Preprints of the 5th international conference on
Electric Utility Deregulation and Restructuring and Power Technologies
November 26-29, 2015. Changsha, China

Bi-level Distributed Optimal Dispatch of Micro Gird Clusters Based on Mutual Communication

Jie Yu
School of Electrical Engineering
Southeast University
Nanjing, China
yujie@seu.edu.cn

Yiping Jiao, Xiaolong Wang
School of Automation
Southeast University
Nanjing, China

Ming Ni
NARI Technology Co. Ltd
Nanjing, China

***Abstract*—Micro Gird Cluster (MGC), connecting to the medium or low voltage distribution network, usually contains certain number of Micro Grids, distributed generators, energy storages and loads. Considering coordinated operation in MGC, this paper proposes a hierarchical control architecture- the upper layer operated in distributed mode among multiple MGs and the lower layer were controlled by each micro grid center. This hierarchical architecture not only shows the excellent features of distributed control, but also integrates the advantages of centralized control. According to this hierarchical architecture, bi-level distributed optimal dispatch of MGC is analyzed. With the aim of minimizing MGC total costs in upper layer and minimizing each Micro-Grid costs in lower layer, bi-level optimal mathematic model take global and local aims into account synthetically. The distributed primal-dual sub-gradient algorithm is designed to solve the upper layer optimal model, alternating gradient iteration algorithm for the lower optimization model. Simulation cases show that bi-level distributed optimal mathematic model successfully fulfill the aim of coordinated operation in MGC, and distributed primal-dual sub-gradient algorithm is an effective solution to this optimal model.**

Keywords—micro gird cluster(MGC); Bi-level distributed optimal dispatch; hierarchical control architecture

I. INTRODUCTION

With the continuing growth of energy consumption and environmental pollution, the distributed generation are getting more and more popular. But as distributed generators connected to the grid, it becomes a problem to deal with large number of them effectively. Micro Grid (MG) is an independent control system containing distributed generators, loads and storage devices [1]. It can operate in island modes or connected modes and integrate the advantages of distributed generation, weaken the negative impact of distributed generation to the grid, and reduce the burden on distribution network. Since the concept of micro grid was proposed firstly in the late 1990s, related researches were rapidly launch in United States, European Union, Japan, China and others, with valuable research results [2-4] established. However, with the large scale of distributed generators connecting to the grid, how to maximize micro grid cluster efficiency would be of great research importance and practical value. Recently, more and more researchers concern on Micro Gird Cluster (MGC), which usually contains certain number of micro grids, distributed generators, energy storages and loads [5], all these are connecting to the medium or low voltage distribution network. The effective coordination among MGC would be beneficial to enhance the power system controllability, so as to achieve greater performance and higher reliability of power grids.

Indubitable advantages of MGC coordinated operation are practically embodied in voltage control, frequency control, and optimal dispatch. In the respect of voltage control, J. Vasiljevska [6] presented a control functionality for micro-generators, loads and storage devices, to get acclimatized to stress medium voltage distribution network circumstance involving overload or excessive voltage drops, and so on. With respect to frequency control, N. J. Gil [7] proposed an operating control strategy for micro grid in islanded mode, to maintain coordinated frequency control according to real-time status of each distributed generation unit, and try to make power grid frequency return to the rated value after disturbances. C. Yuen [8] classified the frequency control into two kinds of modes- centralized mode and decentralized mode.

Not alone, but with a good prototype. In respect of optimal dispatch, the optimal control architecture contains three types- centralized, decentralized and distributed dispatch. The centralized control architecture sets up a central controller to send control command from the center to all controlled units, and receive all information from all controlled units to the center, lying on communication links among the center and each unit. That means all information of each unit would be transfer to the center and all control function would be fulfilled in the center. The control center, without doubts, is the most critical part and the most vulnerable point in the whole control system. Another great virtue of centralized optimization, of course, has the greatly potential to achieve the global optimal operation and converge to the global optimal solution. J. Vasiljevska [9] aimed to maximize the profits of multiple micro grids and used Multi Criteria Decision Aid techniques to capture decision maker's preferences. M. Fathi [10] addressed energy consumption scheduling optimization on multiple micro grids, containing multi objectives. P. Li [11] concerned an integrated energy exchange scheduling strategy with the objective of minimalizing the total electricity cost of multiple micro grids while meeting the market obligation, to achieve an adjustable price via

