A MULTIPORT NON-ISOLATED DC-DC CONVERTER FOR HYBRID ENERGY SOURCES BY USING ANN CONTROLLER

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Abstract

The purpose of this paper is to develop a multiport non-isolated DC-DC converter by using an Artificial Neural Network (ANN) based controlling algorithm. In the existing works, various multiport converter and controlling algorithms are developed for improving the power quality and regulating the voltage of hybrid energy storage systems. Still, some of the models are difficult to understand, requires an increased component, high power loss, and reduced efficiency. Therefore, the proposed work intends to develop an ANN based multiport converter, where helps to properly regulate the voltage according to the desired level. Moreover, this converter many inputs that are connected and operated simultaneously. The hybrid energy sources considered in this work are solar Photovoltaic (PV) cells, wind, and fuel cells. These sources connected in parallel, and their output is fed to the non-isolated converter as a single input. Since, the input sources are fluctuating, so their output voltage does not maintain the constant value. In order to maintain the constant outputs, an ANN based controlling algorithm is deployed in this paper, which helps to properly boost the level of output voltage. In addition to that, the Maximum Peak Point Tracking (MPPT) controlling method is utilized to obtain the maximum energy from the input DC source. Then, a rechargeable battery utilizes the backup supply for power generation. During simulation, the whole system is implemented and tested by using the MATLAB/Simulink platform. The obtained results reveal that the ANN based controlling technique could efficiently reduce the spikes, and maintain the constant output at all times.

Keywords: ANN controller; fuel cell; multiport non-isolated converter; PV cell; rechargeable battery; wind energy

Introduction

Recently, the Renewable Energy Sources (RES) has been increasingly used in many applications, due to their benefits of zero gas emission, reduced maintenance cost, reliability, and etc. The solar cells, wind turbine, biogas, hydrogen fuel cells, and thermal plants are some of the major RES widely deployed in present days. Specifically, it is more popular and helps to improve the power generation,

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in which the solar panels are highly depends on the irradiance and temperature. RES (Natarajan *et al*., 2018) have become more popular, which helps to improve the generation of power, but there are some limitations. As a consequence, the RES supports the energy demands of both the current and future power generation systems. Solar energy is dependent on temperature and radiation, and wind energy is dependent on airspeed. Moreover, when the constant voltage is required, the most effective Renewable energy interface fails. Therefore, special techniques are applied to mitigate these problems. Traditionally, suppose more than one storage device has to be connected. In that case, solar/wind energy has to be introduced and varied with each and different in a specific state to achieve certain reliability and requirements, but the performance suffers. Also, for stability, a multi-input DC-DC converter must use renewable energy with a secondary source.

The multi-input converter is using for both unidirectional and bidirectional power transmission. In the multiport switch, the problems that come across in the traditional approach reduce. Thus, the multiport by the devices is increasing day by day to interact with non-traditional assets. Besides unconventional sources of the powers, various sources of regular production to connected. The DC converter (Muthubalaji *et al*., 2022) was especially is used for a hybrid source that required exciting battery power requirements for power operators and wide load variations. These have simple structure of most two-way DC converters (Balaji *et al*., 2017) with single-pass fed current or voltage. Depending on the auxiliary power source area, the powers can be are transferred by a two-way DC converter between two DC voltage entities. The device's overall dynamic performance, reliability, and efficiency is the function that determines how the two-way DC converter is using. The build size of the multiport converter should be highly efficient and capable to has offer compact size and centralized control at a low cost, increasing its importance over the conventional DC-DC converter.

Developing a simple and efficient controlling algorithm for the hybrid energy sources are still remains one of the major tasks. In the existing works, the different types of multiport converter and controlling techniques are developed for voltage regulation and power loss minimization. However, it has the primary challenges of complex system modeling, difficulty in understanding, reduced efficiency, presence of harmonics, and high components utilization. Therefore, the proposed motivates to develop an effective Artificial Neural Network (ANN) based controlling and multiport non-isolated DC-DC converter for hybrid power sources. The original contribution of this work is to maintain the constant outputs at all time by properly regulating and boosting the output of energy sources with reduced loss. Moreover, it targets to obtain an improved results in terms of high gain outputs, minimal power loss, and regulated DC voltage.

