Solar Operated BLDC Drive for Agriculture Purpose

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Abstract - *This paper deals with the development of a solar photovoltaic (PV) based reliable water pumping system. An uninterrupted and full volume of water delivery and hence the reliability is ensured by providing a continuous power grid support to the PV generation unit which is installed for the water pumping. The water pump is powered by a brushless DC (BLDC) motor drive with high efficiency and reduced sensor based. The power transfer from the utility grid to the common DC bus is enabled through controlling a power factor corrected (PFC) buck-boost converter. In order to make the control of the converter simple and cost-effective, it is operated in discontinuous conduction mode (DCM) which requires a single voltage sensing, and also offers an inherent power quality improvement in terms of total harmonic distortion (THD) and unity power factor (UPF). The applicability and reliability of the proposed scheme are demonstrated by the various simulated results using MATLAB/Simulink platform.*

1. INTRODUCTION

Reliability is a major concern of solar photovoltaic (PV) based water pumping. Due to the intermittency of PV generation, water pumping is severely interrupted and it is not possible at night. The demand for a continuous water delivery calls for a pumping system which is independent of the climatic condition. An external power source is obviously required to meet this demand. The so called external power backup may be battery energy storage (BES) or a utility power grid. The BES reduces the service life, and increases the installation cost and maintenance requirements [1]–[2]. To get over this complications with a battery technology, an alternate solution is reported in [3]–[5] wherein a utility grid is used as the backup in a PV based induction motor driven water pumping. These recently recognized technologies, in reality, interface a PV generating unit into a utility grid. The prime attention is to achieve an uninterrupted and full volume of water delivery irrespective of the climatic conditions, whether day or night. However, no such system with a brushless DC (BLDC) motor is developed or reported as of now.

The BLDC motor has gained a wide attention since last decade for PV based water pumping. The attractive merits of this motor drive include a high efficiency, high power density, high power factor, high torque/inertia ratio and compactness [6]–[8]. This work aims at the development of reliable water pumping with grid supported PV generation unit which feeds a BLDC motor-pump. The power is drawn from the grid in case the PV array is unable to meet the required power demand; otherwise the PV array is preferably used. To enable a power transfer from the utility grid to the DC bus, a DC-DC buck-boost converter is used as an intermediate converter. An amount of the power required to be transferred is governed through an appropriate control of power flow.

In addition to the power transfer, a secondary objective of the buck-boost DC-DC converter is to maintain the power quality (PQ) at the utility grid. Therefore, this is used as a power factor corrected (PFC) converter. The various PFC converter configurations for BLDC motor drive are broadly classified in [10]. Among the numerous topologies, a PFC buck-boost converter, possessing a minimum number of components is adopted in this work. Operating this converter in CCM (Continuous Conduction Mode) although leads to a reduced switching stress on its devices, it causes an increased number of sensing elements and complex control [11]. Therefore, in this work, it is operated in a discontinuous conduction mode (DCM) and controlled through a voltage follower approach, which need only one voltage sensor. Moreover, the DCM operation offers an additional benefit of inherent power factor correction at the power grid.

The maximum power point (MPP) operation [9], [12]–[14] of the PV array is carried out using another buck-boost converter between the PV array and VSI (Voltage Source Inverter) which feeds the brushless DC motor-pump. However, this converter is operated in CCM to obtain a least switching stress on its components and devices. It is capable to operate as both boost and buck converters thus does not possess any sort of confinements on MPP tracking dissimilar to a boost or buck converter [6]. On the other hand, the BLDC motor is operated through an electronic commutation [6], [8]–[11]. A reduced sensor based speed control which obviates the phase current sensors is adopted for simplicity and cost benefit. In addition, in order to minimize the converter switching losses, a fundamental frequency switching of VSI is adopted. The proposed topology is designed and simulated in MATLAB platform, and its functionalities are tested to demonstrate the reliability.

