

Analog controller for Photovoltaic array fed inverter driven Single-phase induction motor

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Abstract

PV array is increasingly employed for water pumping system. In this project, a controller to vary the amplitude of the inverter output voltage interposed between the PV array and single phase induction motor is developed. The detailed modeling of the components of proposed scheme has been taken up. The developed controller varies the pulse-width of a SPWM generator, so that that the inverter output voltage varies with irradiation and temperature. The variation of the amplitude is to maximize the power output (speed) for a given irradiation and temperature. Experimental investigation presented gives the utility of such a control approach.

1. Introduction

As the sources of conventional energy are deteriorating fastly with a corresponding rise in cost, considerable attention is being paid to other alternative energy sources. It is well known that non-conventional energy sources are friendly to the environment, sustainable and are attractive alternatives in places where a connection to the utility network is either impossible or unduly expensive. Hence, there is an increasing interest in stand-alone generating systems based on renewable energy. Among them, solar energy which is free and abundant in most parts of the world has proven to be a challenging source of energy in many developing and developed countries. Photovoltaic (PV) technology which converts solar energy into electrical power has not found much favor because of its cost of installation. There has been, however a lot of research effort in recent years towards economic generation of PV power for houses, intermediate size industrial installations and the construction of large central power stations. One other application area where PV energy has been established is, in space applications where cost is secondary consideration. PV power systems range in size from watts to megawatts. They are the most modular of all electric power generating systems. In operation, these systems have the least environmental impact with no emissions, noise, or other potentially disturbing characteristics. A stand-alone PV system generally consists of a PV array, a storage component, control and power processing components. The PV array converts sunlight into dc power. The array is made up of inter-connected PV modules. The storage component (usually a group of batteries) stores the electrical energy for use when needed. The control components manage the operation of the systems. They may include a tracker to point the PV array towards the sun to improve energy collection. The power processor converts the dc output of PV array into the form needed by the user, in

addition it also operate the PV array at the peak power tracking (PPT). Small stand-alone systems provide electrical energy to power lights, signals, water-pumps, and many other small power applications.

PV pumps have recently received considerable attention due to major development in the field of solar cell material and technology. A number of 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 (IM) can be an attractive proposal where reliability and maintenance-free operations are important. Tracking the peak power from a PV array is usually an essential part of a PV system. As such, many peak power tracking (PPT) methods have been developed and implemented. The methods vary in complexity, sensors required, convergence speed, cost, range of effectiveness, implementation hardware, popularity and other aspects. However, operating PV array at PPT will not guarantee the operation of the IM at maximum efficiency. It was demonstrated in that minimum input power and maximum efficiency operation of an IM can be achieved with a characteristic optimum slip value. Most of the existing IM based systems employ two power converters for achieving PPT and maximum efficiency operation of Induction Motor. However, such systems require a minimum of seven power semiconductor switches leading to increased switching losses as one of the switch is operated at high switching frequency. This has led to development of an inverter stage (which employs four power semiconductor switches) fed IM based PV water pumping system

2. Proposed scheme

The schematic of the proposed system is shown in Fig 1. The block diagram of the proposed scheme is as shown in Fig1 the output variation of PV array in solar power technology depends on the temperature and intensity of a sunlight (radiation). The block diagram consists of main block like PV array, inverter unit, filter circuit, step transformer, SPWM technique used for pulse generation to IGBTs of the inverter output voltage (36) obtained from PV array is converted to ac 24v rms using 1-phase, 2-leg inverter. The ripples in the ac voltage obtained from inverter are minimized using LC filter circuit. The ripples free inverter output is stepped-up to 230v using step up transformer

