Microcontroller Based MPPT Photovoltaic System under Partial Shading Conditions Using Particle Swarm Optimization Algorithm

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Abstract

This Paper presents Maximum Power Point Tracking (MPPT) of Photovoltaic Array under partial shading condition. The power available at the output of photovoltaic cells keeps changing with solar insolation and ambient temperature because photovoltaic cells exhibit a nonlinear current voltage characteristic. A good number of publications report on different MPPT techniques for PV system most of the existing schemes are unable to extract maximum power from the PV array under partial shading conditions. This paper proposes PSO algorithm to track the global power peak under partially shaded conditions. The Proposed MPPT algorithm is developed in Low cost C2000™ Piccolo™ Launch Pad™, LAUNCHXL-F28027 microcontroller. All the observations and conclusions, including results are presented.

Index terms- Solar Energy, Maximum power point tracking (MPPT), Photovoltaic Array (PV),Perturb&Observe(P&O) method, Particle Swarm optimization(PSO) method, LAUNCHXL-F28027 microcontroller.

1. Introduction

Photovoltaic (PV) is envisaged to be a popular source of renewable energy due to several advantages, mostly low operational cost, almost maintenance free and environmentally friendly. To optimize the utilization of large arrays of PV modules, maximum power point tracker (MPPT) is normally employed in conjunction with the power converter (dc–dc converter).The objective of MPPT is to ensure that the system can always harvest the maximum power generated by the PV arrays. However, due to the varying environmental conditions, that is temperature and solar insolation, the P–V characteristic curve exhibits a maximum power point (MPP) that varies nonlinearly with these conditions thus posing a challenge for the tracking algorithm. To date, various MPP tracking methods have been proposed. These techniques vary in complexity, accuracy, and speed. Each method can be categorized based on the type of the control variable it uses: i) voltage, ii) current, or iii) duty cycle. An ideal is modeled by a current source in parallel with a diode. However no solar cell is ideal and there by shunt and series resistances are added to PV cell diagram the model as shown in the Figure 1. RS is the intrinsic series resistance whose value is very small. RP is the equivalent shunt resistance which has a very high value[1].

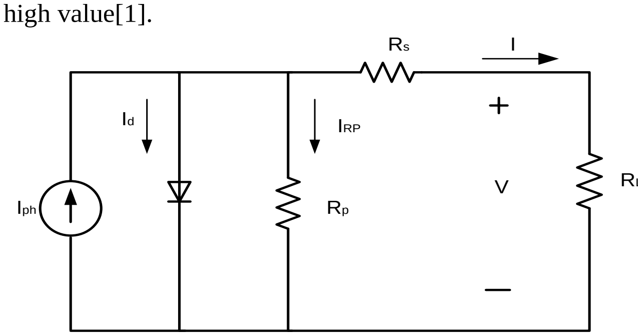

Figure 1 Equivalent circuit of a PV cell

$$I = I_{ph} - I_{R_P} - I_D \quad (1)$$

$$I = I_{ph} - I_O.\left[\exp\left(\frac{V + I.R_S}{V_T}\right) - 1\right] - \left[\frac{V + I.R_S}{R_P}\right] \quad (2)$$

Where, I_{ph} is the Insolation current, I is the Cell current, I_0 is the Reverse saturation current, V is the Cell voltage, R_S is the Series resistance, R_P is the Parallel resistance, V_T is the Thermal voltage (KT/q), K is the Boltzman constant, T is the Temperature in kelvin, q is the charge of an electron with different irradiation level the MPP will change as shown in Figure 2

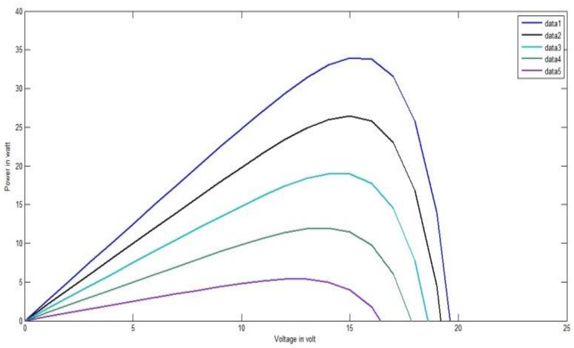

Figure 2 P-V characteristic of a solar array for a fixed temperature but varying irradiance

