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Single Stage Autonomous Solar Water Pumping System Using PMSM Drive

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Abstract*: Water supply technology has advanced significantly with the development of autonomous solar water pumping devices. These solar-powered systems offer a dependable and sustainable way to pump water in remote and off-grid areas. They are the perfect solution for solving problems with water delivery in places with restricted access to power because of their capacity to function independently and without the requirement for grid electricity. Autonomous solar water pumping systems present a viable and creative approach to a sustainable water supply at a time when demand for renewable energy solutions is only expected to increase. Sustainable and effective agricultural techniques have advanced significantly with the introduction of autonomous solar water pumping equipment. These solar-powered devices provide an economical and environmentally responsible way to address the problems of declining water supplies and growing energy expenses. Adoption of autonomous solar water pumping devices will be essential to maintaining the productivity and long-term sustainability of our world's food supply as the agricultural sector develops.*

Keywords: Water Pumps, PMSM, Solar PV array, MPPT, Smart grid.

I. INTRODUCTION

Permanent Magnet Synchronous Motor (PMSM) drives have gained increasing popularity in industrial and commercial applications due to their high efficiency, high power density, and precise speed control capabilities. PMSMs utilize permanent magnets to create a magnetic field in the rotor, eliminating the need for additional excitation equipment. This design results in reduced losses and improved energy efficiency compared to other types of motors, making PMSMs an attractive option for applications that require high performance and reliability[1].

Permanent Magnet Synchronous Motor (PMSM) drives have emerged as a leading solution for high-performance industrial applications due to their superior efficiency, power density, and torque characteristics. PMSM drives utilize permanent magnets mounted on the rotor, which interact with a stator winding to generate torque. This unique design eliminates the need for field excitation, reducing energy losses and enhancing overall efficiency. Additionally, PMSMs offer high power density due to the compact arrangement of the magnets and stator windings, allowing for smaller and lighter motors. The precise control of the rotor position and torque is achieved through advanced control algorithms, such as vector control or field-oriented control, enabling precise and dynamic performance. PMSM drives are widely employed in various industries, including robotics, machine tools, electric vehicles, and renewable energy systems, where high efficiency, reliability, and responsiveness are crucial[2]. The ongoing advancements in power electronics and control techniques continue to push the boundaries of PMSM drive capabilities, making them an increasingly attractive option for demanding applications seeking optimal performance and energy efficiency[3].

One key advantage of PMSM drives is their ability to provide precise speed control over a wide range of speeds. This is achieved through the use of sophisticated control algorithms, such as field-oriented control (FOC), which allow for precise control of the motor's torque and speed. This level of control is essential in applications where accuracy and consistency are critical, such as in robotics, machine tools, and electric vehicles. In addition, PMSMs are inherently more reliable than traditional motors due to their simplified design and lack of wear-prone components, making them an ideal choice for applications that require long-term reliability.

Furthermore, PMSM drives offer the potential for regenerative braking, allowing them to capture and convert energy back into the system during deceleration. This capability not only improves overall energy efficiency but also reduces heat generation and extends the lifespan of the motor. Additionally, PMSM drives are compact and lightweight, making them well-suited for space-constrained applications where size and weight are critical factors. Overall, PMSM drives represent a cutting-edge technology that offers significant advantages in terms of efficiency, reliability, and performance, making them an attractive choice for a wide range of industrial and commercial applications.

Solar water pumping systems are innovative technologies that utilize the power of the sun to provide water for various applications. These systems consist of solar panels that generate electricity through photovoltaic cells, which then power a water pump that extracts water from a well or other water source. The benefits of solar water pumping systems are numerous, as they are environmentally friendly, reduce reliance on fossil fuels, and provide a sustainable solution for communities in remote areas that lack access to electricity[4,5,6].

One of the key advantages of solar water pumping systems is their ability to harness renewable energy sources, such as solar power, to provide a reliable and cost-effective solution for water supply. By utilizing the energy from the sun, these systems are able to operate without requiring a constant fuel source, which reduces operational costs and minimizes the environmental impact of water pumping activities. In addition, solar water pumping systems can be installed in remote locations where electricity grid connectivity is limited or nonexistent, making them ideal for rural communities in developing countries[7,8].

Furthermore, solar water pumping systems offer a sustainable solution for water supply by providing a consistent and reliable source of water for agricultural irrigation, livestock watering, and domestic use. In regions where water scarcity is a pressing issue, these systems can help improve access to clean water, promote food security, and enhance livelihoods for communities that rely on agriculture for their sustenance. As solar technology continues to advance and become more affordable, the adoption of solar water pumping systems is expected to increase, leading to greater efficiency and sustainability in water resource management[9].

An autonomous solar water pumping system is a cutting-edge technology that harnesses the power of the sun to pump water without the need for grid electricity. This system consists of solar panels that capture sunlight and convert it into electricity, which is then used to power a water pump. This innovative solution addresses the challenges of providing water in remote areas where access to electricity is limited or unreliable. By utilizing renewable energy sources, autonomous solar water pumping systems offer a sustainable and environmentally friendly alternative to traditional pump systems[10].

One of the key advantages of autonomous solar water pumping systems is their ability to operate independently of the power grid. This makes them ideal for rural communities and off-grid locations where access to electricity is limited. By harnessing the abundant energy of the sun, these systems provide a reliable and cost-effective solution for pumping water. Additionally, autonomous solar water pumping systems require minimal maintenance and have a long lifespan, making them a practical and durable solution for water supply challenges in remote areas.

