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Design of Battery Charging from Solar Using Buck Converters with MPPT Algorithm

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Abstract- Photovoltaic power generation system implements an effective utilization of solar energy, but has very low conversion efficiency. The major problem in solar photovoltaic system is to maintain the DC output power from the panel as constant. Irradiation and temperature are the two factors, which will change the output power of the panel. In this article it is shown that for charging lead acid batteries from solar panel, MPPT can be achieved by perturb and observe algorithm. MPPT is used in photovoltaic systems to regulate the photovoltaic array output. A buck converter is utilized as a DC-DC converter for the charge controller. It is used to match the impedance of solar panel and battery to deliver maximum power. Voltage and current from the solar panel is sensed and duty cycle of gating signal is varied accordingly by the algorithm to attain maximum power transfer. It is obtained by using MATLAB Simulink Model.

Index Terms- Photovoltaic (PV), Buck converter, MPPT, P&O algorithm, Battery, MATLAB, Simulink

I. INTRODUCTION

Renewable energy sources have gained significant attention as the global community faces challenges related to climate change, depleting fossil fuels, and energy security. Among these, solar energy stands out as a clean, abundant, and sustainable energy source. Harnessing solar energy reduces carbon emissions, mitigates environmental degradation, and promotes sustainable development.

Solar energy has the potential to meet a substantial portion of global energy demands. Photovoltaic (PV) technology, which converts sunlight directly into electricity, is at the forefront of solar energy applications. PV systems are particularly advantageous for standalone and remote applications, providing a reliable and renewable alternative to conventional energy sources. However, optimizing the efficiency of solar energy systems remains a key challenge.

The integration of solar panels with battery storage systems ensures a continuous and reliable power supply. Batteries store excess energy generated during peak sunlight hours and release it when solar power is insufficient. However, solar panels and batteries operate at varying voltages, requiring efficient power electronics to regulate and manage energy transfer. DC-DC converters, such as buck converters, play a crucial role in stepping down voltage levels to match battery requirements. Additionally, Maximum Power Point Tracking (MPPT) algorithms are essential for maximizing the energy extracted from solar panels under varying environmental conditions.

II. SOLAR PHOTO VOLTAIC SYSTEMS

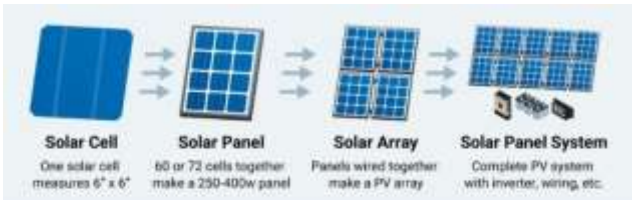

Figure 1 Solar PV Systems

As shown in Figure 1, Solar photovoltaic (PV) systems are an essential component of renewable energy generation. They convert sunlight directly into electrical energy using semiconductor materials that exhibit the photovoltaic effect. These systems are commonly used for off-grid and grid-connected applications, such as residential power systems, large solar farms, electric vehicles, and battery charging stations. This section provides a detailed overview of the basic principles of solar panels, the effects of temperature and irradiance, PV system configurations, and the performance metrics used to evaluate solar energy systems.

Basic Working Principles of Solar Panels

The working principle of a photovoltaic (PV) cell is based on the photovoltaic effect, which is the process by which a material generates electric current when exposed to light. This is achieved using semiconductor materials, commonly silicon-based, that absorb photons from sunlight and release electrons. These electrons then flow through an external circuit, generating an electric current.

Photovoltaic Effect and the Conversion of Sunlight to Electricity:

When sunlight strikes a PV cell, it is absorbed by the semiconductor material (typically silicon). The energy from the sunlight excites electrons in the material, causing them to break free from their atoms. This creates electron-hole pairs, where the electron is negatively charged and the hole is positively charged. The electric field within the PV cell drives the electrons toward the external circuit, while the holes are directed to the opposite side of the cell. The movement of these free electrons through the external circuit generates an electric current. The amount of electrical energy generated depends on the intensity of the incident sunlight and the physical properties of the PV cell, such as its efficiency in converting sunlight into electricity.

1. Battery Management Systems

Battery charging is a critical component of solar energy systems, as it ensures efficient energy storage from photovoltaic (PV) panels. The selection of battery types, charging techniques, and the use of proper management systems play a pivotal role in maximizing system efficiency and battery longevity. This section discusses different battery types used in solar systems, charging methods, the importance of Battery Management Systems (BMS), voltage regulation, and the efficiency of battery storage in solar applications.

