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MPPT BASED RESONANT CONVERTER FOR A STANDALONE WATER PUMPING SYSTEM

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***Abstract* — The stand-alone photovoltaic system can be implemented in places where electricity is not available from a utility grid. This paper proposes a water pumping system which is supplied from a PV source and controlled by an MPPT algorithm. A resonant converter is provided in between the PV source and three phase inverter to boost the voltage to the rated level of motor. This converter has the characteristics like ZVS of semiconductor switches and high boost ratio. Moreover, the equivalent voltage stress of the semiconductor devices is lower than other resonant step up converters. TMS320C2000 which provides a high level of computational performance and programming flexibility is used as a controller. Instead of conventional pulse width modulation, Switching Frequency Modulation (SFM) is used in this converter. Both fractional open circuit voltage method and Perturb & Observe (P & O) algorithm are implemented for extracting maximum power from a photovoltaic array. A resonant converter which is suitable for the water pumping system is simulated using MATLAB/SIMULINK. Performance of resonant converter with MPPT is also verified from indoor experimental arrangement.**

*Keywords—***Maximum power point tracking, Switching frequency modulation, Voltage stress, Zero voltage switching**

I. INTRODUCTION

In recent years, even though all countries are in development stage, there are still many remote areas where electricity is not available for water pumping. In such places source of water will be from distant rivers or rain. So the conventional method of supplying water cannot be implemented because of unavailability of electric energy. One of the promising solutions for providing water supply is the use of renewable sources such as photovoltaic source. This paper presents a complete system to control the supply of water with the control of PV source.

PV source which is directly connected to a converter without any control will not provide maximum power, because any changes in insolation affect the maximum operating point of solar panel. In order to operate the PV at maximum power, there are various methods already existing. In this paper, we are dealing with widely used perturb and observe (P&O) algorithm because of its benefits like (a) it is PV array independent (b) can be implemented in both analog as well as digital platforms (c) no need of periodic tuning (d) simple feedback arrangement [1].

The majority of commercial systems use low-voltage DC motors, thus avoiding a booster stage between the PV module and the motor [2]. But DC motors have higher maintenance costs and lower efficiency compared to induction motors. So voltage from a PV source will not be sufficient for operating an induction motor of required power. In order to step up the voltage level, a converter which is more efficient than conventional step up converter should be provided. The design of a motor drive system powered directly from a PV source demands creative solutions to face the challenge of operating under variable power restrictions and still maximize the energy produced by the module and the amount of water pumped [3]. These requirements demand high efficiency for the converter. Soft switching technology can be implemented using LC networks in different combinations and thereby achieving better efficiency at the high switching frequency operation of converting.

The aforementioned water pumping system needs a motor like three phase induction motor which works with high efficiency and lower maintenance. Therefore, stepped up voltage from the resonant converter is fed to a three phase inverter to produce three phase output voltage at the output stage. V/f control is the most popular and has found widespread use in industrial and domestic applications because of its ease of implementation and this method can be used for a wide range of speed control.

This paper proposes a new water pumping system which is accompanied with a PV source and a resonant converter with appropriate control strategies to make water supply easier in remote areas.

II. PROPOSED SYSTEM

In order to reduce the installation cost, a PV array with a combination of two PV module of required power is designed to supply a ½ HP induction motor. The system should be able

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to provide more than enough to supply water for domestic purposes. Fig.1 represents the complete outline of the proposed water pumping system. The energy produced by PV panel is fed to a step up resonant converter and then converted to AC which is used to drive a three phase induction motor thereby operating a centrifugal pump which is coupled mechanically with motor.

The characteristics of a PV module will alter with solar insolation level and atmospheric temperature [4]–[5]. Efficiency of the PV system primarily depends on the operating point on the characteristic curve (P-V curve, I-V curve) of the PV module. Therefore, maximum power point tracking is an unavoidable method of control in a PV system. Until now a large number of MPPT algorithms have been developed [6]–[8] to increase the efficiency and reliability of the PV system. Out of these methods, P & O are widely used because of its remarkable advantages. So the system simulation is performed with P & O algorithm and in hardware setup MPPT is verified by the method known as fractional open circuit voltage. In most of the converters, duty ratio is controlled to obtain maximum power point of PV panel. But in this converter, frequency control is adopted in order to operate the switches at zero voltage condition.