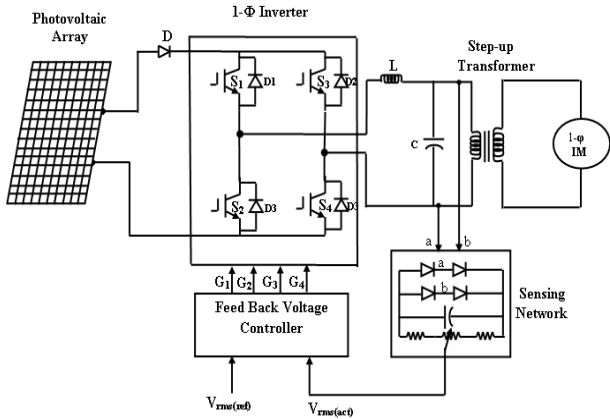


Fig.1. Block diagram of proposed scheme

This supply is given to drive the single-phase induction motor. For obtaining required induction motor performance suitable control circuit is designed by taking the output of the inverter and comparing with reference values using PI controller. The error output of PI controller is compared with sinusoidal wave to obtain pulses to IGBTs of inverter circuit using SPWM technique, thereby required speed of induction motor can be obtained even though there is variation in temperature and radiation parameter.

2.1. Control Circuit

The irradiation, a controller which will automatically vary the widths of the pulses is necessary to obtain a constant amplitude ac supply. A feedback controller is attempted to vary the pulse-widths of the inverter output voltage waveform until actual rms value and set rms value of the inverter output voltage are in conformity. The amplitude of the reference sine-wave is employed for generating the triggering pulses (by comparison with a fixed triangular wave) is altered by a DC voltage obtained from the PI controller; RMS load voltage is fed back to the controller instead of instantaneous values. Further, the design of such a controller using classical techniques like (Zeigler Nicholes) is easier with DC quantities (rms values) as compared to a sine wave.

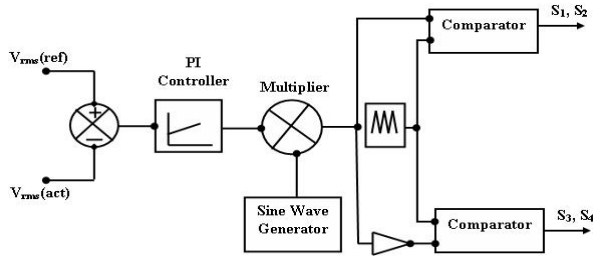


Fig.2. Schematic of the Controller

The block diagram of the controller is shown in Fig 2. The deviation from the set-value is given to the PI controller and the output of the PI block in turn varies the amplitude of the reference sine wave of the SPWM controller. This varying amplitude sine wave reference is then compared with a triangular wave to generate the required firing pulses for the inverter. The detailed operation of the controller is given in

Section 2.2.

2.2. Development of the Controller

As the inverter input dc voltage varies with irradiation, to obtain supply from the inverter, a feed-back controller mentioned in below.

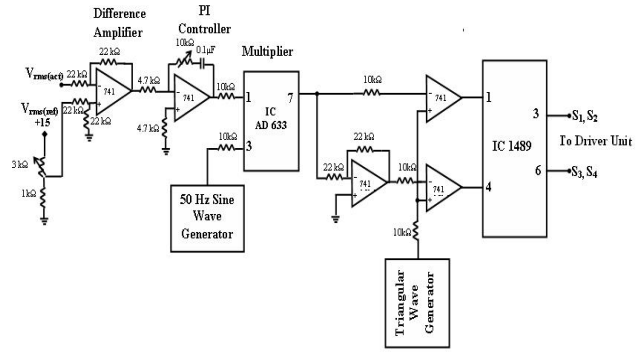


Fig.3. Analog control circuit

The controller consists of four stages as shown in Fig 3. The first stage and the last stage of the control loop are difference amplifiers. The feed-back voltage is derived as $V_{rms}(act)$ from a calibrated transducer connected at the output of the inverter. The set voltage $V_{rms}(ref)$ which represents the desired constant ac voltage at the output of the inverter and feedback voltage $V_{rms}(act)$ are given as inputs to the difference amplifier of the first stage, the output of which is given as input to the proportional-integral (PI) stage, with K_p and K_i as the gain of the proportional and integral controller stage. Which gives an output voltage corresponding to the sum of the proportional and integral signals. The fourth stage multiplies the output of the summer with a fixed sine wave reference to get the control signal $v_c(t)$ as the output. Hence,

