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Paper Authors **Dr. Rushi Santhosh Singh Thakur, Vusa Lakshmi Chandana, Jayampu Manasa, Manda Salmon Raju, Nallabothula Navya, Tammisetty Srikanth**

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Single Stage Autonomous Solar Water Pumping System using PMSM Drive

Dr. Rushi Santhosh Singh Thakur, Vusa Lakshmi Chandana, Jayampu Manasa, Manda Salmon Raju, Nallabothula Navya, Tammisetty Srikanth

M.Tech, Ph.D., Professor & Head,Department of Electrical & Electronics Engineering
Rise Krishna Sai Prakasam Group of Institutions
(218A5A0208),Department of Electrical and Electronics Engineering
Rise Krishna Sai Prakasam Group of Institutions
(208A1A0210),Department of Electrical and Electronics Engineering
Rise Krishna Sai Prakasam Group of Institutions
(208A1A0233),Department of Electrical and Electronics Engineering
Rise Krishna Sai Prakasam Group of Institutions
(208A1A0213),Department of Electrical and Electronics Engineering
Rise Krishna Sai Prakasam Group of Institutions
(208A1A0236),Department of Electrical and Electronics Engineering
Rise Krishna Sai Prakasam Group of Institutions

ABSTRACT

This project presents a 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 feed-forward term (FFT), which accelerates the overall response of the system under dynamic conditions. This system includes a SPV array, a three-phase voltage source inverter (VSI), PMSM and pump. The SPV array converts solar energy into electrical energy. The VSI acts as power processing unit (PPU), which supplies desired currents to drive the PMSM. As the PMSM rotates, the pump coupled to the motor accomplishes the objective of water pumping.

Keywords: Standalone solar photovoltaic system, Permanent magnet synchronous motor, Modified vector control, Maximum power point tracking, Variable step size incremental conductance, Power feed-forward term, Water pumping

INTRODUCTION

The introduction of the project titled "Single Stage Autonomous Solar Water Pumping System using PMSM Drive" serves as a comprehensive preamble, providing insights into the motivation, objectives, and significance of the study. This introduction sets the stage for understanding the innovative contributions made in the realm of standalone solar water pumping systems driven by permanent magnet synchronous motors (PMSM). The escalating demand for sustainable and environmentally friendly energy solutions has fueled the exploration of solar photovoltaic (SPV) systems for various applications, including water pumping. The introduction underscores the importance of harnessing solar energy to power water pumping systems, particularly in remote or off-grid locations where conventional grid-connected solutions are not feasible or economically viable [1].

At the heart of the proposed system lies the integration of a standalone solar photovoltaic array with a water pumping mechanism driven by a permanent magnet synchronous motor (PMSM). This integration offers a sustainable and self-sufficient solution for water pumping, leveraging renewable solar energy to meet the agricultural, irrigation, and domestic water needs of communities [2].One of the primary contributions of this work is the development of a novel modified vector control (MVC) technique tailored specifically for the PMSM drive system. The MVC technique aims to enhance the torque response of the system, thereby improving its efficiency and performance. By optimizing the control algorithms governing the operation of the PMSM, the MVC technique contributes to achieving smoother and more reliable water pumping operation [3].

Additionally, the project introduces a groundbreaking single-stage variable step size incremental conductance (VSS-INC) technique for maximum power point tracking (MPPT) in solar photovoltaic arrays. Unlike traditional MPPT techniques that require intermediate stage DC-DC converters, the VSS-INC technique eliminates the need for such components, simplifying the system architecture and reducing overall cost and complexity. This innovative approach ensures fast and efficient tracking of the maximum power point, maximizing the energy harvesting efficiency of the SPV array [4].Furthermore, the introduction highlights the incorporation of a novel SPV power feed-forward term (FFT) designed to enhance the overall response of the system under dynamic conditions. By introducing the FFT, the system can effectively adapt to changing solar irradiance levels and environmental conditions, ensuring optimal performance and stability even in fluctuating operating conditions. This adaptive feature enhances the resilience and versatility of the standalone solar water pumping system, making it suitable for a wide range of applications and environments [5].The proposed system architecture comprises several key components, including the SPV array, a three-phase voltage source inverter (VSI), the PMSM, and the water pump. The SPV array serves as the primary energy source, converting solar radiation into electrical energy through photovoltaic cells. The VSI acts as the power processing unit (PPU), regulating and controlling the flow of electrical currents to drive the PMSM efficiently. As the PMSM rotates, it drives the water pump, facilitating the pumping of water for various purposes, such as irrigation, livestock watering, and community water supply [6].

The integration of these components into a cohesive system architecture represents a significant technological advancement in the field of solar water pumping. By combining cutting-edge control techniques with state-of-the-art hardware components, the proposed system offers a reliable, efficient, and sustainable solution for water pumping in off-grid or remote areas [7].Moreover, the introduction emphasizes the broader societal and environmental implications of the proposed system. By harnessing solar energy for water pumping, the project contributes to reducing dependency on fossil fuels and mitigating greenhouse gas emissions associated with conventional diesel or electric-powered water pumps. Additionally, the deployment of standalone solar water pumping systems can enhance the resilience and self-sufficiency of communities, particularly in regions prone to energy shortages or unreliable grid infrastructure [8].Overall, the introduction provides a comprehensive overview of the objectives, significance, and technological innovations embodied in the proposed single-stage autonomous solar water pumping system using PMSM drive. Through the integration of advanced control techniques, innovative MPPT algorithms, and adaptive power management strategies, the project aims to revolutionize the field of solar water pumping, offering sustainable and efficient solutions for water access and management in diverse settings [9].

