INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–9

Available online at www.sciencedirect.com

ScienceDirect

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

Real-time battery state of charge estimation in smart grid application by Multi Agent System

Soukaina Boudoudouh *, *Mohamed Maâroufi*

Department of Electrical Engineering, Mohammadia School of Engineers (EMI), Mohammed V University, Rabat, Morocco

ARTICLE INFO

Article history:
Received 25 February 2017
Received in revised form
8 June 2017
Accepted 9 June 2017
Available online xxx

Keywords:
SOC estimation
Smart grid
Multi-Agent System
Photovoltaic (PV)
Decision-making
Co-simulation

ABSTRACT

This paper presents a SOC estimation model in real-time applications such as smart grid. Authors list the existing SOC estimation methods and propose a SOC model to overcome the limitations of the precedent methods presented in the literature. Furthermore, this paper proposes a scalable, self-adaptive, and generic SOC model to meet the smart grid requirement. Multi-agent system approach is proposed to manage the smart grid and a co-simulation is proposed enabling the physical variables modeling while the discrete decision-making is given by developing agents under Jade framework. The results analyses have shown a SOC model which depends on the battery use conditions that can match with all batteries technologies and therefore can be suitable for smart grid applications.

Introduction

The battery is an electrochemical system; it stores the chemical energy and converts it into electrical energy. This conversion is reversible. The electricity storage is a strategic issue. The battery system follows the actual energetic transition. It is the key profile for the electric vehicle development [1–3] as well as the Renewable Energy Sources (RES) implementation [4–6]. A large expansion of intermittent renewable energies (solar and wind) will therefore require in the future an important deployment of storage facilities. Solar energy and wind energy are available intermittently and subject to large fluctuations. The electricity storage smoothes out these variations in output and reduces the use of fossil fuel. Furthermore, storing large quantities of electricity during off-peak hours helps to meet daily fluctuations and peak demands. This allows possible to store the electricity when it is not expensive to resell it when it is expensive. Therefore a smart control is strongly needed.

In the smart grid a battery safe use is ensured by avoiding the battery over-charge or over-discharge that can lead to prematurely battery lose. For this reason, the real-time battery state of charge (SOC) should be permanently updated. The SOC indication plays a significant role to compute the battery available energy and therefore to predict its autonomy. Because in real-time application, for instance, smart grid control, the battery behavior varies while operating according to non-controllable conditions as the RES intermittent generation which is not correlated with the demand changes and

* Corresponding author.
E-mail address: soukainabdh@gmail.com (S. Boudoudouh).
http://dx.doi.org/10.1016/j.ijhydene.2017.06.077

Please cite this article in press as: Boudoudouh S, Maâroufi M, Real-time battery state of charge estimation in smart grid application by Multi Agent System, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.06.077

the distributed generation with different capacities and properties flowing within the grid. Thus a reliable SOC estimation which takes over the battery online variation especially, for real-time applications is quite complex and also a challenging issue [7].

The battery is a complex electrochemical system, the battery SOC cannot be directly measured by a sensor. Thus it should be estimated. The available SOC estimation methods have some limitations and cannot be generalized for unknown battery dynamics configurations, and therefore are not generic. Furthermore these methods do not take into account the variables battery internal characteristics and its uncontrollable use conditions in real-time applications. Sometimes the battery should be disconnected to compute parameters to give a SOC estimation [8] which is not possible during smart grid operation. Accordingly, providing a reliable SOC estimation for any battery technology regardless of its internal characteristics and its use conditions in real-time applications such as smart grid is strongly required.

The Multi-Agent System (MAS) is extensively suggested as a suitable approach to manage complex distributed systems such as smart grid architecture [9–14]. The distributed behaviors, and responsibilities of each agent in parallel, let the control of unforeseen events or faults reliable without implying the system exhaustively. The parallelism in agents' interaction was the subject of [15] where authors have proposed a framework which is MacsimJX to overcome the parallelism issue enabling distributed system modeling with Simulink, because S-functions of Simulink are unable to handle multiple threads of execution such as MAS architecture. They become unstable if several processes run concurrently inside Simulink [15] as shown in Fig. 1. In the previous paper JADE was chosen to be the framework to assist agent modeling for Simulink. It is the most used platform when developing agent, Jade provides a runtime environment for agents and a library of specified classes. However, it is not well appropriated for modeling physical systems, where variable parameters are continuously updated in an evolving environment, as the battery internal characteristics and SOC estimation model.

Indeed, the SOC model can be estimated through a physical or electrochemical model based on monitoring physical quantities which are continually updated and variable. Therefore a SOC estimation model taking into account the random change of external conditions of use in smart grid application managed by MAS is necessary.

In this paper, the SOC estimation of any battery technology according to its external use conditions operating in a smart grid managed by MAS is proposed. Furthermore, a tool enabling physical agent modeling is shown. This allows combining the simultaneous use of Simulink facilitating the proposed SOC estimation model graphically and Jade framework to develop agents. Section II overviews the existing SOC estimation models which can be limited when are applied in real-time. Section III describes the proposed estimation model while section IV introduces the battery agent behavior allowing a smart SOC estimation and demonstrates the co-simulation Matlab/Simulink and JADE enabling to model the SOC under Simulink and to control agents by Jade in smart grid application. Section V concludes the paper.

SOC estimation models

Many studies have brought more interest to give accurate SOC estimation methods. It was proposed methods based on the linear relations between the SOC and the variables parameters allowing the SOC estimation following look-up table. Electrochemical methods, that model the battery electrochemical phenomena as well as physical methods that depict the battery dynamics by an equivalent electric circuit. More details are given hereafter.

Methods based on linear relations with SOC

There is a linear and a direct relation between the battery open circuit voltage (OCV) and the battery SOC [16,17] as expressed in (1) [18]. As well as between the battery internal impedance and the electrolyte density that characterise the battery dynamic behavior. These relationships are expressed by look up table [19,20]. The OCV expressed in Volts is the measured terminal voltage for zero battery current [21], when no load is applied. Admittedly this method gives a precise SOC estimation, but an accurate measurement requires a long rest period [22] and however the use of this method is limited in real-time applications such as smart grid operations because the battery should be disconnected or offline to give the OCV or the impedance measurements. Moreover, this method is

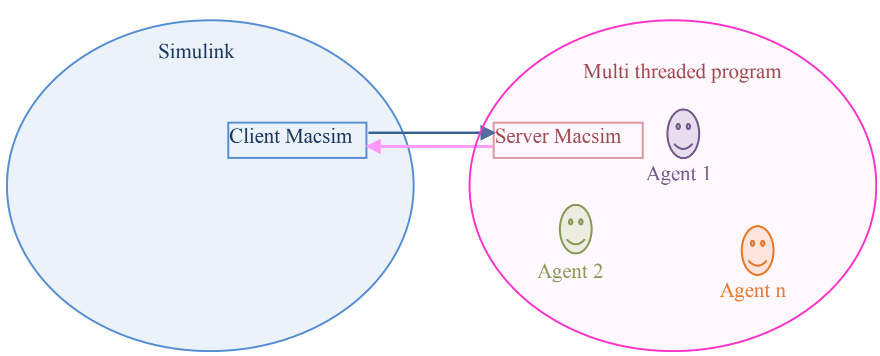

Fig. 1 – MacsimJX architecture.