## Research Article
# Comparative Study of Different Hill Climbing MPPT through Simulation and Experimental Test Bed

T.H. Tuffaha, M. Babar, Y. Khan and N.H. Malik
Saudi Aramco Chair in Electrical Power, EE Department, College of Engineering,
King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia

**Abstract:** Hill climbing MPPT technique is commonly used in photovoltaic systems in order to achieve maximum power from it. Due to the massive numbers of the MPPT techniques in this field, it becomes essential to find and verify the most effective, simplest and reliable technique to be used. In this paper comparative studies of two different climbing MPPTs that are conventional perturb and observe and modified perturb and observe has been performed. The paper verifies their tracking performance through calculations. Simulations are also performed using MATLAB SIMULINK and results are analyzed. In addition, hardware implementation has been carried out which verifies simulation results. This study should serve as a strong evidence for practical feasibility of the modified perturb and observe method for MPPT.

**Keywords:** MPPT, P&O, photovoltaic, renewable energy

## INTRODUCTION

As the conventional electrical energy sources have rapidly depleted and due to their shortage and environmental drawbacks, renewable energy sources especially solar energy is growing significantly nowadays (Yafaoui *et al*., 2007). The main advantages of the PV system are that it does not consist of moving parts, it doesn't produce noise and it doesn't need maintenance. The photovoltaic system converts the solar energy into electricity, but generally it is costly and has low power conversion efficiency. However, it would be more beneficial if it can produce the maximum power continuously at all weather conditions (Nedumgatt *et al*., 2011). The PV system has a highly nonlinear I-V characteristic which varies with irradiance and temperature that substantially affect the array output power. The MPPT (Maximum Power Point Tracking) control of PV therefore is critical to make the PV system work efficiently (Liu and Dougal, 2002). Many MPPT techniques have been developed such as fuzzy logic, hill climbing technique i.e., perturb and observe P&O, incremental conductance IC, Fractional Open-Circuit Voltage, Fractional Short-Circuit Current and Neural Network, etc. Each one of these techniques has been simulated and implemented and their dynamic performances were reported by Esran and Chapman (2007). Their concluding discussion serves as a useful guide in choosing the right MPPT method for specific PV systems. Calavia *et al*. (2010) discussed three MPPT techniques: three points perturb and observe fixed-step incremental conductance and variable-step incremental conductance. They compare them considering three criteria: simplicity of implementation, capability to follow irradiance variations and sensitivity to noise in the required measurements. He concluded that the first method, three-point perturb and observe, is the simplest to implement, but it shows the worst behavior in power tracking both with and without the noise. The two incremental conductance methods are more difficult to implement, but they have better power tracking characteristics. The fixed-step method is the one showing higher immunity to noise measurements, since it only requires the valuation of the sign of the generated power derivative, for evaluation purpose.

From the previous discussion, the hill climbing technique (P&O) has been widely used in MPPT control due to its simplicity and ease of implementation. However, power tracking has been compensated by the modified P&O. The basic principle about the hill climbing is that the voltage is continuously being perturbed and the power is observed to determine if it is increasing or decreasing accordingly (Calavia *et al*., 2010). This study discuses two MPPT algorithms i.e., conventional P&O and modified P&O and compares their performance according to their tracking efficiencies using simulation and DSP based practical implementation.

## METHODOLOGY

This section describes the MPPT algorithms and equations needed to verify the results.

**Corresponding Author:** T.H. Tuffaha, Saudi Aramco Chair in Electrical Power, EE Department, College of Engineering, King Saud University, P.O. Box 800, Riyadh 11421, Saudi Arabia

**Power and efficiency calculations:** For the sake of tracking efficiency evaluation, a reference power is needed in order to compare with other power values. The reference power level will be taken as the ideal maximum power from the solar module. This power can be calculated by Eq. (1):

$$P_{ideal} = FF * V_{oc} * I_{sc} \qquad (1)$$

where,
$P_{ideal}$ = The ideal maximum expected power
$V_{oc}$ = Open circuit voltage
$I_{sc}$ = Short circuit current
FF = Fill Factor ≈0.811 (Das, 2011)

