Educational Administration: Theory and Practice
2024, 30(6), 1919-1927
ISSN: 2148-2403
https://kuey.net/
Research Article

Solar Powered Water Pump with Zeta Converter and BLDC Motor

Krishna Kumar R[1*], Dheepika R[2], Nishanth G[3], Shafeer Ahamed S[4], Selvakumar S[5]

[1*]Department of EEE Karpagam College of Engineering, Tamil Nadu, India Kumaran23011991@gmail.com
[2]Department of EEE Karpagam College of Engineering, Tamil Nadu, India dheepikaraja2003@gmail.com
[3]Department of EEE Karpagam College of Engineering, Tamil Nadu, India nishanthgovintharajan@gmail.com
[4]Department of EEE Karpagam College of Engineering, Tamil Nadu, India Shafeerahamed321@gmail.com
[5]Department of EEE Karpagam College of Engineering, Tamil Nadu, India, Selvakumarselvaraj46@gmail.com

Citation: Krishna Kumar Ret al. (2024) Solar Powered Water Pump withZetaConverterand BLDC Motor, *Educational Administration: Theory And Practice*, *30* (6), 1919-1927
Doi: 10.53555/kuey.v30i6.5617

ARTICLEINO

ABSTRACT

In nature, solar energy is a plentiful and essential renewable energy source and doesn't require continuous operating costs, even though the initial installation cost may be higher. Solar energy is captured and utilized to power motors for a variety of uses. Direct current (DC), induction, and brushless DC (BLDC) motors are the types of motors used in these applications; the latter kind offers more widely used benefits. Using a ZETA converter in a PV system is the focus of this project. To obtain maximum PV system efficiency and enable a soft start for the PV system, a water pump can act as an inverter (VSI), acting as a mediator in the DC-DC conversion process between the photovoltaic system and an energy source. A brushless DC (BLDC) motor with permanent magnet is driven by an appropriate control system. With two inductors and two capacitors, the Zeta converter functions as a DC-DC converter with a fourth-order configuration that can function in both buck and boost modes. A brushless DC motor drives a centrifugal water pump because it is compatible with the PV generator's maximum output position. The water pumping system that is recommended driven by a Zeta converter and operated by a BLDC motor, is assessed under rapid and slow changing atmospheric circumstances utilizing the power systems simulation toolboxes of the MATLAB/Simulink environment. The suggested solar water pumping system is the subject of modeling, simulation, and experimental validation in this paper. To examine the system's performance under various load and solar irradiation scenarios, simulations are run. To confirm the viability and efficacy of the suggested method, a working prototype is also created and put to real-world testing. The results show that adding the Zeta converter in solar water pumping technique to the BLDC motor significantly improved the dependability and efficiency. The system exhibits efficient power management, guaranteeing the best possible use of solar energy for the purpose of pumping water. In areas where traditional power sources are unavailable, our research advances environmentally friendly and sustainable water pumping systems. The project's conclusions offer insightful information for creating durable, extremely effective, and energy-efficient solar-powered water pumping systems.

Keywords – Energy Efficiency, Environmental Impact, Photovoltaic Technology, Sustainable Development

I. INTRODUCTION

Water pumping systems that use solar photovoltaic (SPV) arrays are becoming more and more common for providing clean drinking water and assisting with agricultural tasks. Increasing water pump efficiency has several benefits, one of which is increased profitability [1,2]. Using the variable speed drive approach limits the size of the suggested water pumping setup and provides opportunities for energy consumption reduction in water pumping systems. The pump's rotational speed is usually determined by the speed of the impeller attached to it and the pump shaft. Reduce the impeller's rotating speed to lessen the energy transferred to the water, which lowers the water pump's power needs [3].
The purpose of setting up a water pumping mechanism powered by solar energy using a BLDC motor and Zeta