In general, a PV array source is operated in conjunction with a dc–dc power converter, whose duty cycle is modulated in order to track the instantaneous MPP of the PV source. Several tracking schemes have been proposed. Among the popular tracking schemes are the perturb and observe (P&O) or hill climbing, incremental conductance, short-circuit current, and open-circuit voltage modified techniques have also been proposed, with the objective of minimizing the hardware or improving the performance. The tracking schemes mentioned above are effective and time tested under uniform solar insolation, where the P–V curve of a PV module exhibits only one MPP for a given temperature and insolation. Under partially shaded conditions, when the entire array does not receive uniform insolation, the P-Characteristics get more complex, displaying multiple peaks only one of which is the global peak (GP);rest are local peaks as show in Figure 3.It is found that the conventional MPPT can track the maximum power point under normal atmospheric conditions, but the MPPT algorithm has to track the MPPT under partial shading conditions. The presence of multiple peaks reduces the effectiveness of the existing MPP tracking (MPPT) schemes, which assume a single peak power point on the P–V characteristic. The occurrence of partially shaded conditions being quite common (e.g., due to clouds, trees, etc.), there is a need to develop special MPPT schemes that can track the global peak GP under these conditions [2][3].

A) Critical observations under Partial shading conditions

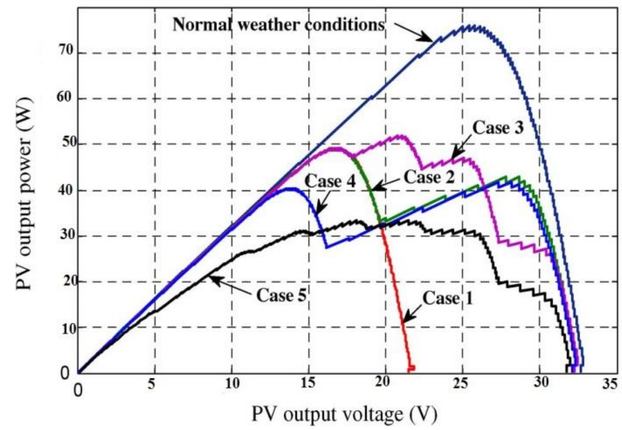

Figure 3.P-V curve of PV array under normal and Partial shading conditions

i) Under partially shaded conditions have multiple steps, while the P–V curves are characterized by multiple peaks.

ii) In addition to insolation and temperature, the magnitude of GP, and the voltage at which it occurs are also dependent on the shading pattern and array configuration.

iii) Fig.3 shows that the GP may lie on the left side of the load line.

iv) The peaks on the P–V curve occur nearly at multiples of 80% of V_{OC}_module (Figure. 3).

v) The minimum displacement between successive peaks is nearly 80% of VOC_module (Figure. 3).

vi) Extensive study of P–V curves, as well as practical data, have revealed that when the P–V curve is traversed from either side, the magnitude of the peaks increases.After reaching the GP, the magnitude of the subsequent peaks (if they are present) continuously decreases

Case1) : One module in each column is completely shaded

Case 2) : One module in each column is partially shaded with equal radiation levels.

Case 3): One module in each column is partially shaded with unequal radiation levels

Case 4) : Two modules in the first column and one module in each other column are partially shaded with equal radiation levels

Case 5): All modules are partially shaded with different radiation levels.

2. MPPT ALGORITHMS

The different algorithms are as follows

a) Incremental Conductance method

The incremental conductance method is based on the fact that the slope of the PV array power curve (Fig. 2) is zero at the MPP, positive on the left of the MPP, and negative on the right, as given by

$$\begin{aligned} dI/dV &= 0 && \text{at MPP} \\ dI/dV &> 0 && \text{Left of MPP} \\ dI/dV &< 0 && \text{Right of MPP} \end{aligned} \quad (3)$$

The increment size determines how fast the MPP is tracked. To track the MPPT fast, bigger increments needed but the system might not operate exactly at the MPP and oscillate about it instead; so there is a tradeoff[5][6].

