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Design And Implementation of Maximum Power Point Tracking (MPPT) Controller for PV Water Pumpin

Eldhose K A[1], Thajun Nisha T M[1], Lakshmi Baburaj[2], Roshan Joe Shiji[2], Keerthana Remesh[2], Devasy G Chakiath[2]

[1]*Assistant Professor, Department of Electrical and Electronics Engineering, Mar Athanasius College of Engineering Kothamangalam, APJ Abdul Kalam Technological University, Thiruvananthapuram, Kerala, India.*

[2]*Student, Department of Electrical and Electronics Engineering, Mar Athanasius College of Engineering Kothamangalam, APJ Abdul Kalam Technological University, Thiruvananthapuram, Kerala, India.*

Corresponding Author: lakshmibaburajcn@gmail.com

Abstract— This paper presents an affordable solution for water extraction in remote regions through a photovoltaic water pumping system equipped with maximum power point tracking (MPPT). The MPPT algorithm optimizes power extraction from PV panels, enhancing battery charging efficiency. A DC-DC converter within the MPPT compares PV module voltages to battery voltage, ensuring optimal power utilization. MATLAB simulations validate the DC-DC converter design and hardware implementation. The system comprises a microcontroller (ESP32), sensors, synchronous buck converter, USB-TTL UART, line buck regulators, PV panel, and battery, with all circuitry programmed within the microcontroller. To ensure peak efficiency, the system will employ the Maximum Power Point Tracking (MPPT) algorithm for control. The DC-to-DC converter model will be programmed in MPPT mode, utilizing an optimal duty ratio to attain maximum output. The proposed systems' portable design provides users with significant advantages. Furthermore, its eco-friendly nature, coupled with battery backup and cost-effectiveness, enhances its appeal.

Index Terms—**Maximum Power Point Tracking (MPPT), Solar photovoltaic (SPV) array, BLDC motor, Arduino, Synchronous Buck Converter, P&O MPPT Algorithm.**

1. Introduction

The utilization of solar energy for powering water pumps through PV conversion is rapidly gaining traction, albeit with notable challenges. This technology offers scalability and presents an environmentally friendly alternative to conventional fossil fuel-based pumps. With the depletion of oil reserves, uneven electricity distribution, and escalating costs, especially in developing nations like India, the significance of solar PV energy for water pump operations is paramount.

PV panels exhibit a nonlinear voltage-current characteristic, with a distinct maximum power point (MPP) influenced by environmental factors such as temperature and irradiation. Maximizing harvested power requires dynamic adjustment of the duty ratio based on load and climate changes, a process known as Maximum Power Point Tracking (MPPT). The primary objective of this study is to design an efficient charge controller. This entails developing a system comprising a microcontroller, sensors, and necessary electronics to monitor and optimize power consumption while maximizing power output.

This paper focuses on implementing a cost-effective Maximum Power Point Tracker (MPPT) solar charge controller aimed at consistently optimizing power output from a solar panel. The system utilizes a DC/DC synchronous buck converter and a microcontroller to achieve this goal. The MPPT algorithm, employing the perturb and observe method, is implemented using an Arduino Uno. Voltage and current sensors are employed to monitor the panel's output, enabling the system to track the maximum power point. Under conditions of stable or gradually changing irradiance and temperature, the perturb and observe method efficiently tracks the MPP, determining the operating point where maximum power can be extracted from the solarphotovoltaic(SPV) array. The controller adjusts the duty cycle by providing a PWM signal, subsequently modifying the voltage through the Buck converter. During operation, if power output increases, the system continues to adjust the duty cycle in that direction until no further increase is observed. A prototype of the system has been developed and thoroughly evaluated to assess its performance.