This work was funded by the State Grid Corporation of China project: Key Technologies for Power System Security and Stability Defense Considering the Risk of Communication and Information Systems, the National Natural Science Funds 51407030 and China Postdoctoral Science Foundation 121809.

dual linear programming. K. Amin [12] constructed an interline power flow controller, via a multi-objective optimal power flow algorithm, to minimize operating cost of multiple micro grids and total energy loss, as well as the voltage profile deviation of all buses.

Centralized control architecture is consistent with traditional power system control mode. While MGC probably striding across different distribution networks and containing numerous micro grids geographically dispersed, it seems unrealistic to construct a control center for MGC. Decentralized control architecture, without a control center, just sets up a data exchange processor which can provide market prices, weather forecasting, data records and other valuable information to each unit [13,14]. N. Kumar [15] proposed a multi-agent frame for two layer MGC, where each micro grid agent was viewed as not only load agent but also generator agent. H. K. Nunna [16], based on JADE (Java Agent Development) framework, simulated multiple micro grids operations to shorten the supply-demand gap among micro grids via forming virtual market environments. In the decentralized control architecture, each unit or agent makes their decision just according to common information via the data exchange processor, in other words, it is difficult to demand every units or agents shot on the same target.

Different from centralized and decentralized mode, distributed dispatch, based on distributed control, complicatedly combines the excellent advantages of centralized control and decentralized dispatch. The distributed control is actually a kind of network control based on mutual communication links, integrating local autonomy with global targets as extensively as possible. The distributed units would communicate with their neighbor units and achieve others current status parameters using already existing communication links [17]. Distributed control has been increasingly utilized in extensive engineering fields, without any exception, in the power system specially. As an earlier research, Zhang Ziang [18] explored decentralized optimization used to multiple traditional generators economic dispatch. Furthermore, Xin Huanhai [19,20] researched the distributed control to coordinate the outputs of a number of photovoltaic generators. The control strategy not only makes a group of Photo Voltaic (PV) cells operate at the same ratio of available power, but also optimally dispatches the total active and reactive power outputs for PV cells. It is just such another. Yang Hongming [21] made distributed dispatch simulation for virtual power plant (VPP), which maximize the VPP profits by coordinating individual decision-making of distributed energy resources via limited communication.

Objectively to say, it is unpractical to newly construct a control center for MGC, which is always composed by multiple micro grids and distributed generaotrs with dispersed geographical location. Furthermore, these micro grids or distributed generaotrs included in MGC sometimes switch operation modes via plug-in or plug-out according to the power system circumstances. It appears that MGC is suitable for distributed control architecture. This paper introduces a novel distributed hierarchical architecture for MGC control, building two-layer control strategy to optimize MGC total exchange power costs in upper layer and minimize each micro grid generation cost in lower layer, considering real-time generation constraints of each distributed generator. A novel bi-level distributed algorithm is designed to solve this mathematic model. In the upper layer, distributed optimal algorithm is used to solve upper optimal models; in the lower layer, traditional sub-gradient algorithm is used for the lower layer optimal models; upper and lower iterations are alternating in the solving process until converged to global optimal solutions.

II. THE MGC BASED ON MUTUAL COMMUNICATION

In this paper, MGC contains several micro grids, loads and batteries, and each micro grid contains several uncontrollable generators such as wind and photovoltaic, and controllable generators such as fuel cell and diesel generator, as well as batteries undertaking energy storage. The single micro grid just determines optimal operation strategy and control energy to balance itself interior. While as the MGC, coordinated operation among the multiple micro grids should be considered, such as coordinated the frequency control, voltage control and economic dispatch. Considering the characteristics of multiple decision makers in MGC, this paper proposed a two layer hierarchical structure for the MGC coordinated operation. This two layer hierarchical structure would synthetically integrate global aims with local aims of each micro grid. In other words, the decision makers in upper and lower layers can interact with each other. The upper decision makers guide the lower decision makers by its own decisions but does not interfere with the lower decision directly, while the decision makers in lower layer only need to take the upper decisions as an argument, and then make their own decisions within the scope of freedom. Based on the hierarchical structure we can build a bi-level programming for MGC with different objective functions [22-24].