The other portions of this paper are split into the following units: Section 2 investigates the existing works related to the different types of DC-DC converter and controlling algorithms. Section 3 provides the clear explanation about the proposed ANN based controlling methodology incorporated with the multiport non-isolated DC-DC converter. Section 4 presents an extensive simulation analysis of the proposed controlling technique, and also it verifies the superiority of ANN controller by comparing it with the existing topologies. At last, the entire paper is summarized with the findings and future scope in Section 5.

Related Works

Typically, the RES are more suitable for the environment, owing to its characteristics of eco-friendly nature, zero carbon emissions, and high availability. This unit investigates the different types of multi-port converter and controlling algorithms used in the existing works. Moreover, it discusses about the pros and cons of each work based on its system model and simulation analysis. (Wu *et al*., 2020) designed a multiport power flow controller for efficiently resolving the coupling issue among the capacitor voltage and transmission line current. This work mainly focused on improving the adjustment flexibility and reducing the port expansion cost of the transmission system. The key features of this controlling algorithm were, port expansion, and direct tracking of line current command. Yet, it could be suitable for the medium voltage system, and it is required to improve the fault tolerance capability of controller. Chaudhury and Kastha (2020) deployed a high gain DC-DC converter for improving the energy storage capability of micro-grid systems. The purpose of this work was to design de-coupled closed loop strategy for maintaining the voltage control and improving the energy management grid systems under varying operating conditions. Kolahian *et al*. (2019) utilized a bipolar DC-DC converter integrated with the neutral point clamp topology for micro-grid systems. The purpose of this work was to obtain high power density with reduced number of switching components. Here, the hybrid power generation system has been used, which comprises the sources of PV, fuel cell, and batteries. Moreover, the switching control was performed at the primary

Table 1. Comparative analysis among various multiport converter designs

Converter Type	Drawbacks	References
Multi-input converter with buck-boost configuration	Inefficient power delivery	(Raghavendran *et al*., 2018, Pushpavalli *et al*., 2021)
Bidirectional multiport converter	It does not having the control for batter charge	(Pourjafar *et al*., 2021, Shayeghi *et al*., 2021; Zeng *et al*., 2021)
Double input full-bridge converter	High controlling complexity	(Chen *et al*., 2021, Bakeer *et al*., 2021; Valadkhani and Mirsalim, 2021)
Bi-directional dual active transformer based converter	It requires an increased count of semiconductor devices	(Cao *et al*., 2021; Dash *et al*., 2021, Wang *et al*., 2021)
3-Port bidirectional converter	It requires more number of switching components	(Adarsh and Nagendrappa, 2021; Kurm and Agarwal, 2022)
Bi-directional LLC resonant converter	More number of capacitor and switching components	(Bopearachchi *et al*., 2021, Sofiya and Sathyan, 2022)
Full-Bridge with multi-winding transformer based converter	Increased components usage, and reduced efficiency	(Feizi *et al*., 2021; Marcinek *et al*., 2021; Younis *et al*., 2021)
Multiport resonant converter	Power sharing problem	(Ma *et al*., 2020; Nasiri and Jean-Pierre, 2020)

side switches for properly regulating the output voltage. The performance of this converter and controlling topologies was assessed by using the steady state waveforms under different switching frequencies. Liang *et al*. (2020) introduced an Improved Virtual Capacitor (IVC) controlling algorithm for regulating the output voltage of multi-port isolated DC-DC converter. Here, the frequency modulation control has been utilized to analyze the charging and discharging characteristics of the capacitor. Moreover, the energy storage device was efficiently managed by using the coordinated controlling algorithm. The key benefit of this work was, it provides the feasible solution for enhancing the large capacity optical storage systems. Wang *et al*. (2020) used a modular multi-port DC-DC converter topology for improving the voltage and power of micro-grid systems. Here, bridge arm voltage component controlling mechanism was adapted to stabilize the DC voltage, which controls the amplitude and phase of the AC voltage component. Moreover, it has the major characteristics of fault current reduction ability, and better energy management.

