A Review of Multi-Agent Based Energy Management Systems

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Abstract. This paper proposes a review of Energy Management Systems (EMSs) based on Multi-Agent Systems (MASs). Also, goal, scale, strategy and software are discussed as different characteristics of the EMSs. Then, multi agent-based structure of the EMSs is described. Finally, challenges and future discussions related to the EMSs are presented in this paper.

Keywords:
Energy management system, multi-agent system, smart grid, power market.

1 Introduction

Smart Grids (SGs) improve energy efficiency in power and energy systems through intelligent control and automation technologies. Also, SG is accounted as an appropriate solution to utilize intermittent energy resource. However, these energy resources create challenges due to uncertainty of its power generations in the system. Moreover, restructuring causes to appear new agents in the power system. Hence, all in all make power systems as complex ones. Different technologies have been used in SGs to realize these aims e.g. MASs. While there is no any unique definition for agents, MAS is a set of independent units that can make decision and interact with other ones [1]. Hence, MASs can make a possible environment for SG's players -e.g. electrical generation, consumers, system operators, aggregators, etc.- to act autonomously and communicate with each other [2].

Various researches have been presented for energy management of power system, and different methods have been represented based on their goals, scales, strategies, and software. For instance in [3], the scale is considered to be power grid. Also, the goal is to minimize the operating cost. besides, the hierarchical and decentralized strategy is presented based on MAS. Moreover, CPLEX [4] and JADE [5] are used to implement the problem in a real system. Also, multi-micro grid system has been operated cooperatively in [3]. In [6], the authors have reviewed how SGs are modeled as MASs. Besides, they compared some projects based on their view and objects related to the system in. In [7], the authors have reviewed the agent-based technologies of large-scale energy systems and SG projects. A hierarchical central approach of Micro-Grids (MGs) has been presented in [8]. The primary control is done in level of distributed energy resources, while the secondary control is done in the level of MG by an Automatic Generation Control (AGC) to control frequency and voltage. Also, the tertiary control is applied to provide the ancillary services for load regulation in the host-grid level. In [9], a new method has been presented to solve AC optimal power flow problem in the multi-agent decision-making framework. In [10], the multi-objective problem has been defined to minimize energy costs and estimate state based on bottom-up approach.

In [11], each smart home has been considered as an autonomous agent that can buy, sell, and store electricity. Furthermore, the uncertainty is modeled through generating the random data and functions in [11]. In [12], a MAS has been demonstrated in the distribution network scale, while agents consist of home agents and retailer agents. In [12], the purpose of the authors was to minimize the payment cost of the electricity. In [13], home energy management problem in connection with transactive energy nodes has been discussed. Moreover, co-simulation of smart homes and transactive energy market has been studied in [13]. In [14], economic dispatch problem has been solved by decentralized and self-organizing strategy. The proposed strategy of [14] is non-hierarchical, and the operation costs is minimized locally and then applied to the system globally. In [15], an energy management system has been presented based on integration of smart meters. The authors have proposed the hierarchical method to manage the energy in [15]. In [16], an intelligent method has been demonstrated to manage energy dynamically in the MG. The proposed method of [16] has been defined to optimal or sub-optimal. Besides, providing the critical loads continuously is the purpose of [16]. In the model of [16], intelligent dynamic energy management system is responsible to send dispatchable control signals of energy. Moreover, forward-looking network is responsible to evaluate the dispatched control signals. The main aims of [16] are to maximize the reliability, utilization of renewable energies, and consumers' welfare. Moreover, the operating cost has not been considered in the decision-making problem of [16].

In [17], the agent-based approach has been represented to optimize the operating cost of the SG and the Residential Energy Management System (REMS). Also, Particle Swarm Optimization (PSO) method has been used to maximize welfare and energy efficiency in [17]. In [18], authors has discussed about the necessities of using Computational Intelligence (CI) in REMSs. CI has been applied to three parts of the REMS in [18]. These parts consist of the prediction of building required power, forecasting the purchasing electrical load from the power grid, and ANN-based controllers. Minimizing the bulding energy cost is the goal of controllers. Also, PSO has been utilized for optimization problem of BEMS. In [19], building energy management has been defined as an intelligent MAS. Energy management system includes two parts: demand-side management and supply-side management. Furthermore, the JADE has been used to implement the model of [19]. In [20], an adaptive and integrated method has been presented for Demand Response (DR) and REMS based on real-life conditions. In [21], the method is proposed to apply the local energy resources optimally through minimizing the loss of energy. Also, in [21], authors had studied comparatively different battery control strategies. The main purpose of [21] is to minimize the purchasing cost of the electricity. In [22], the scheduling problem of the REMS has been solved considering DR. The objective function of [22] was the trade off between the purchasing cost of electricity and dissatisfaction of the consumers.

