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Article Title: Intelligent MPPT for High Gain Zeta Converter for Standalone PV Application with Galvanic Isolation

Intelligent MPPT for High Gain Zeta Converter for Standalone PV Application with Galvanic Isolation

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ABSTRACT

In this paper, Standalone PV system is designed to operate without the need of electric utility grid which are commonly designed to supply specific DC electric loads. These type of PV system are generally powered using photovoltaic array and consist of solar charging modules, controllers and regulators. The objective of this work is to implement the Radial Basis Function Neural Network (RBFNN) based Maximum Power Point Tracking (MPPT) technique to attain constant DC-link voltage of the ZETA converter. This method utilizes a ZETA converter to achieve better voltage gain and lower ripple in the output current and voltage. Using an Artificial Neural Network (ANN) controller to operate a high-frequency converter, which improves power conversion efficiency. To ensure safety and prevent electrical faults, an isolation transformer provides galvanic isolation between the high-frequency converter and the PV system. Galvanic isolation avoids electrical faults from being transmitted and safeguards connected loads. The rectifier is used to supply the Direct Current (DC) load with the output from the isolation transformer. The rectifier changes the transformer's Alternating Current (AC) output into DC current to power DC loads. An intelligent MPPT is employed to stabilize the converter's output voltage and address the intermittent characteristics of PV, and also assists in sustaining the DC-link voltage without alterations and ripples from the converter. The efficiency of this work is authenticated via MATLAB simulation 2021a.

Key Words: Photovoltaic (PV) system, Radial Basis Function Neural Network (RBFNN), Maximum Power Point Tracking (MPPT), ZETA converter, Artificial Neural Network (ANN), Galvanic isolation, Direct Current (DC), Alternating Current (AC), MATLAB 2021a.

1 Introduction

Solar energy is a renewable form of electrical energy, which is derived from the radiant of sun, and it is harnessed via PV cells. Solar panels are primarily known as PV cells, it utilises photoelectric effect to convert sunlight into electricity [1]. PV cells composed of semiconductor materials like germanium and silicon. To increase the output voltage, more number of PV cells are connected in series and parallel to form PV module, because a single

PV cell generates very low voltage. However, the maximum efficiency of solar module is 29% and it is very sensitive to irradiance [2] [3].

MPPT technique is employed in the PV system to improve the output voltage of the solar panel. The main goal of MPPT is to regulate the maximum DC voltage level from the PV system by tracking maximum power point. Most commonly used MPPT methods are incremental conductance, constant voltage, perturb and observe, and fuzzy logic [4]. The primary MPPT technique of used to track maximum power point is perturb and observation [5]. Fuzzy logic along with ANN controller based MPPT techniques are used to maintain steady state performance of PV. ANN controller is used in MPPT to calculate the output voltage and power. ANN controller is employed in the proposed standalone PV system to provide better dynamic performance in under varying irradiance level compared to other methods [6] [7].

PV system is always interconnected with DC-DC converter to control the DC at variable load conditions. Many researchers have developed various converters like SEPIC, ZETA, buck, boost, buck boost, and isolated converters for high power applications. Among these converters, ZETA converters are used in many applications like battery charger, PV system, DC power supply, and power factor correction [8]. ZETA converter is used in this work as an interface between PV system and the load to increase performance and maintain stable operation. A ZETA converter along with ANFIS MPPT is employed in the solar PV system for off-grid application is proposed in the existing system. However this model is limited in response speed and have problem in voltage stability [9]. In order to overcome these problems, RBFNN model is utilized in this standalone PV system. The standalone PV system is one of the important sustainable, renewable, and environment friendly energy sources. Developing standalone PV system is necessary for providing high gain electricity, it depends on the availability of load [10]. This model sustain voltage in DC loads by removing voltage constancy problems. It increases the output gain of the converter and decreases the ripple current.

The optimization of this system is intensively discussed below,

- To implement and develop a Zeta converter for fast power transformation between the load and the solar panel.
- To create an efficient RBFNN based MPPT algorithm for tracking the solar panel's maximum power.
- To incorporate a forward converter system in the stand-alone solar system to provide continuous power during low solar irradiance.
- Employing ANN controller to control a high-frequency converter to simplify the transformation of electrical power.

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- To integrate an isolation transformer into the system by providing galvanic isolation to increase safety.

2 Recent Works

Sachin Jain et al (2021) (11) have developed a simple voltage control strategy for enhancing the power management control and prevents toggling among various operating modes of the Photovoltaic (PV) battery. To protect the system from toggling, voltage band technique is deployed which reduces the issues between charging and discharging mode within switching cycle thereby, increasing the overall performance efficiency of the battery. Therefore, by utilizing voltage control strategy ensures better power control management with simple and easy implementation. However, this techniques struggles with computational complexity hence considered unreliable.