The MGC hierarchical structure in this paper was showed as Figure 1. The upper layer contains several micro grids, and different micro grids communicate with adjacent micro grids based on the communication links. The upper layer operates in accordance to distributed coordinated mode among each micro grid, where is no need to construct an upper control center. Whereas, each micro grid was managed by inside control center in micro grid with centralized mode, which is called lower layer.

III. MATHEMATIC MODEL OF HIERARCHICAL DISTRIBUTED OPTIMIZATION

The aim of the upper model is to minimize MGC total costs of exchange power between each micro grid and the main power grid, with power exchange constraints and transmission lines constraints. The objectives of lower layer are minimalizing each micro grid costs with the operating constraints of distributed generations and energy storage units.

A. Upper Layer Distributed Optimization of MGC

1) Objective Function

$$\min TC = \min \sum_{i=1}^{I_{MG}} \left(\rho P_{ex}^{i} \right) \tag{1}$$

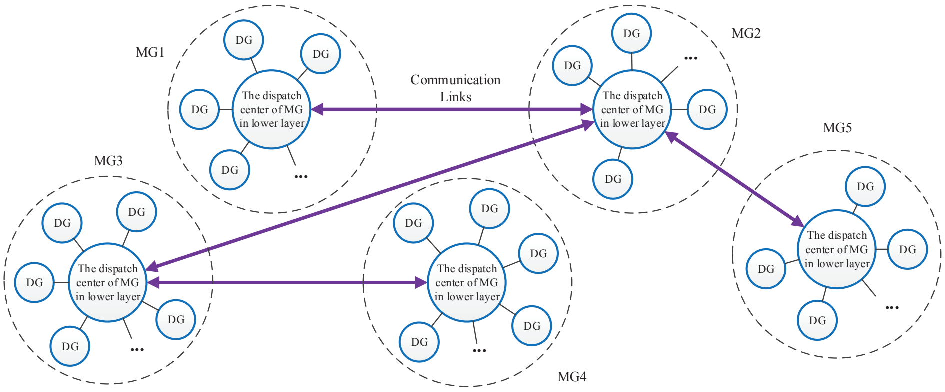


Fig. 1. Micro Grid Clusters based on Mutual Communication

Where, *TC* expresses the total cost of multiple micro grids, I_{MG} is the number of micro grids controlled by distributed dispatch. ρ is the energy price exchange between each micro grid and the main power grid, P_{ex}^i is the exchange power between micro grid i and the main grid, $P_{ex}^i > 0$ represents the main grid transfers power energy to micro grid i, otherwise, $P_{ex}^i < 0$ means micro grid i transfers power energy to the main grid.

2) Constraints

a) The upper and lower bound constraints of the exchange power between the main power grid and micro grid i.

$$P_{ex,\min}^i \le P_{ex}^i \le P_{ex,\max}^i \quad i = 1, 2, \ldots I_{MG} \tag{2}$$

where, $P_{ex,\min}^i$, $P_{ex,\max}^i$ represent the lower and upper bounds of the exchange power.

b) Power Lines Flow Constraints.

$$-T_m \le \sum_{i=1}^{I_{MG}} \eta_{i-m} P_{ex}^i \le T_m \quad m = 1, 2, \ldots M \tag{3}$$

where η_{i-m} is the sensitivity of power injection from micro grid i to line m, T_m is the power flow limit of line m.

B. Lower Layer Optimization of each micro grid

Taking micro grid i for instance, each micro grid optimal model is similar as follows.

