As per UGC guidelines an electronic bar code is provided to secure your paper

International Journal for Modern Trends in Science and Technology
Volume 10, Issue 04, pages 415-422.
ISSN: 2455-3778 online
Available online at: http://www.ijmtst.com/vol10issue04.html
DOI: https://doi.org/10.46501/IJMTST1004065

Solar Based PMBLDC Drive System for Water Pumping Application

S. Ramaraj[1], D. Aravindh[2], S. Abishek[3], T. Arunkumar[4]

[1]Associate Professor, Department of Electrical and Electronics Engineering, P.S.R. Engineering College, Sivakasi, India
[2,3,4]UG Scholar, Department of Electrical and Electronics Engineering, P.S.R. Engineering College Sivakasi, India

To Cite this Article
S. Ramaraj, D. Aravindh, S. Abishek, T. Arunkumar, Solar Based PMBLDC Drive System for Water Pumping Application, International Journal for Modern Trends in Science and Technology, 2024, 10(04), pages. 415-422. https://doi.org/10.46501/IJMTST1004065

Article Info
Received: 11 April 2024; Accepted: 27 April 2024; Published: 30 April 2024.

ABSTRACT

Our research centers on the development of a Solar-Powered Permanent Magnet Brushless DC (PMBLDC) Drive System designed specifically for water pumping applications. We delve into the integration of solar photovoltaic technology with the PMBLDC drive to bolster efficiency, particularly in off-grid settings. Our primary objective is to refine energy extraction methods and operational efficiency through the implementation of robust control schemes and comprehensive performance evaluation techniques.

1. INTRODUCTION

The increasing global demand for sustainable and efficient water pumping systems, particularly in remote and off-grid regions, has spurred the exploration of renewable energy-driven solutions. Solar energy, in particular, emerges as a promising resource owing to its abundance and environmental sustainability. Conventional water pumping systems reliant on fossil fuel-based generators or grid connections frequently encounter issues such as high operational costs, restricted accessibility, and environmental ramifications. In addressing these challenges, this study presents a Solar-Based Permanent Magnet Brushless DC (PMBLDC) Drive System specifically designed for water pumping applications.

The incorporation of solar photovoltaic (PV) technology with PMBLDC drives offers an innovative approach to tackle these challenges. By harnessing solar energy and capitalizing on the efficiency of PMBLDC motors, this system aims to offer a dependable and sustainable solution for water pumping requirements in remote regions. This paper outlines the design, implementation, and assessment of the Solar-Based PMBLDC Drive System. It underscores the significance of renewable energy utilization and delves into the technical aspects and benefits of integrating PMBLDC technology into water pumping applications. The system's efficiency, reliability, and suitability for off-grid environments are explored, highlighting the contributions of this study to the realm of renewable energy-powered water pumping solutions.

This paper presents a brushless DC (BLDC) drive integrated with a single-sided matrix converter (SSMC) designed for an electro-hydrostatic actuation system in aerospace applications. The utilization of an SSMC with a BLDC motor is a novel approach aimed at achieving operation without requiring a microprocessor. A straightforward hysteresis current control strategy is implemented to regulate motor torque. The multi-phase SSMC offers high reliability and fault tolerance, albeit with the trade-off of increased power device requirements. A prototype of a five-phase SSMC is constructed, and experimental results are provided to validate the drive's performance.

Furthermore, a fault-tolerant BLDC motor serving as a pump drive in an EHA system is designed and tested. The novel integration of an SSMC with hysteresis current control alongside a BLDC motor offers simplified control, leading to reduced size and weight. Although there is a complexity involved in power electronic switch packaging, the penalty in the size of the power electronic circuit can be minimized by packaging all power devices per phase into a single package.

