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Two Inductor Boost Converter Fed Induction Motor for Photovoltaic Water Pumping System

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Abstract: A Two inductor boost converter (TIBC) for photovoltaic applications is proposed in this paper. The proposed converter provides better solutions to renewable energy sources. The proposed system is mainly based on a current resonant converter which is also known as TIBC. The classic topology of the TIBC features is increased voltage gain and reduced current ripple. The proposed system is efficient and low cost. The analysis of TIBC with PV array has been simulated using MATLAB Simulink. In this paper, it is further modified with snubber along with hysteresis controller to improve its efficiency. The converter is designed to drive three phase induction motor directly from PV energy. For tracking maximum available solar power, maximum power point tracking hill climb algorithm is used. The use of a three-phase induction motor presents a better solution to the commercial dc motor water pumping system. The development is oriented to achieve a more efficient, reliable, maintenance-free, and cheaper solution than the standard ones that use dc motors or low-voltage synchronous motors.

Keywords: Induction motor, dc-dc power conversion, dc-ac power conversion, solar power generation.

I. INTRODUCTION

Solar energy is the most low cost, competition free, universal source of energy as sun shines throughout. This energy can be converted into useful electrical energy using photovoltaic technology. The steady state reduction of price per peak watt and simplicity with which the installed power can be increased by adding panels are attractive features of PV technology. Among the many applications of PV energy, pumping is the most promising. In a PV pump storage system, solar energy is stored, when sunlight is available as potential energy in water reservoir and consumed according to demand. There are advantages in avoiding the use of large banks of lead acid batteries, which are heavy and expensive and have one fifth of the lifetime of a PV panel. A number of experimental DC motor driven PV pumps are already in use in several parts of the world, but they suffer from maintenance problems due to the presence of the commutator and brushes. Hence a pumping system based on an induction motor can be an attractive proposal where reliability and maintenance free operations with less cost are important [1]. The effective operation of Induction motor is based on the choice of suitable converter-inverter system that is fed to Induction Motor. Converters like Buck, Boost and Buck-Boost converters are popularly used for photovoltaic systems. But these converters are limited to low power applications. For PV applications like pumping these converters could do a good job as pumping is carried out at high power. Thus a new TIBC converter which is two switch topology can do justice by giving a high power throughout [3].

II. PROPOSED CONVERTER

The requirements demand the use of a converter with the following features: high efficiency due to the low energy available; less cost enables the deployment where it is needed; autonomous operation no specific training needed for operating the system; robust and less maintenance possible; and high life span comparable to the usable life of 20 years of a PV panel. This chapter proposes a new dc/dc converter and control suitable for PV water pumping and treatment that fulfil most of the aforementioned features. The existing topology based on either voltage fed or current fed converters which have limitations such as reduced life span, high voltage stress, high voltage spikes and switching losses [6]. The solution of this is application of resonant topology. In this paper, modified TIBC provides zero current switching condition enables to operate at high frequency with greater efficiency. To ensure low cost and accessibility of system, it was designed to use a single PV module. The system is able to drive low power water pumps in range of 1/3 hp. The block diagram of proposed system is shown in Fig.1. It consists of a PV panel, modified two inductor boost converter, voltage source inverter, three-phase induction motor and the pump. The voltage from the PV panel is given to the two inductor boost converter, which step up the voltage to the desired value. The two inductor boost converter then drives the induction motor via the voltage source inverter.

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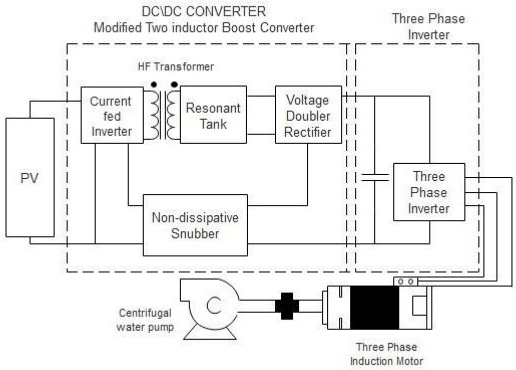

