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The impact of the time delay on the load frequency control system in microgrid with plug-in-electric vehicles

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ABSTRACT

Our power system is evolving in the form of small entities called Microgrids. In this scenario, different renewable and conventional energy sources are integrated together to form the Microgrid and to satisfy a specific load. The frequency is an indication of the balance between the generation and the demand. In the conventional power system, the generators are used to balance the frequency. The emerging new technologies such as the Plug-in-Electric vehicles can play a great role in the stability of the load frequency control system. In this paper, the stability of a Microgrid with plug-in-electric vehicles and communication delay is investigated. The Microgrid controller communicates wirelessly with the plug-in electric vehicle and they form a kind of time delay system. A Microgrid model with plug-in electric vehicles and communication delay is presented in this paper. Lyapunov-Krasovskii functional is used to derive stability criterion in form of Linear Matrix Inequalities. Through solving the Linear Matrix Inequalities the maximum time delay that guarantees the stability of the Microgrid is determined. The parameters that affecting the stability and the maximum allowable delay are determined which are; the PI controller gains, the Microgrid inertia, the PEV gain and the PEV time constant.

1. Introduction

The emergence of new renewable energy technologies brought many challenges to the power system control. The renewable energy sources are intermittent and unpredictable. These sources are integrated into the Microgrid which forms our future power system. With a high renewable energy penetration level in the Microgrid, the stability of the system becomes questionable. The frequency is one of the power system stability indicators which is must be properly controlled. The load frequency control is one of the well known centralized control tasks since the beginning of the interconnected power system. The load frequency control is necessary in Microgrids. The Microgrid is defined as cluster of microsources, storage systems and loads (Lasseter, 2001). The Microgrid concept gained a lot of attention after the blackouts in the US in 2001, where the Microgrid was proposed as solution to prevent the wide range blackouts (Wouters, 2015). The Microgrid concept was introduced by the Consortium for Electric Reliability Technology Solutions (CERTS) (Almeida, 2011). The microsources in the Microgrid are PV panels, fuel cells, wind turbines, microturbines, diesel generators in addition to storage units such as the batteries, flywheels, and supercapacitors. These microsources and storage units must operate altogether to deliver a specific power to the loads. The loads are classified into critical and noncritical loads. Microgrid believed to be the future power system (Markvart, 2006). The Plug-in Electric Vehicle (PEV) is one of the basic components in future Microgrid. A Microgrid with Plug-in Electric Vehicles (PEVs) is shown in Fig. 1. In the last few years, the PEVs markets has increased considerably (Lamedica, Teodor, Carbone, & Santini, 2015). PEVs are becoming widely used and they are the future vehicles (Erol-Kantarci, Sarker, & Mouftah, 2011). PEVs are sustainable alternative to fossil fuel vehicles (Brady and O'Mahony, 2016). The PEVs can be regarded as batteries where the PEV can be connected to the grid or the Microgrid for charging and discharging. PEVs can also be connected to the buildings during the parking and during the night (Tanguy, Dubois, Lopez, & Gagné, 2016). In the conventional load frequency control system the generators have to balance the change in the load (Khalil and Wang, 2015b; Khalil, Wang, & Mohammed, 2017). The main energy sources in the Microgrid are renewable which are stochastic. This fluctuation can result in losing the stability. Fortunately, the PEVs can be used as generators or loads and hence reduce the generation/demand fluctuation, and improve the load frequency response. The PEVs are believed to contribute to the frequency control in Microgrids (Baboli, Moghaddam, & Fallahi, 2011). In this manner, PEVs can participate in primary and secondary frequency control (Zarogiannis, Marinelli, Traholt, Knezovi, & Andersen,

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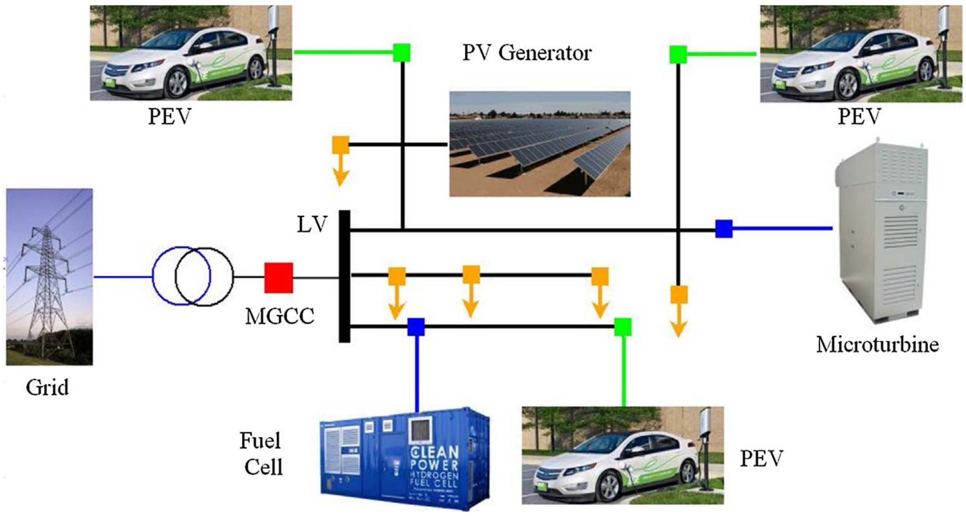

Fig. 1. A Microgrid with Plug-in Electric Vehicles.