2. Synchronous Buck Converter

Switched mode power converters are widely utilized across industries today, offering efficient solutions for diverse applications. Among these, the DC: DC step-down converter, commonly referred to as the buck converter, stands out in the

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consumer electronics sector. Employing a synchronous buck topology, this converter efficiently regulates output voltage lower than its input, while efficiently managing high currents with minimal power loss. Its core components include two power MOSFETs, an output inductor, and a capacitor. The synchronous buck converter, depicted in Figure 1, consists of two power MOSFETs, an output inductor, and an output capacitor. Its nomenclature stems from the synchronized control strategy applied to the MOSFETs, ensuring regulated output voltage and preventing simultaneous activation. This synchronization is crucial for maintaining efficiency and stability in the conversion process, enhancing overall performance and reliability.

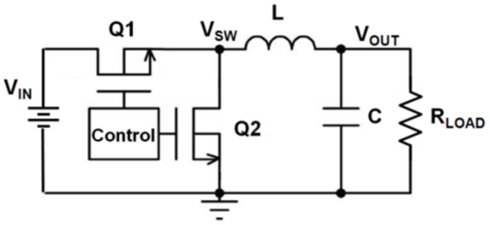

Fig.1. Synchronous Buck Converter

In the synchronous buck converter operation, Q1, serving as the high side MOSFET, connects directly to the input voltage of the circuit. When Q1 switches on, it allows current to flow to the load. Meanwhile, Q2 remains off, enabling the current through the inductor to increase, thus charging the LC filter. Upon Q1 switching off, Q2 turns on, facilitating current flow to the load through the low side MOSFET. Consequently, the current through the inductor decreases, leading to the discharge of the LC filter. Additionally, the low side MOSFET serves another vital function when both MOSFETs are off. It acts as a clamp, utilizing its body diode to limit the voltage at the switch node (VSW). This prevents VSW from dropping excessively negative when the high side transistor initially switches off.

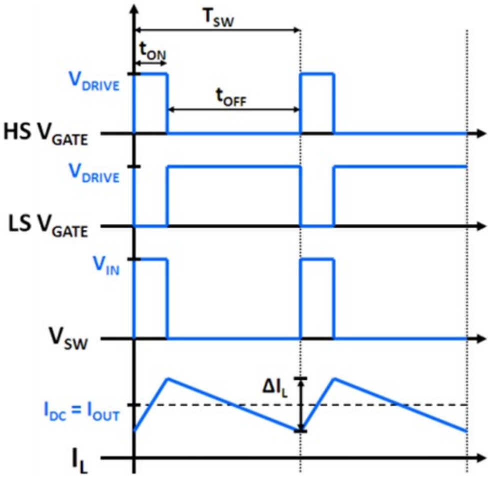

Fig.2. Synchronous Buck Converter Waveforms

In Figure 2, the fundamental waveforms for the synchronous buck converter operating in continuous conduction mode are illustrated. The total variation in inductor current, known as the peak-to-peak inductor current (IL), is depicted. Additionally, the switch node voltage experiences smoothing through the LC output stage, resulting in a regulated DC voltage at the output. To ensure proper operation and prevent damage, the MOSFETs are synchronously controlled. This synchronous control mechanism prevents shoot-through, a scenario where both the high side and low side MOSFETs are concurrently activated, leading to a direct short circuit to ground. By coordinating the switching of the MOSFETs, shoot-through is effectively avoided. The duty cycle (D) of the synchronous buck converter, which is determined by the on-time of the high side MOSFET, can be calculated using Equation 1.

$$D = \frac{t_{ON.HS}}{t_{ON.HS} + t_{OFF.HS}} \cong \frac{V_{OUT}}{V_{IN}}$$

Equation1.

When the duty cycle (D) equals 1, the high side MOSFET remains on throughout the entire switching cycle, resulting in the output voltage being equal to the input voltage. Conversely, a duty cycle of 0.1 indicates that the high side MOSFET is on for only 10% of the switching cycle. Consequently, the output voltage will be approximately 10% of the input voltage, reflecting the proportion of time the high side MOSFET is conducting relative to the entire switching cycle.