The PV output power can be calculated by Eq. (2):

$$P_{MPP} = I_{MPP} * V_{MPP} \qquad (2)$$

where,
$P_{MPP}$ = PV power at maximum power point
$I_{MPP}$ = PV current at MPP
$V_{MPP}$ = PV voltage at MPP

Eventually, tracking efficiency will be calculated according to Eq. (3):

$$\eta = \frac{P_{MPP}}{P_{ideal}} * 100\% \qquad (3)$$

where,

$\eta$ = Tracking efficiency

**MPPT algorithms:** The two main versions of the hill climbing algorithms i.e., P&O and MP&O which are being analyzed in this study are described below:

- **Conventional P&O:** The P&O algorithm operates by periodically perturbing (i.e., incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the PV array operating voltage changes and power increases ($dP/dV_{PV}>0$), the control system moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way (Song, 2011). The logic of this algorithm and the flowchart are given in Fig. 1.
  A common problem in P&O algorithms is that the array terminal voltage is perturbed every MPPT cycle; therefore when the MPP is reached, the output power oscillates around the maximum power point, thereby resulting in power loss in the PV system.

- **Modified P&O:** The Modified Perturb and Observe (MP&O) method was proposed to solve the oscillation problem by decoupling the PV power fluctuations caused by hill-climbing process from those caused by the irradiance changing (Liu *et al.*, 2004). This method adds an irradiance-changing estimate process in every perturb process to measure the amount of power change caused by the change of atmospheric condition and then compensates it using a perturb process. Figure 2 shows the flow chart of the MP&O method.
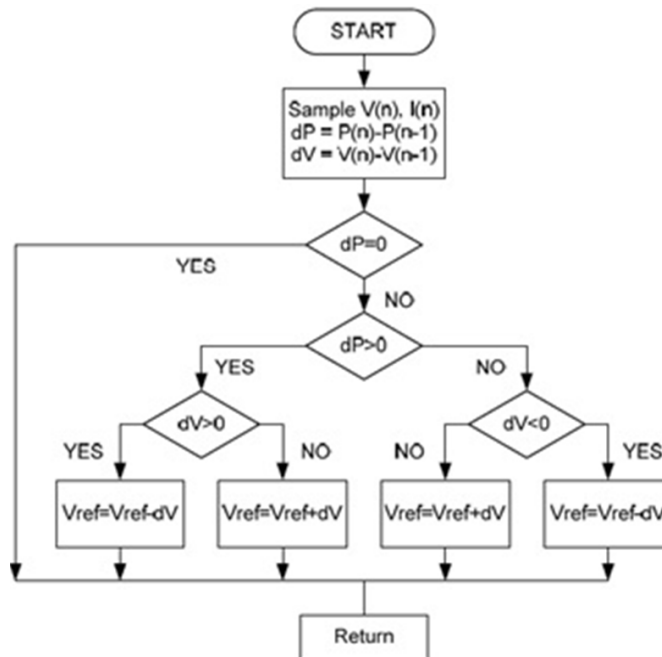