Muhammad Najwan Hamidi et al (2021) (12) have introduced perturb and observe (P&O) based voltage regulator (POVR) and a capacitor compensator (CC) circuit for DC-link inverter. The implementation of POVR enhances the voltage regulation and transfers maximum power during full load conditions. Therefore, using PVOR assures enhanced system functioning with attaining desired DC voltage output even under varying environmental and load conditions. Despite this, POVR technique suffers from poor efficiency and not applicable for rapidly changing atmospheric conditions.

Rishi Kant Sharma et al (2021) (13) have analysed DC droop based hierarchical control for PV-BES-DG system in which Power Management Scheme (PMS) is implemented to ensure reliable functioning of the PV system during source and load power inconsistency. PMS enables improved working condition even under critical state of charge limit conditions of BES. Therefore, by deploying PMS ensures improved stability and optimal regulator gain thereby, enhancing the performance efficiency. Nevertheless, PMS are not completely reliable due to its high cost implementation.

Rahmat Khezri et al (2021) (14) have implemented demand side management (DSM) approach to incorporate in optimal sizing of solar photovoltaic (PV), wind turbine (WT), and battery storage (BS) which works based on the state-of-charge level of the battery. DSM functions using fuzzy logic method which provides efficient load shifting and load curtailment. Therefore, DSM ensures improved system management performance with enhanced configuration at low cost of electricity. However, DSM struggles with high operational complexity when compared to other traditional techniques.

Anjeet Verma et al (2021) (15) have innovated solar photo voltaic (PV) array and a storage battery integrated three phase electric vehicle charging station (EVCS) in which affine projection sign algorithm (APSA) is utilised to obtain increased power quality at the grid side. APSA works by combining output of two APSA with large step size and small step size

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thereby, attaining fast convergence and low steady-state error even under abruptly changing input conditions. Therefore, APSA assures improved power quality with rapid convergence rate and reduced error which in turn improves the overall system performance. Nonetheless, APSA struggles with low convergence rate and poor tracking efficiency.

3 Proposed System

The main goal of this work is to enhance the output power which is generated by the solar panels by utilizing RBFNN based MPPT technique for standalone PV application. The block diagram of the proposed model is illustrated in the below figure 1.

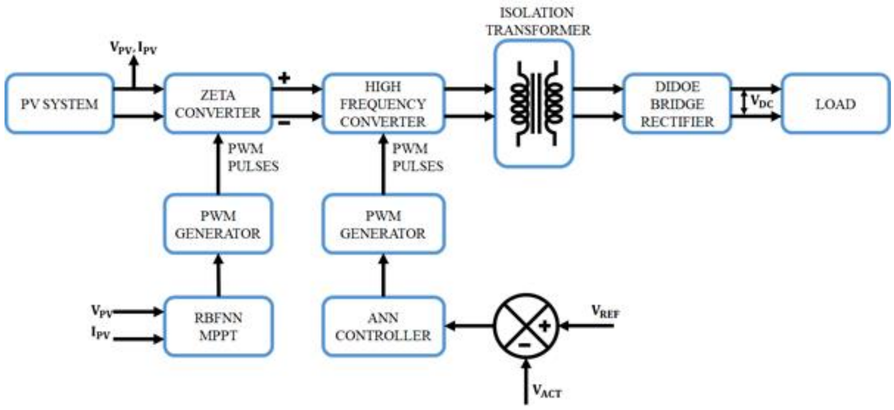

Figure 1: *Proposed block diagram*

Initially, the solar panels produce DC power, which is then subjected to the ZETA converter, and the load is connected to the converter 'output. The maximum power point of the solar panel is continuously tracked by the RBFNN MPPT algorithm and consequently regulates the converter output. The output of the ZETA converter is fed into high frequency converter, which is controlled by an ANN controller. It ensures maximum reliability and accuracy of the output voltage. The high frequency converter is essential for converting electrical power, simplifying the subsequent distribution stages of power, and increasing efficiency. In order to produce galvanic isolation, this method incorporates an isolation transformer. It separates the output of high frequency converter from the PV system and other modules to increase the safety. Galvanic isolation safeguards the connected loads and prevents electrical faults from being transmitted. The rectifier is used to transport the output of the isolation transformer to a DC load. The rectifier is appropriate for powering the DC loads, because it transforms the output AC current of the transformer into DC current.

3.1 PV System

The solar cell, which generates DC voltage by harnessing the PV effect, is the most crucial part of a photovoltaic system. Whereas the expansion of the series connection increases

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current, the extension of the parallel connection increases voltage. A PV array is made up of several PV panels. Fig. 2 depicts the matching circuit for the PV cell.