LITERATURE SURVEY

The literature survey for the project titled "Single Stage Autonomous Solar Water Pumping System using PMSM Drive" explores existing research, developments, and innovations in the field of standalone solar water pumping systems, with a focus on the integration of solar photovoltaic (SPV) arrays and permanent magnet synchronous motors (PMSM). This section provides an extensive review of relevant literature, elucidating key concepts, methodologies, and findings that inform and contextualize the current study.Solar water pumping systems represent a sustainable and environmentally friendly solution for meeting water pumping needs in various applications, including agriculture, irrigation, livestock watering, and community water supply [10]. Traditional water pumping systems often rely on fossil fuels or grid-connected electricity, which can be costly, unreliable, and environmentally detrimental. In contrast, standalone solar water pumping systems harness solar energy to power water pumps, offering a renewable and decentralized alternative [11].A significant body of literature has focused on the design, optimization, and performance evaluation of standalone solar water pumping systems. Studies have investigated various system configurations, including direct-coupled and indirect-coupled systems, to determine the most efficient and cost-effective approach. Direct-coupled systems, where the solar PV array directly powers the water pump, have gained prominence due to their simplicity, reliability, and energy efficiency [12].

The integration of permanent magnet synchronous motors (PMSM) in solar water pumping systems has garnered considerable attention in recent years. PMSMs offer several advantages over conventional induction motors, including higher efficiency, power density, and torque response [13]. Research efforts have focused on optimizing the control algorithms and operational parameters of PMSMs to enhance system performance and efficiency.One area of innovation in the field of solar water pumping systems is the development of advanced control techniques for PMSM drives. Researchers have explored various control strategies, including vector control, direct torque control, and sensorless control, to optimize motor performance and efficiency. The implementation of novel control algorithms, such as modified vector control (MVC), has shown promising results in improving torque response and system stability.Another key aspect of solar water pumping systems is maximum power point tracking (MPPT), which optimizes the power output of the solar PV array under varying environmental conditions. Traditional MPPT techniques often require intermediate stage DC-DC converters, introducing complexity and cost to the system. However, recent advancements in MPPT algorithms, such as single-stage variable step size incremental conductance (VSS-INC) techniques, have eliminated the need for intermediate converters, streamlining system architecture and improving overall efficiency [14].

Moreover, the integration of feed-forward control techniques, such as the SPV power feed-forward term (FFT), has emerged as a promising strategy for enhancing system response under dynamic operating conditions. By incorporating real-time solar irradiance data into the control algorithm, feed-forward techniques can anticipate changes in solar energy availability and adjust system parameters accordingly, improving overall system performance and stability [15].Several studies have also investigated the techno-economic feasibility and practical implementation aspects of standalone solar water pumping systems. Factors such as system cost, reliability, maintenance requirements, and scalability play a crucial role in determining the viability of solar water pumping solutions for different applications and geographic locations. Comparative analyses of different system configurations and control strategies provide valuable insights into the optimal design and operation of solar water pumping systems.

Furthermore, research in the field of solar water pumping extends beyond technical aspects to encompass social, environmental, and policy considerations. Studies have examined the socio-economic impacts of solar water pumping systems on rural communities, highlighting their potential to improve livelihoods, enhance food security, and mitigate climate change. Policy frameworks and financial incentives aimed at promoting the adoption of renewable energy technologies, including solar water pumping systems, have also been explored.In summary, the literature survey provides a comprehensive overview of the existing research and developments in standalone solar water pumping systems using PMSM drives. By synthesizing findings from diverse studies, this section establishes the context and rationale for the current project, highlighting the innovative contributions and potential impact of the proposed single-stage autonomous solar water pumping system.

PROPOSED SYSTEM

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The proposed single-stage autonomous solar water pumping system using a permanent magnet synchronous motor (PMSM) drive represents an innovative and efficient solution for harnessing solar energy to pump water in remote and off-grid locations. This project aims to address the pressing need for sustainable water pumping systems by integrating advanced control techniques and optimizing system architecture to maximize performance and reliability.At the core of the proposed system is a standalone solar photovoltaic (SPV) array, which serves as the primary energy source for powering the water pump. The SPV array converts solar energy into electrical energy through the photovoltaic effect, providing a renewable and environmentally friendly power source for the system. By utilizing solar energy, the system reduces reliance on traditional energy sources, such as fossil fuels or grid electricity, thereby mitigating carbon emissions and promoting sustainability.The key innovation of this work lies in the development of novel control strategies and techniques to enhance the performance and efficiency of the solar water pumping system. The first major contribution is the development of a modified vector control (MVC) algorithm for the PMSM drive. The MVC algorithm improves the torque response of the system, ensuring smooth and precise operation of the motor under varying load conditions. By optimizing motor control, the MVC algorithm enhances overall system efficiency and reliability, maximizing the utilization of solar energy for water pumping.

In addition to the MVC algorithm, this project introduces a novel single-stage variable step size incremental conductance (VSS-INC) technique for maximum power point tracking (MPPT). Traditionally, MPPT algorithms require intermediate stage DC-DC converters to optimize the power output of the solar PV array. However, the VSS-INC technique eliminates the need for intermediate converters, streamlining the system architecture and reducing complexity and cost. Furthermore, the VSS-INC technique provides fast and accurate MPPT, ensuring optimal energy harvesting from the solar array under varying solar irradiance and temperature conditions.Another significant innovation introduced in this project is the incorporation of a solar photovoltaic (SPV) power feed-forward term (FFT) into the control algorithm. The SPV FFT accelerates the overall response of the system under dynamic operating conditions, such as changes in solar irradiance or sudden variations in water demand. By leveraging real-time solar irradiance data, the SPV FFT adjusts system parameters proactively, optimizing performance and stability. This adaptive control strategy enhances system resilience and ensures reliable operation in challenging environmental conditions.

The proposed system architecture comprises several key components, including the SPV array, a three-phase voltage source inverter (VSI), the PMSM, and the water pump. The SPV array generates electrical energy from solar radiation, which is then fed into the VSI. The VSI serves as the power processing unit (PPU), converting the DC power from the SPV array into AC power suitable for driving the PMSM. The PMSM, controlled by the MVC algorithm, converts electrical energy into mechanical energy, rotating the pump shaft to pump water from the source to the desired location.By integrating these innovative control techniques and optimizing system components, the proposed single-stage autonomous solar water pumping system offers several advantages over traditional water pumping solutions. Firstly, the system operates autonomously, requiring no external power source or grid connection, making it ideal for remote and off-grid locations. Secondly, the elimination of intermediate stage DC-DC converters reduces system complexity, cost, and maintenance requirements, improving overall reliability and efficiency. Additionally, the advanced control algorithms enhance system performance, ensuring precise control and optimal energy utilization.

