

Feasibility and Performance Issues of employing ECM Drives for Solar PV based Pumping Applications

Vinayaksingh S Rajaput ¹, Dr. Basavaraj S Shalavadi ²

¹Research Scholar, Department of Electrical & Electronics Engineering ,S.D.M. College of Engineering & Technology. Dharwad, Karnataka, India, affiliated to Visvesvaraya Technological University Belagavi Karnataka India,

²Professor, Department of Electrical and Electronics Engineering S.D.M. College of Engineering & Technology. Dharwad, Karnataka, India, affiliated to Visvesvaraya Technological University Belagavi Karnataka India

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Abstract

This paper work presents an innovative approach utilizing a non-electrical input-based artificial neural network (ANN) for maximum power point tracking (MPPT) in solar-powered water pumping systems driven by brushless DC (BLDC) motors. The proposed method aims to design a step-size-independent MPPT algorithm employing a neural network to enhance water pumping efficiency. A DC-DC boost converter is integrated to harness optimal power from the solar photovoltaic (SPV) array while facilitating smooth startup of the BLDC motor. The system incorporates pulse-width modulation (PWM) control via a voltage source inverter (VSI) regulated by a DC-link voltage controller to manage the BLDC motor's speed. Electronic commutation is achieved through Hall effect sensor signals, which generate the necessary PWM signals. The performance of the BLDC motor-based pumping system is thoroughly analyzed under varying solar irradiance conditions using MATLAB/Simulink. The study evaluates system efficiency and operational effectiveness, emphasizing its adaptability to dynamic environmental inputs.

Keywords: ANN, BLDC motor, Boost Converter, MPTT (Maximum power point tracking), Solar Photovoltaic (SPV) array.

1. Introduction

Water is a necessity for surviving. It is needed for drinking and domestic uses, and it is required for large-scale irrigation, construction, and power production. Water plays a significant role in the development of any country. The quality of life in any country greatly depends upon the quantity and quality of available water resources in that country. It is estimated that an average of 10 liters of fresh water is required per person per day for daily survival (1). Although a large amount of high-quality water is present in the world, often it is not available at locations where it can be readily used. This raises the need to pump high-quality water from its source to the locations where it is in demand. For this purpose, water pumps have been in use for decades.

A solar powered pumping system method needs to take account of the fact that demand for irrigation system water will vary throughout the year. The output of solar power system varies with changes in weather conditions (2). Peak demand during the irrigation system season is often more than twice the average demand. Now a day the most convenient available energy is a solar energy used by the photo voltaic cell that converts light energy into an electrical energy directly from the Sun (3). The irrigation pump system should minimize water losses, without imposing significant additional head on the irrigation pumping system and be low of cost. Pumping water system using this PV technology simple and not require a lot of maintenance (4).

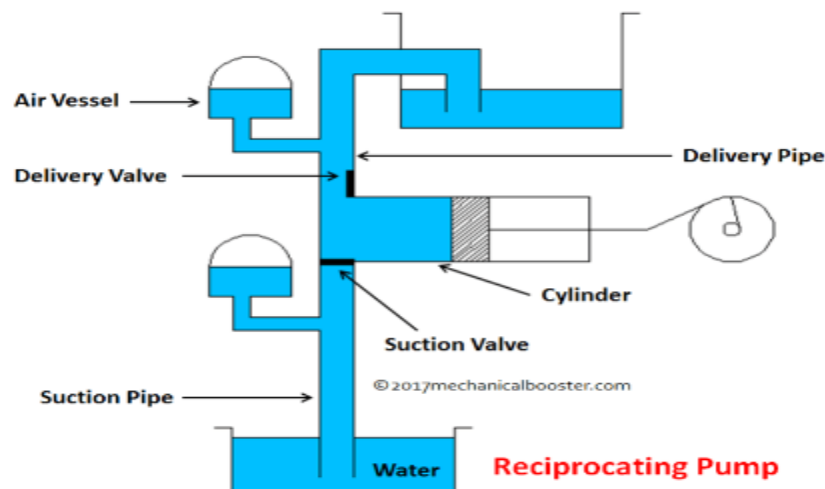


Figure 1: Reciprocating Pump

There are several technology alternatives for supply power including wind turbines, windmills, generators, solar arrays and hand powered pumps. When the sun is shining you need more water and so the solar power is there for the pump (5).

