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CLOSED LOOP CONTROL ANALYSIS OF MODIFIED SEPIC CONVERTER

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Abstract

The objective of this paper is the examination of closed loop control analysis for a five-level bridge inverter coupled Isolated Single Ended Primary Inductance Converter (SEPIC) topology. The proposed SEPIC converter structure is based on conventional SEPIC converter design except the change that instead of the inductor (L_2), a linear transformer will deliver two added isolated voltage levels to the inverter. Low power Fuel Cell based renewable energy system is used as the input source. A battery is kept as a secondary supply/storage to the converter topology to enhance the voltage stability at the source-end. A comprehensive assessment of the proposed model with a Proportional Integral (PI) controller and Fuzzy Logic Controller (FLC) under different source and load variations is also evaluated. PI controller is used to prove the cogency of the proposed FLC controller performance in the above mentioned conditions. Adequate MATLAB/Simulink simulation results are presented for the modified five-level bridge inverter coupled Isolated Single Ended Primary Inductance Converter (SEPIC) topology discussed above.

Keywords: Battery, Fuzzy Logic controller, Modified SEPIC converter, PI controller.

Introduction

Nowadays, we are stepping into an era where replacements of the conventionally running fossil fuels with renewable sources take place rapidly. Thus, many renewable sources like solar, fuel cell, wind and also hybrid systems are blooming in the renewable energy systems.

The Proton Exchange Membrane Fuel Cell (PEMFC) is chosen as the best among the various fuel cell types, because of its unique characteristics and also it is the most commercially available and user friendly standard type[1]. Fuel cells have several advantages than conventional power sources, such as batteries or internal combustion engine systems. Even though some of the fuel cell's attributes are only valid for some applications, it has proven to be superior.

Whenever we step into a DC source, there rises a need for a DC-DC converter. Many types of conventional converters are now available and also research works are going on with modified converter topologies [2]-[3]. The 5 main types of dc-dc converters are buck converters that reduce voltage, boost converters that increase voltage, and buck-boost, cuk and SEPIC converters that increase or decrease voltage. Some major drawbacks of any type of converters like pulsating nature of output, high voltage stresses on switches, dependence to source variation and switching losses. SEPIC converters have relatively less drawbacks compared to the other converter topologies [4]-[7]. Unlike the number of switches used in the conventional multilevel inverter topologies, many topologies are arriving with the count falls in switching devices [9]-[13]. It is relevant that each switch produces a loss in the system during ON and OFF operations. If the number of switching devices decreases, the collective switching losses in the inverter will also be drastically reduced [14]-[15].

FLC has been adapted to a wide variety of engineering applications, offering several merits such as stability even for a large supply and load variations. The behaviour of FLC is compared with the standard PI controller which is non-linear in nature. A PI controller is a widely available closed loop feedback mechanism which is being used in major applications to have a desired and stable output [16]-[17]. Due to its complex dynamic behaviour and nonlinear nature, PI controller is the best alternative to provide required responses.

In this paper, the detailed behaviour of the modified SEPIC converter is analysed with proposed controllers to maintain the stable output. The modified SEPIC converter delivers two added isolated voltage levels to the modified five-level inverter design by the help of isolated transformer. The performance of those controllers is evaluated under different operating conditions such as supply variations, load variations and different steady state conditions. If there is any variation in the source or load, it will be taken care by a closed loop analysis. The feedback voltage was taken from the output of the modified SEPIC converter. Depending upon these voltage variations, the switching pattern will also change. This paper is structured as follows:

The proposed concept and overview of the topology is described in Section 2. The closed loop control of the modified SEPIC converter is analyzed in Section 3 for PI controller and fuzzy logic controller with fuzzy rule set respectively. The simulation results and prototype results are given in Section 4.

1. THE PROPOSED CONCEPT AND TOPOLOGY

The concept adapted for the modified SEPIC converter system is that the converter is capable of synthesizing the better performance of the integrated fuel cell as input source. The block diagram of the proposed system is shown in fig 1.

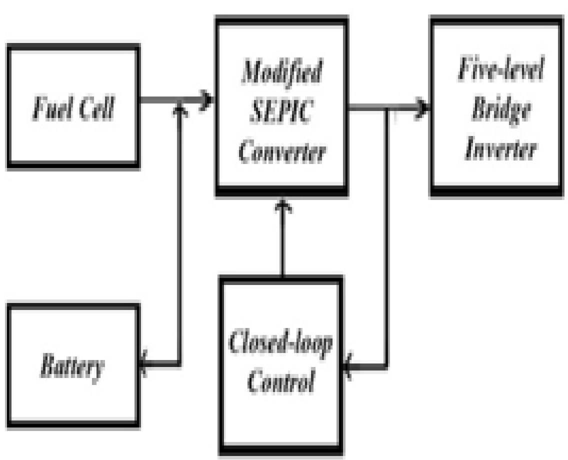


Figure 1: Block diagram of Fuel cell based converter system

The block diagram in Fig 1 clearly shows the chronological flow of the system operation. The fuel cell is the main input source of the system wherein the battery is kept as a secondary source. The battery backup is given to the fuel cell circuit in parallel to supply voltage when the fuel cell voltage level is affected by the source/load variations.

