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Voltage control of stand-alone wind and solar energy system

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ABSTRACT

In this paper wind and solar based stand-alone hybrid energy system is presented for the remote area power system applications. The wind, solar, battery, fuel cell and dump load (i.e., aqua-electrolyzer) are connected to the common dc bus. An ac load is connected to dc bus through a pulse width modulation (PWM) based inverter. Ac voltage at load bus can be maintained at rated value by regulating dc-link voltage (V_{dc}) at its reference value and by controlling modulation index of PWM inverter. Novel control algorithms are developed to maintain V_{dc} at its reference voltage irrespective of variations in wind speed, solar irradiance and load. Along with the regulation of V_{dc}, dc–dc converter (connected between battery and dc-link) acts as a maximum power point tracker (MPPT) for photovoltaic (PV) array. Hence an extra dedicated MPPT circuit is not required to extract maximum power from PV. Control technique for the PWM inverter has been developed to make the line voltages balanced at the point of common coupling (PCC) when the load is unbalanced. Hence, efforts are made to supply quality voltage to the consumers through the stand-alone power system. Detailed modeling of various components of stand-alone system is presented. Extensive simulation results using Matlab/SIMULINK established that the performance of the controllers is quite satisfactory under balanced as well as unbalanced load conditions. Moreover, results with real time digital simulator (RTDS) are presented.

1. Introduction

In many countries there are remote communities where connection with power grid is too expensive or impractical and diesel generators are often the source of electricity. Under such circumstances, a locally placed small scale off-grid distributed generation system can supply power to the customers. Recently hybrid power systems consisting of integrated operation of two or more different types of energy sources and storage devices are being deployed for rural electrification or electrification of remote areas in many countries across the world [1]. Autonomous wind plus solar power systems are among the most interesting and environmentally-friendly technological solutions for the electrification of remote consumers. A viable solution is to combine those different renewable energy sources to form a hybrid energy system (i.e., micro-grid) [1–5]. Such hybrid system gives more reliability and may be cost effective.

Supplying the customers with a quality voltage is the main challenge in a stand-alone system. Voltage variations, flickers and harmonic generation are the major power quality (PQ) problems that occur in wind/solar energy conversion system. The voltage variations are mainly due to the change in load. Flicker or voltage fluctuations are primarily caused by variations in the wind speed and solar irradiation. Unwanted harmonics are generated in the voltages at the point of common coupling (PCC) due to converters connected between source and load. Moreover, in distribution system PCC voltages are always unbalanced due to single phase loads. Those power quality problems may not be tolerated by the customers and hence require mitigation techniques. Hence, in this paper, along with control of voltage and frequency, mitigation of the above mentioned power quality problems are addressed.

The proposed stand-alone hybrid energy system (shown in Fig. 1) consists of a permanent magnet synchronous generator (PMSG) based variable speed wind energy conversion [6], PV array, battery, fuel cell and dump load (i.e., aqua-electrolyzer). Both the sources i.e., wind and solar are equipped with maximum power point tracking (MPPT) and connected to the common dc bus. Battery is used as a storage device and is connected to dc bus through dc–dc bidirectional converter. Wind power depends on weather conditions and during night hours solar power is zero. Therefore under the situation of long term no-wind or low-wind condition, battery alone cannot cater the load demand. Hence, fuel cell (FC) is integrated to make system more sustainable. In case of high power generation from wind and solar for a long time and the battery hits its upper limit of charge storage, the dump load (i.e., aqua-electrolyzer) comes into effect and consumes the surplus power. The hydrogen generated from the electrolyzer can be stored and used as input by FC. Since, life time of battery is very less as compared to FC, the use of battery for short-term storage and use of FC