b) Fractional open circuit voltage method

The near linear relationship between V_mpp and V_oc of the PV array, under varying irradiance and temperature levels, has given rise to the fractional V_oc method[6].

$$V_{mpp}=k_1V_{oc} \quad (4)$$

where k_1 is a constant of proportionality. Since k_1 is dependent on the characteristics of the PV array,it usually has to be computed before hand by empirically determining V_{mpp} and V_{oc} for the specific PV array at different irradiance and temperature levels.

c) Fractional short circuit current method

Fractional I_{sc} results from the fact that, under varying atmospheric conditions,I_{mpp} is approximately linearly related to the I_{sc} of the PV array.

$$I_{mpp} =k_2Isc \quad (5)$$

where k_2 is a proportionality constant. Just like in the fractional V_oc technique, k_2 has to be determined according to the PV array in use[6].

d) Perturb and Observe method

Perturb & Observe (P&O) is the simplest method. This is the most widely used MPPT scheme. The method involves moving operating voltage by one step and then examining the change in generated power. If the power increases, the operating point moves in the same direction. This process goes on until reach MPP [7]-[10].

A detailed MPPT control technique based on the Particle swarm optimization (PSO) is discussed in the following section

3. PARTICLE SWARM OPTIMIZATION (PSO) APPLIEDTO MAXIMU POWER POINT TRACKING CONTROL

The PSO method is a simple and effective metaheuristic approach that can be applied to a multivariable function optimization having many local optimal points. Several cooperative agents are used, and each agent shares or exchanges information obtained in its respective search process. In this method, each agent moves with a velocity V^k in the search space, and this movement depends on two factors: 1) its own previous best position and 2) the previous best position attained among all the agents. These points are expressed mathematically in two equations which specify the velocity and position update of the agent [11]-[13].

$$V_i^{k+1} = wV_i^k + C_1r_1P_{best_i} + C_2r_2g_{best_i} \quad (6)$$

$$S_i^{k+1} = S_i^k + V_i^{k+1} \quad (7)$$

Where w is the learning factor; C_1 and C_2 are positive constraints; r_1 and r_2 are normalized random numbers and their ranges are (0-1).The variable $P_{(besti)}$ is used to store the best position that i^{th} ant has found so far, and its position (8), is updated if condition (9) is satisfied.

$$P_{(besti)})= S_i^k \quad (8)$$

$$f(S_i^k) = f(P_{besti}) \quad (9)$$

Here f is the objective function that is maximized in each iteration cycle. The variable $g_{(besti)}$ is used to store the best position obtained among the agents.

a) PSO applicable to Maximum Power tracking control under partial Shading Conditions

The P-V characteristic exhibits multiple local MPP. When two PV modules are connected in Parallel and one of them is partially shaded, the shaded module's terminal voltage is different from that of the unshaded module. Under this condition, their terminal voltages are V_1,V_2; total power is P; and their variation, it is clear that tracking to a global maximum is nothing but a multidimensional MPPT control problem, wherein both V_1 and V_2 must be controlled simultaneously. In general, if the PV array contains N number of modules, then each individual module voltage (V_1, V_2,…, V_N) must be controlled. Here, the terminal voltages of the individual PV modules are grouped together and represented in the form of an N-dimensional row vector as

$$S^k=[V_1^k,V_2^k\ldots\ldots V_N^k] \quad (10)$$

Where N is the size of the row vector and it indicates the number of PV modules in the system. The velocity vector v can be written as

$$v_1^k=[V_1^k-V_1^{(k-1)},V_2^k-V_2^{(k-1)}\ldots\ldots\ldots\ldots V_N^k-V_N^{(k-1)}] \quad (11)$$

Here, the objective function f is the generated power P, which is the summation of power generated by each module. Assuming that there are M number of agents involved in the search process, the terminal voltage vector S_k changes in the following order and also computes the power $P(S_k)$ at each stage

$$S_1^k\rightarrow S_2^k\rightarrow\cdots\rightarrow S_M^k$$
$$S_1^{(k+1)}\rightarrow S_2^{(k+1)}\rightarrow\cdots\rightarrow S_M^{(k+1)} \quad (12)$$

This process is continued until the global optimum is reached, and in each iteration the velocities and position are updated as per the relationships defined by (6) and (7).

$$\left|(v_{(i+1)})\right| < -\Delta V \quad (13)$$

$$(\left|P(S_{(i+1)})-P(S_i)\right|)/(P(S_i))>\Delta P \quad (14)$$

Equations(11) and (12) basis for convergence detection of the agents and sudden changes in insolation, respectively.

