Vol.2012-CDS-4 No.2
2012/5/10

アイランドモードのマイクログリッドにおける電力配分のためのマルチエージェントに基づく配分法とアーキテクチャ

加藤 匠[1,2,a)] 高橋 秀幸[1,2,b)] 木下 哲男[1,2,c)]

概要：近年電力の重要性が増すにつれ，新たなパラダイムがスマートグリッドやマイクログリッドの分野において多く提案されてきている．日本では特に東日本大震災後，持続可能な耐久性のある電力網の実現が期待されている．本論文ではマイクログリッドに焦点をあて，災害時の様々な障害に耐えうる，マルチエージェントを基にした電力配分法を提案する．具体的には災害時に孤立したマイクログリッド内で需要家の性質を考慮しつつ電力配分を行うものである．実験により，提案手法によってマイクログリッドの持続可能性と耐久性の向上を確認した．

キーワード：マルチエージェントシステム, 負荷分散, マイクログリッド, スマートグリッド, 電力配分

Multiagent-Based Power Allocation Scheme and Architecture for Load Shedding in Islanded Microgrid

Takumi Kato[1,2,a)] Hideyuki Takahashi[1,2,b)] Tetsuo Kinoshita[1,2,c)]

Abstract: As the importance of electricity has been significantly increasing, there are several new paradigms of power grid proposed in the field of Smart Grid and Microgrid. In Japan, especially after the Great East Japan Earthquake, new power grid paradigms are expected to be more sustainable and resilient to survive several difficulties during a disaster situation. In this paper, we focus on microgrid and propose a multiagent-based power allocation scheme to realize the sustainable and resilient power grid. The proposed power allocation scheme allocates electricity regarding the priority of loads in an islanded microgrid during a utility grid disturbance, and the effectiveness of the scheme is confirmed in the experiment.

Keywords: Multiagent System, Load Shedding, Microgrid, Smart Grid, Power Allocation

1. Introduction

As the importance of electricity has been significantly increasing, there are several new paradigms of power grid proposed in the field of Smart Grid and Microgrid. In general, ensuring energy security to face the dwindling oil and gas reserves, require a radical improvement in the way in which energy is generated, distributed and consumed. In Japan, especially after the Great East Japan Earthquake, new power grid paradigms are expected to be more sustainable and resilient to survive several difficulties during a disaster situation.[1] [2].

This paper focuses on microgrid, which is a small-scale power supply network designed to provide power for a small community. The microgrid is composed of distributed generation systems (DGs), distributed storage systems (DSs), and loads such as commercial buildings, schools, hospitals, industrial plants and so on [3] [4]. The configuration overview of Microgrid is shown in Figure 1.

MGOCC stands for Microgrid Operation and Control

[1] Graduate School of Information Sciences, Tohoku University
[2] Research Institute of Electrical Communication, Tohoku University
[a)] takumi@k.riec.tohoku.ac.jp
[b)] hideyuki@riec.tohoku.ac.jp
[c)] kino@riec.tohoku.ac.jp

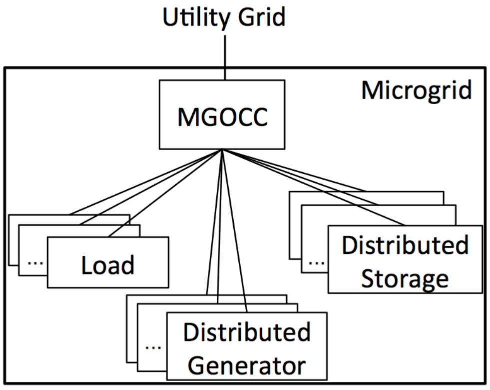

図 1 マイクログリッドの構成概要
Fig. 1 Microgrid Configuration Overview

Center, which is in charge of gathering information in the microgrid and making decisions to operate and control the microgrid. Load, Distributed Generator, Distributed Storage are the components of microgrid. Load is basic component which simply consumes electricity in the grid. Distributed Generator is a power generator in the grid that supplies the power in the microgrid. Distributed Storage is a component that stores electricity and it charges / discharges power regarding the situation of the grid.

