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Development and Testing of SPV Powered 1HP AC Water Pumping System

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Abstract— This paper presents development and testing of 1 HP AC, SPV powered water pumping system. Limitation associated with SPV DC pumps are identified and an attempt to overcome issues is presented with AC pumps. In the proposed system 1.5 kVA inverter is designed for 900W SPV panel connected to 1HP AC pump. The experimental setup is builtin Energy Park, Basaveshwar engineering college (Autonomous), Bagalkot, India. Solar PV based pumping systems without battery is tested for its efficient operation. The tests are condcuted with different solar radiations and results are presented. Various charecterstics of the pumps are drawn. Further, it is concluded that SPV powered AC irrigation systems are much suitable to small scale agriculture.

Index Terms— Solar photovoltaic system, Radiation, Inverter, Centrifugal pump, Hydraulic Head.

1 INTRODUCTION

One of the main hurdles in the growth of rural India is lack of electricity. Grid system is noticeably under developed in India, because the majority portions are still surviving on off-grid. Hence, in the Indian condition, solar systems are becoming a very viable solution due to many sunny days are existing during the year. Moreover, ecological issues such as population and global warming effects are driving researchers towards the development of renewable energy sources including solar systems.

Solar energy is the richest source of energy in the earth. Solar power is not only an answer to today's energy crisis but also an environmental sociable form of energy. Photovoltaic generation is efficient approaches for using the solar energy. Farmers are using solar photovoltaic system in agriculture field. During past few years in rural areas farmers uses DC pumps based on SPV even though they suffer with many problems with DC pumps. To solve this issue, the system of AC water pumping inverter is designed. Designing inverter of the capacity 1.5KVA which is very small when compared with inverters used in large scale. To overcome these problems, design of inverter and experimentation is carried out.

2 METHODOLOGY

The proposed work is taken in two major parts. Design of 1.5KVA inverter and Testing of 1HP AC water pumping system with designed inverter.

2.1 Proposed Block Diagram

The solar AC water pumping system block diagram is shown in Fig.1. The main concept of work is to design the inverter of 1.5KVA for 1HP AC motor water pumping system. It includes SPV array, buck converter and Inverter & AC motor. The six solar panels are connected in parallel each panel is rated 150W which is connected to AC motor coupled to centrifugal pump. At discharge side the Pressure gauge is connected to note hydraulic pressure. Solar radiation data are collected from Automatic Weather Station, installed in theEnergy Park. Inverter will result in 230 V AC voltages from 24-32 V variable DC output from SPV panels.

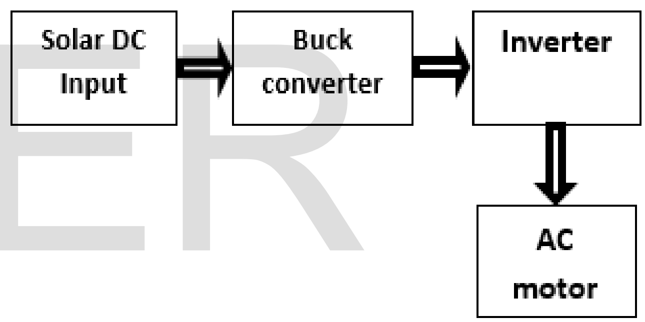

Fig.1: Block diagram of AC solar water pumping system

2.2 Inverter Components

A Buck converter coupled with inverter is designed. IGBT are employed in the circuit as switching devices. Two channel parallel IGBT bank is developed and a transformer switching circuit is developed. Center-tapped transformer is used in the system, which will step up 24V DC to single phase 240V AC.

The inverter is a key system element for power conditioning. It circuit consists of three parts: oscillator, amplifier and transformer. The supply of AC frequency is 50Hz; an oscillator frequency is 57Hz. To produce a sine wave output the high frequency inverter is used. This is carried by encoding program in controller. A pulse width modulator IC-SG3525 is employed to generate PWM. The power IGBT-P25NF120 will amplify the inverting AC signal from the oscillator and these amplified signals are served to the step up transformer with its central tap connected to 24V.

