Reactive Power Optimization Based on AVC Time-division Control Strategy

XM Wang¹, HB Wang², J Zhang³, SC Liu¹, YF Ma¹ and W Yan²
1. State Grid Qinghai Electrical Power Maintenance Company, Xining, Qinghai, 810008, China
2. Chongqing Electric University, Chongqing, 400053, China
3. Qinghai Electric Power Science Research Institute, State Grid Qinghai Electrical Power Company, Xining, Qinghai, 810008, China
Email: ruyunz@36haojie.com

Abstract. In order to avoid frequent actions of transformer taps and capacitor banks caused by reactive power optimization, this paper proposes a reactive power optimization based on AVC time division control strategy. The time division control strategy is used to segment the load curve of the next day, and the reactive power optimization process of each period is calculated by genetic algorithm. The strategy and algorithm are applied to the reactive power and voltage optimization of IEEE 30 bus system. The simulation results show that the method can realize reactive power optimization more efficiently.

Keywords. Reactive Power Optimization; Time-division; Control Strategy

1. Introduction
Reactive voltage optimization control is an effective means to ensure the safe and economic operation of power system, as well as an indispensable tool to guide dispatchers to arrange the operation mode and planners to carry out grid reactive power planning. Its mathematical model can be described as a multi-variable, nonlinear, discontinuous and multi-constraint planning problem. Many algorithms used to solve reactive power optimization problems have their characteristics and shortcomings, such as Newton method[1], sequential quadratic programming algorithm[2], interior point method[3] and other numerical algorithms. When variables increase, the convergence becomes worse. However, the genetic algorithm shows good convergence when dealing with discrete and multivariable problems [4].

2. Genetic algorithm
Genetic algorithm (GA) is a search algorithm based on natural selection and genetic principles. From many initial points, the algorithm search along different lines, and the variable coding processing, using genetic operation of code strings instead of direct operation of variable, which can deal with discrete variables more naturally, less to the objective function request, does not require differentiable, and does not require continuous, derivative, inverse complex mathematical operations, such as larger probability to find the global optimal solution of optimization problem, it is in solving the multivariable, nonlinear and discontinuous constraint problems, shows the unique advantages, which makes it application in the field of reactive power optimization is becoming more and more attention by people, its effectiveness has been confirmed for many research institute. The algorithm calculation steps are as follows:

Step 0. Encoding and maternal: A characteristic of GA is that the optimized variables must be encoded to form specific structures similar to genetic factors. In this paper, binary code is adopted: H=[b₁,b₂,...,bₙ,...]
and equipment, the system load is minimal. However, if a continuous integer variable B is defined and its value range is equal to the number of taps, that is, 1 ≤ B ≤ 5, it is obvious that the corresponding relation exists between B and the transformer tap position: 

\[ T = -5\% \times \frac{B-1}{5} \times 2.5\% \]

and the corresponding ratio can be obtained by binary coding of the integer B. A group of randomly generated initial solutions in GA in the above form is called the ancestor, namely the first generation of matrix. The number of matrix N is an important parameter of GA, and the size is specified externally. N should not be too small, should not be too large, generally from 20, with 10 as the unit increase.

Step 1. Evaluation: The evaluation value in GA is called Fitness. In this paper, Fitness(Xi)=1/Fi, Fi is the objective function value of the ith individual, namely active power network loss, and the reciprocal is taken because the Fitness values are arranged from the largest to the smallest in the usual order.

Step 2. Crossover and mutation: Hybridization is the most important means to obtain new and excellent individuals in GA. Two parents are randomly selected from the breeding library to start the hybridization, and the logarithm of the hybridization is determined by the hybrid rate C and the number of individuals in the breeding library N. For example, the crossover rate is selected in operation according to different characteristics of the system, and the empirical value range is generally 0.60 ~ 0.95. Variation operation is to simulate the process of gene mutation caused by various accidental factors in the natural environment of organisms. Variation rate is also an important parameter in GA, which is distributed between 0 and 1, and usually takes a number between 0 and 0.01.

Step 3. Stop optimization when the predetermined maximum evolutionary algebra or retention algebra of the optimal individual is reached. Max evolutionary algebra should not be too large and can be selected at run time.

3. Time-division Control Strategy

Generally, dispatching center to make short-term prediction, the load control strategy based on its load curve, different time periods will load into several load level during the next day, and choose the appropriate load value respectively in each period to represent the load, so it can be obtained by the use of genetic algorithm and the period of compensation capacity and optimal operation mode of the regulating transformer, to determine the action of the equipment control strategy. The number of segments depends on the frequency of load curve, especially for the load peak, flat, valley to be segmented, the greater the frequency of change, the more segments.