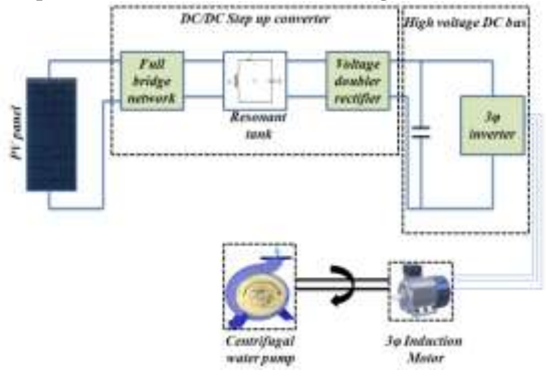

Fig. 1. Block diagram of proposed system

The required DC/DC converter system should have a high voltage gain because of low voltage characteristics of PV panel. Step-up converters are theoretically able to achieve infinitely high voltage conversion ratios; however, the maximum gain is practically limited by circuit imperfections, such as parasitic elements and switch commutation times. Resonant converters have been found to be a feasible option for high power converter. They allow high frequency operation which results in the magnetic component size reduction without decreasing the converter efficiency. Increasing the switching frequency of the power converters can help to reduce the size and volume of the passive components, such as the inductors, transformers, and capacitors, so that the power density can be increased. However, as the switching frequency increases, the switching losses also increase. The soft switching technique is one of the effective solutions to reduce the switching loss at high switching frequency. With Zero-Voltage Switching (ZVS), the converters exhibit lower switching loss and are widely used in many applications. In this system, a step up resonant converter which can realize soft switching technique and low voltage stresses for semiconductor is included in DC/DC conversion stage.

At the output stage of DC/DC converter, high voltage is to be given to the inverter. The inverter is based on conventional topology with three legs, where each leg consists of two switches. The control strategy used for inverter is sinusoidal pulse width modulation (SPWM) to improve the output voltage level compared to conventional PWM method.

To implement water pumping system with less complexity, control methods should also be easier. V/f Control is the most popular and has found widespread use in industrial and domestic applications because of its simplicity. The various advantages of V/f Control are as follows: (a) It provides a good range of speed (b) It gives good running and transient performance (c) It has low starting current requirement (d) It has a wider stable operating region (e)Voltage and frequencies reach rated values at base speed (f) The acceleration can be controlled by controlling the rate of change of supply frequency. Simulation of the complete system is performed in MATLAB/SIMULINK and experimental results are verified up to the converter stage.

A. Resonant converter –

The converter [9] used in water pumping system consists of a full bridge network, a resonant tank, a voltage double rectifier and two input blocking diodes. The circuit configuration of converter is shown in Fig.2. Full bridge network at the input side composed of four switches Q_1, Q_2, Q_3 and Q_4. Modes of operation and ZVS operation are studied from the literature review [9].

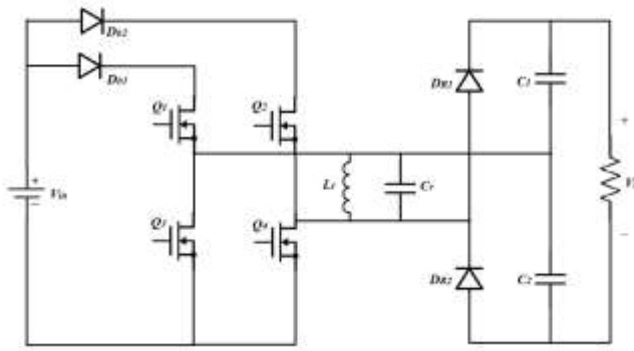

Fig. 2. Circuit diagram of the converter

Analysis and design of the converter –

Resonant frequency f_r of L_r and C_r is given by the equation,

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}} \quad (1)$$

Under no load condition, $f_s = f_r$, where f_s is the switching frequency. From the detailed analysis [9] of the converter, we have the equations,

$$V_O I_O T_S = \frac{V_{in}^2 T_1^2}{L_r} + V_{in} T_1 \sqrt{\frac{C_r(V_O^2 - 4V_{in}^2)}{L_r}} \quad (2)$$

Gain of the converter is expressed as

$$\frac{V_O}{V_{in}} = \frac{2}{\cos(\omega_r T_4)} \quad (3)$$

It can be seen that the gain depends on T_4 which depends on the switching frequency of the converter. From the above equations value of L_r and C_r can be designed by assuming certain conditions.

