Kinetic-Molecular Theory Optimization Algorithm Based on Crystallization Process for Optimal Reactive Power Dispatch

Chaodong Fan, Han Qi and Lingzhi Yi

ABSTRACT

In this paper, a kinetic-molecular theory optimization algorithm based on crystallization process (C-KMTOA) for optimal reactive power dispatches proposed. The method is based on kinetic-molecular theory optimization algorithm (KMTOA), the optimization process is redefined by simulating the physical crystallization process. Based on the minimum active network loss of the system, a mathematical model of reactive power optimization is established. The simulation experiment of IEEE30 node test system. The results show that compared with several other algorithms, the proposed C-KMTOA algorithm is more effective in solving the problem of reactive power optimization, more practical value.

Keywords: Reactive power optimization, KMTOA, Crystallization process, Active loss

INTRODUCTION

Reactive power optimization is an important means to improve the safety of power system and reduce network loss. It has always been a hot issue in scientific research and engineering application. Therefore, it is very important to study this problem[1-3]. Has been a hot issue in scientific research and engineering applications, so it is important to study the problem. But it has many constraints, non-linear, multi-variable and so on [4-5]. The premise of this method is that the control variables must be continuous, the optimization process is relatively simple, takes a long time, with great limitations, need to choose intelligent

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optimization algorithm to solve. The intelligent optimization algorithm generally includes genetic algorithm [6], particle swarm algorithm [7], firefly algorithm [8], universal gravitational algorithm [9], neural network [10] and so on. Compared with the traditional mathematical methods, the intelligent optimization algorithm has obvious advantages, the optimization is better, but each algorithm has its own shortcomings.

Kinetic-Molecular Theory Optimization Algorithm (KMTOA) was a new type of optimization algorithm proposed by Dr. Chaodong Fan in 2013. Compared with other algorithms, it has the characteristics of simple structure, good robustness and population diversity. The improved molecular motion theory based on the crystallization process is proposed to improve the shortcomings of the molecular dynamics optimization algorithm. In this paper, the improved molecular dynamics theory optimization algorithm is used to solve the reactive power optimization problem. Through the testing of IEEE-30 standard nodes, the optimization performance of several algorithms is compared, analyze the advantages and disadvantages, and detect the rationality of the improved algorithm.

PROBLEM FORMULATION

The mathematical model of reactive power optimization

Select the system with the least active power loss as a reactive power optimization objective function:

\[
P_{\text{loss}} = \sum_{k=1}^{\text{NTL}} g_k \left( V_i^2 + V_j^2 - 2V_iV_j\cos\delta_{ij} \right)
\]

\[
f = P_{\text{loss}} + \lambda_V \sum_{i\in\text{Nvlim}} (V_i - V_i^{\text{lim}})^2 + \lambda_Q \sum_{i\in\text{Nvlim}} (Q_{Gi} - Q_{Gi}^{\text{lim}})^2 \quad (1)
\]

Where \(P_{\text{loss}}\) for the system active loss, \(NTL\) is the number of branches of the system, \(g_k\) is the conductance of branch \(k\), \(V_i\) is the voltage of the node, \(V_j\) is the voltage at node \(j\), \(V_{ij}\) is the phase angle difference between nodes \(i\) and \(j\), \(Nvlim\) is the number of load nodes, \(Nvlim\) is the number of generator nodes, \(V_i\) is the load node voltage, \(Q_{Gi}\) is the generator reactive power output, \(\lambda_V\) and \(\lambda_Q\) are the penalty factors for the load node voltage and the reactive power of the generator, \(V_i^{\text{lim}}\) and \(Q_{Gi}^{\text{lim}}\) are the set values when the corresponding state variable exceeds the upper and lower limit values, respectively.