2. PROPOSED SYSTEM

The suggested grid-interfaced solar PV-based water pumping scheme. The BLDC motor-pump is supplied by a PV array via a DC-DC buck-boost converter and a VSI. The DC-

DC converter is used here as an MPP tracking converter. The operating point of PV array is controlled through an MPP tracking algorithm which needs a sensing of the PV array voltage and current. The VSI performs an electronic commutation of the Brushless DC motor using three inbuilt Hall Effect sensors. The Hall Effect signals are logically converted, using a decoder circuit, into the six switching pulses for the VSI. The speed is maintained at its rated value by a DC bus voltage regulation and the motor-pump is operated at its full capacity.

As shown in Fig. 1, the DC bus is supported by a single phase utility grid. The grid supply voltage is first rectified using a single phase uncontrolled bridge rectifier and then filtered with a low pass L-C filter. The filtered output is used as an input to the PFC buck-boost converter. The inductor of this converter is designed such that it unconditionally operates in DCM. The developed control enables an influence transfer from the utility grid to the DC bus if PV-generated power is insufficient to satisfy the ability demand; otherwise no power.

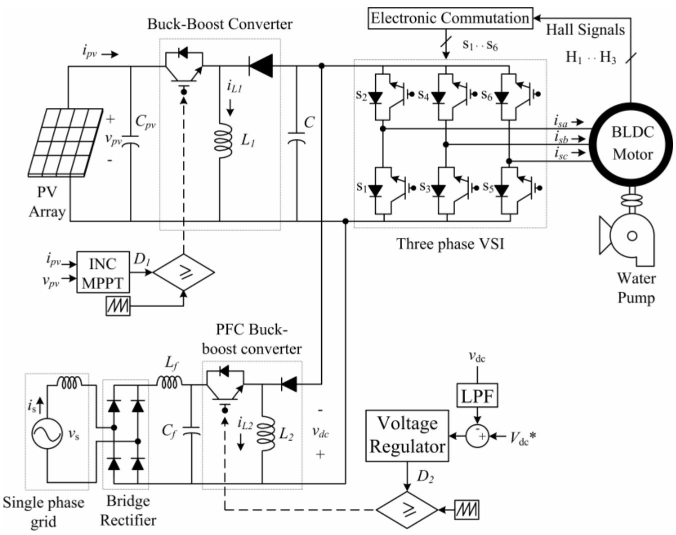

Fig. 1: Schematic of proposed grid interfaced solar PV based water pumping system

The operation of PFC buck-boost converter in DCM is thoroughly described in [11]. This operating mode inherently improves the power factor at the ac mains. The DCM is ensured by selecting a sufficient low value of the inductor. The inductor current is symmetrically placed with sinusoidal ac mains current to achieve a unity power factor. To control the power transfer form ac mains, the DC bus voltage is regulated by a voltage PI (proportional-integral) controller as shown in Fig. 1. The full power is drawn from the ac mains when the water pumping is required at night. Therefore, the flow of power is from the ac utility grid to the DC bus only. The power quality at the ac mains is met in terms of total harmonic distortion (THD) and power factor as per IEEE-519 standards. An absence of EMF (electromotive force) at standstill causes a high inrush current at the starting which harms the windings of the motor and power devices of the converters. To prevent these current surges at starting, the rate of rise of DC bus voltage is required to be controlled. This is achieved by initializing the duty cycle at zero value in the MPP tracking algorithm. As the duty cycle increases, the DC bus voltage also builds up from its zero value. On the other hand, when the water pump is operated by the utility grid only, the rate of rise of common DC bus voltage is controlled by linearly increasing the reference DC voltage from zero to the rated DC voltage of brushless DC motor.

The motor speed is maintained at its rated value, throughout the operation, regardless of the availability of sunlight such that the pump delivers a full volume of water. This is achieved by the DC bus voltage regulation. A concept of current sensor-less based speed control [6], [8]–[11] is applied which eliminates the phase current sensors and governs the operating speed as per the DC bus voltage. So long as the power grid backup is available, the bus voltage is regulated, no matter what is the instant operating condition. However, in case the grid is not available, the DC bus voltage is not regulated at the rated DC voltage of BLDC motor under bad climatic conditions, and the speed is governed by a variable common DC bus voltage.

