ENERGY MANAGEMENT OF HYBRID ELECTRIC VEHICLES USING CASCADED FUZZY-ANN CONTROLLER

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ABSTRACT: This study presents a new way to manage energy in hybrid electric vehicles (HEVs) by using a hybrid cascaded fuzzy and Artificial Neural Network (ANN) controller to make the whole system run better. The main goal is to make the vehicles more energy-efficient and independent while also lowering the costs of running them. The system combines a photovoltaic (PV) source with a battery and uses a SEPIC integrated boost converter to improve and optimize the power output from these sources. A single-phase voltage source inverter (VSI) is also used to change direct current (DC) into alternating current (AC), which makes the system even more efficient. The hybrid controller is very important since it dynamically controls the flow of energy, uses fuzzy logic to deal with the system's non-linear nature, and learns how to adapt to different driving situations. We used MATLAB/Simulink to run simulations to test the proposed method. The results showed that the system produces more energy, lowers harmonic distortion, and greatly increases the overall efficiency of the HEV. This shows that the hybrid control system could be a more reliable and long-lasting way to get energy.

KEYWORDS: Electric vehicle, fuzzy logic, ANN, renewable resources, energy management.

1. INTRODUCTION

An effective conveyance and vitality producing system with an inferior carbon footmark is being encouraged in recent times owing to growing concerns about the damaging repercussions of global heating and climate alteration. Cars and power plants that run on fossil fuels are the main sources of dangerous carbon emissions that get into the air. So, using PV-powered electric car technology is necessary to find a solution to global warming that works. Electric cars are better for the environment because they don't produce any carbon and are more efficient. Since the PV system are non-linear with low voltage output, a DC-DC converter is crucial in enhancing its low output voltage. The fundamental converters like boost are largely employed for PV requirements, but they are hampered by their inability to give step down voltage conversion. The buck boost converter are achieved of together accumulating and lowering the voltage level but its efficiency is impacted by its discontinuous input current. SEPIC converter, which also derives from buck boost converter are achieved of together cumulative and reducing the voltage level but its efficiency is affected by its discontinuous input current. SEPIC converter, which also derives from buck-boost domestic is completed of together voltage step down and step up but its input current ripples is quite large. So, for enhancing the operation and efficiency of fundamental converters, integrated converter are established. The integrated converters feature wide range of voltage conversion ratio in addition to reduced switching loss.

A good supervisor is crucial in improving the process of the converter. The traditional PI controller are basic and are useful in case of linear processes. They are not ideal for non-linear systems and it is also influenced by peak overshoot situations. The AI based Artificial Neural Network (ANN) and Fuzzy Logic Controller (FLC) are also efficiently monitors the working of the converter. The problem-solving strategy of FLC uses fuzzy rules to arrive at a conclusion, yet the membership function is difficult to construct in this method. The ANN, which is based after the biological brain, is made up of a massive amount of densely consistent machinery known as neurons that collaborate to address challenges. However, for training and modelling the system, more processing time is required. Therefore, Cascaded FLC (Fuzzy Logic Controller) is utilized for controlling the procedure of the SEPIC integrated Boost converter [12. This research study provides an energy management Hybrid Electric Vehicle employing cascaded fuzzy-ANN control technique. Here, the PV production power is improved by integrated SEPIC converter. The Cascaded FLC is used to monitor the operating of the converter. The PV control is carried from the converter to the network via a solitary phase inverter and the working of the inverter is controlled by a PI controller.

2. PV SYSTEM

Fig 1 represents equivalent circuit of a PV cell model. It has a current source for sunlight-generated current, a diode for the p-n junction, a parallel connect resistance (Rp) for leakage loss, and a series connected resistance (Rs) for internal losses. This model analyses proposed PV cell performance.

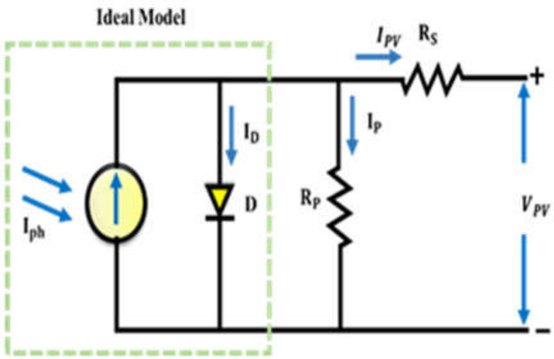


Fig. 1. Structure of Solar-PV cell

$$I_{pv} = I_{ph} - I_{sd}\left(exp\left(\frac{qV_{pv}+R_sI_{pv}}{nKT}\right)-1\right) - \frac{V_{pv}+R_sI_{pv}}{R_p} \quad (1)$$

Whare,

K denotes the Boltzmann constant, q represents the electron charge, I_sd refers to the reverse saturation current, n is the ideality factor, and T represents the temperature. The integrated SEPIC converter receives the output from the photovoltaic (PV) source.