B. Maximum power point tracking –

In order to operate PV source at its maximum efficiency, one of the most used tracking methods called perturb and observe (P & O) method is implemented. Even though it is a simple method, current sensor of high accuracy is required to track exact maximum power. So in hardware, fractional open circuit voltage method is used to verify the operation of the converter at its maximum efficiency.

Fractional open circuit (FOC) voltage method –

The maximum power point voltage has a linear dependency on the open circuit voltage V_{OC} under different irradiance and temperature conditions.

$$V_{MPP} = K_v V_{OC} \quad (4)$$

The constant k_V depends on the type and configuration of the PV panel. Usually V_{MPP} is taken as 80% of V_{OC}. The controller is programmed to operate the PV at maximum power point. A PI controller is implemented with their respective gains to obtain the converter operation at maximum power point of PV source. Block diagram of FOC voltage method is shown in Fig. 3.

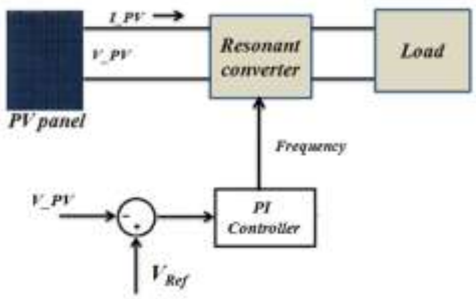

Fig. 3. Block Diagram of FOC voltage method

Perturb and Observe (P & O) method –

P & O algorithm is developed based on the slope dP/dV variation in the P-V characteristics of the panel. The duty cycle/frequency has to be perturbed in order to track the peak power and flowchart of the P&O MPPT algorithm is shown in Fig. 5. Voltage and current will be sensed from the PV panel and it will be send to the control algorithm as shown in Fig. 4. According to the direction of change in power and voltage, frequency will be perturbed to obtain the maximum power.

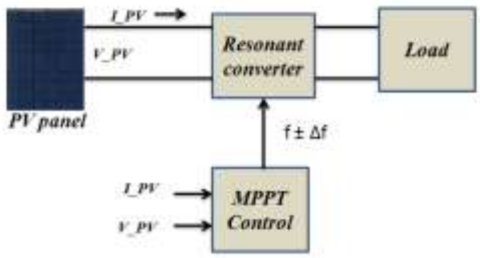

Fig. 4. Block Diagram of P & O method

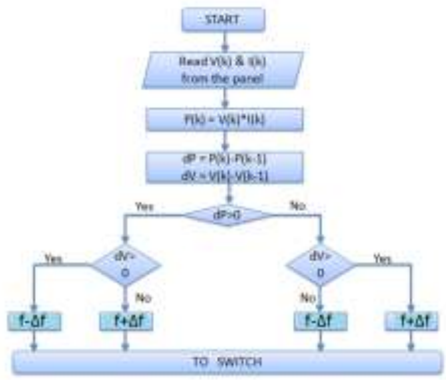

Fig. 5. Flow chart of P & O algorithm

C. Motor control –

It is important to analyse the minimum DC voltage on the inverter DC bus necessary to drive the motor at a specific power level. For this application, the volt/hertz control was used to maintain approximately constant motor flux. By this method, the controller maintains the capability of the motor to generate nominal torque at any speed below its rated value. The volt per hertz (V/f) induction motor drives with inverters are widely used in a number of several industrial applications promising not only energy saving but also improvement in productivity and quality. The low cost applications usually adopt V/f scalar control. Variable speed pumps, fans and appliances are the examples. The main advantage of V/f control is its simplicity and for this reason it has been traditionally implemented using low cost microcontrollers. In inverter, SPWM strategy is implemented to generate the PWM gate pulses for the semiconductor switches.