The main driving factors for selecting the appropriate technology are regional feasibility, water demand, systems efficiencies, and initial and long term costs. Solar powered pumping systems are used principally for three applications: town and city water supply, livestock watering and irrigation (2). Solar powered water pumping systems can provide drinking water without the extensive maintenance required by diesel pumps. Solar power is one of the alternatives but is costly and unaffordable. The main advantages of the ECM (electronically commutated motor) over the brushed motors are less maintenance requirements, reduced environmental effects and less electromagnetic radiation I-2. Within the last three decades, several improved magnetic materials are developed for high-performance PM motors. The features of high operating efficiency, brushless construction, maintenance-free operation and increasing awareness about energy conservation have given a scope to the demand of the PMBLDC motor in water pumping application operated by PV-array, particularly, in remote villages where electric supply is not available. The target is to analyze the feasibility and Performance Issues of employing ECM drives for solar based Pumping Systems

2. Literature survey

The continuous utilization of fossil fuels has motivated a shift towards renewable energy sources such as solar, wind, and biogas for powering water pumping systems. Transitioning to these renewable energy sources, including hybrid systems, is considered an optimal solution to address the energy crisis in India. Most commercially available water pumps operate on electricity or diesel fuel. Traditionally, electricity generated from fossil fuel combustion is supplied through national grids. However, this creates challenges in providing water to remote areas that lack direct connectivity to the grid.

Among renewable energy options, solar photovoltaic (PV) systems have proven to be the most suitable for water pumping applications due to their clean and sustainable nature. Solar energy availability is directly correlated with water demand, making it an efficient choice. Economically, the challenges associated with fossil fuels, including limited availability, high transportation costs, fluctuating prices, and environmental impact, have been significant. Simultaneously, advancements in PV technology have reduced panel costs, further enhancing the feasibility of solar-powered water pumps.

S.A. Shufat et al. developed a dual-plane solar tracking system, demonstrating the conversion of solar radiation into electricity and its application in remote water supply systems. Similarly, M.M. Haque designed a solar water pump using PV modules for irrigation, establishing its cost-effectiveness compared to diesel systems. Solar and wind energy are abundant, require no permissions for use, and are eco-friendly with minimal waste, making them promising resources for localized power generation due to their geographical advantages.

Technological advancements have led to the development of smaller, cheaper materials like copper-indium gallium-selenide, which can be formed into flexible, usable films. While solar energy itself is free, the materials required for manufacturing efficient solar panels remain costly. However, ongoing reductions in PV panel costs, driven by technological progress, have improved the affordability and viability of solar water pumping systems.

Solar energy systems are categorized into active and passive technologies based on their energy collection, conversion, and distribution methods. Active systems, such as photovoltaic panels and solar thermal collectors, harness energy, while passive systems involve building designs that optimize sunlight utilization, thermal mass, and natural ventilation. The sun, as the primary energy source, provides an immense amount of power—enough to meet global energy demands multiple times over if just a small fraction of its energy is utilized.

The development of clean, sustainable, and affordable solar energy technologies enhances energy security, reduces dependence on finite resources, mitigates environmental pollution, lowers the cost of climate change mitigation, and stabilizes fossil fuel prices. These benefits make solar energy a critical solution for addressing global energy challenges.

2.1 Solar Powered Water Pumping System:

With growing global awareness of the energy crisis, solar-powered water pumping systems have garnered significant attention from researchers over the years. There are multiple potential designs for solar-powered water pumping systems, with the most commonly used being those that incorporate photovoltaic (PV) panels. To operate the water pump effectively, the power generated by the solar collection system must be conditioned appropriately.

The system typically involves a water pump installed at the source, which transfers water to a reservoir positioned at a higher elevation. The vertical distance between the pump and the reservoir inlet, referred to as the pump head, plays a crucial role in determining the design parameters of the pumping system.

2.1.2 Global scenario of solar powered water pumping system:

Solar-powered water pumping has been identified as an effective solution for rural, off-grid areas in low-income countries where solar radiation levels are high. These systems are often preferred in developing nations over other alternative energy sources due to their durability and long-term economic benefits. Small-scale farms, villages, and livestock in such regions typically require hydraulic output power below one kilowatt. However, many of these users are located too far from the electrical grid to make grid power feasible, and engine-driven pumps are often impractical due to the high cost of fuel and the lack of proper maintenance and repair services.