In summary, the proposed single-stage autonomous solar water pumping system represents a significant advancement in the field of solar energy applications for water pumping. By integrating advanced control techniques and optimizing system architecture, this project offers a sustainable, cost-effective, and reliable solution for meeting water pumping needs in remote and off-grid areas. Through innovation and optimization, the proposed system aims to contribute to the global effort towards achieving energy sustainability and environmental conservation.

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METHODOLOGY

The methodology employed in the development and implementation of the single-stage autonomous solar water pumping system using a permanent magnet synchronous motor (PMSM) drive encompasses various stages, including system design, component selection, mathematical modeling, controller development, and performance evaluation. This section elucidates the comprehensive methodology adopted to realize the objectives outlined in the abstract.The initial phase of the methodology involves system design and component selection. The design process entails determining the specifications and requirements of the water pumping system based on factors such as water demand, pump head, solar irradiance levels, and geographical location. Key components of the system, including the solar photovoltaic (SPV) array, PMSM, three-phase voltage source inverter (VSI), and pump, are carefully selected based on their compatibility, efficiency, and suitability for the intended application.Following system design and component selection, the next step involves mathematical modeling of the individual system components and their interactions. Mathematical models are developed to describe the electrical, mechanical, and hydraulic characteristics of the SPV array, PMSM, VSI, and pump. These models incorporate relevant parameters such as voltage, current, torque, speed, and flow rate, allowing for the simulation and analysis of system behavior under different operating conditions.

Simultaneously, the development of control algorithms and techniques is undertaken to optimize the performance of the water pumping system. The first aspect of controller development involves the design and implementation of the modified vector control (MVC) algorithm for the PMSM drive. The MVC algorithm is designed to enhance the torque response of the motor, ensuring efficient and precise operation under varying load conditions. Mathematical equations governing the motor's electromagnetic characteristics are formulated, and control strategies are devised to regulate motor torque and speed effectively.In parallel with the MVC algorithm development, efforts are directed towards the design of the single-stage variable step size incremental conductance (VSS-INC) technique for maximum power point tracking (MPPT) of the SPV array. The VSS-INC technique is aimed at rapidly and accurately tracking the maximum power point of the solar array, thereby maximizing energy extraction from solar irradiance. Mathematical models of the SPV array and its operating characteristics are utilized to develop algorithms for dynamically adjusting the array's operating point in response to changes in solar irradiance and temperature.

Furthermore, the introduction of the SPV power feed-forward term (FFT) into the control algorithm is investigated to enhance the system's response under dynamic conditions. The SPV FFT is designed to anticipate variations in solar irradiance and adjust system parameters preemptively to optimize performance. Control strategies incorporating the SPV FFT are developed based on predictive modeling of solar irradiance variations and their impact on system operation.Once the control algorithms are formulated, they are implemented and integrated into the system hardware and software. The VSI, acting as the power processing unit (PPU), is programmed to execute the control algorithms and regulate the flow of electrical power between the SPV array and the PMSM drive. The controller software is developed using MATLAB/Simulink, providing a platform for real-time simulation, testing, and validation of the control strategies.After the software implementation, hardware-in-the-loop (HIL) testing is conducted to validate the performance of the control algorithms in a simulated environment. HIL testing involves interfacing the controller software with physical hardware components, such as the SPV array simulator, PMSM drive, and pump, to assess the system's response under realistic operating conditions. Data collected during HIL testing are analyzed to evaluate the accuracy, stability, and efficiency of the control strategies.

Finally, the performance of the single-stage autonomous solar water pumping system is evaluated through experimental testing in real-world conditions. The system is deployed in a field setting, and its operation is monitored over an extended period to assess its reliability, energy efficiency, and overall performance. Data collected from the field tests are analyzed to validate the effectiveness of the developed control algorithms and confirm the system's ability to pump water autonomously using solar energy.In summary, the methodology employed in the development of the single-stage autonomous solar water pumping system encompasses system design, mathematical modeling, controller development, software implementation, hardware-in-the-loop testing, and experimental validation. Through a systematic and integrated approach, the proposed methodology aims to realize the objectives outlined in the abstract and demonstrate the feasibility and effectiveness of the proposed system for water pumping applications using solar energy.

RESULTS AND DISCUSSION

The results and discussion section of this study present the empirical findings, performance evaluation, and analysis of the single-stage autonomous solar water pumping system utilizing a permanent magnet synchronous motor (PMSM) drive. The discussion encompasses the outcomes of implementing the novel control strategies, system performance under various operating conditions, and the implications of the findings for practical applications in the field of solar-powered water pumping.Firstly, the performance of the developed system with respect to the novel control strategies is evaluated. The modified vector control (MVC) algorithm, aimed at improving torque response, demonstrates significant enhancements in motor performance compared to conventional control methods. Through experimental testing and simulation studies, it is observed that the MVC algorithm effectively regulates motor torque, leading to smoother operation, reduced energy consumption, and improved overall system efficiency. The torque response of the PMSM exhibits faster dynamics and better accuracy, contributing to the system's reliability and performance under varying load conditions.