3. Basic Working Principle

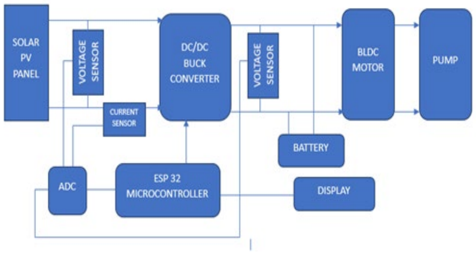

Fig.3. Block diagram of SPVWPS using Buck converter and BLDC motor

The proposed system is a PV-fed BLDC motor-driven water pumping system, outlined in Figure 3. It comprises several components including a solar photovoltaic array, solar charge controller, voltage, current, and temperature sensors, Li-ion battery, BLDC motor, and pump.

The solar charge controller integrates tracking sensors (voltage, current, and temperature), a synchronous buck converter, LCD display, ADC, microcontroller (ESP32), wireless module, and USB charging circuit. The ESP32 microcontroller orchestrates the entire system's operation. The primary principle of Maximum Power Point Tracking (MPPT) is to optimize the PV module's performance by operating it at the most efficient voltage for maximum power extraction. The MPPT algorithm compares the PV module's output with the battery voltage to determine the optimal power level and voltage for charging the battery efficiently. Additionally, it can supply power to a DC load connected directly to the battery. In this proposed system, the MPPT is implemented using the perturbed algorithm (hill-climb algorithm). The MPPT device adjusts the duty cycle while comparing the harvested power to approach the highest possible power from the solar panels. Analog-to-Digital Converter (ADC) interfaces with analog sensors, converting physical parameters such as voltage, current and temperature into measurable digital signals for the microcontroller. A synchronous buck converter regulates the input voltage to safely charge the battery. The system's status, including battery charging level, output power, voltage, and current, is displayed on an LCD and LEDs. With the battery and MPPT system integrated, the BLDC motor drives the water pump, drawing power from the solar PV array.

In summary, the system efficiently utilizes solar energy to power the water pumping system, employing MPPT for optimal power extraction and a range of sensors and control circuits for effective operation and monitoring.

4. Hardware

A. Solar Panel Module

In the proposed system, two solar panels are connected in series to form a photovoltaic module. Each solar panel has the following specifications:

Maximum Power= 50W ±5%
Maximum Power Voltage = 21 V
Maximum Power Current = 2.62 A
Open Circuit Voltage = 24.50 V
Short Circuit Current = 2.83 A
Weight= 4 Kgs

B. MPPT Unit

The MPPT unit in the system features essential components to optimize solar panel performance. It includes a DC-to-DC synchronous Buck Converter, voltage and current sensors, and an LCD for displaying output parameters. Solar panel output is directed to a synchronous buck mode DC-DC converter, adjusting voltage for battery charging. PWM signals required for converter operation are generated by the ESP32 microcontroller, with duty cycle variation managed by the MPPT algorithm. Solar voltage, current, and battery voltage readings are transmitted to a PC for monitoring. Digital pins D8 and D9 of the ESP32 control PWM signals to the IR2104 MOSFET driver IC. Analog inputs A1, A2, and A3 are used for PV voltage, current, and battery voltage sensing, respectively, interfacing with a 12-bit external ADC.

C. Solar and Battery voltage sensors

In the proposed system, constant monitoring of both battery and solar voltage is essential for efficient operation. To achieve this, a voltage divider circuit is employed, utilizing resistors R1 and R2 with values of 200K and 5.1K, respectively. Before being input into the ESP32, the analog voltage undergoes filtering to ensure accuracy. This involves passing the voltage through a 100 nf filtering capacitor (C1) to smooth the output and suppress noise spikes, preventing erroneous readings. Subsequently, the filtered signal is directed to the analog pin of the 12-bit ADC for precise measurement. Additionally, current sensing is facilitated by a 30 Amp ACS 712 hall effect sensor, with its output connected to the A2 pin of the ADC. Furthermore, an NTC temperature sensor, requiring less precision, is directly connected to an ESP32 ADC pin for temperature monitoring purposes.