In conclusion, autonomous solar water pumping systems represent a significant advancement in the field of water supply technology. By harnessing solar energy, these systems provide a sustainable and reliable solution for pumping water in rural and off-grid locations. Their ability to operate autonomously and without the need for grid electricity makes them an ideal choice for addressing water supply challenges in areas with limited access to power. As the demand for renewable energy solutions continues to grow, autonomous solar water pumping systems offer a promising and innovative solution for sustainable water supply.

The agricultural industry is a cornerstone of human civilization, providing sustenance and livelihood to billions of people worldwide. However, the traditional methods of irrigation and water management are becoming increasingly unsustainable due to factors such as climate change, water scarcity, and rising energy costs. In response to these challenges, the development of autonomous solar water pumping systems has emerged as a promising solution. This article explores the concept, benefits, and potential of autonomous solar water pumping systems in revolutionizing the agricultural sector.

An autonomous solar water pumping system is a self-sufficient, eco-friendly solution for agricultural irrigation. It harnesses the power of the sun to pump water from a source, such as a well, river, or reservoir, to the fields where it is needed. The system comprises solar panels, a water pump, a controller, and a storage tank.

The solar panels convert sunlight into electricity, which is then used to power the water pump. The controller manages the system's operation, ensuring that the pump runs efficiently and effectively. The storage tank collects the pumped water, which can be used for irrigation as needed.

Benefits of Autonomous Solar Water Pumping Systems:

1. Sustainability: Autonomous solar water pumping systems are powered by renewable energy, reducing the reliance on fossil fuels and minimizing the carbon footprint of agricultural operations.
2. Cost-effectiveness: Solar energy is free, and once the initial investment in the system is made, the operational costs are minimal. This makes autonomous solar water pumping systems a cost-effective solution for farmers, especially in remote areas where access to electricity is limited.
3. Water conservation: The system's efficient operation ensures that water is pumped only when needed, reducing wastage and promoting water conservation.
4. Improved crop yields: By providing a reliable and consistent water supply, autonomous solar water pumping systems can help improve crop yields, leading to increased agricultural productivity.
5. Reduced labor costs: The system's autonomous nature eliminates the need for manual labor in water pumping, freeing up resources for other tasks and reducing labor costs.
6. Scalability: Autonomous solar water pumping systems can be easily scaled to meet the needs of different farm sizes and irrigation requirements.
7. Remote monitoring and control: With the integration of IoT (Internet of Things) technology, farmers can remotely monitor and control the system's operation, ensuring optimal performance and reducing the need for on-site maintenance.

Challenges and Future Prospects:

While autonomous solar water pumping systems offer numerous benefits, there are still some challenges to overcome. These include:

1. Initial investment: The upfront cost of the system can be a barrier for some farmers, especially those with limited financial resources.
2. Maintenance: Regular maintenance is required to ensure the system's optimal performance, which may be a challenge in remote areas with limited access to technical expertise.
3. Climate variability: The efficiency of solar panels can be affected by weather conditions, such as cloud cover or extreme temperatures.

Despite these challenges, the future of autonomous solar water pumping systems looks promising. As technology advances and costs continue to decrease, these systems are expected to become more accessible and widespread. Furthermore, the integration of IoT and machine learning technologies will enable the development of intelligent, self-optimizing systems that can adapt to changing environmental conditions and user needs.

Autonomous solar water pumping systems represent a significant leap forward in sustainable and efficient agricultural practices. By harnessing the power of the sun, these systems offer a cost-effective, eco-friendly solution to the challenges of water scarcity and rising energy costs. As the agricultural sector continues to evolve, the adoption of autonomous solar water pumping systems will play a crucial role in ensuring the long-term sustainability and productivity of our global food supply.

II. LITERATURE SURVEY

This article presented by Murshid et al(2020)[12], was a single stage standalone solar photovoltaic (SPV) array fed water pumping system using a permanent magnet synchronous motor (PMSM). This system includes a SPV array, a three-phase voltage source inverter (VSI), a PMSM and a pump. The SPV array converts solar energy into electrical energy. The VSI acts as power processing unit, which supplies desired currents to drive the PMSM. As the PMSM rotates, the pump coupled to the motor accomplishes the objective of water pumping. This system is modeled and simulated using MATLAB/Simulink with available simpower system toolbox and the behavior of the system under varying atmospheric conditions are validated experimentally on a developed prototype in the laboratory.

The paper presented by Thallapally et al(2022)[13], a single stage standalone solar photovoltaic (SPV) array fed water pumping system using a permanent magnet synchronous motor (PMSM). The vital contribution of this work includes: (i) development of the novel modified vector control (MVC), which improves the torque response of the system, (ii) development of a novel single stage variable step size incremental conductance (VSS-INC) technique, which provides a fast maximum power point tracking (MPPT) and eliminates the need of intermediate stage DC-DC converter and (iii) introduction of SPV power feedforward term (FFT), which accelerates the overall response of the system under dynamic conditions.

In the paper byPrabhakaran et al(2022)[14], a photovoltaic (PV) fed boost inverter-based permanent-magnet synchronous motor (PMSM)-driven water-pumping system for stand-alone applications is proposed. The proposed system comprises PV panel, six switches, three inductors (*L*), three capacitors (*C*) and a water pump. In this work, the boost inverter is designed with a gain of two and thereby the direct current input required to run the motor is considerably reduced. Hence, the size of the system is reduced. The voltage gain factor depends upon the placement of the *L* and *C* components and their values. The speed reference is generated using a perturb and observe maximum power point tracking algorithm. Vector control is employed to control a boost inverter-fed PMSM drive. The proposed system is simulated using a MATLAB/Simulink environment and experimental validation is performed on a PMSM laboratory prototype using a field programmable gate array controller. The simulation and experimental results demonstrate the effectiveness of the proposed system.