Alsokhiry and Adam (2020) utilized a high capacity multiport converter for improving the performance of smart grid application systems. The motive of this paper was to design the converter with reduced size, power loss, optimized cost, and weight. Moreover, the control flexibility of the converter was validated and tested under different operating conditions. Ebadpour (2021) deployed a multiport isolated DC-DC converter incorporated with the MIMO controller for the power grid systems. The contribution of this paper was to efficiently regulate the battery voltage by adjusting the gain parameters of the converter. Moreover, the entire system controlling could be properly performed by using the MIMO technique. During analysis, the simulation results of this converter and controlling techniques are validated under changing operating conditions. Samende *et al*. (2018) intended to reduce the power loss of DC grid applications by using the multiport DC-DC converter. Here, the triple active bridge converter modelling topology has been utilized, in which the phase shift controlling was performed to maintain the current flow. Moreover, it objects to minimize the condu ction loss, switching loss, power loss in passive components, and transformer. The benefits of this work were increased efficiency, and consistency. Yet, it could be difficult to understand the mathematical modeling of this system. Table 1 presents the comparative analysis of the conventional multiport converter topologies. Similarly, Table 2 compares the conventional controlling algorithms used for improving the output of DC power source.

Proposed Methodology

This section presents the detailed explanation about the proposed ANN-multiport non-isolated DC-DC converter topology for hybrid energy sources. The contribution of this work is to develop an intelligent controlling algorithm for maintaining the constant outputs with reduced power loss and increased efficiency. According to the literature review, it is analyzed that the different types of multiport DC-DC converter and controlling algorithms are developed in the existing works. Due to their limitations mentioned in the previous section, the proposed work intends to implement a simple and efficient controlling methodology for the hybrid

Table 2. Comparative analysis among various controlling techniques

Controlling Methods	Drawbacks	References
Genetic Algorithm (GA)	Difficult to understand, and expensive implementation	(Mayer *et al*., 2020, Ding *et al*., 2021)
Particle Swarm Optimization (PSO)	Slow convergence and high searching time	(Sarma and Ganguly, 2020)
Simulated Annealing (SA)	Complex mathematical operations	(Zhou *et al*., 2021)
Hybrid Model	High cost and time complexity	(Vahid and Ayman, 2021)
Iterative Models	Increased time consumption and processing complexity	(Zhang *et al*., 2021)
Deterministic models	Inefficient computations	(Madhana and Geetha, 2022)
Probabilistic models	System complexity and difficulty in understanding	(Bian *et al*., 2020)

power sources such as solar PV, wind and fuel cells. In this work, three scenarios have been considered, which includes the followings:

Scenario 1: Electricity flows from three sources to the load.

Scenario 2: Electricity flows from two sources, the battery to the load.

Scenario 3: Electricity flows from three sources to load and battery.

Moreover, the overall flow of the proposed system is depicted in Figure 1.

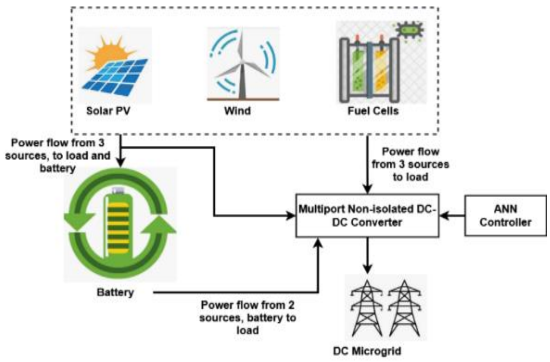

Figure 1. Flow of the proposed system

Multiport Non-Isolated Converter

This converter integrates the photovoltaic cell and battery into a DC micro grid. The input voltages supply port for photovoltaic (PV) cells is related to Vin, while the battery port is related to Vbat. These have been giving as a DC micro-grid output port V0. In the converter, Vin will provide powers to charge Vbat, but not the other way around anymore. Diode D1 is a great strategy to prevent a short circuit on the input power assets while the battery is still on. In this converter, a switched capacitor (SC) cell includes two capacitors and a diode. Therefore, it works as a voltage divider circuit. When the diodes are facing forward, a capacitor should be recharge in parallel.

However, when the diodes are reversing biased, the capacitors will discharge sequentially. The circuit contains an unpaired inductor and three switches (S1, S2, and S3), making the topology simple, light, and less luxurious. Nice one to SC cell, overvoltage gain is obtained at a high switching frequency low-duty cycle. The transformer has an electrical source for photovoltaic input, a powerful storage machine built into a DC micro-grid.