Since microgrid has several components to control, it is challenging to operate microgrid in a conventional, fully centralized method. It is required that each component gathers, distributes, and act on information about the behavior of other participants. Therefore each component needs to be autonomous, reactive and in some case cooperative to work as a microgrid. In order to meet these criteria, applying agent system to microgrid is proposed in the existing research. It is well established that application of agent system to microgrid is effective [3] [4] [5].

The microgrid has two operational modes: grid connected mode and island mode. In the grid connected mode, the power balance between supply and demand in the microgrid is maintained by power exchange with the utility grid, which is the upper grid of the microgrid. In the island mode, the microgrid is electrically isolated from the utility grid, thus there is no power exchange with utility grid. In contrast to the grid connected mode, maintaining the power balance between supply and demand is challenging in islanded operation. In case of supply shortage, load shedding [6] needs to be performed in the islanded microgrid, which is a control action to reduce the amount of load intentionally. Discharging of distributed storage is also performed to meet the supply-demand balance.

As mentioned above, island mode is one of two operational modes of microgrid, although there is a difference between being island mode intentionally and accidentally. If switching into island mode is the decision of microgrid operator, the microgrid is islanded intentionally, however if the microgrid is isolated from the utility grid by accident, e.g. blackout of upper grid system, the microgrid is islanded accidentally. There is a research to distinguish these two kinds of island mode [7].

In power grid operation, performing load shedding causes a critical problem because loads usually do not expect that their demands do not meet the power supply. However, for instance, a disaster situation like Great East Japan Earthquake [2] forces microgrid to be isolated from utility grid and the microgrid need to handle the power shortage until the utility grid became available again. In addition, in the situation like the scheduled rolling blackout [8] performed by TEPCO [9], microgrid needs to be operated in islanded mode and it is crucial to protect the important loads in it.

2. Related Works and Problems

2.1 Related Works

Several existing research on autonomous operation of microgrid is explained to examine the issues in the field of microgrid operation. An agent (or intelligent agent) can perceive its environment, can make a decision against changes of the environment, and can act to resolve them autonomously according to its design purpose using its reactivity, proactiveness, and social ability [10]. Since the characteristics of agent (or intelligent agent) system are well suited for the operation of microgrid, it is well established that agent based operation is efficient for microgrid operation, as well as for Smart Grid operation [3] [5] [11] [12].

In the field of agent-based microgrid operation, there are several types of research for autonomous microgrid operation. One of them is introducing mobile agent to observe and operate microgrid [13]. A mobile agent collects information and make decisions by moving from one component to another in the microgrid. The advantage of this method is that the system does not need to have one centralized operation center. Instead, the mobile agent moves around makes decisions and operates the microgrid. However, once the scale of the microgrid is expanded, it is challenging to operate the whole microgrid with only one mobile agent.

In order to deal with the large number of components and to achieve scalability, there is a research focusing on multiagent based hierarchical operation of microgrid [14]. This research introduces multiagent to operate microgrid. Also this research focuses on the islanded microgrid operation. The issue that occurs by having several components in microgrid is the overhead to deal with a number of messages sent from a number of agents. This research has introduces 4 kinds of agents, namely "Microgrid Agent," "Coordination Agent," "Area Agent," "Component Agent." The key role of agents to achieve scalability is Area Agent and Coordination Agent. Area Agent receives several messages from Component Agents which are dealing with each component of microgrid. Area Agent comprehends the messages from Component Agents and pass the essential information to the Coordination Agent. After receiving the message from Area Agents, Coordination Agent makes decision about microgrid operation in the microgrid and commands Area Agents to change something. Then Area Agents comprehends the message from Coordination Agent and send messages to each Component Agent to follow the command from Coordination Agent. The role of Microgrid Agent is to exchange power with other microgirds when power shortage happens. The power shortage is reported by Coordination Agent.