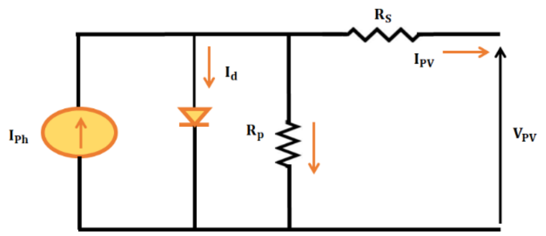

Figure 2: *Circuit diagram of PV System*

The V-I distinctive purpose is implied by,

$$I_{PV} = I_{PH} - I_D - I_{RP} \tag{1}$$

Equation (1) becomes the following when N coupled series and parallel PV cells:

$$I_{PV} = NI_{PH} - I_D - I_{RP} \tag{2}$$

The characteristic equation of the PV array is stated as follows by using Equation (2):

$$N_p I_{PH} - N_p I_o \left[\exp\left(\frac{q(V_{PV}+R_S I_{pv})}{N_S ZKT}\right) - 1\right] - \frac{V_{PV}+R_S I_{pv}}{R_p} \tag{3}$$

I_{PV}-Photocurrent

R_S-Series resistance

R_P-Shunt resistance

I_D-Current through diode

V_{PV}-Input Voltage

As a result, the PV system is created, and the input and output power are calculated using (3). As will be discussed in the next section, a Zeta converter raises the PV panel's low output voltage.

3.2 ZETA Converter

Zeta converters are similar to DC-DC power converter which converts voltage in both step-up and step-down directions. Zeta converters works based the magnetic components like inductors and capacitors which are used to store and transfer energy among the input and output parts. In energy storage stage, input charges the inductor meanwhile the energy transfer stage, transfers energy to load through the capacitor. One of the most important aspects for considering Zeta converters is its ability to maintain consistent input and output current thereby, producing reduced current ripples, electromagnetic interference (EMI) and enhanced efficiency. Therefore, Zeta converter is deployed to assists the conversion of input

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V_{PV} to required level of output voltage V_{DC} where voltage V_{DC} is assimilated with set reference value V_{ref} for obtaining error voltage which are further fed to the selected controller that produces changes in the duty ratio command of the converter. In addition, the output obtained using the controller is given to PWM generator which creates PWM pulses for controlling the switching process of the converter. Furthermore, driver circuit is deployed to step-up the voltage level of the PWM generator. Thus, by controlling the duty ratio of converter, steady state error in the output is diminished.

Zeta converter consists of two capacitors C_1&C_2, Switch MOSFET, two Inductors L_1 &L_2, the load Resistor (R) and only one Diode (D). Figure 3 represents the zeta converter circuit diagram with switching conditions like ON and OFF.

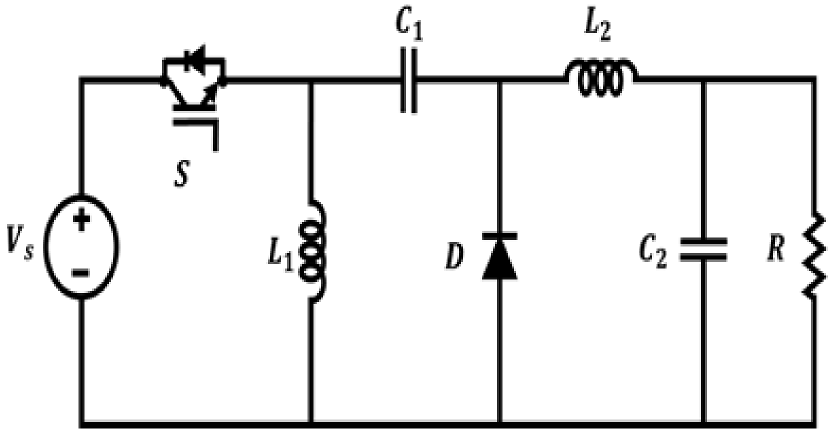

Figure 3: *Circuit diagram of Zeta Converter*

Mode 1: In mode 1 operation, an inductor draws current from (Vs) where diode is reverse biased. When switch is in ON condition it allows current to pass via the inductor which aggregates linearly and stores energy in which the source voltage is equivalent to the inductor voltage. Simultaneously capacitor C_1 charges output voltage. When MOSFET is turned ON, the two inductors L_1, L_2 is where the energy from supply is stored and the output current is generated by $C_1$and L_2.

