

Management of Energy in Hybrid Electric Vehicles using a Cascaded Fuzzy Logic Controller

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Abstract - The proposed Hybrid Electric Vehicle uses cascaded fuzzy control technique for energy management. The creation of a large international market for hybrid electric vehicles depends on good and intelligent energy management. Hybrid electric vehicles are a viable alternative to traditional gasoline-powered cars. The problem of energy management has to be tackled to make the electric hybrid vehicles more cost effective and environmentally sustainable. This research indicates that the power reserve of hybrid electric car is enhanced by employing a Cascaded Fuzzy Logic Controller (CFLC). A solar panel system and batteries provide energy. An integrated SEPIC type boost converter is used to enhance the power output of photovoltaic system. The output of the converter is used as input to the network through a single-phase voltage source inverter to convert the DC voltage to AC voltage. LC filter improves the efficiency of the inverter. The suggested system is modelled in MATLAB/Simulink platform.

Key Words: Cascaded Fuzzy Logic Controller (CFLC), SEPIC integrated Boost converter, Voltage Source Inverter (VSI).

1. INTRODUCTION

An increasing number of individuals are concerned about the adverse effects of climate change and global warming, prompting them to advocate for a more efficient energy and transportation infrastructure with a reduced carbon footprint. The predominant source of detrimental carbon emissions released into the atmosphere originates from fossil fuel-based power generating and transportation systems. Thus, to provide an effective solution to climate change, it is crucial to advance photovoltaic-powered electric vehicle technology. Due to their enhanced efficiency and absence of emissions, electric vehicles are more environmentally friendly. To enhance the inadequate output voltage of photovoltaic systems, which exhibit non-linearity and low voltage levels, a DC-DC converter is essential [1-5]. The majority of photovoltaic demands utilise fundamental converters such as boost converters; nonetheless, these have constraints regarding step-down voltage conversion. A buck-boost converter can sequentially lower voltage levels, although its efficiency is affected by the discontinuity of the input current. A SEPIC converter, similar to a buck-boost converter, can

progressively lower voltage levels; however, its efficiency is affected by the discontinuity of the input current. Although SEPIC converters, similar to buck-boost converters, can simultaneously reduce and elevate voltages, the input current fluctuations they generate are considerably more pronounced. As a result, integrated converters are developed to improve the performance and efficacy of fundamental converters. The combined converters provide reduced switching losses and an extensive array of voltage conversion ratios [6-9].

To optimize the converter process, a skilled superintendent is necessary. For linear processes, traditional PI controllers function effectively due to their simplicity. Peak overshoot scenarios may potentially affect them, and they are detrimental to non-linear systems as well. Furthermore, the functioning of the converter is proficiently overseen by the AI-driven Fuzzy Logic Controller (FLC) and Artificial Neural Network (ANN).

Constructing the membership function inside the problem-solving framework of FLC is arduous due to its dependence on fuzzy rules for decision-making. A multitude of interlinked devices known as neurones collaborate to address problems in an artificial neural network, which is modelled after the structure of the human brain. Extended duration is required for processing during the training and modelling of the system. As a result, the regulation of the SEPIC integrated Boost converter employs a Cascaded Fuzzy Logic Controller (FLC) [12-15].

This study presents a Hybrid Electric Vehicle for energy management through a cascaded fuzzy control methodology. In this instance, the integrated SEPIC converter enhances the output of photovoltaic productivity. The functioning of the converter can be monitored by the Cascaded FLC. The management of the photovoltaic system is delegated from the converter to the grid via a single-phase inverter, which is regulated by a PI controller.

2. Proposed System Explanation

The small ecological footprint of electric vehicles and photovoltaic systems is leading to more and more people selecting them. The purpose of this project is to develop

a grid linked photovoltaic (PV) hybrid electric vehicle with energy management functions using a cascaded fuzzy control algorithm. The energy from the photovoltaic system is harvested via a high-voltage-gain integrated SEPIC converter. The converter is controlled by the cascaded FLC. The generated error signal is processed by the cascaded FLC to compare it with the actual power output of the converter. The output of the Cascaded FLC can be also used with a PWM generator to control the functioning of the converter. Image one shows the whole control technique.