Permanent Magnet Synchronous Motor (PMSM) and Brushless DC motor (BLDC) are the two mostly used variants of permanent magnet machines. Solar water pumping system includes a SPV array, a three-phase inverter, a BLDC motor and a pump is suggested by Alan et al(2023)[15]. SPV array converts solar energy into electrical energy. Maximum Power Point Tracking (MPPT) from the SPV is implemented by using Single Ended Primary Inductor Converter (SEPIC). The inverter acts as Power Processing Unit (PPU), which supplies desired currents to drive the BLDC motor. As the motor rotates, the pump coupled to the motor accomplishes the objective of water pumping. The controller used for the system is ESP32. The MPPT and motor control algorithms are loaded into the controller. It generates the gate pulses for the SEPIC and inverter switches. The use of BLDC for driving the pump has increased the system efficiency, and has reduced the system size, consequently resulting in reduction of cost, complexity and further increase in the system efficiency and compactness. The system is cost efficient and switching to a normal grid must be provided when there is low irradiance.

The work by Nouaiti et al(2023)[16], presents a study of a single-stage DC-AC converter for a solar water pumping application. The topology was based on solar panels connected to a new structure of a three-phase multilevel inverter through DC-bus capacitors. The inverter offers simplicity, requires fewer components compared to conventional ones, and provides optimal voltage and current waveforms with reduced harmonics, eliminating the need for filters. The applied control technique aimed to stabilize the input DC-bus voltage, extract the maximum power using a simple MPPT algorithm, and enhance the efficiency of the water pump through scalar V/f control, regardless of weather changes. A simulation was conducted using the PSIM software, considering a variable daily climate scenario. The results obtained demonstrate the efficiency of the system in extracting energy with optimal torque and current for the pump compared to a classic design based on a three-phase H-bridge inverter.

III. PROPOSED METHOD

A representation of the SWP system's configuration can be found in Figure 1 and Figure 2. Figure 1 represent the block diagram of proposed system, where Figure 2, shows the circuit description of proposed system. A three-phase voltage source inverter (VSI), a water pump, a photovoltaic array (SPV), and a PMSM are the components that make up this system, which is arranged from left to right. To prevent any reverse current from flowing into the SPV array, a diode, denoted by the letter D, is placed between the SPV array and the VSI. It is necessary to have a enough number of series and parallel combinations of SPV modules in order to construct the SPV array. At the moment when the photons make contact with the surface of the SPV array, electrical energy is produced. This electrical energy that is generated is then supplied to the DC link of the VSI. As a power processing unit, the VSI comes into play. This electrical energy is converted into rotational mechanical energy as a result of the PMSM being rotated by the pump that is attached to it with this device. Within this SWP system, there is just one component that stores energy, and that component is the DC link capacitor.