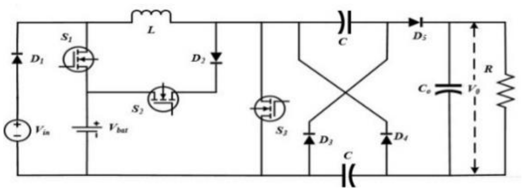

Figure 2. Shows topology of multiport non-isolated converter for PV cell

Figure 2 shows the circuit model of the proposed multi-port non-isolated converter. The proposed converter has an integrated structure with three input sources, a power storage device, and a DC micro-grid. There are three sources such as photovoltaic (PV) cells, wind, and fuel cells. The diode is connected in a series with each input source to control the reverse flow of the electrical state. There are three ports, including the input port shown by Vin, the battery port shown by Vbat, and the output port shown by Vout. One inductor connected to them.

These are the three switches associated with it. S1 and S2 are used for battery charging and discharging status. A switching capacitor cell (SC) is should containing two capacitors and two diodes. Therefore, it works like a voltage divider circuit as shown in Figure 3.

For example, when the diodes are forward biased, the capacitors are in the charging position. The two diodes are in the opposite state as the two capacitors can be in the discharge position.

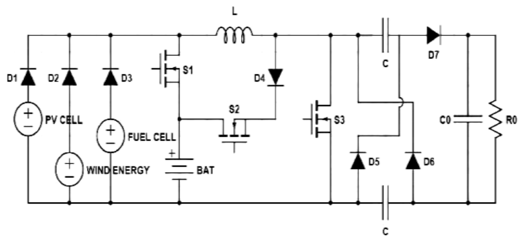

Figure 3. Schematic representation of the proposed system

In this scenario, the battery, which contains all three sources, should be act as charging for them. The rechargeable battery must be in the charging position, and electricity flows from the sources to load and battery.

System Model

The hybrid system includes two additional power sources connected in parallel. The energy assets of this device are photovoltaic solar cells, wind, and fuel cells. The various elements of the system design are as follows:

The nonlinear load of 15kW and an SG of 10kW, 415V, 50Hz coupled to a wind turbine system. The PV array can have been designing to give maximum power from MPPT strategies.

Boost Converter

The traditional boost converter modeled with the ANN controller for the effective generation of pulses for the MOSFET switching operating at peak efficiency. The inductor value in the converter topology is a design from:

$$L = \frac{(Vo-Vin)*Vin}{\Delta Ipv*frequency*Vo} \text{ Henry} \quad (1)$$

DC-Link Capacitor and Battery System

The capacitor value calculated from:

$$Cdc = \frac{(Vo-Vin)*Vin}{2w*Vdc^2} \text{ farad} \quad (2)$$

A battery of a higher power rating is having chosen to withstand the power generated from the boost converter and mitigate the disturbances and harmonics by incorporating the required filters.

Modeling of Wind Turbine Based Synchronous Generator

The wind turbine converts the wind power into the electrical powers through an arrangement of mechanical gear settings. The modeling equations related to wind turbine is given as:

$$Pw = \frac{p\,A\,v^3 w}{2} \quad (3)$$

In power generated from the wind depends on the turbine efficiency and given as

$$Pm = Pw *Cp=0.5\rho L2v3\ Cp \quad (4)$$

The parks transformation equations for the alternator are as follows:

Stator Side Equations:

$$ed = p\psi_d - \psi_q\omega_r - R_a id \quad (5)$$

$$eq = p\psi_q + \psi_d\omega_r - R_a iq \quad (6)$$

$$ed = p\psi_d - \psi_q\omega_r - R_a id \quad (7)$$

$$eq = p\psi_q + \psi_d\omega_r - R_a iq \quad (8)$$

$$eo = p\psi_o - R_a i_o \quad (9)$$

$$\psi_d = -L_d i_d + L_{afd} i_{fd} + L_{akd} i_{kq} \quad (10)$$

$$\psi_o = -L_o i_o \quad (11)$$

Rotor Side Equations:

$$efd = p\psi_{fd} - R_{fd} i_{fd} \quad (12)$$

$$0 = p\psi_{kd} + R_{kd} i_{kd} \quad (13)$$

$$0 = p\psi_{kq} + R_{kq} i_{kq} \quad (14)$$

$$\psi_{fd} = L_{ffd} i_{fd} + L_{fkd} i_{kd} - 1.5 L_{afd} i_d \quad (15)$$

$$\psi_{kd} = L_{fkd} i_{fd} + L_{kkd} i_{kd} - 1.5 L_{akd} i_d \quad (16)$$

$$\psi_{fq} = L_{ffq} i_{fq} + L_{fkq} i_{kq} - 1.5 L_{afq} i_q \quad (17)$$

$$\psi_{kq} = L_{kkq} i_{fq} + L_{fkq} i_{kq} - 1.5 L_{akq} i_q \quad (18)$$

Power output is:

$$Pe=0.67(edid +eqiq) \quad (19)$$

Depending on the equation, the simulation model is designed for the system to analyze the performance of the variables.

Modeling of Fuel Cell

A fuel cell is a device that uses a chemical reaction to create electricity. The positive and negative electrodes, which make up each fuel cell,

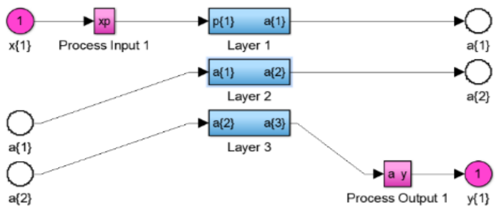

Figure 4. Architecture model of ANN controller

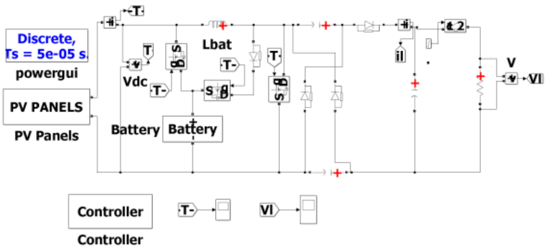

Figure 5. Schematic representation of multiport Non-isolated Converter for PV Cell sources with PI controller

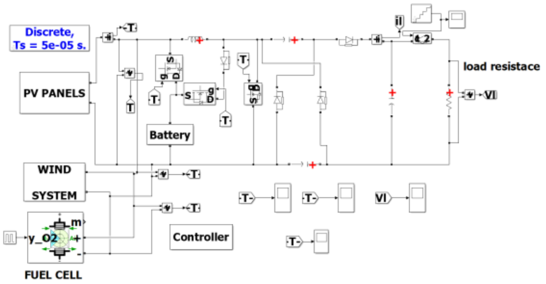

Figure 6. Schematic representation of multiport controller

are made up of one positive electrode and one negative electrode. At the electrodes, power generation reactions take place. Each moving gas also contains an electrolyte that transfers electrically charged particles from one electrode to another and a catalyst that speeds up reactions at the electrodes. Hydrogen is the primary gas, but gasoline cells require oxygen as well. The unique enchantment of fuel cells is that they produce energy with relatively few pollutants - masses of hydrogen and oxygen used in power creation eventually mix to make a harmless by-product, particularly water. A single gaseous stirrer produces a small amount of direct current (DC) power. Figure 4 represents the schematic representation of the proposed ANN controlling model. Figure 5 and Figure 6 shows the circuit model of the multiport non-isolated converter and multiport controllre respectively.

PI Controller

The controller contains both proportional and integral control action. The controller has been used for the feedback control loop to calculate an error signal by taking the differences between the output systems. The proportional terms have been using to obtain a value for the outputs. Proportional to the current errors by varying by multiplying the error value by a constant value Kp. The Integral terms have been using for controlling both the magnitude and duration of the error value. Figure 7 depicts the circuit model of the PI controlling structure.