3. RESULTS AND DISCUSSION

A MATLAB/Simulink platform is used to simulate the performances and to demonstrate the applicability of the system. A 3000 RPM @ 310 V (DC), 5.18 kW motor-pump is powered by a 6.7 kWp PV array and supported by a single phase 230 V, 50 Hz utility grid. The developed system and its control are tested for starting, dynamic, and steady state operations.

1) When Only PV Array Feeds BLDC Motor-Pump

No grid support is required under the standard test condition as the full sunlight is available. The PV array is able to feed the sufficient power to run the pump at its full capacity. Therefore, the power flow control disables the power transfer from the grid. 6. 7 kWp power is generated by the PV array and the DC bus voltage is 310 V. The MPP tracking buck-boost converter operates in CCM. The various motor-pump indices refer to back-EMF, ea, stator current, speed, N, electromagnetic torque, Te, and load torque, TL. The stator current rises with a controlled rate which evidences a soft starting of the motor.

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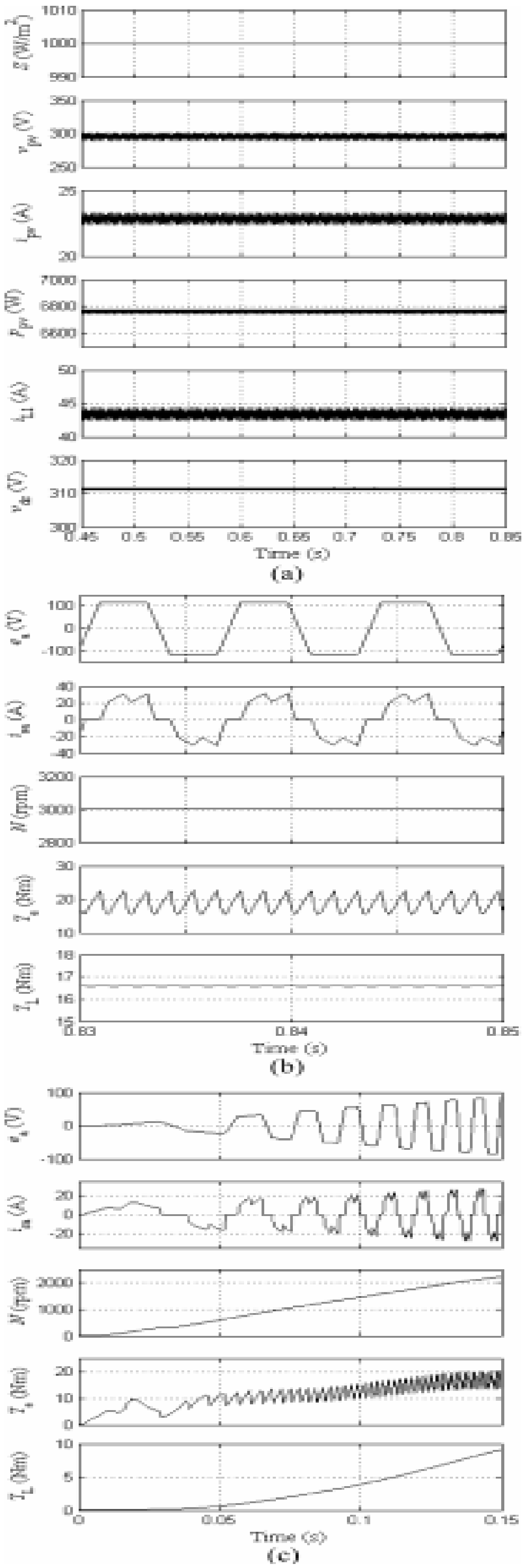
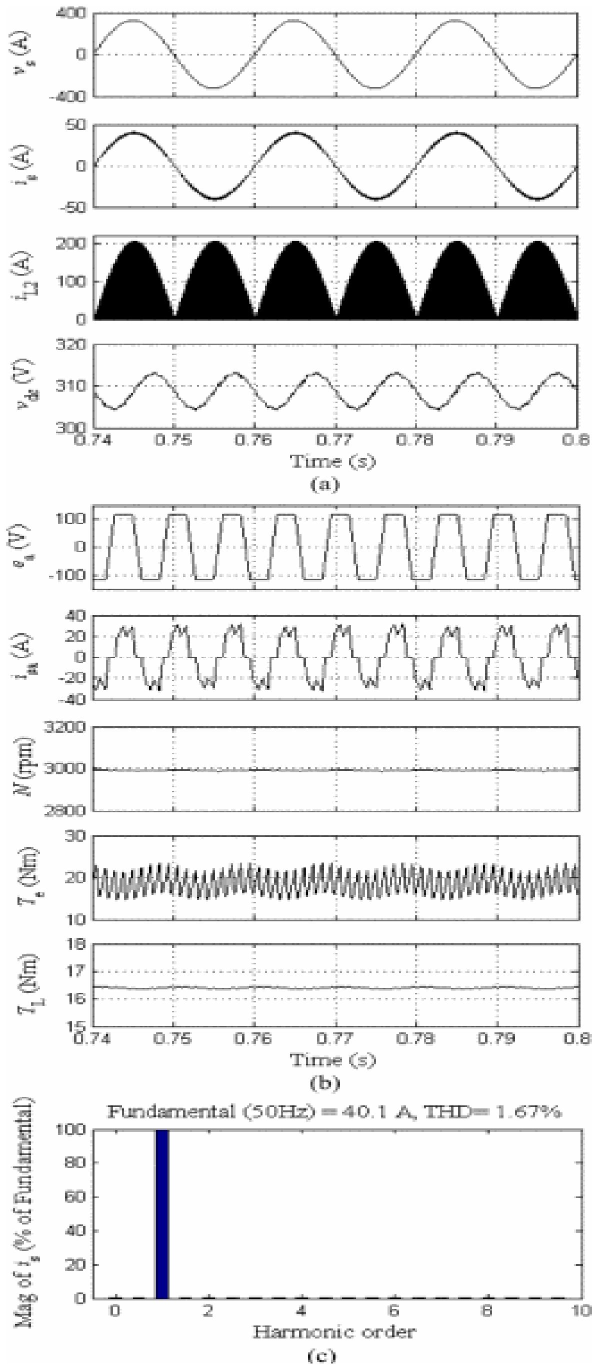


2: Steady-state behavior of (a) PV array and (b) BLDC motor-pump, and (c) starting performance of BLDC motor-pump 2) When Only Utility Grid Feeds BLDC Motor-Pump

2) When Only Utility Grid Feeds BLDC Motor-Pump

When the sunlight is not available and the water pumping is required (at night), the full power required by the motor-pump is drawn from the depicts that a peak supply current, is of 40.1 A is drawn at unity power factor. The supply current is symmetrically placed with the discontinuous inductor current, and the DC bus voltage, vdc, is controlled at 310 V.



3: Steady-state behavior of (a) utility grid and (b) BLDC motor pump, and (c) THD and harmonic spectrum of supply current

4. CONCLUSIONS

A single phase grid interfaced solar PV-water pumping system with a brushless DC motor drive has been proposed and its performance has been demonstrated through MATLAB/Simulink platform. A power flow control has been developed and realized with a PFC buck-boost converter in order to enable a power transfer. The PFC converter has been operated in DCM which has offered a power factor correction at the utility grid and reduced sensor based power flow control. This control has enabled uninterrupted water pumping with full volume of water delivery irrespective of the climatic conditions. A full utilization of the motor-pump system has been achieved. Thus, the proposed topology has emerged as a reliable and efficient water pumping system.

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