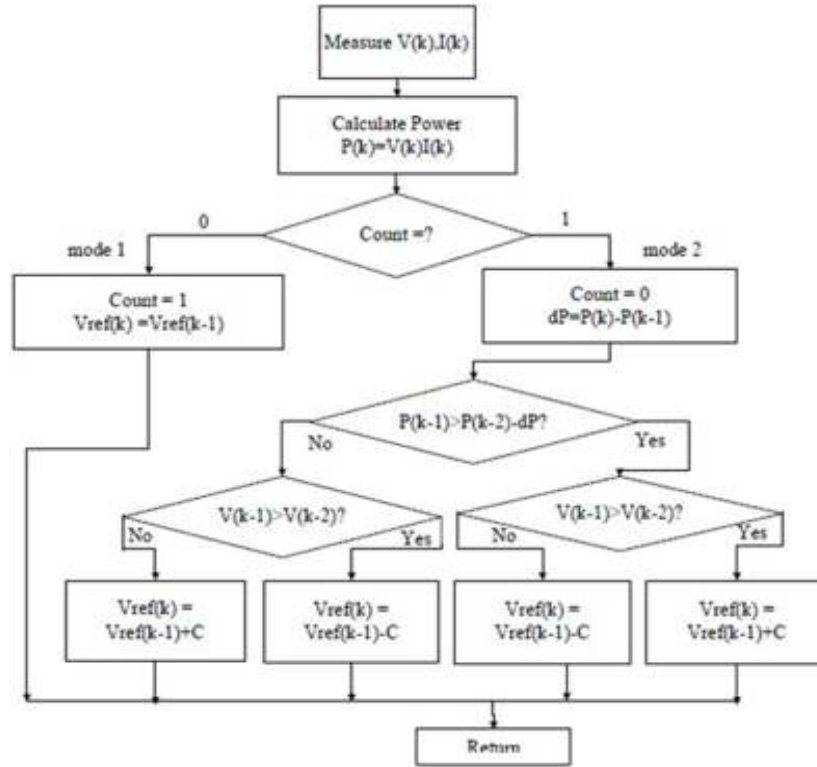Fig. 1: Conventional P&O algorithm (Song, 2011)
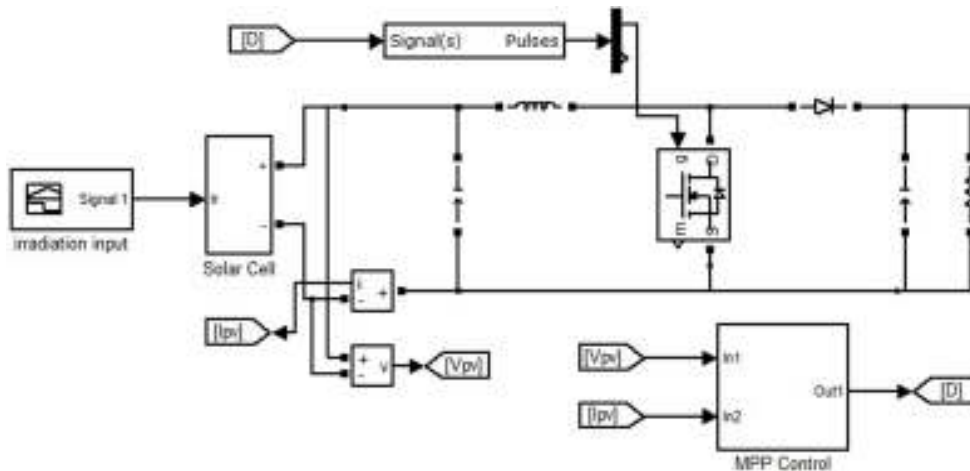
Fig. 2: MP&O algorithm (Liu *et al*., 2004)



Fig. 3: Complete model of PV system together with its MPP controller

## SIMULATION RESULTS

The simulations have been performed using MATLAB SIMULINK model as shown in Fig. 3. The model consists of DC-DC boost converter, solar module, the MPP Controller and a load of 10 Ω. The model was used to simulate two MPPT algorithms, i.e., Conventional P&O and Modified P&O. For simulation purposes, the input irradiation is set to be a step function of 560 W/m$^2$ for the first second and then it steps up to 900 W/m$^2$ for the next second. The simulation results are presented in Fig. 4 which shows
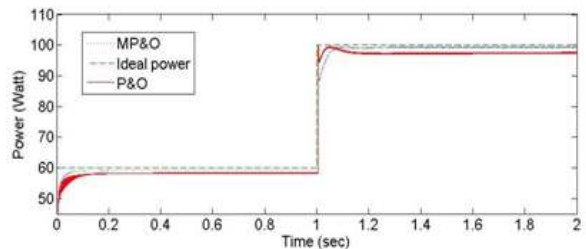