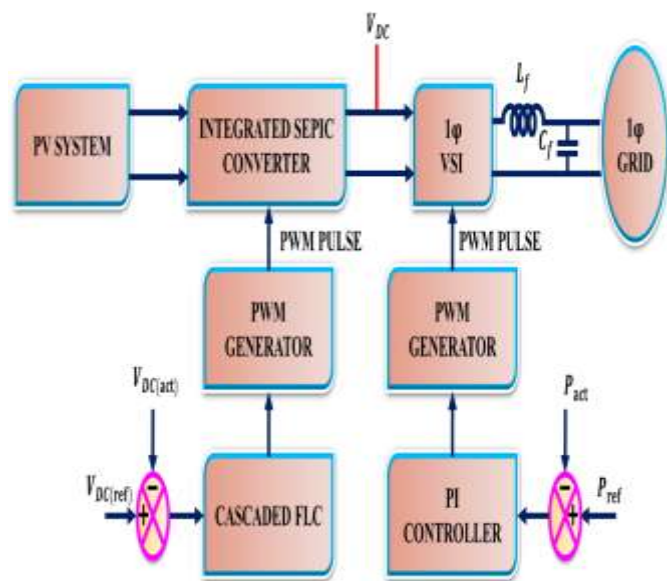


Fig.1. Proposed control model

A. Photovoltaic System Example As shown in Figure 2, a photovoltaic cell, or PV cell, is similar to a large semiconductor diode and operates on the principle of the photovoltaic effect. The equivalent circuit of the PV cell is shown in Fig. 2. The PV output current V_{pa} is given by:

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

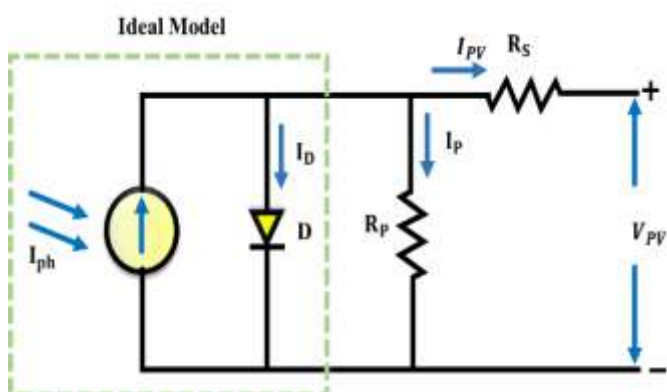


Fig.2. Structure of PV cell

K is the Boltzmann constant, q is the charge of the electron, V_{yd} is the reverse saturation current, n is the ideal factor and T is the temperature. The output of the solar cells is fed to the integrated SEPIC converter.

B: Integrated SEPIC Converter

The connection of a SEPIC converter with a boost converter result in an integrated converter with improved efficiency and high voltage gain and wide voltage conversion range. Figure 3 shows the circuit diagram for the integrated SEPIC converter. The many modes of operation of the converter are shown in figure 4.

