Digitally Controlled Converter with an Adaptive Step Size for Maximum Power Point Tracking for Photovoltaic Applications.

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***Abstract*-Maximum power point trackers (MPPTs) are required to ensure optimum utilization of photovoltaic (PV) arrays in renewable energy systems, both as stand-alone and as supplementary sources of energy. In this paper, a MPPT algorithm is presented based on the perturb and observe (P & O) approach, implemented with an adaptive perturbation step size to allow fast convergence to the required operating point.**

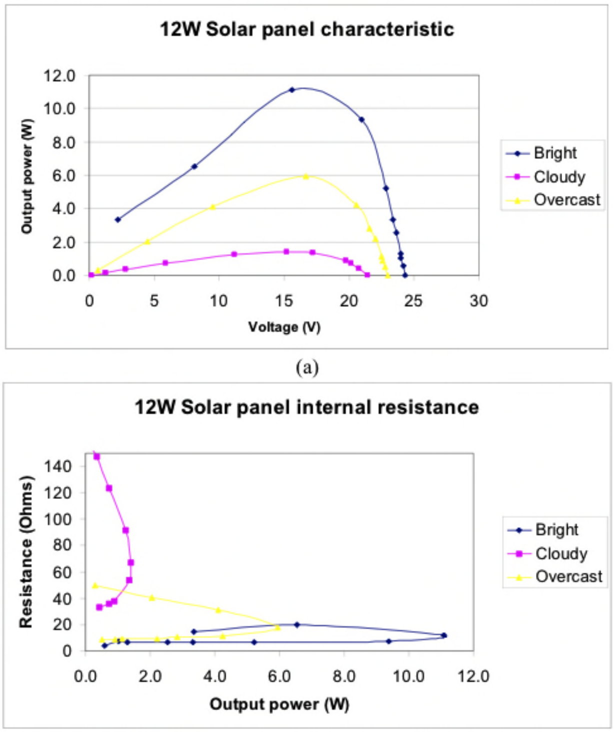
I. INTRODUCTION

Increasingly, photovoltaic (PV) cells and arrays are being used as a supplimentary source of energy, allowing electricity to be generated with little impact on the environment in terms of carbon emissions. However, the energy available from such devices is not constant, being dependant on insolation intensity, temperature and aging of the PV array.

Fig. 1 shows experimental measurements from a typical 12W (nominal) PV panel used for charging a lead-acid battery in small scale PV applications. The output power vs voltage curve being typical for all PV arrays, and shows a maximum power point (MPP) at which the power available from the panel is a maximum. The MPP value is dependant on temperature and insolation intensity. To achieve maximum efficiency from the system, the PV panel must be operated at the MPP with the use of conditioning power electronics to ensure a match between the panel and the battery being charged.

Many methods for MPPT are currently being researched [1], including operating at a simple percentage of the open circuit voltage of the PV cell, the use of incremental conductance of the PV cell [2], and the perturb and observe (P & O) algorithms based on fuzzy logic controllers [3]. However the use of a constant perturbation (step) size in these methods can lead to excessive 'lock' times in which the system locks on to the MPP of the PV array, which is a problem in these applications given that insolation levels are dynamic with respect to environmental conditions. Other methods, relying on single sensors for example, have also been reported [4..7] that trade-off the number of sensors for processing power within the system. Faster convergence with the MPPT has also been reported in systems that switch between two tracking algorithms to give either fast tracking or accurate tracking [8].

In this paper a MPPT system is presented based on a boost converter fed from a 12W (nominal) PV panel, charging 2 series connected 45Ah sealed Lead-acid batteries. The PV is characterized in fig. 1. The converter, fig. 2, is controlled by a basic Microchip PIC microcontroller (18F258), which monitors the input voltage and current for MPPT control, together with the output voltage for charging control and battery management. The measured parameters, together with the power being drawn from the PV panel, are passed to an RS232 communications port, shown on the left in fig. 3, at 1 second intervals for external data logging as required.



(a)

(b)

Fig. 1. Characteristics of the 12W photovoltaic panel used for the prototype system, highlighting typical characteristics of photovoltaic panels.

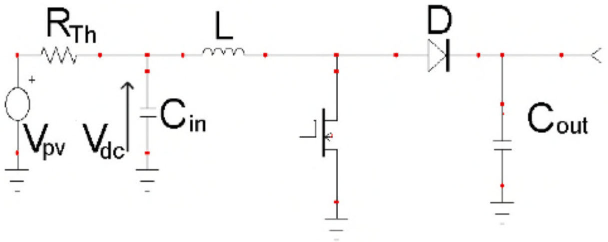


Fig. 2. Circuit diagram for the power stage of the converter showing the Thevenin voltage source and series resistance at the input, and the boost converter power stage..

