Energy Conversion and Management 90 (2015) 336–346

Contents lists available at ScienceDirect

Energy Conversion and Management

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

A smart monitoring infrastructure design for distributed renewable energy systems

Ersan Kabalci

Department of Electrical and Electronics Engineering, Faculty of Engineering and Architecture, Nevsehir Haci Bektas Veli University, Nevsehir, Turkey

ARTICLE INFO

Article history:
Received 29 September 2014
Accepted 30 October 2014
Available online 5 December 2014

Keywords:
Power line communication (PLC)
Renewable energy sources
Smart grid
Quadrature phase shift keying (QPSK)
Automatic meter reading (AMR)

ABSTRACT

The automatic meter reading is essentially required in renewable grids as in conventional grids. It is intended to propose a reliable measurement system that is validated in a photovoltaic power system to meet the requirement of a renewable grid. In the presented study, the photovoltaic plants are controlled by using a widely known maximum power point tracking algorithm that is named as "Perturb and Observe". The distribution line at the output of inverter is modelled according to realistic parameters of 25 km line. Besides carrying the generated line voltage, the grid is used as a transmission medium for the generated power measurements of photovoltaic plants and power consumptions of load plants separately. The modem constituting the power line communication manages the dual-channel transfer and transmits the consumed energy ratios of the load plants. One of the modems is located at the output of voltage source inverter and the other one of the load plants. The power consumption values of each load plants are individually measured and successfully transmitted to monitoring section in the modelled system. The obtained data that is only used for monitoring in this application can also be evaluated for automatic meter reading applications.

1. Introduction

The renewable energy usage is rapidly increasing since each economic crisis and source deficiencies cause to increments on per kWh cost of fossil-fuel based energy [1]. Although the governments and private sector leaders discuss on cheaper energy generation methods, those all agree to increase the renewable energy source (RES) shares to decrease energy generation costs [2]. The RES used in electricity generation include wind energy, solar energy, geothermal energy, and tidal waves. The income of any electricity generation and distribution company in the market is as important as its outcomes [3]. Since the conventional grid is a passive model, the remote detection of the consumed energy is prevented by the losses occurred on the distribution line. Researchers also extensively study the microgrid and load classification issues. Zhou et al. presented an optimal load distribution model and load classifications [4,5]. The main components of a conventional grid can be classified into five topics that are electricity generation plant, transmission substations, distribution substations, control centre, and end-users. Although the conventional grid has many deficiencies to be solved such as voltage sags, blackouts, and overloads, several novel technologies are being researched in order to improve the qualifications of the grid technology [6].

The smart grid concept, which is expanded since early 2000s, implies for a data communication network based on conventional grid that collects and carries the measured and modulated data of transmission, distribution, and consumption units [3,7]. The developments seen in a conventional grid led the researchers to power line communication (PLC) and the smart grid concepts. The smart grid is assumed as a conversion of conventional grid to a communication medium that carries the data obtained from remote sensing, control, and monitoring processes. These communication issues are expected to be performed in a secure and sustainable way over wired and/or wireless communication infrastructures [8]. The wireless technologies used in smart grid are WI-Fi, WiMax, ZigBee, and Bluetooth while the wired communication technologies cover PLC, fiber optics, and copper wires [9–11]. Even though the wireless smart grids are more flexible compared to PLC, the communication may fail because of the probable problems such as interference, shadowing, and/or fading [12,13]. Furthermore, weather conditions directly affect the wireless network and cause to unexpected attenuations and several problems in transmission length. Zhang et al. stated several problems related to smart home management systems that are based on communication methods [14,15]. The PLC systems are categorized as narrow band

E-mail address: kabalci@nevsehir.edu.tr

http://dx.doi.org/10.1016/j.enconman.2014.10.062
0196-8904/

(NB-PLC) and broad band (BB-PLC) according to operating bands [9,10]. The proposed study in this paper deals with a renewable energy generation and distribution system and monitoring the power consumption rates of various consumers by operating multi-carrier based PLC infrastructure.

The generation part of the modelled system consists of three photovoltaic (PV) plants that are assumed to be located in separate fields. The converted PV energy is conducted to a DC busbar and supplies the input voltage of the inverter. The converted energy is distributed to load models over a transmission line that is modelled with 25 km length. The power consumptions of two load plants are observed over transmission line constituting the automatic meter reading (AMR) process. The quadrature phase shift keying (QPSK) modem at the energy generation plant is capable of demodulating the multi-channel input data on the various carrier frequencies. The carrier frequencies are set to 6 kHz and 8 kHz in the designed QPSK modulator systems and the demodulators are arranged to recover the carrier frequencies. It is possible to reconfigure the QPSK demodulator in case of increasing the number of load plants. The renewable energy generation system is introduced in the second section with PV energy plants, energy conversion part and distribution line subsections. The PLC infrastructure is handled in the third section with modelled QPSK modulator and demodulator structures. The analysis methods, optimization steps, and analysis results are discussed in the fourth section.