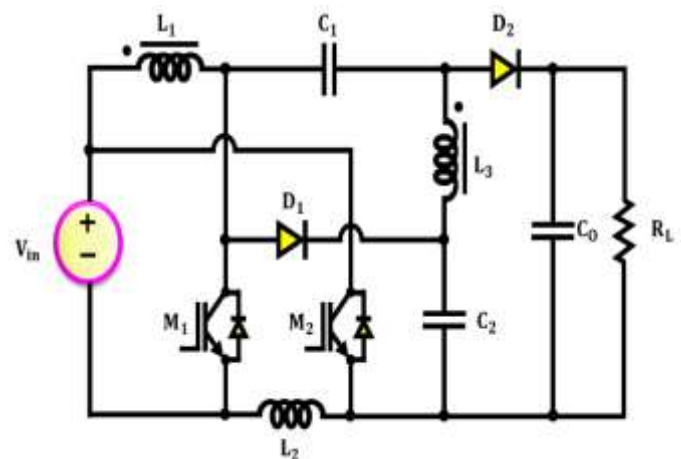


Fig.3. Integrated SEPIC converter

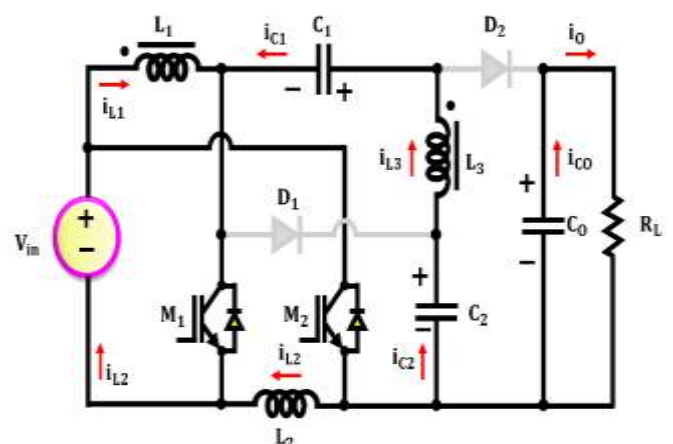
The integrated converter contains binary switches, two diodes, three inductors and three capacitors. The converter can operate in two modes: (0 to s):

In this scenario switches are turned on and diodes are turned off. At this stage, the output capacitor discharges to deliver power to the load while all the inductors are being energised. The supplied values $L1$ and $L2$ are the voltage drops across the inductors.

$$VL1=VL2=V_{in} \quad (2)$$

The voltage $VL3$ is given as,

$$VL3=VC2=VC1+V_{in} \quad (3)$$



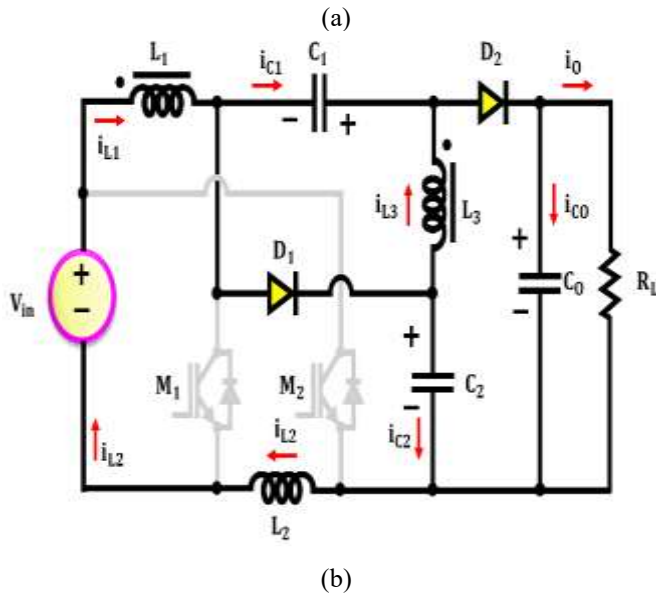


Fig.4.Integrated SEPIC (a) mode 1 and (b) mode

Mode 2 ($DTs < t < Ts$):

In this condition, both switches are deactivated while the diodes are activated. Mode 2 additionally encompasses the discharging of the inductors and the charging of the capacitor. Diodes facilitate the transfer of energy from the inductor to the capacitor and subsequently to the load. The voltages $VL1$ and $VL2$ are presented here:

$$VL1=VL2=(Vin-Vo+Vc1)2 \quad (4)$$

The voltage $VL3$ is given as,

$$VL3=-VC1 \quad (5)$$

In CCM, the voltage gain is given as,

$$M=Vo/Vin=3D+11-D \quad (6)$$

The value of input current is given as,

$$Iin=3D+11-DIo \quad (7)$$

The Integrated SEPIC converter improves the output power of the PV to a desired level and the functioning of the converter is optimized using a Cascaded FLC.