3. PROPOSED SEPIC-CONVERTER

The SEPIC-converter is connected with a boost-converter to form an integrated converter that offers improved efficiency, high voltage gain, and a wide voltage conversion range. The circuit-diagram of the integrated SEPIC converter is shown in Fig.2

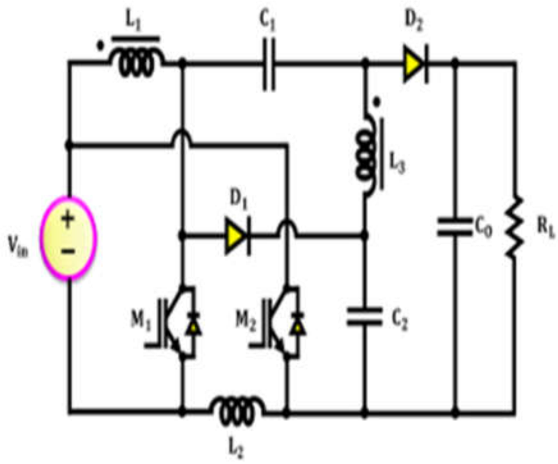


Fig. 3. Proposed SEPIC-converter

The integrated converter consists of two switches, two diodes, three inductors, and three capacitors. The operation of the converter is explained in two modes, as described below:

Mode-1 mode, both switches are in the ON-state, while both diodes remain OFF. All inductors are charged during this period, and the output capacitor discharges to supply power to the load. The voltages across inductors **L_1** and **L_2** are given as:

$$V_{L_1} = V_{L_2} = V_{in} \quad (2)$$

The voltage V_{L_3} is given as,

$$V_{L_3} = V_{C_2} = V_{C_1} + V_{in} \quad (3)$$

In this mode-2, both switches are in the OFF-state, while the diodes are in the ON-state. The inductors discharge, and the capacitors are charged. Energy from the inductors is transferred to the capacitors and the load through the diodes. The voltages across **L_1** and **L_2** are given as:

$$V_{L_1} = V_{L_2} = \frac{(V_{in} - V_o + V_{C_1})}{2} \quad (4)$$

The voltage V_{L_3} is given as,

$$V_{L_3} = -V_{C_1} \quad (5)$$

In CCM, the voltage gain is given as,

$$M = \frac{V_o}{V_{in}} = \frac{3D+1}{1-D} \quad (6)$$

The value of input curent is given as,

$$I_{in} = \frac{3D+1}{1-D} I_o \quad (7)$$

The integrated SEPIC-converter boosts the output power from the solar-PV system to the desired level, and its operation is optimized using a cascaded Fuzzy Logic-ANN Controller (FLC-ANN).

4. PROPOSED CONTROLLER STRATEGY

The hybrid cascaded Fuzzy Logic (FLC) and Artificial Neural Network (ANN) controller in enhancing the performance of the SEPIC-integrated Boost converter. The cascaded structure combines two controllers, where the output of one feed into the other. This integration improves dynamic response, enhances adaptability, and minimizes disruptions. The controller, shown in Fig. 5, features inner and outer loops, both upgraded to neuro-fuzzy systems. While the fuzzy logic provides rule-based control, the ANN adds learning and adaptability, enabling real-time optimization for improved performance. To effectively control the system, the hybrid controller uses a structured approach to represent, apply, and manage control knowledge. By combining the nonlinear processing ability of fuzzy logic with the adaptive learning of an ANN, the controller continuously refines the control strategy, making it highly efficient in formalizing and optimizing the overall control process.

