DESIGN AND IMPLEMENTATION OF A MICROPROCESSOR – BASED INVERTER WITH MAXIMUM POWER POINT TRACKING FOR PHOTOVOLTAIC APPLICATIONS

BY

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ABSTRACT

This paper presents the design and implementation of a microprocessor-based inverter for maximum power point tracker for photovoltaic applications. Photovoltaic module is characterized with unstable output power, which varies with different environmental conditions. . The inverter is controlled by a microprocessor via the MPPT program. The microprocessor-based inverter with maximum power point tracker is made up of a PV module, Analog-to-Digital converter (ADC), microcontroller, frequency divider, buffer inverter, power inverter circuit and power regulator. A fairly constant output voltage (V_o) and current (I_o) was realized throughout the daytime as presented in the results.

SIGNIFICANCE

The maximum power point tracker (MPPT) is employed to correct for variations of photovoltaic (PV) output voltage and current, which varies in accordance to solar radiation, temperature of the PV array and electrical load conditions.

Keywords: Photovoltaic, MPPT, Inverter, Microprocessor, switching frequency

1. INTRODUCTION

Photovoltaic arrays are used to provide energy. However, this energy varies in accordance with solar radiation, temperature of the PV array, consistency of cell quality and the electrical load conditions (Oparaku. 2000). Thus, maximum power point trackers are used to correct for these variations. The maximum power point tracker maximizes the energy that can be transferred from the photovoltaic array to an electrical system. This can be achieved by either controlling the operating voltage or current of the PV array (Nathan et al. 1998).

Current designs of maximum power point tracker consist of three basic components i.e. switch mode converter, a control and tracking unit, and an auxiliary power supply. Most switch mode converter have output voltage limiting such that when load is disconnected, output voltage will rise without bound, leading to the destruction of the power unit. In the past, the auxiliary power supply is characterized by loading of the PV array under early morning sun. When the auxiliary supply would try to start, it would draw excessive current and the array voltage would drop too low repeatedly leading to self-destructive oscillation. Other common problems include destruction of output power stages as a result of overvoltage, unreliable starting in the morning, lack of telemetry data directly from the tracker, inefficient operation and unreliability in a rugged environment. For the past years many researches have focused on various MPP control algorithms to obtain maximum power of the PV array. Notable methods includes Charge controller method, Constant voltage (CV) method, Perturbation and Observation (P$O) method and the Incremental conductance (Income) method (Yu et al. 1999).

In this paper, microprocessor-based inverter with maximum power point tracker for photovoltaic is developed. The microprocessor-based inverter with maximum power point tracker is made up of a PV module, Analog-to-Digital converter (ADC), microcontroller, frequency divider, buffer inverter, and power inverter circuit and power regulator. The PV module voltage is monitored and the appropriate switching frequency of the inverter is utilized to provide constant inverter output voltage.

2. MAXIMUM POWER POINT TRACKER

Figure 1 shows the simulated current-voltage characteristics for a silicon type PV cell at different insolation levels. It is seen that as the output potential of the string (cells connected together) rises, the string will produce a significantly small current. Hence the current-voltage curve will change depending on temperature, illumination (insolation) and consistency of the cell quality in the string (Nathan et al. 1998, Reinji et al. 2000). This shown by Reinji et al. (2000) in equations (1), (2) and (3).