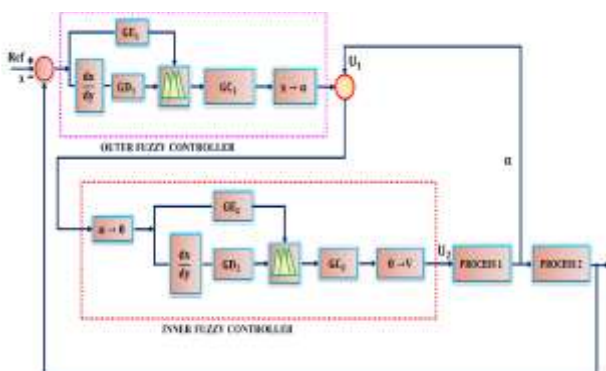


Fig.5.Structure of CFLC

C: Cascade Type Fuzzy Logic Controller

The design and modelling techniques are reviewed and this course provides an insightful overview of the function of CFLC in improving the performance of SEPIC integrated Boost converters. In a cascaded configuration, two separate Fuzzy Logic controllers (FLCs) are integrated, which enhances the dynamic responsiveness and frees the system from computational complexity and undesirable disruptions. One FLC takes the output of the other FLC. Cascaded modelling is a good method for eliminating fluctuations with quick reaction. So, in this study, cascaded modelling was utilised to produce ideal outcomes quickly. Figure 5 shows the schematic of this CFLC, which comprises an outer ring and an inner ring that work together to control the output of the converter. This CFLC provides a formal methodology to implement, describe and manipulate the domain control knowledge which is one of the major components of this technology for efficient system control. This controller is a valuable option in practice since it can formalise control information and has an inherent non-linear feature. For the implementation of the outer loop of the fuzzy controller, the following rules have to be followed:

$$Rk: Ei \text{ is } A1k \text{ and } \Delta Ei \text{ is } A2k \text{ then } Ui=Bk \quad (8)$$

The regulator has current numerical charge Bk , error revolution Ei , output Ui and inner and outer loop errors both Ei . The defined values of the linguistic worth of error and mistake change are $A2k$ and $A1k$. The following figures explain how the effective amount of activation for each control rule is determined as

$$\text{inner loop: } W1k = \min\{\mu A1k(E), \mu A2k(\Delta E)\} \quad (9)$$

$$\text{outer loop: } W2k = \min\{\mu A1k(E), \mu A2k(\Delta E)\} \quad (10)$$

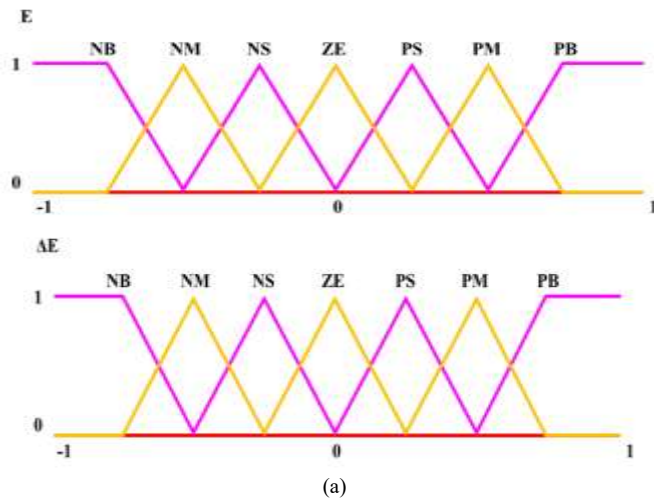
The subsequent equations are involved in determining this control's inferred values in an efficient manner as,

$$U_1^* = \frac{\sum_{k=1}^m W_{1k} B^k}{\sum_{k=1}^m W_{1k}} \quad (11)$$

$$U_2^* = \frac{\sum_{k=1}^m W_{2k} B^k}{\sum_{k=1}^m W_{2k}} \quad (12)$$

In the cumulative operation of the system the membership functions of E and ΔE are expressed as Positive Big, Positive Medium, Positive Small, Zero, Negative Small, Negative Medium and Negative Big. The participation functions of the output variables of the controller are shown in Table 1, which are PB ($m3$), PM ($m2$), PS ($m1$), ZO (0), NS ($-m1$), NM ($-m2$), and NB ($-m3$). Additional parameters, $m3$, $m2$, and $m1$, are also specified. The triangular membership functions of the

input spaces of the fuzzy set are shown quite clearly in Figure 6. The outer loop FLC provides a reference value to the inner loop FLC, which helps in the effective control of the operation of the converter.



