Design and Analysis of a Photovoltaic P&O-Based MPPT Lead-Acid Battery

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Abstract. The solar is one of the leading energy producer when it comes to renewables therefore extending our knowledge on the connection between the solar module and the battery charging process has vital role in today's sceneries. PV Solar module's power is affected by changing temperature & insolation, which are mitigated with the help of an MPPT system. To obtain the greatest power out of the solar system, we used a perturb and observe based MPPT technique in this work. A PV system requires an appropriate battery charge and to stabilize the power flow from the solar PV module to the battery and load a controller is utilized, allowing solar electricity to be used efficiently. In this situation, a boost regulator is in charge of the battery's charging mechanism. For the boost converter, PV module, parameter extraction and evaluation MATLAB/Simulink models are utilized for analysis.

Keywords: Solar energy · Photovoltaics (PV) system · Perturb and observe (P&O) · Converter · Li-ion batteries · Maximum Power Point Tracking (MPPT)

1 Introduction

Despite supply chain issues and construction delays caused by the pandemic, renewable capacity additions in 2020 increased by more than 45% over 2019 and set a new high. The expansion was fueled by a 90% increase in global wind capacity expansions. The development of new solar PV installations by 23% to nearly 135 GW in 2020 also contributed to this record growth [1]. This is owing to the consistent decline in the cost of solar modules over the last decade. Furthermore, because there are no moving apparatus included in its procedure, it is generally acknowledged by various commerce due to its ease of flexible scalability, inexpensive maintenance and installation. The photovoltaic system generates power using sunlight. As a result, it can only be utilized during the day when there is sufficient sunlight. One way for harnessing solar energy during any interval of the day even when solar radiations isn't accessible, is battery energy storage.

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Solar power is regarded as clean, great reliability, and source of energy renewable with an extended lifespan. The system introduced could be installed around or near where the prevention in transmission losses and contribute to CO_2 emission reductions in metropolitan areas can take place. A solar array is built out of numerous PV cells associated in series and parallel. The connections in parallel are accountable for boosting the current in array, while the connections in series are accountable for enhancing the voltage of the modules. The amount of power collected from a PV module is determined by the voltage generated in the solar PV module, the cell's temperature, and the amount of solar radiation received. The biggest downside of PV is its minute power conversion effectiveness when equated to other substitute energy sources. PV is a non-linear energy source that operates in response to irradiance and temperature. To derive maximum about of power from the solar PV module MPPT is utilized. The P&O technique is now the supreme and commonly utilized method in compared to other methods [4]. There appears to be a limited number of PV models in the Matlab/Simulink Sim Power System programmed to integrate with current electronics modelling technology. As a result, assessing and simulating a PV power system is quite difficult [17]. This study incorporates the solar PV modules, MPPT approach based on P & O technique, boost converter, and charging system of Li-ion battery.

The structure of chapter-

Section 2 delivers a gist literature review.
Section 3 talks about the methodology used.
And finally, the result and discussion are concluded in the Sect. 4.

2 Literature Review

In this section, research on charging Li+ batteries, MPPT, and charge controllers is reviewed and examined, as well as information on MPPT, charging Li+ batteries, and charge controllers that do both is discussed. This part is intended to serve as the primary source of background information while maintaining the research's reliability [16].

The charging process of battery by PV modules is often very private, and the ideas behind how it function is rarely made public. However, significant research has been conducted on a few of distinct combined topologies for charging batteries with the help of solar PV module. The fundamental notion behind creating a solar PV module charger for a battery is to integrate MPPT concepts with efficient battery charging. The P&O algorithm MPP is used to track a solar panel system in this work [5]. This method is overridden by a CC/CV charging algorithm. Because the maximum power capability of the solar PV module may exceed the capacity of the battery, CC/CV is employed. Despite its resemblance to other chargers, this method utilizes a lead-acid battery rather than a Li+ battery [10].

This work [6] revisits a lead-acid battery based P&O algorithm. They don't say how they charge, but it's safe to presume they're utilizing MPPT. Because of the P&O algorithm's constant step sizes, their MPPT skills are limited.