$$v_c(t) = [(K_p(V_{rms}(ref) - V_{rms}) + K_i \int (V_{rms}(ref) - V_{rms}) dt)] (K_v \sin \omega t)$$

$$V_c(t) = A_c \sin \omega t \quad (1)$$

where,

$$A_c = [(K_p(V_{rms}(ref) - V_{rms}) + K_i \int (V_{rms}(ref) - V_{rms}) dt)] * K_v$$

$$\text{Modulation Index } M \text{ is defined as } M = \frac{A_c}{K} \quad (2)$$

and K is the magnitude of the triangular signal. The value of K_v is set as equal to 1 Volt. The inverter output voltage is varied by varying the modulation index by means of controlling the modulating signal (A_c). The control voltage $v_c(t)$ is then modulated with a triangular wave to generate the SPWM pulses for the inverter. A frequency of 1 kHz is selected for the triangular wave so that in a cycle of 50 Hz, 10 pulses will be present in a half-cycle.

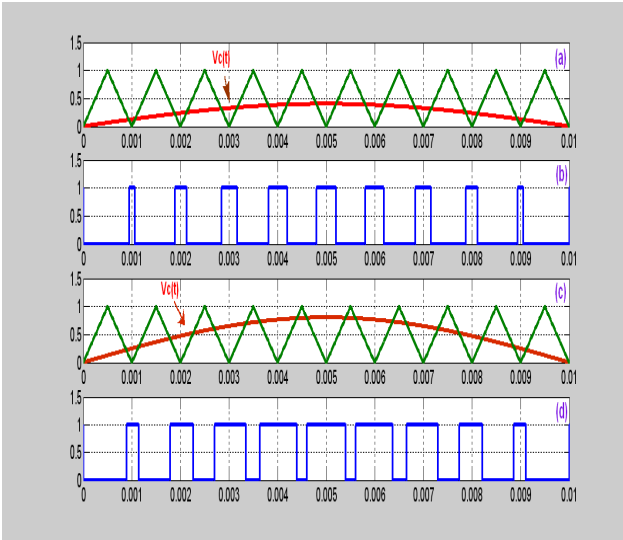


Fig 4: Waveform of the feed-back controller
 (a) Comparison of triangular wave with $v_c(t)$, for a modulation index of 0.4 (b) Trigger pulses for modulation index of 0.4 (c) Comparison of triangular wave with $v_c(t)$ for a modulation index of 0.8 (d) Trigger pulses for modulation index of 0.8.

Fig 6 (a) and (c) shows the two inputs to the comparator together. The corresponding outputs of the comparator which are a train of pulses are shown in Fig 4 (b) and (d). From equation (11), it is seen that the reference sine wave amplitude increases as the output of the summer increases and vice-versa. An increase in $v_c(t)$ will increase the width of the pulses and hence the rms voltage at the output of the inverter and similarly a decrease in $v_c(t)$ will decrease the output voltage. A square wave of 50 Hz from an astable multivibrator is used to gate the pulses to the respective pair of IGBTs in the inverter. For example, during the on-time of the astable multivibrator, IGBTs S_1 and S_2 are fired and during the off-time, the other pair S_3 and S_4 is fired. This results in constant frequency supply at the output of the inverter.