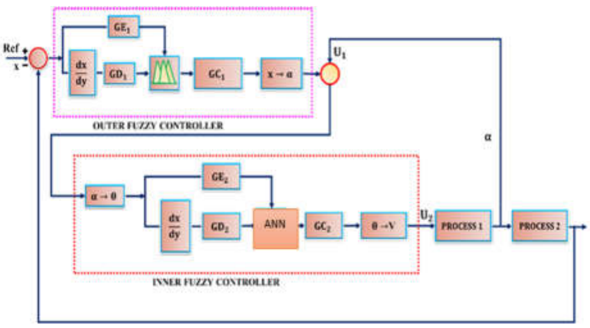


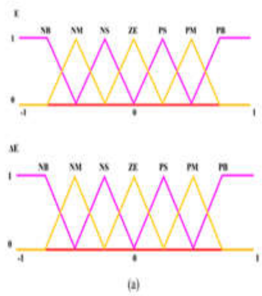
Fig. 5. Structure of CFLC-ANN

A. Outer Fuzzy Controller

The following rules are used to implement the outer loop of the fuzzy controller:

$$R^k: E_i \text{ is } A_1^k \text{ and } \Delta E_i \text{ is } A_2^k \text{ then } U_i = B^k \quad (8)$$

Here, the numerical value of the controller is denoted as $\mathbf{A_k}$, the change in error is represented as $\Delta\mathbf{E_i}$, and the output is expressed as $\mathbf{U_i}$. The error for both the inner and outer loops is indicated by $\mathbf{E_i}$. The linguistic values for the error and change in error are defined as $\mathbf{A_{1k}}$ and $\mathbf{A_{2k}}$, respectively. The activation level of each control rule is efficiently calculated using the following expressions. Fig 6(a),6(b) represents the fuzzy controller structure.



ΔE \ E	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	Z
NM	PB	PB	PB	PM	PS	Z	NS
NS	PB	PB	PM	PS	Z	NS	NM
ZO	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NB	NB	NB
PB	Z	NS	NM	NB	NB	NB	NB

(b)

Fig. 6. (a) membership and (b) Rule-FLC

B. Inner Fuzzy Controller

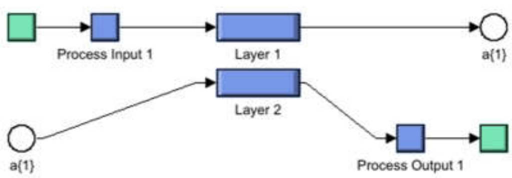


Fig.7 ANN-Structure

The Inner Artificial Neural Network (ANN) functions as the controller for the inner loop in a cascaded control system. It manages fast-changing, non-linear secondary variables, such as those found in power converters. Unlike traditional controllers, the Inner ANN structure Fig.7 adapts and learns system behaviour without needing exact mathematical models. It receives the setpoint from the outer loop and ensures a quick, accurate response, maintaining stability and rejecting disturbances. This adaptive control enhances system efficiency and improves overall dynamic performance by isolating the outer loop from rapid fluctuations.

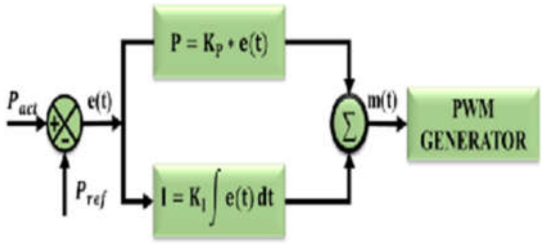


Fig. 8. Grid-side PI controller

The stable voltage output from the converter is fed to the single-phase Voltage Source Inverter (VSI). This DC power is then converted into AC and supplied to the single-phase grid. The operation of the VSI is regulated using a Proportional-Integral (PI) controller. The structure of the PI controller is illustrated in Fig. 8.

5. PROPOSED SIMULATION & RESULT

Fig. 9 presents a complete MATLAB/Simulink model of a grid-tied photovoltaic (PV) power generation system. The process begins with the solar-PV system block, which simulates variable dc output from solar panels. This power is regulated by an integrated SEPIC-converter, ensuring voltage stability and likely implementing MPPT. The converter is controlled by a cascaded fuzzy-ANN controller, which intelligently generates PWM signals to optimize system performance through adaptive and nonlinear control. The stabilized dc is then converted to ac using a single-phase vsi. A passive lc filter is used to eliminate switching harmonics, delivering a smooth sinusoidal waveform to the grid. The model includes a results block for output analysis, a pi controller (disconnected, for comparison), and the essential power Gui block for simscape electrical simulation.

The performance of the proposed grid-tied PV system, managed by the advanced hybrid cascaded fuzzy and Artificial Neural Network (ANN) controller, was validated through simulation. The following analysis of Figures demonstrates the system's superior performance and stability under dynamically changing solar conditions. Fig.10 shows the input solar irradiance signal used to test the system's dynamic response. To mimic real-world conditions like passing clouds, the simulation introduces sharp step changes. The irradiance starts at a standard 1000 W/m², drops to 600 W/m² at t=0.1s, and then partially recovers to 850 W/m² at t=0.2s. This variable input provides a rigorous test for the controller's robustness.

