Reactive Power Optimization in Area Power Grid Based on Improved Tabu Search Algorithm

Wennan Lin, Yihua Li, Xingtao Xu, and Maojun li

***Abstract*--In order to meet the requirements of real-time control for reactive power optimization, this paper puts forward a new reactive power optimization method in area power grid, which is the secondary optimization control of voltage and reactive power in area power grid based on improved Tabu search algorithm. firstly, the minimum active power loss is chosen as objective function, and the improved Tabu search algorithm is applied to the reactive power optimization, in which the top *10* solutions are recorded; secondly, static voltage stability margins for the top *10* solutions are calculated; thirdly, by using fuzzy set theory, the two objectives including the minimum active power loss and the maximum margin index are converted into single objective, at last, solution corresponding the maximum of single objective function is the final optimal result of reactive power optimization in area power grid. Simulation results indicate that, not only is the improved Tabu search algorithm suitable to solve reactive power optimization in area power grid, but also the secondary optimization control of voltage and reactive power in area power grid based on improved Tabu search algorithm and considering static voltage stability is practicable and effective.**

***Index Terms*-- Area power grid; improved Tabu search algorithm;reactive power optimization; static voltage stability**

I. Introduction

REACTIVE power optimization in power system is a very important approach to improve voltage quality, reduce transmission loss and increase the voltage stability margins. In substance, the reactive power optimization is a hybrid optimization problem with the traits of discrete, nonlinear and multiple variables, multiple constraints. Recently, there are many measures in this field, such as linear programming, nonlinear programming, quadratic programming, low sensitivity analysis and mixed integer programming. Although these methods have their certain superiorities and adaptabilities, the ways mentioned above need to assume that each controlled variable is continuous, and each objective function is differentiable, what's worse, those means can not explore solution space thoroughly and they are sensitive to initial solution. More recently, great attention was paid on the random methods which can search solution space thoroughly, such as genetic algorithm, simulated annealing algorithm and Tabu search algorithm. As different kinds of improved genetic algorithm are advanced and in deep research, genetic algorithm has been made great progress. The technology of fuzzy control, expert system and neural network applied to reactive power optimization also takes good effect. Tabu search algorithm is heuristic, which can search the global solution more efficiently. This paper applies improved Tabu search to reactive power optimization in area power grid, at the same time, takes into account the static voltage stability. Simulation indicates that the secondary optimization control of voltage and reactive power in area power grid based on improved Tabu search and considering static voltage stability is practicable and effective.

This work was supported by Hunan Provincial Natural Science Foundation of China (05JJ30106) and Scientific Research Fund of Hunan Provincial Education Department (05A018)

Wennan Lin is with Changsha University of Science and Technology, China, lwn8394250@163.com.
Yihua Li is with Changsha University of Science and Technology, China, Lyh19640612@163.com.
Xingtao Xu is with Information center of Taizhou supply bureau, Jiangsu, China, xxt3322@sina.com.
Maojun Li is with Changsha University of Science and Technology, China, limaojun3672@yahoo.com.cn.

II. Improved Tabu Search Algorithm

Tabu search method is a modern heuristic optimization technology. The basic idea of the novel algorithm is to make use of an agile "memory" technology. It can record and select the moves during the optimization procedure, and guide the search direction. In order to escape from local optimality, the search direction will back off to the direction whose target degenerates the least, and take it as the new initial search direction. The huge amount of research on the large-scale non-linear integer programming has proved this method can search the global solution very effectively. But through the simulation experiment, when there are stronger constraints in the optimization, maybe in some iterative, test solution is either tabooed because its opposite move labeled in Tabu table, or eliminated because it can not meet all the restrictions, at the moment ,it can not produce a new iterative solution, even worse, Tabu search can not continue. To solve this problem, this paper puts forward the following way –release the moves conditionally: In an iterative, for those solutions which meet the restrictions, their corresponding moves have already exited in Tabu table, if all the tests before this one do not meet the restrictions, this test solution should update local optimal solution to ensure that the iterative can go on.