ΔE \ E	NB	NM	NS	ZE	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
ZE	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. 7 (a) membership functions of E and ΔE and (b) Rule base of CFLC

The FPGA Spartan 6E controller takes advantage of the improved output of the CFLC to supply the pulses required by the converter to efficiently optimise its output.

D. PI Controllers

The single stage VSI is fed from the constant voltage output of the converter. The DC power source is converted to AC and the electricity is then transmitted to the single-phase grid. VSI is controlled by a PI regulator, in contrast. An example of a PI controller is shown in Fig. 7.

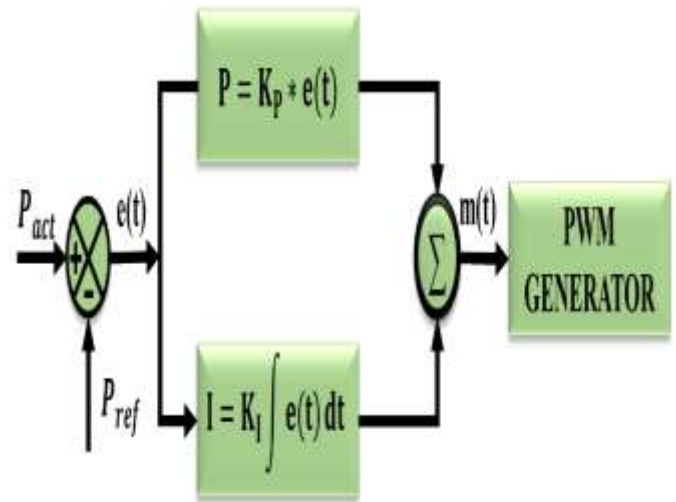
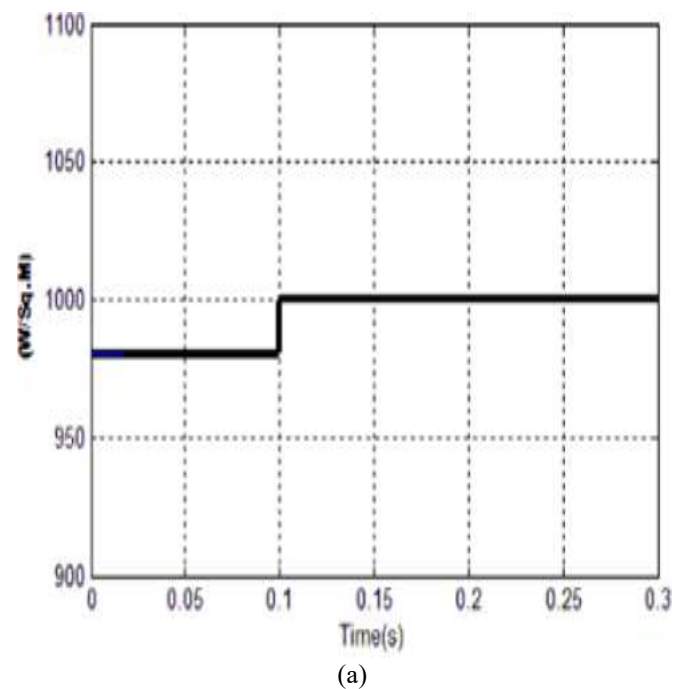


Fig.7.Structure of PI controller

The value P_{act} is analogised with P_{ref} and the attained mistake indication is given to the PI regulator.

3.Simulation Results

The purpose of this project is to design and develop a grid connected photovoltaic (PV) hybrid electric vehicle with cascaded fuzzy control algorithm for energy management. The PV system delivers a high-voltage-gain integrated SEPIC converter. Operation of the converter is regulated by cascaded FLC. The overall control scheme is defined in MATLAB.