Battery Types for Solar Systems

In solar energy systems, the choice of battery plays a crucial role in determining the system's performance, energy storage capacity, and operational longevity. The three most common battery chemistries in solar systems are Lead-Acid, Lithium-Ion, and Nickel-Metal Hydride (NiMH) batteries. Each type has its own strengths, weaknesses, and use cases, depending on factors like cost, efficiency, lifespan, and space constraints.

Charge/Discharge Cycles and Lifespan

The cycle life of a battery refers to the number of complete charge and discharge cycles it can undergo before its capacity significantly degrades. This is influenced by the depth of discharge (DoD) — the deeper the discharge, the fewer the cycles the battery can endure. Batteries like lithium-ion can handle deeper discharges with less degradation, while lead-acid batteries are more sensitive to deep discharges, which shorten their lifespan.

Battery Charging Techniques

Constant Current (CC) Charging: In Constant Current (CC) charging, the battery is charged at a fixed current until it reaches its maximum voltage. This method is suitable for the initial phase of charging when the battery is discharged. Once the voltage limit is reached, the charging method switches to Constant Voltage (CV).

Constant Voltage (CV) Charging: Once the battery reaches its set voltage, the charging process switches to Constant Voltage (CV), where the voltage is maintained at a fixed level, and the current decreases gradually as the battery approaches full charge. This method is commonly used for lithium-ion batteries.

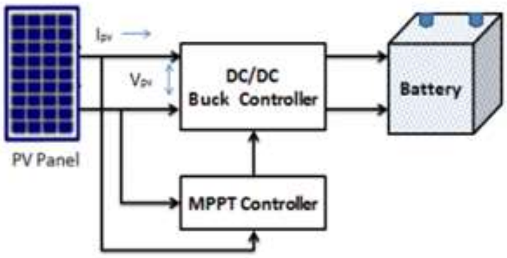

Figure 2 Block diagram of the system

III. OVREVIEW OF THE SYSTEM

In Figure 2 Block diagram of the system shows the method adopted in this work to charge batteries by sensing the battery charging current. To increase the maximum power output from the solar panel MPP tracking systems are used. Even though the temperature, irradiation and the load characteristics varies it helps in maintain the output of the solar PV panel constant. For better efficiency output from the PV panel buck converter is used for DC-DC power transmission.

In standalone PV systems buck converters are effective in dc-dc step down operation and for battery storing operations. For battery charging application step down converters gives better efficiency, tracking solar power from PV panel many MPPT techniques are available, perturb and observe, incremental conductance algorithm etc. among all the control algorithms the P&O algorithm is widely used and more effective with simple control algorithm.

The insolation and temperature problems can be overcome by using P&O, this is effective, flexible and earliest control algorithm. Insolation (short for incident or incoming solar radiation) is a measure of solar radiation energy received on a given surface area and recorded during a given time.

Irradiation expressed in watts per square meter (W/m2). In photovoltaic a proportion of radiation reflected or absorbed depends on the object's reflectivity. The insolation into a surface is largest when the surface directly faces the Sun.

As the angle increases between the direction at a right angle to the surface and the direction of the rays of sunlight, the insolation is reduced in proportion to the cosine of the angle. The buck converter performs buck operation where voltage is stepped down, this can used for low power applications and battery charging.

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Buck Converter
A DC-DC Buck Converter is a type of switching regulator used to step down a higher input DC voltage to a lower output DC voltage, while maintaining energy efficiency. In the context of solar energy systems, the converter ensures that the solar panel's output, which can fluctuate based on sunlight and temperature, is converted to a stable voltage that can safely charge the battery.

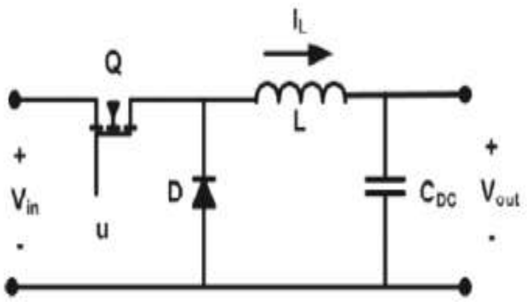

Figure 3 Buck Converter

Basic Operation of a Buck Converter
Figure 3 shows Buck Converter. A buck converter operates using an inductor, a switching element (typically a transistor), a diode, and a capacitor. The basic operation involves the switching element turning on and off at high frequencies to regulate the energy transfer from the input source (solar panel) to the output (battery). The inductor stores energy when the switch is on and releases it when the switch is off, while the capacitor smoothens the output voltage.

Key Operational Stages Include
When the switch is closed: Current flows from the input source through the inductor to the load, causing the inductor to store energy.