The drive not only boasts high efficiency and a compact structure but also offers a crucial advantage in terms of high reliability, particularly suited for aerospace applications. This is attributed partially to simplified commutation and partially to inherent redundancy. The SSMC is demonstrated to effectively drive the BLDC motor with either the SB or DB controller. The test results underscore the significant reliability potential of the five-phase drive system

SIMULATION BESS SYSTEM

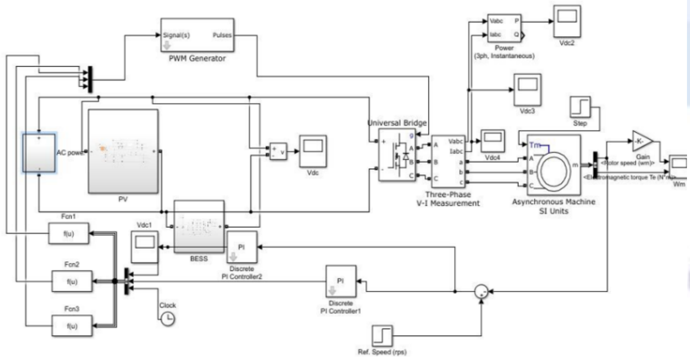

Fig: 1 – Simulation Diagram of Full Block Diagram

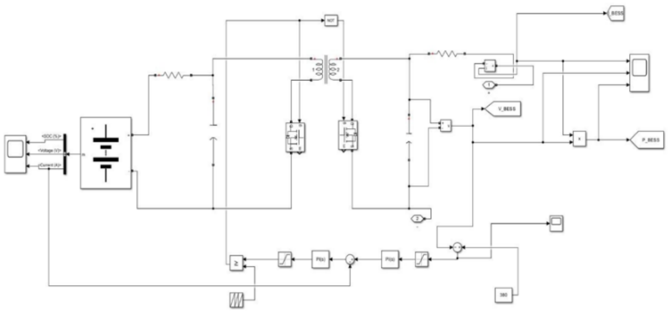

Fig: 2 – Simulation Diagram of BESS System

2. SOLAR SYSTEM

Block Diagram

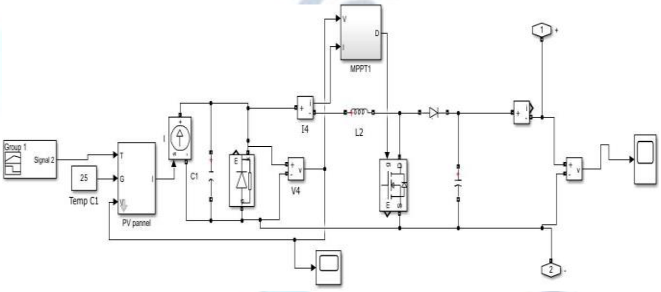

Fig: 3 – Simulation Diagram of Battery System

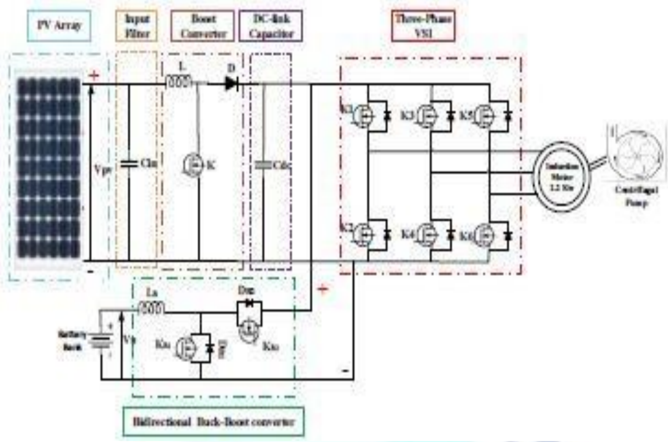

Fig: 4 – Overall Block Diagram

3. RELATED WORK

Xiaoyan Huang, Andrew Goodman, et al. (2012) present a paper detailing a brushless DC (BLDC) drive integrated with a single-sided matrix converter (SSMC) for an electrohydrostatic actuation (EHA) system in aerospace applications. The incorporation of an SSMC with a BLDC motor is innovative, aiming to achieve operation without the need for a microprocessor. A simple hysteresis current control strategy is employed to regulate motor torque. The authors highlight the high reliability and fault tolerance provided by the multi-phase SSMC, despite the increased requirement for power devices. They construct a prototype of a five-phase SSMC and present experimental results to validate the drive's performance. Additionally, they design and test a fault-tolerant BLDC motor as a pump drive in the EHA system. The utilization of an SSMC with hysteresis current control alongside a BLDC motor is novel, enabling simple control and ensuring a compact size and weight. Despite the complexity involved in power electronic switch packaging, the authors assert that there is minimal penalty in the size of the power electronic circuit when all power devices per phase are packaged into a single package. The paper emphasizes the advantages of the drive, including high efficiency, compact structure, and critical reliability suitable for aerospace applications. This reliability is attributed to simplified commutation and built-in redundancy. The SSMC is demonstrated to effectively drive the BLDC motor with either the SB or DB controller. The test results showcase the high reliability potential of the five-phase drive system.