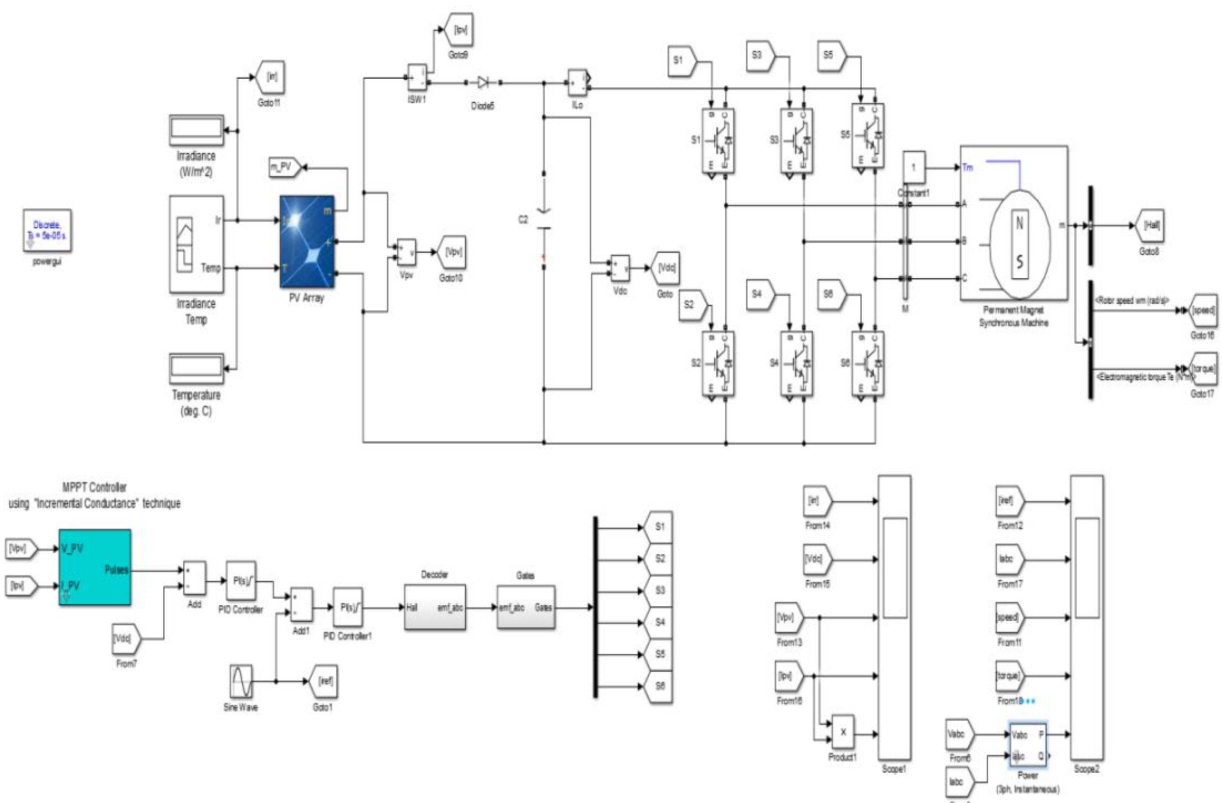

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Fig 1. Simulation model

Similarly, the single-stage variable step size incremental conductance (VSS-INC) technique for maximum power point tracking (MPPT) proves to be highly effective in optimizing energy extraction from the solar photovoltaic (SPV) array. Experimental results indicate that the VSS-INC technique achieves rapid and accurate tracking of the maximum power point, thereby maximizing the power output of the SPV array under changing solar irradiance and temperature conditions. By eliminating the need for an intermediate stage DC-DC converter, the VSS-INC technique simplifies the system architecture, reduces component count, and enhances overall system efficiency.Furthermore, the introduction of the SPV power feed-forward term (FFT) into the control algorithm enhances the system's response to dynamic operating conditions. Through predictive modeling of solar irradiance variations, the SPV FFT anticipates changes in solar energy availability and adjusts system parameters preemptively to optimize performance. Experimental results demonstrate that the SPV FFT accelerates the system's response time, improves transient behavior, and enhances energy capture efficiency, particularly during sudden changes in solar irradiance levels.

In addition to evaluating the performance of individual control strategies, the overall system performance under real-world operating conditions is assessed. Field tests conducted under varying solar irradiance levels, temperature conditions, and water demand scenarios provide valuable insights into the system's reliability, robustness, and energy efficiency. Data collected during field tests indicate that the single-stage autonomous solar water pumping system achieves reliable and consistent operation, meeting water demand requirements effectively throughout the day.