converter is to give a self- sufficient and long-lasting water pumping solution. The specific goal is to efficiently collect solar energy and transform it into mechanical energy to power the water pump, decreasing reliance on fossil fuels and minimizing the environmental impact associated with existing pumping systems [4,5]. This system intends to encourage the use of renewable energy and contribute to water resource management in an environmentally and economically sustainable manner [6].
The project's focus on water conservation is of paramount importance in a world where water resources are increasingly strained. By enabling precise control over water flow, the system minimizes wastage, aligning with the ethos of eco-conscious choices [7,8]. This aspect holds particular significance in arid or water-scarce regions, where water conservation is imperative. Governments and organizations globally recognize the value of such sustainable initiatives.
Many offer incentives and subsidies to foster the adoption of solar- powered systems, thereby rendering the initial investment more financially accessible for individuals, communities, and industries [9,10]. By harnessing the energy of the sun through photovoltaic panels, these systems offer a sustainable and cost-effective alternative to conventional fuel-powered pumps or grid-dependent systems [11,12]. Enhancing energy resilience is one of the main advantages of using the Zeta converter in solar water pumping system with a BLDC motor [13].

By relying on a renewable energy source like solar power, the system reduces dependence on finite fossil fuels, contributing to energy independence for regions that might otherwise face energy shortages and price volatility [14]. This translates into greater resilience and self- sufficiency, particularly in areas with unreliable access to conventional electricity. In conclusion, the development of a solar driven water supply technique employing a Zeta converter and BLDC motor represents a forward-looking approach to address critical water supply needs while championing sustainability, energy efficiency, and environmental responsibility [15].

II. BLOCK DIAGRAM

The solar powered water pumping technique that is being examined is designed to include a solar PV array along with a zeta converter that uses an MPPT algorithm and a load that consists of a BLDC motor. Figure 1 depicts a block diagram of the solar water pump system illustrates which incorporates a zeta converter in conjunction with a BLDC motor. To convert the voltage generated by the SPV Array at its highest point of power into a variable DC supply is the primary function of the Zeta converter. Voltage Source Inverter is used for converting the direct current to Alternating current and which is delivered to BLDC motor. To increase the effectiveness of these suggested techniques, zeta converter is used. The next sections provide a detailed explanation of the viability of the suggested water pumping approach using a zeta converter in conjunction with a BLDC motor and MPPT analysis.

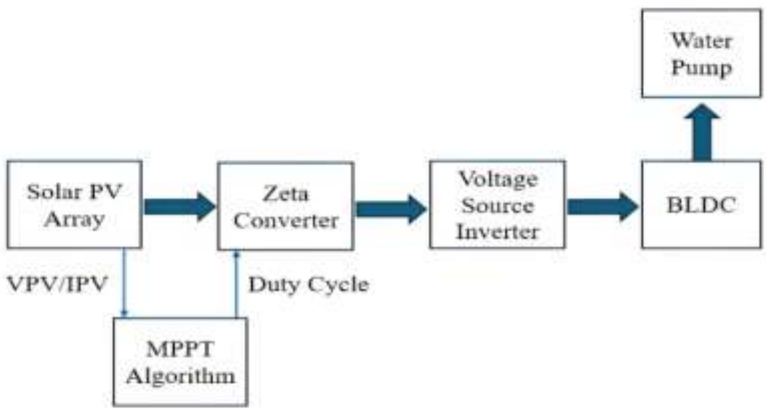

Fig.1. *Solar water system with load BLDC motor*

III. PROPOSED SYSTEM LAYOUT

a) SPV Array Design

Solar panels, also referred to as solar photovoltaic (SPV) arrays, have completely changed how we harvest solar energy. In essence, solar cells, which directly convert sunlight into electricity, make up these arrays. But this electricity must pass through a necessary middleman in order to be used in our homes and businesses. A network of wires and connectors collects the direct current produced by solar panels. To reduce energy losses from resistance in the wiring, cables of the right size and rating are utilized. While micro inverters and power optimizers process DC electricity at the panel level, string inverters receive DC electricity from many panels connected in series.