When that situation takes place, its corresponding local optimal object value should be updated according to the principle as follows: current variables have to be made every effort to fall back some moves, and to be far away from the current disadvantages, then go on to search. So the longer the move corresponding the test solution stayed in Tabu table, the better the local optimal value would be, namely the easier the move would be released. In addition, the tabu move which has already been recorded last time must not be released, or it will be trapped in the cycling in solution investigation. For example, this paper adopts the following formula to calculate the object values.

$$localSSum = (LengthofTabulist - NumofStay) \times currentSSum \tag{1}$$

where, $localSSum$ denotes the object value corresponding the test solution; $LengthofTabulist$ is defined as the length of the Tabu table; $NumofStay$ is denoted as the steps that the moves stayed in Tabu table; $currentSSum$ is defined as the object value corresponding the test solution.

If the local optimal solution's move has already been labeled in Tabu table, the update mode of the Tabu table will be adjusted as follows: each record position under the test solution should remain unalterable; those below the test solution will be updated one by one. The move position corresponding local optimal solution will be replaced by the one above local optimality, and local optimal solution's move will be recorded again on the top of Tabu table.

III. Mathematical Mode Of The Reactive Power Optimization

The optimal target of reactive power optimization is minimizing active power loss in area power grid, it can be denoted by formula (2),

$$\min P_{loss} = \min \sum_{i=1}^{n} \sum_{j=1}^{n} U_i U_j G_{ij} \cos\theta_{ij} \tag{2}$$

and the reactive power optimization problem should meet the following constraints:

$$\begin{aligned} &s.t.1: \ P_i = \sum_{j \in i} U_i U_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right); \\ &\qquad Q_i = \sum_{j \in i} U_i U_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right) \\ &s.t.2: \ U_{Gi}^{\min} \le U_{Gi} \le U_{Gi}^{\max}; \cos\theta_{Li}^{\min} \le \cos\theta_{Li} \le \cos\theta_{Li}^{\max} \\ &s.t.3: \ U_{Li}^{\min} \le U_{Li} \le U_{Li}^{\max}; \ Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \end{aligned} \tag{3}$$

where, s.t.1 denotes equations constraints—power flow equations; s.t.2 denotes the up and down limitations of the control variables (The voltages of high side voltage bus in power plants and the power factors of high side voltage bus in 220 kV and 500kV substations), called "before restrict"; s.t.3 denotes the up and down limitations of the state variables (The voltages of high side voltage bus in 220 kV and 500kV substations and outputs of reactive power of power plants), called "after restrict".

IV. Improved Tabu Search Algorithm And Its Application In Reactive Power Optimization

A. *Control variables and their Binary-codes*

Control variables: The voltages of high side voltage bus in power plants and the power factors of high side voltage bus in 220 kV and 500kV substations.

1. Encoding of the voltages of high side voltage bus in power plants

Assuming that the voltages of high side voltage bus in power plants is V, and the regulation control dead-zone of the VQC devices is 0.005, since $(1.05 - 0.95) \div 0.005 = 20$, when adopting Binary-code, every node voltage should be encoded to 5 bits, the corresponding coding range is [00000, 10100], if certain node voltage decimal value corresponding its binary code is d, its corresponding node value in per unit is: $0.95 + d \times 0.005$.

2. Encoding of the power factors of high side voltage bus in 220 kV and 500kV substations

Assuming that the power factors of high side voltage bus in 220 kV and 500kV substations is $\cos\theta$, it varies from 0.94 to 1.00. if the regulation control dead-zone of the device is 0.01, as $(1.00 - 0.94) \div 0.01 = 6$, when adopting Binary-code, every power factor value should be encoded to 3 bits, the corresponding coding range is [000,110], and its corresponding node value in per unit is: $0.94 + 0.01 \times d$.

3. Hybrid coding of the control variables

The number of the voltages is Nv, and the number of the power factors is Nl. Firstly, encode the voltages and power factors to binary coding, then combine the coding in series to obtain the whole control variable binary coding, the length of the coding is $(Nv \times 5 + Nl \times 3)$ bits.