III. SIMULATION AND RESULTS

The simulation is designed with a PV of given specifications as shown in Table.1. From the characteristics of PV array, it can be found that, PV panel has its MPP at different point for different irradiance level. Both fractional open circuit voltage

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method and P & O algorithm is studied from simulation results.
The motor used in the centrifugal pump is a 0.5HP three-phase induction motor. Considering the nominal power and efficiency of the motor, a 380W PV panel is chosen. The main specifications of the used panel and motor are shown in Table.1.

Table.1. PV Panel & Motor Parameters

Parameters	Values
PV Model	BP SOLAR SX3190
Number of parallel strings	2
PV Power	380W
PV open circuit voltage, V_{OC}	30.6V
PV short circuit current, I_{SC}	17A
PV MPP voltage	24.3V
Motor nominal power	0.5HP
Motor nominal voltage	220V
Motor nominal frequency	50Hz

The main converter parameters used for simulation are summarised shown in Table.2. Output voltage will vary according to the frequency which is settled by the MPPT algorithm. This DC bus voltage must be sufficient to meet the requirement of minimum power needed by the motor.

Table.2. Converter specifications

Parameters	Values
Input voltage V_{in}	20 V
Output voltage V_o	400 V
Resonant inductance L_r	124 µH
Resonant capacitance C_r	1.5µF
Filter capacitance C_1, C_2	22 µF
Duty cycle D	0.35

Simulation diagram of converter block is depicted in Fig.6. Output voltage and stresses across switches are analyzed from the simulation results.

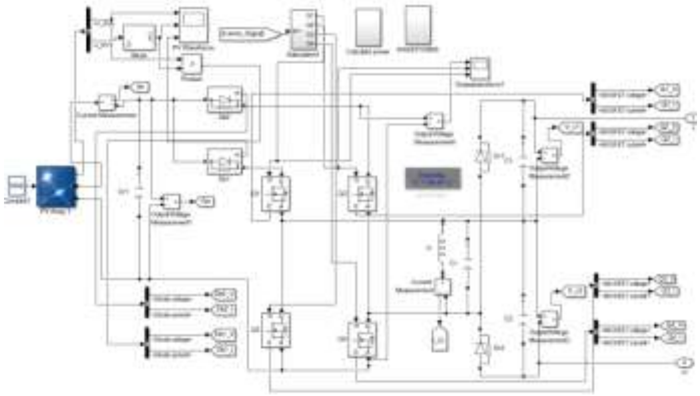

Fig. 6. Simulation model resonant converter

Simulation of FOC voltage method –
The simulink model for fractional open circuit voltage method is shown in Fig. 7.

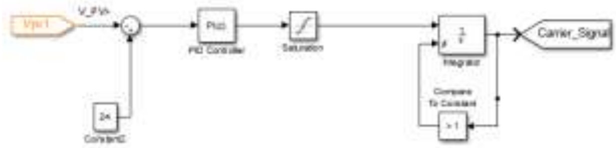

Fig. 7. Simulation model of FOC Voltage method

In order to verify MPPT operation, the condition of changing irradiance from 500W/m^2 to 1000W/m^2, at 25^0 C is set using signal builder. From the P-V characteristics, it can be found that, at 1000W/m^2, maximum power is 380W and for 500W/m^2, maximum power is 190W. The variation in PV power, voltage and current with the change in irradiance is shown in Fig. 8.

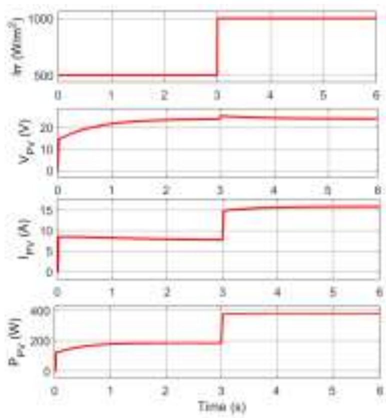

Fig. 8. Simulation results of FOC Voltage method

Simulation of P & O method –
The simulink model for MPPT system is shown in Fig.9. Voltage and current from the PV module is sensed and fed to the MPPT algorithm block to track tha maximum power point frequency.