This kind of hierarchical approach to manage system is common in the field of agent system. There are other research which apply agent based hierarchical control to manage embedded system, which concept is applicable into power grid operation [15].

There is another research which focuses on microgrid operation by applying multiagent system [16]. The agents in the proposed system collects information of each component, send the information to decision making agent, and the decision is sent back to the component agents. Their proposed systems adjusts the amount of thermal power generation regarding to the amount of load demands. Also, since microgrid has distributed generator and usually some of them are using renewable energy, this research applies the transition of power among generated by photo voltaic system (PV). In daytime, the PV generates more power than it does at night.

The research [16] is trying to adjust the load demands, which were the given value in their simulation. Although managing demand from loads is challenging because there are several aspects to deal with [17].

These research mentioned above [13] [14] [15] [16] [17] are mostly about the architecture of the agent system applied into microgrid operation.

In the field of agent agent based microgrid operation, there is also a research which focuses on the division of power in islanded microgrid, which is closely related to the focus of this paper [18]. This research investigates a load-shedding scheme using the Talmud rule in islanded microgrid operation based on a multiagent system. The Talmud rule originating from the Talmud literature has been used in bankruptcy problems of finance, economics, and communications [19]. The research proposes to use talmudic rule to divide power in microgrid.

2.2 Problems

In the previous subsection, the research which is related to the focus of this paper is explained. Since this paper focuses on the autonomous islanded microgrid operation in a disaster situation, in order to achieve the resilience and sustainability, these points mentioned below are considered to be the issues in the exiting research. Firstly, since most of the existing research is simulation based, the modeling of microgrid is simple. However, in order to realize a real operation of microgrid and considering the security of microgrid operation, all the components should not be universally accessible. It should be hierarchical in a way of accessing information and control. Secondly, the exiting research does not focus on protecting the important loads in microgrid during a disaster situation, because this kind of situation is not considered in the existing research. Since this paper focuses on protecting important loads in microgrid, bulk loads such as factories, industry plants should not take a lot of power in the islanded microgrid. The issues are summarized as follows:

P1 All generators, storages and loads are assumed to be simply universally accessible

P2 Bulk loads consume most of the power in the islanded microgrid

In the next section, the proposal to solve these problems are explained.

3. Proposal

3.1 overview

In this section, the solution for the problems mentioned in the previous section we have described two problems in the existing research, and we propose two methods. These solutions are summarized as follows:

S1 Agent-based hierarchical operation of microgrid

S2 Load shedding considering the priority of loads

For Agent-based hierarchical operation of microgrid (S1), since the components of microgrid is assumed to be universally accessible, it is simple solution to introduce one role of agents which are in charge of control, as well as screening from the other agents. By introducing a role of agents like this, components such as generators, storages and loads are not simply universally accessible. S1 solves (P1) All generators, storages and loads are assumed to be simply universally accessible.

For Load shedding considering the priority of loads (S2), in order to protect the important loads in the islanded microgrid, this paper proposes a load shedding scheme considering the priority of loads in the microgrid. S2 solves (P2) Bulk loads consume most of the power in the islanded microgrid.

3.2 Agent-Based Hierarchical Operation of Microgrid

In order to solve P1, we propose a new agent-based hierarchical operational architecture to solve the problem, which is shown in Figure 2. There are 6 roles of agents in the proposed architecture, namely Microgrid Operation and Control Center (MGOCC) Agent, Regional Control (RC) Agent, Local Control (LC) Agent, Load Agent, Distributed Generator (DG) Agent, Distributed Storage (DS) Agent. MGOCC Agent collects information of all the microgrid components and make decision about the operation and control. Load Agents, DG Agents, DS Agents collect information of each component and control it as commanded by LC Agents. LC Agents receive messages from Load, DG, DS Agents about the components in the microgrid and pass the essential information to the upper RC Agents. RC Agents do not have access to the agents under LC Agents. For RC Agents, messages received from LC Agents is all the available information about microgrid's physical components. RC Agent commands several things, e.g. LC Agents to share power with other LC Agents, share power with other region, etc.