Under rapid weather change and partial shade circumstances, this [18] work offers a novel hybrid MPPT-algorithm combining the MIWO (Modified Invasive Weed Optimization) and P&O techniques for effective calculation of MPP (maximum power point) from a freestanding PV dependent hybrid module. In order to obtain speedy global peak (GP) and MPP, MIWO carries the earliest phases of MPPT, which is trailed by the utilization of the P&O in the latter phases.

The perturb and observe technique of MPPT is implemented in this research [19] in the PV solar module to harvest maximum efficiency. A reliable battery charge controller is essential for a PV system to regulate the energy flow provided by the solar PV module to the battery and load in order to properly utilize photovoltaic power. In this situation, a boost regulator is in charge of the battery's charging mechanism. The converter, modal evaluation, and parameter extraction are all done using a MATLAB/Simulink model.

This paper [20] describes a low-voltage grid-connected PV system that is appropriate for industrial, small-scale, and suburban consumer utilization. MPPT approaches are also executed by means of boost converter topology employing INC (incremental conductance) and P&O. The INC algorithm is more precise than the P&O technique at tracking swiftly changing irradiation environments. The voltage never reaches a precise value in the P&O approach, but it fluctuates about the MPP. As a result, the INC technique gets the MPP enhanced and faster than P&O since it does not suffer from drifting and is the most effective under quickly varying situations.

A solar PV boost dc–dc converters based adaptive P&O-fuzzy control MPPT is proposed in this [21] research. Both of these advantages are combined in the proposed technique. It should enhance MPPT performance, particularly in the presence of disturbance. For assessment and comparison analysis, traditional fuzzy logic control and P&O algorithms have also been created. All of the methods were merged and evaluated in MATLAB-Simulink utilizing a solar PV module.

It is the simplest algorithm and is easiest to apply. It does, however, have some typical flaws, which are listed below [21].

1) During rapid fluctuations in irradiance as it moves away from the real MPP, there is insufficient monitoring, intelligence, and efficiency (maximum power point)
2) The ability to determine whether the new higher output power value is due to a duty cycle shift or a change in irradiation has been lost.
3) At low irradiance, constant oscillations around the optimal operating point cause the average power level to depart from the MPP.
4) It swoops back and forth over the MPP, struggling to remain stationary.
5) Sluggish response time.

When the power is changed, the P&O control approach considers whether the voltage is improved or reduced. Understanding which direction the voltage altered when the power changed can help you figure out how to change the duty cycle. This technique has several advantages, including low complexity, continual convergence rates to MPP, and the capability to step in the accurate course a set amount depending on which side it is climbing. Limitations include at MPP the difficulty of achieving 0% steady-state inaccuracy, four different step sizes, and dependency on calculating equipment features [7].

3 Methodology

The solar PV P&O based MPPT battery charge with a boost controller model constructed in the MATLAB/Simulink is shown in Fig. 1.

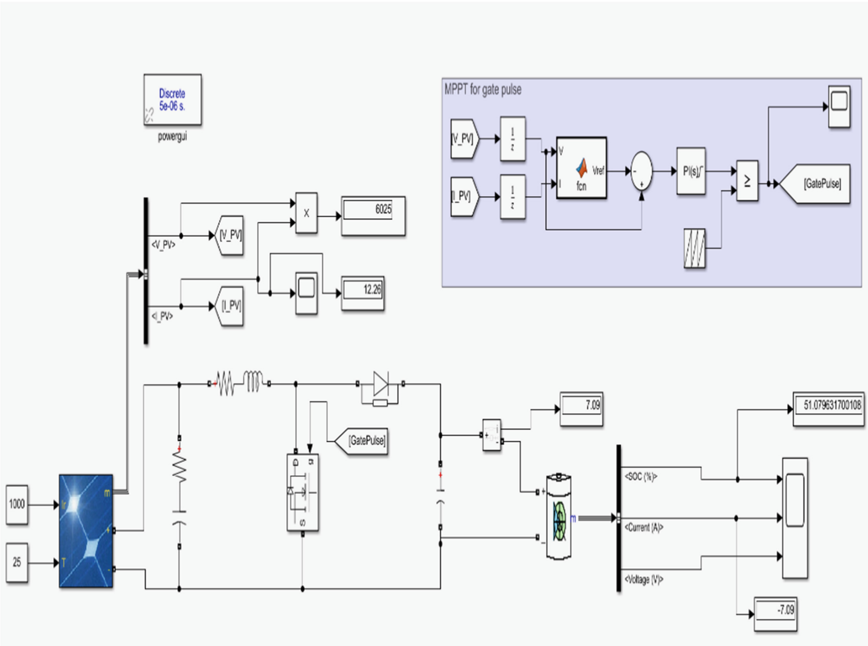

Fig. 1. Overview of solar PV MPPT charge controller mode.