\(V_i^{\text{lim}}, Q_{Gi}^{\text{lim}}\) can be expressed as follows:

\[
V_i^{\text{lim}} = \begin{cases} 
V_i, & \text{if } V_i^{\text{lim}} \leq V_i \leq V_i^{\text{max}} \\
V_i^{\text{min}}, & \text{if } V_i < V_i^{\text{min}} \\
V_i^{\text{max}}, & \text{if } V_i > V_i^{\text{max}}
\end{cases}
\]

\[
Q_{Gi}^{\text{lim}} = \begin{cases} 
Q_{Gi}, & \text{if } Q_{Gi}^{\text{lim}} \leq Q_{Gi} \leq Q_{Gi}^{\text{max}} \\
Q_{Gi}^{\text{min}}, & \text{if } Q_{Gi} < Q_{Gi}^{\text{min}} \\
Q_{Gi}^{\text{max}}, & \text{if } Q_{Gi} > Q_{Gi}^{\text{max}}
\end{cases}
\]

The constraint be shown as Eq. (3):
The control variables and state variables are constrained as follows:

\[
\begin{align*}
\min & \quad V_{Gi}^\text{min} \leq V_{Gi} \leq V_{Gi}^\text{max}, \quad i = 1, \ldots, NG \\
\min & \quad T_i^\text{min} \leq T_i \leq T_i^\text{max}, \quad i = 1, \ldots, NT \\
\min & \quad Q_{Ci}^\text{min} \leq Q_{Ci} \leq Q_{Ci}^\text{max}, \quad i = 1, \ldots, NC \\
\min & \quad V_{Di}^\text{min} \leq V_{Di} \leq V_{Di}^\text{max}, \quad i = 1, \ldots, NL
\end{align*}
\] (4)

where \(V_{Gi}^\text{min}\) and \(V_{Gi}^\text{max}\) represent the upper and lower limits of the generator side voltage amplitude of the node, respectively; \(T_i^\text{min}\) and \(T_i^\text{max}\) respectively, said on-load voltage transformer transformer ratio of the upper and lower limits; \(Q_{Ci}^\text{min}\) and \(Q_{Ci}^\text{max}\) represent the upper and lower limits of the compensation capacity of the reactive compensator, respectively; \(NG, NT\) and \(NC\) represent all generator-side voltage node sets, all sets of on-load tap changer branches, and all sets of reactive power compensation nodes. \(Q_{Gi}^\text{min}\) and \(Q_{Gi}^\text{max}\) are the upper and lower limits of the reactive power of the generator, respectively; \(V_{Di}^\text{min}\) and \(V_{Di}^\text{max}\) represent the upper and lower limits of the voltage amplitude of the \(PQ\) node, respectively.

**Optimization algorithm based on kinetic-molecular theory with crystallization process**

The essence of the crystallization process is separation and purification, from the mixed solution to extract the corresponding solute. By simulating the crystallization process, a new separation operator is used to apply it to the improved KMTOA algorithm.

In order to facilitate the design of the algorithm model, this article makes the following assumptions, all individuals in the population are all solutes of the crystallization process. The fitness function is the solubility of the solute, the variable \(t\) is the temperature of the crystallization process; with the decrease of \(t\), the solute solubility is reduced to varying degrees.

Among them, the solute of the largest change in solubility will precipitate in the form of crystals, followed by the subsequent dissolution of the solute. Solute (individual) is screened according to the change in solute solubility.

\(X\) speed and position update formula is:

\[
\begin{align*}
V_i(t+1) = \left(0.9 - 0.5t \right) V_i(t) + a, \quad (5) \\
X_i(t+1) = X_i(t) + V_i(t+1)
\end{align*}
\]

Separation stage: The current population \(P\) is divided into the optimal individuals (the most easily precipitated solute) by the separation operator, excellent individual (easy to precipitate solute), poor individuals (more difficult or unable to precipitate the solute) three subgroups. Are recorded as: \(P_{\text{best}}, P_{\text{better}}, P_{\text{worst}}\) As shown in:
In Eq. (6), $S(i)$ is the separation operator, $\text{fitness}^*(i)$ is the fitness function value after cooling the individual $i$ , $\text{fitness}'(i)\text{is the initial fitness function value of individual }i$. During the cooling process, the value of the fitness function is larger and the value $S(i)$ is larger, the value of the fitness function is small, the value $S(i)$ is small.