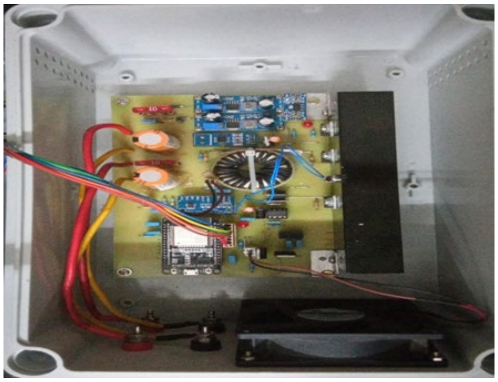

Fig.4. Hardware of MPPT

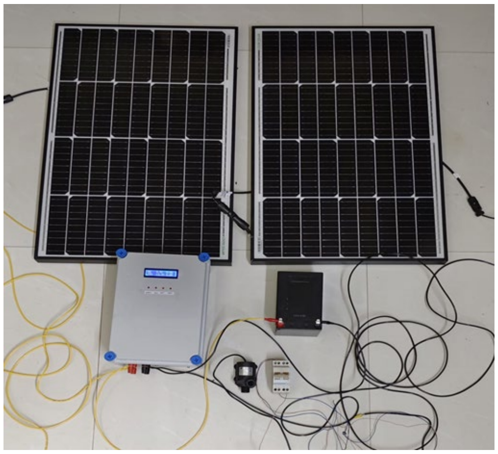

Fig.5. Hardware of entire system

D. Backflow Current Control Unit (BCCU)

The diode inside MOSFET Q2 poses a challenge, allowing current from the battery to flow back to the solar panels during periods when the panel voltage is lower than the battery voltage, such as at night. To address this issue, a reverse blocking MOSFET configuration utilizing Q1 and Q2 is employed. This configuration positions the body diodes of Q1 and Q2 in opposition, preventing current leakage in both directions. Q1, a reverse blocking, high-side N-channel MOSFET, effectively blocks the current leakage from Q2's body diode. The switching of Q1 is controlled by the DC-DC converter B1212. Additionally, resistor R37 acts as a pulldown resistor, ensuring the discharge of Q1's gate charge when the BCCU (Battery Charge Controller Unit) is deactivated. B1212, an isolated 12V DC-DC converter, plays a crucial role by providing a separate ground potential for switching Q1's source and gate pins. When

GPIO27 is set to a logic HIGH state, Q4 conducts, supplying power to U2 from the 12V line. This provides an isolated 12V supply to Q1, enabling it to turn on and conduct. Conversely, when GPIO27 is low, power is disconnected from U2 and Q1. R37 facilitates the dissipation of any remaining charge at the gate and source pins of Q1, causing it to turn off. This comprehensive setup ensures effective control of MOSFETs, preventing unwanted current flow and enhancing system reliability.

E. External ADC

The ESP32 features a built-in ADC with a resolution of 12 bits, providing 4096 values to represent voltages and currents. However, the ADC's linear response may lead to inaccuracies when measuring voltages within the range of 0 to the reference voltage. To address this limitation, external ADCs are utilized for improved accuracy. In the proposed system, analog inputs A0 through A3 are designated for interfacing with an external ADC.