In this paper, a review of multi-agent based energy management systems, its features and challenges are provided. The rest of this paper is organized as follows. Section 2 describes the features of multi agent-based energy management systems. Multi agent-based structure of the EMSs is described in Section 3. Then, challenges and benefits of these systems are discussed in Section 4. Finally, conclusions are given in Section 5.

2 Features of Multi-Agent based Energy Management Systems

As highlighted before, Multi-Agent based Energy Management Systems (MAEMSs) can be classified based on different characters. In this paper, goal, scale, strategy and software are introduced as characteristics to compare different MAEMSs.

Main purpose is one of important characteristics of Energy Management system (EMS). Goal is presented as an objective function in the energy management problem. Goal of EMS can be maximizing profit, minimizing cost, maximizing reliability, etc. In other words, goals of the system si its virtual feature that indicates its desired strategy. Scale of EMSs is another characteristic that represents the system's level that optimum decisions are make for it. Scale of EMSs can be system-wide, MG, Local, Home. etc. It is clear that according to the scale of the system, complexity of the energy management problem can be changed, and different tools can be utilized to solve it.

Strategy is another important characteristic of EMSs. Strategy is defined as a decision-making path to obtain optimum amount of objective function. Centralized, decentralized, and hierarchical are more common strategies in EMSs. As mentioned before, in MASs, a platform is required to provide interaction and communication between autonomous agents in the systems. There are different software and platforms -e.g. JADE, MATLAB, etc.- that are chosen based on goal, scale, and strategy of the proposed MAEMS.

3 Agents of Energy Management Systems

EMSs consist of different agents that each of them has different tasks. In this section, all agents of the EMS will be introduced and their task will be described. Moreover, the physical system of the MAEMS is seen in Fig. 1. MAEMS includes three layers. First layer is the electricity system which is displayed by black lines. However, second layer is the communication system that is shown by blue lines. Third layer presents interaction between users and other agents that is displayed by green line.

Electrical Loads (ELs) are a group of agents that consume electrical energy in the MAEMS. Generally, ELs are classified into different types of loads such as shiftable, controllable, Must-Run Services (MRS), etc. Therefore, ELs can be considered as an organization of different types of agents in the MAEMS.

Distributed Energy Resources (DERs) is a set of agents that is responsible for electrical energy generation. DERs are intermittent energy resources, so they inject uncertainty in the system. However, increasing the prediction accuracy of these stochastic variables can decrease the corresponding uncertainty in the system.

Energy Storage Systems (ESSs) are the agents in the MAEMS that can store electrical energy such as batteries. Batteries can help to smooth the electrical demand profile and improve the performance of energy management system based on demand response programs..

Information Provider (IP) is an agent that is in charge of providing real-time and historical data information. It senses and records information from all the agents as well as environmental conditions.

Users are residents of a home. Each of these residents are an agent of the MAEMS. Therefore, Users is defined as an organization of this group of agents. Users has direct effects on the ELs and EVs. Furthermore, the objective function of the decision-maker system is determined based on the desired of the Users. All interactions of the Users are illustrated in Fig. 1.

Energy Scheduler (ES) is a virtual organization of agents who plays as a system operator in the MAEMS. The ES consists of two agents in the MAEMS: Prediction Engine (PE) and Decision-Maker System (DMS). The tasks of both are described in the following:

PE provides accurate prediction of all stochastic variables of the system such as wind speed, solar radiation, weather temperature, electricity price and electrical unshiftable loads for the DMS. Hence, the outputs of this agent will be the