3.1 Objective Functions and Constraints

For any period, select half of the sum of the maximum and minimum load values to represent the load of that period. When the number of segments and the load representative value of each segment are determined, the operation mode to minimize the active power network loss of each segment is obtained by optimizing each segment, and the switching and cutting scheme of transformer tapping and capacitor bank for each period of the next day is obtained after optimizing all segments. For any time period, reactive power optimization has the following mathematical model:

\[(1)\text{objective function}\]
\[\min F = P_{\text{comp}}(V_g, Q, T)\]

Where, \( P_{\text{comp}} \) is the active power network loss, \( V_g \) is the output voltage vector of generator, \( Q \) is the reactive power vector of reactive compensation equipment, and \( T \) is the tap position vector of transformer.

The active power network loss of the system expressed by node voltage and transformer transformer ratio:

\[ P_{\text{comp}} = \sum_{i \in N} P_{\text{eq}} + \sum_{i \in N} P_{\text{eq}} \]

\[ = \sum_{i \in N} (V_i^2 + V_j^2 - 2V_iV_j \cos \delta_i) + \sum_{i \in N} [T_i V_i^2 + V_j^2 - 2T_i V_i V_j \cos \delta_j V_j] \]
Where, \( G_{ij} \) is the conductance of the circuit branch \( ij \), and \( T_{ij} \) is the transformer ratio of the transformer branch \( ij \). NL and NT respectively represent the set of line branches and transformer branches.

The active power loss of the system expressed in terms of nodal injection power:

\[
P_{\text{loss}} = \sum_{i=1}^{N} \sum_{j=1}^{N} R_{ij} \left[ (P_{ij} + Q_{ij}) \cos \delta_{ij} - (P_{ij} - Q_{ij}) \sin \delta_{ij} \right]
\]

(2) equation constraint

The equation constraint is the power flow constraint, namely the active and reactive power balance constraint of each node. The calculation model is described as follows:

Node active power balance:

\[
P_{ai} - P_{ai} = V_{i} \sum_{j=1}^{N} V_{j} (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij})
\]

Node reactive balance:

\[
Q_{ai} + Q_{ci} - Q_{ci} - Q_{ai} = V_{i} \sum_{j=1}^{N} V_{j} (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij})
\]

Where, N is the total number of grid nodes; \( P_{ai} \) and \( P_{ai} \) respectively represent the active power injection and active load of the node; \( Q_{ai}, Q_{ci}, Q_{ai}, Q_{ci} \) respectively represent reactive power injection, capacitive reactive compensation capacity, inductive reactive compensation capacity and reactive load; \( V_{i}, V_{j} \) respectively represent the node voltage of \( i \) and \( j \); \( G_{ij}, B_{ij}, \delta_{ij} \) respectively represent the conductance, susceptance and phase angle difference of node voltage of \( i \) and \( j \).

(3) Inequality constraint

Inequality constraints are mainly upper and lower limits of variables and branch power constraints.

Upper and lower limits of variables:

Node voltage constraint: \( V_{\text{min}} \leq V_{i} \leq V_{\text{max}} \)

Node reactive power constraints: \( Q_{\text{min}} \leq Q_{i} \leq Q_{\text{max}} \)

Transformer ratio constraints: \( T_{\text{min}} \leq T_{i} \leq T_{\text{max}} \)

Branch flow constraints:

\[
P_{g} = V_{i}^{2} (G_{ai} + G_{ci}) - V_{i} V_{j} (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \leq P_{g,\text{max}} \quad Q_{g} = -V_{i}^{2} (B_{ai} + B_{ci}) + V_{i} V_{j} (B_{ij} \cos \delta_{ij} - G_{ij} \sin \delta_{ij}) \leq Q_{g,\text{max}}
\]

3.2 Time-division Control Strategy Next-day Active Power Loss

For the period \( k \), the representative value of its load is:

\[
P_{ak} = \frac{P_{a,\text{min}} + P_{a,\text{max}}}{2}
\]

Where, \( P_{a,\text{min}} \) is the minimum value of active load in the period \( k \), and \( P_{a,\text{max}} \) is the maximum value of active load in the period \( k \).

When the representative value of the load in the period \( k \) is calculated, reactive power optimization under the load value can be carried out to obtain the minimum active power loss \( \Delta P_{k} \), so as to obtain the next-day active energy loss:

\[
\Delta W = \sum_{k=1}^{N} \Delta P_{k} T_{k}
\]

Where, \( T_{k} \) is the long time in the \( k \) period.