Vashist Bist, Bhim Singh et al. (2013) introduce a Power Factor Corrected (PFC) Bridgeless (BL) buck-boost converter-fed Brushless Direct Current (BLDC) motor drive, offering a cost-effective solution for low-power applications. The paper employs a speed control approach for the BLDC motor by regulating the DC link voltage of the Voltage Source Inverter (VSI) using a single voltage sensor. This method enables the VSI to operate at fundamental frequency switching by leveraging the electronic commutation of the BLDC motor, resulting in reduced switching losses. Furthermore, the paper proposes a bridgeless configuration of the buck-boost converter, eliminating the need for a Diode Bridge Rectifier (DBR) and thereby reducing associated conduction losses. A PFC BL buck-boost converter is designed to operate in Discontinuous Inductor Current Mode (DICM), ensuring inherent power factor correction at the AC mains. The performance of the proposed drive is assessed across a wide range of speed control and varying supply voltages (universal AC mains 90-265V), resulting in improved power quality at the AC mains. The achieved power quality indices conform to international standards such as IEC 61000-3-2. The performance of the proposed drive is simulated using the MATLAB/Simulink environment, and the obtained results are validated experimentally on a developed prototype of the drive. The front-end BL buck-boost converter operates in DICM to achieve inherent power factor correction at the AC mains.

Wei Cui, Yu Gong et al. (2012) introduce a sensorless bifilar wound permanent magnet brushless DC (BW-PMBLDC) motor fan tailored for automotive engine cooling applications. The paper innovatively incorporates bifilar winding design into the conventional half-wave PMBLDC motor, thereby enhancing energy efficiency and suppressing voltage spikes.

The perfect flux-coupling effect between bifilar windings enables a regenerative capability, allowing trapped energy in the conducting winding during the turn-off period to be redirected to the DC source through the other winding in the bifilar pair. This effectively promotes energy efficiency and voltage spike reduction. Furthermore, a complementary scheme developed between the bifilar wound phases enables bipolar excitation on the unipolar converter topology. The BW-PMBLDC motor offers the advantages of a full-wave motor in terms of efficiency, voltage spike reduction, and low torque ripple while retaining the simplicity and robustness of the unipolar converter topology. The feasibility of the proposed approach is validated through both simulation and experimental results. Notably, the paper achieves a sensorless BW-PMBLDC fan motor, demonstrating enhanced energy efficiency compared to conventional half-wave PMBLDC counterparts.

C.C. Hwang, P.L. Li et al. (2012) present a study detailing the design of a three-phase slotless brushless DC (BLDC) motor intended for use as an electromagnetic actuator in robotics. To achieve the high torque-to-inertia and torque-to-weight ratios crucial for fast response in robotic applications, genetic algorithms (GAs) are employed to optimize the initial motor design within reasonable geometrical constraints. The motor comprises a slotless stator accommodating a single-layer short-pitch winding and a sintered two-pole NdFeB magnet rotor with parallel magnetization. The stator laminations are constructed from non-oriented silicon steel with a saturated flux density (Bs) of 1.7 T. The rotor features a unique cylindrical magnet with a remanence (Br) of 1.445 T and a relative recoil permeability (mr) of 1.05, along with a ferromagnetic shaft. Since the rotor length-to-diameter ratio is less than 3, no retaining sleeve is required around the magnets for the intended application. The paper utilizes 3-D finite element analysis (FEA) to examine the machine's performance and validates the results through experimental measurements. The design of a three-phase slotless BLDC motor drive for use as an electromagnetic actuator in robotics is outlined, offering insights into achieving optimal performance in robotic applications.