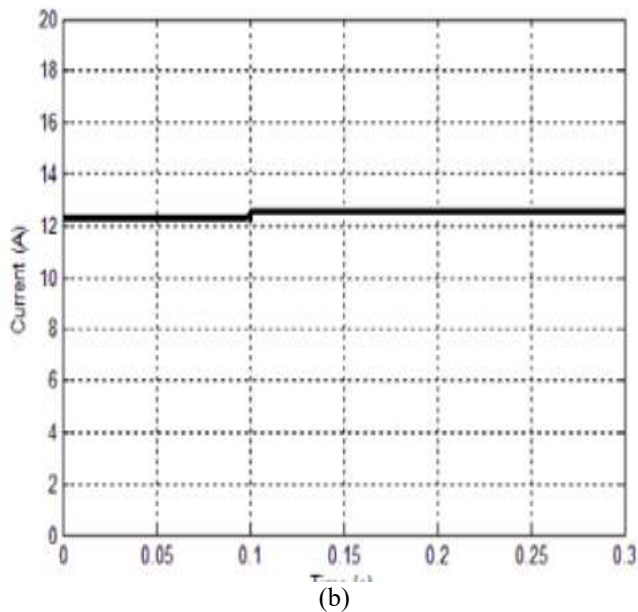


Fig.8. (a) Solar irradiation and (b) Solar panel output current

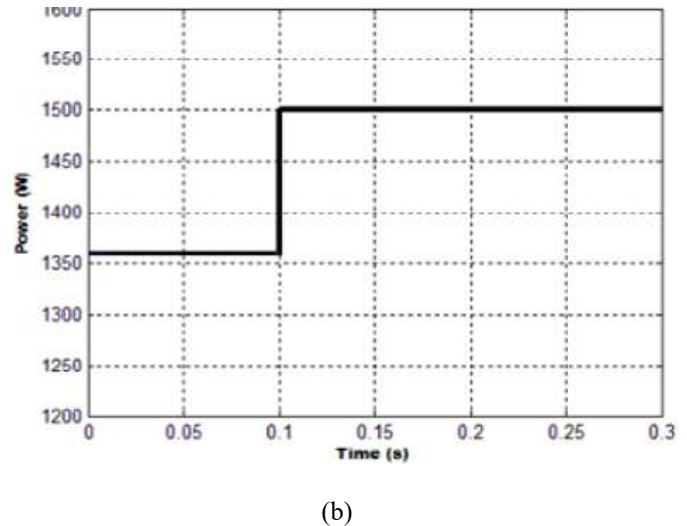


Fig.9.Solar Panel (a) Output Voltage and (b) Output Power

The PV panel output differs with change in operating circumstances like temperature, solar irradiation, etc. From Fig. 8, it is observed that the solar irradiance varies from 980W/m^2 to 1000W/m^2 at 0.1s . The productivity current Similar to PV productivity current, the PV power and PV voltage is also affected by the change in input irradiance at 0.1s as indicated in Fig. 9. The PV output power increases from 120V to 130V at 0.1s , whereas the PV productivity power experiences a rapid increase at 0.1s from 1360W to 1500W at 0.1s .

