Performance Study of LabVIEW Modelled PV Panel and Its Hardware Implementation

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Abstract
Decarbonizing the vitality area and diminishing carbon discharges to confine environmental change are the primary worries of twenty-first century. Renewable energy and efficiency interventions, supported by rapid electrification, will provide more than 90% of the reducing CO$_2$ emissions planned by 2050. By 2050, the transition to renewable energy will also increase the world’s gross domestic product by 2.5% and the number of jobs by 0.2%. Conventional Poly crystalline roof top solar PV has an efficiency of 22.7%. Tropic of cancer passes through eight states of India, The temperature in summers varies from 40 to 50 °C which results in decrease in efficiency of solar panel. So we require efficient MPPT controllers to overcome this gap. In Ghaziabad, the experimental test is performed with latitude of 28, 6692 (N) and longitude 77, 4538 (E). Solar PV simulator is designed using LabVIEW software. Effect of variations of temperature, irradiations, series resistance and shunt resistance on solar panel has been studied. Simulated results are tested using experimental setup with the help of arduino interfaced LabVIEW.

Keywords Solar simulator • MPPT • LabVIEW • Arduino

1 Introduction
Non renewable electricity supply is not adequate to meet current and future power requirements. With growing worries about air pollution and global warming, it is projected that clean renewable sources of power will play an essential part or even a major role in the future sustainability of the world’s infrastructure. If we want to ensure that every individual in the country has access to electricity 24 h a day, the most promising solution in the medium term appears to be solar energy. India’s geographical qualities make it an excellent source of solar energy. Solar energy gives the most promising and eternal gist of sources from which we can

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extract the finest potential output by utilising artificial intelligence to improve its performance. In light of the increasing usage of LEDs, low-voltage electronics, and energy-efficient direct current motor technologies, it is becoming increasingly necessary to supply electricity to homes directly from solar panels. This has the potential to lower energy consumption by more than 50%. Renewable solar energy is the most evident alternative renewable energy source for the future expansion and development of the world’s population. For solar energy there has been research on MPPT algorithms for PV systems and battery systems [1]. Using the simulation tool LabVIEW, 10 widely-adopted MPPT algorithms has been compared in terms of energy efficiency [2]. Cotton wicks based heat spreaders reduces the temperature up to 12% [3]. One device with minimum hardware changes compares seven popular MPPT algorithms [4]. The article reviews the technology’s development trends, focusing on recent advances and future efforts [5]. Glazed and unglazed PV thermoelectric panels are also studied [6]. In the same solar cell size, glass/backsheet modules produce 2.2 percent more electricity than glass/glass modules [7]. The MPPT technique has been utilized to maximize the power output from a PV system by matching the load resistance, resulting in the generation of the maximum amount of electricity [8]. MPPT’s design process (and, indeed, the method by which the algorithm’s parameters are computed) falls into four categories: classical, intelligent, hybrid, and optimization [9]. Solar panel monitoring is easy with LabVIEW’s built in Web Server [10]. Solar PV cell simulation is done in Matlab/Simulink [11]. SQ80 and KC200GT single diode models have been examined for various modelling equations [12]. Specific temperature control methods are used to increase solar panel performance [13]. Specifically, the proposed solution comprises of a water pump that is driven by an induction permanent magnet synchronous motor and controlled by the traditional field oriented control approach [14]. Article explores the comparison of different G2GPVT and G2T efficiencies and it is reported that the G2GPVT performance is higher than the G2T performance [15]. Glazed and unglazed PV thermoelectric panels are also studied [16]. A comparison of MPPT algorithms for solar modules made in crystalline silicon under unfavorable weather conditions [17]. Portable data acquisition system is designed for solar power plant. Yearly data gathered from plant is compared with commercial equipment’s [18]. MATLAB and Simulink based solar cell model is explained. 150 W solar panel with PWM technique is simulated using LabVIEW [19]. Various problems are discussed while interconnection of solar PV and grid [20]. Data acquisition system for solar cell using LabVIEW has been discussed [21]. Solar cell behaviour has been studied using MATLAB/Simulink [22]. Pulse width modulator has been designed for 150 W solar PV module [23]. This addresses the data acquisition approach using LabVIEW for solar cell model [24]. Realtime monitoring of solar PV using Dashboard studied [25]. Unregulated charging and discharging affects the battery; a commercial solar charge controller prototype is aimed to reduce harms [26]. SVM has been used to distinguish cloud types for better PV power predictions. SVM weather categorization enhanced PV power prediction results [27]. The narrow forecast uncertainty amplifies the mismatch while having no effect on operating expenses. Incrementing regulation reserves to adjust for PV generation unpredictability improves system balance while increasing production costs [28]. Problems associated with integration of power grid with solar power plant has been studied [29]. Environmental effects on solar PV performance [30]. Degradation of solar PV under different environment conditions has been studied [31]. Feasibility of rooftop installed solar PV has been studied [32]. Dealt with both divergence and oscillation. Although the solutions vary depending on the instance, the algorithms fail in some scenarios, as illustrated in [33]. FF, ACO, PSO, and GW have recently been combined with P and O to track global peak during partial shading [34]. The hybrid approach [35]. Solar PV characteristics measuring and monitoring based on LabVIEW environment [36]. In the given article, solar energy is used to power a DC motor, which
is controlled by an IMC (Internal Model Control Method) controller rather than a normal controller in order to achieve higher speed accuracy [37]. The goal of this paper is to analyse solar PV panel output using LabVIEW by mathematical modelling in graphical environment. An experimental model is developed to validate the simulated model using arduino and LabVIEW. Paper is divided into following parts:

1. Modelling of a Photo voltaic Cell
2. MPPT Control algorithm (Perturb and Observe)
3. Simulation Results
4. Hardware Implementation

2 Modelling of a Photo Voltaic Cell

For better outcomes performance of the solar panel should be optimized [12]. The I–V and P–V characteristics of a PV cell should be explored for the one diode model, which is depicted in Fig. 1.

The use of a single diode model for the modelling of a PV panel has been demonstrated due to its simplicity and precision in mathematical calculation [11].

PV cell current output:

\begin{equation}
I = N_p \left[ I_{ph} - I_0 - I_0 \exp \left( \frac{V * N_p + N_s * I * R_s}{n * V_t * N_s * N_p} \right) \right] - I_{sh} \quad (1)
\end{equation}

\begin{equation}
V_t = \frac{K * T}{q} \quad (2)
\end{equation}

\begin{equation}
I_{sh} = \frac{V * N_p + N_s * I * R_s}{N_s * R_{sh}} \quad (3)
\end{equation}

Fig. 1 Model of a photovoltaic cell that is similar to a single diode
In the following equations, PV cells connected in parallel are denoted by $N_p$, $N_s$ series connected cells, $R_s(\Omega)$ series resistance, shunt resistance $R_{sh}(\Omega)$, and the thermal voltage of the diode is denoted by $V_t(V)$. Fill Factor is a very critical aspect deciding the PV cell efficiency, and cells with a number greater than or comparable to 0.8 are considered healthy.

$$\text{Fill Factor} = \frac{I_m \times V_m}{I_{sc} \times V_{oc}}$$  \hfill (4)

The maximum power point current is denoted by $I_m$, and maximum power point voltage is denoted by $V_m$.

Solar PV efficiency

$$\eta = \frac{I_{sc} \times V_{oc} \times \text{Fill Factor}}{P_{in}}$$  \hfill (5)

$P_{in}$ is incident irradiation.

3 MPPT Control Algorithm (Perturb and Observe)

P&O algorithm MPPT algorithm is implemented to track the maximum power for 200 W solar panel. Flow chart of implementation of basic P&O MPPT algorithm is shown in the Fig. 2. Module voltage has experiencing a perturbation intermittently and related output power of the cell has been correlated with the past cycle. Perturb and Observe continuously increment or decrements the panel voltage and compare the current output power of PV module with that of the previous [1, 2]. Tracking of MPP using P&O algorithm is performed in closed loop manner [19]. Output voltage and current of solar panel is acquired using Arduino. Operating power of the panel has been calculated by the voltage sensor and current sensor (ACS-712) output. Arduino is used for data acquisition. LabVIEW program of P&O based algorithm is shown in Fig. 3. Based on P&O algorithm variable duty cycle is generated which is feeded to boost converter. Variable duty cycle is generated using Arduino PWM pin. Using this process MPP is achieved for 200 W solar Panel.

Perturb and Observe based MPPT algorithm using math script window of LabVIEW is presented in Fig. 3. It provides variable duty cycle for boost converter.

Here ‘D’ is the initial duty cycle for Boost converter, ‘$dD$’ is the small change in duty cycle. ‘$DP$’ is small variation in power and ‘$DV$’ is small variation in small variation in voltage. Based on these a P&O algorithm is created using math script window in LabVIEW. It will provide variable duty cycle for boost converter. Here duty cycle is denoted by ‘$d$’.

