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Modeling and analysis of a smart grid monitoring system for renewable energy sources

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ABSTRACT

The observing and metering processes are necessary in renewable energy conversion systems as applied in smart grid applications of conventional grid. In this study, the requirements of the renewable energy sources examined with a solar microgrid model that is developed via Matlab/Simulink. The dc-ac conversion system utilized in this paper contains three solar power plants with maximum power point tracking (MPPT) system and a multilevel inverter to create three-phase ac line voltages. The transmission line is modeled at the output of the inverter with a length of 25 km by using real line parameters. The infrastructure of power line communication (PLC) is managed by binary phase shift keying (BPSK) modems that are located in different places. The usage of the proposed energy monitoring technique eliminates additional monitoring costs due to the fact that the power lines are not only exploited to carry the generated voltage, but also utilized to convey the drawn power rate of loads at the back-end of the microgrid.

1. Introduction

The microgrid is defined as a small autonomous system that is constituted with combining several distributed energy sources such as solar, wind, fuel cells, biomass, and so on together. The distributed generation (DG) systems based on renewable energy sources demonstrate a rapid emerging. Small scale power generators in the level of medium and low-voltage power systems can be established by the DG systems. Therefore, smart grid (SG) systems are important parts of the DG systems. The SG applications include two main infrastructures that are smart transmission grid (STG) and smart distribution grid (SDG). The emerging smart grid systems require sensing of data from all the sensors located on the system within a few power cycles (Kabalci et al., 2012; Ginot et al., 2010; Kurohane et al., 2010; Zhang et al., 2010). The power line communication (PLC) term is exploited to describe transmitting and receiving process of any type data over the conventional transmission lines. This notion also defines the main framework of the smart grid. The usage of power lines as a transmission medium prevents the supplementary establishment costs to get the systems communicated together. The PLC applications allow data rates of transmission as much as 200 Mbps using single phase with 220 V/50 Hz (Mannah et al., 2011; Kosonen and Ahola, 2010; Son et al., 2010; Tsuzuki, 2006; Lin et al., 2009).

The most studied area of the renewable energy sources is the use of the PVs since generating energy via solar energy sources offers several advantages such as precluding air pollution, soundless operation in consequence of the motionless, and reduced maintenance costs. Although the PVs are frequently assumed as a costly process to generate electrical energy, the most appropriate solution to supply the required energy is the usage of stand-alone PV applications. In grid connected systems, voltage source inverters (VSI) capable of pulse-width modulation (PWM) are generally employed to connect renewable energy sources and the grid. In addition, the current control is an important feature of this type converter to supply high quality power to the utility grid. When the cost of the grid connected systems is considered, the cost can be reduced by employing fewer power conversion stages and components (Kabalci and Kabalci, 2010; Kabalci, 2013; Kabalci, 2015; Ma et al., 2013).

Several remote monitoring methods in terms of energy monitoring, weather monitoring and fault detection systems have been proposed for both traditional and renewable energy sources (Wilkinson et al., 2014; Almas et al., 2014; Ahmed et al., 2016; Padilla et al., 2014; Silvestre et al., 2013; Kamel et al., 2015; Vanfretti et al., 2016; Senthilnathan and Annapoorani, 2016; Venkatraman et al., 2016; Silva et al., 2017; Tina and Grasso, 2014; Shariff et al., 2013; Gaurav et al., 2014; Kabalci et al.,

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2016; Fateh et al., 2013; Madueño et al., 2016; Cabanas et al., 2007; Mohamed et al., 2014; Shariff et al., 2015; Tung et al., 2014; Chi et al., 2016; Collotta and Pau, 2015; Le et al., 2016; Fabrizio et al., 2017; Harid et al., 2016; Atalik et al., 2014; Zaker et al., 2014) so far. When the studies related to the remote monitoring are examined, it is clearly seen that these systems can be classified as wired, wireless and hybrid remote monitoring systems. Remote monitoring systems utilizing wired communication infrastructure cover Supervisory Control and Data Acquisition (SCADA) (Wilkinson et al., 2014; Almas et al., 2014) and Ethernet-based systems (Ahmed et al., 2016; Padilla et al., 2014; Silvestre et al., 2013; Kamel et al., 2015; Vanfretti et al., 2016; Senthilnathan and Annapoorani, 2016; Venkatraman et al., 2016; Silva et al., 2017; Tina and Grasso, 2014). Wireless remote monitoring systems widely utilize GSM (GPRS, 3G or LTE), ZigBee or Bluetooth systems (Shariff et al., 2013; Gaurav et al., 2014; Kabalci et al., 2016; Fateh et al., 2013; Madueño et al., 2016; Cabanas et al., 2007; Mohamed et al., 2014; Shariff et al., 2015; Tung et al., 2014; Chi et al., 2016; Collotta and Pau, 2015; Le et al., 2016; Fabrizio et al., 2017; Harid et al., 2016). In addition, few systems associated with wired systems and wireless communication systems, for instance combining fiber or Ethernet systems with wireless methods exist (Venkatraman et al., 2016; Atalik et al., 2014; Zaker et al., 2014). While a remote monitoring system based on SCADA for observing status of the various parameters of wind turbines are investigated in Wilkinson et al. (2014), a phase measurement unit (PMU) for a laboratory is considered by open source SCADA system in Almas et al. (2014). Ahmed et al. (2016) investigated an Ethernet based optical communication system for small scale wind turbine farms. In another study, in Padilla et al. (2014), authors aimed to provide a remote monitoring, control and protection system for electrical power systems. In addition, several remote monitoring and fault detection systems based on Ethernet communication protocol are considered in Kamel et al. (2015), Vanfretti et al. (2016), Tina and Grasso (2014).