The PV solar module in this model was rated at 349 W, with three parallel strings and ten series strings, totaling 30 solar panels connected. The solar arrays inputs are 1000 W/m^2 irradiance and the temperature around 25 °**C**. The solar PV module's output is taken through the measurement port and routed to a block, which is then routed to the MPPT controller. The P&O algorithm was utilized for the MPPT controller. The panel voltage was compared to the reference voltage, which was then supplied to the PI controller, which was then compared to a repeating sequence for accuracy, and maybe a gate pulse was created. The boost converter's MOSFET was now supplied this gate pulse. A capacitive filter was integrated to the load end of the converter to get a smooth voltage and current waveforms. The battery utilized has a capacity of 40 KWh and is a Li-ion battery. For performance study, the waveforms of its SOC, Voltage, and Current Gate pulse, the PV characteristics and VI characteristics of the solar array are evaluated and simulated in the Simulink.

a) Boost converter
A resistive load connected to boost converter is coupled to a solar PV module, as shown in Fig. 1. A switching-mode regulator can be utilized in a Dc-Dc converter to convert an uncontrolled dc voltage to a controlled dc output voltage. The voltage is regulated using the PWM (pulse-width modulation) approach and a MOSFET switching device. To increase the dc voltage, a boost converter is employed. When the MPPT algorithm changes and modulates the boost Dc-Dc converter's PWM duty cycle, maximum power is achieved. The duty cycle D of the power switch modulates the power transmission from the input source to the load [13].

$$V_{pv} t_{on} = \left(V_{out} - V_{pv}\right).t_{off} \tag{1}$$

And,

$$V_{out} = \frac{t_{on} + t_{off}}{t_{off}} V_{pv} \tag{2}$$

Where;

$$T = t_{on} + t_{off} \tag{3}$$

The report ton/T is referred to as the duty cycle α, and as a result

$$\alpha = \frac{t_{on}}{T} \tag{4}$$

The voltage release can be calculated using Eq. (3):

$$V_{out} = \frac{1}{1 - \alpha} V_{pv} \tag{5}$$

where:

- V_{out}: is the output voltage.
- V_{pv}: is then voltage input (solar cell).
- t_{on}: is the duration of time when the switch is closed.

b) Maximum power point tracking algorithm
In this article, the P&O MPP algorithm is used to model a solar panel system. The P&O MPPT is widely employed in medium and small commercial PVgrid-connected inverters and charge controllers, due to its tracking efficiency and ease of utilization. The MPPT algorithm monitors the peak power of the PV generator and communicates the duty cycle of the PV generator to the battery charge controller, which is relevant to the monitored peak power [11]. This method, which is based on trial and error, is used to track the highest performance point (Figs. 2 and 3).

The duty cycle of the converter switching device is altered, which changes the boost converter's actual input resistance, the software detects power fluctuations and disrupts the photovoltaic panel's working voltage. Then wait until it reaches peak performance,