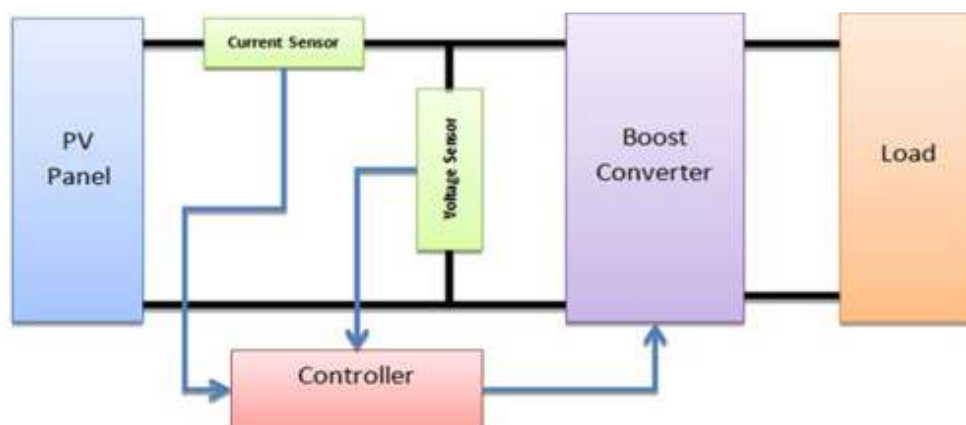Fig. 4: Output power comparison between P&O and MP&O MPPT algorithms

Fig. 5: Block diagram of photovoltaic system

Table 1: Solar panel electrical characteristics

| Electrical characteristics | BCT100-12 |
|---|---|
| Maximum power at STC ($P_{MAX}$) | 100W |
| Optimum operating voltage ($V_{mp}$) | 17.2 V |
| Optimum operating current ($I_{mp}$) | 5.8 A |
| Open circuit voltage ($V_{oc}$) | 21.6 V |
| Short circuit current ($I_{sc}$) | 6.46 A |
| Short circuit current temperature coefficient | 0.015 %/°C |
| No. of cell and connection | 36 cell (4X9) |

Poly-crystal silicon solar cell; STC: Irradiance 1000 W/m$^2$; Module temperature 25°C; AM = 1.5

the power against time curve of both methods. It can be observed that MP&O is closer to ideal calculation than P&O. Thus, it can be inferred that MP&O has better efficiency than the conventional P&O.

**Experimental setup:** The proposed photovoltaic system is implemented using a digital controller based on the Texas TMS320F2808 DSP, as shown in Fig. 5. The system consists of a solar panel, a DC/DC boost converter, a 100 W filament lamp set as the load and a DSP-based circuit as the controller and data acquisition part. The digital controller consists of two A/D converters, a digital signal processor and a gate drive circuit. The prototype photovoltaic peak power tracking converter and the DSP controller were built and tested. The electrical characteristics of the solar module are shown in Table 1.

The program code was written in C language. This code was downloaded to the DSPs memory for use with the external hardware. The experiment was scheduled for 5 h. The temperature varied between 27 and 32°C which was measured by the temperature sensor. Moreover, the dew point was at 9.5°C. During this experiment, three separate solar panels: one for open circuit measurements and other of the MP&O and one for the P&O were used. After every 15 min, open circuit voltage and short-circuit current of the panel were measured and for the two remaining solar panels the voltage and current of each one was measured by using the DSP debugging tool.

**Experimental results:** Many current and voltage readings were taken during the experiment. These data were acquired by the DSP debugging tool, which means that the values of the current and voltage are in digital form as shown in Table 2. *Digital $I_{p\&o}$* and *Digital $V_{p\&o}$* represent the current and voltage measured for the P&O algorithm by the DSP. Similarly, *Digital $I_{mp\&o}$* and *Digital $V_{mp\&o}$* represent the current and voltage measured for the MP&O algorithm by the DSP. Then, for the analysis, these values were simply converted from digital to analog. For example, consider serial # 3 of Table 2, the values of *Digital $I_{p\&o}$* and *Digital $V_{p\&o}$* were found to be 2486 and 3077, respectively. The digital to analog conversion of the digital current values can be expressed as:

$$I\text{ - D/A conversion} = \frac{[(\text{ADC bit resolution x Digital value}) \text{ - biasing voltage}]}{\text{sensor's gain}} \tag{4}$$