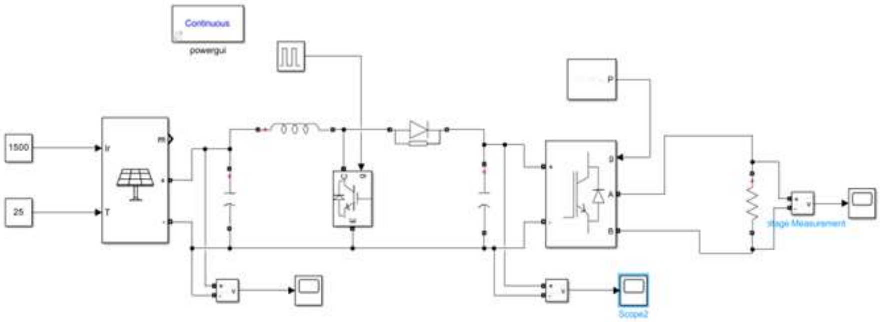

Fig.2a. *Solar panel without capacitor*

Depending on the system architecture, inverters are usually placed in a centralized area or close to the SPV arrays. While micro inverters and power optimizers are fixed to the racking system or directly on the solar panels, string inverters are typically installed on walls or other structures.
Solar Photovoltaic (SPV) arrays have emerged as a beacon of hope, capturing the sun's energy and transforming it into electricity. Integrating these arrays with inverters not only converts this solar energy to AC electricity from DC electricity, allows it to be utilized in our residences and commercial establishments, but it also opens the door to a world of possibilities, including achieving a stable 240-volt output. This synergy between SPV arrays and inverters, coupled with innovative boosting technologies, stands at the forefront of the renewable energy revolution.
The use of Voltage Boosting Converters is essential to getting a consistent 240-volt output from SPV arrays. In order to compensate for variations in the array's output, these devices boost the voltage of the generated electricity to the appropriate level. Modern semiconductor technology is used by sophisticated boost converters to effectively raise voltage while preserving great reliability and energy economy. These converters can be used with MPPT controllers to enable solar power systems to continuously produce a dependable 240-volt output, regardless of the outside environment.
Solar panel output is initially in the form of direct current (DC) electricity, which is generated from sunlight. To make this DC electricity usable for most applications, including feeding into the electrical grid, it often needs to be converted into alternating current (AC). A Zeta converter can serve as an intermediary step in this conversion process.
Solar panel DC electricity can be effectively transformed using a power electronic converter called a Zeta converter. It operates by taking the input DC voltage from the solar panels and converting it to an intermediate DC voltage. Depending on the specific application and requirements, this intermediate voltage can be either greater or lesser than the original DC voltage.