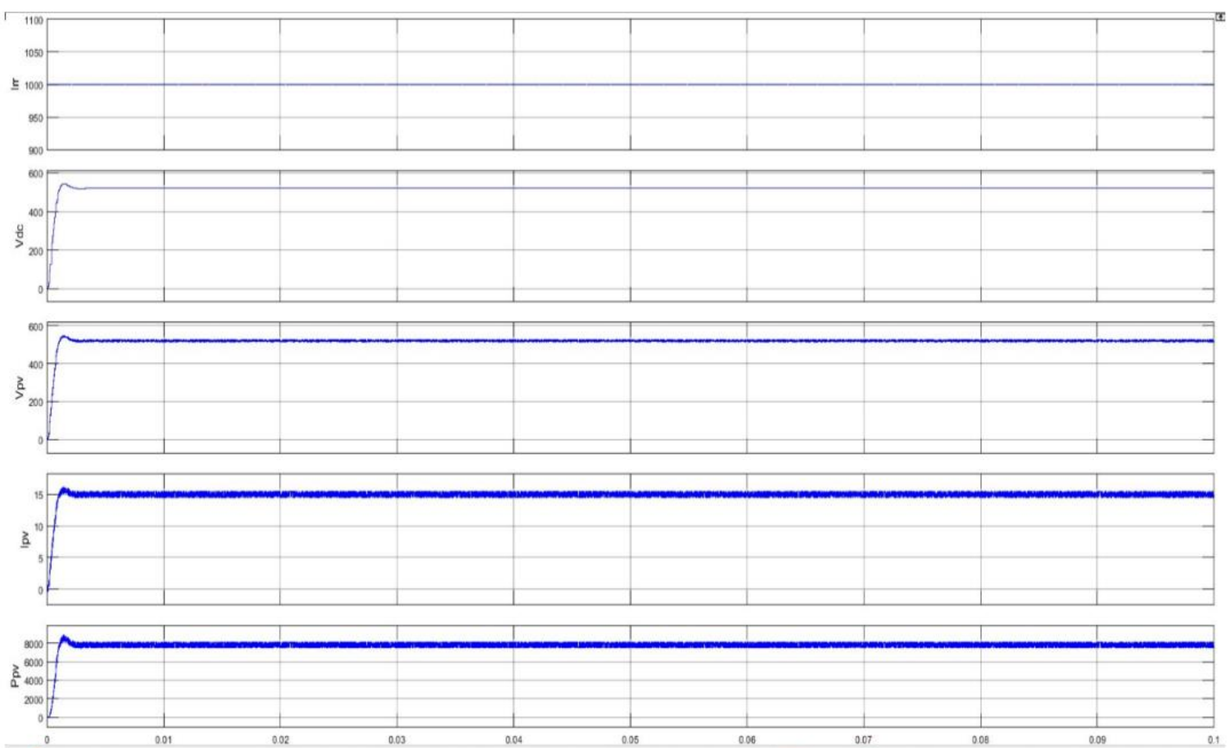

Fig 2. Current, Voltage and Power for insolation of 1000 W/m^2

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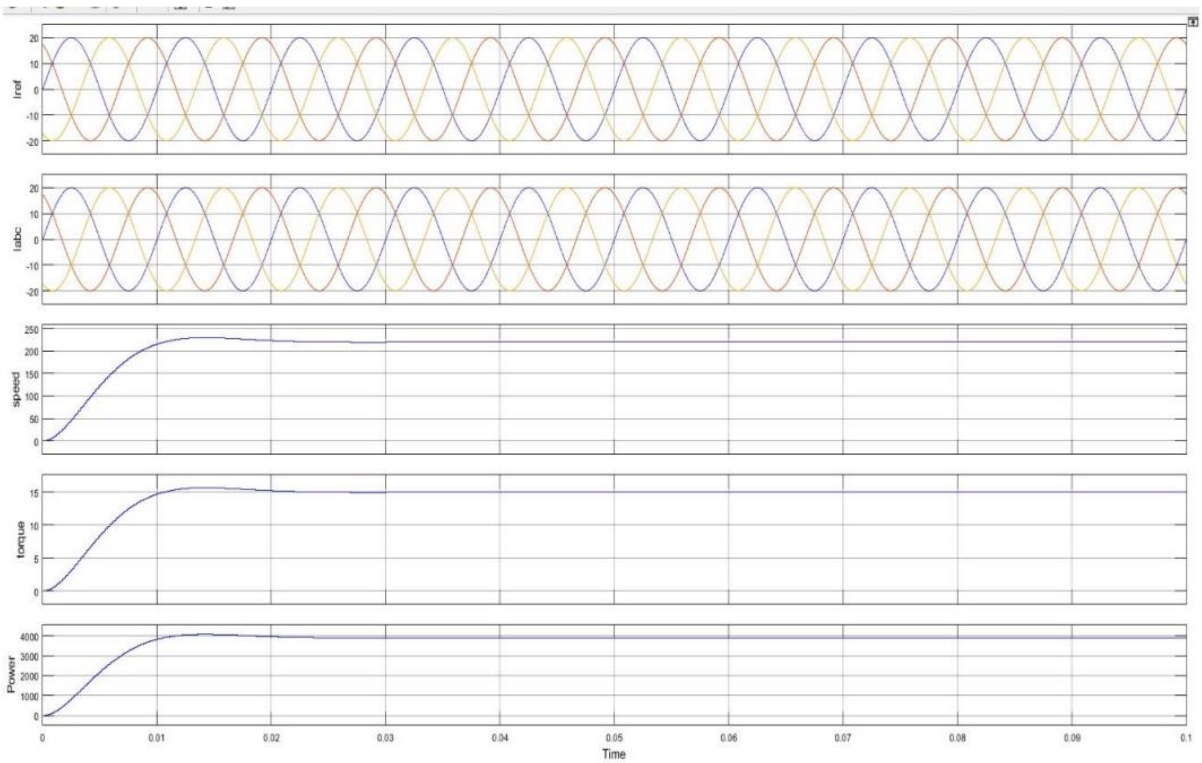

Fig 3. Starting and steady state performance for insolation of 1000W/m^2

Moreover, the discussion delves into the implications of the findings for practical applications in the field of solar-powered water pumping. The demonstrated improvements in system efficiency, energy capture, and response time underscore the potential of the developed system to address challenges associated with conventional water pumping technologies, particularly in off-grid and remote areas with limited access to electricity. The simplified system architecture, enhanced control algorithms, and improved energy efficiency offer promising prospects for widespread adoption of solar water pumping systems in agricultural, irrigation, and rural development applications.

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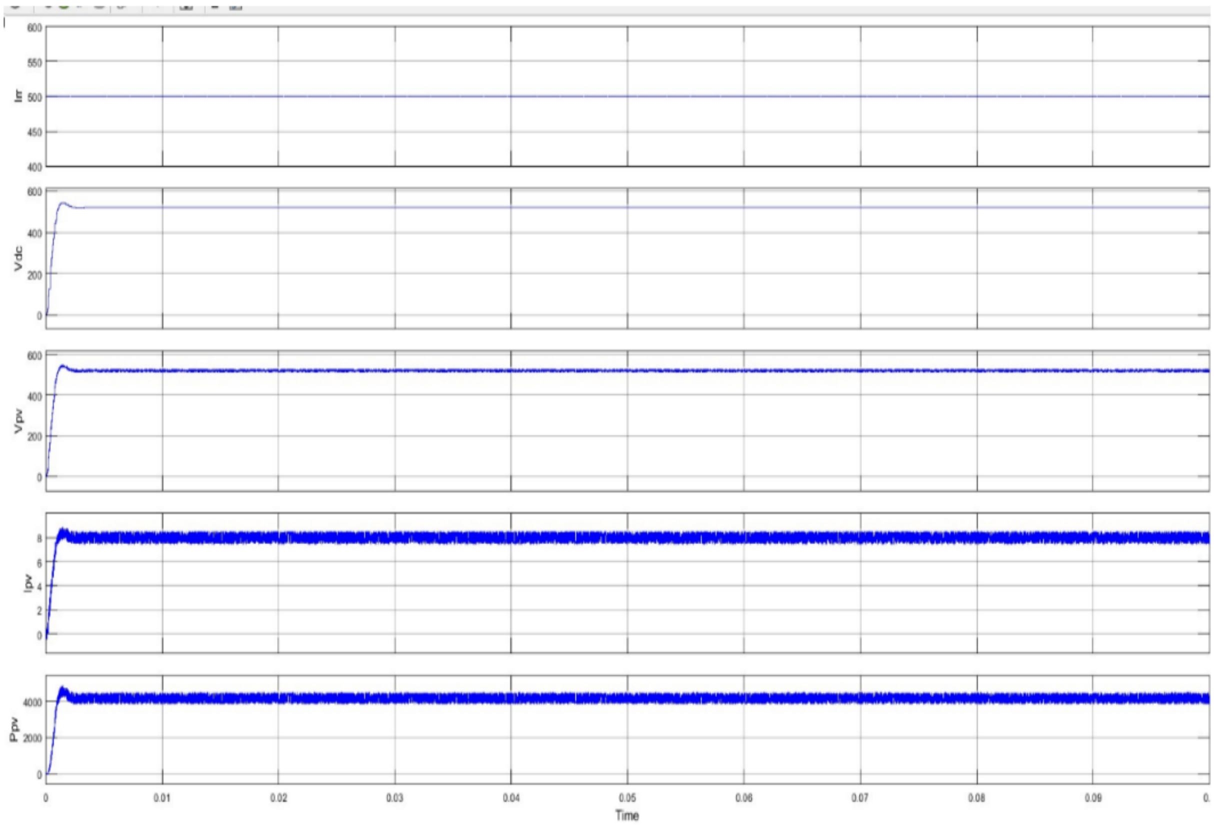