4 Simulation Results

Saturation current, photocurrent, and reverse saturation current are all represented mathematically in Fig. 4, which shows a LabVIEW programming block diagram of a PV panel. The single diode variant with series and parallel resistors was chosen for accuracy. To simulate the detailed modelling, MATLAB/Simulink is used because it is widely used and effective [38]. Solar Panel of 200 W is simulated in LabVIEW. Its Performance is studied
Fig. 2  P&O algorithm flow diagram

Fig. 3  P&O algorithm based MPPT program
under variation of different parameters like temperature, irradiance, series resistance and parallel resistance. Solar PV Module specifications and constant are listed in Table 1.

The one-diode model was used in the development of LabVIEW VI. A 200 W solar panel is simulated using Table 1 Parameters. In this VI Temperature and Irradiance are input variable for solar Panel. Based on different values of Temperature and Irradiance, Power and current graphs are simulated.

### 4.1 Effect of Temperature Variations

To find the effect of temperature variation, Irradiance level is set to a constant value 1000 W/m².

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**Table 1** Parameters governing the intake and output of solar PV

| Variable (abbreviation)               | Value               |
|---------------------------------------|---------------------|
| Open circuit voltage ($V_{oc}$)       | 32.9 V              |
| Short circuit current ($I_{sc}$)      | 8.21 A              |
| Optimum operation voltage ($V_{m}$)   | 26.4 V              |
| Open operation current ($I_{m}$)      | 7.58 A              |
| Band gap energy ($E_{g}$)             | 1.1 eV              |
| Boltzmann constant ($K$)              | $1.38 \times 10^{-23}$ J/K |
| Coulomb constant ($q$)                | $1.6 \times 10^{-19}$ C |
| Reference temperature ($T_r$)         | 298 K               |
| Ideal factor ($n$)                    | 1.3                 |
| Module cell in series ($N_s$)         | 54                  |
| Module cell in parallel ($N_p$)       | 1                   |
| Temperature coefficient ($K_t$)       | 0.0032              |
| Series resistance ($R_s$)             | 0.221 Ω             |
| Series resistance ($R_{sh}$)          | 415.405 Ω           |
| Rated power ($P_m$)                   | 200 W               |

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**Fig. 4** Customized for LabVIEW Solar PV module block diagram
Results shows that for a fixed irradiance level of 1000 W/m² there is a large variation in power as the temperature fluctuates between 25 and 45 °C. With increase in temperature voltage decreases rapidly while there is a very small variation in current, in turn there is a decrease in power of solar cell [39]. With decrease in temperature voltage increases rapidly while there is a very small variation in current, in turn there is increase in power of solar cell. From Fig. 5 it is clear that when temperature is 25 °C maximum power point is 199.5 W, at 30 °C maximum power point is 158.995 W, at 35 °C maximum power point is 118.116 W, at 45 °C maximum power point is 76.9244 W and 36.4265 W is maximum power point at 45 °C temperature. Maximum power point decreased from 199.5 to 36.4265 W as the temperature fluctuates between 25 and 45 °C.

4.2 Effect of Irradiance Variations

The average quantity of solar energy that reaches the earth’s atmosphere is 1368 W/m², according to NASA data. During a clear day, sunlight is lowered in strength, and the intensity of irradiation at the ground is roughly 1000 W/m². The ecosystem has a significant impact on the intensity of solar radiation. The temperature level is set to a constant value of 25 °C in order to investigate the influence of irradiance change.

Solar radiation is lowering due to presence of cloud, motion of the earth and due to shadow effect. Results shows that: at constant temperature 25 °C current decreases rapidly while there is a very small variation in voltage, As a result, the power of the solar cell decreases as the amount of solar irradiation decreases. From Fig. 6 it is clear that maximum power point is 199.5 W when the irradiance level is 1000 W/m², 191.13 W when the irradiance level is 800 W/m², 182.741 W when the irradiance level is 600 W/m², and 174.34 W when the irradiance level is 400 W/m², and 165.935 W is maximum power point at irradiance level of 200 W/m². Maximum power point decreased from 199.5 to 165.935 W as irradiance level decreased from 1000 to 200 W/m².

Figure 7 contains the data of solar panel output current under variations of both temperature and irradiance.

as the temperature fluctuates between 25 and 45 °C at constant level of irradiance (800 W/m²) there are small variations in output current (6.57416–6.6251 A) of solar

![Fig. 5  I–V and P–V curve under varying temperature](image-url)
As irradiance varies from 1000 to 200 \( \text{W/m}^2 \) at constant temperature (30 \( ^\circ \text{C} \)) output current decreased from 8.23011 to 1.65054 A. From the simulation results it is observed that effect of variation of temperature is very less as compared to variations of irradiance on solar panel current.