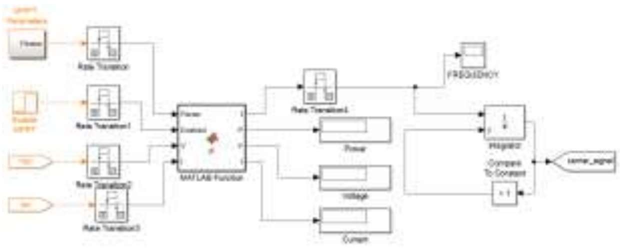

Fig. 9. Simulation model of P & O method

Similar to FOC voltage method an irradiance change from 500W/m^2 to 1000W/m^2 is given to test the MPP tracking. Maximum power point tracking is evident from the simulation graph shown in Fig. 10.

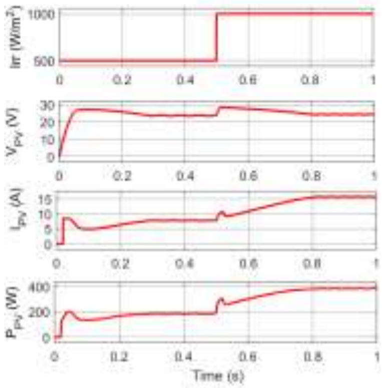

Fig. 10. Simulation results of P & O method

Simulation results of converter –
Fig. 11(a, b) shows the simulation results at the input voltage 24V.

Fig. 11. (a) Output voltage at f_s = 3kHz (b) Output voltage f_s = 11kHz

The peak voltage across the LC resonant tank is $V_o/2$, only half of the output voltage (fig.12) and hence voltage rating of capacitor can be taken as half of output voltage.

Fig. 12. Resonant voltage and current

As the figure shows, the voltage stress of Q_1 and Q_2 is $V_o/2$, the voltage stresses of Q_3 and Q_4 is also less compared to output voltage. From the Fig. 13(a) and Fig. 13(b), it can be seen that, Q_1 through Q_3 are turned on under zero voltage condition and when they are turned off, the voltage across the device increases slowly from zero.

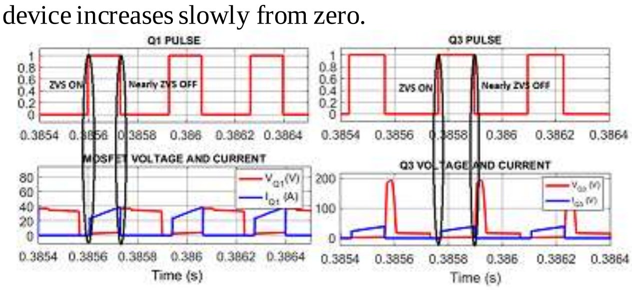

Fig. 13. (a) ZVS of Q_1 (one of the upper switches) (b) ZVS of Q_3 (one of the lower switches)

Simulation of inverter and motor load –

Simulink model of inverter block and motor is shown in Fig. 14. Sine generator is used for generating modulating signal. Output voltage and current waveform is shown in Fig. 15.