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Components used for designing inverter:

- Pulse Width Modulator U1 IC-SG3525D
- Diode- D1 and D2(UF4007)
- Resister- R1 and R3 (100ohms)
- Resister- R2 and R4 (10kohms)
- Resister- R5 pot (1Mohms)
- Resister- R6 to R11 (1.2kohms)
- Resister- R12 to R17 (470ohms)
- Transistor- Q1 &Q6 (55NF06)
- Capacitor- C1 (100μF)
- Capacitor- C2 (10μF)
- Capacitor- C3 (0.02μF)
- Capacitor- C4 to C9 (0.01μF)
- Centre-tapped transformer- Input voltage DC & Output voltage AC

Oscillator: An oscillator circuit is implemented by programming for generating time delayed pulsating signals in microcontroller IC SG3525. Input supply to the IC is 12V DC, given using 7809 regulator circuit. The IC SG3525 pin diagram is shown in Fig.2.

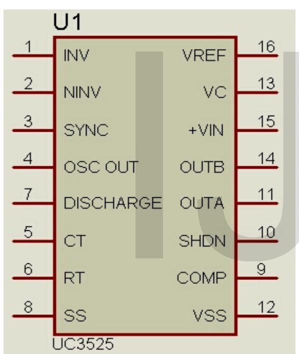

Fig.2: SG3525D PWM IC

Output of oscillator is fed to the amplifier which drives the circuit. By supplying a constant 24Volt DC through a buck converter to the IC SG3525 PWM, the frequency of the oscillating signal was determined using a 1MΩ variable resistor connected in series with another 125KΩ resistor and both connected in parallel with 0.2μF to form the RC time constant network.Frequency of oscillation is given by the equation,

$$f = 1/0.2 * 10^{-6} * \left(07 * \left(125 * 10^{3}\right) + 3 * 100\Omega\right) = 56.94 Hz$$

Where,
Time Capacitor, CT = 0.2μF
Variable Resistor, VR= 1MΩ
Time Resistor, RT=125KΩ

In the present work, variable resistor was varied until 1MΩto obtain the frequency of signal as 57Hz.

The integrated circuit diagram of the oscillatory section is shown in Fig.3. The IC SG3525D works at a fixed frequency. It is used to generate the 50 Hz frequency required to generate AC supply by the inverter. By using one timing resistor and one timing capacitor, oscillation frequency is determined. A constant charging current for timing capacitor is set up by resistor. There exists a direct ramp voltage, which is attached to the comparator.

The SG3525 IC incorporates an inbuilt 12V regulator that serves as a reference voltage. By using a subsequent resistor divider network the output is detected and the error signal is amplified. In order to produce a PWM pulse, the voltage is then matched with the linear voltage ramp at capacitor. Using the pulse steering flip flop, the resulting PWM pulsation from the comparator is then distributed to the following output bypass switches, which is synchronously controlled ON/OFF by the oscillator output.

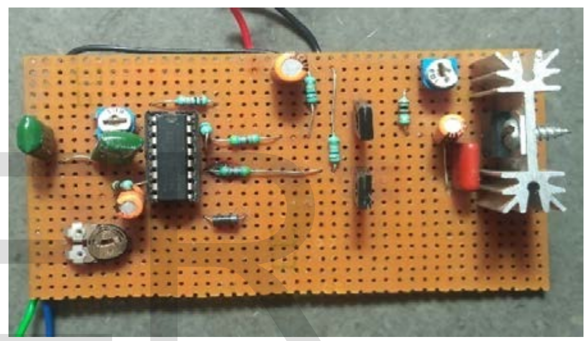
Fig.3: SG3525 PWM integrated circuit

IGBT P25NF120: IGBT is an Insulated Gate Bipolar transistor. It is cost effective and robust trench construction. It provides superior performance in demanding switching application. The IGBT has a feature like high impedance and low on state condition losses. This is a minority-carrier device and bipolar current carrying capacity.