When the Switch is Open: The energy stored in the inductor is released to the output through the diode, providing continuous current to the battery.

The efficiency of the converter is critical because it directly impacts the amount of usable energy delivered to the battery.
Role of Buck Converters in Solar Battery Charging Systems:

In solar energy systems, the buck converter serves two primary functions:

- **Voltage Regulation:** The converter steps down the voltage from the solar panel to a level that matches the battery's charging requirements. Solar panels typically generate higher voltages than what most batteries can safely handle, and the buck converter adjusts the voltage to the optimal charging level.
- **Improving Power Efficiency:** Since solar irradiance is dynamic and can fluctuate throughout the day, a buck converter can maintain a consistent voltage output to charge the battery effectively, despite variations in the solar panel's input.

Design Considerations
The design of a buck converter for solar systems must take into account:

- **Input Voltage Range:** The solar panel's output varies with changing sunlight, and the converter must be able to handle the range of voltages.
- **Output Voltage Requirements:** The battery to be charged will have specific voltage requirements, and the buck converter must match these requirements to avoid damage to the battery.
- **Efficiency:** The converter should operate with high efficiency, ideally above 90%, to minimize energy losses.
- **Inductor and Capacitor Selection:** Proper component selection ensures stable operation and smooth voltage conversion.

Integration of MPPT with Buck Converters
One of the challenges in solar systems is that the power output from solar panels is not constant and varies with environmental factors such as solar irradiance and temperature. The Maximum Power Point Tracking (MPPT) algorithm is used to dynamically adjust the operating point of the solar panel to ensure it operates at its peak power output under varying conditions.

Working Principle of MPPT
The MPPT algorithm continuously monitors the solar panel's output voltage and current. It then calculates the Maximum Power Point Tracking (MPPT), which is the combination of voltage and current at which the solar panel produces the maximum power. By adjusting the operating voltage or current, the MPPT controller ensures the panel operates at this optimal point, thus maximizing energy harvest.

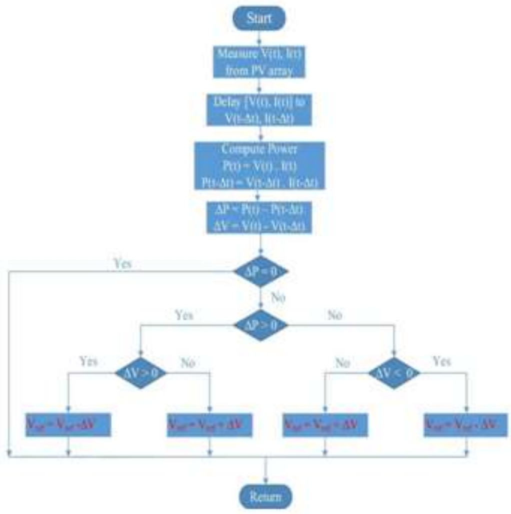

Figure 4 Flow Chart

There are several MPPT algorithms, including:
Perturb and Observe (P&O): This method periodically adjusts the voltage and measures the resulting change in power. If the power increases, the algorithm continues in the same direction, otherwise, it reverses the adjustment.

Explanation of the Flowchart
As shown in the Figure 4 Flow Chart, at first the voltage and current from PV array are measured. After that, the product of voltage and current gives the actual power of PV module. Then, it will check status what whether $\Delta P = 0$ or not. If this status is satisfied, then operating point is at the MPPT. If it is not satisfying, then it will check another status that $\Delta P > 0$. If this status is satisfied, then it will check out that $\Delta V > 0$. If it is satisfied, then it indicates that operating point is at the left side of the MPP. If $\Delta V > 0$ status is not satisfied, then it indicates that operating point is at the right side of the MPPT. This process is continuously repeated until it reached the MPPT. So, at all times there is a compromise between the increments and the sampling rate in the P&O algorithm.

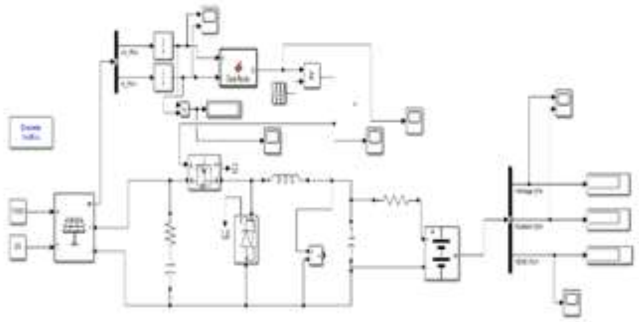

Figure 5 Simulink Model

IV. SIMULATION

In Figure 5 Simulink Model, Simulation is done using MATLAB/Simulink the entire system is simulated. Here the maximum output power from solar PV is obtained by using P&O algorithm. MPPT or Maximum Power Point Tracking is algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called 'maximum power point' (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature.

