Microprocessors and Microsystems 42 (2016) 235–244

Contents lists available at ScienceDirect

Microprocessors and Microsystems

journal homepage: www.elsevier.com/locate/micpro

A fair energy resource allocation strategy for micro grid

Hung-Lin Chao*, Pao-Ann Hsiung

Department of Computer Science and Information Engineering, National Chung Cheng University, Chiayi 62102, Taiwan

ARTICLE INFO

Article history:
Received 1 June 2015
Revised 4 February 2016
Accepted 13 February 2016
Available online 8 March 2016

Keywords:
Smart grid
Micro-grid
Fair energy resource allocation
Fairness index
Cost saving opportunity

ABSTRACT

The design of smart grid systems have been proposed in several literature. However, the actual commercial feasibility of smart grids or micro grids still faces several problems including technical infrastructure related issues and market economy issues. One critical issue in the design of commercially feasible smart grids is how the electricity trading can be performed fairly among micro grids. In existing works, this issue has been mainly addressed by using some sort of priority scheme among buyers and sellers in electricity trading, which obviously does not guarantee a fair trading scheme. As a result, the commercial feasibility of existing works is at stake and will not work as proposed. This work tries to address this issue by proposing a *Fair Energy Resource Allocation* (FERA) method for smart grids. The proposed method has been implemented in a FIPA-compliant *Multi-Agent System* (MAS) based smart grid control system and evaluated against state-of-the-art round robin and priority based allocation methods. For trading among 30 micro grids, it is demonstrated that the proposed method results in a high fairness index of 96.22% even in the worst case, while the round robin scheme and the priority scheme result in a worst-case fairness index of only 57.8% and 11.29%, respectively. Thus, in the long term under different ratios of buyers and sellers, the proposed method is the only method that can achieve a very high fairness index in the worst case. Averaging over different ratios of buyers and sellers, the proposed method results in a fairness index of 99.57%, which is much higher that achieved by the round robin method (84.04%) and the priority scheme (63.56%). As far as cost saving is concerned, based on the *cost saving opportunity* (CSO) metric, in the long term (10,000 rounds of trading), the proposed method results in a CSO of 51.48%, which is much higher than that by the other two methods; round robin method results in 14.07% and priority-based method results in 34.44%.

1. Introduction

With progress in technology, since the industrial revolution in the 18th century, the electricity industry is consuming larger amounts of natural resources such as fossil fuels, coal, gas and oil. The global warming and shortage of natural resources are the greatest challenges faced by humanity today. Thus, most governments expect to adopt an intelligent and efficient Smart Grid (SG) to solve these problems. For example, the U.S. has passed ARRA2009 (American Recovery and Reinvestment Act of 2009, ARRA 2009) [1] to invest an amount of $4.5 billion in green research and development.

In traditional power grids, usually electricity is generated by large scale power stations, such as coal-fired power station, hydraulic power and nuclear power plants, which can be collectively termed as the *centralized power plant*. They are responsible for satisfying the power demands of a large area of consumers. The downside of this type of power generation is that it causes severe environmental pollution. Thus, more and more power grids are trying to integrate *Distributed Energy Resources* (DER) such as photovoltaic cells and wind turbines.

Compared with the traditional grid, smart grid is a modernized distributed electrical grid that uses novel technology to gather power utilization information and analyze the behavior of power suppliers and power consumers from distributed micro grids. Smart grid not only provides an intelligent power supply, but also reduces power cost and environment pollution. A smart grid is mainly composed of several small scale Micro Grids (MG), each of which contains numerous different types of power loads and DERs. These DERs usually comprise a number of renewable energy generators, for example, the solar panels in residential areas. A modern DER is equipped with sensors, and is responsible for data collection from the environment. For example, a temperature sensor installed in solar panels, provides valuable information for the analysis of solar cell energy efficiency. In the power demand

* Corresponding author at. 168 University Rd., Min-Hsiung, Chiayi, 62102, Taiwan, R.O.C. Tel.: +886-5-2720411 ext. 33132.
E-mail addresses: kenyclapton@gmail.com (H.-L. Chao), pahsiung@cs.ccu.edu.tw (P.-A. Hsiung).

http://dx.doi.org/10.1016/j.micpro.2016.02.011
0141-9331/

side, the smart meter is responsible for monitoring electricity utilization of end devices, and provides the power demand behavior analysis of end loads to the MG for future power prediction. Thus, MG can manage and coordinate the power loads and DERs by itself. However, it is hard to realize that because the renewable energy resources cannot offer a stable power supply.

The traditional MG works in two operation modes: (1) grid-connected mode and (2) island mode. On a normal day, a MG is connected to a power utility. The MG can choose the power source between power utility and renewable energy depending on the energy buying price or power contracts. However, if power utility is supplying power in abnormal status, the MG may switch to island mode to avoid accident and prevent the situation worsening the SG. In island mode, MG can be disconnected from the power utility, thus, MG will generate power by itself and will be self-sufficient. However, the renewable energy resources in a MG cannot provide a reliable and stable power supply because of their power generation properties.