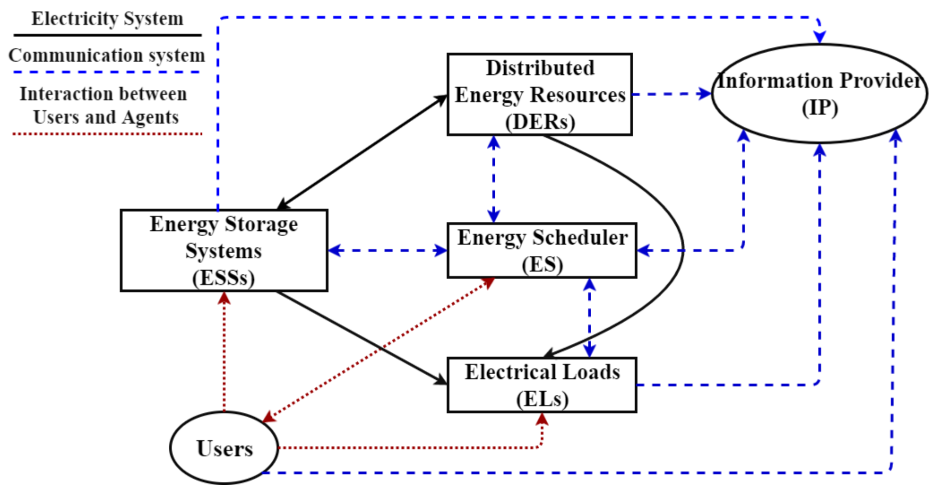

Fig. 1. MAS design of energy management systems.

inputs of the DMS. As the DERS utilized in the MAEMS are non-dispatchable resources, the forecasting of its power output will be very important for the DMS. Hence, accurate forecasting of PE can assist the DMS to make optimum decisions.

DMS makes optimum decisions in the MAEMS. Therefore, after the Objective Function (OF) is defined in the system, this agent should make an optimum decision. In this case, DMS faces a discrete optimization problem under uncertainty of the PE's outputs. This uncertainty causes some problems for the DMS, such as increasing the operating costs of the MAEMS and computational overload. There are different methods to model the uncertainty in the optimization problems such as stochastic programming [23], interval optimization [24], robust optimization [25], etc.

4 Challenges

SGs provides more flexibility for the energy systems and increase energy efficiency of them. For instance, MASs cause platforms that agents can act autonomously. Hence, it increases reliability of the system. Moreover, MAS can be applied to decentralized energy management methods that decreases computational burden of the system. However, there are some challenges to implement these systems. As highlighted before, there are independent agents in this structure. Hence, real-time operation is very important in this case. In real-time, system should be able to connect all devices and exchange all information- this information can be historical and measured data, or real-time decisions- between them. Since balancing between power generation and consumption is vital in the power systems, real-time operation plays as a huge concern in them. Moreover, cyber-security is another challenges in SGs. Another challenge in decentralized energy management systems is related to the optimum decisions of these systems. While local decision-makers decrease computational burden of the system, their decisions are not globally. Hence, a trade-off between local decisions and global optimization is one of main research concepts in these systems.

5 Conclusion

The paper presents a review of multi agent-based energy management systems. Different characters of these systems based on MASs have been discussed. Also, agents of the energy management systems have been described. Finally, paper concludes by expressing challenges and discussion topics related to the decentralized energy management systems.

Acknowledgment

This work has been supported by the European Commission H2020 MSCA-RISE-2014: Marie Sklodowska-Curie project DREAM-GO Enabling Demand Response for short and real-time Efficient And Market Based Smart Grid Operation - An intelligent and real-time simulation approach ref. 641794. Moreover, the authors would like to thank Dr. Juan Manuel Corchado of University of Salamanca for his thoughtful suggestions and supports.

References

1. R. Roche, B. Blunier, A. Miraoui, V. Hilaire, and A. Koukam, Multi-Agent Systems For Grid Energy Management: A Short Review", IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society, Nov. 2010.
2. F. Brazier,H. L. Poutre, A.R. Abhyankar, K. Saxena, S.N. Singh, and K.K. Tomar, A Review of Multi Agent Based Decentralised Energy Management Issues", International Conference on Energy Economics and Environment (ICEEE), Mar. 2015.
3. Van-Hai Bui, A. Hussain, and Hak-Man Kim, A Multiagent-Based Hierarchical Energy Management Strategy for Multi-Microgrids Considering Adjustable Power and Demand Response", IEEE Trans. on Smart Grid, vol. PP, no. 99, June 2016.
4. IBM ILOG CPLEX V12.1 User's Manual for CPLEX 2009, CPLEX Division, ILOG, Incline Village, NV, USA, 2009.
5. Java agent development framework (jade) at http://jade.tilab.com/
6. S. Dave, M. Sooriyabandara, and M. Yearworth, A Systems Approach to the Smart Grid, ENERGY 2011 : The First International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies, 2011.
7. A. Molderink, V. Bakker, M. Bosman, J. Hurink, and J. Smit, A Review of Agent and Service-Oriented Concepts Applied to Intelligent Energy Systems, IEEE Trans. on Ind. Inf., Vol. 10, no. 3, Aug. 2014.
8. M. H. Cintuglu, T. Youssef, and O. A. Mohammed, Development and Application of a Real-Time T estbed for Multiagent System Interoperability: A Case Study on Hierarchical Microgrid Control, IEEE Trans. on Smart Grid, vol. PP, no. 99, Aug. 2016.