Saurabh Nikam, Vandana R et al. (2012) present a study focusing on the design of a motor for in-wheel electric vehicle (EV) applications, where high efficiency and specific torque are essential requirements. While permanent magnet brushless DC (BLDC) motors are commonly used for this purpose, the rising cost of permanent magnets (PM) has sparked interest in magnet-less alternatives. Switched reluctance machines (SRMs) are gaining attention due to their simple and robust construction, along with fault-tolerant operation, despite their lower specific torque compared to BLDC motors. In this paper, the authors propose a new 12/26 pole SRM designed specifically for in-wheel EV applications, aiming to improve its specific torque to make it a viable alternative to BLDC motors. The proposed SRM features segmented rotor construction and a concentrated winding arrangement, which reduces end-winding volume and copper loss, leading to higher efficiency. Several new stator slot/rotor pole combinations are derived for such machines to optimize performance. A prototype of the designed machine is fabricated, and experimental results demonstrate close agreement with simulation. The maximum measured efficiency of the machine is approximately 91%, validating its effectiveness for in-wheel EV applications.

Yie-Tone Chen, Chun-Lung Chiu et al. (2013) present a novel driver for a single-phase brushless DC fan motor featuring a hybrid series/parallel winding structure.

The paper defines the winding symbols and directions of the hybrid motor stator structure and explains the winding steps for the proposed series/parallel winding. An appropriate inverter driving circuit capable of harnessing the advantages of the hybrid structure is also discussed. The overall system of this hybrid brushless DC motor with the proposed driving circuit is implemented to verify the performance of the driver and structure. The analysis includes examining the back-EMF voltage and winding current for the single-phase BLDC motor with two different winding methods at various speeds. A prototype circuit utilizing a Delta fan FFB1212EHE is implemented to conduct performance tests of the proposed motor driver system with a hybrid winding. The analysis reveals that the series winding method exhibits less power dissipation compared to the parallel winding method at the same operational speed of the fan. However, the input voltage of the parallel winding method is approximately half that of the series winding method when the motor operates at the rated speed of the series winding method. Consequently, the speed of the parallel winding method can be increased further to address the drawback of the speed limitation of the series winding method.

Ted K. A. Brekken, Hannes Max Hapke et al. (2010) aim to analyze, test, and compare machines and drives in oscillating applications, with a focus on low-power wave energy generator applications. These applications include autonomous weather and monitoring buoys with power requirements in the 100 W and less range. The ocean environment's oscillating motion of waves necessitates bidirectional and variable speed operation of the generator. The research compares the efficiency of small brushed DC, induction, brushless DC, and synchronous reluctance drives and machines in both constant and oscillating operation scenarios. Results indicate that drives and machines used in low-power oscillating applications, such as ocean wave energy, do not experience significant derating with respect to their nameplate rating. Additionally, the frequency of oscillation, such as ocean wave frequency, has minimal impact on efficiency. Autonomous buoys typically rely on a combination of solar panels, batteries, and occasionally small wind turbines for power. While early pioneers like Yoshio Masuda developed wave-powered navigational buoys based on the oscillating water column principle, modern small buoys rarely utilize wave energy extraction due to the additional mechanical and conversion complexities associated with reliably and efficiently harnessing energy from the oscillating input.

Tze-Yee Ho, Mu-Song Chen et al. (2012) introduce a high power factor brushless DC motor (BLDC) designed to address input current harmonics and inverter switching issues. An active power factor controller is implemented to enhance power factor by mitigating these harmonics. The paper details the design and implementation of the power factor controller along with the BLDC drive. Experimental results confirm the feasibility of the BLDC motor drive with the designed APFC controller, showcasing its superior power factor correction capabilities compared to drives without APFC. In recent years, advancements in power electronics and semiconductor technology have led to the widespread adoption of adjustable speed drives like BLDC drives in industrial and commercial applications. However, the AC-DC conversion required for BLDC motor drives often introduces current harmonics, resulting in poor power factor at the input AC mains.

This paper addresses this issue by presenting the design and implementation of a BLDC motor drive with an active power factor controller. Experimental results conducted under full load conditions demonstrate the effectiveness of both designs, with and without active PFC, showcasing the feasibility of each approach and validating the integrity of the entire system. Furthermore, the installation of the proposed active PFC controller enables smooth output DC link voltage for the BLDC motor drive, resulting in a sinusoidal line current waveform with lower total harmonic distortion.