For the given system, bit resolution of DSP based ADC is 12 bit i.e., (3/4096), the biasing voltage of the sensor is 1.65 V and the sensor's gain is set to be 0.04 mV/A. Thus, for $I_{P\&O}$ evaluation equation could be expressed as:

$$I_{P\&O} = \frac{[(3/4096) * \text{Digital } I_{P\&O} \text{ -1.65}]}{0.04} \tag{5}$$

For instance, consider serial #3 of Table 2, thus by using Eq. (5), $I_{P\&O}$ is found to be 4.3A as shown in series #3 of Table 3. Similarly, the digital to analog conversion of the digital voltage values can be expressed as:

V-D/A conversion = [(ADC bit resolution *Digital value *gain factor)] (6)

where, the ADC bit resolution is the same as above and the amplifier gain was chosen to be 23/3 because the

Table 2: The digital measured data by the DSP

| S. No. | $I_{sc}$ (A) | $V_{oc}$ (V) | Digital$I_{p\&o}$ | Digital$V_{p\&o}$ | Digital$I_{mp\&o}$ | Digital$V_{mp\&o}$ |
|--------|------|-------|------|------|------|------|
| 1 | 2.04 | 19.56 | 2351 | 2990 | 2355 | 3004 |
| 2 | 3.74 | 19.95 | 2433 | 3035 | 2437 | 3048 |
| 3 | 4.83 | 19.91 | 2488 | 3077 | 2490 | 3080 |
| 4 | 5.03 | 19.87 | 2495 | 3042 | 2500 | 3045 |
| 5 | 6.03 | 20.03 | 2545 | 3072 | 2548 | 3078 |
| 6 | 5.66 | 20.05 | 2527 | 3069 | 2529 | 3079 |
| 7 | 5.28 | 20.39 | 2505 | 3118 | 2510 | 3129 |
| 8 | 4.98 | 20.44 | 2490 | 3130 | 2495 | 3138 |
| 9 | 4.09 | 20.50 | 2446 | 3132 | 2451 | 3139 |

Table 3: Conversion of measured data

| S. No. | $I_{p\&o}$ (A) | $V_{p\&o}$ (V) | $I_{mp\&o}$ (A) | $V_{mp\&o}$ (V) |
|--------|------|-------|------|------|
| 1 | 1.81 | 16.79 | 1.85 | 16.87 |
| 2 | 3.30 | 17.04 | 3.35 | 17.11 |
| 3 | 4.30 | 17.28 | 4.34 | 17.30 |
| 4 | 4.41 | 17.08 | 4.50 | 17.10 |
| 5 | 5.36 | 17.25 | 5.40 | 17.28 |
| 6 | 5.02 | 17.24 | 5.04 | 17.29 |
| 7 | 4.61 | 17.51 | 4.68 | 17.57 |
| 8 | 4.34 | 17.57 | 4.38 | 17.62 |
| 9 | 3.54 | 17.59 | 3.61 | 17.63 |

Table 4: Tracking efficiency comparison between the two MPPT algorithms

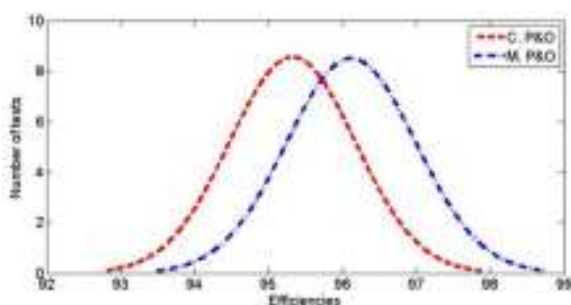| S. No. | $P_{ideal}$ (W) | $P_{p\&o}$ (W) | $\eta_{p\&o}$ | $P_{mp\&o}$ (W) | $\eta_{mp\&o}$ |
|--------|------|-------|------|------|------|
| 1 | 32.0 | 30.76 | 96.12 | 31.24 | 97.63 |
| 2 | 59.7 | 56.70 | 94.98 | 75.28 | 95.95 |
| 3 | 77.0 | 74.36 | 96.58 | 74.79 | 97.13 |
| 4 | 80.0 | 76.60 | 95.76 | 77.01 | 96.27 |
| 5 | 96.7 | 92.43 | 95.59 | 92.95 | 96.12 |
| 6 | 90.8 | 86.60 | 95.37 | 87.23 | 96.06 |
| 7 | 86.2 | 81.57 | 94.63 | 82.21 | 95.37 |
| 8 | 81.4 | 77.10 | 94.71 | 77.65 | 95.40 |
| 9 | 74.9 | 70.25 | 93.79 | 70.99 | 94.77 |