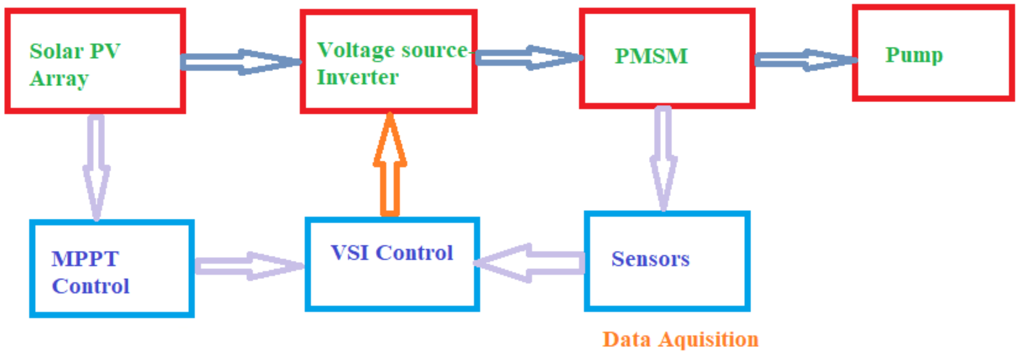

Figure 1- Block diagram of proposed configuration

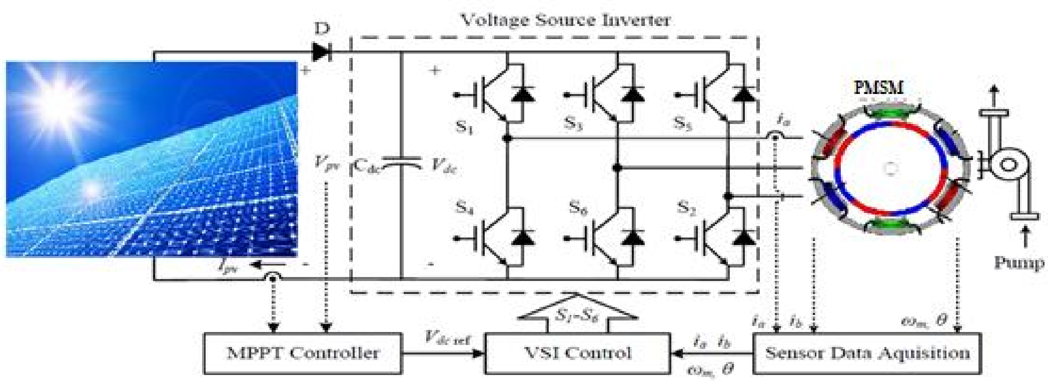

Figure 2- Proposed system

The power of the SPV array, denoted as Ppv, is directly proportional to the cube of the motor speed, denoted as ω_m. As an illustration, it is essential to obtain the reference motor speed (ω_{ref}) in the correct manner in order to ensure proper MPPT tracking. The reference system, denoted by ω_{ref}, is composed of two components, namely ω_{ref1} and ω_{ref2}, as visualised in Figure 3. As a result of the DC link voltage controller, $\omega_{ref}1$ originated. The VSS-INC algorithm takes the voltage (Vpv) and current (Ipv) of the SPV array as inputs, and these two variables are responsible for producing the reference DC link voltage (Vdc_{ref}) that is necessary for the operation at MPP. Since the DC link voltage (Vdc) and the voltage at the point of voltage (Vpv) are same for single stage topology, it is possible to use them interchangeably. A comparison is made between Vdc_{ref} and Vdc, and the error is then sent to the DC link voltage controller. The DC link voltage controller then adjusts $\omega_{ref}1$ in order to bring the DC link voltage error down to zero. A function of SPV power (Ppv), ω_{ref2} is derived from the Fast Fourier Transform (FFT). As a result of the fact that ω_{ref2} is a direct function of Ppv and does not include any controller in between, every change in Ppv directly leads to a change in ωref_2, which in turn makes the system respond more quickly. Following the determination of ω_{ref}, the speed of PMSM is regulated through the utilisation of MVC. This comparison is made between ω_{ref} and ω_m, and the speed error, denoted as ω_{error}, is then transmitted to the speed controller. In the context of reference electromagnetic torque (Te_{ref}), the output of the speed controller is taken into consideration. The torque error, also known as Te_{error}, is calculated by comparing the Te_{ref} with the estimated electromagnetic torque, which is denoted by Te_{est}. The torque controller receives the $Te_{error,}$ and the output is regarded as the reference quadrature axis current (iq_{ref}). This current is then utilised for the purpose of controlling the speed of the PMSM. Both the conventional and MVC approaches to the creation of iq_{ref} are depicted in Figure 3.

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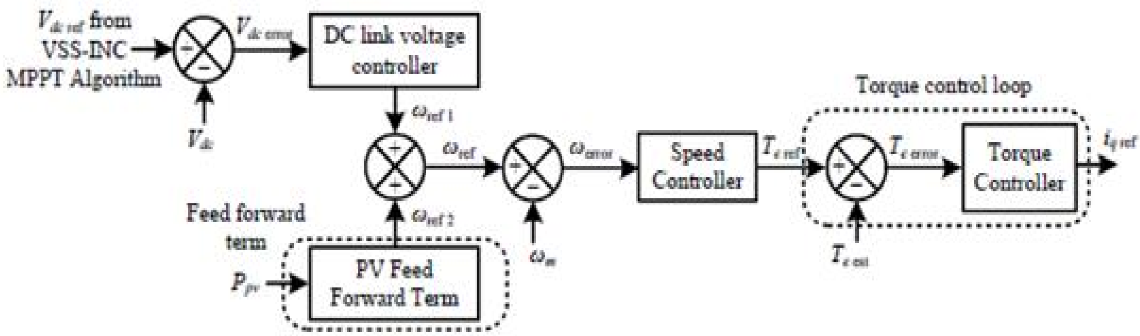
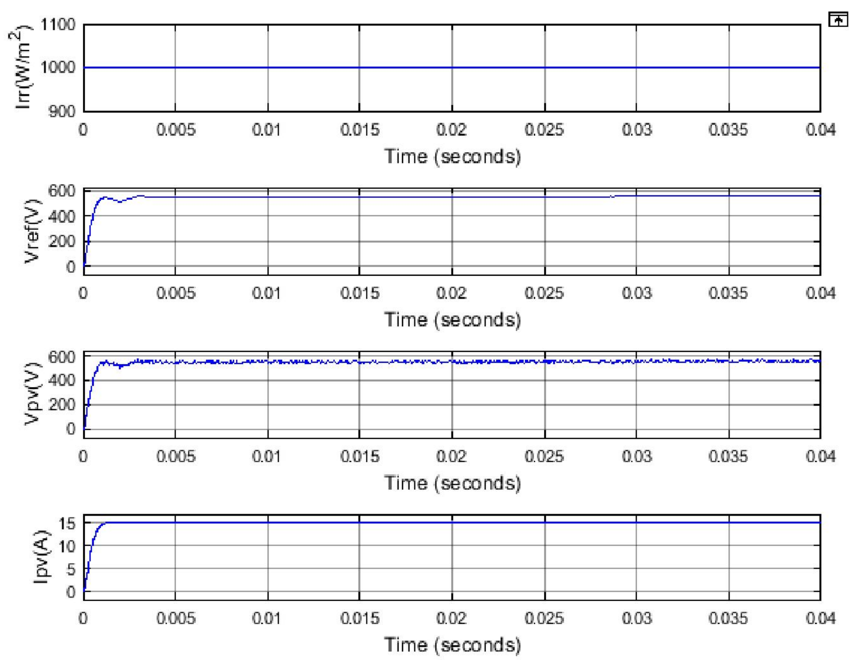


Figure 3- Proposed VSI circuit.

IV. RESULTS AND DISCUSSION

Through the use of simulation studies, the performance of this device is being evaluated. A simulation of the entire system is carried out with the help of MATLAB/Simulink, and its performance is investigated both during the starting and steady state phases, while the insolation levels are varied. Within the context of dynamic conditions, the performance of the system is also investigated. The analysis of dynamic response is performed by rapidly changing the temperature and the amount of insolation outside. An evaluation of the performance is conducted by analysing the variations in the parameters of the SPV array, which include insolation (S), SPV array voltage (Vpv), SPV array current (Ipv), and SPV array power (Ppv). Additionally, the PMSM parameters, which include motor current (iabc), motor speed (ω_m), load torque (Tl), and load power (Pl), are also evaluated. Additionally, reference parameters, which include reference DC link voltage (Vref) and reference motor current (i_{ref}), are also evaluated.

