{jt}
\end{align*}
\]

Where \( P_{dt} \) system is load prediction value in the \( t \)th period, and \( P_{lt} \) is system network loss value which is approximately calculated by using the simplified general loss coefficient matrix B.
Inequality Constraint. Unit output and ramp / landslide Rate Constraint is expressed as follows:

\[
\begin{align*}
P_i^{\text{min}} \leq P_i \leq P_i^{\text{max}} \\
-D_{Ri} \leq P_i - P_{i(t-1)} \leq U_{Ri}
\end{align*}
\]  

(5)

Where \( P_i^{\text{max}} \) are the maximum output; \( U_{Ri} \) and \( D_{Ri} \) are ramp and landslide rate.

The strong constraint and nonlinear characteristics of DEED make it difficult to solve the model. The core of efficient and fast solving nonlinear dynamic optimization problem is to seek relevant methods to deal with constraints. In this model, an equality constraint formula considering network loss is relatively difficult, the method of solving equations can be found in the reference [6] is used here to deal with equality constraints.

3. The Implementation of PMDE Algorithm

3.1. Differential Evolution (DE)

The way to calculate Differential Evolution was put forward by Rainer Storn and Kenneth Price in 1995. By using real number coding way for selection, crossover and mutation operation, DE has high optimization speed, convergence precision, good global search function, etc. The most commonly used DE/best evolution strategy is as follows:

\[
Y_i^{G+1} = X_{\text{best}}^G + F(X_{r1}^G - X_{r2}^G)
\]

(6)

Where \( i \neq r_1 \neq r_2 \neq \text{best} \), \( r_1 \) and \( r_2 \) can be selected randomly; \( F \) is Evolutionary step; \( X_{\text{best}}^G \) and \( X_r^G \) is the best and \( r \)th individual in the \( G \)th iteration. When solving complex optimization problems, the diversity of the individuals usually declines in the later stage and the value of \((X_{r1}^G - X_{r2}^G)\) tends to zero, which can directly lead to the premature stagnation.

3.2. Molecule Differential Evolution (MDE)

Molecule Differential Evolution algorithm, is a way to improve DE algorithm by using the interaction potential energy between molecules in chemical calculation. The interaction force between molecules is shown in Figure 1.

\[\text{Figure 1. The interaction force between molecules.}\]

The calculation of potential energy ‘V’ can be described by ‘L-J’ potential energy function which is proposed by mathematician Jones Lennard. Only considered the repulsive relationship between similar individuals, the potential energy \( V_{i,j} \) between the individual \( X_i \) and individual \( X_j \) can be described as follows:

\[\text{Figure 1. The interaction force between molecules.}\]
The DE/best evolution strategy can be improved into MDE evolution strategy as follows:

\[
Y_i^{G+1} = X_i^{G} + F(X_i^{G} - X_j^{G} + V_{i,j}^{G})
\]  

Where \( V_{i,j}^{G} \) is the potential energy in the \( G \)th iteration.

3.3. Parallel Molecule Differential Evolution (PMDE)

By using the similarity of swarm intelligence algorithm individual computing operations and the advantages of multi-core parallel computing, PMDE divides the populations of MDE algorithm into multiple sub populations which synchronous parallel computing in the subroutine at each calculation unit[7]. In the process of parallel program optimization, the effect of optimization depends majorly on the strength of data communication between subroutine which described by gap (the communication interval) and pool (the individual communication scale).

On the premise of ensuring the accuracy of parallel optimization, how to balance the communication and improve the quality of data communication is of great significance [8]. In the paper, the gap and pool carry on dynamic adjustment according to the equations as follows:

\[
\begin{align*}
D_i &= \text{I}_i \cdot \text{iter max} / i \\
\text{gap} &= \text{round}(D_i \cdot \text{I}_i / 100) \\
\text{pool} &= \text{round}((x_{\text{NP}} / (10 \cdot D_i)))
\end{align*}
\]  

Where \( \text{I}_i \) is the total number of iterations; \( x_{\text{NP}} \) is the population size of each core; \( D_i \) is a dynamic parameter which decrease as \( i \) increase.

