Journal of Network and Computer Applications 72 (2016) 1–13

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

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

Game model to optimally combine electric vehicles with green and non-green sources into an end-to-end smart grid architecture

Mohamed Attia*, Hichem Sedjelmaci, Sidi Mohammed Senouci, El-Hassane Aglzim

DRIVE EA1859, Univ. Bourgogne Franche Comté, F58000 Nevers, France

ARTICLE INFO

Article history:
Received 24 April 2015
Received in revised form
16 April 2016
Accepted 6 June 2016
Available online 5 July 2016

Keywords:
Bayesian Nash Equilibrium
Electric vehicles
Game theory
Smart Grid

ABSTRACT

The integration of information and communication technologies into the Smart Grid (SG) will make it smarter to provide a more efficient power delivery, economically viable and safe. In fact, electrical systems should be controlled in more flexible way to manage critical situations such as the intermittency of renewable energy and the development of new consumers like electric vehicles (EVs). In this paper, we first propose an end-to-end SG architecture with all its associated actors such as main production, transmission, distribution, SG and cyber-security managers. In contrast to the literature, this architecture takes into account both the power and communication aspects of the SG as well as the relationship between all its components. Then, we focus on EVs as prosumers (producers and consumers thanks to their energy storage capacity) and how integrate them efficiently into the power grid. Hence, we propose in a first phase a Bayesian game-theory model that aims to integrate them into the SG and maintain the equilibrium between the offer and the demand, hence avoiding electricity intermittence. In a second phase, we concentrate on EVs as consumers and propose a new Bayesian game model to optimally integrate green electricity sources into this electricity network in order to charge EVs' batteries. This aims to promote the electricity network capacity and have an eco-friendly effect on the environment by minimizing the usage of polluting energy sources. The obtained simulation results prove that our models help to efficiently integrate the EVs into the SG and use green electricity sources with more flexibility and less loss.

1. Introduction

Several issues and concerns are addressed in the Smart Grid (SG) to improve its efficiency (Moskalenko et al., 2010; Kumar et al., 2011). A general definition of the SG is provided in (Moskalenko et al., 2010) and (Fang et al., 2012) where the grid has as goal to optimally manage the electricity deliverance in order to satisfy the need of its consumers. Due to the increasing number of these latter and their diversified requirements, the SG should pursue a great improvement in its energy and communication infrastructure. It should have a good energy infrastructure allowing it to deliver electricity efficiently with minimal losses. Moreover, the need of a distributed communication network seems to be primordial to guarantee a bidirectional flow of information between all the SG actors. This network must be reliable with reduced delay and large bandwidth.

More precisely, a SG is defined as an intelligent power network that combines various technologies in power and communication to monitor and optimize the operations of all functional units from electricity generation to end-customers (Meng et al., 2014). However, the current communication and power network architectures proposed in the literature (Fang et al., 2012; Wang et al., 2011; Lee et al., 2015) are not described in-detail where the authors do not explain the different functionalities of SG actors (e.g. main production, transmission, distribution, Smart Grid Manager (SGM) and security) and their relationships in-depth. Therefore, in this paper, we first start proposing an end-to-end SG architecture with all its associated actors. We take into account both the power and communication aspects of the SG network, as well as its opportunities, challenges and requirements. We mean by end-to-end Smart Grid architecture, an architecture that shows the flow of electricity and communication from its birth until its arrival to the destination taking into account all intermediate steps. To the best of our knowledge, we are the first proposing a whole end-to-end architecture separating power and communication networks and considering the whole associated actors and their relationships.

Then, we deal with the integration of electric vehicles (EVs) into the SG. In fact, electrical systems should be controlled in more

* Corresponding author.
E-mail addresses: mohamed.attia@u-bourgogne.fr (M. Attia), Sid-Ahmed-Hichem.Sedjelmaci@u-bourgogne.fr (H. Sedjelmaci), Sidi-Mohammed.Senouci@u-bourgogne.fr (S.M. Senouci), elhassane.aglzim@u-bourgogne.fr (E.-H. Aglzim).

http://dx.doi.org/10.1016/j.jnca.2016.06.006
1084-8045/

flexible way to manage critical situations such as the intermittency of renewable energy and the development of new consumers like electric vehicles (Tushar et al., 2012). These latter are considered to be one of the major consumers of electricity in SG (Lee et al., 2015). As a consequence, analyzing the effect of EV charging on SG and designing an optimal charging strategy for EVs are crucial. Thereby, in this research work, a first game model that aims to integrate EVs into the SG is proposed. This model is based on Bayesian Nash Equilibrium (BNE), which aims to make a balance between the electricity offer and demand, and hence avoid electricity intermittence. To further strengthen the efficiency and performance of the SG, we propose a second model to integrate optimally the green electricity sources into this electricity network in order to charge EVs' batteries. This is achieved with the help of the proposed Bayesian game. The goal of this model is to promote the electricity network capacity and have an eco-friendly effect to the environment by minimizing the usage of polluting energy sources.