The optimal voltages will be carried out by VQC devices, meanwhile, the optimal power factors will be implemented by AVC of district power network.

B. *The selection of the initialization value and control stability*

In reactive power optimization, there are two methods to select initialization solution: one is to choose current operation value gained in SCADA system. To reflect more effectively on the operation state of power grid and to enhance the optimization efficiency, the other is to regard the average of the load obtained from short-term load forecasting or history data. This paper adopts the former one.

Compared with the initialization voltages and power factors values, the optimal voltages of high side voltage bus in power plants and the optimal power factors of high side voltage bus in 220 kV and 500kV substations can not have big jumps, or not only is it hard for the subordinate to carry out, but also it will bring large disturbance to the power grid and make a strong impact on the stability of the power grid.

To solve this problem, this paper sets the upper limit of regulation for voltages and power factors as Δ max. Take regulation for voltages for example, assuming that initialization voltage value is V0, and the up and down limitations of voltages is Vmax、Vmin, respectively. So the upper and lower limits of the practical operation voltages can be calculated as follows, respectively: min(Vmax, Vo+ Δ max), max(Vmin, Vo- Δ max).

C. Select the active moves by means of sensitivity analysis method

We could only select those nodes with high sensitivity by means of sensitivity analysis method to do Tabu "move" experiments, because it will bring few but active solutions. Seen from the mathematical meanings of sensitivity, it only explains how the tiny variation for current solution changes its object function value, known from the analysis on sensitive method, we conclude that it makes no sense to do Tabu "move" experiment for those nodes whose sensitivity is zero. So we could avoid doing experiments for those nodes, which will save execution time.

D. Criteria of quitting iterative and optimization time control

Convergence criterion of the improved Tabu search method is generally heuristic. The quitting iterative criteria often used is whether to reach the maximum iterating times, and the maximum iterating times are often given by experience.

E. Management for the Tabu table

The size of Tabu table has a significant impact on efficiency and final optimization results of the search. This paper adopts "first in first out" queue management method to manage it. The size of Tabu table equals to twenty percent of the whole length of the binary code string.

F. Aspiration criteria design

Aspiration criteria adopted in this paper is: after a move takes actions on the current solution, if the new solution is better than any solutions which has already searched, namely up to now, the object function of the new solution is the best, it is called that the move satisfies aspiration criteria, and it can be released from Tabu table. The improved Tabu search flow chart is shown on fig.1.

As for reactive power optimization in area power grid, static voltage stability must be taken into consideration. The traditional way of solving multi-object optimization in reactive power optimization is to calculate each objective, and then convert the multi objectives into single one, the solution corresponding the maximum of single objective function is the final optimal result. If we take the static voltage as one of the membership function of reactive power optimization, as it will take a huge amount of time to calculate static voltage stability margins, if continue to deal with it by using the way mentioned above, It will be time-consuming, accordingly it can not meet the requirements of real-time control for reactive power optimization.

This paper proposes the AVC schemes which adopts the following method to solve such problem: firstly, the minimum active power loss is chosen as objective function, and the improved Tabu search algorithm is applied to the reactive power optimization, in which the top 10 solutions are recorded; secondly, static voltage stability margins for the top 10 solutions are calculated; thirdly, by using fuzzy set theory, the two objectives including the minimum active power loss and the maximum margin index are converted into single objective. This method, not only can save optimization time, but also can meet the needs in theory design and project practice.

V. STATIC VOLTAGE STABILITY INDEX

Voltage stability is one of the most important optimization objectives, which must be considered in reactive power optimization in area power grid. This paper adopts load margins index of P-U curves based on power flow, and calculate the load margins by way of improved continuation power flow method.

