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A wireless metering and monitoring system for solar string inverters

Ersan Kabalci[a,*], Yasin Kabalci[b]

[a] Electrical and Electronics Engineering, Faculty of Eng. and Arch., Nevsehir Haci Bektas Veli University, Nevsehir, Turkey
[b] Electrical and Electronics Engineering, Faculty of Engineering, Omer Halisdemir University, Nigde, Turkey

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ABSTRACT

The design and implementation studies of a real time monitoring and smart metering system are presented in this study. The proposed design is improved in terms of smart metering infrastructure based on current, voltage, and power measurements. The communication among the string inverter and host PC is performed by the designed ZigBee transceiver system. Sensing circuits are the most significant devices for measuring both current and voltage magnitudes of the systems. The measured data are processed by the microcontroller unit (MCU) and are modulated after signal processing operations for serial communication. Although the transceiver is configured to execute bi-directional communication, unidirectional data flow is performed where the smart metering system transmits data to monitoring substructure. The monitoring software is also implemented in the context of the presented study. The Visual Studio software development kit is used to design and to code the software by using C#. The performed experimental studies showed that the proposed real time monitoring and smart metering system could be exploited to monitor current, voltage and power magnitudes of the string inverters in an efficient way.

1. Introduction

The increased energy demand and distributed generation (DG) approaches have brought numerous challenges in the last few decades. The balance between the demand and generation is expected to be met by integrating the renewable energy sources (RESs), enabling the microgrid based DGs, and improving the legal arrangements. Almost all the reformist countries prepared set of regulations to promote the DG and RES usage for industrial and residential demands [1,2].

In the last decade, the distributed energy sources (DES), DG and demand control, smart grids (SGs), and energy quality issues have been extensively studied. Besides these physical improvements on generation and distribution, the cyber issues such as monitoring, data management, real time monitoring, control, and remote metering requirements are highly involved. The most innovative improvements of SG and DG technologies have been seen in Europe and North America where both revised generation and distributions systems [3,4]. Autonomously operating numerous power generators and independent sources constitute a flexible and efficient infrastructure for the microgrid systems. The energy sources in a microgrid infrastructure can be fossil fuel based generators and/or RESs such as wind turbines, fuel cells, photovoltaic (PV) panels, and hydro-generators. The wind turbines are the prominent RES since they present the multi MW rated power themselves. Although the PV based generation presents lower efficiency with high installation costs, they are most important competitor of wind turbines owing to their low maintenance requirement and higher operating lifetime due to not including rotational equipment. The recent researches and improvement in PV manufacturing technologies have increased the cost efficiency of PV modules. Furthermore, the modular structure of a PV plant provides more flexible sizing and installation opportunity comparing to other RES plants.

The degraded structure of the conventional grid makes complicate to integrate innovative technologies to transmission and distribution lines. The most recent researches and studies on transmission and distribution lines cover SG topics such as information and communication technologies, remote monitoring, advanced metering infrastructure (AMI), and automated meter reading (AMR) issues. The low voltage (LV) grids are not quite appropriate to these novelties owing to their current structure [5]. However, the smart metering systems can be the key component of LV grids to integrate them to recent SG and microgrid improvements. The smart metering and bidirectional communication infrastructures play important roles in terms of demand response, system planning, demand management and home automation systems in SG challenge of this century. These control features require gateway connection among the monitoring or control centre and node point that is intended to be connected. The most widely used method in the gateway policies is the wide area networks (WAN) [6–8].

The AMI is one of the most widely used technologies that enable to

* Corresponding author.
E-mail addresses: kabalci@nevsehir.edu.tr (E. Kabalci), yasinkabalci@ohu.edu.tr (Y. Kabalci).

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convert former grids to SGs owing to its support at both sides of customer and energy supplier. Furthermore, AMI provides a wide scope on metering data management systems (MDMS) for smart metering. The measured consumption data is received by the host of AMI system and then transferred to MDMS for management, storage, and analysis operations [4,5].

The PV plants are also mostly installed in the rural areas as other RES plants where the distance to monitoring centre is more than a few kilometres. In such cases, wired remote monitoring and management processes requires expensive installation costs. However, wireless communication systems such as internet or cellular phone based can be easily adapted to the AMI system. There some studies have been proposed for remote monitoring and remote metering processes in the literature. Le et al. proposed a wireless monitoring system for PV panels that is based on Bluetooth communication system in [9]. The proposed system had been tested for 87Wp power, which is not quite adequate for PV plants. Silvestre et al. [10] have proposed a remote monitoring system for fault detection. Another remote monitoring system has been proposed in [11] where authors utilized widely known Supervisory Control and Data Acquisition System (SCADA) to monitor some significant data of a 960 kWp PV plant. The cost is one of the most crucial parameter while deciding the most appropriate monitoring and metering infrastructure that is comprised of sensors, data processors, microprocessors, and communication modules. Some secure communication systems such as SCADA provide reliable data transfer, but the installation cost of the whole system directs researchers to find out alternative measurement and communication solutions at lower costs. Wang et al. proposed a similar remote monitoring study based on SCADA in [12] that the study is performed to determine sensor requirement in a remote metering system, and to reduce the sensor complexity. Some alternative monitoring and measurement systems to SCADA have been proposed with LabVIEW and .NET based software development kits where MDMS system can be easily configured and particular application interfaces can be implemented according to requirements [10,13,14]. Such a low cost and internet based remote metering and monitoring study has been proposed in [14] where novel measurement and communication devices are implemented with lower costs comparing to similar studies. The study presented in [14] provides a comprehensive solution on long distance communication, remote monitoring and metering, and database management targets. Some other monitoring solutions have been proposed in [15–17] that are based on internet, cellular communication methods and ZigBee based serial transmission.