2. Renewable energy generation system

Fig. 1 illustrates an example of smart grid applications, which is a microgrid structure consisting the main components of a conventional grid system [16]. All components of a smart grid, such as sensing, monitoring, protection, and control units can be seen in the figure that is originally shown in [16].

The complete schematic diagram of the modelled smart grid is seen in Fig. 2. The modelled system can be handled in three sections as illustrated in energy generation, energy conversion and monitoring, and microgrid distribution and load sections. The energy generation part is constituted with PV plant models, boost converters, and DC busbar.

The maximum power point tracking (MPPT) algorithm is also included to boost converter part. The energy conversion and monitoring section covers a three-phase full bridge inverter besides QPSK modem and monitoring part. The distribution line that follows the energy conversion stage carries the line voltages to the loads. The modelled system is tested with two different load plants to figure out QPSK communication over the same transmission line. The drawn current and the consumed power by loads are measured and are modulated at each load plant. The modulated data are overlapped to line via coupling interfaces over S and T phases namely after the measurement and modulation processes are done. The parts of modelled system are analysed in the following subsections in detail.

2.1. Energy generation plants

The analytical model of a PV panel is built using the electrical equivalent circuit that is seen in Fig. 3. The specific parameters of PV panels are defined according to a model of Sharp that provides 170 W maximum output power [17–19]. The developed model adjusts the main parameters of PV panel such as short circuit current (I_{sc}), open circuit voltage (V_{oc}), cell number, maximum power current (I_{pm}), and maximum power voltage (V_{pm}) referring to any PV panel. The current of PV panel is determined using Eq. (1) [20–22];

$$I_o = I_{pv} - I_D \cdot \left[\exp\left(\frac{q(V_o + I_o R_s)}{mk_B T}\right) - 1\right] - \frac{V_o + I_o R_s}{R_{sh}} \quad (1)$$

where, I_o is output current of panel, I_{pv} is the generated PV current, I_D is the diode current, V_o is the output voltage, V_T is thermal voltage, R_{sh} is shunt resistance, R_s is series resistance. In addition, q is the electron charge, m is the equivalent ideality factor, k_B is the Boltzmann constant, T is the cell temperature of the junction.

Table 1 shows the PV panel parameters such as short circuit current, open circuit voltage, maximum power voltage, and maximum power current that are used in Simulink design. The current–voltage (I–V) characteristic curve of the modelled PV module is illustrated according to variable irradiation levels that vary from 200 W/m^2 to 1000 W/m^2 in Fig. 4(a).

The power characteristics generated according to same test conditions to define the maximum power point of PV module are shown in Fig. 4(b). The simulated curves verify that the modelled PV module operates properly to reference module of Sharp according to the same irradiation values. The modelled PV panels are

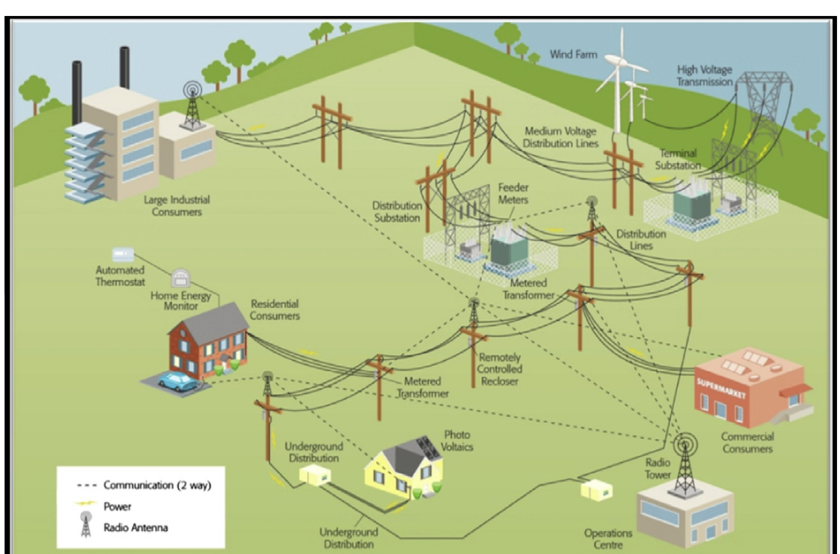

Fig. 1. An example structure for wired and wireless smart grid applications in a generation and distribution scheme [16].