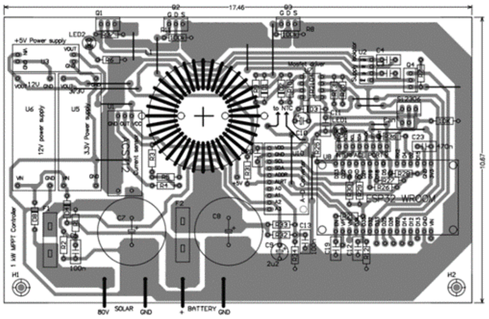

Fig.6. Component layout of MPPT

F. Synchronous Buck converter

The synchronous buck converter is a vital component in power electronics, capable of efficiently producing a regulated output voltage lower than its input voltage while handling high currents with minimal power loss. In its typical configuration, illustrated in Figure 1, the synchronous buck converter comprises two power MOSFETs, an output inductor, and an output capacitor. The key characteristic of this buck topology is its synchronized control method for the two power MOSFETs. By synchronizing the on/off control of these MOSFETs, the converter ensures a stable and regulated output voltage while preventing both MOSFETs from conducting simultaneously. This synchronization is essential for maintaining efficiency and preventing potential damage to the components by avoiding shoot-through conditions. Overall, the synchronous buck converter provides an efficient and reliable solution for a wide range of applications, offering precise voltage regulation and high current capabilities while minimizing power losses.

G. Line Buck Regulators

In the MPPT system, two XL7005A buck regulators, labeled U6 and U5, are utilized to provide regulated voltages to various components. U6 is configured to output a fixed voltage of 3.3V, which is achieved through resistor values set by R17, R18, and R19. This regulated voltage is supplied to all components requiring 3.3V. U5, on the other hand, outputs a fixed voltage of 10.625V, established by resistor values set by R14, R15, and R16. This voltage is directed to the cooling fan port, the BCCU (Battery Charge Controller Unit), and the MOSFET driver gate drive supply pin. To provide the 5V required by the ACS712 IC, a linear regulator labeled U3 (AMS1117) is employed. U3 is connected to the 10.625V output of U5, ensuring a stable 5V supply for the proper operation of the ACS712 IC. Overall, this arrangement of buck regulators and linear regulators ensures that the various components in the MPPT system receive the appropriate and stable voltage levels required for their operation.

H. Perturb and Observe Algorithm(P&O)

The method described is indeed common and straightforward, utilizing two sensors, namely the voltage sensor and current sensor, to monitor the PV array voltage and current. This approach offers a cost-effective implementation and is relatively easy to deploy. The operation revolves around the Perturb and Observe (P&O) algorithm, where the operating voltage is sampled periodically. The algorithm adjusts the operating voltage towards the maximum power point (MPP) by iteratively increasing or decreasing the PV array voltage. This adjustment is based on comparisons of power quantities between the present and past instants. If the power at the present instant exceeds the previous value, the perturbation continues in the same direction in the next cycle. Conversely, if the power decreases, the perturbation direction is reversed. Through this iterative process, the system gradually converges towards the MPP. The flow chart of the P&O method provides a visual representation of this iterative process, guiding the implementation of the algorithm.

Utilizing a sole voltage sensor to detect PV voltage and quantify power, this method strives for consistent power by adjusting the operating point accordingly.

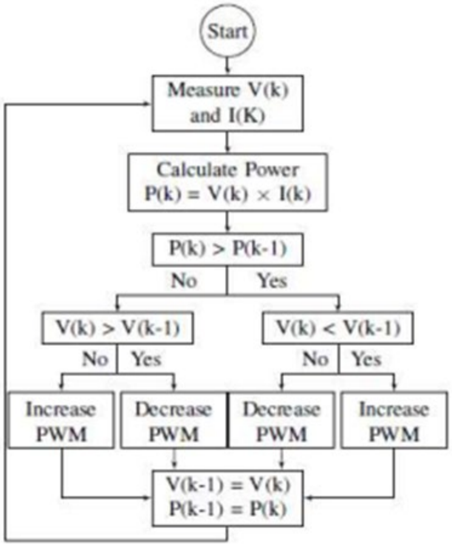

Fig.7. Perturb and Observe Algorithm

Yet, its tendency to induce power oscillations stems from its relentless perturbations, persisting even upon reaching the maximum power point (MPP). The remedy lies in imposing an error limit to halt this recursive adjustment process, thereby curbing oscillations. Renowned as the hill climbing method, its essence lies in navigating the power vs. voltage curve, leveraging the ascent and descent around the MPP to optimize performance with minimal complexity. Overall, this method offers a practical and efficient means of tracking the MPP of the PV array, ensuring optimal power generation.