4. SIMULATION OF THE PSO AND P&O BASED MPPT

The MATLAB–Simulink simulation model of the PV system with boost converter used in this study as shown in Figure 6. The converter is designed for following specifications: C= 47μF,L = 1.036 mH, and 40-kHz switching frequency. To evaluate the performance of the PSO method, comparison is made with the P&O. Three challenging scenarios are imposed to the system: 1) large step change in (uniform) solar insolation; 2) step change in load; and 3) partial shading conditions. These are discussed in subsequent sections.

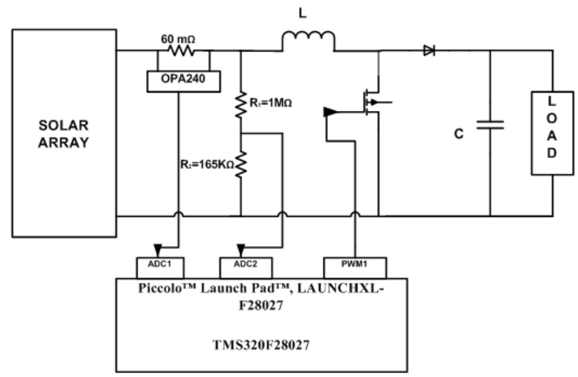

Figure 4 Block diagram of PV system with the Boost converter and MPPT.

5 .EXPERIMENTAL SETUP

The tracking performance of PSO and P&O are tested in laboratory under normal and partial shading conditions as follows. The controller used to produce the switching pulse for the controller is The C2000™ Piccolo™ Launch Pad™, LAUNCHXL-F28027,which is a complete low-cost experimenter board for the Texas Instruments Piccolo F2802x devices.

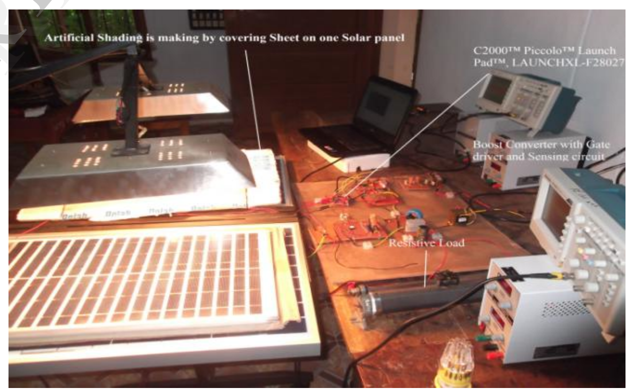

Figure 5. Experimental setup in lab

Its features are :

High-Efficiency 32-Bit CPU (TMS320C28027™) 60-MHz Devices, Single 2.3-V Supply, Up to 22 Multiplexed GPIO Pins, Two Internal Zero-pin Oscillators, On-Chip Flash, SARAM, OTP Memory, Three 32-Bit CPU Timers

Enhanced Control Peripherals, Enhanced Pulse Width
Modulator (ePWM)

- High-Resolution PWM (HRPWM)
- Enhanced Capture (eCAP)
- Analog-to-Digital Converter (ADC)
- On-Chip Temperature Sensor

- Comparator

Converter is designed for the experimental set up is same as simulation values. The Gate Driver is used for drive the MOSFET is TLP250, sensing the voltage and current of solar array by potential divider for voltage and arrange 60mΩ resistor in between PV array and boost converter, measure the voltage drop across the series resistor and amplify in the range between 0-3V by AD8215 and OP340.The MPPT algorithms P&O and PSO are developed in the Low cost microcontroller and tested the tracking performance under normal and partial shading conditions. The Partial shading conditions are tested by arranging some artificial sheet on one panel as shown in Figure 5.