2014). The PEVs have a significant impact on the stability of the Microgrid dominated by renewable energy, where the PEVs can reduce the fluctuations resulting from the renewable energy sources (Wu, Ekanayake, & Samarakoon, 2011).

Plug-in Electric Vehicles can be recharged/discharged from the main grid or the Microgrid. The storage battery in the PEV is used to drive the vehicle wheels. PEV is a clean mean of transport. The most attractive advantage of the PEV is that it can discharge and contribute to the generation when the demand increases suddenly or the generation from the renewable sources decreases. The Microgrid has two operational modes. In the islanding-mode, the Microgrid operates independently and provides the energy from its own sources; when the loads exceed the generation form either the renewable energy sources or the conventional sources, the frequency will drop. For a stable operation of the Microgrid, the matching between the demands and the generation must be in real-time so that the system's frequency is maintained at its nominal value (Elkawafi, Khalil, Elgaiyar, & Wang, 2016). This task can be achieved through the Load Frequency Control (LFC) mechanism (Safdar, Cotilla-Sanchez, & Guizani, 2013). The Microgrid central controller (MGCC) distributes the loads between the generators and keep the system frequency at a nominal value through the load frequency control (Singh, Singh, & Yadav, 2013). In the conventional power system the control signals are distributed through a dedicated communication network. With the advances in the computing and the communication networks they are promoted as a fast communication medium for the control signals exchange. However, the presence of the communication network in the load frequency control loop induces time delay and some of the data may be lost. The stabilization of the load frequency control system with the presence of the time delay has been reported by many researchers (see, for example, (Jiang, Yao, Wu, Wen, & Cheng, 2012)). There are two approaches for stabilizing the Microgrid. The first is through Microgrid centralized control center and the second is based on the decentralized control. The stability of the Microgrid can be maintained by decentralized control, for example, the droop control is used to adjust the real power and the reactive power according to the deviation in the frequency and the voltage (Fattahi et al., 2016).

With the increased number of PEVs their impact on the stability of the Microgrid should be investigated. There are many research on the stability of the LFC in the Microgrid with the PEVs, however, the effects of both the PEVs and the delay have not been studied deeply. In (Baboli et al., 2011) the effects of the PEV penetration on the load frequency control system is investigated. The PEVs have a strong impact on the primary LFC and they can enhance its performance. The utilization of the PEV to support the primary LFC is proposed in (Izadkhast, Garcia-Gonzalez, Frias, Ramirez-Elizondo, & Bauer, 2016). A proposed aggregated model of the PEV is presented where the distribution network characteristics are incorporated into the model. The PEV is modeled as a first-order transfer function in (Mu, Wu, Ekanayake, Jenkins, & Jia, 2013) and the authors investigate the impacts of the PEVs charging and discharging on the load frequency control in Great Britain power system. The PEVs load characteristics are modeled using a probabilistic approach. The PEVs are proposed to support the thermal plants in the load frequency control as reported in (Pham, Trinh, & Hien, 2016). A four-area power system is chosen as a case study and the multivariable generalized predictive theory is applied in (Yang et al., 2015) for load frequency control in Microgrid with PEVs. The energy flow of the PEVs is manipulated intelligently. In (Khoobana, Niknam, Blaabjerg, & Dragicevic, 2016) the general type-2 fuzzy logic sets combined with Modified Harmony Search Algorithm are used to tune the PI controller in a Microgrid with PEVs. The PEVs are used to absorb the frequency fluctuations caused by the renewable resources. The impact of the communication delay on the LFC in multi-area power system has been investigated in (Fan, Jiang, Zhang, & Mao, 2016). The particle swarm optimization and the linear matrix inequalities techniques are used to derive a robust PID controller.

Most of the research focuses on the droop control which is a typical decentralized control strategy (Khalil, Ateea, & Elbarsha, 2015). Some researchers address the enhancement of the droop control with the aid of the communication between the units. In general the control in the Microgrid can be divided into primary, secondary and tertiary control (Etemadi, Davison, & Iravani, 2014; Guerrero, Chandorkar, Lee, & Loh, 2013). Many researchers consider the communication network in the stability analysis of Microgrids. In (Lai, Zhou, Lu, Yu, & Hu, 2016; Lu, Yu, Lai, Guerrero, & Zhou, 2017) the authors introduced a robust distributed secondary control in the Microgrid. The information are shared between the distributed energy generators through communication network. The distributed control relies on low bandwidth communication network which is needed only to update the voltage and the frequency values. The droop control is used where the change in the real and reactive power is sensed by the change in the frequency and the voltage respectively. The analysis of the Microgrid into the networked control system framework is presented in (Kahrobaeian and Mohamed, 2015) where the communication is used to enhance the performance of the droop control and reduce the sharing error where the total power demand is calculated in the Energy Management Unit (EMU).

In (Baghaee, Mirsalim, Gharehpetian, & Talebi, 2017b) a robust H_∞ controller is designed while taking the communication delay and the nonlinearity into account. The controller design problem is formulated