The IGBT is suitable for many applications in power electronics such as PWM and three-phase drives requiring high dynamic range control and low noise. In this work P25NF120 is used. High powered IGBTs with maximum source current of 25A, where each IGBT is having voltage rating of 1200V is used. But due to resistors, it is unable to deliver the specified amount of current to the load. Therefore, in the present work two parallel IGBT power bank with each channel of 10 no's IGBTT are used such that the load driving capacity of the inverter is increased.

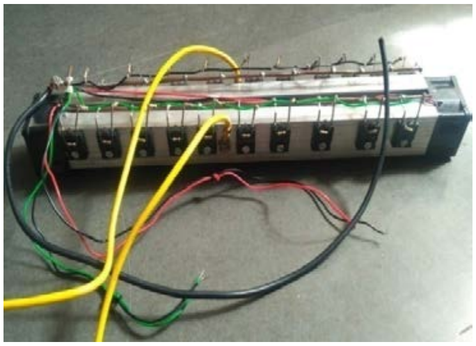

Fig.4: P25NF120 IGBT Bank

Buck Converter: A buck converter is a switch mode DC to DC converter in which the output voltage can be transformed to a level less than the input voltage. The LM2576 buck converter is a series of regulator monolithic integrated circuit. The magnitude of output voltage depends on the duty of the switch. It is also called as step down converter. This convert is switch-mode power supply, its efficiency is significantly higher in comparison with popular three-terminal linear regulators, especially with high input voltages.

Fig.5: LM2576 Buck Converter circuit

The main working principle of buck converter is that the inductor in the input circuit resists sudden variations in input current. When switch is on the inductor stores energy from the input in the form of magnetic energy and discharges it when switch is closed. The capacitor in the output circuit is assumed large enough that the time constant of RC circuit in the output stage is high. Constant output voltage exists across load terminals.

Transformeris an inductively coupled circuit used for transmitting alternating current energy. It is also used for matching impedance between the generator and the load. The central tap transformer is designed to generate an output of 240V AC by taking the input of 24V DC from solar array. The positive of the source is connected to the zero potential of the transformer and drain pin of the IGBT is connected to the ground of the system. As the available solar input is 24V, the transformer is designed for the ratio of 24:280 such that there are 24 turns of primary winding and 280 turns of secondary windings for generating initially 280V and additionally two tapping positions are made at the output side that is of 220V and 280V. 280V is considered because inductive load should give the required output, as the output voltage of AC motor is 230V. The output voltage of central tap transformer is connected to the inductive load to drive the pump.

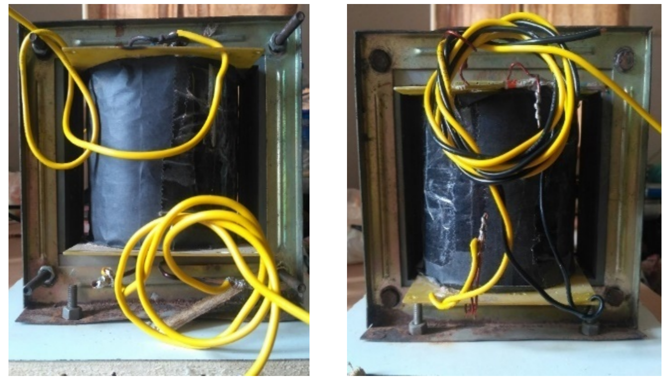

Fig.6: Centre-tapped transformer-Primary and Secondary

A polyester capacitor of 1uF, 400v is used, which is highly efficient to filter out affecting harmonics. As it is necessary to get 240V output, it is preferred to use a step up transformer which will step up the voltage depending upon the requirement. In the present work 24V/240V central tapped step up transformer is employed for experiments.

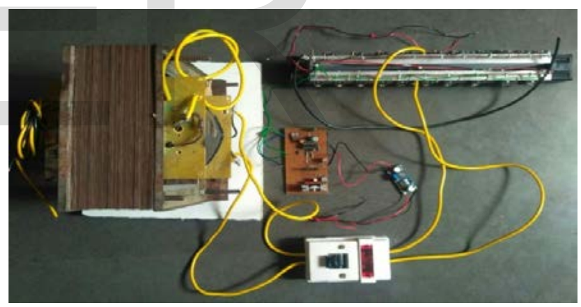

Fig.7: Developed and tested Inverter setup for SPV based 1 HP AC water pumps.