5. MATLAB Simulations and Results

The MATLAB simulation prototype represents a comprehensive system integrating a 100W, 12V solar PV panel, and an MPPT for efficient energy extraction. The MPPT optimizes power output, and its output is fed into a Boost converter, elevating the combined solar panel and battery output to 24V. Adding sophistication, a Bidirectional DC-DC converter, specifically a Synchronous Buck Converter, manages the charging and discharging cycles of the battery. The battery operation is refined through a PI controller, ensuring precise control. The BLDC motor, regulated by a hall sensor, com-pletes the system, providing a versatile and adaptable model for analyzing the dynamic interplay of components. This simulation prototype serves as a valuable tool for understanding and refining the proposed project, offering insights into system behavior and performance optimization.

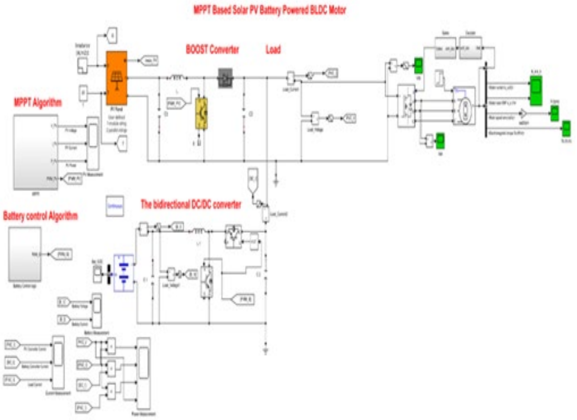

Fig.8. MPPT standalone model

The presented results showcase essential measurements from the solar PV system, including voltage, current, and power. Notably, the voltage remains consistently stable at approximately 18V, indicating a reliable output. In contrast, both current and power exhibit dynamic variations throughout the day, reflecting the solar panel's response to changing environmental conditions. This dynamic behavior underscores the system's adaptability and responsiveness to fluctuations in sunlight intensity, offering valuable insights into the temporal performance trends of the solar PV system.

Such observations are crucial for understanding the system's reliability and its potential optimization for diverse operating conditions and environmental scenarios.

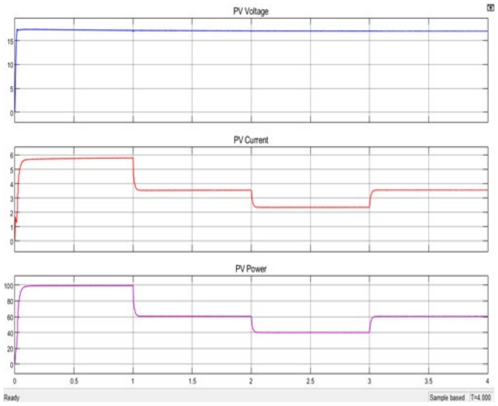

Fig.9. Solar PV Measurements

The depicted figure.10 illustrate the currents in the PV converter, battery converter, and load. Notably, during the discharging phase, a distinctive reversal in battery current is evident. This reversal highlights the bidirectional functionality of the system, where the battery not only stores energy during charging but also releases stored energy during discharging, showcasing the versatility and dynamic control capabilities of the battery converter in managing bidirectional energy flow within the system.

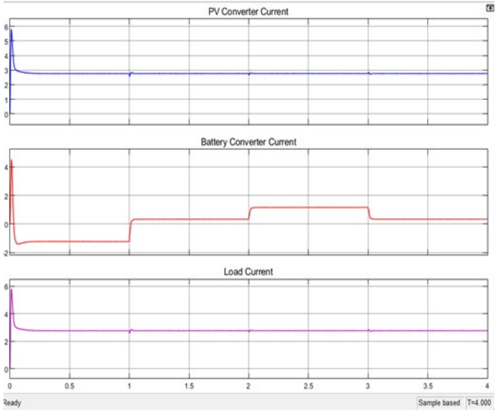

Fig.10. Current Measurement

The presented results offer insights into the battery dynamics, encompassing both charging and discharging phases. Notably, the battery voltage remains consistently stable at 12V throughout the entire process. This steadiness in voltage reflects the effective regulation and control mechanisms in place, underscoring the reliability and stability of the system's energy storage component. The accompanying battery current profiles provide a comprehensive view of the energy flow dynamics during both charging and discharging operations, contributing to a thorough understanding of the system's performance.