The following data illustrated in Figure 4 and Figure 5 shows the starting and steady state performance of the system under conditions of a constant temperature of 25 degrees Celsius and a solar insolation of 1000 watts per square metre and 500 watts per square metre, respectively.



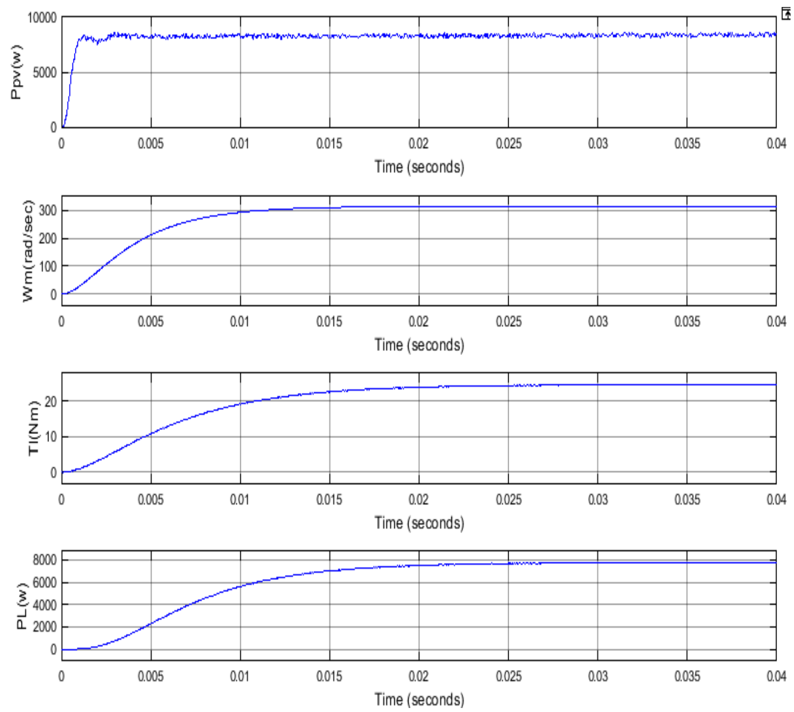


Figure 4- Result and performance of proposed system

When the engine is starting, it is drawing twice as much current as it would in a stable condition. It takes a longer amount of time for the motor parameters to reach a steady state when compared to the SPV array parameters. This is due to the fact that PMSM is an electromechanical device and has a bigger time constant in comparison to the electrical system. When the motor begins, it is moving at a speed of zero, and it will achieve its steady state speed in less than 0.04 seconds.

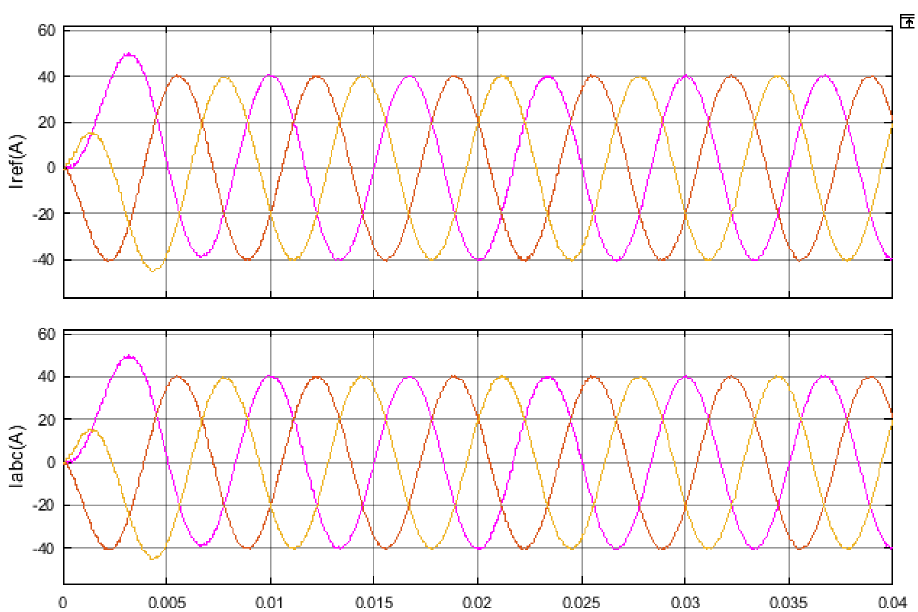


Figure 5- Starting and steady state performance for insolation of 1000 W/m^2

A constant insolation of 1000 W/m^2 is shown in Figure 5 & Figure 6, which depicts the dynamic performance of the system for temperature variations ranging from 25^{0}C to 50^{0}C (Figure 7) and from 50^{0}C to 25^{0}C (Figure 8), respectively.

The change in temperature causes the SPV array current (Ipv) to increase somewhat, while the SPV array voltage (Vpv) decreases significantly. This is due to the fact that the SPV array has a relatively modest positive temperature coefficient of current and a relatively big negative temperature coefficient of voltage. As a consequence of this, the power output of the SPV array (Ppv) is decreasing. Additionally, the motor speed (ω_m), load torque (Tl), and loadpower (Pl) are decreasing in a corresponding manner, and they are approaching a steady state value within a second and a half. Upon resetting the temperature from 50^0C to 25^0C, the system operates in the opposite direction.