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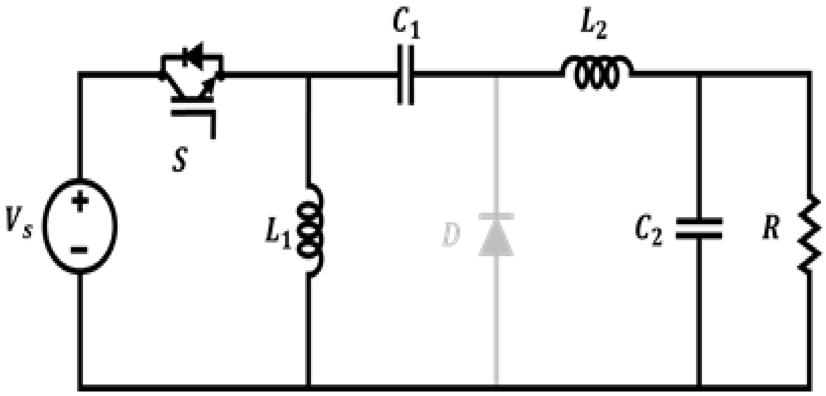

Figure 4: *Equivalent circuit diagram during switch is ON*

Figure 4 Displays the Mode 1 operation of the zeta converter during switch ON condition.

Mode 2: In mode 2 operation, switch in in OFF condition and the diode is forward biased where capacitor is kept parallel to L_2 inductor. The output voltage passes through inductor because C_1 is discharged and C_2 is charged to output voltage. The energy stored in inductor (L) is transferred to the load resistor. Therefore, this type of operation is considered for discharging situations.

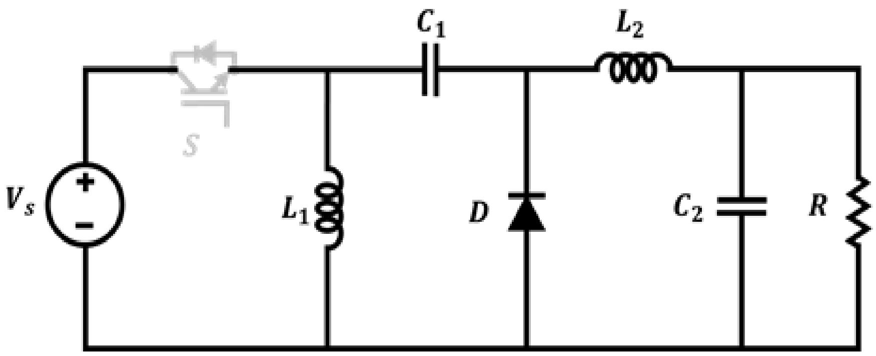

Figure 5: *Equivalent circuit diagram during switch is OFF*

Figure 5 Show the mode 2 operation of the zeta convertor during switch OFF condition.

The duty cycle of Zeta converter is given in Equation (4)

$$D = \frac{V_O}{V_i + V_O} \tag{4}$$

The inductor value is measured under the premise that magnetically connected with an inductor which are employed and have similar amount of ripple current for both indicators L_1 & L_2 is given by the equation,

$$L_1 = L_2 = \frac{DV_{in}}{F * \Delta I} \tag{5}$$

The equations for capacitors are given as follows,

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$$C_1 = \frac{DV_O}{F * R\Delta V} \tag{6}$$

$$C_2 = \frac{DV_{in}}{8 * F^2 * L_2 * \Delta V} \tag{7}$$

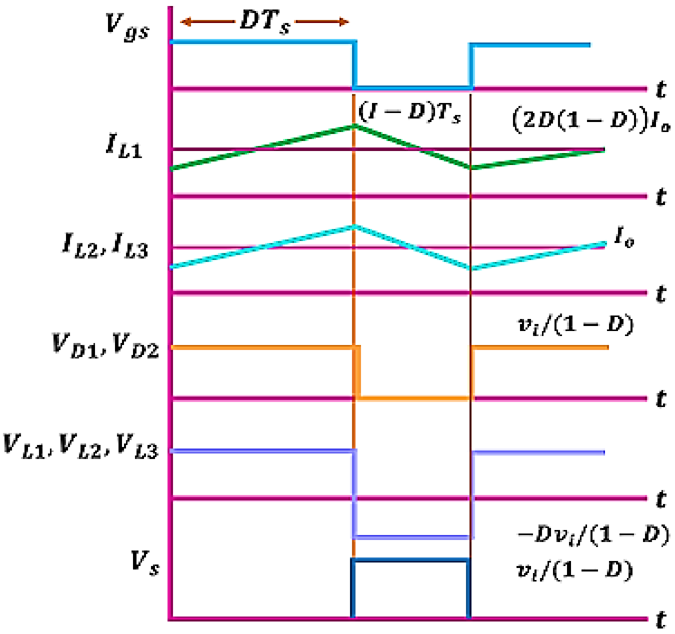

Figure 6: *Timing diagram of Zeta converter*

Figure 6 represents the timing diagram of zeta converter. The output obtained from zeta converter is made constant by utilizing a controller. Hence, DC-DC switched zeta converter is designed and located between solar PV module and load thereby, enabling to transfer maximum power to load by altering duty cycle of DC-DC switched zeta converter.