The flow chart of the parallel molecular differential evolution algorithm is shown in Fig. 2, assuming that the number of computer cores is \( n \) (corresponding to the calculation unit lab1~labn).

4. Simulation Example

By comparing with DE and MDE algorithm, 10-unit power system is used in the paper to verify the effectiveness of the PMDE algorithm. The units parameters and load data can be found in the reference [9]. All of the above algorithms have been simulated in MATLAB 2014a at PC (Intel core i7-7700HQ, 6GB, 2.60GHz, 64-bit Win10 operating system), the specific parameters are set as follows:

The parameters of DE: the maximum number of iterations \( I_{\text{iter max}} = 5000 \), the population size \( I_{\text{NP}} = 480 \), the evolutionary step size \( F = 0.85 \), the critical distance for molecular differential evolution \( r_{i,j} = 0.001 \). The parallel computing parameters are set as follows: the number of cores \( n = 4 \), The mode can be set to single, dual-core, three-core, four-core parallel.

4.1. Comparison of Pareto Optimal Solution between DE Algorithm and MDE Algorithm.

The comparison of pareto optimal front by using DE Algorithm and MDE Algorithm is shown in Figure 3. It is demonstrated that the MDE is obviously better than DE whatever in the Pareto optimal front, non-dominated solution distribution uniformity and convergence characteristics.
Figure 2. The flow chart of PMDE algorithm.

Figure 3. Comparison of Pareto Optimal Front.
Then the fuzzy set theory is employed to extract the best compromise solution which can get the largest value of satisfaction function. The comparisons of the best compromise solution between DE and MDE algorithm are shown in the Table 1.

**Table 1.** Comparison of optimization results.

| Algorithm | Running Time(s) | Best compromise solution |
|-----------|----------------|-------------------------|
|           |                | Generation Cost (10^5$) | Pollution Emission(10^5lb) |
| DE        | 8618.1         | 2.548917                | 3.084189                  |
| MDE       | 8290.6         | 2.514424                | 2.996616                  |

The graph of system dynamic active power is shown in Figure 4, coming from the MDE best compromise solution. The power balance constraint of the system was satisfied well due to the fact that the deviation of power at each time interval close to zero.

![Figure 4. Graph of System dynamic active output.](image)

4.2. Comparison of Operation Efficiency between MDE Algorithm and PMDE Algorithm.

Table 2 shows running time, best compromise result, efficiency and so on obtained from dynamic dispatch by respectively using MDE algorithm and PMDE algorithm in various core conditions. Obviously, the more numbers of parallel core, the higher CPU utilization rate, either the efficiency which including the acceleration ratio and the calculation efficiency are significantly boosted.

**Table 2.** Comparison of algorithm results.

| Operation Mode | Individual Number of each Communication | Utilization of CPU (%) | Running Time (s) | Best compromise solution | Parallel efficiency |
|----------------|-----------------------------------------|------------------------|-----------------|--------------------------|---------------------|
| 1-core MDE     | -                                       | 19                     | 8104.6          | 2.514424                 | -                   |
| 2-core PMDE    | 12~119                                  | 34                     | 4210.9          | 2.511152                 | 1.925               |
| 3-core PMDE    | 8~79                                     | 48                     | 2744.3          | 2.512849                 | 2.953               |
| 4-core PMDE    | 6~59                                     | 63                     | 2028.7          | 2.513923                 | 3.995               |
5. Conclusion
In this paper the match objectives minimal generation cost and pollution emission has been introduced in dynamic environment economic dispatch model in power systems. The generation cost fully consider energy cost caused by the valve point effect of the conventional thermal power unit. The model has been calculated by MDE algorithm, which ensure the Population diversity and avoid the premature convergence. Meanwhile, considering Matlab possess the ability of multi-core parallel compute, PMDE algorithm continues to improve the speed and efficiency of calculation. According to the simulation results, PMDE algorithm has a brilliant global search capability, obtain the more uniform Pareto front, thus parallel compute will supply the better result and faster speed for decision-maker. In the new era which the increasing generation rate of renewable energy and the more deeper research in the energy internet, DEED considering renewable energy is becoming a key research work.

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