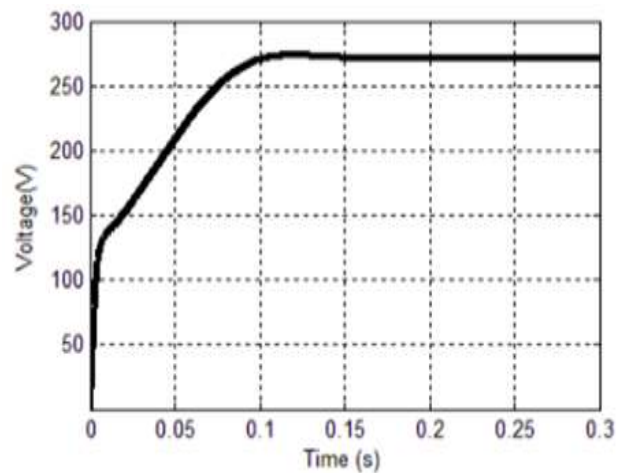
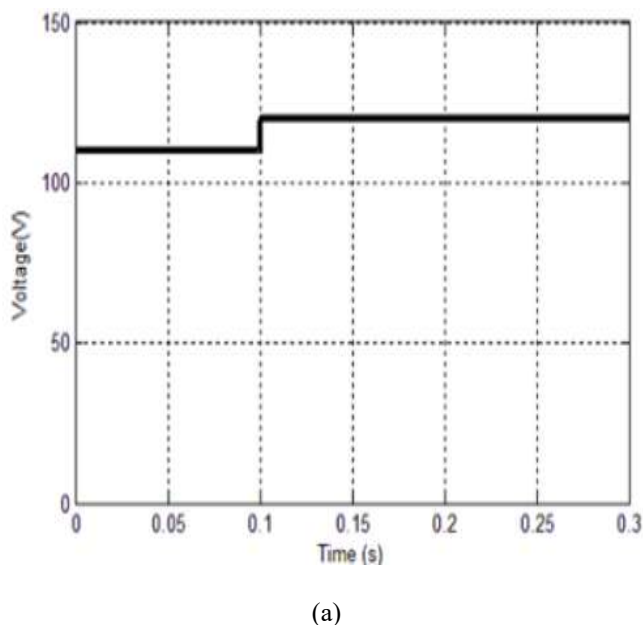


Fig.10.Integrated SEPIC converter output voltage

Figure 10 shows the productivity of the integrated SEPIC. It is clear from the figure that the cascaded FLC implementation has eliminated the problem of peak overshoot in the waveform. Moreover, the output of the converter is not affected by the variation of the sun irradiation. After conversion, a constant voltage of 270V is obtained in 0.15 seconds.



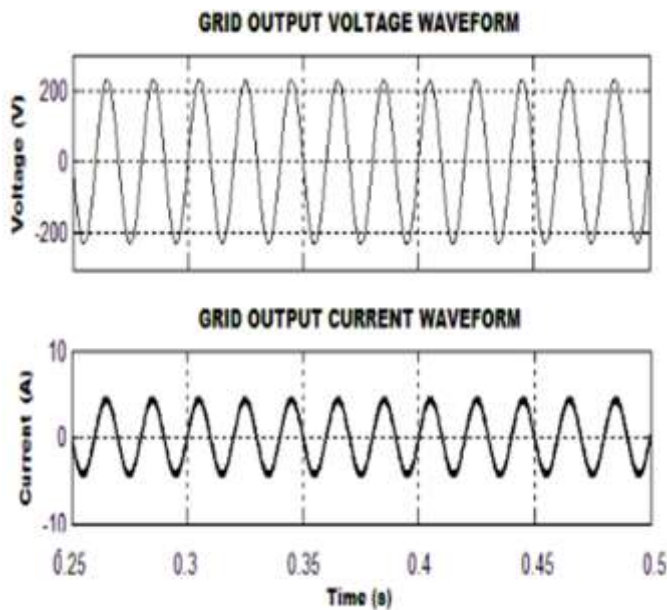


Fig.11.Grid output voltage and current waveform

It is known that the grid supplies a constant current and power with no variations after the wave speeds, which represent the grid current and the network power, have been measured. The current is 5A and the voltage is 230V as shown in figure 11.

4. CONCLUSIONS

This research studies a cascaded fuzzy control approach for power management in hybrid electric vehicles. The intelligent and efficient energy organisation of hybrid electric vehicles poses a threat to the global growth of the gasoline-powered vehicle sector. If we want to regain financial independence and stability with hybrid electric autos, we need to take energy organization seriously. The Integrated SEPIC converter is a combination of the advantageous features of a Boost converter and a SEPIC converter, which enables better voltage conversion, higher voltage gains, and a wider range of voltage conversion, all of which are vital for converting PV productivity into the desired voltage level. Cascaded FLC improves the performance of the converter. Not only the good performance improvement on hybrid electric automobiles, the recommended approach also predicts less value of THD.

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