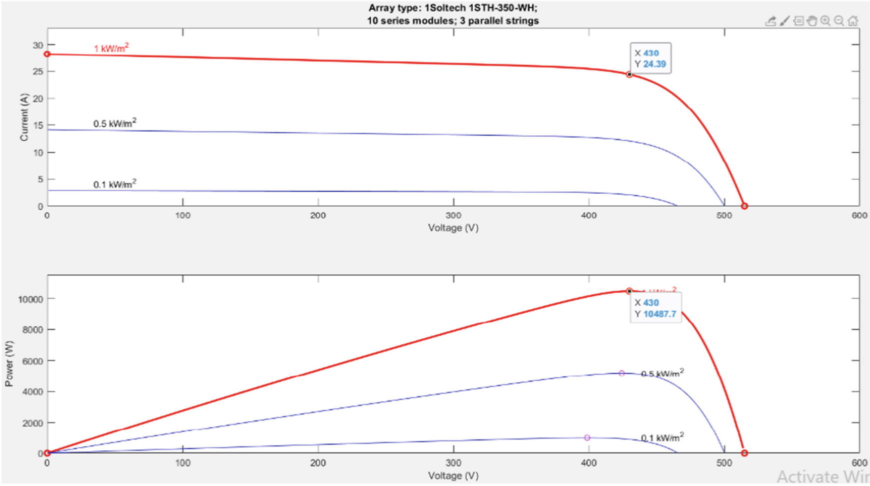

Fig. 2. Waveforms of VI characteristics and PV characteristics of the solar module.

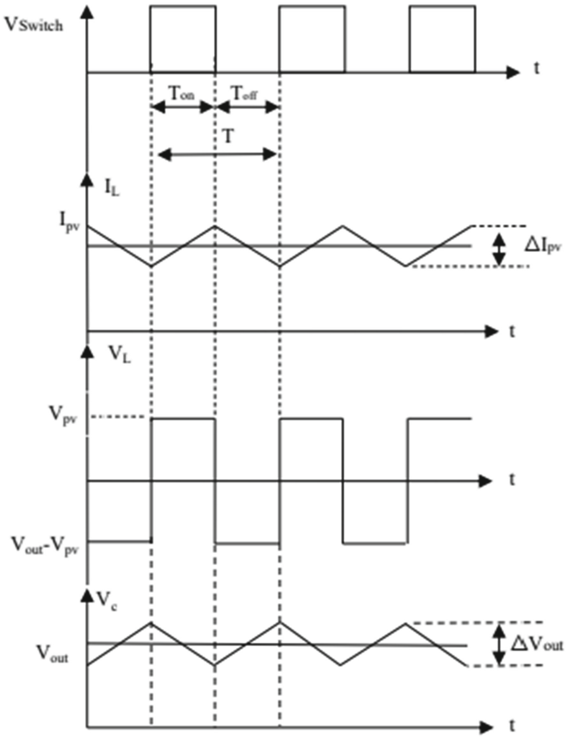

Fig. 3. Typical waveforms of boost converter.

then repeat the process forever. Because just voltage is measured in this manner, it is simple to implement. The power output of the system is verified using this method by adjusting the provided voltage. If power rises in tandem with voltage, the "is increased further; otherwise, the" is reduced. Similarly, if there is a reduction in voltage the power is increased, the duty cycle is reduced. These processes are carried out till the time the MPP has been attained. The voltage at which MPP is obtained is referred to as the reference point (Vref). As shown in Fig. 4,

If the PV module's operating voltage changes and power increases, the control system shifts the operating point in that direction; otherwise, it shifts in the other direction. As a result, depending on which side of the hill you're on, smaller or bigger duty cycle increments may be more favorable. In comparison to the hill-climbing approach, this results in less ripple at MPP. Because of its intuitive nature and strong convergence to MPP, this is the most extensively used approach in the industry. Adding a variable size to the duty cycle increments, on the other hand, improves the process even more. This approach is also vulnerable to rapidly changing weather conditions, though this can be mitigated by updating at a higher frequency [14, 15].