Solar energy is particularly suitable for replacing fossil fuels in regions with abundant sunlight, such as the Middle East and North Africa (MENA). The absence of reliable electrical grids and poor transportation infrastructure are key factors driving the adoption of renewable energy in rural areas. Rising oil prices have further encouraged Western countries to develop PV-based pumping systems to meet both drinking water and irrigation needs in remote locations.

For example, in Sonora, Northwest Mexico, the price of PV modules decreased by 80%, while diesel prices surged by 250% over the last decade. In Eastern Asia, the focus of solar pumping system development has been to supply fresh water to smaller communities while forecasting future expansion levels. Setiawan et al. (21) documented the use of solar pumping systems to supply water to a village in Indonesia and explored business models for farmland and grassland conservation. Similarly, Zhang and Yan (22) analyzed existing and enhanced business models for PV systems in China, examining their feasibility, limitations, and accessibility while comparing four different scenarios for PV applications.

2.1.3 Indian scenario of solar powered water pumping system

Solar PV water pumping systems are widely utilized in India for both irrigation and drinking water purposes. Many regions in India face challenges in accessing drinking water, especially in rural and remote areas. Hand pumps are commonly used in villages to address this issue, but they require manual operation, making them difficult for children and women to use due to the physical effort involved.

Studies have indicated that solar-powered water pumping systems are ideal for small-scale irrigation and minor drinking water needs, particularly in areas where conventional energy sources are either unavailable or too expensive (23). Akker and Lamba (24) highlighted the installation of 1,000 small solar water pumping systems across various regions of Punjab, funded by the Indian Renewable Energy Development Agency.

In India, diesel and grid electricity are the primary energy sources for operating water pumps for irrigation and household use. By adopting solar pumps, electricity consumption can be reduced, along with the subsidies provided for diesel fuel. To further promote this transition, the Indian

government has launched the Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM KUSUM) scheme, which aims to install off-grid solar pumps and replace existing grid-connected agricultural pumps (25).

3. Methodology of the work

This diagram outlines the methodology for a solar-powered water pumping system driven by an Electronically Commutated Motor (ECM). The system begins with a PV array that converts solar energy into electrical energy. Voltage and current sensors monitor the PV output, providing real-time data to ensure efficient operation. These sensors feed their data into a MATLAB function, which acts as a control algorithm, optimizing system performance by determining the required duty cycle for the DC-DC converter. The optimized duty cycle ensures maximum power point tracking (MPPT), thereby extracting the maximum available power from the PV array under varying irradiance conditions.

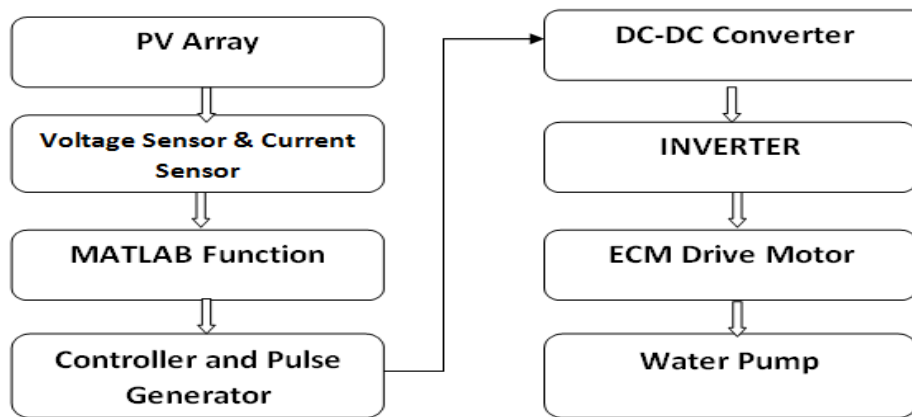


Figure 2: Block diagram representation implementation of the solar water pump

The output of the MATLAB function drives a controller and pulse generator, which produces the required switching signals for the DC-DC converter. This converter conditions the PV power for compatibility with the ECM drive motor. The ECM motor, known for its energy efficiency and variable-speed operation, drives the water pump to meet varying demand. The system operates in a closed-loop manner, where feedback from the sensors ensures stable operation under dynamic conditions like changes in sunlight, temperature, or water requirements. This methodology ensures reliability, efficiency, and adaptability of the solar water pumping system.