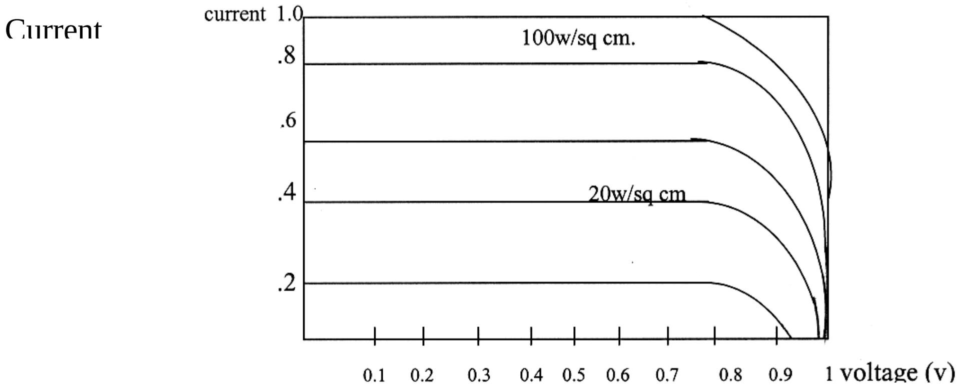

Figure 1: PV voltage-current characteristics

$$I_0 = I_g - I_{sat}\{\exp[q(V_0 - I_0 R_s)/AKT] - 1\}V_0 / R_{sh} \quad \ldots \quad (1)$$

$$I_{sat} = I_{0r}[T/T_r]^3 \exp\{qE_{g0}/KT(1/T_r - 1/T)\} \quad \ldots \quad (2)$$

$$I_g = [I_{sc} + K_L(T - T_r)]\lambda/100 \quad \ldots \quad (3)$$

Where V_0 and I_0 are output voltage and current respectively of the PV. I_g is the generated current under a given insolation, T is the temperature, K_L is the short-circuit temperature coefficient, K is the Boltmans constant, A is the arbitrary curve fitting constant, I_{sat} is the saturation current of the p-n junction, T_r is the temperature and λ is the solar insolation.

Therefore, from figure 1 and equations 1-3, power transfer is never maximum at all times. A process is then necessary to remedy this defect associated with photovoltaic; this process is called Maximum Power Point Tracking (MPPT) and must be incorporated into the inverter in order to obtain, at least 90% inverter efficiency.

As earlier stated, since the Maximum Power Point (MPP) of PV power generation depends on array temperature and solar irradiation, it is necessary to track MPP of PV array all the time

3. SYSTEM DESIGN AND IMPLEMENTATION

The design and implementation procedure will be considered from two perspectives, vis-à-vis; hardware and software. Figure 2 shows the block diagram of the inverter with MPPT. It is made up of a PV module, Analog-to-Digital converter (ADC), microcontroller, frequency divider, buffer inverter, power inverter circuit and power regulator.

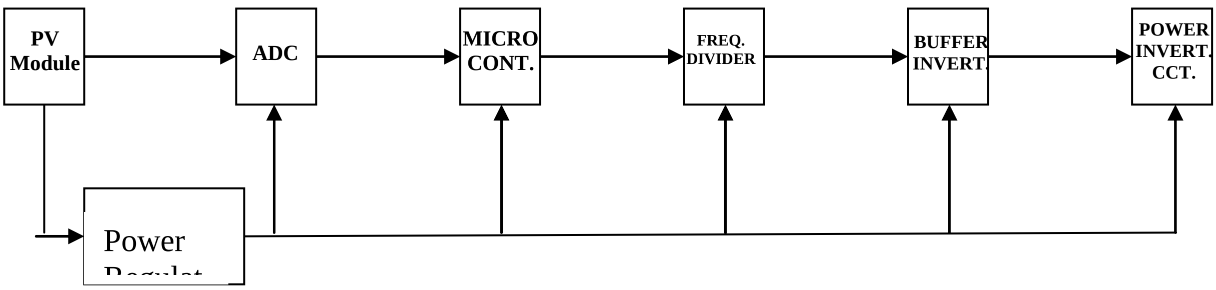

Figure 2: Inverter with MPPT

3.1 Hardware

3.1.1 PV array

The PV cell is the power element of the PV system. These cells are held together by a stainless steel or aluminum frame to form an electrical module. For this work, the available PV module is that manufactured by Solarex incorporated named MOX40. It has the following specifications; V_{oc}=20.5V, I_{sc} =2.45A, P_{noct} =25.2W, I_{noct} =2.22A, V_{noct} = 15.5V. P_{nom}=38.6wp at stc and P_{min} =37.5wp at 100mw/cm^2

3.1.2 Analog- to- Digital Converter

Analog- to- Digital Converter converts from analog to digital form. ADC interprets the PV module's information to the microcontroller. The ADC0804 is utilized. It is a CMOS 8-bit successive approximation converter which uses a modified potentiometer ladder and are designed to operate with 8080A control bus via a three state output (Intersil American's incorporated, 2002). Figure 3 shows the interconnection of the ADC unit. The WR signal is provided from an astable circuit designed to produce a pulse a every one second, thus sample time is 1second.