On the other hand, a large part of wireless communication systems exploited for remote monitoring are concentrated on using of the GSM protocols (Shariff et al., 2013; Gaurav et al., 2014; Kabalci et al., 2016; Fateh et al., 2013; Madueño et al., 2016; Cabanas et al., 2007; Mohamed et al., 2014). A GSM based remote monitoring system by employing several sensor structures is proposed for photovoltaic energy generation systems in Shariff et al. (2013). A different GSM system is examined for both solar and wind energy generation systems in Gaurav et al. (2014). Kabalci et al. (2016) proposed a remote monitoring system for solar irrigation systems thanks to GSM and internet based communication. Other GSM based works (Fateh et al., 2013; Madueño et al., 2016; Cabanas et al., 2007; Mohamed et al., 2014) are focused on for monitoring of transmission lines and electrical power systems in terms of leakage, fault detection and partial discharge. The most widely utilized wireless communication method rather than the GSM based systems is ZigBee communication systems. A wireless remote monitoring system based on ZigBee communication protocol to observe grid connected PV systems is reported in Shariff et al. (2015). While Tung et al. (2014) proposed an AMI system for high-rise buildings, Chi et al. (2016) reported another AMI system for high-traffics smart metering by exploiting ZigBee communication system. In (Collotta and Pau (2015), authors studied for a measurement and energy management system that is originated from Bluetooth low energy. A monitoring and fault detection system for photovoltaics in which Bluetooth data transmission method is utilized is reported in Le et al. (2016). Apart from these studies, there are some studies related to wireless sensor networks (WSN) (Fabrizio et al., 2017) and wireless local area network (WLAN) (Harid et al., 2016) for energy demand issue and leakage current detection, respectively.

The conducted literature review is obviously showed that the remote monitoring systems are generally based on either wired communication systems utilizing fiber and Ethernet or wireless communication systems using GSM, ZigBee and Bluetooth. Even though energy monitoring or remote monitoring systems can be accomplished by employing these mentioned different communication protocols, these energy-monitoring methods come up with a significant amount of additional cost. On the other hand, there is a significant gap in the literature about usage of power lines as a communication medium both for remote monitoring and for AMI applications. In this study, a new method to eliminate this expense is proposed in which the conventional electrical power lines are not only exploited to transmit the generated electricity, but also exploited to carry the measurements of solar plants located in different places. Therefore, the main aim of this study is to contribute at this point to the literature by considering power lines as an alternative communication medium for remote monitoring applications of the smart grids. In addition, this proposed method provides several significant advantages such as eliminating channel installation cost, ability to use existing power lines more efficiently and the possibility of different channel environments that do not require obtaining license and possibility to create smart grid infrastructure.

The outline of this paper is as follows: Section 2 describes the designed distributed generation and energy conversion stage, and the designed PLC modems are presented in Section 3. The measurement and analysis results of the proposed system are given in Section 4, and finally, conclusions are drawn in Section 5.

2. Generation and energy conversion stages

The modeled microgrid structure comprised by generation, energy conversion, transmission and monitoring stages is illustrated in Fig. 1. It is clear that the structure of the microgrid is associated with microgrid loads at the end of the transmission line. Three separate solar farms placed in different locations are taken into account in the electricity generation part of this study. The modeled solar plants cover solar arrays and strings of 150 solar panels at each solar plant that are controlled with regular Perturb and Observe (P&O) maximum power point tracking (MPPT) algorithm. The output voltage of each solar plant are regulated by buck converters and supplied to five-level diode clamped multilevel inverter (MLI) that is controlled with PI regulator and phase disposition sinusoidal pulse width modulation (PD-SPWM) algorithm. The sections of generation and energy conversion stages are introduced in the following subsections.

2.1. Solar plants and DC conversion

The voltage and current parameters of the modeled solar panels are adjusted regarding to NE-170UC1 Sharp PV panel that provides maximum power out around 170 W (NE-170UC1 Multipurpose Module, 2008). The voltage-current (V-I) and voltage-power (V-P) analysis of the modeled PV module is shown in Fig. 2 where irradiation is changed up to 1000 W/m^2 by 200 W/m^2 steps while temperature is stable at 25 °C.

The obtained curves clearly verify that the modeled PV module is perfect agreement with the PV module of the Sharp. Moreover, the modeled solar panel infrastructure can be also used to set several parameters such as open circuit voltage (V_{OC}), maximum power voltage (V_{MP}), short circuit current (I_{SC}), and maximum power current (I_{MP}) for any type of PV module. The designed solar plant models produce rated power at 25.5 kW.

The solar plants are tested by applying various irradiation values assuming all are located at geographically spanned areas.