3.3 RBFNN MPPT Controller

Radial Basis Function Neural Network Maximum Power Point Tracking (RBFNN) ia an enhanced utilised for tracking and extracting maximum power from the solar panels. By deploying MPPT technique ensures that PV system is operating at its masimum power point (MPP) even under varying environmental situations which includes deviations in solar irradiance and tempearture. RBFNN is similar to neural network which is commonly used for several apllications involing pattern recognition and time serires prediction which is significantly suitable for applications that require non-linear mapping and generalization capabilities.

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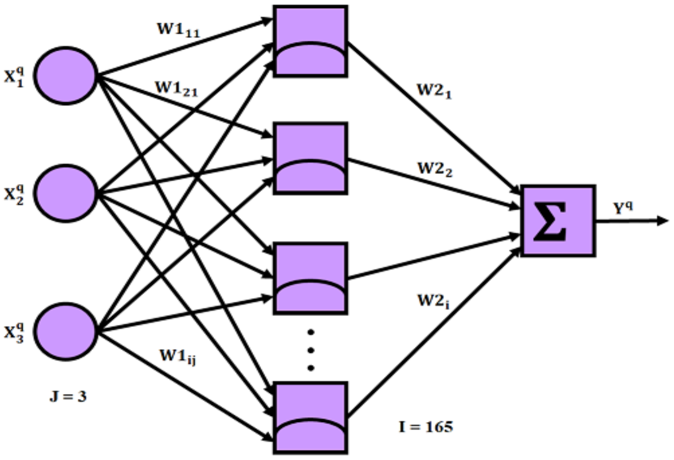

Figure 7: *RBFNN MPPT*

RBFNN commonly contains three main layers which are input layer, hidden layer and output layer.

Input Layer: This layer contains the input data such as features or patterns which needs to be classified or other input values for a function approximation problem.

Hidden Layer: This layer contains set of radial basis function neurons where each neurons measures its output on the basis of the distance between its centre and input data. Radial basis function is significantly a gaussian function which allocates higher value to input that are closer to the neurons centre.

Output Layer: This provides the final output of the network which is either one or multiple neourons depending on the particular problem. Each output neurons depict different class for classification task. Meanwhile, for regression tasks, single output neuron is represented for predicting the value.

Initialization: The centers of the radial basis functions and the weights connecting the hidden layer to the output layer are initialized randomly.

Training: In this phase, networks alters the weights and centers on the basis of the training dataset which is accomplished using optimization techiques like gradient descent algorithm. The main objective goal is to reduce the variations among the networks predicted output and the desired output.

After training of RBFNN it is utilised for making predictions or calssification for new dataset or unseen dataset. The input data is passed through the network, and the output is generated based on the learned weights and centers.

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3.4 ANN Controller

An Artificial Neural Network (ANN) Controller is an advanced control system designed to optimize and manage intricate, nonlinear processes by utilizing the computational capacity of neural networks as shown in Fig.2. Since ANN controllers are built to learn and adapt based on input data, they are much more effective than traditional controllers, which rely on predetermined mathematical models. This is especially useful for systems whose dynamics are too complicated or unpredictable to adequately represent. An ANN controller is made up of layers of linked neurons that process input data based on weighted connections. Through a training procedure that modifies these weights, the ANN controller gains the ability to generate desired outputs in response to particular inputs, allowing it to perform tasks like defect detection, regulation, and optimization with exceptional accuracy and adaptability.

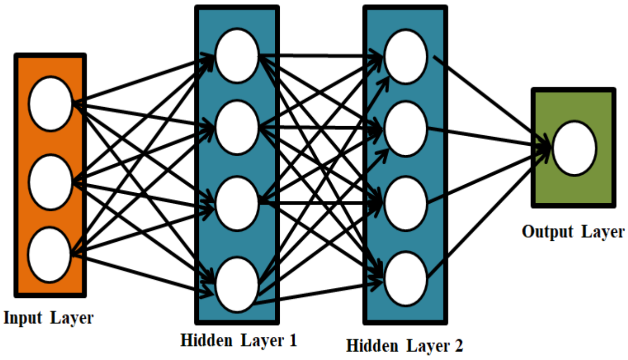

Figure 8: *ANN Controller*

The flexibility of ANN controllers is especially useful in situations where accurate modelling is challenging or where system parameters fluctuate over time, as in robots, autopilots, and renewable energy systems. When trained, an ANN controller handle novel and unknown circumstances by generalizing from its learning experiences, offering reliable performance in a range of situations. To improve overall system performance, ANN controllers can also be used in conjunction with other control schemes like fuzzy logic or PID controllers. Because they increase responsiveness, stability, and efficiency in complicated applications, they are therefore a dynamic tool in contemporary control systems.