Nikola Milivojevic, Mahesh Krishnamurthy et al. (2011) introduce a straightforward digital control strategy for brushless DC generators, aiming to mitigate the complexity associated with expensive position sensors and intricate controllers. This digital control technique offers ease of implementation and versatility across various applications, including renewable energy systems, automotive systems, and flywheels. The strategy demonstrates satisfactory performance, reliability, and robustness in regulating both speed and voltage, crucial for industrial generator applications. The paper outlines the fundamental principles of the control technique and provides detailed simulation results to validate its effectiveness. Furthermore, the proposed scheme is implemented and tested on a laboratory prototype generator to verify its feasibility and performance under diverse operating conditions. The simplicity of the digital control strategy lies in its working principle, wherein the generator operates at two specific predefined operating states: state 1 with a lower reference value and state 2 with a higher reference value. This approach offers a practical and efficient solution for controlling brushless DC generator drives, enhancing their usability and applicability across a range of industries.

In this study, the focus is on addressing the challenges posed by the increasing cost of permanent magnets (PM) in in-wheel electric vehicle (EV) applications, prompting interest in machines that do not rely on PMs. The Switched Reluctance Machine (SRM) emerges as a promising alternative due to its simple construction, robustness, and fault-tolerant operation. However, SRMs traditionally exhibit lower specific torque compared to Permanent Magnet Brushless DC (BLDC) motors, necessitating design enhancements to make SRMs competitive in this domain. To address this gap, a novel 12/26 pole SRM with high specific torque is proposed for in-wheel EV applications. This SRM features a segmented rotor construction and utilizes a concentrated winding arrangement to minimize end-winding volume and copper loss, thereby enhancing efficiency. The design improvements aim to maximize torque output while maintaining high efficiency levels. To validate the design, a prototype of the proposed SRM is fabricated, and experimental results are presented. The experimental findings closely align with simulation outcomes, confirming the effectiveness of the design approach. The measured efficiency of the machine reaches up to approximately 91%, demonstrating its potential for high performance in real-world applications. Overall, this research contributes to advancing SRM technology for in-wheel EV propulsion, offering a viable and efficient alternative to PM-based BLDC motors. The innovative design features and performance characteristics of the proposed SRM underscore its suitability for addressing the evolving needs of the automotive industry towards sustainable and cost-effective electric propulsion solutions.

In this study, solid-state switch-mode AC-DC converters with high-frequency transformer isolation are developed in various configurations, including buck, boost, and buck-boost, aiming to enhance power quality by reducing total harmonic distortion (THD) of input current, implementing power-factor correction (PFC) at AC mains, and delivering precisely regulated and isolated DC output voltage across a wide power range, from a few Watts to several kW. The paper provides a comprehensive examination of the state-of-the-art power factor corrected single-phase AC-DC converter configurations, encompassing control strategies, component selection, design considerations, performance evaluation, power quality assessments, selection criteria, potential applications, recent advancements, and future prospects. Simulation results and comparative analyses are presented for the proposed topologies, offering insights into their effectiveness and suitability for different scenarios. A thorough review of high-frequency transformer isolated AC-DC converters is presented to furnish application engineers, manufacturers, users, and researchers with detailed insights into various topologies and their design considerations. The classification of these converters into 12 categories, along with the number of circuits and concepts, facilitates the selection of suitable topologies for specific applications. These AC-DC converters are demonstrated to offer superior power quality at AC mains, delivering well-regulated and ripple-free isolated DC outputs. Additionally, they exhibit robust operation across a wide range of AC mains voltage and frequency variations, demonstrating the concept of universal input compatibility. Overall, this study contributes to advancing the understanding and adoption of high-quality AC-DC converter technologies, addressing the evolving needs of diverse applications and industries.