A. Improved continuation power flow method-- adaptive variable step-size method

The most key factor which affects calculation efficiency of continuation power flow is the selection of step-size. Tiny step-size is often chosen during calculation, which can always ensure the convergence, but too many calculation steps will lead to low efficiency of calculation., correlation literatures' points of view in describing step-size control strategy are the same: automatic step size variation, namely, use big step size in fat part of steady-state locus to enhance the calculation efficiency, use the step size as small as possible at the critical point to ensure good convergence. However, we did not know the curve figure in advance, so it is very hard to select an effective step size which can adapt to all the circumstances.

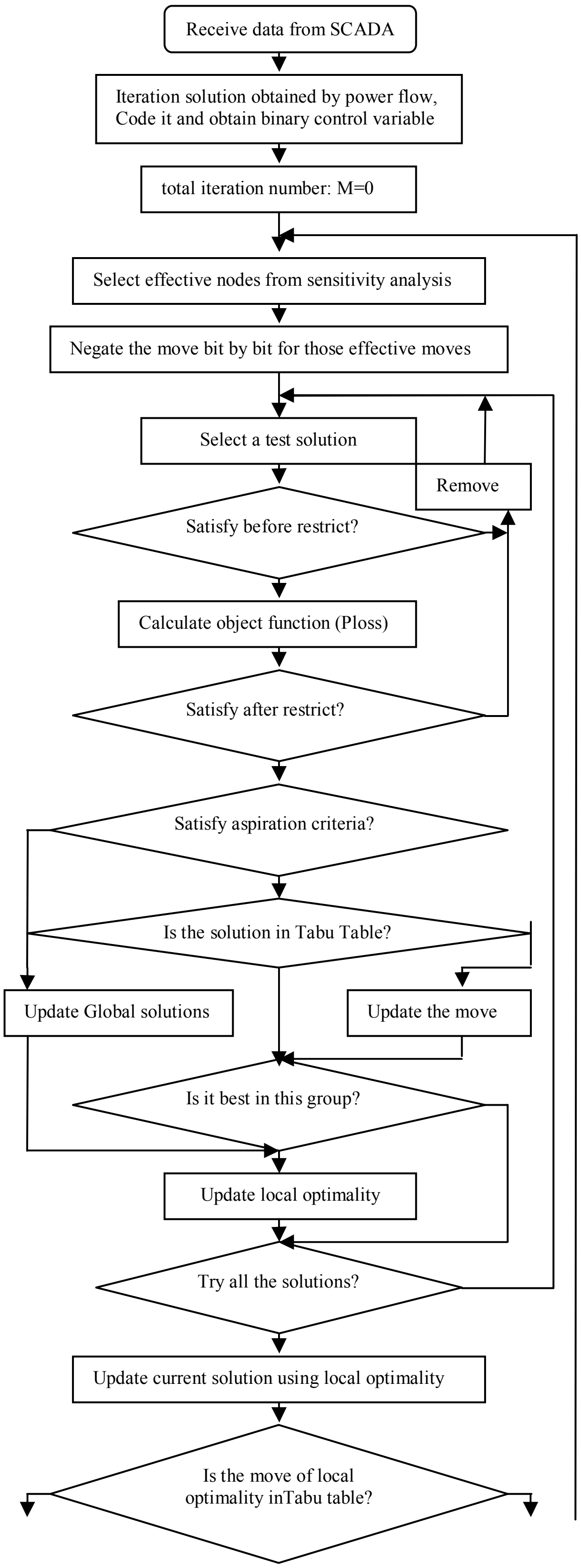
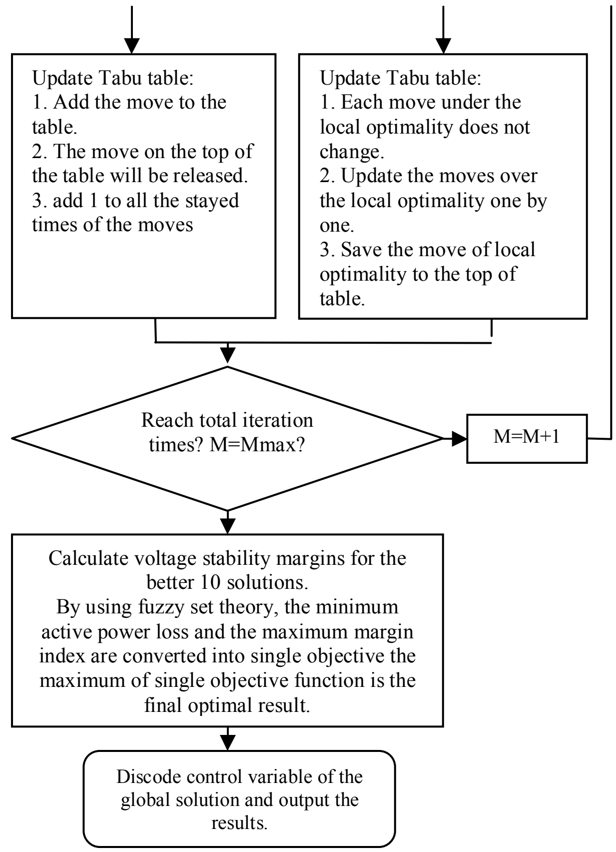