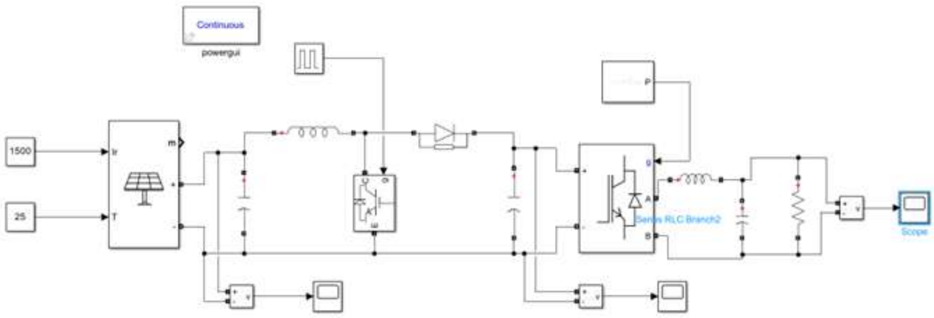

Fig.2b. *Solar panel with capacitor*

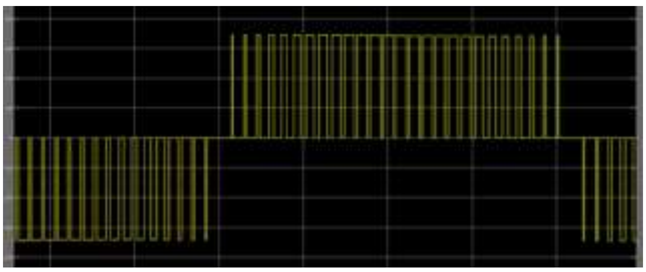

Fig.2c. *Output of solar panel without capacitor*

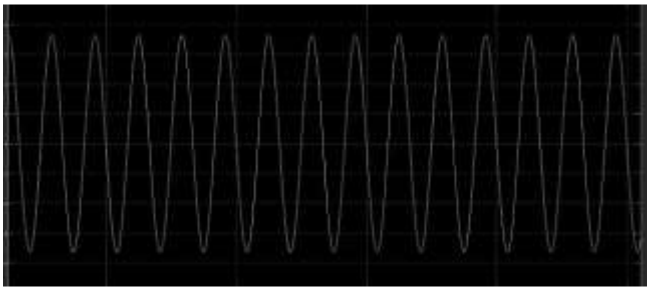

Fig.2d. *Output of solar panel with capacitor*

The process of achieving a pure AC output waveform in a solar power system is essential for seamless integration into standard electrical grids and the operation of household appliances. This multi-step process begins with the direct current (DC) output generated by solar panels, which is incompatible with most electrical systems.

To address this, an inverter is employed to convert the DC power into alternating current (AC), ensuring compatibility with the grid and appliances. The inverter's critical function is to generate a clean and sinusoidal AC waveform that closely mimics the typical waveform of grid electricity.

Additionally, it controls the frequency and voltage parameters to match local grid standards. Isolation and safety features are integrated to protect both the electrical system and users, and grid-tied systems also include synchronization features for efficient power transfer. In grid-tied systems, MPPT technology is used to maximize solar panel performance.

In essence, this comprehensive process ensures that solar power systems produce a pure AC output waveform that is seamlessly integrated into existing electrical infrastructure, allowing for efficient use of renewable energy while maintaining compatibility with standard appliances and power distribution systems.

b) Zeta Converter Design

One example of how electrical engineering is always improving is the Zeta converter, a revolutionary advancement in power electronics. This adaptable circuit topology offers special benefits in terms of efficiency, voltage regulation, and simplicity by combining elements of both Sepic and buck- boost converters.

Its name, which is derived from the Greek letter "Zeta," represents how transformative it is when it comes to converting electricity. A buck (step-down) converter and a boost (step-up) converter are smoothly integrated to operate as a single unit in the Zeta converter.

This is accomplished by using two power switches and a single inductor, which enables the circuit to control the output voltage regardless of whether it must be more or less than the voltage applied. The Zeta converter's high efficiency is achievable in both step-down and step-up modes because of its design. In contemporary power systems, when energy conservation is critical, this efficiency is essential. Reduced heat loss from high efficiency leads to more ecologically friendly and energy-efficient solutions.