3. Experimental investigations

The laboratory prototype was constructed using a PV array (2 panels connected in series each rated for 80W, 18.5V, 4.2A). The proposed scheme is tested with R load, RL load and motor load (single-phase permanent capacitor induction motor). The rating of the motor is 80W, 230V, 1500 rpm. A single-phase IGBT inverter was fabricated and an analog circuit based- firing scheme described in Section.3.2 is used to trigger the IGBTs in unidirectional switching mode of operation. The PV array voltage is tied to the input of the inverter. The control signal for the inverter is generated by using analog circuit. The feed-back voltage controller is constructed using low cost analog components like IC 741, IC 1489, HCPL 3010 and IC AD633. A reference DC voltage is given to the controller and is compared using IC 741 with the actual rms load voltage. The error signal is processed by a simple classical PI controller using another IC 741 with its associate components. The controller gives a controlled DC signal for further processing. A 50Hz sinusoidal signal is generated by using IC 741, and this signal multiplied with the DC signal by using multiplier circuit (IC AD 633). The output of IC AD633 is the modulating signal. The modulating signal decides the output voltage of the inverter and its magnitude is based on the error signal generated by the

differential amplifier. A triangular wave of 1 kHz is generated by using IC741. The modulating signal is compared with the triangular signal to generate the required unidirectional SPWM pulses.

The inverter output fed to a 24/230 V transformer through LC filter for driving an 80 W induction motor. The Fig.6. shows the generation of gate pulse for the pair of IGBT's S_1, S_3 and S_2, S_4 . The load voltage waveform for R load is shown in Fig 7. The experimental load voltage and load current waveforms for RL and motor load are shown in Fig 8 (a, b) and 9 (a, b). The resistance is 10Ω and the inductance is 9mH for the RL load. The Fig8 shows the variation of PV output power, which is observed from morning to evening in the month April. The change in irradiation causes change in short circuit current, which is an indication of the peak power of the PV array, is shown in Fig.11 This Fig shows that a change in irradiation causes a corresponding change in speed of the motor, thereby drawing maximum power output from the PV array.

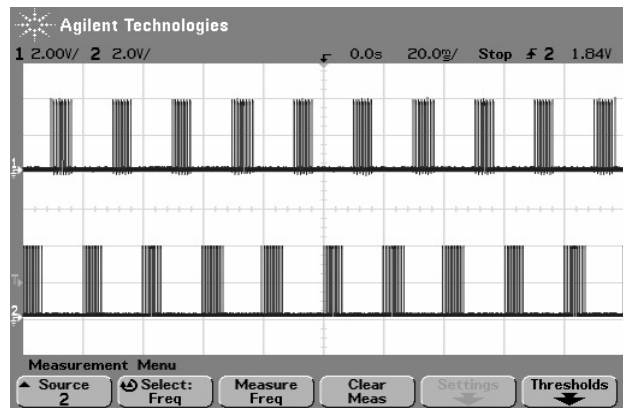


Fig6: Gate Pulse for IGBT
 (a) Gate pulse for IGBT S_1, S_3
 (b) Gate pulse for IGBT S_2, S_4

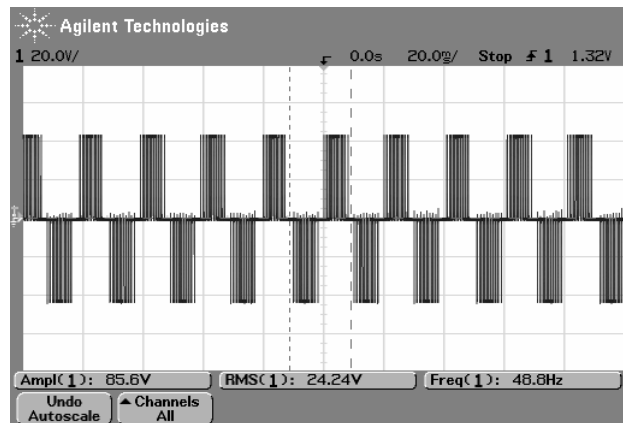


Fig 7: Load Voltage Waveform –R Load
 (Irradiation at 3 Amps)