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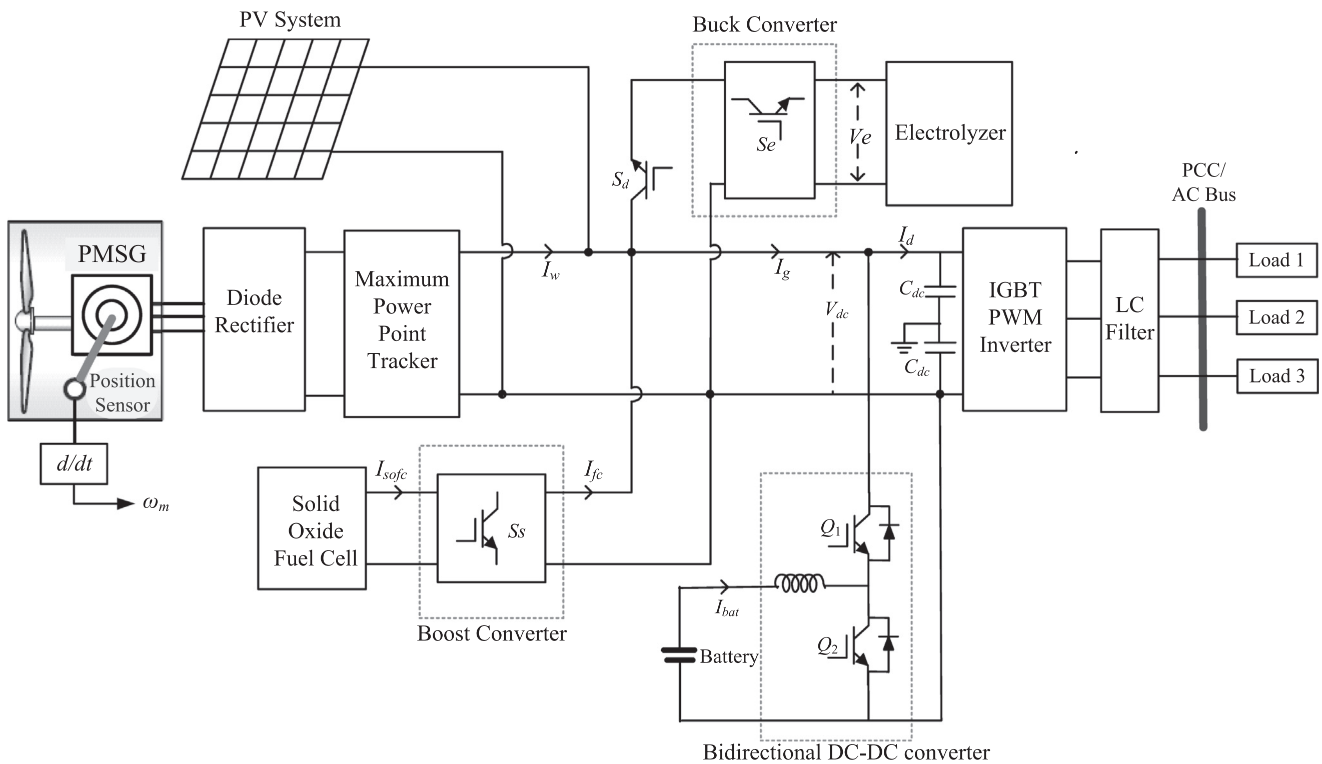

Fig. 1. PMSG and solar based stand-alone wind turbine with energy storage, fuel cell and dump load.

for long-term storage finds some technical and economical advantages [7,8]. Hence, in this paper battery is used in transient period and FC is used in steady state. Ac loads are connected to dc bus through PWM based inverter. The proposed system can feed single phase as well as three phase loads.

The similar stand-alone hybrid energy system is presented earlier by few researchers [2–4,9–15]. In [2] authors present the generation of hydrogen using different sources, however, authors did not mention about voltage and frequency control of stand-alone system. In [3], authors present overall power management strategy among different sources and storage units. However, in [3] the actual control of the inverter is not presented. In [4], authors present wind–PV hybrid system to the supply the dc loads. However, battery is directly connected to dc bus and its charging/discharging control is not mentioned. In [5], authors present the control of autonomous hybrid system for single phase and not for three-phase. Moreover, in [5] authors did not consider storage and dump load which will make the system unreliable. In [9], authors present the system for generating and utilization of hydrogen with renewable energy sources, however, authors did not mention the controller for unbalanced load. Moreover, in [9] various sources as well as storage systems have individual converters connected to dc bus, which makes system more expensive. In [10], authors present dc system for generation of hydrogen from renewable sources, however this system is for only dc loads. In [11] PV having own dc–dc converter for MPPT and electrolyzer is connected to AC bus through AC/DC converter, which system makes more expensive and also authors did not mention about power quality issues. In [12], authors present AC coupled hybrid system in which individual MPPTs are required to all sources and individual ac–dc converters are required for battery and electrolyzer which makes more expensive. In [13], authors present power generation system for green building; however system is valid for only single phase system. Authors used FC but electrolyzer is not incorporated as dump load since through electrolyzer hydrogen can be produced which in turn can be used by FC as input source. In [14], authors proposed energy management system for stand-alone power generation system; however, authors did not consider unbalanced load and power quality issues, moreover author did not connect MPPT for wind generation system. In [15], authors propose renewable sources based hybrid system for a green house, however proposed system is only for single phase. Moreover, in references [9–13], designed controllers are based on measurement of various powers (i.e., sources, storage and load), which require more number of sensors.

In this paper, a stand-alone power system is developed using renewable sources with following objectives:

(a) To achieve intelligent control coordination among different sources, FC, battery and dump load.
(b) To regulate voltage at load bus irrespective of fluctuations in wind/PV and variations in load.
(c) To supply quality voltage to the customers.
(d) To maintain constant and balanced three phase supply at load bus under condition of unbalanced load scenario.
(e) Along with control of dc-link voltage, dc–dc converter (connected between dc bus and battery) acts as MPPT circuit for PV system, hence extra MPPT circuit is not required to extract the maximum power from PV panels.

The paper is summarized as follows: in Section 2, brief description of PV system and its MPPT control is presented. In Section 3, a control strategy is developed to regulate the voltage and hence coordination among sources, storages and dump load. PWM inverter control for unbalanced load compensation under various conditions is explained in Section 4. Unit sizing of wind generation, PV, electrolyzer and FC is given in Section 5. Detailed simulation results (including RTDS results) are presented in Section 6 by presenting different case studies. The findings of paper are given in the conclusions in Section 7.