3.3 Process Chart of Time-division Control Strategy
4. The example analysis

In this paper, genetic algorithm and time-sharing control strategy are used to simulate the IEEE30 node system. The original nodes and branch parameters of the system can be seen in literature [8], including 6 generators and 4 adjustable transformers. Nodes 10, 24 and 29 are selected as reactive compensation points. There are 13 control variables in the optimization process. According to the characteristics of the load curve, it is divided into four periods in this paper, and the peak load is 283.4MW. The optimization results are shown in Table 1 ~ Table 3.

| Time         | 10 | 24 | 29 |
|--------------|----|----|----|
| 07:00～12:00 | 2  | 3  | 3  |
| 12:00～17:00 | 3  | 2  | 4  |
### Table 2. Generators output of reactive power (Mvar)

| Time          | Reactive output of each generator node |
|---------------|----------------------------------------|
|               | 1 | 2 | 5 | 8 | 11 | 13 |
| 07:00~12:00   | -12.65 | 14.24 | 25.23 | 26.83 | 9.98 | 0.21 |
| 12:00~17:00   | -11.23 | 15.62 | 24.11 | 25.86 | 10.62 | 0.94 |
| 17:00~23:00   | 6.32 | 21.25 | 23.61 | 26.54 | 22.51 | 2.54 |
| 23:00~07:00   | -14.42 | 5.11 | 20.25 | 10.65 | 2.51 | 0.12 |

### Table 3. The position of transformers

| Time          | Transformer ratio of each load regulating transformer |
|---------------|--------------------------------------------------------|
|               | 6~10 | 6~10 | 4~12 | 28~27 |
| 07:00~12:00   | 3 | 1 | 2 | 3 |
| 12:00~17:00   | 2 | 2 | 3 | 3 |
| 17:00~23:00   | 4 | 3 | 5 | 3 |
| 23:00~07:00   | 2 | 1 | 1 | 1 |
In order to verify the applicability of time-sharing control strategy in economic dispatching, the load curve is divided into 4 sections, 6 sections and 24 sections, and the next-day active power loss is calculated under each division scheme. The results are shown in Table 4:

| Table 4. comparing of power loss in every method (MW·h) |
|--------------------------------------------------------|
| Segmentation scheme | n=4 | n=6 | n=24 |
| Next-day active power loss | 85.68 | 84.72 | 84.19 |

It can be seen from Table 4 that the more the number of segments, the less the next-day active power loss, and the second-day energy loss after optimization in 6 hours is only 0.53MW·h less than that after optimization in 24 hours. Therefore, the reactive power optimization calculation and frequent action of transformer joints and capacitor Banks all the time do not produce obvious economy.

5.Conclusions
In this paper, the good convergence of genetic algorithm and the time-division control strategy are used for reactive power optimization.

Due to the power grid in different load cases, the optimized result is also different, in order to avoid the frequent movement of transformer tap and capacitor group, will load curve segment, select the time half of the sum of the maximum load value and the minimum load to represent the time load, and respectively in each period of the optimization calculation, this approach not only to calculate the active power loss not too big effect, and greatly reduced the number of optimization, saves the manpower and equipment depreciation expense.

Through the simulation test of IEEE30 node system, the results show that the algorithm and strategy can be applied to the actual economic scheduling.

Acknowledgement
Project supported by Scientific research project of state grid Qinghai electrical power company " Study on the State evaluation and parameter setting method of AVC system in new energy grid with high proportion", NO.52280719004B.

6.References
[1] Sun DI, Ashley B and Brewer B 1984 Optimal Power Flow by Newton Approach[J] IEEE Trans On PAS 103(10) pp 2864-2880
[2] Grudin N 1998 Reactive Power Optimization Using Successive Quadratic Programming Method[J] IEEE Trans on Power Systems 13(4) 1219-1225
[3] Sergio G 1994 Optimal Reactive Dispatch Through Interior Point Method[J] IEEE Trans On power systems 9(1) pp 136-146
[4] Cheng HZ 1998 Reactive power optimization of power system based on genetic algorithm [J] Journal of Shanghai jiao tong university 1 pp 321-331
[5] Tang YS 2001 Control strategy of reactive voltage regulator of power system[J] Electrical automation equipment 6 pp 1231-1243
[6] Luo Y and Tu GY 2004 Reactive voltage optimization control of regional power grid based on multi-area chart control strategy [J] Relay 3 pp 521-534
[7] Zhou RJ 2005 Reactive power optimization strategy for distribution network taking control cost and frequency into account [J] Chinese journal of electrical engineering 5 pp 573-586

[8] Zhang BM and Chen SS 1994 Advanced Power Network Analysis [M] Beijing: Tsinghua University Press