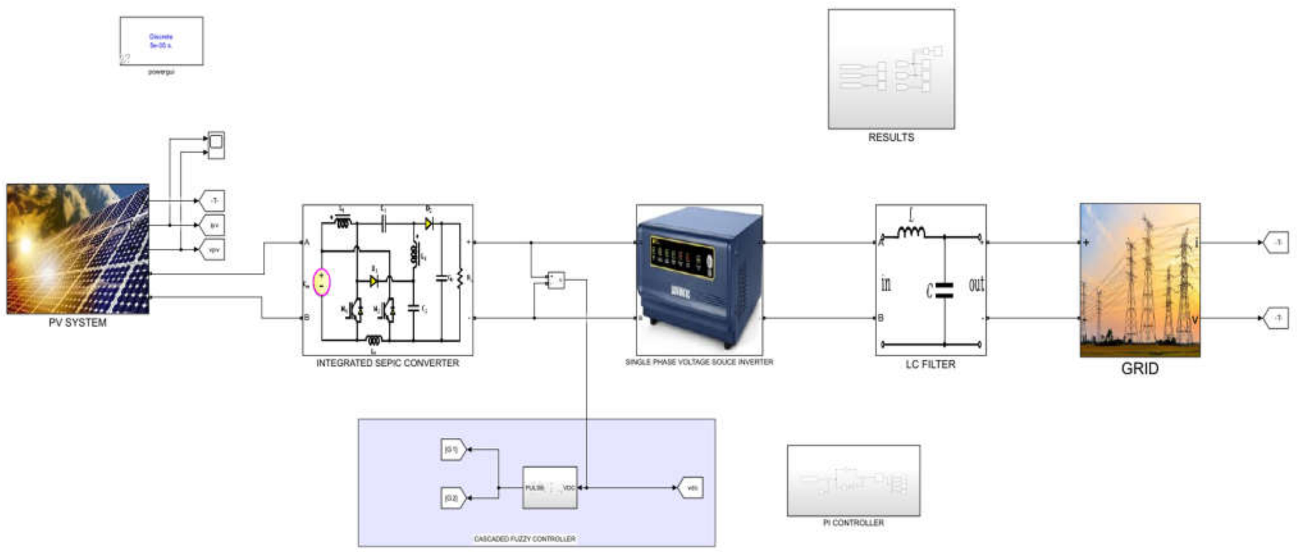


Fig. 9 Simulation model

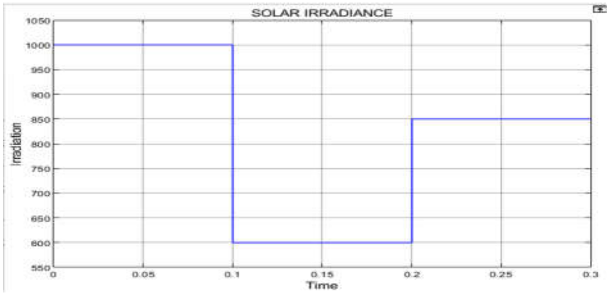


Fig.10 Solar Irradiance

Fig.11 PV Voltage, Fig.12 PV Current, and Fig.13 Power Watt collectively illustrate the exceptional Maximum Power Point Tracking (MPPT) performance of the hybrid controller. As the irradiance in Fig.10 changes, the controller instantly adjusts the PV array's operating voltage and current to extract the maximum possible power. The power waveform in Fig.12 perfectly mirrors the irradiance steps, confirming that the system operates at peak efficiency throughout the disturbances.