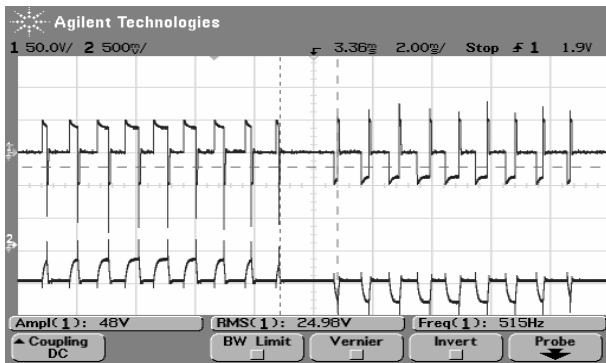


Fig 8: Load Voltage and Load Current Waveform RL Load
 (a) Load voltage waveform (2 ms/div; 50 V/div)
 (b) Load current waveform (2 ms/div; 5 A/div)

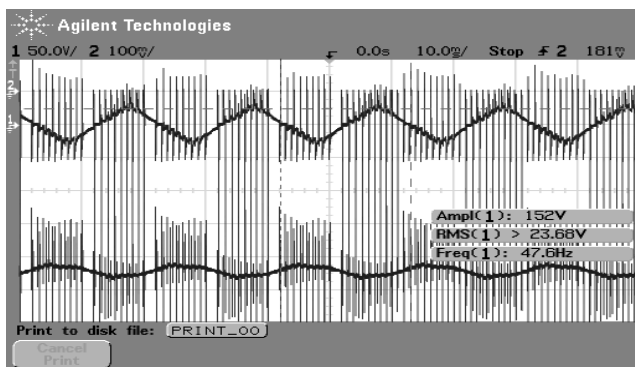


Fig 9: Load Voltage Waveform –Motor Load
 (a) Load voltage waveform (5 ms/div; 50 V/div)
 (b) Load current waveform (5 ms/div; 5 A/div)

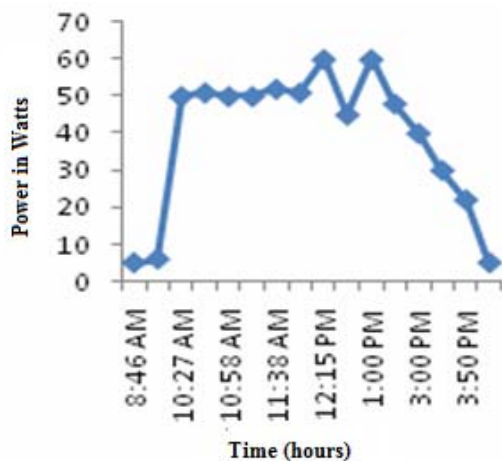


Fig 10: Change in irradiation with change in output Power

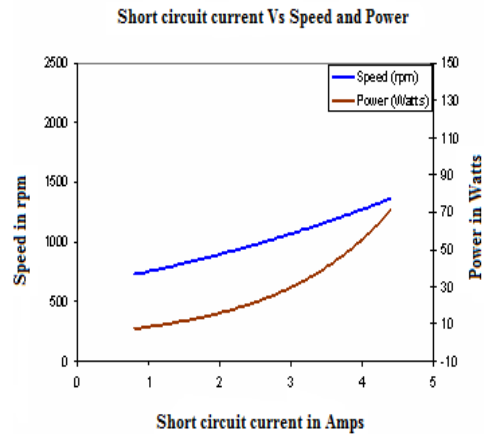


Fig11: Change in irradiation with change in output Power and change in speed

4. Conclusions

The system described here is a PV system for water pumping, employing a single phase SPWM inverter and single-phase induction motor. The variable-modulation index of the inverter serves as the peak-power tracking element. The controller is set to change its modulation index with changing irradiation conditions. The proposed scheme is thus successfully used to track the peak power of PV fed inverter driven single phase induction motor. The closed loop feed-back PI controller was developed for extracting the peak power from the PV source by varying the pulse-width of the SPWM based IGBT inverter. The experimental results on a laboratory test-rig are presented to validate our control strategy. The control technique is easy to implement economically with analog components.

5. References

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