Fig.1 The improved Tabu search flow chart

There are 3 phases to draw the P-U curve adopted in this paper, but when in the same phase, the step size is immoveable. This algorithm is called continuation power flow with “adaptive variable step-size”. The improved continuation power flow’s flow chart is as follows:

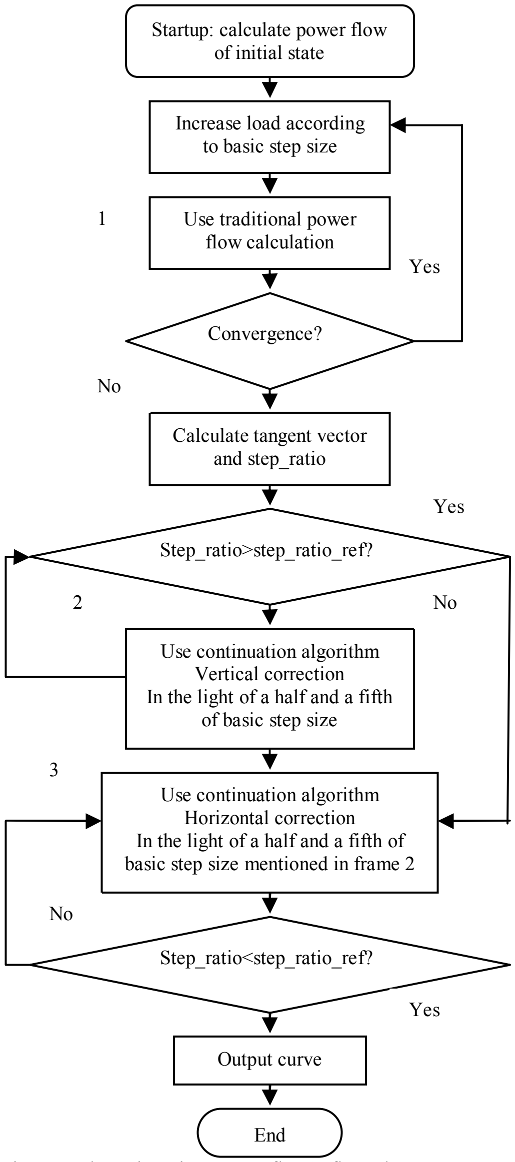

Fig.2 the improved continuation power flow's flow chart

VI. Multi-Objective Optimization Based On Fuzzy Set Theory

In this paper, there are two objectives in reactive power optimization, which consist of the minimum active power loss and the maximum margin index, respectively.

(1) Sub-objective membership function of the minimum active power loss is

$$\mu_P = (P_0 - P)/(P_0 - P_{\min}) \tag{4}$$

where P_0 is the active power loss in area power grid before optimization; P is the active power loss of current solution in area power grid; $P_{\min}$ is the minimum active power loss after optimization.