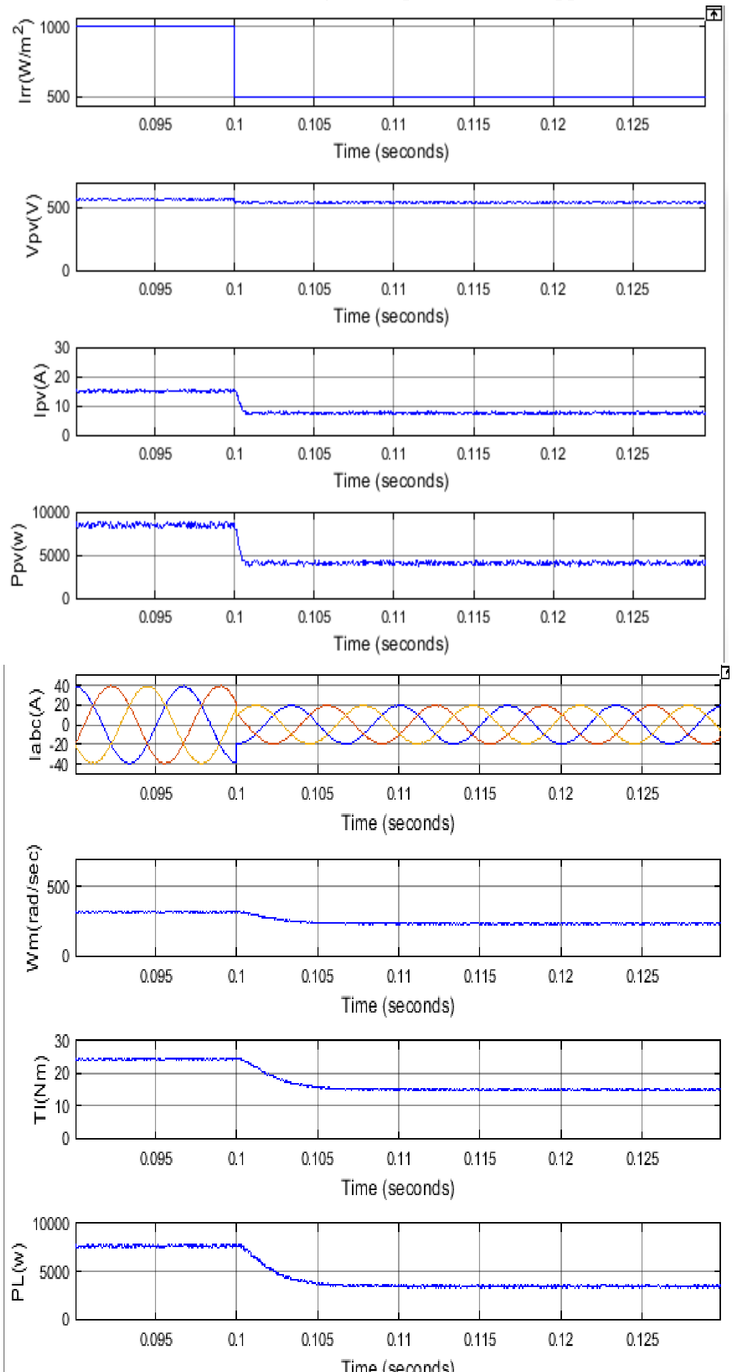


Figure 6- Dynamic performance during insolation change from 1000 W/m^2 to 500 W/m^2