II. MPPT TRACKING

The MPPT algorithm employed by the described converter is based on a P & O approach, with the step size being dependant on the gradient of the power (P) / voltage (V_{pv}) curve at the observation.

Conventionally with P & O methods,

$$\frac{dP}{dV_{pv}}(n)=\frac{P(n)-P(n-1)}{V_{pv}(n)-V_{pv}(n-1)} \tag{1}$$

with

$$\frac{dP}{dV_{pv}}(n)>0 \tag{2}$$

requiring an increase in the duty cycle of the switch of a fixed step, whereas

$$\frac{dP}{dV_{pv}}(n)<0 \tag{3}$$

leads to the duty cycle of the converter being decreased by the same step. The case where the gradient is zero being the MPP of the PV panel. The use of a fixed increment size tends to lead to slow acquisition of the MPP for the PV panel.

In the prototype system described, the size of the perturbation step is made proportional to the gradient of the power / voltage characteristic at the previous sample, with limits being placed on the maximum and minimum step sizes to ensure correct operation.

The size of the perturbation step has an influence on the speed with which the converter converges to the MPPT, and also, the oscillation about the MPPT. Large step sizes intrinsically lead to fast convergence to the MPPT, however large oscillations about the ideal operating point are also produced, small step sizes give the opposite effect. Here, the step in the demanded current from the photovoltaic array is made proportional to the gradient of the power / voltage characteristic using (4).

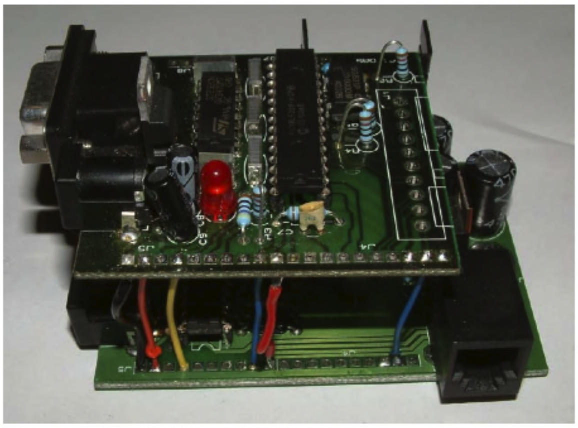


Fig. 3. Microchip PIC controlled converter.

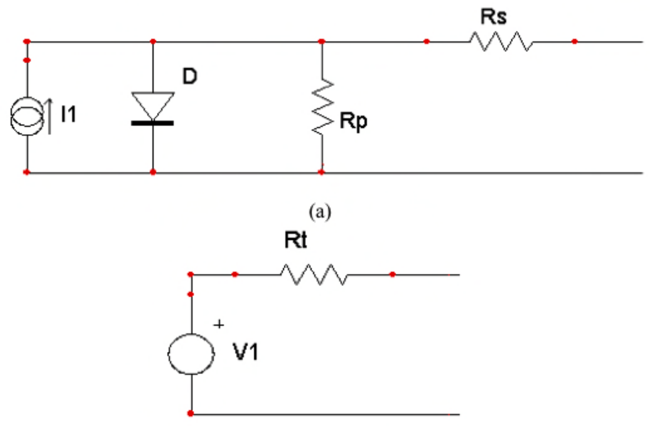
$$\Delta I_{pv}(n)=k_p.\frac{dP}{dV_{pv}}(n) \tag{4}$$

In this way, once the MPPT has been found, the gradient will be shallow and the perturbation current step small. When a transient change in the insolation occurs, the gradient will be larger, and hence a larger perturbation step size will be used to ensure rapid lock onto the new MPPT.

III. PRACTICAL IMPLEMENTATION

The practical system is built around a microchip 18F258 device, measuring the photovoltaic current (I_{pv}) via a low value series resistance. The system is designed to report input current, input voltage and power to the RS232 port for data logging. The system also monitors the output voltage to prevent overcharging the two series connected 45Ah sealed lead acid batteries on the output acting the energy storage. Whilst it is widely recognized that the equivalent circuit of a photovoltaic array is given in fig. 4(a), initial testing of the practical system was carried out by simulating the PV panel by a Thevenin equivalent circuit fig. 4(b) as this circuit is simpler to implement, and provides a maximum power point to track. The test circuit comprise a voltage source and a series resistance, the values for the Thevenin series resistances (R_t =11.4Ω and 47Ω) being obtained from Fig 1b, as close approximations to the PV internal resistance under bright or shaded conditions. (The maximum power curves for this equivalent circuit being shown in Fig. 5. The four curves are for open circuit voltages of 22V and 25V, together with the two series resistances above).