4. EXISTING SYSTEM

The conventional power factor correction (PFC) scheme for brushless DC (BLDC) motor drives typically employs a PWM-VSI (Pulse Width Modulated-Voltage Source Inverter) for speed control with a constant DC link voltage. However, this approach results in higher switching losses in the VSI, as these losses increase significantly with the square of the switching frequency. Since the speed of the BLDC motor is directly linked to the applied DC link voltage, speed control is achieved by varying the DC link voltage of the VSI. This facilitates fundamental frequency switching of the VSI, known as Electronic Commutation, leading to reduced switching losses.Several alternative approaches have been proposed to address the limitations of conventional PFC schemes. For example, Singh introduced a buck-boost converter feeding a BLDC motor, maintaining a constant DC link voltage while using PWM-VSI for speed control. However, this method still incurs high switching losses. Another proposal by Gopalarathnam involves a SEPIC (Single Ended Primary Inductance Converter)-based BLDC motor drive, However, these approaches often face challenges such as increased losses in the Voltage Source Inverter (VSI) due to Pulse Width Modulation (PWM) switching and the need for a higher number of current and voltage sensors, which can limit their suitability for low-cost applications. To address these challenges, Singh proposed a solution involving a buck converter-fed BLDC motor drive with a variable DC link voltage concept. This method aims to reduce switching losses in the VSI by operating at the fundamental switching frequency for electronic commutation of the BLDC motor, while achieving speed control by adjusting the voltage at the VSI's DC bus. However, this approach requires Continuous Conduction Mode (CCM) operation of the Cuk converter, which may not be ideal for low-cost or low-power applications due to the need for three sensors. To further improve efficiency, bridgeless converters have been introduced, allowing for the elimination of the Diode Bridge Rectifier (DBR) in the front end. Among various bridgeless converter configurations, the buck-boost converter configuration is considered the most suitable for enhancing efficiency and reducing switching losses in BLDC motor drives. However, these converters often have limitations in providing voltage buck or voltage boost, which restricts their applicability for applications requiring a wide range of DC link voltage control (i.e., bucking and boosting mode).

A Bridgeless (BL) buck-boost converter feeding a Brushless DC (BLDC) motor drive with a variable DC link voltage of the Voltage Source Inverter (VSI) is proposed to improve power quality at AC mains while reducing components. Brushed motors such as DC motors and synchronous motors are unsuitable for in-wheel applications due to their bulky size. Singly excited motors like induction motors (IMs) and switched reluctance motors (SRMs), with simple and rugged constructions, are potential candidates for this application. SRMs have been shown to exhibit better efficiency and specific torque than IMs, along with the advantages of fault-tolerant operation and the ability to operate at high temperatures. However, the specific torque output of SRMs is lower compared to BLDC motors. Therefore, measures are necessary to enhance the specific torque of SRMs to make them competitive with BLDC motors. It has been demonstrated that SRMs with a higher number of rotor poles than stator poles result in increased specific torque. Additionally, recent research has revealed that SRMs with segmented rotors exhibit higher specific torque than conventional SRMs. This paper combines these concepts by fabricating a

Segmented Rotor SRM (SSRM) with 12 stator poles and 16 rotor segments. It is demonstrated that such SSRM topologies offer up to a 65% improvement in specific torque over conventional SRMs. Thus, SSRMs appear to be an attractive option for in-wheel EV applications. The objective of this paper is to identify the most suitable SSRM design for in-wheel EV applications by studying different SSRM designs with full-pitch windings and analyzing the effect of multiplicity on their performance. The exploration of the number of coils per phase reveals that increasing coils per phase up to 2 can yield high specific torque with low losses. The choice of the number of coils per phase is significantly influenced by operating current densities. Conventional power generation sources, primarily based on coal and other fossil fuels, face challenges such as resource depletion, pollution, and global warming. Consequently, there has been a shift towards developing power systems that rely on clean and renewable energy sources. Renewable energy generation systems, including wind and hydro units, typically incorporate a generator drive powered by a prime mover, such as wind and water. Permanent magnet (PM) brushless DC (BLDC) machines controlled in generating mode offer numerous advantages, including high efficiency across a wide operating range, low maintenance, enhanced durability, compactness, and higher power density.