4. Results and discussions

This Simulink model represents a solar-powered water pumping system comprising a photovoltaic (PV) array, a DC-DC converter, and a motor that drives a pump. The PV array converts solar irradiance into electrical energy (DC power), with inputs including steady irradiance (representing consistent sunlight) and dynamic irradiance (for changing sunlight conditions). The array generates DC voltage and current as output. To optimize power output, a Maximum Power Point Tracking (MPPT) controller adjusts the operating point of the PV array,

providing a duty ratio to control the DC-DC converter. The DC-DC boost converter, consisting of an inductor, capacitor, and diode, steps up the DC voltage to the required level for driving the motor and pump load.

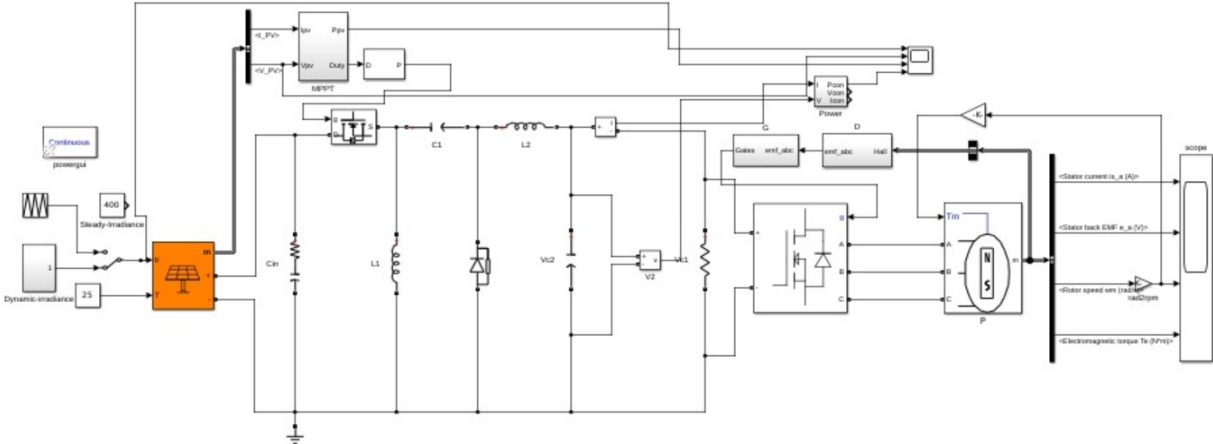


Figure 3: MATLAB simulink implementation of the solar water pump.

The motor drive system features a brushless DC motor (BLDC) powered by an inverter that converts the boosted DC voltage to AC voltage. The system also incorporates a control mechanism using a Hall sensor and feedback loops to regulate motor speed and torque. The motor drives the pump, which lifts water from a source to a reservoir. Key parameters such as rotor speed, electromagnetic torque, and stator currents are monitored during operation. The model includes scopes that plot stator current, back EMF, rotor speed, and torque, allowing for performance evaluation. Overall, solar irradiance powers the PV array, with the MPPT ensuring maximum efficiency, while the DC-DC converter, motor drive, and pump work seamlessly to deliver water efficiently.