4 Result and Discussion

The proposed work is implemented using MATLAB simulation and the results obtained are discussed below.

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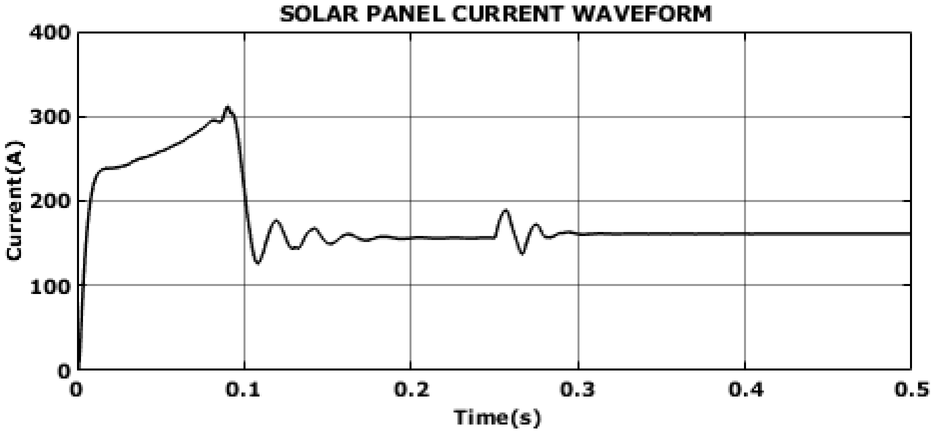

Figure 9: *Input current of the converter*

The figure 9 represent solar panel current waveform obtained using an input current of 168A at varying temperature and irradiance.

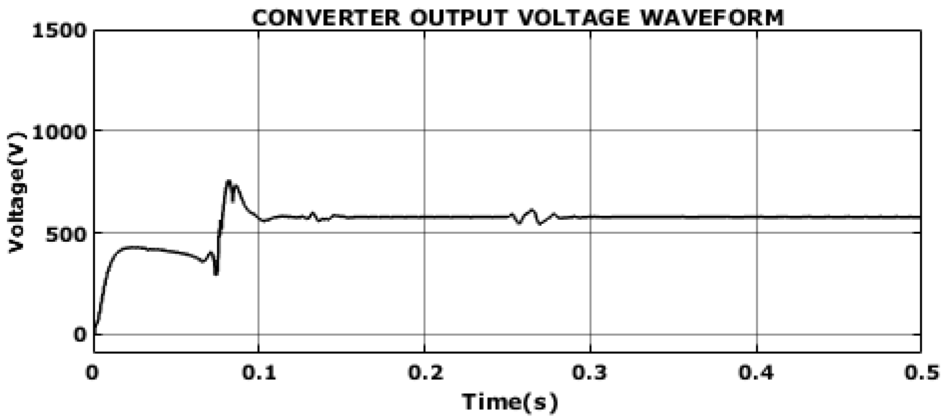

Figure 10: *Converter output voltage*

The Figure 10 represent converter output voltage waveform obtained using a voltage of 610V.

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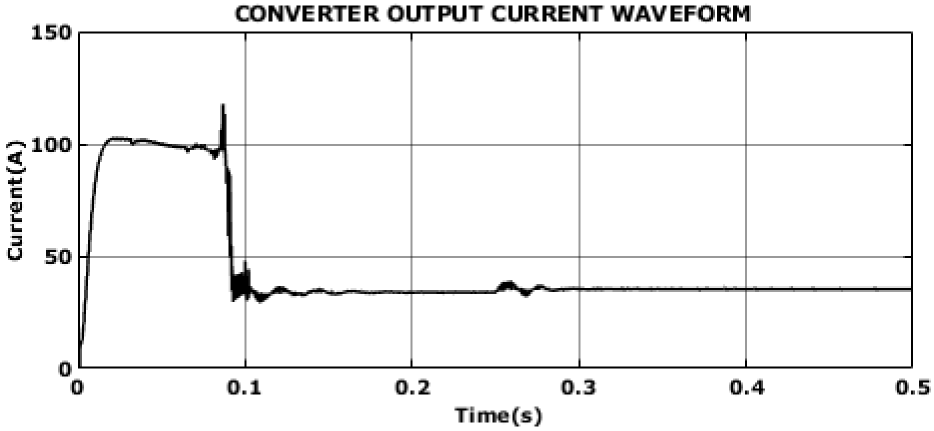


Figure 11: *Converter output current*

The Figure 11 represent the converter current waveform obtained using a current of 47A.