The $i$ individual in different subgroups is based on their current position, According to Eq.(7) to determine its movement:

$$
X' = \begin{cases} 
X_i, & X_i \in P_{\text{best}} \\
X_i (1 + D(\cdot)) + \text{rand} \times (X_i - X_j), & X_i \in P_{\text{better}} \\
X_i (1 + N(0,1)) + \text{rand} \times (X_i - X_j), & X_i \in P_{\text{worse}} 
\end{cases} 
$$

Where $X'$ is the result of $X_i$ moving, $D(\cdot)$ is a random variable for the Cauchy probability distribution, $N(0,1)$ is the standard Gaussian distribution, $\text{rand}$ is the random number between $(0,1)$.

**THE REACTIVE POWER OPTIMIZATION STEP OF C-KMTOA**

The detailed steps of reactive power optimization based on C-KMTOA algorithm are as follows:

Step 1: Enter the power system raw data and algorithm parameters.
Step 2: Initialize the population. The position and velocity of the individual are initialized according to Eq.(8)

$$
\begin{align*}
E_{id} &= E_{id}^{\min} + (E_{id}^{\max} - E_{id}^{\min}) \times \text{rand}(\text{Size},1) \\
V_{id} &= V_{id}^{\min} + (V_{id}^{\max} - V_{id}^{\min}) \times \text{rand}(\text{Size},1)
\end{align*}
$$

$E_{id}$ and $V_{id}$ are the values and the speed of the control variables in the $i$th individual in the population. $E_{id}^{\max}, E_{id}^{\min}, V_{id}^{\max}, V_{id}^{\min}$ represent the upper and lower limits of the $i$th individual in the dimension, respectively.

Step 3: Perform the power flow calculation. According to Eq.(3).
Step 4: Calculate individual fitness values.
Step 5: Update the location and fitness of the individual population. According to Eq.(5).
Step 6: According to the current population of the individual fitness value of the pros and
cons, according to Eq.(7) to determine its movement, and to the optimal merit loss close to.
Step7: Elite reservations for individuals who have reached the optimal value of the active loss in the current population.
Step8: Algorithm iteration is completed, the output; otherwise, return to Step 3, continue to cycle calculation.

The flow chart of reactive power optimization based on C-KMTOA algorithm is shown in Figure. 1.

![Figure 1. Steps of C-KMTOA algorithm.](image)

![Figure 2. IEEE-30 node test system structure.](image)

**SIMULATION EXPERIMENTS**

In order to verify the C-KMTOA algorithm in a larger scale system in the practicality and superiority, PSO[11], DE[12], TLBO[13], KMTOA[15], C-KMTOA and so on on the IEEE-30 node test system for reactive power optimization simulation experiment. The single line diagram and initial parameters of the IEEE 30-bus system are taken from [11]. The limits for control variables are given in Table 1. The system structure shown in Figure 2, expressed in a matrix:
\[
x = \left[ V_g \right] \begin{bmatrix} T_{6-9} & T_{6-10} & T_{4-12} & T_{28-27} & Q_{3} & Q_{10} & Q_{28} \end{bmatrix} (9)
\]

Parameter settings: the reference power is 100 MVA, the parameters of each node and the calculation are used per unitary value. The voltage phase angle is in radians, under initial conditions. Set the generator terminal voltage to 1.0 p.u, Transformer ratio is set to 1.0. The reactive power compensation capacity is set to zero. Total load, total loss:

\[
P_{\text{load}} = 2.834 \text{ p.u}, \quad Q_{\text{load}} = 1.262 \text{ p.u}
\]

\[
\sum P_G = 2.8938 \text{ p.u}, \quad \sum Q_G = 0.9801 \text{ p.u}, \quad P_{\text{loss}} = 0.0598 \text{ p.u}, \quad Q_{\text{loss}} = -0.0643\text{ p.u}
\]

Table I. IEEE-30 node test system control variables in the upper and lower limits[11].