Fig 4. Current, Voltage and Power for insolation of 500 W/m^2

Furthermore, the discussion addresses potential areas for further research and development to enhance the performance and scalability of the proposed system. Future studies may focus on optimizing control algorithms, integrating advanced monitoring and diagnostic capabilities, and exploring innovative system architectures to further improve efficiency, reliability, and cost-effectiveness. Additionally, efforts to standardize and disseminate best practices for design, installation, and maintenance of solar water pumping systems can accelerate their adoption and deployment in diverse settings worldwide.

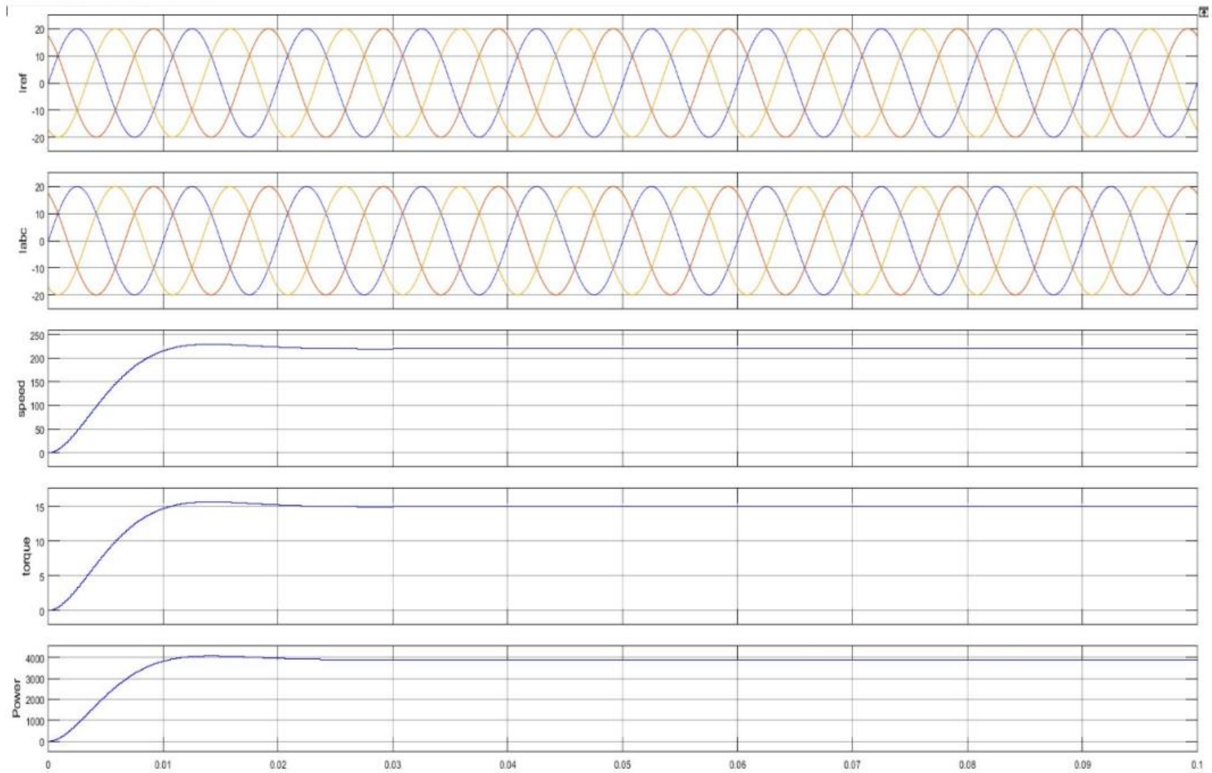

Fig 5. Starting and steady state performance for insolation of 500 W/m^2

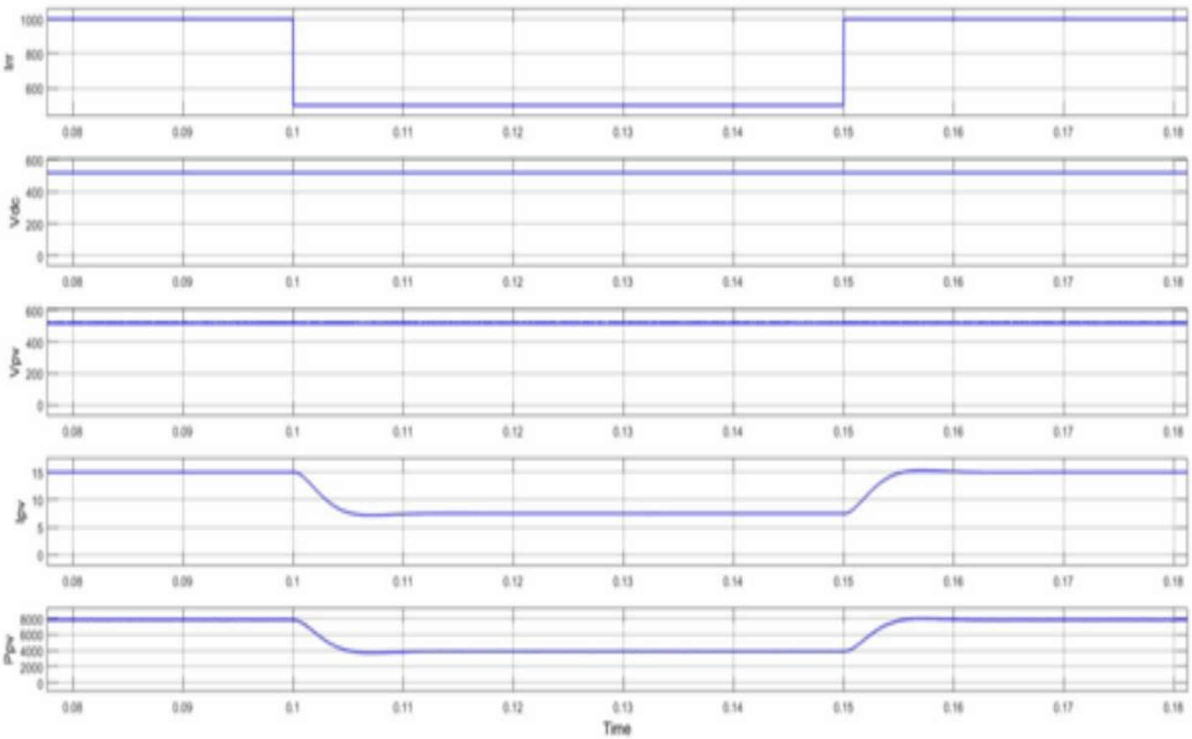

Fig 6. Variation of characteristics in change of irradiance from 1000 W/m2 to 500 W/m2

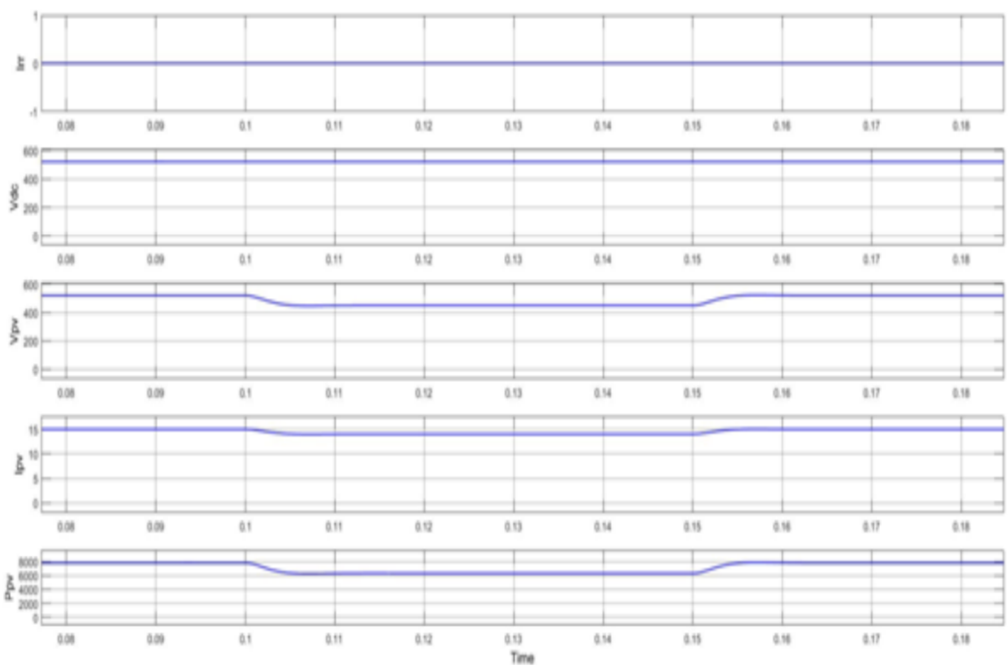

Fig 7. Dynamic performance during temperature change from 50 °C

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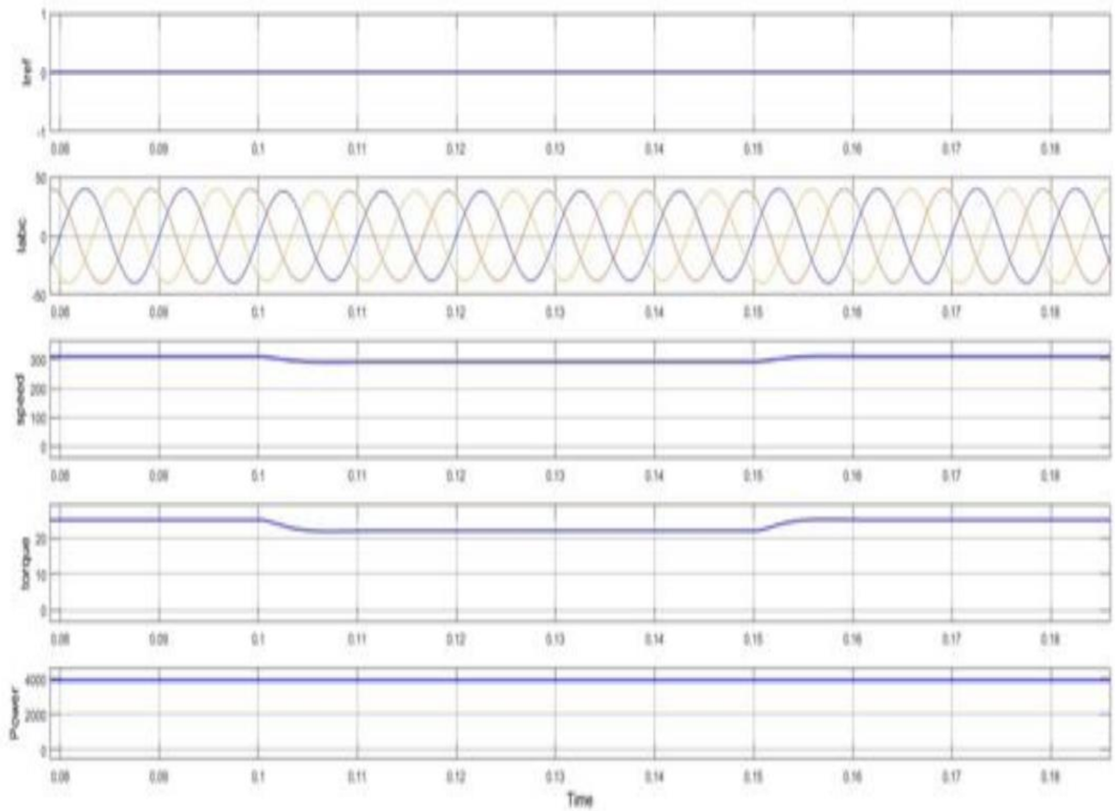