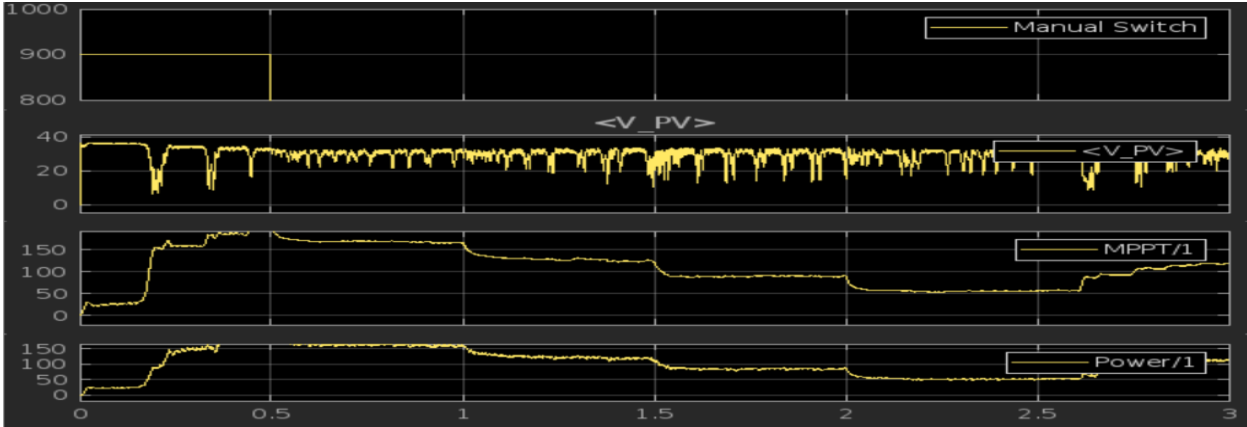


Figure 4: Outcome of the PV fed water pump applications (manual switch).

The provided graph illustrates the performance of a solar-powered water pumping system. The first plot shows the manual switch status, indicating system activation. The second plot

($\langle V_{PV} \rangle$) represents the photovoltaic array's output voltage, which fluctuates due to varying irradiance conditions. The third plot shows the MPPT (Maximum Power Point Tracking) controller output, demonstrating its role in optimizing the PV array's operating point. The fourth plot displays the system's power output, which closely follows the MPPT adjustments, ensuring maximum power utilization. Together, these plots highlight the system's ability to dynamically adapt to changing solar conditions and maintain efficient operation.

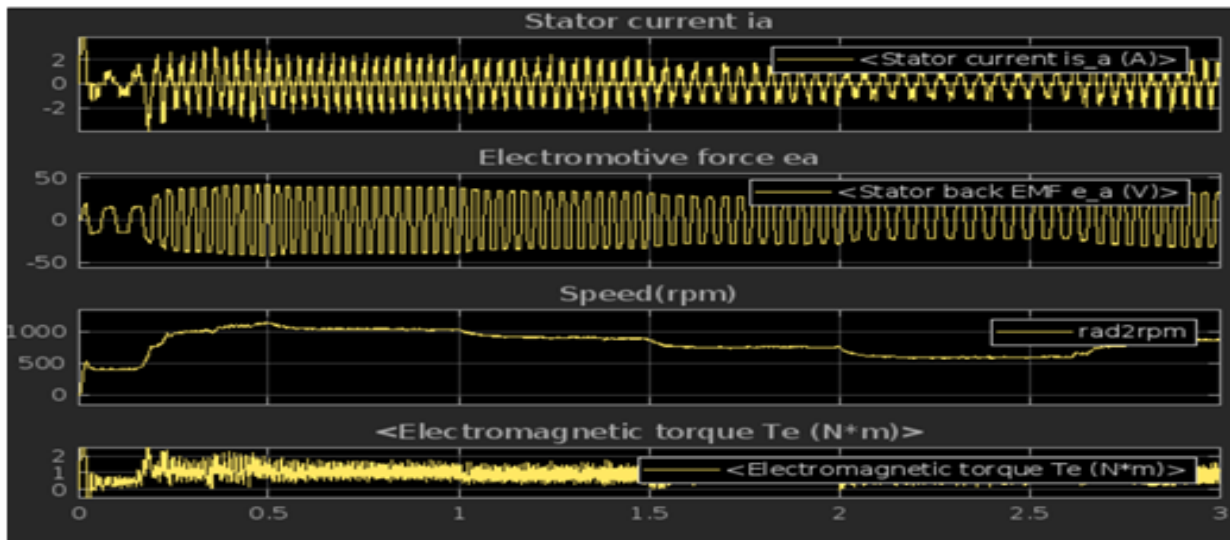


Figure 5: Outcome of the PV fed water pump applications (manual switch).

The graph illustrates the key parameters of the motor drive system in the solar-powered water pumping system.

- **Stator Current (ia):** The first plot shows the current waveform in the stator winding, fluctuating as the motor operates.
- **Electromotive Force (ea):** The second plot represents the back EMF, which is proportional to the rotor speed and exhibits a sinusoidal pattern.
- **Speed (rpm):** The third plot indicates the rotor speed in RPM, stabilizing after initial transients.
- **Electromagnetic Torque (Te):** The fourth plot shows the generated torque, which fluctuates initially before stabilizing to meet the load requirements. These parameters collectively demonstrate the motor's dynamic performance during operation.