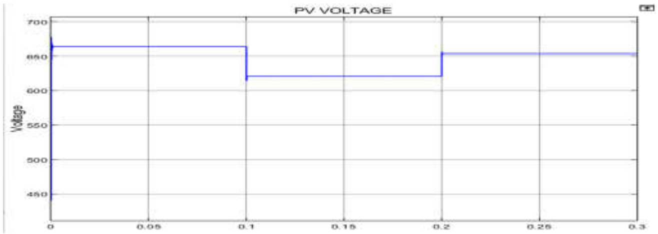


Fig.11 PV Voltage

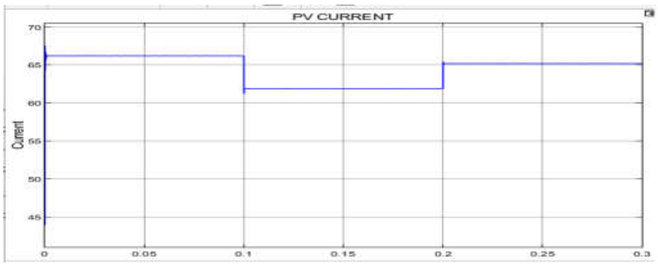


Fig.12 PV Current

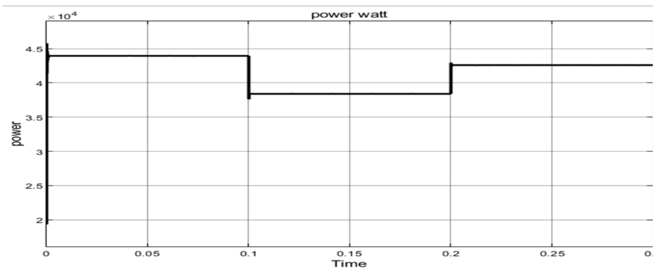


Fig.13 Power Watt

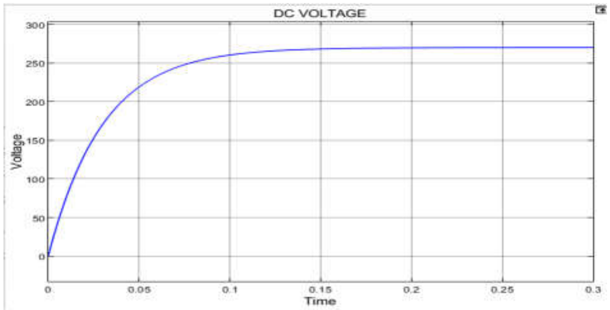


Fig.14 DC Link Voltage Regulation

Fig.14 displays the output DC voltage from the integrated SEPIC converter. This is a critical result demonstrating the controller's primary regulation task. Despite the significant power fluctuations at the input, the controller provides a highly stable DC voltage of approximately 270V. The waveform shows a smooth rise to the setpoint with a fast-settling time and, most importantly, a complete absence of any peak overshoot. This highlights the superior stability provided by the adaptive capabilities of the fuzzy-ANN hybrid controller.

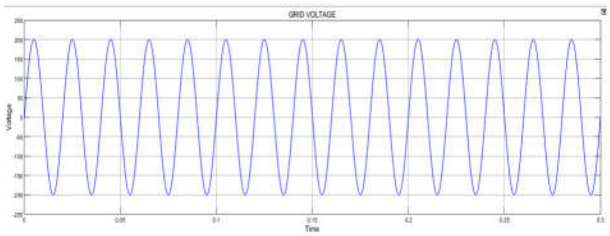


Fig.15 Grid Voltage

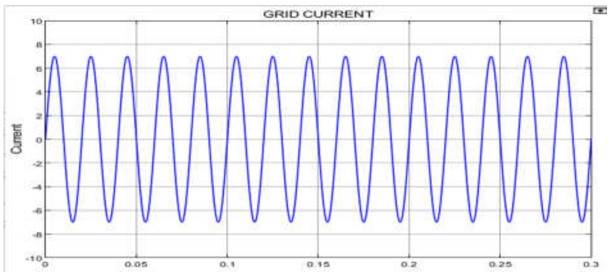


Fig.16 Grid Current

The final outputs of the system are shown in Fig.15 Grid Voltage and Fig.16 Grid Current.Fig.15 shows the stable AC voltage of the grid, which serves as the reference. Fig.16 shows the current injected into the grid The current waveform is a clean, pure sinusoid, indicating very low harmonic distortion and high-power quality. By observing that the current waveform is perfectly aligned with the voltage waveform, it is clear the system is operating at a unity power factor. This ensures maximum efficiency, as only useful active power is delivered to the grid.

6. CONCLUSION

This study focuses on a cascaded Fuzzy-ANN control-based approach for energy management in hybrid electric vehicles (HEVs). As HEVs present a viable alternative to traditional gasoline-powered vehicles, efficient and intelligent energy management becomes essential for supporting their global adoption. Effective energy control not only enhances vehicle performance and range but also helps reduce operational costs. In the proposed system, power from the photovoltaic (PV) source is converted to the required voltage level using an Integrated SEPIC Converter, which combines the advantages of both SEPIC and Boost converters. This design offers a wider voltage conversion range, higher voltage gain, and improved efficiency. The performance of the converter is further enhanced by employing a Cascaded Fuzzy Logic Controller–Artificial Neural Network (FLC-ANN), which provides adaptive and intelligent control. The proposed method also achieves a lower Total Harmonic Distortion (THD), making it highly effective in improving the overall performance and efficiency of hybrid electric vehicles.

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