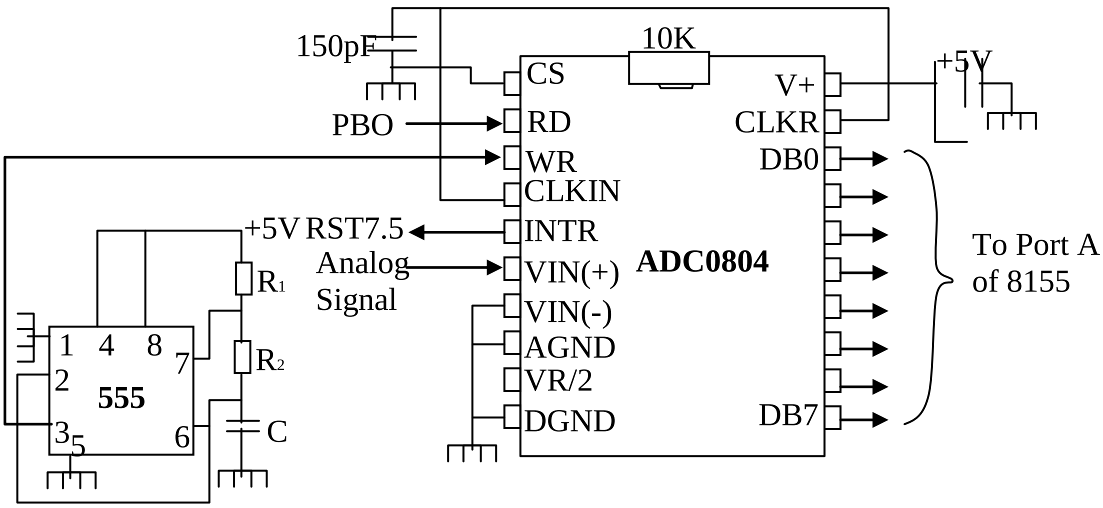

Figure 3: ADC unit circuit implementation

3.1.3 Microcontroller

The microcontroller unit is responsible for the entire control process of the system. It comprises of a microprocessor, RAM, decoder, latch and an EPROM. The 8085A microprocessor is utilized. The used interrupt, applied to INTA of ADC, is the RST7.5 interrupt. This interrupt is activated by a transition in the INTA (pin 5) of the ADC. Furthermore, this interrupt is maskable through the use of the SIM instruction. They are enabled using the EI and disabled using DI. Figure 4 shows the connection of the microcontroller circuit.

The 8155 RAM is utilized. It has I/O port that can be programmed to be an input or output port, a 14-bit programmable Timer/Counter on chip to provide either a square wave or a pulse wave, depending upon the mode to which it is set. The output count length that can be loaded into the Timer/Counter is from 0002H to 3FFFH (Howard, 1987). In this design, the switching is generated in the microcontroller via the TIMER-OUT (pin 6) of the 8155 RAM. Bits 6 & 7 of the command register are set to 11 to allow for restarting and continuous frequency variation. Continuous square wave is desired, hence, 01 is loaded into the Timer mode. Port A is configured for input and Port B for output. The timer loading is given by Gaonkar (1985)

$$Timer\ loading = \frac{Microprocessor\ crystal\ oscillator\ \ frequency * 0.5}{Desiref\ \ \ switching\ \ \ frequency} \quad \dots \qquad (4)$$

It is implemented as shown in figure 4.