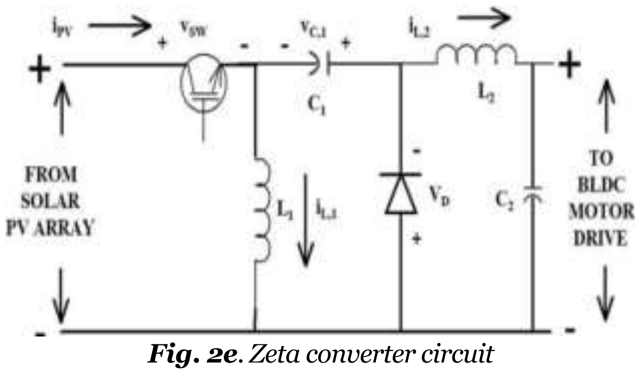

Fig. 2e. *Zeta converter circuit*

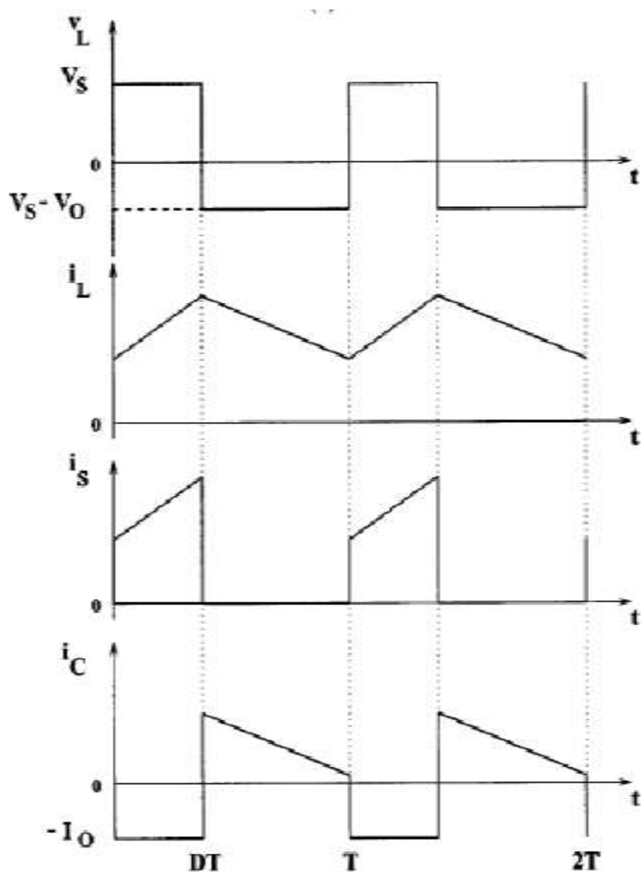

Fig. 2f. *Current flow waveform*

Step-up and step-down voltage functions are well-known to be executed by zeta converters. This makes it versatile and adaptable to different solar panel configurations and varying sunlight conditions.

It typically consists of electronic components such as switches, a coupled inductor, and a diode. After the Zeta converter has transformed the DC voltage from the solar panels into an intermediate DC voltage, this intermediate DC power can then be further processed to generate AC electricity. This AC electricity can be synchronized with the grid's frequency and voltage levels, allowing it to be seamlessly integrated with the electrical grid.

c) BLDC Motor Design

BLDC motors consist of permanent magnets implanted in the rotor and coils looped around the stator. BLDC motors, as opposed to brushed motors, use electronic commutation. The order in which the stator windings are energized is determined by the location of the rotor. Variable speed possibilities, increased efficiency, and smoother operation are made possible by this accurate control.

Because of their high power density, dependability, and low maintenance requirements, BLDC motors are the best choice for applications requiring precise and continuous operation voltage Origin Electronic devices called inverters change an input of direct current (DC) into an output of alternating current (AC) with varying voltage and frequency. VSIs are essential in the context of BLDC motors because they supply the regulated AC power required to operate these motors effectively.

Since brushless DC (BLDC) motors are accurate, dependable, and efficient, they have become the motor of choice for many consumer, automotive, and industrial applications. These motors rely on electronic commutation for functioning and are built without brushes, which eliminates the wear and tear that comes with conventional brushed motors. Voltage Source Inverters (VSI) turn BLDC motors into extremely efficient systems that can run a variety of machinery and gadgets.

d) VSI operation

A Voltage Source Inverter (VSI) is a key component in the domain of power electronics, engineered to transform into AC electricity from direct DC electricity. At its core, a VSI maintains a constant DC voltage on its input side while producing an AC output voltage with precise control over parameters like magnitude, frequency, and phase. This technology is widely employed in a diverse range of applications, including variable-speed motor drives, grid-tied inverters for solar and wind power and in renewable energy systems.

VSIs rely on Pulse Width Modulation technique to regulate the switching of power transistors, such as insulated gate bipolar transistors, allowing for the generation of synthetic AC waveforms with great accuracy. The ability to control the frequency, amplitude, and phase angle of the output voltage makes VSIs versatile and essential in industries where precise AC power generation and conversion are paramount, contributing to improved efficiency, reduced harmonics, and better power quality.

The VSI receives the DC output produced by the Zeta converter and changes it into AC. The BLDC motor is then powered by this AC power, and it drives a water pump that is connected to the motor's spindle. Significantly, the VSI utilizes fundamental frequency modulation while electronically controlling the BLDC motor, aided by its built-in encoder. This project effectively reduces the adverse effects of high-frequency switching, resulting in improved system efficiency.