Fig. 6: Normal distribution for P&O and MP&O

maximum voltage of the panel is 21V and the maximum allowable ADC input voltage is 3V. Thus, for $V_{P\&O}$ equation could be expressed as:

$$V_{P\&O} = \frac{3}{4096} * DigitalV_{P\&O} * 23/3 \qquad (7)$$

Again, consider serial #3 of Table 2, thus by using Eq. (7), $V_{P\&O}$ is found to be 17.28 V as shown in series #3 of Table 3.

Table 4 shows the power and tracking efficiency which is calculated by using Eq. (3), where, $P_{MPP} = P_{p\&o}$ for $\eta_{p\&o}$ and $P_{MPP} = P_{mp\&o}$ for $\eta_{mp\&o}$. For an explanation, let's consider serial # 5 in Table 4. Here, it can be observed that $P_{ideal}$ is found to be 96.7 Watt. However, the $P_{p\&o}$ and $P_{mp\&o}$ are found to be 92.43 and 92.95 Watt, respectively. It means, if their efficiencies are calculated using Eq. (3), they are 95.59 and 96.12% for conventional and modified P&O, respectively.

Figure 6 shows the overall normal density curve of all measured values of conventional and modified P&O, which clearly suggests that the tracking efficiency of MP&O is located around 96.5% where the conventional P&O efficiency is located around 95.5%. This result indicates that the MP&O algorithm has a better tracking efficiency than the conventional P&O.

**CONCLUSION**

In this study, for simplicity and effectiveness, Ideal MPP, conventional P&O and Modified P&O were selected for verifying the analysis. For simulation purposes, a simplified model of the PV system was developed. Multiple simulations were executed to check the dynamics of the proposed MPPTs.

The performances of the Conventional P&O and Modified P&O were compared with the ideal maximum power reference based on the results of the simulation and experiment. It is shown that the modified algorithm performs better than the other. MP&O MPPT tracking efficiency is found to be up to 97%. This kind of Hill climbing techniques i.e., (P&O, MP&O) are limited to track the maximum power effectively only under the standard non-shading condition of the solar panels.

In the next step, the MP&O will be used to track the global maximum power point under the effect of shading on the PV system.

**REFERENCES**

Calavia, M., J. Perié, J. Sanz and J. Sallán, 2010. Comparison of mppt strategies for solar modules. Proceeding of the Internatinal Conference on Renewable Energies and Power Quality, pp: 22-25.

Das, A.K., 2011. An explicit J-V model of a solar cell for simple fill factor calculation. Sol. Energy, 85(9): 1906-1909.

Esran, T. and P.L. Chapman, 2007. Comparison of photovoltaic array maximum power point tracking techniques. IEEE T. Energy Conver., 22(2): 439-449.

Liu, S. and R.A. Dougal, 2002. Dynamic multiphysics model for solar array. IEEE T. Energy Conver., 17(2): 285-294.

Liu, C., B. Wu and R. Cheung, 2004. Advanced algorithm for mppt control of photovoltaic systems. Proceeding of the Canadian Solar Buildings Conference, Montreal.

Nedumgatt, J.J., S. Jayakrishnan, S. Umashankar, D. Vijayakumar and D. Kothari, 2011. Perturb and observe mppt algorithm for solar pv systems-modeling and simulation. Proceeding of the 2011 Annual IEEE India Conference (INDICON), pp: 1-6.

Song, I.K., 2011. Simulation and analysis of existing MPPT control methods in a PV generation system. J. Int. Council Electr. Eng., 1(4): 446-451.

Yafaoui, A., B. Wu and R. Cheung, 2007. Implementation of maximum power point tracking algorithm for residential photovoltaic systems. Proceedings of the 2nd Canadian Solar Building Conference.