Eventually from the above results it is clear that the PV Module based power system which is simulated here is fully capable of delivering maximum power about 210W under cell temperature of 25C and irradiance of 1000 W/m2 with maintaining the MPPT and controlling of a 12V battery. Here simulation has been performed for a set of temperature and irradiation levels, so it can be said that this model can be used to test any PV module or even any PV Array based power system under any irradiation and temperature conditions. If the irradiation level is decreased then the power of the array will go down similarly the output charging current will also go down and vice versa.

Again, the temperature level is increased then the power of the array will go down similarly the output charging current will also go down and vice versa. Also, if the number of parallel strings increases both the power and charging current increases. From fig 10.6, it is seen that the SoC of the battery varies from 45%to 45.004% in one second.

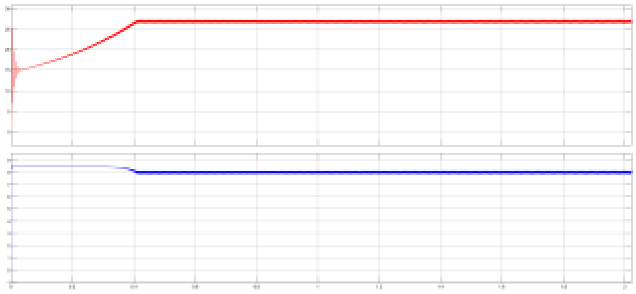

Figure 6 Battery state of charge

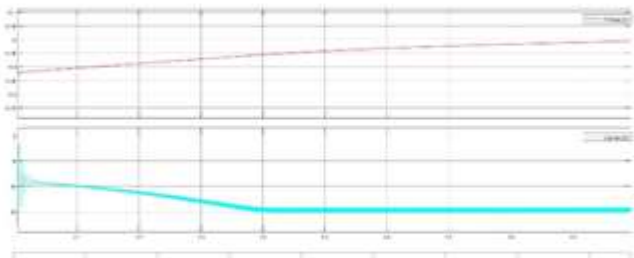

Figure 7 voltage and current of PV array

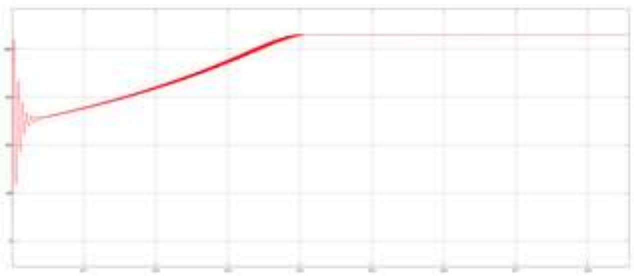

Figure 8 PV power

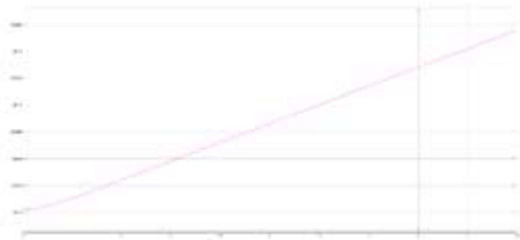

Figure 9 output charging voltage and current of battery

In Figure 6, 7 shows the Battery state of charge, voltage and current of PV array respectively. In Figure 8, 9 shows PV power. And the output charging voltage and current of battery respectively.

V. CONCLUSION

This article presents modelling of a Solar PV MPPT battery charge controller model in Simulink. A buck converter which provides the battery, to run at 12V. The power conversion is performed by the buck converter. The maximum power point tracking algorithm used is the perturb and observe algorithm is coded in MATLAB, the amplitude of the reference current which is used to control the switching of buck converter. With the change in irradiation the amplitude of the current also changes.

The algorithm would ensure maximum power point tracking by controlling the MOSFET of the buck converters by varying its duty cycle. The Simulink Model of the solar array gives the output power and the output current. The variation in solar irradiation and the temperature also gives a varying output power and output current. Buck converter is used in controlling the charging current supplied to the battery based on the power obtained from the PV system. This proposed work can be used in connecting directly to load or even connected to appliances through inverter circuit. This will reduce the pollution that results from burning of the fuels, The battery life can be improved and constant power can be supplied to the load.