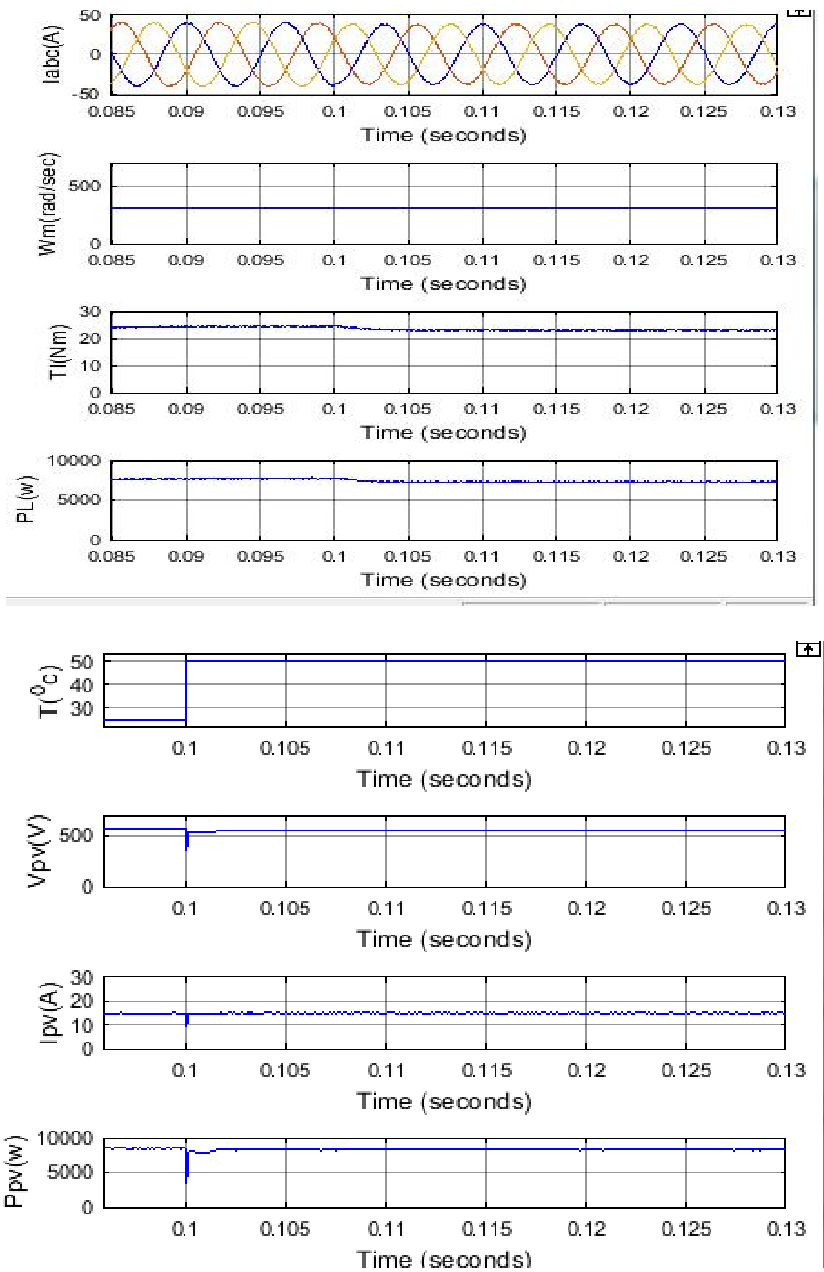


Figure 7- Dynamic performance during temperature change from 25 °C to 50 °C

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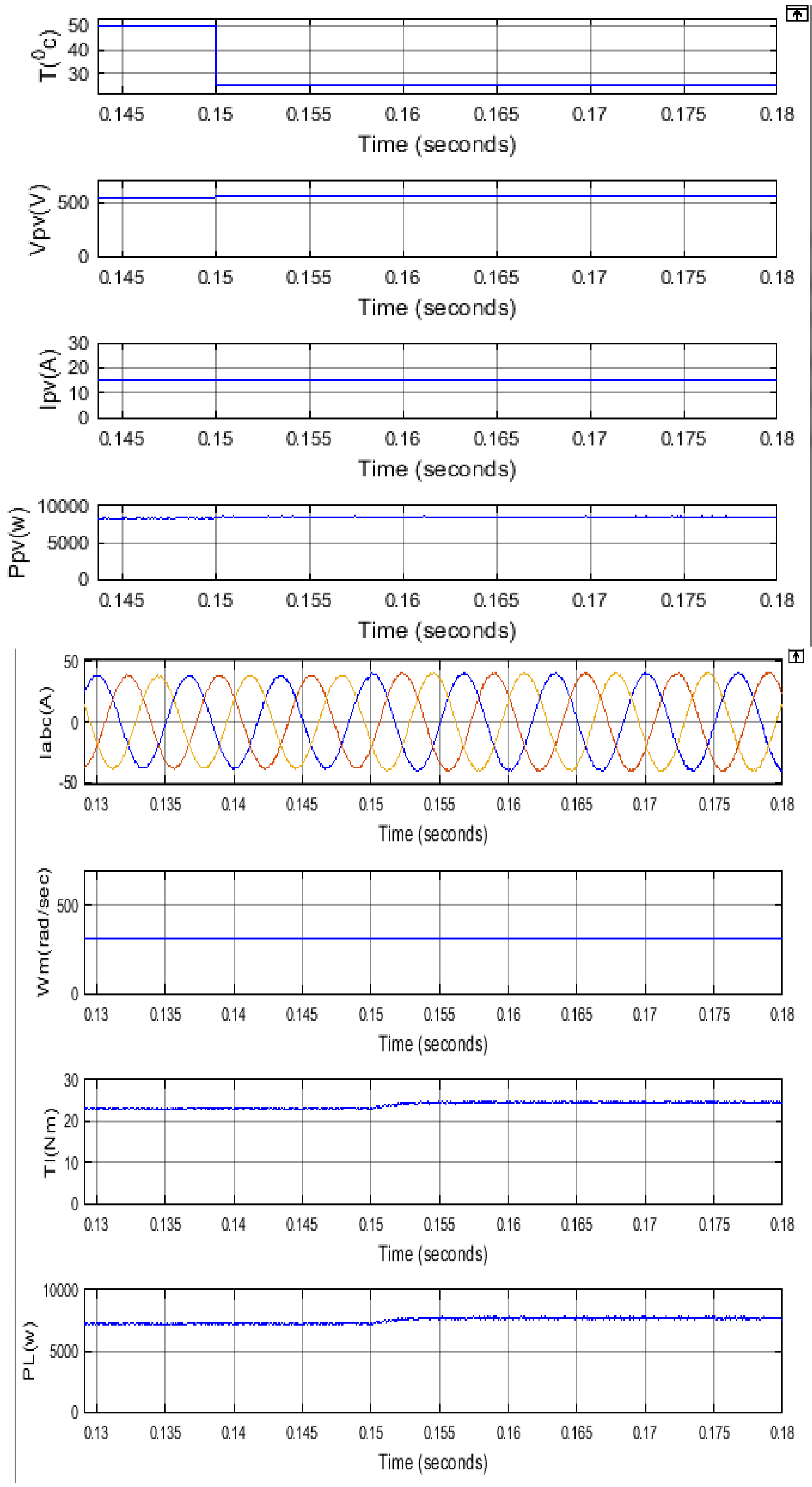