1) Objective Function

$$\begin{aligned} C_F^i &= \min \sum_{j=1}^{J_i} C_j^i(P_j^i) \\ &= \min(C_{wind-om}^i P_{wind}^i + C_{pv-om}^i P_{pv}^i + C_{mt}^i P_{mt}^i + C_{mt-om}^i P_{mt}^i \\ &\quad + C_{bs-om}^i (P_{BT-disch}^i + \left|P_{BT-ch}^i\right|) \end{aligned} \tag{4}$$

where, C_F^i is the cost of micro grid i, $C_j^i\left(P_j^i\right)$ is the generation costs function of generator j in micro grid i, J_i is the numbers of distributed generators in micro grid i, P_{wind}^i is the outputs of wind generation in micro grid i, $C_{wind-om}^i$ is the operation and maintenance cost of wind power equipment, P_{pv}^i is the outputs of photovoltaic generation in micro grid i, $C_{\text{pv}-om}^i$ is the operation and maintenance costs of photovoltaic power equipment, $C_{\text{mt}-om}^i$ is the operation and maintenance costs of micro turbine, P_{mt}^i is the outputs of micro turbine in micro grid i, C_{mt}^i is the fuel costs of micro turbine, $C_{\text{bs}-om}^i$ is the operation and maintenance costs of storage units, $P_{BT-ch}^i / P_{BT-disch}^i$ is the charge/discharge power of the storage units, which is positive while discharging and negative while charging.

2) Constraints

a) Power Lines Flow Constraints.

$$\sum_{j=1}^{J_i} P_j^i + P_{BT\_ch}^i \cdot \eta_{BT\_ch}^i - P_d^i = P_{ex}^i \tag{5}$$

$$\sum_{j=1}^{J_i} P_j^i + P_{BT\_dis}^i \cdot \eta_{BT\_dis}^i - P_d^i = P_{ex}^i \tag{6}$$

where, P_{ex}^i is the exchange power between micro grid i and the main grid, P_d^i is the loads of micro grid i.

b) The upper and lower bounds of each distributed generator in *ith* micro grid.

$$P_{j,\min}^i \le P_j^i \le P_{j,\max}^i j = 1, 2, \ldots J_i \tag{7}$$

where, $P_{j,\min}^i$ and $P_{j,\max}^i$ are the upper and lower bounds of distributed generator j.

c) The energy storage constraints of *ith* micro grid.

$$P_{BT\_ch,\min}^i \le P_{BT\_ch}^i \le P_{BT\_ch,\max}^i \tag{8}$$

$$P_{BT\_dis,\min}^i \le P_{BT\_dis}^i \le P_{BT\_dis,\max}^i \tag{9}$$

$$SOC^i{}_{\min} \le SOC^i \le SOC^i{}_{\max} \tag{10}$$

where, $P^i_{BT\_ch,\min}$, $P^i_{BT\_ch,\max}$ are the upper and lower charging power and $P^i_{BT\_disch,\min}$, $P^i_{BT\_disch,\max}$ are the upper and lower discharging power in micro grid i. SOC^i is the battery storage status in micro grid i. $SOC^i_{\min}$ and $SOC^i_{\max}$ are the upper and lower limits of battery storage status respectively.

IV. NUMERICAL SIMULATIONS

The process to search the solution of bi-level optimal model is described as below.

① If starting iteration, *k*=0; else *k*=*k*+1; MG *i* gets neighbors' information *Pj(k)* via communication connection;

② Calculate *Pi(k+1)* in MG *i* including from ③ and ⑤;

③ *Pj(k)* is assigned to local optimization model of MG *i*;

④ The local optimization model is solved according to (4) to (10);

⑤ Each micro generator's generation are achieved in MG *i*;