6. RESULTS AND DISCUSSIONS

a) Simulation Results

This section presents the simulation results with PSO and P&O, tested in different insolation conditions. Partially shading can be tested by two ways. One way is one module is fully illuminated (1000W/m^2) and second module partially illuminated (800 W/m^2) and second condition is tested by one module fully

Illuminated (1000W/m$_2$) and second module is partially illuminated (500W/m^2). The tracking performance of P&O based MPPT is shown in Figure 7 under 1000W/m^2,800W/m^2 and 500W/m^2 insolation levels. Due to low insolation level in insolation levels from 1sec to 2 sec, the power generated by PV array is decreased. The PSO based MPPT performance is shown in Figure 8 under 1000W/m^2,800W/m^2 and 500 W/m^2 insolation levels. In Figure 7, normal insolation level from 3 sec to 5 sec, the P&O MPPT algorithm tracked the MPP without any problem, but due to Partial shading applied in from 1 sec to 3 sec, the algorithm couldn't find MPP and the operating point is oscillating after reaching MPP.

The PSO based MPPT tracking performance under partial shading condition are tested .This algorithm searching process is goes on up to reach global MPP. The P&O based MPPT algorithm tracks Local MPP and PSO MPPT algorithm tracked Global MPP. The results of both PSO based MPPT and P&O based MPPT algorithm results are tabulated in Table1. It can be observed that PSO giving good results than P&O MPPT algorithm.

b) Hardware Results

The Hardware results are shown in the Figures 9 and Figure 10.The Tracking performance of both PSO and P&O MPPT algorithms are tested under different insolation conditions. When the insolation level changes, the MPPT algorithm tracks MPP by changing duty cycle of converter. The test results are tabulated in Table 2.

As the proposed scheme (PSO) is a multidimensional search-based technique, it is able to find the global MPP even under complex partial shading conditions. The developed algorithm is simple and also reduces the cost of the data acquisition system. Experimental comparison with P&O tracking schemes demonstrated its novelty as well as its validity. The PSO algorithm took about 1 to 2 s to find the global MPP.

Table 1.Simulation Performance of the MPPT algorithms

Irradiation Level	Perturb&observe method			Particle swarm optimization(PSO)		
	V_{mpp}	P_{mpp}	%η	V_{mpp}	P_{mpp}	%η
1000W/m^2	16.33	39.68	99.2	17.3	39.79	99.47
800W/m^2	14.56	28.7	71.75	17.39	32.3	80.75
500W/m^2	9.17	11.5	28.75	13.64	17	42.5
1000W/m^2 and 800W/m^2	15.05	33.4	83.5	16.23	35.5	88.75
1000W/m^2 and 500W/m^2	13.02	24.3	60.75	15.44	28.4	71

Table 2. Hardware Performance of the MPPT algorithms

Irradiation Level	Perturb&observe method			Particle swarm optimization(PSO)		
	V_{mpp}	P_{mpp}	%η	V_{mpp}		
Maximum irradiation level(800W/m^2)	17.6	35	87.5	17.6	38	95
Minimum irradiation level(200 W/m^2)	17.2	30	75	20.8	33	82.5
One panel shaded partially	10.5	19.5	48.75	10.5	22	55
One panel shaded fully	5.3	11.3	28.5	9.3	19.3	48.25