IV. PROPOSED SYSTEM CONTROL

a) Control of MPPT Algorithm

Calculate the power (P = V × I) using the sensor data (V and I), then use the algorithm logic to get the ideal operating point. Establish control loops to appropriately modify the solar panel's working parameters. Include feedback systems to keep an eye on the system's operation. Make repeated adjustments to the control techniques and algorithm parameters based on this feedback.

To achieve optimal MPPT, real-time monitoring and modifications are essential to your MPPT-controlled system's performance. Provide information on energy output, efficiency gains, and a comparison of the situation with and without MPPT control. To ensure understanding, include visual aids such as tables and graphs.

Incremental Conductance (IncCond):

Increase voltage $dP / dV - (V / I) > 0$ →Increase voltage Decrease voltage $dP / dV - (V / I) < 0$ →Decrease voltage Fractional Open-Circuit Voltage (FOCV):

Vmpp = Voc × F

Vmpp = Maximum Power Point Voltage

The advantages of MPPT are numerous. Without MPPT, solar panels might operate at a point on the V-I curve that is not the MPP, resulting in lower power output and reduced energy production. MPPT ensures that the panels consistently operate at their peak, even when environmental factors fluctuate. This leads to improved energy production, increased system efficiency, and a higher return on investment for solar power systems. By optimizing the power output of solar panels through MPPT, solar power systems become more efficient and reliable, making them a valuable and sustainable source of renewable energy.

The continuous tracking and adjustment of the operating point allow solar panels to generate the most electricity possible under varying environmental conditions, making them an excellent choice for a wide range of applications, from residential and commercial installations to off-grid and remote power generation. Furthermore, as technology advances, MPPT controllers continue to improve in precision and efficiency, contributing to the ongoing development of clean and sustainable energy solutions.

V. RESULT ANALYSIS

Solar energy application for water pumping systems has become a game-changing application in the search for sustainable energy solutions. Modern technologies such as the Brushless DC (BLDC) motor and Zeta converter have been integrated into solar water pumping systems to make them incredibly dependable, efficient, and eco-friendly. This creative method has a ton of promise, especially in isolated or off-grid locations where traditional power sources are scarce. By incorporating the Zeta converter and VSI, we reduce power losses during the process of energy conversion and eliminate high frequency switching losses, ultimately resulting in a cost-effective and sustainable water pumping system.