The EPROM utilized is the M2732. It is responsible for holding the control program. The EPROM is in programming mode when pin V_{pp} is at 21V. The 8-bit data to be programmed is applied to the data output pins. Before the EPROM's programming, the following connections were made;
The EPROM's output data buses were connected to the address-data bus of the 8085 microprocessor on the SDK-85 kit. The address buses of the EPROM were connected to the address bus of the latch on the SDK-85 kit. An opto-coupler was used to connect pin V_{pp} to 21V supply. A 0.1μF capacitor was placed across pin V_{pp} and ground to suppress spurious voltage transients. Then the program was written onto the SDK-85 memory following the number lines. The program was then executed when the opto-coupler was operated to switch pin V_{pp} at 21V. At the end of the program execution, pin V_{pp} was connected to ground. The EPROM was put in verification mode to check for the program written onto it. Its implementation is shown in figure 4.
The Address decoder is saddled with the responsibility of selecting a device for interaction with the microprocessor. The 74LS138 is the chip chosen to provide this selection. It is a 3-line to 8-line decoder. Address A_{11}, A_{12} and A_{13} are for selection, while A_{14} and A_{15} are for enabling. The first output Y_0 selects the EPROM (CS_0) and the second output, Y_1 selects the static RAM (8155). It is implemented as shown in figure 4.
The latch unit attaches information to the data bus. The 74LS373 is used to provide this function. It is a transparent octal 'D' latch with three state output. It is implemented as shown in figure 4.

3.1.4 Frequency Divider
The frequency divider section is incorporated to make for accuracy, precision and void of irregularities on the switching signal. The decade counter implemented to divide the output of the microcontroller by ten (10) is the 7490 chip.

3.1.5 Buffer Inverter
The power switching circuit is of two levels, upper and lower. These are to be switched alternatively, that is, 180 ^{o} out of phase. Therefore there is the need to split the frequency divider output signal into two. The Hex buffer inverter provides this splitting through 74S04 chip.

3.1.6 Power Inverter
The power inverter circuit has a DC driver circuit, the switching circuit and the transformer. The driver circuit is tasked with the duty of providing excitation to another circuit while also providing isolation between control and power supply. The chip that provides the isolation is the Opto-coupler (4N25). Figure 5 shows the implementation of the power inverter circuit. The 100Ω resistors are used as limiters. The switching circuit presents to the input of a transformer a DC that is sampled at a particular frequency. This unit is built around MOSFET (Metal Oxide Semiconductor Field Effect Transistor) as shown in figure 5.

3.1.7 Power Regulator
The transformer unit transforms the sampled signal at its input into a useful AC voltage (230V). A center-tapped transformer is utilized, the DC (from the PV module) to be inverted is connected to the center tap. All units are connected to the power regulator unit for their V_{cc} (+5V). A voltage regulator, LA1605, provides this. Its source is from the PV module, connected to its pin 1and its output, pin 2 supplies the +5V.

3.2 Software
A program is a set of instructions to be followed in carrying out a task. The method of MPPT implemented in this design is the Perturbation & Observation method, where the observed parameter is the PV DC output voltage and the perturbed parameter is the frequency of the switching signal. The design requirement is to ensure that the output voltage of the inverter is maintained constant.
The control algorithm is illustrated in the following steps:

- Step 1 Initialize the Port/Stack Pointer.
- Step 2 Enable RST 7.5 Interrupt
- Step 3 Wait
- Step 4 Interrupt Service Routine
- Step 5 Input data from Port A
- Step 6 Compare data with set value
- Step 7 If zero, load frequency to Timer and switch power inverter at that frequency
- Step 8 If not zero, compare again with next set value
- Step 9 Compare with other all set values
- Step 10 If not zero, compare with all average set values (AVS) and load Timer with appropriate frequency
- Step 11 Goto Step 3

The control program is written in Assembly language. It occupied about 460 bytes location.