3.3 Load Shedding Considering the Priority of Loads

For P2, we propose a new power allocation scheme to protect important loads in an islanded microgrid in a disaster situation. The overview of proposed power allocation scheme is shown in Figure 3. In Figure 3, loads are house and factory. Distributed generators are solar power generator, wind power generator and power plant. Storage is energy storage. When the utility grid is unavailable, the microgrid allocates the power to important loads, in this case houses before factories. It does not mean microgrid cuts the power for all the other loads, but allocate the power to the important loads first, then allocate the remaining power to the other loads. Since this paper is not focusing on demand management or generation scheduling of generators, demand from loads and available energy of DG and DS are assumed to be given for the rest of this paper.

The proposed power allocation scheme is described as a flowchart in Figure 4. This flowchart illustrates the decision making flow of MGOCC Agent after collecting all necessary information from the other agents. Firstly, MGOCC assigns which loads are the important loads in the situation, then calculate the available power and the demands from the loads in the microgrid. If the total demand is greater than the total available power, then MGOCC compares the available power with the total important load demands. If the available power is enough to power the important loads, then power all the important

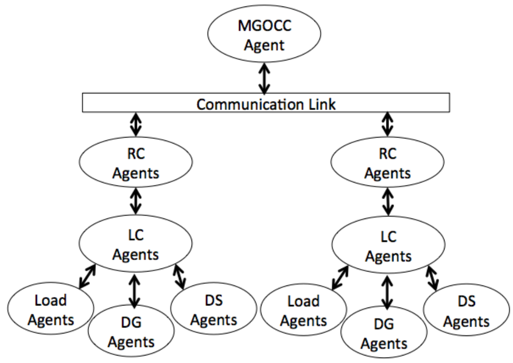

図 2 エージェントの組織構造
Fig. 2 Proposed Agent Organization Architecture

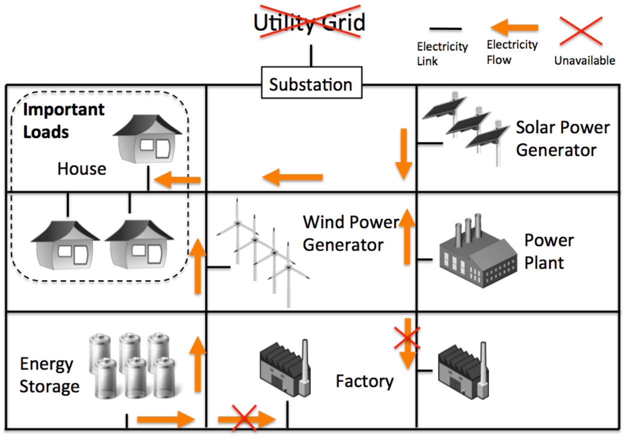

図 3 需要家の重要度を考慮した Load Shedding の概要
Fig. 3 Overview of Proposed Load Shedding Considering the Priority of Loads