(2) Sub-objective membership function of the maximum static voltage stability margins is

$$\mu_\lambda = (\lambda_0 - \lambda)/(\lambda_0 - \lambda_{\max}) \tag{5}$$

where λ_0 is the initial static voltage stability margin in area power optimization before optimization; λ is the static voltage stability margin of current solution; $\lambda_{\max}$ is the maximum static voltage stability margin after optimization.

The multi-objective optimization can convert into single objective one, which can be described as follows:

$$\max\left\{\min\left(\mu_P,\ \mu_\lambda\right)\right\} \tag{6}$$

VII. Computational Results

This paper adopts IEEE_BUS14 network as illustration example. Calculate static voltage stabilities for the top 10 solutions, then calculate membership functions of active power loss and static voltage stability margins, respectively, choose the smaller one between them, and take it as final objective value of this solution. Computational results of illustration example can be seen from table 1.

Table I Tradeoff Of The Two Objectives.
(The Minimum Of Active Power Loss And The Maximum Of Static Voltage Stability Margin)

Ordinal number of solution	normalized value of active power loss	Static voltage stability margin	Membership function of active power loss	Membership function of Static voltage stability margin	Hybrid objective value
1	0.0577324	3.77482	1	1	1
2	0.0577356	3.77461	0.99707	0.99903	0.0.99707
3	0.0577361	3.77471	0.99667	0.99651	0.99667
4	0.0577381	3.77376	0.99485	0.99497	0.99485
5	0.0577390	3.77284	0.99401	0.99052	0.99401
6	0.0577413	3.77356	0.99195	0.99398	0.99195
7	0.0577416	3.77253	0.99176	0.98903	0.98903
8	0.0577418	3.77366	0.99152	0.99447	0.99152
9	0.0577428	3.77341	0.99066	0.99325	0.99066
10	0.0577441	3.77270	0.98948	0.98985	0.98948
Initial status	0.0631785	3.528687	0	0	0

Membership functions of active power loss and static voltage stability margins in this table are calculated according to formula (4) and (5). Seen from the table, the 1st solution is the final global optimal solution, whose selection process can be seen from Fig.3.

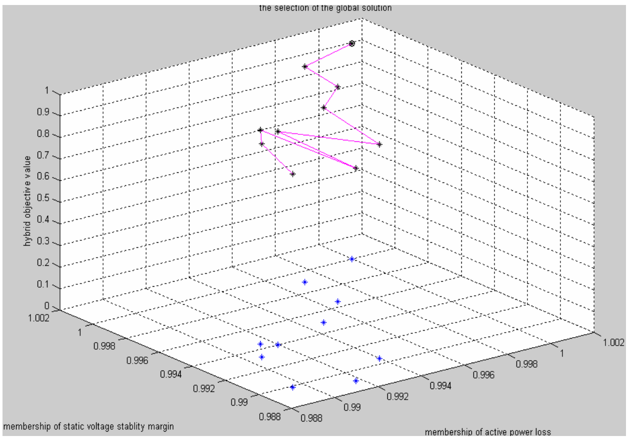

Fig.3 objective hybrid and selection of optimal solutions

In the figure. 4, the two P—U curves before and after optimization are traced aimed at the node 14 bus in IEEE_BUS14 network, the curve on the left is node 14 bus P—U curve in initial status. The other is the P—U curve of node 14 bus in final chosen optimization status. Tracing method for P—U curve is adopted by continuation power flow—adaptive variable step size method, there are 3 stages to trace P—U curve. Calculation points of the first stage is marked by '×', points of the second stage is signed by '+', and points of the last stage is identified by '○'.

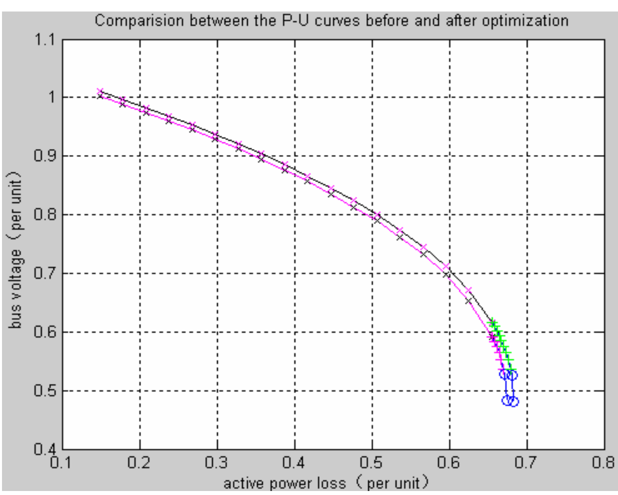

Fig. 2. Comparison between the P—U curves before and after optimization.