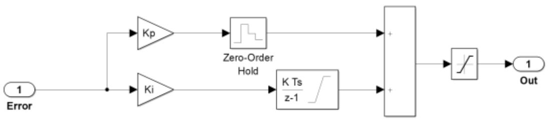

Figure 7. Shows PI controller structure controller

ANN Controller

Artificial neural networks are commonly called the “neural networks," or ANN for short, are computational devices modeled on interconnections between neurons in the neuronal structures of the human brain and some other organisms. Mathematically, neural networks are not linear. Instead, each layer represents a nonlinear selection of the previous layer’s nonlinear properties. Each neuron is a MIMO that receives input impulses, generates a result signal, and transmits that signal to all outputs. The neurons of ANN are structure in layers in practice. The input layer is the first layer that interacts with users to obtain data. The output layer is the final layer that interacts with the output to deliver the processed statistics. Hidden layers are secondary layers between input and output layers that do not interact. The increased complexity of ANN and its processing capability need adding more hidden layers and neurons to each layer. Hidden neurons are neurons that can’t be mention in either the input or output layers. The range and overlap from these neurons are terms as a black field for those interacting with the system because they are essentially hiding from view.

The device’s processing power and flexibility have increased by using multiple layers of hidden neurons. However, this increased flexibility comes at the expense of the training algorithm’s increased complexity. With too many hidden neurons, the device is over-targeted and unable to generalize, similar to an equation device with higher equations than unfixed variables. Having too few buried neurons, on the other hand, can prevent the system from appropriately placing the input data and reduce the device's power.

Non-isolated Converter for hybrid sources with ANN controller

Results and Discussion

This section presents the simulation and comparative analysis of the proposed system by using various parameters. Here, the MATLAB/ Simulink tool is used to validate the results in terms of input voltage, output voltage of power sources, and load variations. The output voltage waveform of PV cell is shown in Figure 8. The PV Cell Output is Varied in between (40-56) V. The waveform shown in Figure 9 demonstrates the output voltage of the multiport converter. Initially the voltage is zero, after some time voltage rises to 400 V after it will be a constant value. Voltage spikes are getting up to 409 V. Figure 10 shows the output voltage variation with respect to change in load. The change in load is realized by the change is resistance. According to the results, it is analyzed that the output voltage of three power sources such as PV, wind and fuel cells are highly improved with respect to varying time instances.

Input source 1 (PV Cell) - The voltage from the input source PV cell is represented in Figure 11. The voltage is changed every 2 sec, and after 10 sec, it achieves a value of 56V.

Input source 2 (Wind Energy) - The waveform in Figure 12 depicts output voltage from wind source. From this graph it reveals that the input voltage is maintained as 48V.

Input source 3 (Fuel Cell) - The output voltage from fuel cell is shown in Figure 13 as a waveform. The voltage is kept at 48 V, as shown in this graph.

The relationship between voltage and time is depicted by the waveform in Figure 14. The voltage is zero at time T = 0 sec, climbs to 400 V for a certain amount of time, and then remains constant. Voltage surges can reach 406 volts.

The waveform in Figure 15 illustrates how load (in terms of resistance) varies over time. The resistance fluctuates up to 56 ohms for 2 sec while the load increases by 4 ohms.

The spikes in output voltages are significantly decreased when the ANN controller is employed, as seen in the Table 3. Furthermore, the ANN controller can maintain a consistent output level even when the converter is fed from numerous sources. Table 4 validates the settling time (s), steady state error, output voltage, and efficiency of the conventional (Kumar *et al*., 2022) and proposed controlling techniques, then its corresponding graphical illustrations are presented in Figures 16

