Electrical Power and Energy Systems 64 (2015) 50–57

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Integrated circuit and system design for renewable energy inverters

Yeong-Chau Kuo [a,*], Yi-Ming Huang [a], Li-Jen Liu [b]

[a] Department of Electronic Engineering, National Kaohsiung First University of Science and Technology, Kaohsiung 824, Taiwan
[b] Department of Computer Science and Information Engineering, Chung Chou University of Science and Technology, Chang-Hua 510, Taiwan

ARTICLE INFO

Article history:
Received 18 July 2013
Received in revised form 6 June 2014
Accepted 6 July 2014

Keywords:
Integrated circuit (IC) and system
Pulse-width modulation (PWM)
Renewable energy inverter

ABSTRACT

This study proposes that a novel integrated circuit (IC) and system design for renewable energy inverters can harvest renewable energy to power direct current (DC) and alternating current (AC) loads. In addition, an intelligent synthesis and management tool is developed to design the proposed system and to judge the system's operational maintenance decisions. Finally, a renewable energy inverter's information is posted to an online system. Users can obtain the proposed system's information at any time and place. The accurate and superior performance of the proposed IC and system is confirmed by computer simulations and experimental results.

1. Introduction

The most common renewable energy sources are solar and wind power [1–11]. The output power of solar panels and wind turbines is affected by environmental factors, including irradiance, temperature, and wind speed, and are unstable for practical application. A power converter is used to track the maximum power point of the renewable energy source based on various maximum power point tracking (MPPT) methods, such as perturb and observe (P&O) [2], incremental conductance [3], fractional open-circuit voltage [4], fuzzy control [5], and neural networks [5]. These MPPT controllers are similarly applied to wind energy products [6,7]. Power converters can be used to charge batteries and provide power to DC loads [8,9].

In previous studies on renewable energy inverters, [10,11] used two types of renewable energy inverters: (1) grid-connected inverters, and (2) stand-alone inverters. Grid-connected inverters are used to output a sine wave current to the utility grid. This type of inverter combines a large amount of series and parallel renewable sources, transferring energy to the utility grid. In contrast, stand-alone inverters are used to output a sine wave voltage to the alternating current (AC) load. This type of inverter is suitable for areas that are far from the utility grid, such as islands or highlands.

For renewable energy inverter designs, efficiency and stability are the most critical concerns. Therefore, numerous controller integrated circuits (IC) have been used for renewable energy converters and inverters [12–18]. Digital controller ICs can be used for small semiconductors and low supply voltage designs [12]. Additional advantages associated with digital designs include programmability, lower sensitivity to various processes, and parameter variation [13,14]. However, the limited resolutions and performances of digital design are substantial drawbacks. For analog controllers, ICs with pulse-width modulation (PWM) [15,16], pulse-frequency modulation (PFM) [17], and dithering skip modulation [18] have been proposed in recent years. In analog designs, the most critical concerns are high-speed response and efficiency. When a converter operates in discontinuous conduction mode (DCM) for easy stabilization, its power losses result in reduced efficiency. In contrast, the continuous conduction mode (CCM) operation can acquire enhanced efficiency, although the stability is more difficult than in the DCM operation.

In this study, a novel IC and system is synthesized for renewable energy inverters. The switching frequency can be adaptively controlled by using various operation modes, such as CCM and DCM, to improve the proposed system's efficiency and stability. In this design, an 8-bit microcontroller chip is used to sense and transform the voltages and currents of a solar panel, wind turbine, and battery into digital output values. These output values are calculated in the microcontroller chip to construct a control algorithm. Thereafter, the proposed controller IC follows the microcontroller's output command to control the solar panel or wind turbine at the maximum power point (MPP) and offers power to the battery and DC load. Thereafter, the controller IC is used to control the full-bridge configuration to output the sine wave voltage and current to the AC load, as shown in Fig. 1. The proposed IC

---

* Corresponding author. Address: Department of Electronic Engineering, National Kaohsiung First University of Science and Technology, 1 University Road, Kaohsiung 824, Taiwan. Tel.: +886 7 6011000 2514; fax: +886 7 6011386.

E-mail address: yckuo@ccms.nkfust.edu.tw (Y.-C. Kuo).

http://dx.doi.org/10.1016/j.ijepes.2014.07.033
0142-0615/© 2014 Elsevier Ltd. All rights reserved.

and system can be used for wind–solar complementary inverters. As shown in Fig. 1, the top inverter is operated in standalone mode that controls the system to support the sine wave voltage, which is the voltage-controlled mode. The bottom inverter is operated in the grid-connected mode that controls the system to output the sine wave current, which is the current-controlled mode. The operating information of the solar panel, wind turbine, battery, and renewable energy inverter is transferred to a notebook computer so that the proposed synthesis and management tool can judge the system operation situation and make a maintenance decision.