<table>
<thead>
<tr>
<th>Bus no.</th>
<th>Q_{\text{min}}</th>
<th>Q_{\text{max}}</th>
<th>V_{\text{max}}</th>
<th>V_{\text{min}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.298</td>
<td>0.596</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>-0.24</td>
<td>0.48</td>
<td>1.05</td>
<td>0.98</td>
</tr>
<tr>
<td>5</td>
<td>-0.265</td>
<td>0.6</td>
<td>1.03</td>
<td>0.95</td>
</tr>
<tr>
<td>8</td>
<td>-0.075</td>
<td>0.53</td>
<td>1.04</td>
<td>0.94</td>
</tr>
<tr>
<td>11</td>
<td>-0.15</td>
<td>0.15</td>
<td>1.05</td>
<td>0.95</td>
</tr>
<tr>
<td>13</td>
<td>-0.078</td>
<td>0.155</td>
<td>1.05</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Because there are random factors in the algorithm, keep the algorithm parameters unchanged, independent repeat of the IEEE-30 node test system program for PSO, DE, TLBO, KMTOA and C-KMTOA 30 times. Among them, Table II for the algorithm for IEEE-30 node system for reactive power optimization of the optimal solution when the optimal value of the control variable, Figure 3 shows the iterative characteristic curves of the Plunes for the active power loss of the PSO, DE, TLBO, KMTOA, C-KMTOA algorithm for the reactive power optimization of the IEEE-30 node test system. Table III shows statistical details such as the best value, worst value, mean value and standard deviation of different methods for 30 independent runs.

Table II. Optimization of Control Variables in IEEE-30 Node System (p.u.).

<table>
<thead>
<tr>
<th>Control variable</th>
<th>Algorithms</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{G1}</td>
<td>1.0725</td>
</tr>
<tr>
<td>V_{G2}</td>
<td>1.0633</td>
</tr>
<tr>
<td>V_{G5}</td>
<td>1.041</td>
</tr>
<tr>
<td>V_{G8}</td>
<td>1.041</td>
</tr>
<tr>
<td>V_{G11}</td>
<td>1.0648</td>
</tr>
<tr>
<td>V_{G13}</td>
<td>1.0597</td>
</tr>
<tr>
<td>T_{6-9}</td>
<td>1.03</td>
</tr>
<tr>
<td>T_{6-10}</td>
<td>0.95</td>
</tr>
<tr>
<td>T_{4-12}</td>
<td>0.99</td>
</tr>
<tr>
<td>T_{28-27}</td>
<td>0.97</td>
</tr>
<tr>
<td>Q_{C3}</td>
<td>0.0</td>
</tr>
<tr>
<td>Q_{C10}</td>
<td>0.16</td>
</tr>
<tr>
<td>Q_{C24}</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Table III. The algorithm has the value of active power loss on IEEE-30 node system.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Best (p.u.)</th>
<th>Worst (p.u.)</th>
<th>Mean (p.u.)</th>
<th>Std.</th>
<th>%P_{ave}</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSO[11]</td>
<td>0.049239</td>
<td>0.050576</td>
<td>0.04972</td>
<td>1.712*10^{-4}</td>
<td>17.02</td>
</tr>
<tr>
<td>MAPSO[11]</td>
<td>0.048747</td>
<td>0.048759</td>
<td>0.048751</td>
<td>-</td>
<td>18.408</td>
</tr>
<tr>
<td>DE[12]</td>
<td>0.049121</td>
<td>0.05241</td>
<td>0.049981</td>
<td>8.783*10^{-3}</td>
<td>17.97</td>
</tr>
<tr>
<td>TLBO[13]</td>
<td>0.049047</td>
<td>0.049875</td>
<td>0.04944</td>
<td>5.274*10^{-4}</td>
<td>18.09</td>
</tr>
<tr>
<td>KMTOA[15]</td>
<td>0.049052</td>
<td>0.049273</td>
<td>0.049273</td>
<td>3.253*10^{-4}</td>
<td>18.081</td>
</tr>
<tr>
<td>C-KMTOA</td>
<td>0.048832</td>
<td>0.049109</td>
<td>0.048916</td>
<td>9.713*10^{-4}</td>
<td>18.448</td>
</tr>
</tbody>
</table>

Figure 3. Convergence comparison graph of active loss in each algorithm in IEEE-30 system.

CONCLUSION

In this paper, the molecular dynamics optimization algorithm based on crystallization process is proposed, the introduction of the crystallization process in physics. Redefine the optimization process, which improves the optimization of the algorithm and the optimization of the algorithms. The simulation experiments of DE, PSO, KMTOA and C-KMTOA of IEEE-30 nodes show that the algorithm of this paper is more scientific and effective to solve the problem of reactive power optimization.

REFERENCES