Figs. 1 & 5 clearly illustrate that the slope of the curves near the maximum power point is shallow, especially at high internal impedances. As an example of this, the intersections of the curves with the horizontal lines on figure 5 (representing a 1% drop in the peak power value) show the permitted spread in input voltage which would give an output power within 1% of the peak. A consequence of this shallow gradient in the power characteristics is the ‘hunting’ of the dc link voltage (V_{dc}) of the system around the maximum power point, shown in figs. 6 (a) and (b). Subsequent to the initial



(a)

(b)

Fig. 4. Equivalent circuit of a photovoltaic cell (a), and Thevenin equivalent circuit (b).

transient when powering the system up (at t=2 sec), fig. 6 shows the system operation from a 25V Thevenin source, the internal resistance of which is initially 47Ω. The internal resistance is reduced to 11.4Ω at t=800s and returned to 47Ω at t=1050s, these times being illustrated by vertical lines on fig. 6a. Fig 6b, shows an expanded timescale of between 5 and 6.5 seconds, allowing the system 'hunting' action to be clearly seen about the maximum power point. This is also evident in fig. 7, where the maximum theoretical power is plotted for each condition, together with the power drawn by the prototype from the test system. The algorithm can be seen to converge to the maximum power on the lowest curve from the higher voltage at system start-up, and then oscillate around the maximum power point on the curve until the series resistance is switched to a lower value. At this value, the algorithm then tracks the MPP on the upper curve until returning to the lower curve when the series resistance is increased again.

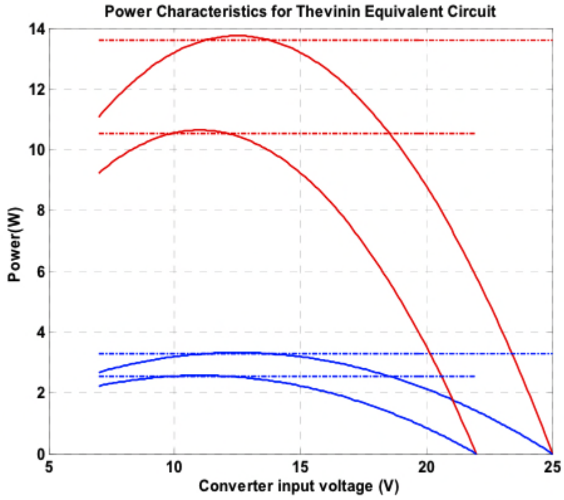
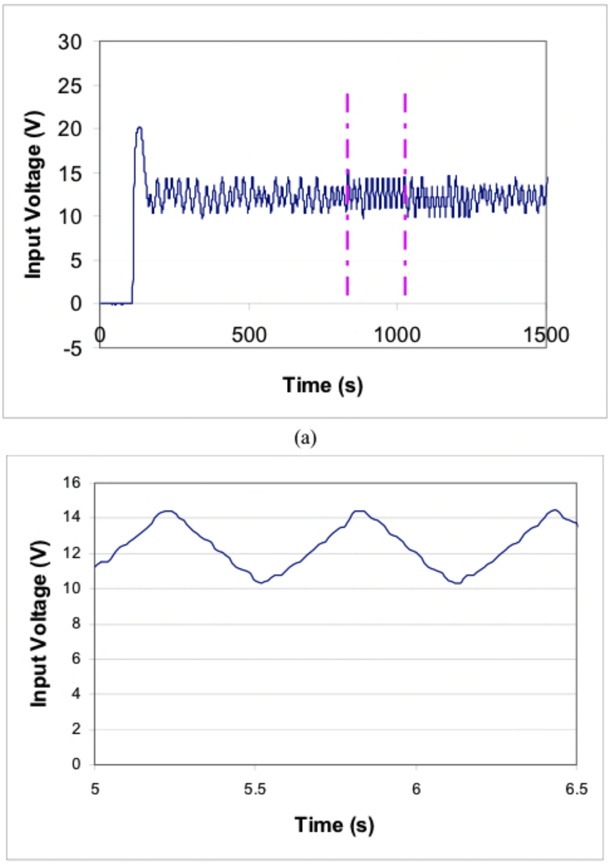


Fig. 5. Output power characteristics for Thevenin equivalent circuit the photovoltaic cell, showing the shallow maximum power area. The lines show the possible spread in input voltage for a 1% reduction in power drawn.