5. RESULT AND DISCUSSION

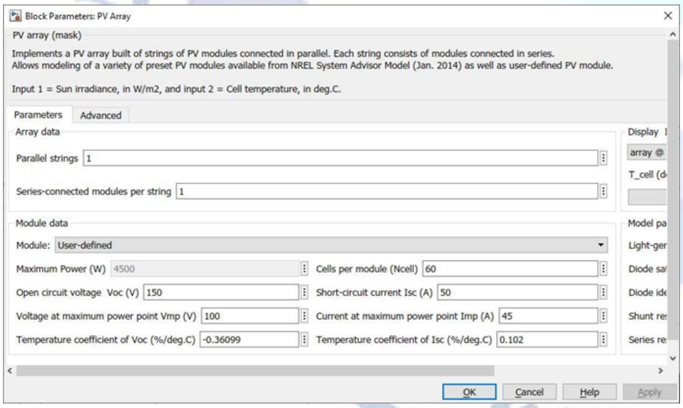

Fig: 5 – Image of PV Array Value setting

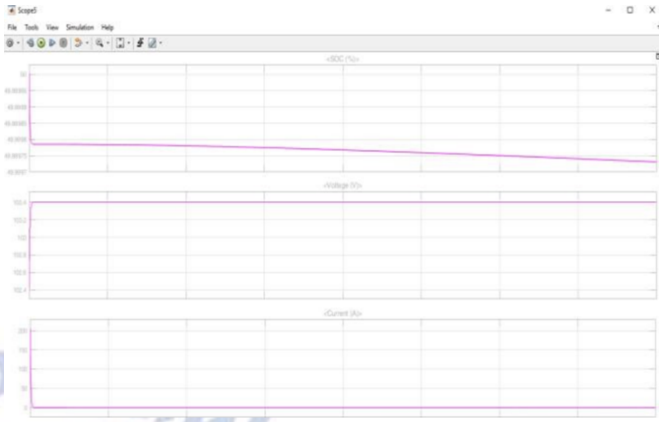

Fig: 6 – Image of Output

6. CONCLUSION

The comprehensive exploration of a foundational photovoltaic system has been meticulously undertaken, delving into the intricate workings of solar energy harnessing. Beginning with the fundamental principles of photovoltaics, a sophisticated PV model has been developed, capturing the nuanced interplay between solar irradiation levels and system output. Within this framework, a cutting-edge DC-DC converter has been engineered, adept at seamlessly converting variable DC voltages corresponding to solar irradiation bands into a uniform, high DC voltage. Subsequently, the transformation of this potent DC voltage into a robust three-phase AC output has been elegantly orchestrated through a meticulously controlled three-phase inverter, leveraging the precision of Sinusoidal Pulse Width Modulation (SPWM) techniques. This intricate system architecture has been meticulously brought to life through rigorous simulation using the powerful Simulink MATLAB environment, ensuring accuracy and reliability in modeling its dynamic behavior. In a culmination of this simulated endeavor, the output from the inverter yields a formidable 236 volts and 5 amperes, primed to power a robust 3-horsepower induction motor.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

REFERENCES

[1] V. Jyothi, K. V. Rao, & P. Ramesh. (2018). "Design and Implementation of Solar PV Based Water Pumping System Using BLDC Motor Drive." 2018 5th International Conference on Advanced Computing & Communication Systems (ICACCS). IEEE. DOI: 10.1109/ICACCS.2018.8473323

[2] A. K. Rai, S. Kumar, & S. K. Singh. (2020). "Performance Analysis of Solar PV Fed BLDC Motor Drive for Water Pumping System." 2020 11th International Conference on Computing, Communication and Networking Technologies (ICCCNT). IEEE. DOI: 10.1109/ICCCNT49239.2020.9225579

[3] S. P. Chavan & S. G. Taralkar. (2019). "Modeling and Simulation of Solar PV Array Fed BLDC Motor Drive for Water Pumping System." 2019 IEEE International Conference on Power, Electrical, and Electronics & Communication Engineering (PEECE). IEEE. DOI: 10.1109/PEECE.2019.8696961

[4] R. Gupta & M. Srivastava. (2017). "Performance Analysis of Solar PV Array Fed BLDC Motor Drive for Water Pumping System." 2017 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET). IEEE. DOI: 10.1109/WiSPNET.2017.8300196

[5] M. E. Al Hosani, M. R. A. Chughtai, & S. Mekhilef. (2020). "Maximum Power Point Tracking Techniques for Photovoltaic Systems under Partial Shading Conditions: A Review." Renewable and Sustainable Energy Reviews, 119, 109549. DOI: 10.1016/j.rser.2019.109549

[6] A. Mishra, R. Pandey, & S. K. Srivastava. (2016). "Design and Implementation of Solar Photovoltaic Water Pumping System Using BLDC Motor." 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES). DOI: 10.1109/ICPEICES.2016.78532376.