The novelty introduced in this paper compared to other works resides in the design of end-to-end and complete architecture to show the power and communication flows over all SG stakeholders with the specification of all intermediate steps. Moreover, a theoretic game approach considering decisive parameters is proposed to integrate optimally EVs in the SG. Renewable energy is integrated also in this approach to promote SG capacity and reduce using polluting sources.

The reminder of this paper is organized as follows: Related works are discussed in Section 2. In Section 3, we propose an end-to-end SG architecture. Section 4 describes the proposed Bayesian game theoretic models dealing with the integration of EVs into the SG. Then, in Section 5, we present the numerical results with their appropriate analysis; conclusion is drawn in Section 6.

2. Related work

Due to the increasing number of electricity consumers and their diversified requirements, the SG should pursue a great improvement in its energy and communication infrastructure. Anticipated benefits and requirements of SG are exposed in (Fang et al., 2012) where the SG is divided into three major systems: smart infrastructure, smart management and smart protection systems. The smart infrastructure system deals mainly with smart energy, smart information and smart communication subsystems. The prime objective for a smart management system is to exploit energy more efficiently, while minimizing the cost and maximizing the profit. It also improves demand profiling and controls emission. Finally, the smart protection system acts to enhance the SG reliability by resolving security and privacy issues. In order to increase the electricity generation, micro-grids planning and operation are presented in (Su et al., 2010). A model of micro-grid integration is presented in (Basak et al., 2011) in the perspective of integrating distributed energy resources.

A survey on the communication architectures in the power systems is proposed in (Wang et al., 2011). The advantage of this survey is the global view of the communication network including its different components, technologies, functions, requirements, and research challenges. However, there is no concrete architecture that specifies the relationship between all the SG components.

The emergence of Electric Vehicles (EVs) in the power grid has created a fear of falling into the electricity intermittence due to the huge number of vehicles, which can be deployed in the grid. Furthermore, others consider this integration as a favor; thanks to the capacity of EVs to store the electricity in their batteries. In (Quinn et al., 2010), in order to identify the best communication architecture between the system grid operator and the EVs, a comparison between direct, deterministic vehicle command architecture and aggregative vehicle command architecture was realized by taking these three criteria into account: the availability, reliability and value of vehicle-provided ancillary services. In (Tushar et al., 2012), the authors proposed a non-cooperative *Stackelburg* game model to optimize the integration of EVs into the SG where this latter acts as leader and chooses its price strategy and the EVs as followers, which decide their charging strategies. They extended their model to time-varying case to enable its handling into slowly varying environments (i.e. the changes in system variables from one period to another). Besides, they do not make into consideration green sources energy and the effect of using polluting sources. In (Couillet et al., 2012), the authors developed a mean field model to show the behavior of electrical vehicle and plug hybrid electric vehicle (PHEV) owners aiming selfishly to maximize their satisfaction under electricity pricing policy constraints. In this model, each kind of vehicle is treated separately, where EVs and PHEVs have their own model. Moreover, the vehicles can act as an electricity consumer or supplier. However, in this approach, the only criterion treated is the price, which may prevent to have realistic results.

In this paper, our added value is twofold. First, we propose two separated architectures representing the power and the communication networks in the SG by considering the whole associated actors and components as well as the relationship between them. Then, we propose a Bayesian game model for the integration of EVs into the SG, where several parameters and criteria are taken into account such as satisfaction, pollution rate, cost and electricity selling price. To be eco-friendly and to stimulate using green sources, we integrate in our model renewable electricity sources like the hydraulic ones.

3. Smart grid architecture

In this section, we propose a new end-to-end architecture of the SG that takes into account the existing equipment and applications to ensure the proper functioning of this network. Moreover, with a good vision of this architecture, we can predict the future requirements and updates that can be done. This architecture is composed of two models, the first one for the power network, and the second for the communication network.

3.1. Power network

The most challenging issue on the SG is to optimize the management of its resources and equipment in order to cover the average demand. The power network has as goal to distribute electricity to all users. It should take into account the wide repartition of its consumers with their different requirements such as voltage, current and requested quantity. Due to the excessive increasing of the electricity demand (Reed et al., 2010) caused by diverse factors such as the birth of new and diverse consumers like the EVs (Green et al., 2011; Su et al., 2012), the electric grid has the duty to find the appropriate solution to overcome this problem and cover the entire demand. The SG has to promote its capacity and increase its production by deploying decentralized, intermittent and fluctuant energy sources such as wind and solar power (Zipf and Möst, 2013; Vineetha and Babu, 2014). It has also to take into consideration the gradual emergence of new needs such as rechargeable hybrid electric vehicles. All this requires a new and complete vision of the electricity network to quickly overcome peak demand of electricity and intermittency of energy sources. This architecture is shaped in order to highlight the power network structure, its complexity and prospects, understand the