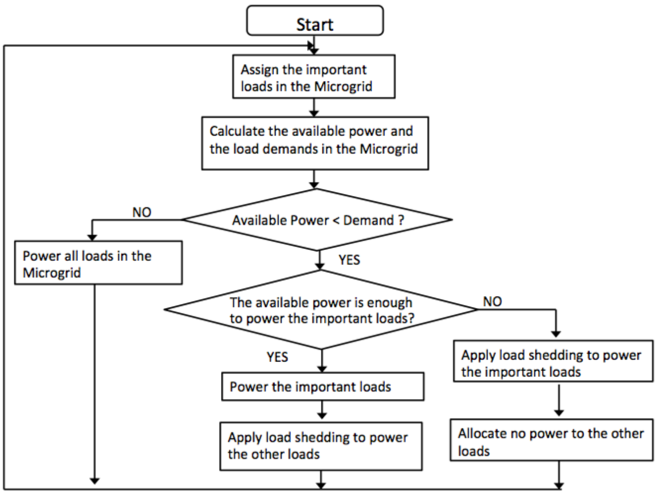

図 4　電力配分のフロー
Fig. 4　Proposed Flow of Power Allocation

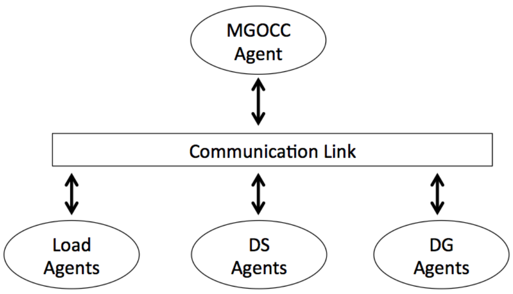

図 5　エージェントの構成
Fig. 5　Agent Configuration

loads and then allocate the remaining power to the other loads, if necessary with load shedding. If the available power is even not enough to power the important loads, apply load shedding to share the available power among the important loads, and allocate no power to the other loads.

4. Implementation

In order to evaluate the proposed power allocation scheme, we have implemented a multiagent system. For the ease of evaluation, the agent configuration for this implementation is as shown in Figure 5. In this implementation, MGOCC directly communicates with Load, DS, DG agents. The message flow in this configuration is shown in Figure 6. Firstly, MGOCC request necessary information from other agents. After sending the request, Load agent sends its demand power, DS agent sends its charged power, and DG agent sends the amount of power generated by the generator. After receiving all the information, MGOCC make decision to allocate power to the participants. After the decision making, MGOCC informs

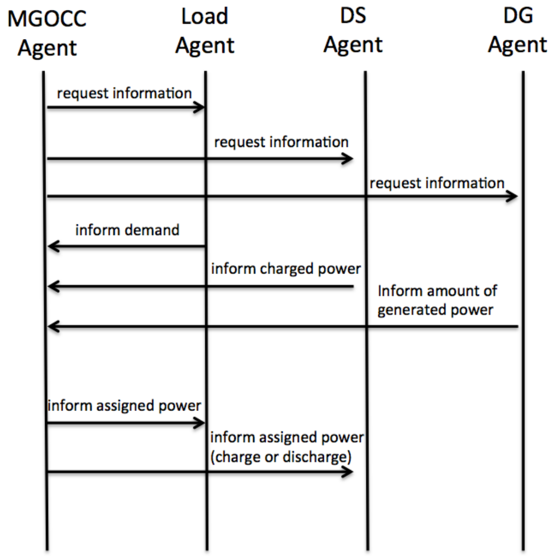

図 6　エージェント間のメッセージフロー
Fig. 6　Message Flow Among Agents

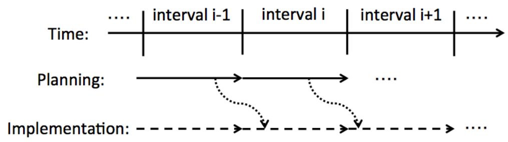

図 7　マイクログリッドの運用周期
Fig. 7　Microgrid Operation Cycle

assined power to the loads and DSs. If MGOCC allocates all the available power in the microgrid, assigned power for DS is zero. If there is remaining power in the microgrid after the allocation, the power is charged to DS. We have used ADIPS/DASH agent and IDEA agent development environment to implement this system [20] [21].

Information gathering, decision making, implementation of the decision are all done in the message flow of Figure 6, which is counted as 1 interval of microgrid operation. The microgrid operation cycle is illustrated in Figure 7. Interval is a time unit of microgrid operation, and MGOCC plans and implements its operation in each interval. For example, in interval i, MGOCC plans the next operation which is implemented in interval i+1. The plan is decided based on the current implementation, which is planned in interval i-1.