The graphs depict the current-voltage (I-V) and power-voltage (P-V) characteristics of a photovoltaic (PV) array under varying irradiance levels (0.2–1 kW/m²).

- **I-V Curve:** As irradiance increases, the current output rises proportionally, while the voltage remains nearly constant at higher levels.

- P-V Curve:** The power output peaks at a specific voltage (maximum power point) for each irradiance level, with higher irradiance yielding greater power.

These curves highlight the dependency of PV array performance on solar irradiance.

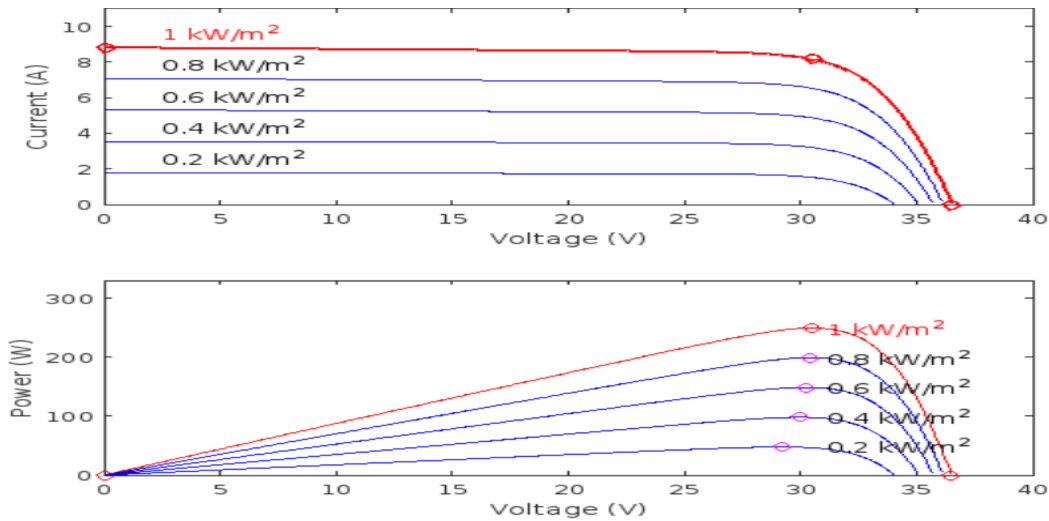


Figure 6: IV and PV of the Solar Panel for different irradiances at 25 degrees

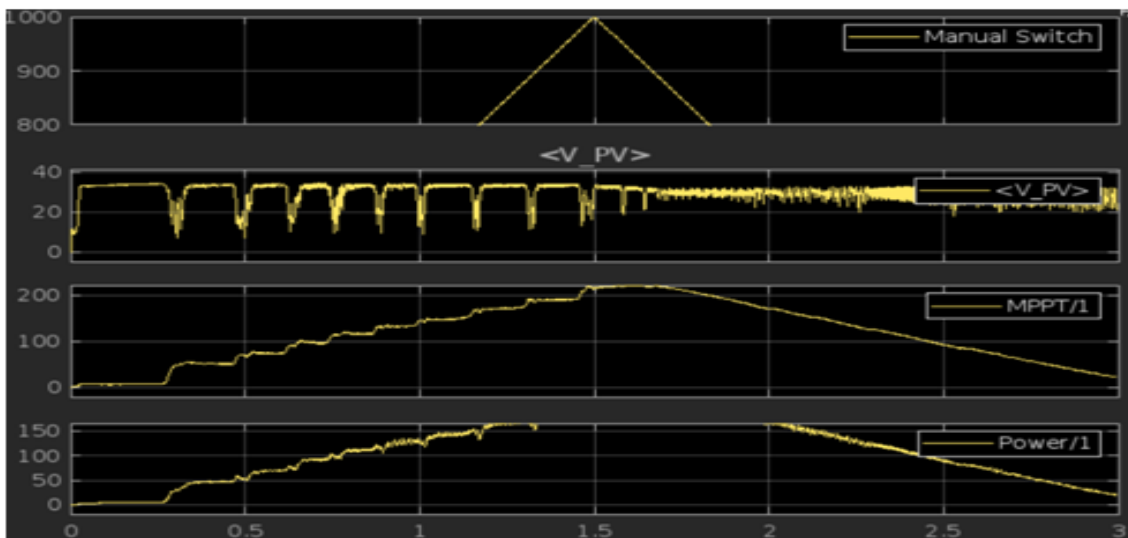


Figure 7: Outcome of the PV fed water pump applications (repeating)