2.3 Experimental setup

The SPV panels installed in BEC Bagalkot and the experimetal set up built to study the performance of the 1HP AC pump.

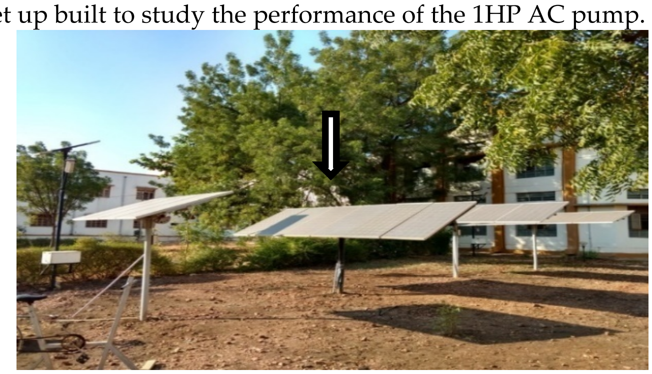

Fig.8: SPV panels installed at Energy Park, BEC, Bagalkot

Table.1: Specifications of the components used

SPV Array	
PV Array Capacity (W)	900
Power Rating of panel (W)	150
OpenCircuit Voltage V_{oc}(V)	36.5
Short Circuit Current I_{sc}(A)	32.5
Voltage at Max Power (V)	28.5
Current at Max Power (A)	25
DC-AC Converter	
Power rating	1.5KVA
Input voltage DC (V)	24
Output voltage AC(V)	230
Centrifugal regenerative AC Motor-pump	
Capacity (HP)	1
Power in watts (W)	746
Voltage (V)	230
Current (A)	3.24
Maximum current (A)	5.5
Rotor speed (RPM)	2800
Capacitor value (μF)	20

3 RESULTS AND DICUSSION

The proposed buck converter circuit is coupled between the SPV array and the AC pump. With nominal radiation of 750 W/m², the pumping unit starts discharging the water. With increased radiation, the water discharge rate and pressure developed at discharge terminal is increased. Detailed performance analysis of SPV powered AC motor coupled with centrifugal pump is carried out and readings are tabulated during the experiments. Fig.9 shows the water discharge from AC pump and Table.2 presents the performance of the system with suction head of head of 3m.

Fig.9: SPV based AC water pumping system-Water Discharge

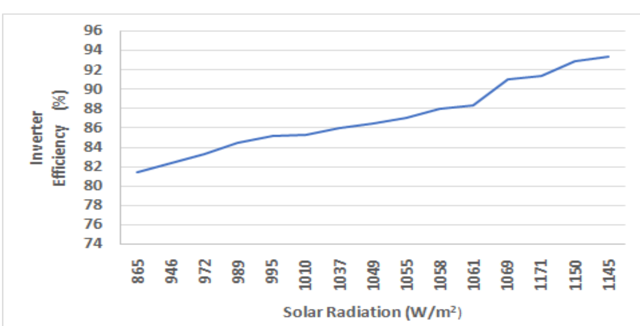

Fig 10: Variation of inverter efficiency with reference to solar radiation

Table 2: Performance analysis of the 1HP AC water pumping system of suction head, discharge terminal left open