When there is a shortage of electricity in a MG, this grid can buy electricity from the utility or from other MGs. On the contrary, when the electricity in a MG is self-sufficient, this grid can sell the excess electricity to the utility or the other MGs. Hence, the electricity trading process in the smart grid field is an important research issue. Most existing works are only considering the individual rights such as buying the electricity at a lower price or selling the electricity at a higher price. The trading policies are usually designed and refer to the customers participating in the market based on frequency and size of demand load, which is called *priority*-based trading process. When the electricity trading with a specific priority of customers, it may lead to a fatal problem in such small-scale MGs or economically depressed MGs because they have a lower trading priority. Thus, they are most likely to cause an energy starvation situation and result in economic losses. To address these issues, we propose a *multi-agent system* based smart grid framework with a *fair energy resource allocation* (FERA) method. FERA not only guarantees a long term fair energy allocation among MGs, but can also reduce the power cost for real smart grid operation.

The article is organized as follows. Section 2 introduces the related work. The proposed micro grid framework is described in Section 3. Section 3.4 describes the proposed fair energy resource allocation method for micro grids. Experimental results are given in Section 4. Finally, Section 5 summarizes our contributions and outlines some directions for future work.

2. Previous work

Since the focus of this work is on smart grid design, especially multi-agent system based design models, we will survey some related works. Further, the target of this work is energy resource allocation, thus we will exemplify on the state-of-the-art technology in how this is currently being done.

Multi-agent system (MAS) modeling has been applied to the design and evaluation of smart grid systems in several research works [2–5]. In such a model, power generators, power loads, and energy storages are represented by agents, which communicate with each other in a distributed manner. MAS-based simulator of smart grids generally conform to the standards set by the Foundation for Intelligent Physical Agents (FIPA). Java Agent Development Framework (JADE) [6] and ZEUS [7] are two FIPA-compliant MAS platforms that have been used to simulate smart grids, in cooperation with Matlab/Simulink platform [2–4]. Xiao et al. [2] and Li et al. [3] have proposed hierarchical MAS based architecture for controlling MGs. The authors have used ZEUS and the Matlab/Simulink platform to simulate MGs, while operating in grid-connected mode and island mode. Shao et al. [4] proposed a MAS-based control strategy for MGs. This approach focused on area control based optimization strategy by adding a coordination control level to the hierarchical MAS-based structure. The coordination control level is responsible for controlling and communicating with multiple areas in a MG through agents. The agents can be used to reflect the status quo of a MG. Another important research issue in MG design is load prediction. Well predicted loads can offer stable power supply and guarantee the quality of power demands. For example, the load prediction can cope with the worst case of peak power usage at noon time. Thus, the wastage of electrical power and environment pollution can be palliated. Li et al. [8] proposed two approaches for modeling and predicting customer load demands. The first one is based on non-stationary Markov chains, and the second is based on time-series analysis. Time-series analysis uses history load information to increase prediction accuracy. Results show that the time-series method is better than the non-stationary Markov chain method. Mathieu et al. [9] proposed a piecewise linear regression approach, which used outdoor temperatures as a variable to explore the relationship between temperature changes and load variation.

To reduce the generation pressure at peak load duration, load scheduling [10–13] and load shedding [14–18] are two effective methods. Feroze [19] segregated demand loads into two types: (1) critical load and (2) non-critical load. The critical load represents the minimum operating load of a basic unit, and must be maintained. Conversely, the non-critical load represents load which can be scheduled to off-peak duration or shed off. Based on the information on future electricity requests, each MG can sell/buy the surplus/deficit electricity in the energy market.

The traditional trading process can be classified into two categories: (1) priority-based and (2) Round-Robin-based (RR-based) energy allocation method. In priority-based energy allocation method, the energy allocation is according to the amount of energy demand of MG. The priority is higher when energy demand is less, it will be allocated energy to the energy demanders first. In RR-based method, all energy demander has the same priority, the RR-based method serves energy demander one by one until exhausted all energy resources. Most existing work [20–25] only considers the trading strategy with a factor of customers participating in trade, it could lead to an energy starvation situation in some underprivileged MGs. Wang et al. [26] proposed a particle swarm optimization-adaptive attitude bidding strategy. This method adaptively adjusts a trader's decision according to its opponent's trade attitude. Nunna and Doolla [23,24] proposed an agent-based energy management system to facilitate power trading among microgrids with demand response. This paper aims to reducing the peak demand and minimizing the cost of electricity with a priority-based approach. Authors further presents an agent-based demand side management framework [22,25] which based on a priority-based bidding strategy to deal with the supply-demand mismatch problem.

However, as mentioned above, those priority-based methods have a main drawback, that is, it will lead an energy starvation situation in some underprivileged MGs. Therefore, these underprivileged MGs might spend more cost to purchase deficit electricity because of their lower priority. The worst case of energy starvation is lead to power shortage as well as economic losses. To address these issues, we propose a MAS-based smart grid framework with a FERA method. The details of the proposed FERA method will describe in Section 3.

3. Multi-agent system based three-level smart grid architecture

In this section, we first give a definition of smart grid. Second, we introduce the proposed multi-agent system smart grid architecture. Third, we will describe the trading behavior in smart grids.