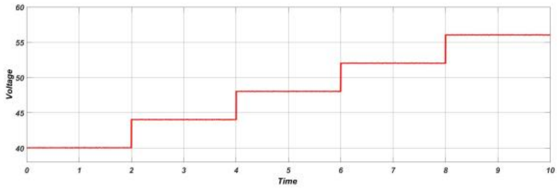

Figure 8. Output voltage of PV cell

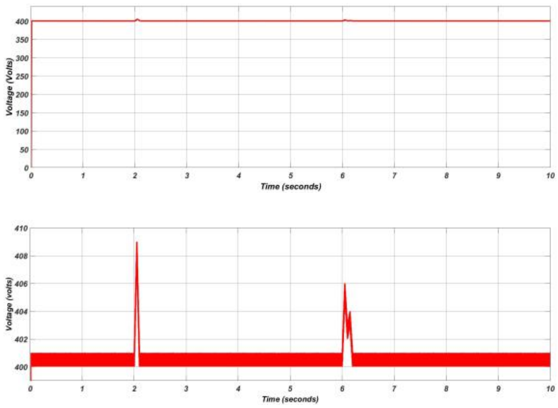

Figure 9. Output voltage waveforms

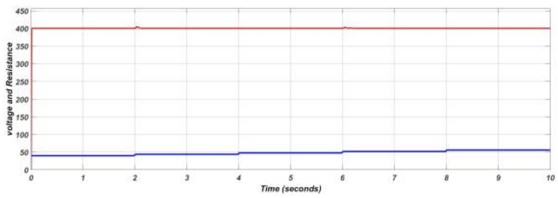

Figure 10. Load variation concerning output voltage

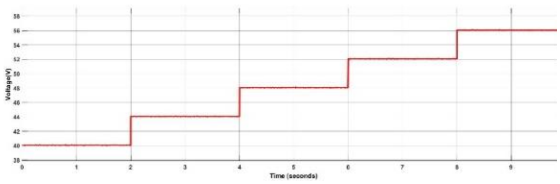

Figure 11. Output Voltage of the PV cell

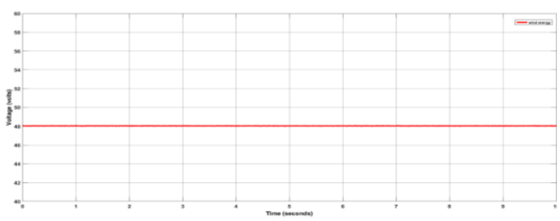

Figure 12. Output voltage of wind energy

and 17. Based on the results, it is evident that the proposed ANN controlling technique provides an improved results compared than the other controlling models.

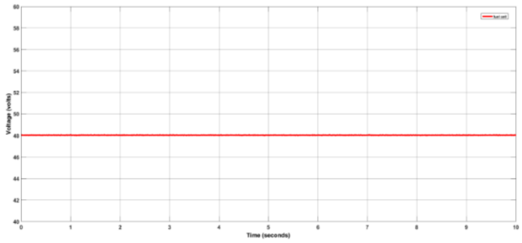

Figure 13. Input voltage of fuel cell

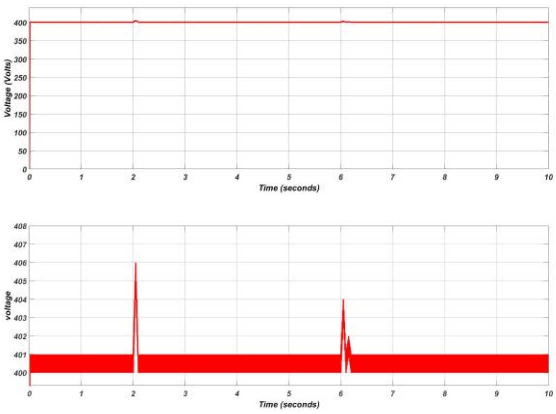

Figure 14. Circuit Output voltage

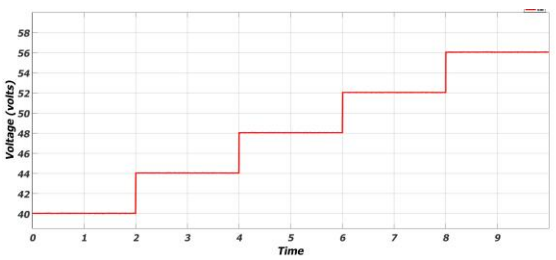

Figure 15. Load variation by using resistance load

Similarly, the overall performance of the existing PI, FLC, Fuzzy PID, ANFIS and proposed ANN controllers are validated and compared in Tables 5 and 6, then its graphical illustrations are presented in Figures 18 and 19. From the results, it is evident that the proposed ANN controller outperforms the other controlling techniques with improved performance outputs, which proves the superiority of the proposed system.