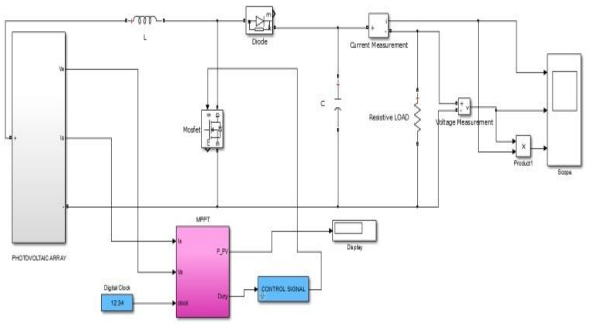

Figure 6 Simulink model of MPPT system

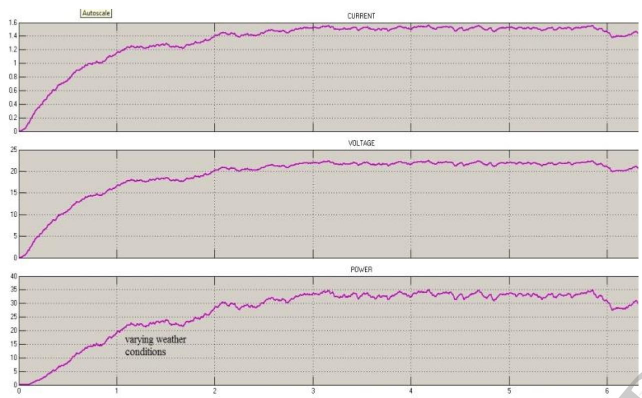

Figure7 P&O Simulation results under varying weather conditions

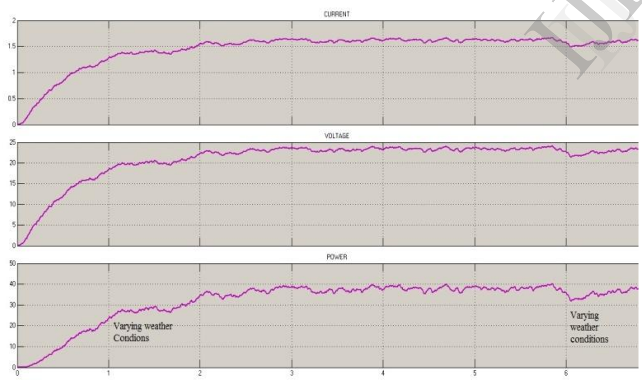

Figure 8 PSO simulation results under varying weather conditions

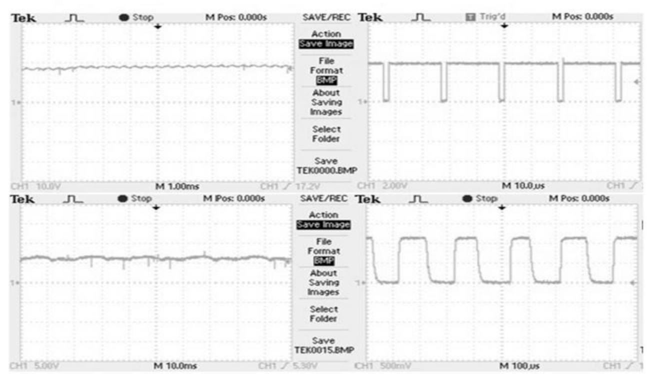

Figure 9 P&O Hardware results under varying weather conditions

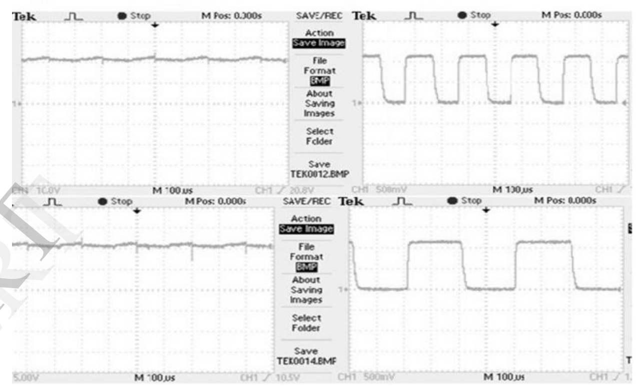

Figure 10 Hardware results of PSO MPPT under varying weather conditions

7. CONCLUSIONS

There are many MPPT techniques available in literature .The Particle swarm optimization (PSO) and Perturb & Observe(P&O) algorithms are simulated and tested under normal and partial shading conditions. Under normal illumination level, PSO based MPPT algorithm tracking MPP without any problem, but the P&O based MPPT, the operating point oscillates around MPP after reached the MPP. In the case of partial shading condition, due to multiple maximum power points (MPP), the PSO based algorithm tracking the global maximum power point (G_{mpp}) where the P&O based algorithm stops the tracking when local maximum power point (L_{mpp}) reached. The same algorithms are developed in laboratory with low cost C2000™ Piccolo™ Launch Pad™, LAUNCHXL-F28027 Microcontroller. The test results are same as Simulation results. The implementation of PSO algorithm is complicated as compare to P&O based MPPT algorithm.

8. References

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