Fig. 1 Block diagram of new topology

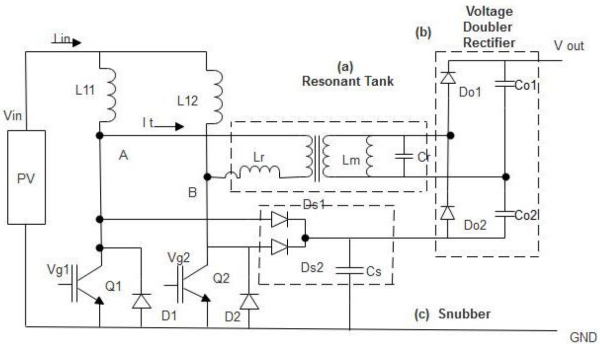

Fig. 2 Modified two inductor boost converter

The TIBC consist of a current fed inverter, resonant tank, voltage doubler rectifier and a snubber circuit. The current fed inverter have an inductor at the input, so the system can be sized to have input current ripple as low as needed, thus eliminating the need of the input capacitor at the panel voltage. Current-fed converters are normally derived from the boost converter, having an inherent high step-up voltage ratio, which helps to reduce the needed transformer turns ratio. They still have problems with high voltage spikes created due to the leakage inductance of the transformers and with high voltage stress on the rectifying diode. For eliminating this resonant tank is used.

Resonant topologies are able to utilize the component parasitic characteristics, such as the leakage inductance and winding capacitance of transformers, in a productive way to achieve Zero Current Switching (ZCS) or Zero Voltage Switching (ZVS) condition to the active switches and rectifying diodes. The main drawback of the classical TIBC is its inability to operate with no load or even in low-load conditions. The TIBC input inductors are charged even if there is no output current, and the energy of the inductor is lately transferred to the output capacitor raising its voltage indefinitely until its breakdown.

The input MOSFET cannot be turned off because there is no alternative path for the inductor current. With the addition of the proposed snubber, the TIBC switches can be turned off. Thus, a hysteresis controller can be set up based on the dc bus voltage level. Every time a maximum voltage limit is reached, indicating a low-load condition, this mode of operation begins. The switches are turned off until the dc bus voltage returns to a normal predefined level. As a result, switching losses are reduced during this period of time. The expanded two inductor boost converter is shown in Fig 2.

The control strategy is in three aspects; hysteresis controller is used during no load conditions, MPP tracking used along PI controller to set speed of motor thereby achieves energy balance of the system and inverter control is by SPWM with third harmonic injection. Fig. 3 represents overview of control system.

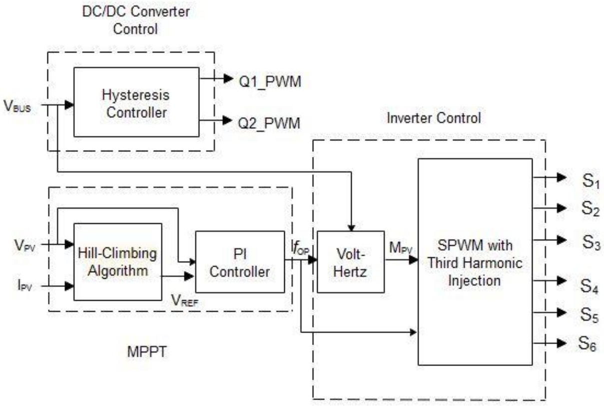

Fig. 3 Control system used in proposed system

III. DESIGN

The motor used in centrifugal pump is 0.5hp (mechanical power) three phase induction motor. The main parameters of PV panel, motor and converter are shown in Table1 and Table2.

Table I Converter Parameter

Parameters	Values
Converter input current ripple	5%
Nominal bus voltage	350V
TIBC switching frequency	100KHz
Inverter switching frequency	7.7KHz
Voltage gain	11.69
Transformer turns ratio	2.25

Table II Panel And Motor Parameters

Parameters	Values
Motor nominal power	0.37KW
Motor nominal voltage	415V 3φ
Motor nominal frequency	50Hz
PV power	210W
PV open circuit voltage	29.9V
PV MPP voltage	26.6V

Static Voltage gain of converter is given by

$$K_v = \frac{Vout}{Vin} = \frac{1}{1-D}\left(2\frac{Ns}{Np}+1\right) \quad (1)$$