5. Evaluation

In this section, we are going to evaluate the proposed power allocation scheme by a simulation. This simulation assumes the situation that the microgrid is suddenly forced to switch into island mode because of utility grid disturbance, and the generators are providing less and less

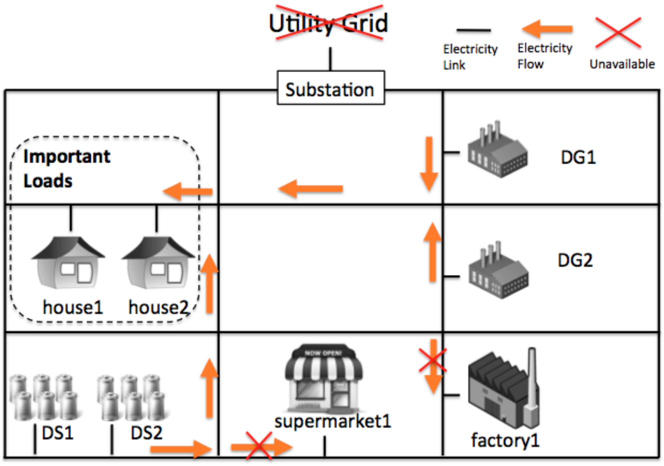

図 8 想定するマイクログリッドの実験シナリオ
Fig. 8 Overview of Simulated Microgrid

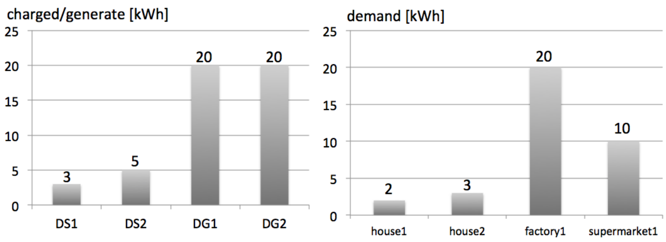

図 9 シミュレーションの初期状態
Fig. 9 Initial State of Microgrid in Simulation

power because generating power needs alternative energy, e.g. fuel, gas, etc.

Firstly, the simulated microgrid in this evaluation is as illustrated in Figure 8. After utility grid disturbance occurs, the power in the microgrid is primarily allocated to the important loads, in this case house1 and house2. Power allocation for supermarket1 and factory1 are shed as the power availability in the microgrid decreases.

We assume the initial state of microgrid is shown in Figure 9. DS1 and DS2 are distributed storages, DG1 and DG2 are distributed generator, respectively. Generated power from DG1 and DG2 changes at each interval. Charged power in DS1 and DS2 are the remaining power from the previous interval. Initial charged power is as shown in Figure 9. The demand of loads are fixed during this simulation. In this simulation, house1 and house2 are assigned as important loads. The other loads are factory1, supermarket1, respectively.

Figure 10 shows the transition of available power provided by DG1, DG2 and DS1, DS2. Figure 11 shows the transition of allocated power to each load. These two figures illustrates the decreasing available power in the microgrid. At interval 9 there is no available power, but at