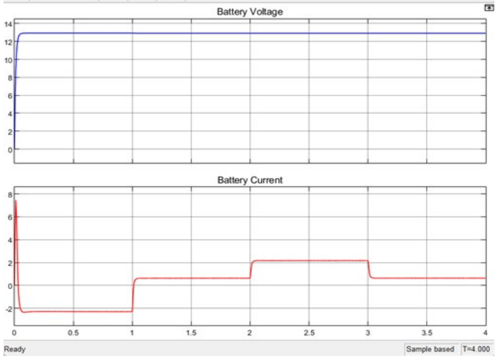

Fig.11. Battery Measurements

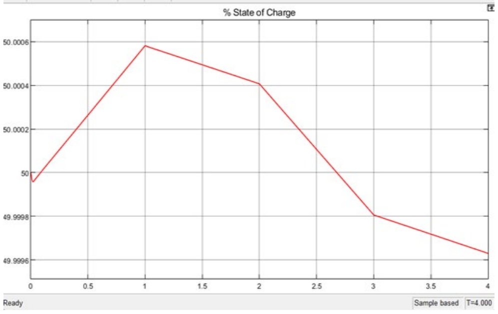

Fig.12. Battery SOC%

The figure 12 indicates the State of Charge (SOC) which is a crucial parameter indicating the current energy content of a battery. This metric, expressed as a percentage, reflects the relative capacity utilization. Monitoring SOC is essential for assessing the available energy and predicting battery performance. In our system, precise SOC measurements contribute to effective energy management, enabling informed decisions on charging and discharging processes for optimized battery utilization and prolonged operational life. The BLDC motor in our system exhibits dynamic performance through key parameters. Stator current influences motor operation, determining torque and speed characteristics. Motor speed is a vital metric representing rotational velocity, while electromagnetic torque signifies the motor's rotational force. Electromotive force (EMF) is generated in the motor winding is shown in figure 14, influencing performance. Monitoring these parameters ensures precise control, optimizing motor efficiency and responsiveness, crucial for applications like solar water pumping, where reliable and efficient motor operation is essential.