The study presented in this paper is performed to constitute an AMI infrastructure for a grid-tie string inverter operating at LV grid. The AMI operations taken into account to include implementation of sensing devices for DC and AC metering, data processing for wireless and internet based communication, and central monitoring software that all are intended to propose a novel system for SG management approach. The smart metering system is designed for a string inverter that can also be used in solar plants at single-phase LV grid codes. The sensing devices that are constituted by the current and voltage measurement systems are implemented to measure amplitudes at the several sections as PV input, output of DC-DC converter and DC bus bar, and at the output of inverter. Therefore, two different sensor boards are designed and are implemented for DC and AC sections of inverter.

A PIC MCU controls the communication by using a ZigBee transceiver between the inverter and the host computer where the central monitoring software has been performed. The central monitoring software has been implemented with C# programming language and database management feature. The acquired measurement data are stored in a database that graphical user interface processes the stored data to monitor the actual amplitudes of the string inverter. The introduction of the proposed AMI structure with monitoring feature is presented in the following section while the designed measurement devices for string inverter are introduced in the 3rd section. The wireless communication system, remote monitoring software and data acquisition systems of the proposed study are presented in the 4th and 5th sections, respectively.

2. The proposed AMI structure with monitoring feature

The SG transformation of conventional grid should be systematically realized. The first SG researches were about the feasibility analyses and design procedures of interactive grid types in terms of generation, transmission, and consuming aspects. The high-level requirements such as sustainability, security, and robustness have been considered in the next steps of researches. In fact, these features were assumed as the crucial components for the third step that includes the bi-directional communication and peer-to-peer energy generation in the context of distributed generation [4,6,7,18].

Kabalci analyses the SG with three technical perspectives as infrastructure, management, and protection in [4], while López et al. expresses these perspectives by three stages or generations of SG [18]. The first step of this innovative grid structure is comprised by generation and transmission systems while the second step includes the monitoring and measurement systems that are vital players of management systems, AMI, and demand response. The final or third stage of SG improvement is handled in operational topics [4,18,19]. The second and third stages of a SG infrastructure require smart metering and monitoring system that is the main motivation of the study presented in this paper. The AMI infrastructure comprised of metering and communication system is illustrated in Fig. 1 [4] where the demand response management is based on bi-directional communication network. The smart metering platform provides an opportunity enabling consumers to monitor the generation and consumption rates of their own DG plant or sources. Furthermore, the AMR technology substituting the

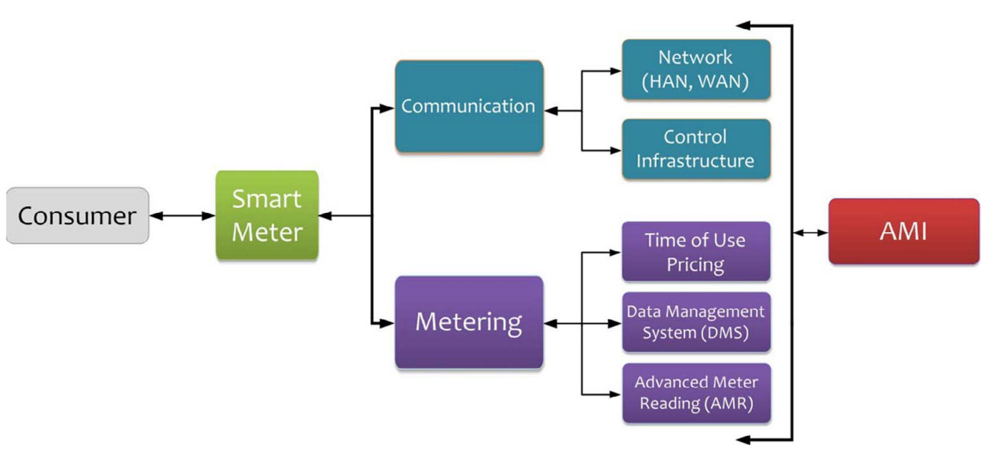

Fig. 1. The block diagram of AMI system with components [4].