Figure 8 contains the data of solar panel output power under variations of both temperature and irradiance.

From the simulation results it is observed that varying temperature and varying irradiance both affect the power of solar panel. It is also observed that output voltage of solar panel is decreases as temperature increases from STC (standard test conditions 25 \( ^\circ \text{C} \)) and voltage increases as temperature decreases below STC. Effect of varying irradiance is very less on solar panel voltage.
4.3 Effect of Variations of Series Resistance

Figure 9 shows the power vs voltage graph of solar panel under variations of series resistance ($R_s$). It is observed that as the series resistance increases output power of solar panel
decreases. As the year goes series resistance of the panel is increased.

When series resistance is 0.221 \(\Omega\), output power of solar panel is 199.5 W. At series resistance 0.442 \(\Omega\) output of panel drop to 186.419 W. At series resistance 0.663 \(\Omega\) output of panel is 173.613 W. At series resistance 0.884 \(\Omega\) output of panel is 161.098 W. From here it is observed that around 6.5% power decreased as series resistance doubled from \((R_s) = 0.221 \Omega\) to \((R_s) = 0.442 \Omega\).

### 4.4 Effect of Variations of Shunt Resistance

Figure 10 shows the power vs voltage graph of solar panel under variations of shunt resistance \((R_{sh})\).

It is observed that as the shunt resistance increases output power of solar panel increases. As the year goes shunt resistance of the panel is decreased. When shunt resistance is 415.405 \(\Omega\), output power of solar panel is 199.5 W. At shunt resistance 100 \(\Omega\) output of panel is 194.325 W. At shunt resistance 50 \(\Omega\) output of panel drop to 178.485 W (Fig. 10).

It has been discovered that the output power of a solar panel increases as the shunt resistance increases. As the shunt resistance, \(R_{sh}\), is doubled to 830.81 \(\Omega\), the output power of the solar panel increases to 200.321 W. From here it is observed that around 0.4% power increased as shunt resistance doubled.
4.5 P&O Based MPPT Control Algorithm

Change in duty cycle with voltage variations of solar cell are delineated in Fig. 11. Change in duty cycle is observed at different time span. When output power of solar panel is below MPP (Maximum Power Point) there is an increase in duty cycle. Initially, there is a decrease of 26.31% in duty cycle after some time there is increase of 11.67% in duty cycle then there is decrease of 10.22% in duty cycle and at last there is 73.68% increase in duty cycle, which is based on the variations in output power of the solar panel. Output power generated from solar panel without MPPT is output power is 152 W, after implementation of P&O MPP algorithm output power of solar panel is boosted to 196 W shown in Fig. 12. Using MPPT algorithm, maximum point is reached early as shown in figure. There is a 28.94% power of solar panel is boosted after using a P&O MPPT algorithm.
5 Hardware Implementation

Hardware implementation for 5 W solar panel is shown in Fig. 13. Here solar panel data (current and voltage) is acquired using Arduino UNO. Arduino is interfaced to LabVIEW using LINX. Sub VI is created for P&O MPPT algorithm.

After acquiring data from solar panel, P&O algorithm is applied using P&O MPPT. Boost converter hardware circuit is shown on zero PCB. To acquire the current ACS 712 current sensor is used its current rating is up to 5 A. To acquire the voltage from solar panel, voltage divider circuit is used. Current is acquired using analog pin (A0) of Arduino UNO. Voltage is acquired using analog pin (A1) of Arduino UNO. Output for boost converter is generated using Arduino digital PWM (DIO-6).
Figure 14 shows the hardware implementation of 5 W solar panel. Arduino UNO is used for data acquisition and to generate variable duty cycle for boost converter. Using Boost converter voltage of solar panel is boosted. Figure 15 shows the data of voltage without (MPPT and Boosted Voltage) with MPPT controller.

6 Conclusion

From the simulation results it is concluded that effect of variation of temperature is very less as compared to variations of irradiance on solar panel current. Output voltage of solar panel is decreases as temperature increases from STC (Standard Test Conditions) and voltage increases as temperature decreases below STC. Effect of varying irradiance is very less on solar panel voltage. When temperature is 45 °C and irradiance level is 200 W/m² power generated by solar panel is 29.7929 W. From the simulation results it is concluded that varying temperature and varying irradiance both affect the overall power of solar panel. After installation of solar panel, as time goes its series resistance increase and shunt resistance decreases which results in decrease in output power of solar panel. Using P&O MPPT control algorithm output power of solar panel is boosted around 28.94%. To increase the power output of solar panel live monitoring
is required. Output of panel can be improved by use of multi level inverters and hybrid MPPT techniques.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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