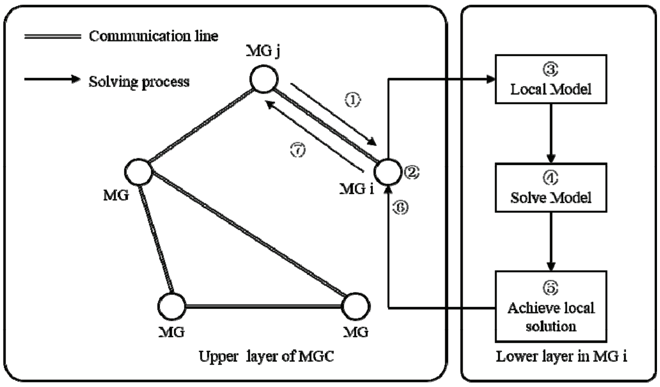
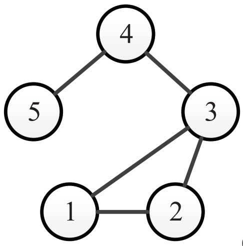


Fig. 2. The flowchart of upper and lower iterative solution

⑥ Update *Pi(k+1)* as the sum of all micro generator's states in MG *i*;

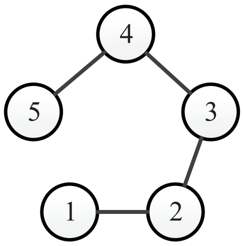
⑦ The modified state *Pi(k+1)* are transfer to neighbor MGs at the beginning of next iteration.

A. Discussion I:the Influence of Communication Topology



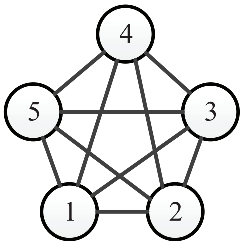
$$A_1=\begin{bmatrix}0.52 & 0.19 & 0.29 & 0 & 0\\ 0.19 & 0.58 & 0.23 & 0 & 0\\ 0.29 & 0.23 & 0.21 & 0.27 & 0\\ 0 & 0 & 0.27 & 0.63 & 0.10\\ 0 & 0 & 0 & 0.10 & 0.90\end{bmatrix}$$

(1) Communication Case1



$$A_2=\begin{bmatrix}0.70 & 0.30 & 0 & 0 & 0\\ 0.30 & 0.41 & 0.29 & 0 & 0\\ 0 & 0.29 & 0.32 & 0.39 & 0\\ 0 & 0 & 0.39 & 0.31 & 0.30\\ 0 & 0 & 0 & 0.30 & 0.70\end{bmatrix}$$

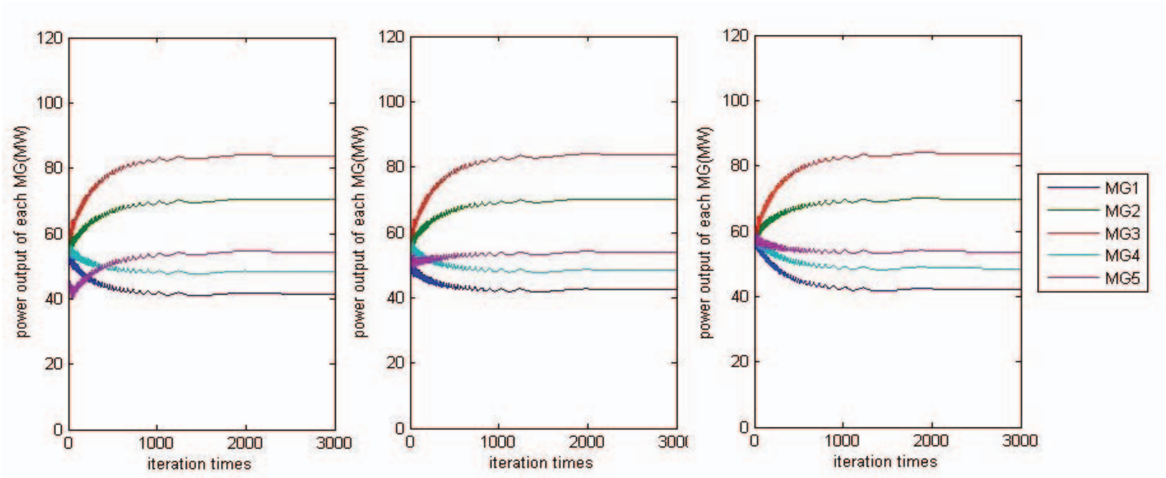
(2) Communication Case 2



$$A_3=\begin{bmatrix}0.2 & 0.2 & 0.2 & 0.2 & 0.2\\ 0.2 & 0.2 & 0.2 & 0.2 & 0.2\\ 0.2 & 0.2 & 0.2 & 0.2 & 0.2\\ 0.2 & 0.2 & 0.2 & 0.2 & 0.2\\ 0.2 & 0.2 & 0.2 & 0.2 & 0.2\end{bmatrix}$$