[7] V. G. Raju & A. R. Jyothi. (2019). "Solar Powered BLDC Motor Pumping System with MPPT Control." 2019 IEEE 9th International Conference on Power Electronics, Drives and Energy Systems (PEDES). DOI: 10.1109/PEDES46596.2019.8967745

[8] S. K. Sahoo, M. Choudhury, & R. K. Panda. (2018). "Simulation and Performance Analysis of a Solar Photovoltaic Water Pumping System Using BLDC Motor Drive." 2018 8th International Conference on Power Systems (ICPS). DOI: 10.1109/ICPESYS.2018.8523925

[9] N. Kumar & V. Gupta. (2017). "Modeling and Simulation of Solar PV Fed BLDC Motor Pumping System with MPPT Controller." 2017 7th International Conference on Power Systems (ICPS). DOI: 10.1109/ICPESYS.2017.8240113

[10] R. K. Aggarwal, S. K. Aggarwal, & A. K. Pandey. (2015). "A Review on Recent Advances in BLDC Motor Drive System for Electric Vehicles." 2015 Annual IEEE India Conference (INDICON). DOI: 10.1109/INDICON.2015.7443666

[11] S. S. Kale, S. V. Pathak, & S. M. Mahajan. (2020). "Development and Simulation of Solar PV BLDC Motor Based Water Pumping System." 2020 IEEE Pune Section International Conference (PuneCon). DOI: 10.1109/PuneCon48149.2020.9359701

[12] A. Sharma, P. Sharma, & S. P. Garg. (2018). "Design and Analysis of a Solar PV Array Fed BLDC Motor Drive for Water Pumping System." 2018 International Conference on Computing, Power and Communication Technologies (GUCON). DOI: 10.1109/GUCON.2018.8653267

[13] M. A. Hossain, M. Hasan, & M. R. I. Faruque. (2017). "Design and Implementation of a Standalone Solar PV System for Water Pumping Application." 2017 International Conference on Electrical, Computer and Communication Engineering (ECCE). DOI: 10.1109/ECACEE.2017.8282743

[14] N. Ahmad, M. Ahmad, & R. Pandey. (2016). "Design and Implementation of Solar Based BLDC Motor Pumping System." 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT). DOI: 10.1109/ICEEOT.2016.7754909

[15] P. K. Sharma, S. Sharma, & S. K. Sahoo. (2015). "Development of Solar Photovoltaic Based Water Pumping System with BLDC Motor." 2015 International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE). DOI: 10.1109/ICEPE.2015.7510183

[16] S. K. Singh, R. K. Singh, & A. K. Rai. (2014). "A Review on Design of Solar PV Based BLDC Motor Pumping System." 2014 International Conference on Power, Control and Embedded Systems (ICPCES). DOI: 10.1109/ICPCES.2014.7012464

[17] S. Das, S. Majumdar, & P. Ray. (2013). "Design and Analysis of a Solar Photovoltaic Water Pumping System Using BLDC Motor."2013 IEEE International Conference on Renewable Energy Research and Applications (ICRERA) DOI: 10.1109/ICRERA.2013.6749941

[18] A. K. Gupta, R. K. Singh, & S. K. Singh. (2012). "Development of Solar Photovoltaic Array Fed BLDC Motor Pumping System." 2012 International Conference on Energy Engineering and Environmental Protection (EEEP). DOI: 10.1109/EEEP.2012.6498187

[19] S. K. Verma, S. D. Rawat, & R. Gupta. (2011). "Modeling and Simulation of Solar PV Array Fed BLDC Motor Pumping System." 2011 International Conference on Emerging Trends in Electrical and Computer Technology (ICETECT). DOI: 10.1109/ICETECT.2011.576