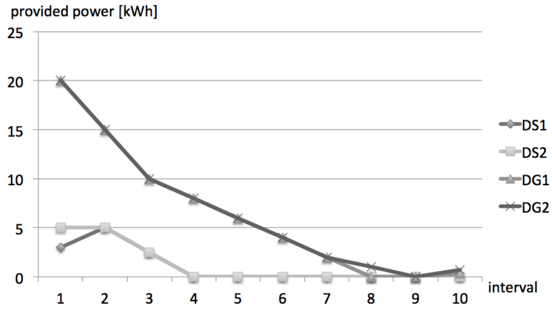

図 10 電力供給源の推移
Fig. 10 Transition of Power Supply

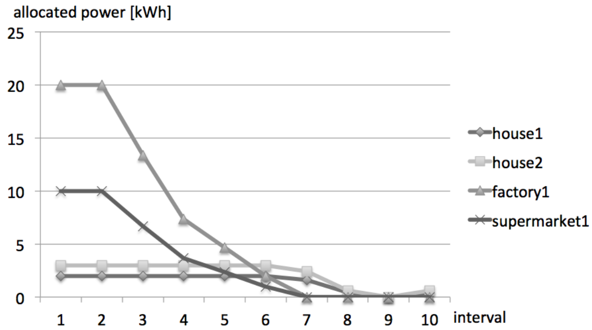

図 11 各需要家への電力配分の推移
Fig. 11 Transition of Power Allocation

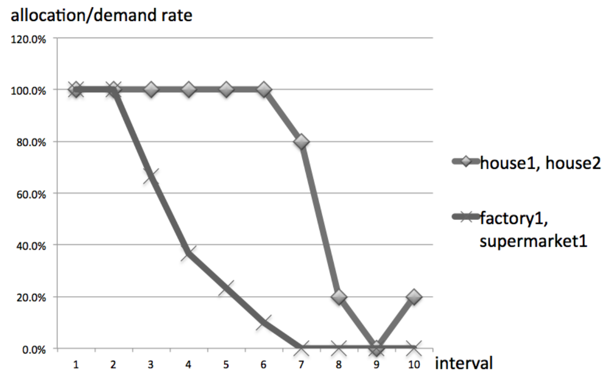

図 12 各需要家の電力要求充足度の推移
Fig. 12 Transition of Allocation/Demand Rate

interval 10 generators start to provide a little power again. From these two figures, it is difficult to see if the proposed power allocation scheme is effective or not. In contrast, Figure 12 clearly illustrates how effective our scheme is. "allocation/demand rate" is a percentile value that indicates the ratio of allocation divided by demand. Since house1 and house2 are both assigned as important loads, these 2 loads get the same allocation/demand rate. Likewise, factory1 and supermarket1 are both not assigned as important loads, therefore they get the same allocation/demand rate. As the available power in the microgrid decreases, allocation/demand rate of not important loads goes down. In contrast, the allocation/demand rate of important loads keep being 100 percent until interval 7. Even the rate becomes zero at interval 9, it quickly recovers to 20 percent by getting a little available power provided by generators. According to this figure, it is certain that proposed power allocation scheme has sustainability to keep important loads as long as possible, also the resilience to recover as quickly as possible. From this result, it is established that we have achieved our goal to realize the sustainable and resilient microgrid in a disaster situation.

6. Conclusion and Future Works

In this paper, we have proposed a new power allocation scheme and architecture to realize resilient and sustainable power grid during a disaster situation. It is confirmed that our method is effective by implementing and performing an simulation of evaluation.

Although our method is confirmed as effective, there are some issue remains in order to make our method into practice. As mentioned in section 2, it is challenging to manage demand in practice, also scheduling and management of generator and storages are complicated. In order to step forward, it is better to consider the demand side, supply side management.

参考文献

[1] Pararas-Carayannis, G.; , "The great tsunami of March 11, 2011 in Japan - analysis of source mechanism and tsunamigenic efficiency," OCEANS 2011 , pp.1-10, 19-22 Sept. 2011.

[2] Adachi, T; , "The restoration of telecom power damages by the Great East Japan Earthquake," Telecommunications Energy Conference (INTELEC), 2011 IEEE 33rd International, pp.1-5, Oct. 2011.

[3] Aris L. Dimeas and Nikos D. Hatziargyrious, "Operation of a Multiagent System for Microgrid Control, "IEEE Transactions on Power Systems, Vol. 20, No. 3, AUGUST 2005.

[4] A. L. Dimeas, and N. D. Hatziargyriou, "A Multi-agent System for Microgrids", 2004 IEEE Power Engineering Society General Meeting, pp. 55-58 June 2004.