Figure 8- Dynamic performance during temperature change from 50°C to 25°C

V. CONCLUSION

A SPV array fed SWP system that makes use of the VSSINC method for MPPT for speed control of PMSM has been constructed, and its performance has been evaluated through the use of MATLAB simulation and hardware validation. It has been determined that the results of simulations and experiments for beginning, steady state, and dynamic performances are quite excellent. When the VSS-INC technique is utilised, neither the steady state performance nor the transient performance are impaired in the same way that they are in the standard INC technique. Because of the MVC, the torque response has been improved. As a result of the implementation of the feed-forward term, the overall reaction of the system has been considerably expedited. There are no steady-state oscillations that have been detected, and the system has become more efficient as a result of the faster response. The effectiveness of this control over the conventional control that is already in use has been demonstrated by in-depth comparative analysis. The use of PMSM for driving the pump has resulted in an increase in the efficiency of the system as well as a reduction in the size of the system. The implementation of a single-stage topology has resulted in the elimination of an intermediate-stage DC-DC converter and a reduction in the number of components. This has led to a reduction in both the cost and complexity of the system, as well as an increase in both its efficiency and its compactness. The system's practicability has been validated as a result of the fact that the results of both simulations and experiments have been determined to be pretty satisfactory.

REFERENCES

[1]. K. K. S. Liyakat, "Detecting Malicious Nodes in IoT Networks Using Machine Learning and Artificial Neural Networks," *2023 International Conference on Emerging Smart Computing and Informatics (ESCI)*, Pune, India, 2023, pp. 1-5, doi: 10.1109/ESCI56872.2023.10099544.

[2]. K. Kasat, N. Shaikh, V. K. Rayabharapu, M. Nayak, "Implementation and Recognition of Waste Management System with Mobility Solution in Smart Cities using Internet of Things," *2023 Second International Conference on Augmented Intelligence and Sustainable Systems (ICAISS)*, Trichy, India, 2023, pp. 1661-1665, doi: 10.1109/ICAISS58487.2023.10250690

[3]. Liyakat, K.K.S. (2023). Machine Learning Approach Using Artificial Neural Networks to Detect Malicious Nodes in IoT Networks. In: Shukla, P.K., Mittal, H., Engelbrecht, A. (eds) Computer Vision and Robotics. CVR 2023. Algorithms for Intelligent Systems. Springer, Singapore. https://doi.org/10.1007/978-981-99-4577-1_3

[4]. Prashant K Magadum (2024). Machine Learning for Predicting Wind Turbine Output Power in Wind Energy Conversion Systems, Grenze International Journal of Engineering and Technology, Jan Issue, Vol 10, Issue 1, pp. 2074-2080. Grenze ID: 01.GIJET.10.1.4_1

[5]. Wale Anjali D., Rokade Dipali, et al, “Smart Agriculture System using IoT”, International Journal of Innovative Research In Technology, 2019, Vol 5, Issue 10, pp.493 - 497.

[6]. Mrunal M Kapse, et al, “Smart Grid Technology”, International Journal of Information Technology and Computer Engineering, Vol 2, Issue 6

[7]. K. Kazi, “Smart Grid energy saving technique using Machine Learning” Journal of Instrumentation Technology and Innovations, 2022, Vol 12, Issue 3, pp. 1 – 10.

[8]. Sultanabanu Sayyad Liyakat (2023). PV Power Control for DC Microgrid Energy Storage Utilisation, Journal of Digital Integrated Circuits in Electrical Devices, 8(3), 1-8.

[9]. Kazi Kutubuddin Sayyad Liyakat (2024). Blynk IoT-Powered Water Pump-Based Smart Farming, *Recent Trends in Semiconductor and Sensor Technology*, 1(1), 8-14.

[10]. Kazi Kutubuddin Sayyad Liyakat (2024). Impact of Solar Penetrations in Conventional Power Systems and Generation of Harmonic and Power Quality Issues, Advance Research in Power Electronics and Devices, 1(1), 10-16.

[11]. Kazi Kutubuddin Sayyad Liyakat. Intelligent Watering System (IWS) for Agricultural Land Utilising Raspberry Pi. Recent Trends in Fluid Mechanics. 2023; 10(2): 26–31p.

[12]. S. Murshid and B. Singh, "Single Stage Autonomous Solar Water Pumping System Using PMSM Drive," in *IEEE Transactions on Industry Applications*, vol. 56, no. 4, pp. 3985-3994, July-Aug. 2020, doi: 10.1109/TIA.2020.2988429.

[13]. Thallapally Soujanya , V.Prashanth, “Single Stage Autonomous Solar Water Pumping System Using Pmsm Drive”, Journal Of Engineering Sciences Vol 13 Issue 10,2022, Issn:0377-9254

[14]. K K Prabhakaran, Varsha Sunkara, A Karthikeyan, Single-stage PV-powered boost inverter-fed permanent-magnet synchronous motor-driven water-pumping system, *Clean Energy*, Volume 6, Issue 5, October 2022, Pages 726–737, https://doi.org/10.1093/ce/zkac053

[15]. Alan John Francis, Gokila Vijayan, Jibin Baby, Vishnupriya Arjunan, Neethu Salim, “Autonomous Solar Water Pumping System Using Bldc Drive”, International Journal of Creative Research Thoughts (IJCRT), Volume 11, Issue 6 June 2023

[16]. Nouaiti, M. Reddak, C. Boutahiri, A. Mesbahi, A. Marhraoui Hsaini, and A. Bouazi, “A Single Stage Photovoltaic Solar Pumping System based on the Three Phase Multilevel Inverter”, *Eng. Technol. Appl. Sci. Res.*, vol. 13, no. 6, pp. 12145–12150, Dec. 2023