(3) Communication Case3

Fig. 3. Different connection topology



1 Results in Case1 2 Result in Case 2 3 Result in Case3

Fig. 4. Distribution Optimization Results in Different Cases

The communication connection topology is denoted by matrix A, which is a doubly-stochastic matrix and a_{ij} (matrix element row i and column j in A). Once communication topology is changed, the matrix A is changed also. If there is no communication connection between node i and j, a_{ij} would be zero; otherwise, a_{ij} means the weight influence from node j to i.

Based on different communication links, we detect the optimization results to analyze communication topology influence. The simulation shows that final optimization is the same numerical results. Shown in Fig.4, the communication connection seems have little effect on optimization results, but more on convergence dynamic process.

B. *Discussion II: Influence of Communication Nodes Number*

If one Micro grid plugs in or plug out in MMG, that means communication nodes number is changed. For example, some of the micro grids separate itself from the power grid. It is obvious that the separation of the micro-grids will influence the MMG communication connection topology (shown in Fig.5) and communication matrix A. The matrix elements in row 5 and column 5 change to zero, corresponding to the separated micro grid 5. In this case, communication connection matrix A transforms to a non-doubly- stochastic matrix.

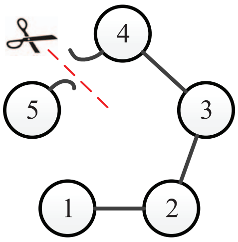


Fig. 5. Connection Topology Changing When Micro Grid 5 Plug Out

$$A=\begin{bmatrix} 0.70 & 0.30 & 0 & 0 & 0 \\ 0.30 & 0.41 & 0.29 & 0 & 0 \\ 0 & 0.29 & 0.32 & 0.39 & 0 \\ 0 & 0 & 0.39 & 0.31 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{11}$$

According to matrix A shown in (11), the optimization is failed to search global solution, since all micro grid optimal processes drop down completely, which is illuminated in Fig. 6.

A new matrix A' is re-constructed as listed in (12), which satisfies doubly-stochastic and denotes each micro grid being connected. Based on the new communication matrix, hierarchical distributed optimization of multiple micro grids could be solved successfully, which is illustrated in Fig.7.

$$A=\begin{bmatrix} 0.70 & 0.30 & 0 & 0 \\ 0.30 & 0.41 & 0.29 & 0 \\ 0 & 0.29 & 0.32 & 0.39 \\ 0 & 0 & 0.39 & 0.61 \end{bmatrix} \tag{12}$$