[5] Zhang Jian, Ai Qian, Jiang Chuanwen, Wang Xingang, Zheng Zhanghua, Gu Chenghong, "The application of Multi Agent System in Microgrid coordination control, " International Conference on Sustainable Power Generation and Supply, SUPERGEN '09, 2009.

[6] Charles Concordia, Lester H. Fink, George Poullikkas, "Load Shedding on an Isolated System," IEEE Transactions on Power Systems, Vol. 10, No. 3, August 1995.

[7] Jinwei Li, Jianhui Su, Xiangzhen Yang, Tao Zhao, "Study on Microgrid Operation Control and Black Start," 2011 4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), 2011.

[8] "Implementation plan of rolling blackout on and after Tue, March 15, 2011," TEPCO Press Release, March 14, 2011, http://www.tepco.co.jp/en/press/corp-com/release/11031406-e.html (Accessed on Feb 6, 2012)

[9] "Tokyo Electric Power Company (TEPCO)," http://www.tepco.co.jp/en/index-e.html (Accessed on April 9, 2012)

[10] M. Wooldridge, An Introduction to Multiagent Systems, 2nd Edition, A John Wiley and Sons, Ltd, Publication, 2009.

[11] A. L. Dimeas and N. D. Hatiziargyriou,"Agent based Control for Microgrids", Power Engineering Society General Meeting, June 2007.

[12] P. Vytelingum, T. D. Voice, S. D. Ramchurn, A. Rogers, and N. R. Jennings, "Intelligent agents for the smart grid," In Proceedings of the 9th International Conference on Autonomous Agents and Multiagent Systems: volume 1 - Volume 1 (AAMAS '10), Vol. 1. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, pp. 1649-1650., 2010.

[13] Junichi Arai, Shuichiro Yamazaki, Motohisa Ishikawa, and Toshiyuki Ito, "Study on a new power control of distributed generation in an isolated microgrid,"Power & Energy Society General Meeting, 2009.

[14] Duo Shao,Qi We, Tingzhi Nie, "A Multi-Agent Control Strategy in Microgrid island mode," 2011 The 6th International Forum on Strategic Technology, 2011.

[15] Fei-Yue Wang and Cheng-Hong Wang, "Agent-Based Control Systems for Operation and Management of Intelligent Network-Enabled Devices," IEEE International Conference on Systems, Man and Cybernetics, 2003.

[16] T. Logenthiran, D. Srinivasan, A. M. Khambadkone, and H. N. Aung, "Scalable Multi-Agent System (MAS) for Operation of a Microgrid in Islanded Mode," Drives and Energy Systems (PEDES) & 2010 Power India, 2010 Joint International Conference on Power Electronics, 2010.

[17] Sarvapali D. Ramchurn, Perukrishnen Vytelingum, Alex Rogers, and Nick Jennings, "Agent-based control for decentralised demand side management in the smart grid," In The 10th International Conference on Autonomous Agents and Multiagent Systems - Volume 1 (AAMAS '11), Vol. 1. International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, pp. 5-12., 2011.

[18] Hak-Man Kim, Tetsuo Kinoshita and Yujin Lim, "Talmudic Approach to Load Shedding of Islanded Microgrid Operation Based on Multiagent System," Journal of Electrical Engineering & Technology Vol.6, No.2, pp.284 292, 2011.

[19] R. J. Aumann, and M. Michael, "Game theoretic analysis of a bankruptcy problem from the Talmud," Journal of economic theory, Vol. 36, pp. 195-213, 1985.

[20] IDEA/DASH Tutorial: http:// www.ka.riec.tohoku.ac.jp/idea/index.html. (Accessed on April 11)

[21] T. Kinoshita, and K. Sugawara, "ADIPS Framework for Flexible Distributed Systems," T. Ishide (ed.), Multiagent Platforms, LNAI 1599, pp. 18-32, 1998.