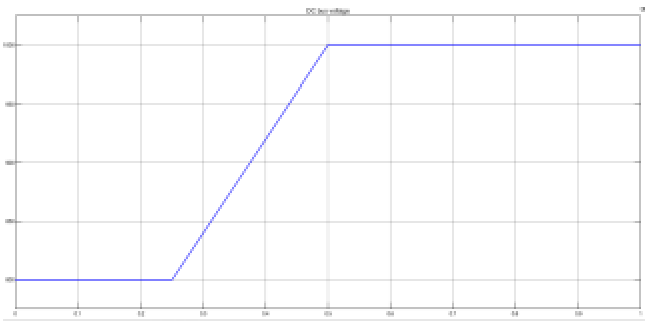

Fig. 3a. Voltage of solar

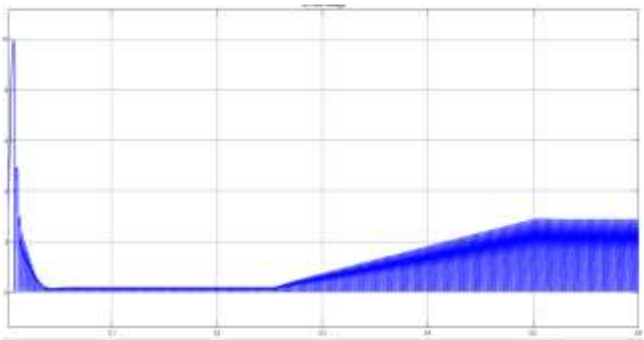

Fig. 3b. Voltage of zeta converter

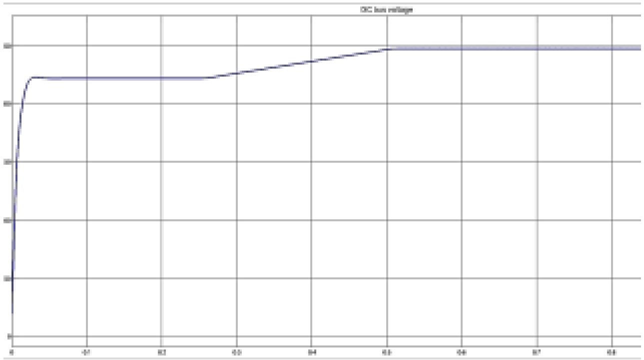

Fig. 3c. Voltage of direct current

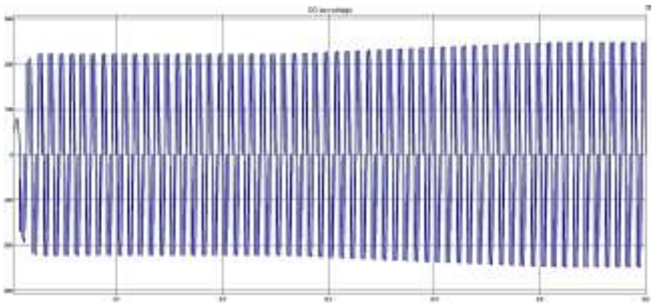

Fig. 3d. Voltage of alternating current

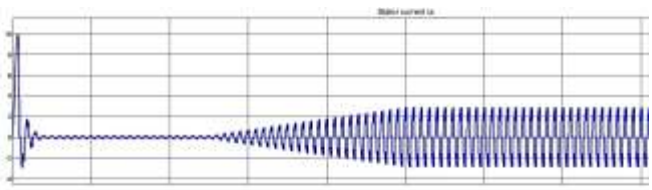

Fig. 3e. Stator current

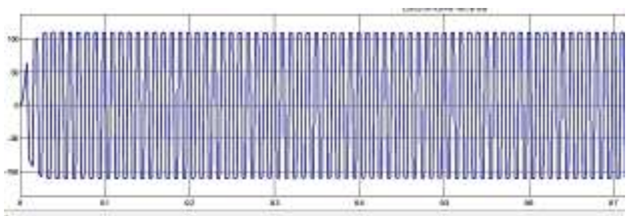

Fig. 3f. Electro motive force

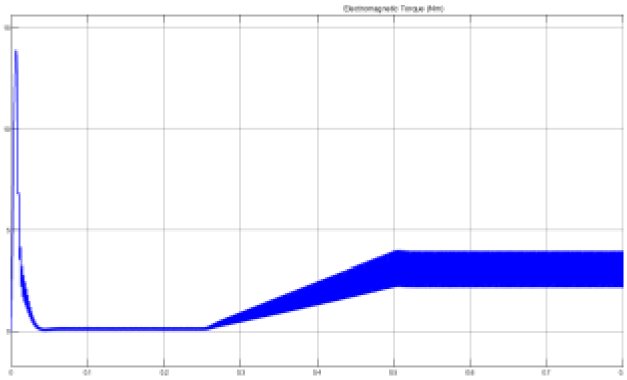

Fig. 3g. Electromagnet torque

VI. CONCLUSION

To sum up, the combination of a Brushless Direct Current (BLDC) motor and a Zeta Converter in a Solar Water Pumping System is a promising development in the field of environmentally friendly water pumping systems. Extensive modeling, simulation, and real-world experiments have shown significant advances in the system's effectiveness, dependability, and capacity to adjust to changing environmental conditions. The BLDC motor's longevity and efficiency, along with the Zeta Converter's capacity to regulate output and handle large input voltage changes, have worked in concert to improve the system's overall performance. MPPT technique is incorporated to guarantee the best possible use of solar energy, enabling the system to function efficiently under varying solar irradiation conditions. By adjusting for changes in the SPV array's output, the Voltage Boosting Converter is essential to sustaining a steady 240-volt output. This characteristic guarantees the system's dependability in offering a steady and stable water pumping solution, particularly in isolated or off-grid areas without access to traditional power sources. The research findings highlight the practicality and effectiveness of the suggested solar water pumping system, establishing it as a green and sustainable substitute for conventional water supply methods. This technology serves as a beacon of innovation, demonstrating the potential of solar energy to power necessary applications like water pumping, while the globe looks for renewable energy alternatives. The Zeta Converter and BLDC motor combination's versatility guarantees that the system will withstand varying solar conditions, which makes it ideal for usage in off-grid areas, remote agricultural settings, and rural communities. The BLDC motor's lower maintenance needs add to the system's long-term dependability and affordability, which makes it a desirable choice for environmentally friendly water supply initiatives.