Radiation (W/m²)	Vin	Iin	Pin	Vout	Iout	Pout	Iverter η (%)	Flow rate (LPM)
865	25.4	23.4	594.3	196	2.47	484.1	81.45	44
946	22.9	23.2	531.2	200	2.19	438	82.44	46.5
972	24.2	22.1	534.8	186	2.49	463.1	83.30	49
989	25.7	21.9	562.8	205	2.32	475.6	84.50	51.6
995	23.1	23.4	540.5	203	2.27	460.8	85.24	51.8
1010	23.9	21.5	531.8	210	2.16	453.6	85.28	54
1037	24.8	22.7	562.9	207	2.34	484.3	86.04	57.9
1049	24.1	23.3	561.5	200	2.43	486	86.54	60
1055	22.6	24.1	544.6	189	2.51	474.3	87.09	62.5
1058	24.5	22.9	561.0	212	2.33	493.9	88.04	65
1061	22.3	25.3	564.1	201	2.48	498.4	88.35	68
1069	22.6	24.7	558.2	210	2.42	508.2	91.03	69.6
1171	24.6	21.6	531.3	204	2.38	485.5	91.37	70
1150	23.9	23.5	561.6	208	2.51	522.0	92.95	71

It is observed from the readings that maximum radiation in a day will be around five hours. During this time water pumping is carried out effectively. Inverter yields the AC voltage at 230V from variable DC voltage. Fig 10 shows the variation of inverter efficiency with reference to solar radiation and Fig.11 shows the increase in the output power of the inverter with increase in solar radiation.

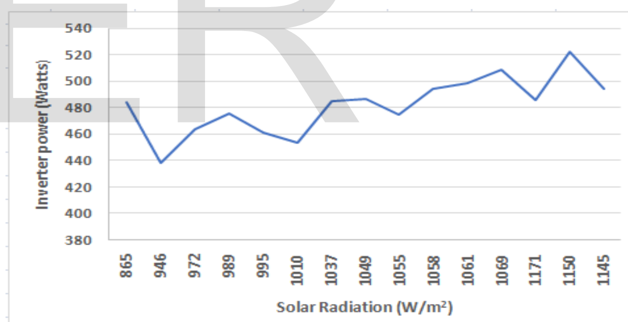

Fig 11: Variation of inverter output power with change in solar radiation

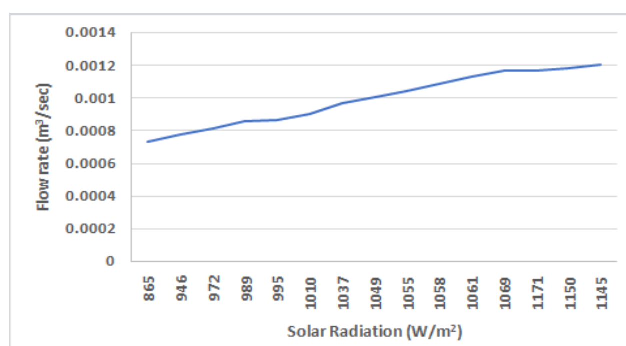

Fig 12: Variation of flow rate with reference to solar radiation

Once the AC electrical power supplied to pump, it is observed that, with increase in solar radiation output from SPV array will increase, which in turn increase the input to motor-pump assembly. Thus power developed by pump will increase with radiation. Fig 12 shows the variation of flow rate with reference to solar radiation for 1 HP AC irrigation pump.

Inverterwill deliver AC power to load only after 750 W/m² radiations during peak sunshine periods (4-5 hrs) of day. Results of one month record clearly shows that pump will start operating after 750 W/m² and performance continue to increase. However, this difficulty will not be faced with DC pumps. Functioning of the 1HP AC water pump is compared with 0.5 HP AC and DC directly coupled water pump. The relative analysis indicated that, DC pumps operate for 7 hours a day with effective operation of 5 hours during mid-noon. On other hand AC pumps works only during peak sunshine hours i.e. when inverter can develop 230 V and supply current to AC pump. But the hydraulic head developed by AC pumps will be much satisfactory. By reference cost employed in both cases the AC pumps proves to be much cost effective and reliable option.

4 CONCLUSIONS

Solar powered water pumping system for 1HP AC motor is developed successfully. Solar based AC water pumping inverters worked efficiently, and it is proved to be cost effective in comparision to DC pumps. 1.5KVA inverter is designed and installed successfully. Detailed performance of the system with varying solar radiations is monitored and tabulated. It was observed that pumping system operated effectively when solar radiation is above 750 W/m². Further, it is concluded that SPV powered AC water pumping system is much suitable for small scale agrcilture.

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