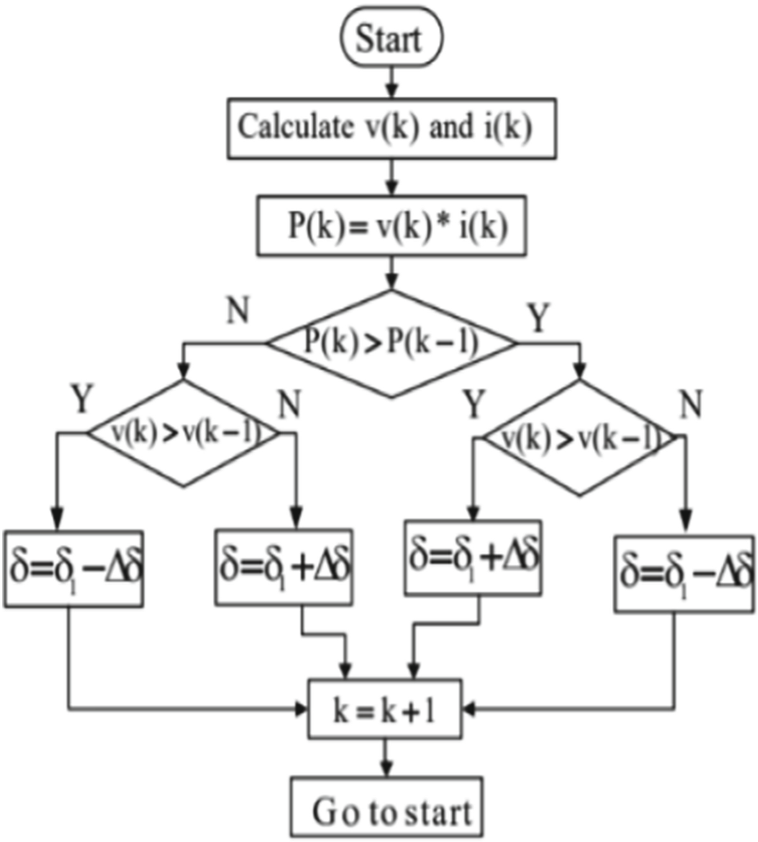

Fig. 4. P&O flowchart

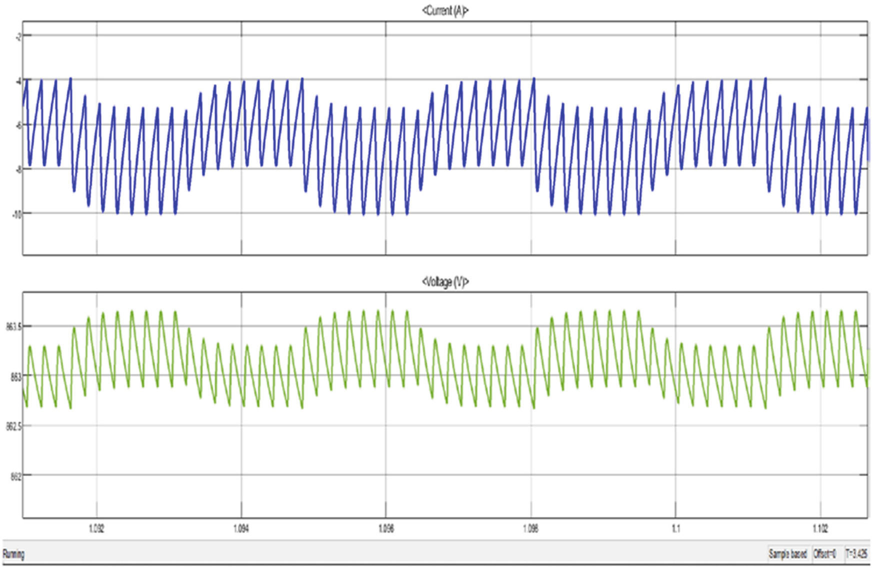

Fig. 5. Waveform of voltage and current of battery

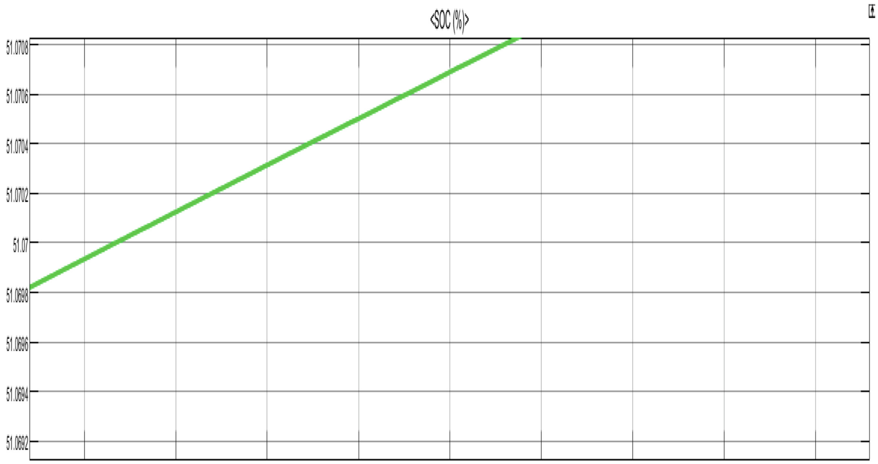

Fig. 6. Waveform of SOC of battery

c) PI Controller

To charge a lead-acid battery, the PI controller was created. The integral controller which is proportional generates an output, u(t), that is proportional to both the input, $v_i(t)$, and the integral of the input, $v_i(t)$.