REFERENCES

1. Geethu Krishnan, Shijoh Vellayikot and Moshe Sitbon, “Enhanced Power Factor Correction and Torque Ripple Mitigation for DC–DC Converter Based BLDC Drive”, Electronics 2023, 12, 3533. 42.
2. Anwar Ulla Khan, Mashhood Hasan, Waleed Zakri and Waleed Hassan Alhazmi, “Parameter estimation and control design of solar maximum power point tracking”, International Journal of Electrical and Computer Engineering (IJECE) Vol. 12, No. 5, October 2022.
3. Aissa Kheldoun, Moufida Belguellaoui, Abdelkarim Ammar and Kahina Hamraoui, “Performance Enhancement of Photovoltaic Water Pumping System Based on BLDC Motor under Partial Shading Condition”, 10–12 December 2021.
4. Amit Choudhary and Vikash Kumar, “Solar Water Pumping Model Using Zeta Converter for Irrigation Application”, Sep 2021, Volume 9, Issue 3.
5. Mukesh Kumar Kumawat, Nagendra Singh, Prashant Garg and Ritesh Chhapre, “PV & Zeta Converter based Irrigation Pumping System using PMBLDC Motor”, Vol.12 No.9 (2021), 709 – 714.
6. K. Siva Sankar, Mrs. P. Vijaya Prasuna and Dr. B. Rajani, “SOLAR ENERGY BASED ZETA CONVERTER FED BLDC MOTOR FOR WATER PUMPING SYSTEM USING FUZZY CONTROLLER”, 21 December 2020.
7. Dr. P. Santosh Kumar Patra, Gannerla Esha and Vishnuvardhan Vadla, “ANFIS CONTROLLER BASED ZETA CONVERTER FED BLDC MOTOR INTERTIE WITH SOLAR PV FED WATER PUMPING SYSTEM”, 23 August 2020.
8. Md Khalid and Tejaswita Katyayani, “BLDC Motor Driven with Solar PV Array Fed Water Pumping System Employing Zeta Converter for speed control”, JETIR October 2018, Volume 5, Issue 10.
9. Ch. Prasad, P. Guruvulunaidu and R. Durgaprasad, “Solar PV Array-Fed Water Pumping System Using Zeta Converter based Closed-Loop Control of BLDC Motor Drive”, (IJERT), Vol.7, Issue 05, May-2018.
10. SATHYA.M and Dr. C. GOVINDARAJU, “Solar Water Pumping System Employing ZETA Converter and BLDC Motor”, Vol. 5, Issue 2, Month: April - June 2017.
11. Mahesh G, Dr. K. Kumarasamy, Badri Narayanan S M and Kishan Surya R I, “Solar Powered Water

Pumping System Using BLDC Motor and Zeta Converter", Vol. 6 , Issue 3, March 2017.
12. Raj Edison A J, Krishnaprasad K S, Sreeyesh T S, Sreelakshmi U M, Varsha K and Vaisakh K J, "A NOVEL METHOD FOR IRRIGATION SYSTEM USING SOLAR FED BLDC MOTOR", International Journal of Advances in Engineering & Scientific Research, Vol.4, Issue 1, Jan- 2017.
13. P. Sriramalakshmi and Kambli Omkar Vijay, "Comparison between Zeta Converter and Boost Converter using Sliding Mode Controller", International Journal of Engineering Research & Technology (IJERT), Vol. 5, Issue 07, July2016.
14. Bhim Singh and Anjanee Kumar Mishra, "SPV Array Powered Zeta Converter Fed SRM Drive for Water Pumping", 2015.
15. Rajan Kumar and Bhim Singh, "BLDC Motor Driven Solar PV Array Fed Water Pumping System Employing Zeta Converter," 2015.