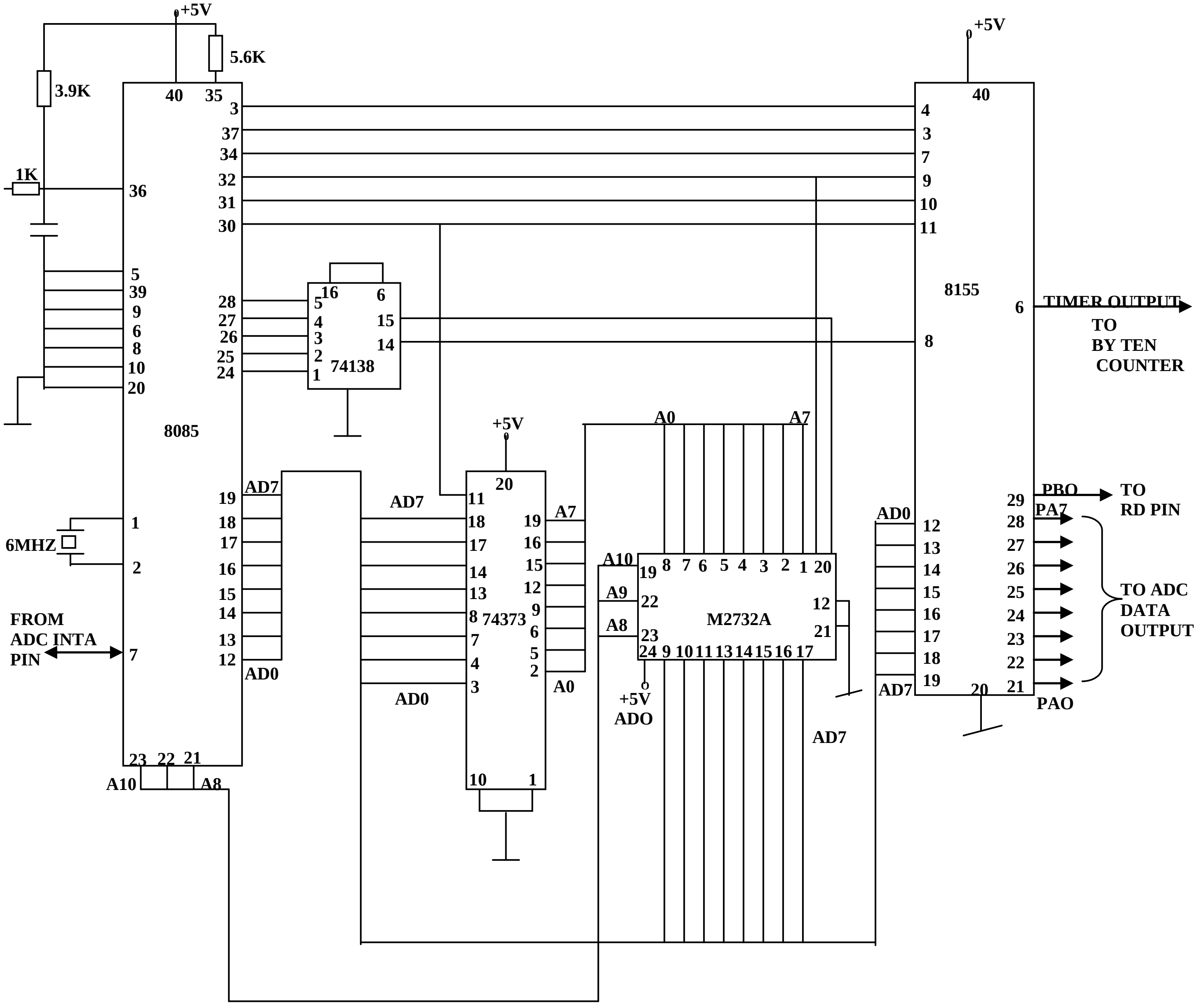

Figure 4: Microcontroller circuit implementation

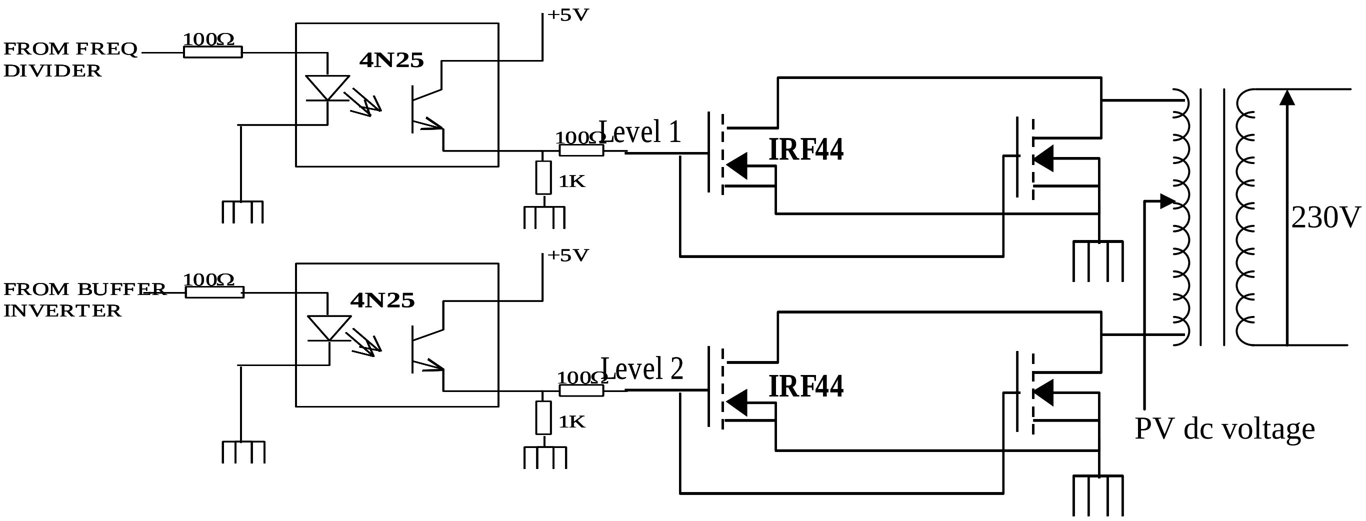

Figure 5: Power inverter circuit implementation

4. TEST, RESULT AND DISCUSSION

The input analog voltage was varied at an interval of 0.1V, while the output AC voltage and current under load condition were measured and the power calculated. The DC voltage variation was plotted against the output power of the inverter as shown in figure 6.