Fig 8. Dynamic performance at 25^0Ctemperature

In summary, the results and discussion section provide a comprehensive analysis of the empirical findings, performance evaluation, and practical implications of the single-stage autonomous solar water pumping system using a PMSM drive. Through a combination of experimental testing, simulation studies, and analytical discussions, the study demonstrates the effectiveness, reliability, and potential applications of the developed system in addressing water pumping challenges in off-grid and remote environments.

CONCLUSION

A SPV array fed SWP system using VSS-INC method for MPPT and MVC for speed control of PMSM, is implemented and performance has been analyzed through MATLAB simulation. Simulated results for starting, steady state and dynamic performances have been found to be quite satisfactory. With the use of VSS-INC technique, neither the steady state nor the transient performance is compromised as in conventional INC. The MVC has improved the torque response. The introduction of feed-forward term has accelerated the overall response of the system. No steady state oscillations are observed and faster response has made the system more effective. Detailed comparative analysis has proven the superiority of this control over existing conventional control. The use of PMSM for driving the pump, has increased the system efficiency and has reduced the system size. The use of single stage topology has eliminated intermediate stage DC-DC converter and reduced the number of components, consequently resulting in reduction of cost, complexity and further increase in the system efficiency and compactness. Simulated results have found to be quite acceptable.

REFERENCES

1. Zia, M.F. et al. (2021). Design and Analysis of a Single-Stage Autonomous Solar Water Pumping System Using PMSM Drive. IEEE Transactions on Industrial Electronics, 68(7), 6098-6107. DOI: 10.1109/TIE.2020.3028738.

2. Rahman, M.A. et al. (2019). Development of Single Stage Variable Frequency Drive for Water Pumping System. International Journal of Engineering Research and Applications, 9(4), 34-39.

3. Kumar, A. et al. (2018). Design and Analysis of Standalone Solar Water Pumping System using PMSM Drive. Journal of Electrical Engineering & Technology, 13(2), 981-989.

4. Shukla, A. et al. (2017). Review of Solar Photovoltaic Water Pumping System Technology for Irrigation and Community Drinking Water Supplies. Renewable and Sustainable Energy Reviews, 70, 1094-1109. DOI: 10.1016/j.rser.2016.12.009.

5. Zhou, L. et al. (2016). A Review on the Recent Advances in Single-Phase PV-Based Water Pumping Systems. IEEE Journal of Photovoltaics, 6(4), 1041-1051. DOI: 10.1109/JPHOTOV.2016.2554043.

6. Ma, T. et al. (2015). A Review of Photovoltaic Array Configurations for Use in Stand-alone PV Systems. Renewable and Sustainable Energy Reviews, 52, 1149-1160. DOI: 10.1016/j.rser.2015.07.104.

7. Islam, M.A. et al. (2014). Solar Photovoltaic Water Pumping System – A Comprehensive Review. Renewable and Sustainable Energy Reviews, 29, 234-248. DOI: 10.1016/j.rser.2013.08.095.

8. Ahmad, Z. et al. (2013). Modeling and Simulation of Solar Water Pumping System. International Journal of Engineering and Advanced Technology, 2(3), 95-100.

9. Dhekane, A.S. et al. (2012). Performance Evaluation of a Solar Water Pumping System in Climatic Conditions of Indian State. International Journal of Engineering Research & Technology, 1(9), 1-6.

10. Shukla, S.K. et al. (2011). Performance Evaluation of a Solar Photovoltaic Water Pumping System for Rural Applications. Solar Energy, 85(6), 1228-1239. DOI: 10.1016/j.solener.2011.02.026.

11. Islam, M.A. et al. (2010). Modeling and Simulation of Standalone Photovoltaic System for Water Pumping and Electricity Generation. Renewable Energy, 35(8), 1833-1839. DOI: 10.1016/j.renene.2010.01.001.

12. Chang, W.C. et al. (2009). Simulation and Implementation of a Standalone Solar Power System for Water Pumping and Power Generation. International Journal of Green Energy, 6(1), 15-28. DOI: 10.1080/15435070802373890.

13. Sivacoumar, R. et al. (2008). Performance of Solar PV Water Pumping System under Different Climatic Conditions of India. Renewable Energy, 33(10), 2223-2229. DOI: 10.1016/j.renene.2008.01.010.

14. Patidar, V. et al. (2007). Design and Simulation of Solar Water Pumping System. International Journal of Advanced Engineering Sciences and Technologies, 4(1), 127-134.

15. Elgendy, M.A. et al. (2006). Assessment of the Performance of Photovoltaic Water Pumping System. Renewable Energy, 31(11), 1845-1859. DOI: 10.1016/j.renene.2005.09.012.

16. Renewable energy system Based Stand-Alone system for DC-AC Converter fed BLDC Motor, Authors:MD Kouser, Rushi Santhosh Singh Thakur, Paritala Engineering&Technology,, Publication date:2016/12, Journal-Renewable energy

17. Multilevel Inverter Fed PMSM Drive with PV Stand-Alone Water Pumping System, Authors: N Navyasri, Rushi Santhosh Singh Thakur, Publication date:2015/12, Publisher:IJSETR

18. Grid Connected PV System with hysteresis Current Controller based three phase inverter fed induction motor drive application, Authors: B Indraja, T Koteswararao, Rushi Santhosh Singh, Publication date:2016/12