2. System design

In this study, the wind turbine and utility power are integrated into the proposed renewable energy inverter to build the complementary energy-harvesting system design for solar, wind, and utility power. The proposed architecture of the renewable energy inverter is shown in Fig. 2(a). The operation of the proposed renewable energy inverter is shown in Fig. 2(b)–(d). In these figures, the PWM signal is generated from the proposed controller IC to control the solar panel or wind turbine during the MPP mode and to charge the battery by using the buck-boost operation mode. Thereafter, operating in boost mode, the battery voltage is boosted into the DC bus. Finally, the renewable energy inverter outputs the sine wave voltage and current to the AC load by operating in the full-bridge buck operation mode [9].

The efficiency equations of the proposed buck-boost operation can be derived as

$$\eta = \left(1 - \frac{D'V_D}{DV_i}\right)\left(\frac{(D')^2 R}{DR_{on} + DR_L + D'R_D + (D')^2 R}\right) \tag{1}$$

where D and D' are the turn-on and turn-off durations of power devices, respectively; V_D is the turn-on voltage of the power diode; V_i and V_o are the input and output voltages, respectively; R is the load resistance; R_L and R_C are the equivalent series resistances of L and C, respectively; and R_{on} and R_D are the turn-on resistances of the power MOSFET and diode, respectively. The efficiency equations of the proposed boost and buck operations can be derived, respectively, as

$$\eta = \frac{1 - D'\frac{V_D}{V_i}}{1 + \frac{R_L + DR_{on} + D'R_D}{(D')^2 R}} \tag{2}$$

$$\eta = \frac{\left(1 - \frac{D'V_D}{DV_i}\right)R}{R_L + DR_{on} + D'R_D + R} \tag{3}$$

The transfer functions of the proposed buck-boost operation can be derived as

$$G_{vg}(s) = \left(\frac{DD'R}{R'}\right)\left(\frac{sR_C C + 1}{\Delta_1(s)}\right) \tag{4}$$

$$G_{vd}(s) = \left(\frac{V_o}{DD'R'}\right)\left[\frac{(D')^2 R^2}{R_C + R} - R_L\right]\left(\frac{sR_C C + 1}{\Delta_1(s)}\right)\left[1 - \frac{sDL}{\frac{(D')^2 R^2}{R_C + R} - R_L}\right] \tag{5}$$

$$\Delta_1(s) = \frac{LC(R_C + R)}{R'}s^2 + \frac{(R_L R + R_C R_L + D'R_C R)C + L}{R'}s + 1 \tag{6}$$

$$R' = R_L + \frac{D'RR_C + (D'R)^2}{R + R_C} \tag{7}$$

where $G_{vg}(s)$ and $G_{vd}(s)$ are the line-to-output and control-to-output transfer functions, respectively. The transfer functions of the proposed boost operation can be written as

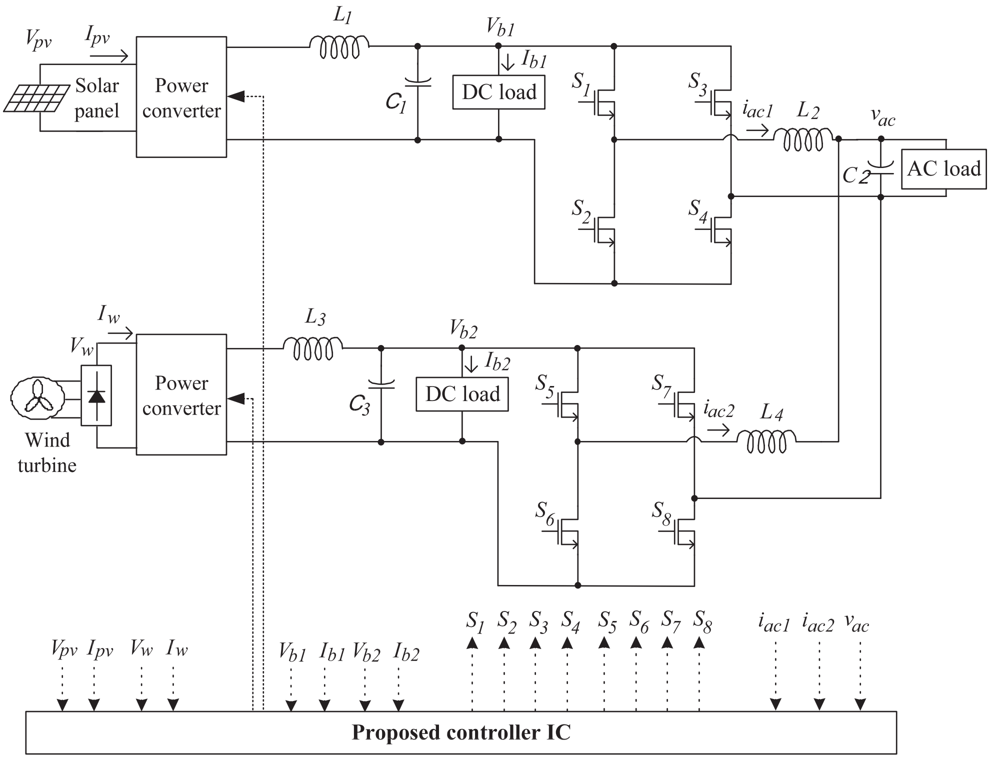

Fig. 1. Proposed IC and system for wind–solar complementary inverters.