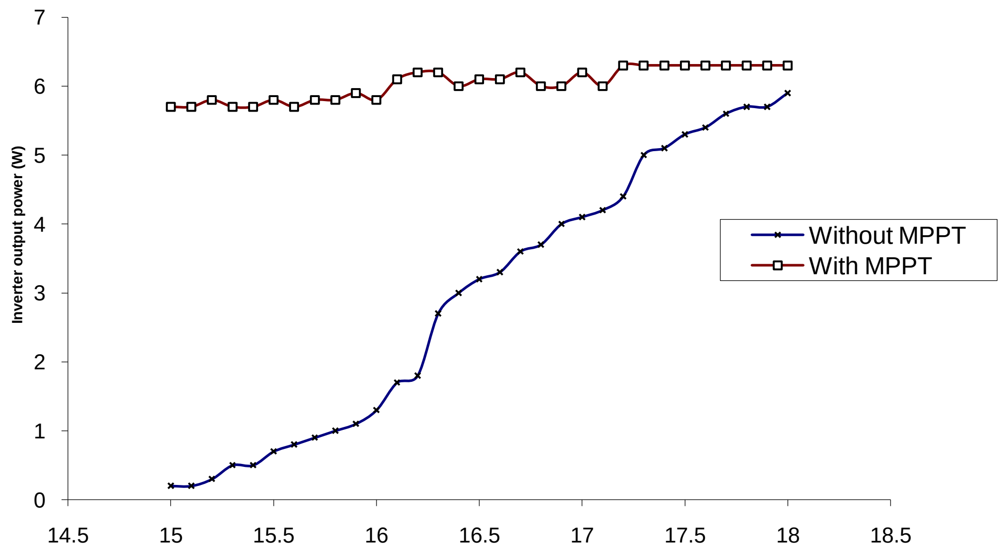

Figure 6:PV DC variation with inverter output power

Figure 6 shows two cases, i.e. when inverter was switched at 50Hz (without MPPT) and when switched with the MPPT control program (with MPPT). From figure 6, it is seen that without MPPT, inverter output power varied sharply with panel voltage. However, with MPPT, a fairly constant output power is maintained.