Future Scope

The integration of renewable energy systems like solar-powered battery charging is a rapidly evolving field with significant potential for innovation and improvements. The following outlines the future scope for the design of a solar battery charging system using a buck converter and the Perturb and Observe (P&O) algorithm:

Enhanced MPPT Techniques

- **Incorporating AI/ML-Based MPPT Algorithms:** Future systems can leverage machine learning (ML) or artificial intelligence (AI) to predict the maximum power point (MPP) more accurately under varying environmental conditions, such as partial shading or sudden weather changes.
- **Hybrid MPPT Techniques:** Combining P&O with other advanced MPPT techniques, like Incremental Conductance (IC), Fuzzy Logic, or Particle Swarm Optimization (PSO), could improve efficiency and adaptability.
- **Adaptive Step-Size P&O:** Implementation of an adaptive step-size approach to reduce oscillations around the MPP and improve tracking speed.

Development of Smarter Converters

- **High-Efficiency Synchronous Buck Converters:** Future designs can adopt synchronous buck converters to further minimize switching losses and increase energy conversion efficiency.
- **Wide Bandgap Semiconductors:** Using materials like silicon carbide (Si C) or gallium nitride (Ga N) in converter design can enhance efficiency, reduce heat generation, and support higher power densities.
- **Integrated Converter Designs:** Integrating multiple functionalities, such as protection circuits and advanced control systems, within the buck converter.

Advanced Battery Management

- **Universal Battery Charging Systems:** Developing systems that can support various battery chemistries, including lithium-ion, lead-acid, and solid-state batteries, by dynamically adjusting charging profiles.
- **State-of-Health (So H) Monitoring:** Incorporating advanced battery health monitoring systems to predict battery lifespan, optimize charging cycles, and improve safety.
- **Temperature Compensation:** Adding real-time temperature monitoring to dynamically adjust charging rates and prevent overcharging or thermal runaway.

Integration with Smart Grids and IoT

- **IoT-Enabled Monitoring and Control:** Embedding IoT modules to allow remote monitoring, real-time performance tracking, and system diagnostics via smartphones or cloud platforms.
- **Smart Grid Compatibility:** Future systems can integrate with smart grids to supply excess energy generated during peak hours or draw power when solar energy is unavailable.
- **Energy Analytics:** Using IoT and AI tools to analyze power generation and consumption trends for optimized energy management.

Handling Dynamic Environmental Conditions

- **Partial Shading Optimization:** Incorporating global MPP techniques or dynamic reconfiguration of PV modules to handle partial shading effectively.
- **Weather-Adaptive Systems:** Designing systems capable of predicting and adjusting for weather changes, such as cloudy or rainy days, to maintain optimal performance.
- **High-Speed Control Algorithms:** Development of high-speed digital control systems to enhance the response time of the MPPT during rapidly changing conditions

REFERENCES

1. Fellipe S. Garcia, José Antenor Pomilio, and Giorgio Spiazzi, “Modelling and Control Design of the

Interleaved Double Dual Boost Converter", IEEE Transactions on Industrial Electronics, Vol. 60, NO. 8, pp. 3283-3290. August 2013.

2. Eftichios Koutroulis, Kostas Kalaitzakis, and Nicholas C. Voulgaris, "Development of a Microcontroller-Based, Photovoltaic Maximum Power Point Tracking Control System", IEEE Transactions on Power Electronics, Vol. 16, No. 1, pp. 46-54, January 2001
3. R. Gules, J. De Pellegrin Pacheco, H. L. Hey, and J. Rnhoff, "A maximum power point tracking system with parallel connection for PV stand-alone applications", Transactions on Industrial Electronics., vol. 55, no. 7, pp.2674–2683, July. 2008.
4. Jae-Jung Yun, Hyung-Jin Choe, Young-Ho Hwang, Yong-Kyu Park, and Bongkoo Kang, "Improvement of Power-Conversion Efficiency of a DC–DC Boost Converter Using a Passive Snubber Circuit", IEEE Transactions on Industrial Electronics, VOL. 59, NO. 4, pp.1808-1841, APRIL 2012.
5. Liang Jia, Zhiyuan Hu, Yan-Fei Liu, and Paresh C. Sen, "Predictable Auxiliary Switching Strategy to Improve Unloading Transient Response Performance or DC–DC Buck Converter", IEEE Transactions on Industry Applications, VOL. 49, NO. 2, pp. 931-941, March/April 2013.
6. F. Liu, S. Duan, F. Liu, and Y. Kang, "A variable step size INC MPPT method for PV system," IEEE Transactions on Industrial Electronics., vol. 55, no. 7, pp. 2622–2628, July. 2008.