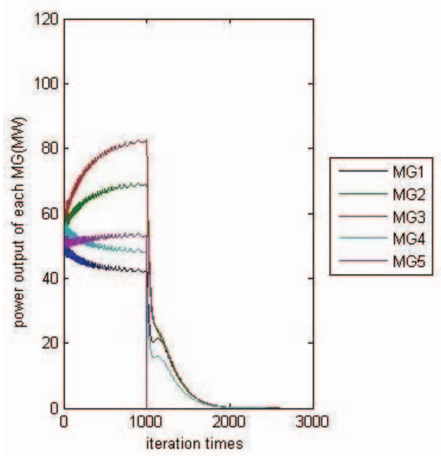


Fig. 6. Resoult of Connection Topology Changing When Micro Grid 5 Plug Out

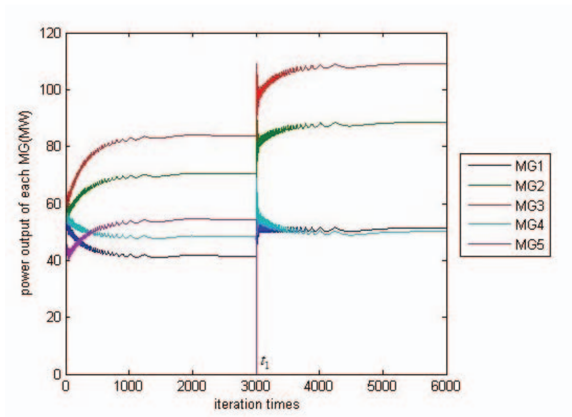


Fig. 7. Optimization progress in case of topology changed

V. Conclusion

In this paper, we proposes a method which uses distributed computation model to realize the optimal dispatch of MGC. The optimization means that the total price power grid pays to the MGC, according to the power generation, is reduced as much as possible. Meanwhile, for each micro grid, it generate a certain amount of power, which is determined by the whole group through the distributed optimization algorithm, by using of all micro power sources belong to it. As for the inner plan, it is obtained by a centralized algorithm.

The simulation results show that under such two-layered optimization algorithm, the whole system can run at a mode which is more beneficial. Furthermore, it can make effective response to some undesirable situations. Such as the generation ability is limited in some micro grids, or the inner components can't achieve the given goal. A necessity of the algorithm is that each member of micro grid is connected to any other micro grid, directed or undirected. In other words, there can't exist any micro grid which is absolutely isolated from any other micro grids. Under such case, communication connection shows have little influence on the optimal solution results.

What's more, the communication connection matrix among MGC, which meets demand for being a doubly-stochastic matrix, is rather difficult to obtained or modified. Once micro grid plug in or plug out, the matrix dimension is changed. However, it is still confused for researchers how to modify matrix elements to maintain the feature of being doubly-stochastic matrix, so as to keep the convergence of distributed optimization, which are worthwhile for further investigation.

REFERENCES

[1] M. Mohammadi, S. H. Hosseinian, G. B. Gharehpetian. "Optimization of hybrid solar energy sources/wind turbine systems integrated to utility grids as microgrid (micro grid) under pool/bilateral/hybrid electricity market using PSO". in *Solar Energy*. vol. 86, pp. 112-125, 2012

[2] Y. H. Chen, S. Y. Lu, Y. R. Chang, et al. "Economic analysis and optimal energy management models for microgrid systems: A case study in Taiwan". in *Applied Energy*. vol. 103, pp. 145-154, 2013

[3] Tasdighi, M.; Ghasemi, H.; Rahimi-Kian, A., "Residential Microgrid Scheduling Based on Smart Meters Data and Temperature Dependent Thermal Load Modeling," in *Smart Grid, IEEE Transactions on* , vol.5, no.1, pp.349-357, Jan. 2014

[4] A. M. Amjad, S. Alireza, N. Taher. "Multi-operation management of a typical micro-grid using Particle Swarm Optimization: A comparative study". in *Renewable and Sustainable Energy Reviews*, vol. 8, pp. 1-14, 2011

[5] Ng, E.J.; El-Shatshat, R.A., "Multi-microgrid control systems (MMCS)," in *Power and Energy Society General Meeting, 2010 IEEE*, pp.1-6, 25-29 July 2010

[6] Gil, N.J.; Peas Lopes, J.A., "Hierarchical Frequency Control Scheme for Islanded Multi-Microgrids Operation," in *Power Tech, 2007 IEEE Lausanne* , pp.473-478, 1-5 July 2007

[7] J. Vasiljevska, J. A. Pecas Lopes, M. A. Matos. "Integrated micro-generation, load and energy storage control functionality under the multi micro-grid concept". in *Electric Power Systems Research*, vol. 95, pp. 292-301, 2013

[8] Yuen, C.; Oudalov, A.; Timbus, A., "The Provision of Frequency Control Reserves From Multiple Microgrids," in *Industrial Electronics, IEEE Transactions on* , vol.58, no.1, pp.173-183, Jan. 2011

[9] J. Vasiljevska, J. A. Pecas Lopes, M. A. Matos. "Evaluating the impacts of the multi-microgrid concept using multicriteria decision aid". in *Electric Power Systems Research*, vol. 91, pp. 44-51, 2012