The above diagram demonstrates the dynamic response of the solar panel system to changing conditions. The MPPT controller is actively adjusting to maximize power output, while the other graphs provide insights into the system's behavior.

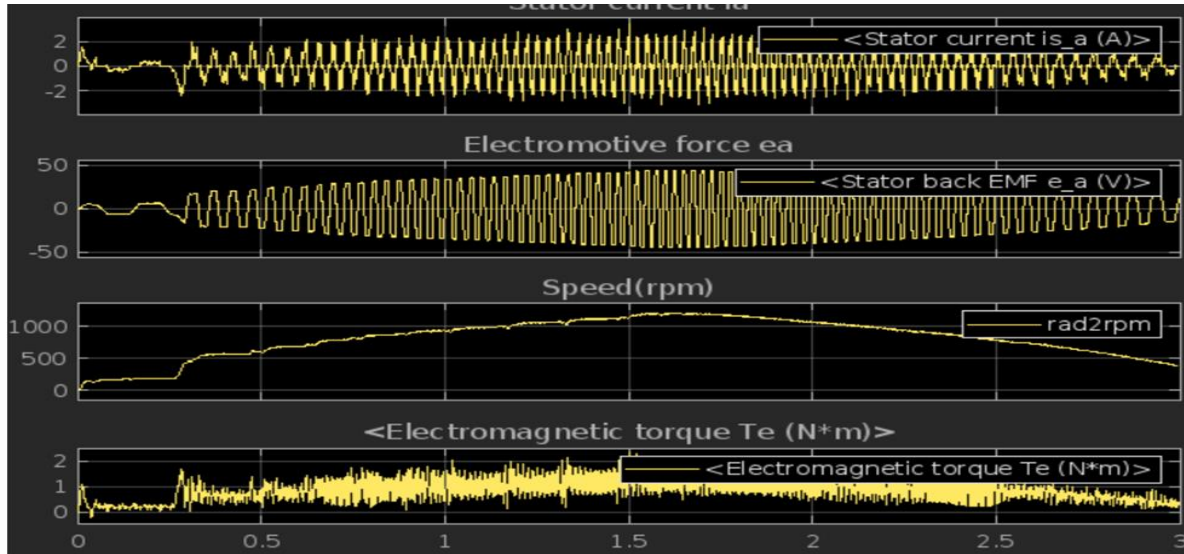


Figure 8: Outcome of the PV fed water pump applications (repeating)

The above diagram demonstrates the relationship between the stator current, back EMF, speed, and torque in an AC motor. As the motor accelerates, the back EMF increases, which affects the current flow and torque generation.

5. Conclusion

The feasibility and performance of employing ECM (Electronically Commutated Motors) drives for Solar PV-based pumping applications is highly favorable. ECM drives are well-suited for integration with solar PV systems due to their energy efficiency, ability to operate under varying light conditions, and precise motor speed control. These drives enable efficient power conversion and reduce energy losses, which is critical for solar-powered pumping applications. In terms of performance, ECM drives provide excellent reliability, low maintenance, and long lifespan, adapting well to fluctuations in solar energy output and ensuring consistent operation across diverse environmental conditions. The integration of ECM with MPPT (Maximum Power Point Tracking) controllers enhances overall system efficiency. However, one performance challenge is the reliance on solar irradiance, which can cause variations in pump speed, though these fluctuations can be addressed with advanced control algorithms. Additionally, ECM drives tend to have higher initial costs compared to conventional motor drives, but their long-term energy savings often offset this upfront investment. Overall, ECM drives are a feasible and beneficial solution for solar PV-based pumping, especially in off-grid or remote areas, offering substantial advantages in energy efficiency around 82% compared to conventional methods, adaptability, and long-term performance despite some challenges.

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