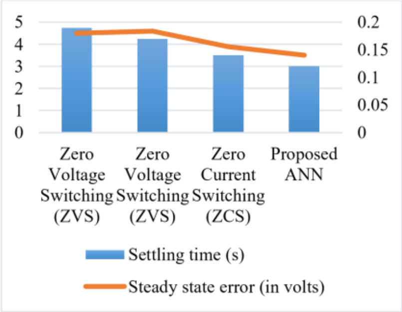

Figure 16. Settling time and steady state error

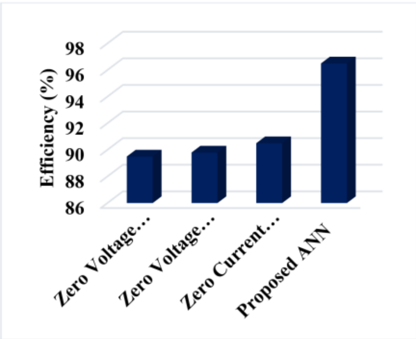

Figure 17. Efficiency

Table 3. Performance Comparison

Controller	PI controller	Artificial Neural Network (ANN) controller
Input sources	1. PV cell	1.PV cell 2.Wind energy 3. Fuel cell
Spike's voltage (Volt) value	409	406
Input voltage (Volt) ratings	1.Vpv cell = (40-56)	1.Vpv cell = (40-56) 2.Vwind = 48 3.V fuel=48
Output voltage (Volt) rating	400	400

Table 4. Comparative analysis

Controlling techniques	Settling time (s)	Steady state error (in volts)	Output voltage (V)	Efficiency (%)
Zero Voltage Switching (ZVS)	0.19	4.5	350	89.5
Zero Voltage Switching (ZVS)	0.17	4.6	250	89.8
Zero Current Switching (ZCS)	0.14	3.9	250	90.5
Proposed ANN	0.12	3.5	380	96.5

Table 5. Comparative analysis among the controlling techniques

Controller	Rise time (s)	Settling time (s)	Overshoot (Volts)
PI	0.0512	0.0343	44.6
FLC	0.0267	0.0158	35.4
Fuzzy PID	0.0129	0.0088	26.5
ANFIS	0.0089	0.0083	12.6
Proposed ANN	0.0076	0.0079	11.4

Table 6. Performance analysis of various controllers

Controller	Steady state error (Volt)	Output voltage (V)	Efficiency (%)
PI	4.2	395.8	87.6
FLC	1.4	398.6	88.5
Fuzzy PID	0.5	400.5	90.5
ANFIS	0.4	400.4	91.1
Proposed ANN	0.3	400.9	96.8

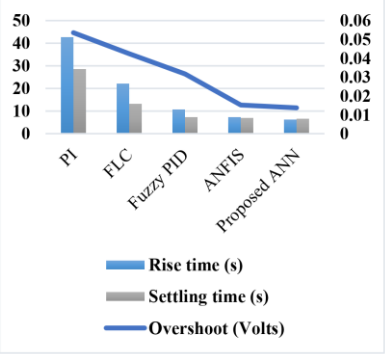

Figure 18. Comparative analysis

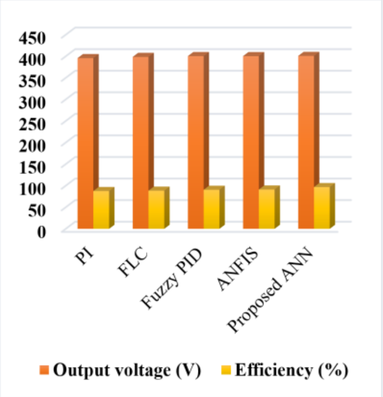

Figure 19. Performance analysis of different controllers

Conclusions

A multiple source fed non isolated multiport converter with an ANN controller was proposed in this study. The ANN controller's performance is evaluated using a traditional multiport converter with a PI controller. The original contribution of this work is to maintain the constant outputs at all time by properly regulating and boosting the output of energy sources with reduced loss. The hybrid energy sources considered in this work are solar Photovoltaic (PV) cells, wind, and fuel cells. These sources connected in parallel, and their output is fed to the non-isolated converter as a single input. Moreover, it targets to obtain an improved results in terms of high gain outputs, minimal power loss, and regulated DC voltage. As a result, the output spikes are more regulated than with the PI controller. Furthermore, the ANN controller outperformed even when numerous sources were included at the converter's input side. Even when the input is fluctuating from various sources, the ANN controller maintains a steady voltage of 400 V.

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