$$u(t) = K_p v_i(t) + k_i \int v_i(t)dt$$

The algorithm works according to the equation of the PI controller.

V_{ref} is the reference voltage attained from the MPPT. This V_{ref} is compared to the PV voltage, V_{pv}, to generate an error signal, which is then sent to the PI control. The appropriate response can be attained by carefully setting the proportional gain, K_p, and integral gain, K_i [12]. When the power from the solar PV module is pumped into the boost converter and the PI controller is turned on, the duty cycle is varied, changing the input value perceived by the PI controller.

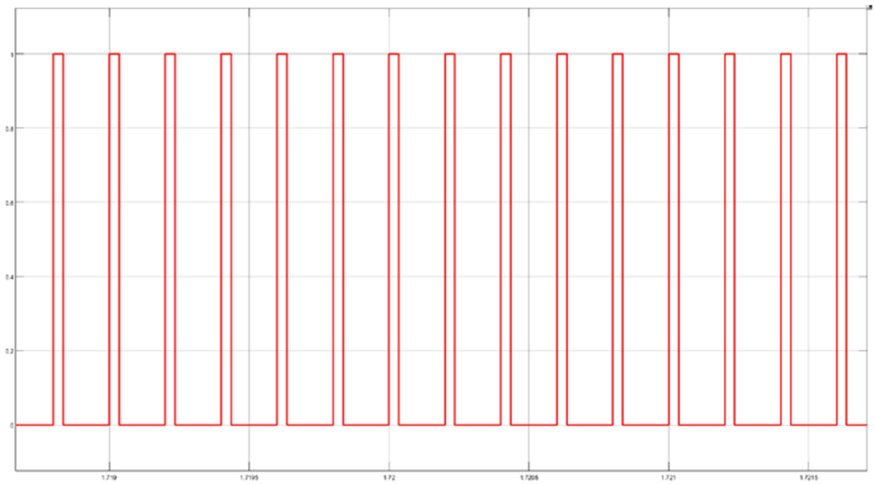

Fig. 7. Waveform of gate pulse of MOSFET

4 Discussion and Results

The simulations of MPPT battery charge controller for an isolated photovoltaic system model was successfully carried out in the MATLAB/Simulink for research‘s performance. This performance investigation verifies the MPPT algorithm's tracking capability. In this system solar panel array was rated 349 W, which is having 3 parallel and 10 series strings, meaning a total of 30 solar panels are connected in this solar array. The input of the solar array are 25 °C temperature and 1000 W/m^2 irradiance. The output of the solar panel is taken through the measurement port and given to go to block which was further given to the MPPT controller. For MPPT controller P and O (Perturb and Observe) algorithm was used. Where we compared the panel voltage with the reference voltage, which was then sent to the PI controller which was then again compared with repeating sequence for accuracy and perhaps a gate pulse was generated. Now this gate pulse was given to the MOSFET of the boost converter. A capacitive filter was added to the load end of the converter to get a smooth voltage and current waveforms. The rating of battery used is of 40 KWh capacity which is a Li-ion battery. Which is charged and the waveforms of its SOC (Fig. 6), Voltage (Fig. 5) and Current (Fig. 5) are also simulated and displayed. And also, Gate pulse (Fig. 7), the PV characteristics and VI characteristics (Fig. 2) of the solar array is simulated and displayed. Any commercialized MPPT charge controller with a comparable architecture can be modified using this Simulink model. An actual commercialized solar PV MPPT charge controller experimental setup was used to test the Simulink model's performance. This validated model assists in the optimum sizing of solar PV module and battery energy storage for small and medium freestanding PV installations.

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