(a)

(b)

Fig. 6. Converter input voltage showing variation in voltage about maximum power point for converter, full time sweep and extended timescale.

The system transient response in tracking the maximum power point under transient changes in internal resistance and open circuit voltage can also be seen in fig. 8. Here, the system is powered up at t=2 seconds, with an open circuit voltage of 25V and an internal series resistance of 47Ω. At t=8 seconds the internal resistance is changed to 11.4Ω, the open circuit (input) voltage being reduced to 20V and then

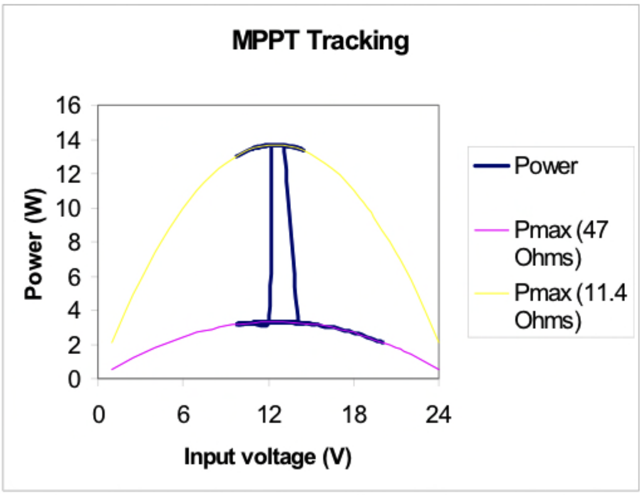


Fig. 7. Practical tracking of the MPPT under transient conditions.

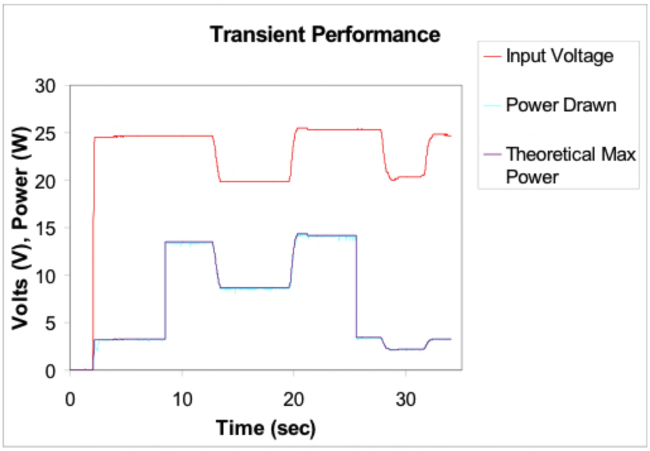


Fig. 8. Transient performance of the MPPT system on test

raised back to 25V before the series resistance is switched back to 47Ω. A further change in open circuit voltage is tracked at the higher series resistance. The figure clearly shows the accuracy of the system in tracking the theoretical maximum power that can be supplied by the source. Figure 9 shows practical data from the system operating on an actual solar panel on a typical cloudy day in the UK. Various small breaks in the cloud permit higher powers to be drawn than the low average.

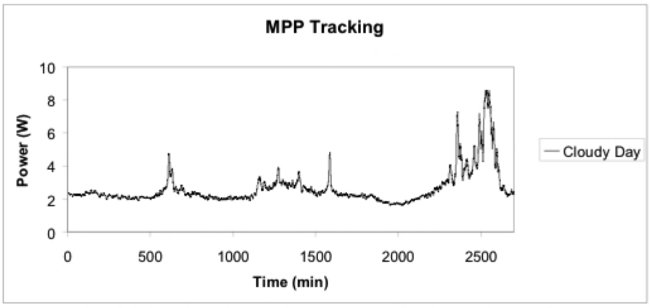


Fig. 9. Tracking the MPP on a solar panel on a cloudy day.

IV. CONCLUSIONS

The paper presents a digital MPPT converter based on a low-cost microchip PIC device.

The system is capable of rapidly locking in to the MPP for a photovoltaic panel, and is tracking the MPP under dynamic conditions employing an adaptive perturbation step size in the P & O algorithm. Results have been presented showing the system operation on a simple equivalent circuit of the panel, and further results showing the system operation on the actual panel has been included.

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