[10] Fathi, M.; Bevrani, H., "Adaptive Energy Consumption Scheduling for Connected Microgrids Under Demand Uncertainty," in *Power Delivery, IEEE Transactions on* , vol.28, no.3, pp.1576-1583, July 2013

[11] Pan Li; Xiaohong Guan; Jiang Wu; Dai Wang, "An integrated energy exchange scheduling and pricing strategy for multi-microgrid system," in *TENCON 2013 - 2013 IEEE Region 10 Conference (31194)*, pp.1-5, 22-25 Oct. 2013

[12] Kargarian, A.; Falahati, B.; Yong Fu; Baradar, M., "Multiobjective optimal power flow algorithm to enhance multi-microgrids performance incorporating IPFC," in *Power and Energy Society General Meeting*, 2012 IEEE , pp.1-6, 22-26 July 2012

[13] Eddy, F.Y.S.; Gooi, H.B., "Multi-agent system for optimization of microgrids," in Power Electronics and ECCE Asia (ICPE & ECCE), *2011 IEEE 8th International Conference on* , pp.2374-2381, May 30 2011-June 3 2011

[14] Mao Meiqin; Dong Wei; Liuchen Chang, "Design of a novel simulation platform for the EMS-MG Based on MAS," in *Energy Conversion Congress and Exposition (ECCE), 2011 IEEE*, pp.2670-2675, 17-22 Sept. 2011

[15] Kumar Nunna, H.S.V.S.; Doolla, S., "Multiagent-Based Distributed-Energy-Resource Management for Intelligent Microgrids," in *Industrial Electronics, IEEE Transactions on* , vol.60, no.4, pp.1678-1687, April 2013

[16] Nunna, K.H.S.V.S.; Doolla, S., "Responsive End-User-Based Demand Side Management in Multimicrogrid Environment," in *Industrial Informatics, IEEE Transactions on* , vol.10, no.2, pp.1262-1272, May 2014

[17] Guanghui Wen; Zhisheng Duan; Guanrong Chen; Wenwu Yu, "Consensus Tracking of Multi-Agent Systems With Lipschitz-Type Node Dynamics and Switching Topologies," in *Circuits and Systems I: Regular Papers, IEEE Transactions on* , vol.61, no.2, pp.499-511, Feb. 2014

[18] Ziang Zhang; Mo-Yuen Chow, "Incremental cost consensus algorithm in a smart grid environment," in *Power and Energy Society General Meeting, 2011 IEEE* , pp.1-6, 24-29 July 2011

[19] Xin, H.; Lu, Z.; Qu, Z.; Gan, D.; Qi, D., "Cooperative control strategy for multiple photovoltaic generators in distribution networks," in *Control Theory & Applications, IET* , vol.5, no.14, pp.1617-1629, September 22 2011

[20] Huanhai Xin; Deqiang Gan; Naihu Li; Huijie Li; Chensong Dai, "Virtual power plant-based distributed control strategy for multiple distributed generators," in *Control Theory & Applications, IET* , vol.7, no.1, pp.90-98, Jan. 3 2013

[21] Hongming Yang; Dexin Yi; Junhua Zhao; Zhaoyang Dong, "Distributed Optimal Dispatch of Virtual Power Plant via Limited Communication," in *Power Systems, IEEE Transactions on* , vol.28, no.3, pp.3511-3512, Aug. 2013

[22] Minghui Zhu; Martinez, S., "On Distributed Convex Optimization Under Inequality and Equality Constraints," in *Automatic Control, IEEE Transactions on* , vol.57, no.1, pp.151-164, Jan. 2012

[23] S. Dempe. Foundations of Bilevel Programming, Opringer Science & Media, 2002

[24] Carrión, M.; Arroyo, J.M.; Conejo, A.J., "A Bilevel Stochastic Programming Approach for Retailer Futures Market Trading," in *Power Systems, IEEE Transactions on* , vol.24, no.3, pp.1446-1456, Aug. 2009