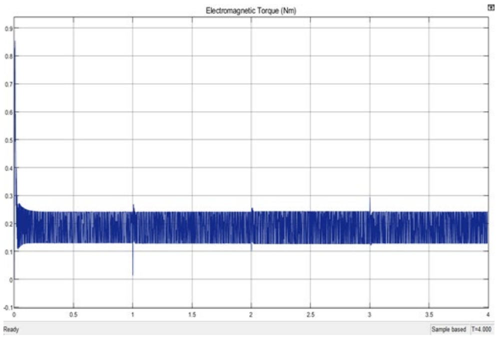

Fig.13. Motor Torque

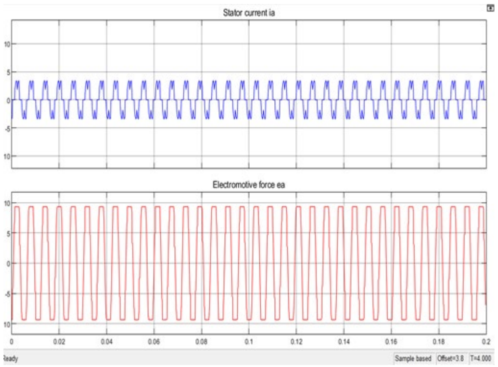

Fig.14. Stator Current & Electromotive force

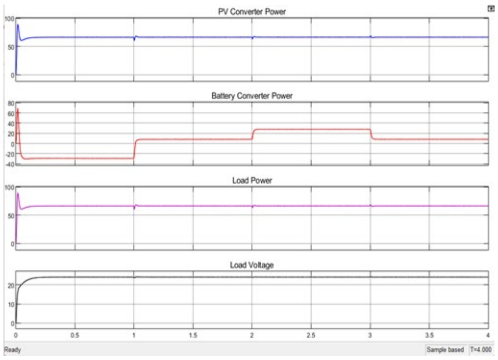

Fig.15. Power at load, battery converter,PV converter and load voltage

In a MPPT-based BLDC motor system, various power measurements provide insights into its performance. Solar PV power output is crucial, indicating the energy harvested. The battery contributes to system autonomy, with charging and discharging powers influencing overall energy flow. Motor input power reflects the electrical power supplied to the BLDC motor, directly impacting its operation. Output power represents the mechanical power delivered by the motor. These power metrics, combined with MPPT efficiency, guide system optimization. Accurate measurement and analysis of these power parameters enable effective control strategies, ensuring the system operates efficiently under varying conditions, making it suitable for renewable energy applications like solar water pumping.

6. Conclusion

Experimental results have demonstrated the superior effectiveness of MPPT-based charge controllers when it comes to extracting the maximum power from solar panels. These controllers not only optimize power generation but also contribute to enhancing battery health by charging at a constant current and preventing overcharging. Moreover, the integration of MPPT with data logging capabilities offers enhanced versatility to users. This enables them to monitor system performance wirelessly, providing valuable insights and facilitating informed decision-making. Furthermore, MPPT systems efficiently cater to DC loads, such as USB charging, demonstrating their adaptability and utility in various applications. Looking ahead, future work could involve extending the system by connecting an inverter to power AC loads. This expansion would enable the utilization of solar energy for a broader range of applications, contributing to further energy efficiency and sustainability.

References

[1]. Hamza Alrajoubi, Selim Oncu, Sinan Kivrak, “An MPPT controlled BLDC motor driven water pumping system”, :10th IEEE International conference on renewable energy research and applications (ICRERA), Istanbul, Turkey, September 2021, pp.116-119.

[2]. Priyatosh Jena, Rajen Pudur, Prakash Kumar Ray, Asit Mohanty, “ANN based MPPT applied to solar powered water pumping system using BLDC motor”, International conference on sustainable energy technologies (ICSETS), Bhubaneswar, India, 2019, pp. 200-205.

[3]. Parag K. Atri, P.S. Modi, Nikhil Shashikant Gujar, “Design and development of solar charge controller by implementing two different MPPT algorithm”, International conference on advances in electrical, computing, communication and sustainable technologies” (ICAECT), Bhilai, India, 2021, pp.1-5.

[4]. Rodney H.G.Tan, Chee Kang Er, Sunil G. Solanki, ”Modelling of photovoltaic MPPT lead acid battery charge controller for standalone system applications”, International conference on power, energy, and electrical engineering , 2020.

[5]. Basit Ali, Qasim Ahmed Khan, Muhammad Adeel, Dr. Abdul Attayyab Khan, Tooba Yamin, “Portable solar powered DC pumping system using pump jack and MPPT”International conference on computing, mathematics and engineering technologies (iCoMET), Sukkur, Pakistan, 2019, pp. 1-5.

[6]. Marwah Q. Al-Obaidi, Nabil Derbel, Wasan A. Hashim, Karim M. Aljebory,” Modelling and simulation of PV pump using MPPT controller”,18th International multi-conference on systems, signals and devices (SSD), Monastir, Tunisia, 2021, pp. 1279-128440.

[7]. Aniket Ujawane, Prof. P.B.Borole "Design and Implementation of Solar Charge Controller with MPPT Algorithm Using Synchronous Buck Converter: Arduino Based" International Journal of Research and Scientific Innovation(IJRSI),Volume3, Issue 6,June 2016.