Figure 7 shows the plot of the inverter output voltage (Vo) against time of the day. Much variation is noticed in the case without MPPT. The case with MPPT has a fairly constant output AC voltage, which is the design requirement.

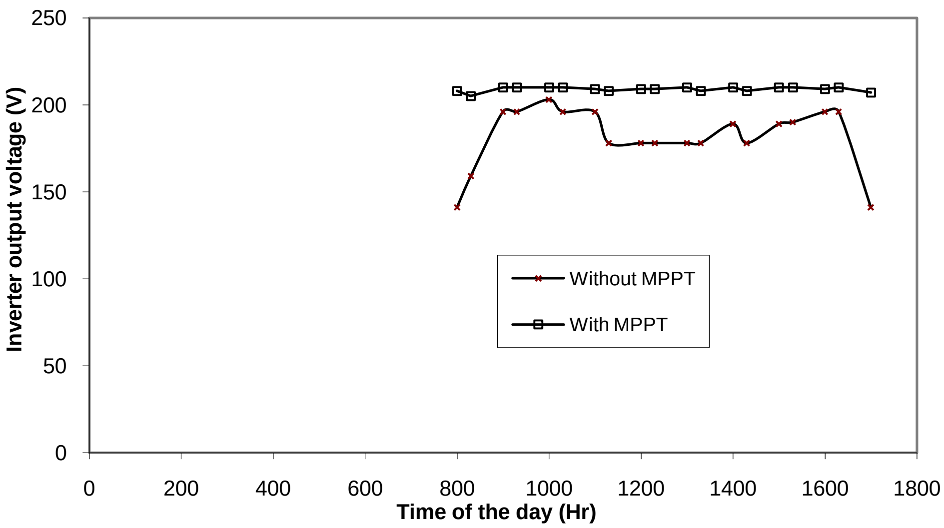

Figure7:Inverter output voltage vs time of the day

The plot of inverter output current (Io) against time is shown in figure 8. With MPPT, output current is seen to be fairly constant reaching a maximum of 30.1mA. This gives a better response than without MPPT.

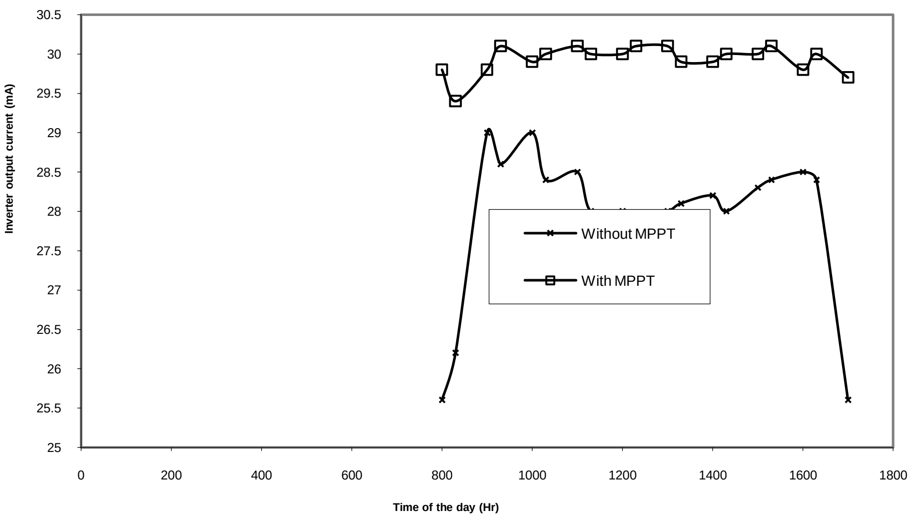

Figure 8:Inverter output current vs time of the day

5. CONCLUSION

This paper developed a microprocessor-based inverter with maximum power point tracker for photovoltaic applications. The developed algorithm has been tested and results obtained are satisfactory. The objective of MPPT is to ensure that maximum power transfer is maintained irrespective of the environmental condition throughout the daytime.

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