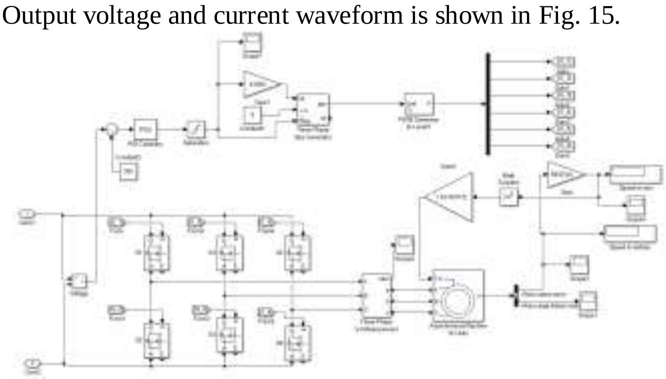

Fig. 14. Simulink model of inverter and motor load

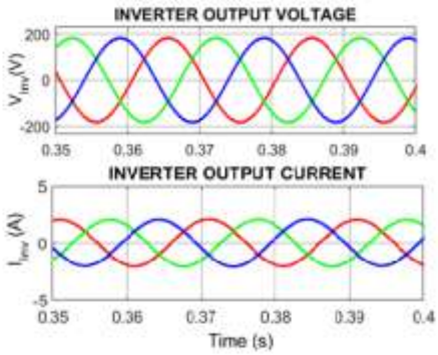

Fig. 15. Inverter output

Speed curves at two different irradiance levels are shown in Fig. 16(a) and Fig. 16(b). At 1000W/m^2, the rated speed 1425 rpm is achieved and at 800W/m^2 a speed lower than rated speed is achieved. As the speed varies, flow of discharge will correspondingly vary. So, whenever the amount of available solar energy is more, pump discharge will be more and also vice-versa.

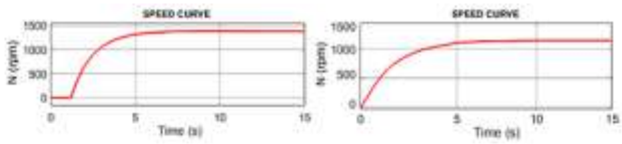

Fig.16. (a) Speed curve at 800W/m^2 (b) Speed curve at 1000W/m^2

IV. EXPERIMENTAL SETUP AND RESULTS

Hardware setup is done only up to the converter section. Future work can be developed into a water pumping system with a PV source. Out of two MPPT methods discussed here, fractional open circuit voltage method is implemented and indoor testing of the circuit has been performed because of certain reasons. Instead of using a PV source, MPP tracking can be verified using an indoor arrangement. Assuming V_{MPP}

of a commercially available solar source is at 10V, reference value of 10V is given in simulink control logic. Component list of prototype is given in Table.3. Experimental setup is shown in Fig. 17.

Table.3. Prototype parameters

Input voltage V_{in} = 10 V	Output voltage V_o = 200 V
Diodes	UF4007
MOSFET	IRF840
Resonant inductance L_r	168 μH
Resonant capacitance C_r	3.3μF
Filter capacitance C_1, C_2	22 μF
Controller	TMS320C2000
Driver IC	TLP250

Fig.17. Experimental setup

As seen from Fig. 17, input voltage source settles at reference set point (here i.e. 10V), because of the control loop provided for FOC voltage operation. 180 degree phase shifted pulse output from the controller is shown in Fig. 18(a) and the output from driver IC is shown in Fig. 18(b).

Fig.18. (a) Pulse from C2000 (b) Output of TLP250

Both voltage across switch and pulse of respective switch are shown in Fig. 19(a) and Fig. 19(b) in order to verify the ZVS operation.

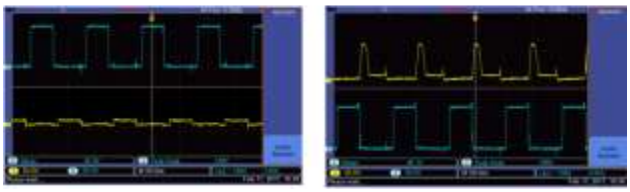

Fig.18. (a) ZVS of Q_3 (lower switch) (b) ZVS of Q_1 (upper switch)

Fig.19. Resonant voltage

V. CONCLUSION

In this project, a standalone water pumping system which can be implemented in isolated areas are presented. The system makes use of solar energy with a proper MPPT control to work with maximum efficiency. A resonant converter is designed to drive a three phase induction motor directly from a PV source. A converter which can achieve high step up voltage gain and which is suitable for high power applications is implemented. The converter can be operated with variable switching frequency. The complete water pumping system is simulated using MATLAB software. Hardware set up is done up to the converter section and MPPT is verified by FOC voltage method with an indoor arrangement. From the analysis, it is found that resonant converter has higher efficiency because of ZVS operation. So this converter can be implemented for water pumping system of variable discharge with better efficiency. In hardware prototype, 13 times voltage gain is achieved and also MPPT is verified assuming a V_{MPP} of 10V.

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