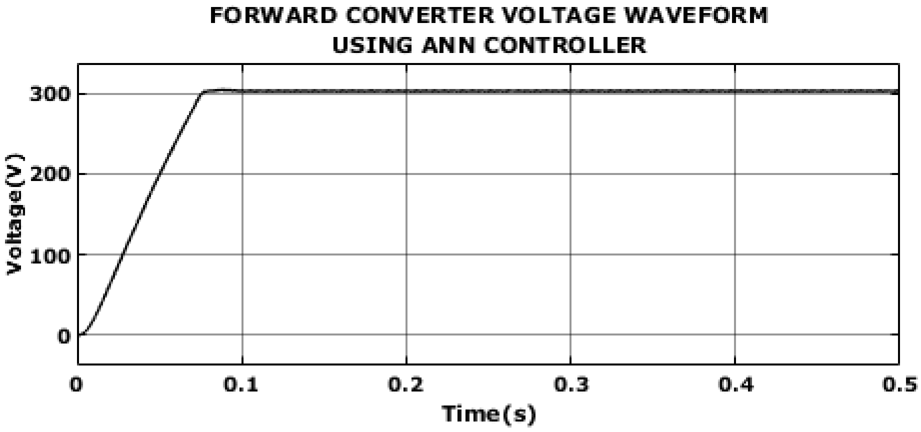
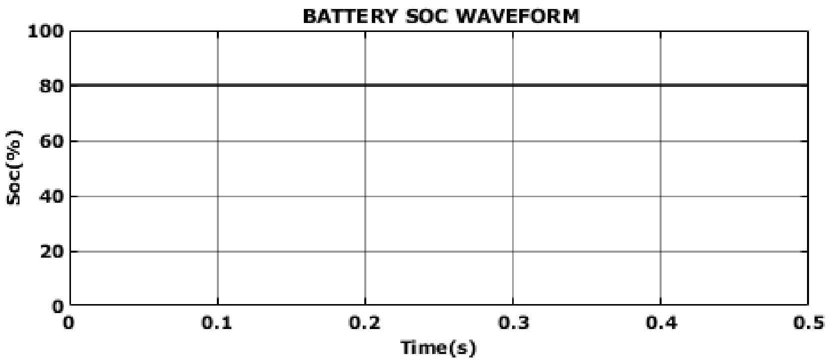


Figure 12: *Forward Converter*

Figure 12 represent Forward Converter waveform for DC load which provide galvanic isolation for protection. The 300V produced by converter using controller is given to DC load as battery.



(a)

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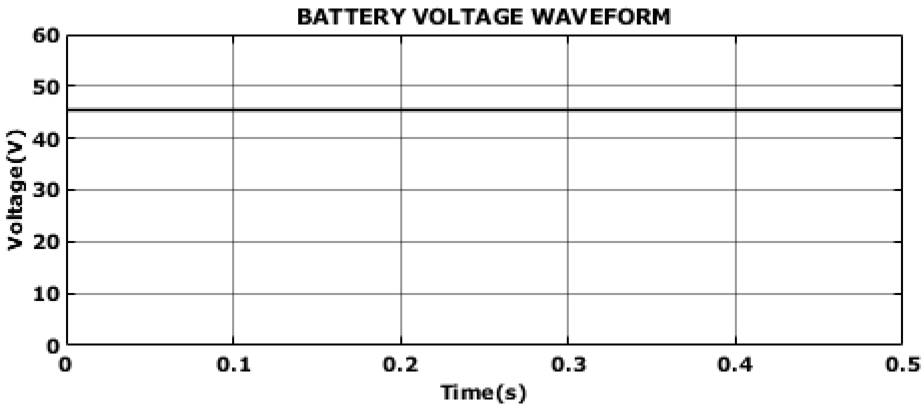

(b)

Figure 13: *Waveforms of battery (a) SOC and (b) Voltage*

Figure 13 represents waveforms level of Battery SOC and battery voltage of 48*V* respectively. The waveforms of SOC is 80% as depicted in Figure 5.10 (b) and is effectively monitored .The surplus power generated from PV is stored in battery. During unavailability of primary source of power supply, battery acts as secondary power source which discharges and transfers power to load.