D represents duty cycle of each switch; chosen be 53% to guarantee overlapping conduction of MOSFETs

$$K_v = \frac{Vrms*\sqrt{2}}{Vmpp,max} = 11.69 \quad (2)$$

To minimize the influence of load on resonant process on the primary current commutation interval, switching frequency should be higher than resonant frequency. Resonant frequency;

$$F_{rs} = \frac{1}{2\pi\sqrt{LmCr}} = \frac{Fsw}{1.1} \quad (3)$$

During primary current commutation interval when both switches turned on, L_r is in resonance with L_m and C_r Frequency for overlapping interval ;

$$F_{rp} = \frac{Fsw}{2D+1} = \frac{1}{2\pi\sqrt{LrCr}} \quad (4)$$

For ZCS condition;

$$T_{ov} = \pi/w_r = (D-5)/F_{sw}$$

IV. SIMULATION RESULTS

The whole system was simulated on MATLAB software. Fig. 4 shows the schematics.

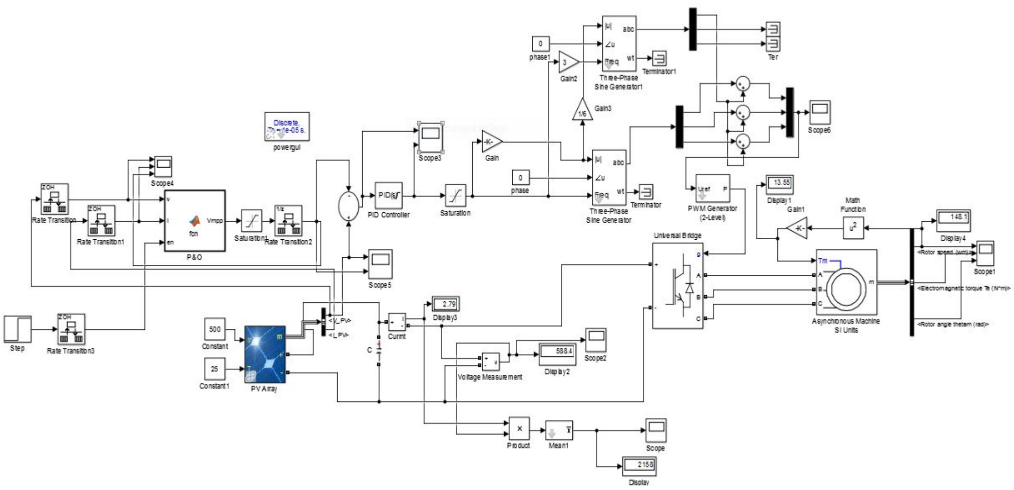

Fig. 4 Simulation of whole system with MPPT, inverter control and pump modelling

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The voltage from the PV panel is given to the three phase voltage source inverter for converting it to ac. The converted ac signal is used to drive the Induction motor. The torque given to the induction motor is based on the torque characteristics of the pump. The torque equation of the pump is be given as

$$T = \frac{30P}{\pi \times n} \qquad (5)$$

Where T is in KNm

P is in KW

n is in rpm

For a 5 hp motor running at 1500 rpm,

$$T = \frac{30 \times 5 \times 746 \times 1000}{\pi \times 1500} = 22\text{Nm}$$

Also, $T = k\omega^2$

$k = 8.91 \times 10^{-4}$

Based on the measured PV panel voltage (VPV) and current (IPV), the MPPT estimates a frequency reference to drive the motor, which indirectly serves to regulate the PV voltage by modifying the amount of power transferred to the motor. A volt–hertz controller calculates the output voltage based on the operating frequency. The inverter is based on a classic topology (three legs, with two switches per leg) and uses a sinusoidal pulse width modulation (PWM) (SPWM) strategy with 1/6 optimal third harmonic voltage injection. The use of this PWM strategy is to improve the output voltage level as compared to sinusoidal PWM modulation and it can minimizes input current ripple. The speed response of the machine is shown in Fig.5, the rated speed of the machine is 1500 rpm. When applying a load of 20Nm the speed reduces to 1400 rpm. As load increases the speed of the machine will decrease. Fig.5 shows the torque characteristics if the machine which has a value around 23 Nm. Fig. 6 shows generated pulses after modulation.