9. Zh. Miao, and L. Fan, A Novel Multi-Agent Decision Making Architecture Based on Duals Dual Problem Formulation, IEEE Trans. on Smart Grid, vol. PP, no. 99, pp. 1-10, June 2016.
10. X. Guan, Z. Xu, and Q. Jia, MAS-Based Modeling of Active Distribution Network: The Simulation of Emerging Behaviors, IEEE Trans. on Smart Grid, vol. 7, no. 6, pp. 2615-2623, Nov. 2016.
11. S. Kahrobaee, R. A. Rajabzadeh, L. Soh, and S. Asgarpoor, A Multiagent Modeling and Investigation of Smart Homes With Power Generation, Storage, and Trading Features, IEEE Trans. on Smart Grid, vol. 4, no. 2, pp. 659-668, Oct. June 2013.
12. Zh. Wang, R. Paranjape, Optimal Residential Demand Response for Multiple Heterogeneous Homes With Real-Time Price Prediction in a Multiagent Framework, IEEE Trans. on Smart Grid, vol. PP, pp. 1-12, Oct. 2015.
13. A. Pratt, D. Krishnamurthy, M. Ruth, H. Wu, M. Lunacek, and P. Vaynshenk, Transactive Home Energy Management Systems, IEEE Elec. Mag., vol. 4, no. 4, pp. 8-14, Dec. 2016.
14. V. Loia, and A. Vaccaro, Decentralized Economic Dispatch in Smart Grids by Self-Organizing Dynamic Agents, IEEE Trans. on Systems, vol. 44, no. 4, pp. 397-408, Apr. 2014.
15. R. Pereira, J. Figueiredo, R. Melicio, V.M.F. Mendesa, J. Martins, and J.C. Quadrado, Consumer energy management system with integration of smart meters, Energy Reports, vol. 1, pp. 12-29, Jan. 2015.
16. G. K. Venayagamoorthy, R. K. Sharma, Prajwal K. Gautam, and A. Ahmadi, Dynamic Energy Management System for a Smart Microgrid, IEEE Trans. Neural Net. and Learning Sys., vol. 27, no. 8, pp. 1643-1656, Aug. 2016.
17. L.A. Hurtado, P.H. Nguyen, and W.L. Kling, Smart grid and smart building inter-operation using agent-based particle swarm optimization, Sust. Energy, Grids and Net., vol. 2, pp. 32-40, Apr. 2015.
18. M. Manic, D. Wijayasekara, K. Amarasinghe, and J. J. Rodriguez-Andina, Building Energy Management Systems The Age of Intelligent and Adaptive Buildings, IEEE Indus. Elec. Magazine, vol. 10, no. 1, pp. 25-39, Mar. 2016.
19. W. Li, T. Logenthiran, and W. L. Woo, Intelligent multi-agent system for smart home energy management, Inn. Smart Grid Tech.- Asia (ISGT ASIA), 3-6, Nov. 2015.
20. D. Zhang, Sh. Li, Min Sun, and Zh. ONeill, An Optimal and Learning-Based Demand Response and Home Energy Management System, IEEE Trans. Smart Grid, vol. 7, no. 4, pp. 1790-1801, July 2016.
21. Ch. Zhao, Sh. Dong, F. Li, and Y. Song, Optimal Home Energy Management System with Mixed Types of Loads, CSEE Journal of Power and Energy Sys., vol. 1, no. 4, pp. 1-11, Dec. 2015.
22. K. Maa, T. Yao, J. Yang, X. Guan, Residential power scheduling for demand response in smart grid, Elect. Power and Energy Sys., vol. 78, pp. 320-325, Dec. 2015.
23. A. J. Conejo, M. Carrion, J. M. Morales, Decision making under uncertainty in electricity markets, Inter. Series in Oper. Res. and Manage. Science, Springer, 2010.
24. H. Pandi, Y. Dvorkin, T. Qiu, Y. Wang, and D. S. Kirschen, Toward cost-efficient and reliable unit commitment under uncertainty, IEEE Trans. Power Syst., vol. 31, no. 2, pp. 1-13, June 2015.
25. A. Soroudi, Robust optimization based self scheduling of hydro-thermal Genco in smart grids, Energy, vol. 61, pp. 262-271, Nov. 2013.