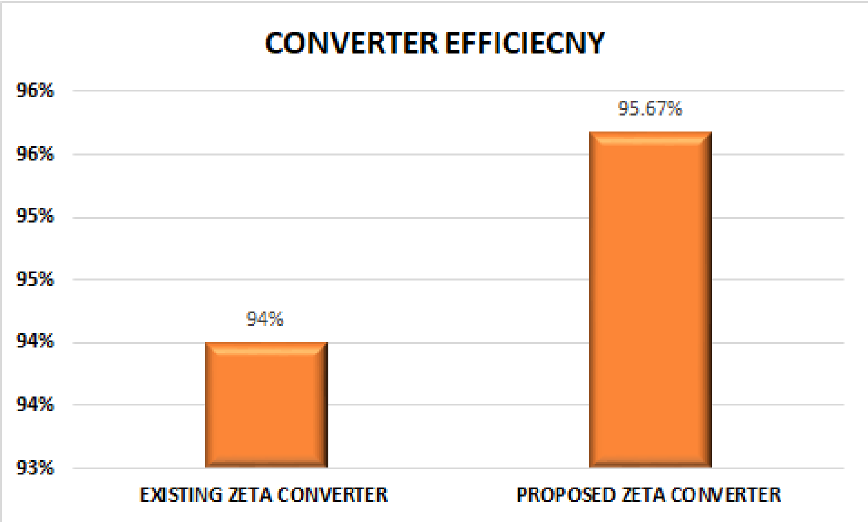

Figure 14: *Comparison of ZETA converter Efficiency*

Figure 14 Represents comparison chart of existing and proposed ZETA converter. From the above chart it notable that the proposed converter attained higher efficiency with 95.67% respectively.

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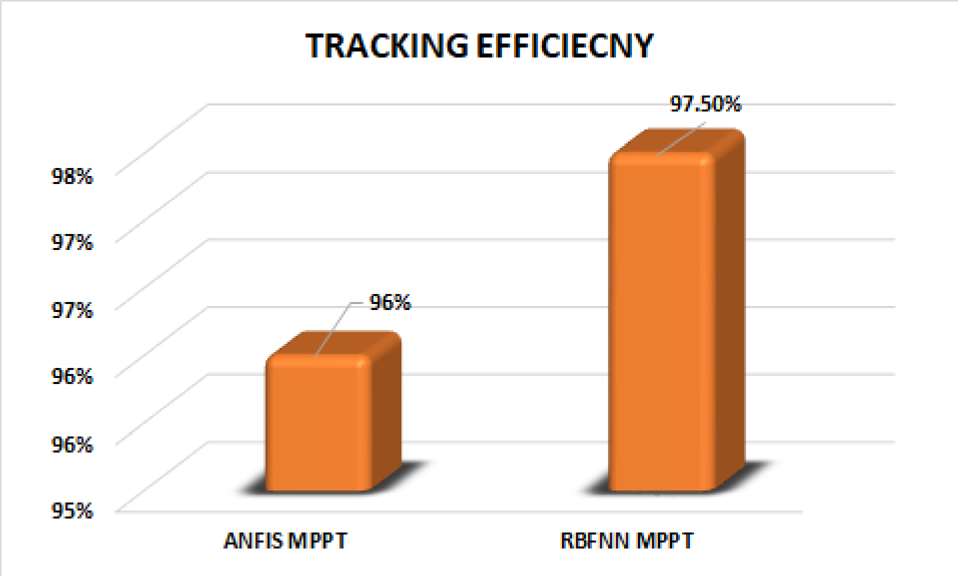

Figure 15: *Comparison of tracking efficiency*

Figure 15 Represents comparison chart of tracking efficiency of exiting ANFIS-MPPT and RBFNN-MPPT controller. From the above chart it evident that proposed MPPT controller attained higher efficiency with 97.50% respectively.

Table 1: *Parameter Specification*

Table 1 Represent the parameter specification of the proposed system.

Parameter	Description
Standalone PV system	
Peak power	250W
Maximum Peak Current	8.35A
Total power	10kW
Maximum Peak Voltage	29.95V
Open Circuit Voltage	37.25V
High gain ZETA converter	
C_1, C_2	4.7µF
L_1, L_2	1mH
Switching frequency f	10kHz

5 Conclusion

In this paper, Zeta converter with RBFNN MPPT for solar PV system in off-grid application is developed and simulated using MATLAB software. The proposed system attained maximum power output with enhanced system efficiency. The output from isolation transformer to given to DC load via rectifier output making it suitable for powering DC loads and the galvanic isolation produced by isolation transformer improve system safety and stability specifically in standalone applications. Additionally, ANN controller is deployed for high frequency converter which in turn improves DC output. This system is developed to operate autonomously as a standalone unit, making it suitable for deployment in areas without access to the main power grid.

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