Fig. 5 Speed and torque characteristics

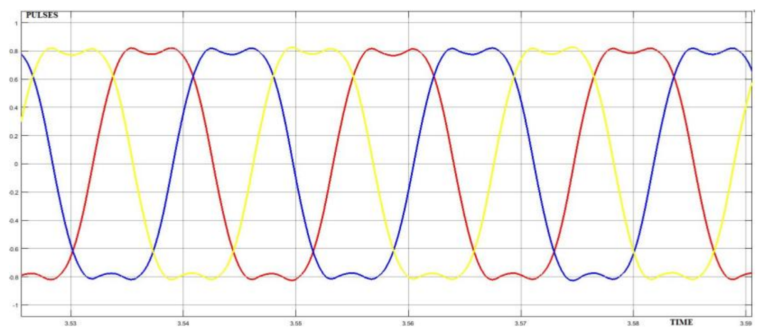

Fig. 6 Pulses generated after SPWM with third harmonic injection

Fig. 7 shows the schematics used for first stage TIBC. All parasitic were included in the transformer and capacitors. The control of the switches was simulated using fixed pulse width modulation. Fig. 8 shows input and output voltages. Fig.9 shows ZCS condition of switches.

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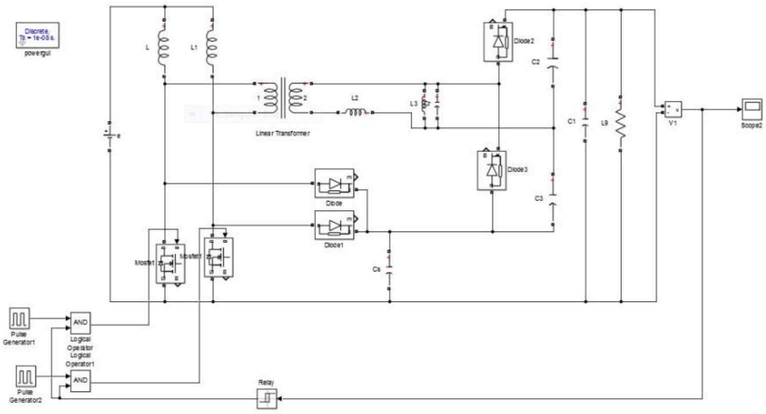

Fig. 7 Simulation of TIBC with hysteresis control

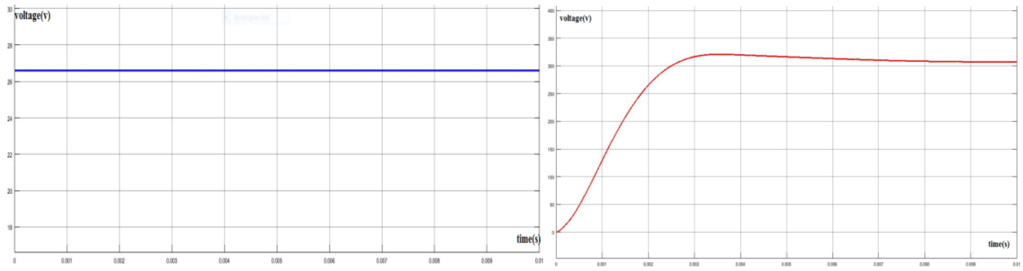

Fig. 8 Input and output voltage of TIBC

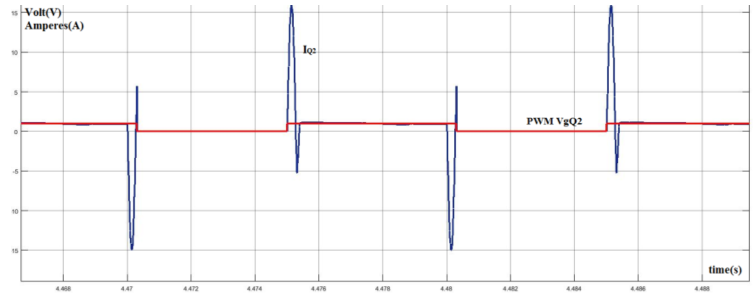

Fig. 9 Verification of ZCS on input switch Q_2

V. CONCLUSION

In this paper, TIBC converter for photovoltaic application without the use of storage elements was presented. The converter was designed to drive a three phase induction motor directed from PV solar energy. This paper presented the system block diagram, control algorithm and design. The simulations result shows the response of the proposed TIBC converter under the variation of solar energy and the reduced voltage ripple in the output of the converter. And also the resonant condition shows the reduced losses in the switching devices by using the transformer parasitic component.

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