In this paper, when trace P—U curve, load variation mode is: synchronously increase global load in proportion with base-load. So the load margins calculated by the method mentioned above denote static voltage stability in the whole area power grid. Known from numerical case datum, static voltage stability in optimal condition has improved than that in initial state, accordingly, achieve the aims of reducing active power loss and enhancing static voltage stability.

VIII. Conclusion

Seen from simulation results, not only is the improved Tabu search algorithm suitable to solve reactive power optimization in area power grid, but also the secondary optimization control of voltage and reactive power in area power grid based on improved Tabu search algorithm and considering static voltage stability is practicable and effective.

IX. References

[1] A. Fortin, N. Hail, and B. Jaumard, "A tabu search heuristic for the dimensioning of 3g multi-service networks," in IEEE WCNC, vol. 3, 2003, pp. 1439-1447.

[2] F. Glover and M. Laguna, *Tabu Search*. Kluwer, 1997.

[3] WANG Jian, L I Xingyuan , QIU Xiaoyan. Power system research on distributed generation penetration. Automation of Electric Power Systems, 2005, 29 (24): 90297.

[4] LIU Yutian, MA Li. Reactive power optimization based on Tabu search approach. Automation of Electric Power Systems, 2000, 24 (2): 61264.

[5] Glover F. Tabu search —part □, ORSA J [J]. Computing, 1989, 1 (3): 190 —206.

[6] Glover F. Tabu Search —Part Ⅱ, ORSA J [J]. Computing, 1990, 2 (1): 4 —32.

[7] Nowicki E, Smutnicki C. A fast taboo search algorithm for the job shop problem [J]. Management Science, 1996, 42 (6): 797 —813.

[8] Minmei Huang and Ronggui Luo, "Heuristic-Tabu-Genetic Algorithm Based Method for Flowshop Scheduling to Minimize Flowtime" in WCICA, vol. 2, 2006, pp. 7220-7224.

[9] Lee C Y, Kang H G. Cell planning with capacity expansion in mobile communication: A tabu search approach [J]. IEEE Trans on Vehicular Technology, 2000, 49 (5):1678 - 1691.

[10] Jaumard Brigitte and Samir Sebbah, "Multi-level Tabu Search for 3G Network Dimensioning", in IEEE WCNC, 2007, pp. 4411-4416.

[11] IEEE/CIGRE. Definition and classification of power system stability. IEEE Transactions on Power Systems, vol. 19 no. 2, May. 2004.

[12] Duan Xianzhong, He Yangzan, Chen Deshu. Fast algorithm of voltage stability safety index including load characteristics [J]. Proceedings of the CSEE, 1995, 15(3): 166-172.

X. Biographies

Wennan Lin was born in Huan, China, on 27 March 1983.He received his B.S degree automation from Changsha University of Science& Technology, China in 2005, and currently he studies M.S degree power system and automation there.

Yihua Li was born in Hunan, China, on 12 June 1964. She received her B.S degree and M.S degree in Central south University, China. Her special fields of interest included power system automation technology.

Xingtao Xu was born in Xinghua, Jiangsu, China, in March 1967. He received his B.S degree electrical engineering in Changsha University of Electric power, His employment experience included Xinghua Power Supply Bureau and Taizhou Power supply Bureau.

Maojun Li was born in Ningxiang, Hunan, China, in 1964. He received his B.S degree, M.S degree and Ph.D. degree automat-ion in Hunan University, China. His special fields of interest included optimal operation and intelligent control of power system.