The fuel cell supplies voltage to the modified SEPIC converter which splits it into two voltage sources using an isolation transformer. The main attribute of this methodology is that the input side and output side are electrically isolated. A single voltage source is split into two voltage sources and is used as the input sources for the modified five-level inverter. The proposed modified topology can provide two DC outputs V_1 and V_2 to the inverter with help of a linear transformer secondary as depicted in the Fig 3 across C_1 and C_2.

The modified five-level inverter is a reduced switch topology. Heading towards such kind of topologies is less number of switches reduces the losses subsequently. The fuel cell input voltage is stepped up and fed to the inverter which provides an AC voltage of 230V, 50Hz.The FCBCS has a modified SEPIC topology and modified inverter structure for converting fuel cell DC voltage into five-level AC supply.

Along with this proposed modified converter, a closed loop mechanism FLC and PI controllers are used to validate the steady state and dynamic responses. The comparative study of both controllers gives the clear view about linear and non-linear closed loop control systems and also ensures the stability of the system.

2. CLOSED LOOP CONTROL FOR THE PROPOSED CONVERTER

The main objective of the controller is to improve the steady state accuracy to make the system more stable by reducing steady state errors. Further the maximum overshoot and noise level of the system can be controlled easily. Irrespective of the source and load variations the controller should provide the stable output as expected. Linear controllers do not have that much advantage over the non-linear controllers in many aspects such as robustness, wide signal stability, reactive capability in transient condition, ensuring stability in all working regions and simple implementation.

A. PI Controller

PI controller computes an error value as the difference between the measured process variable and an integral set point. It minimizes the error by adjusting the values of process variables Kp and Ki of the controller. The mathematical equivalent of PI controller is as follows

$$\mathrm{A}(t) = \mathrm{Ki}\int_0^t e(t)dt + \mathrm{Kp}e(t) \ldots (1)$$

where, Kp and Ki are the proportional and integral constants of the PI controller respectively. The integral term in PI controller reduces steady state error to zero. Due to lack of derivative term, this system becomes steady in steady state operation.

B. Fuzzy Logic Controller

Fuzzy controller is an adaptable control technique that provides the ability to operate under load variations, supply variations and other disturbances for the proposed SEPIC converter. This controller affords consistence performance and maintains stability. The main advantages of a system with fuzzy controller are high flexibility, robustness, reliability, implementation flexibility and good dynamic response compared to other nonlinear control methods.

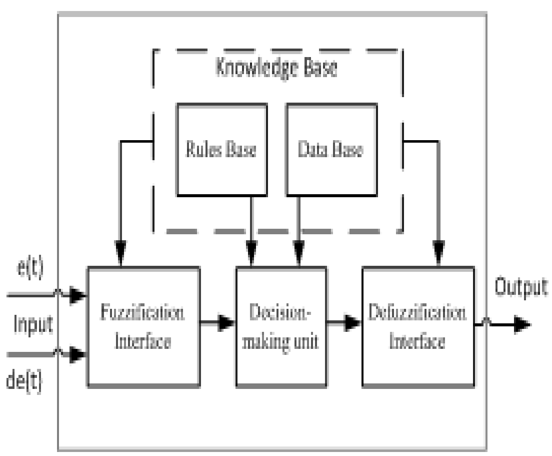


Figure 2: Block diagram of FLC

General block diagram of fuzzy logic controller is shown in figure 2. It consists of fuzzification and defuzzification interface units, decision making unit and knowledge base fuzzy sets that allow partial membership and “if...then...” rules which resemble the way how a human reasonably approaches a real time task. Fuzzy control is needed for systems which are difficult to model due to complexity, nonlinearity and defects. Three steps are necessary to implement the fuzzy theory into a real time application. They are Fuzzification, Fuzzy inference process and Defuzzification as mentioned in the figure.2.

C. Fuzzy Rules

Fuzzy mapping rules and Fuzzy implication control rules are widely utilized for most real time applications. Two fuzzy parameters are used in this paper, they are error, ‘eV_{out}’ and change of error, ‘ΔeV_{out} and for duty cycle of PWM output the single output variable, ‘u’ is used.

The first input is the error in the output voltage (eV_{out})is derived as
$eVout(K) = Vref - Vout(K) \ldots (2)$
The second input is the change in error(ΔeV_{out}) is derived as
$\Delta eVout(K) = eVout(K) - eVout(K-1) \ldots (3)$
Where, $V_{ref}$is the reference output voltage and V_{out}(k) is the measured output voltage in the K_{th} sample.
KeV_{out}, $K\Delta eV_{out}$, Ku are the control gain of the inputseV_{out}, ΔeV_{out} (k) and output u.
The main objective of this control logic is to maintain the output voltage of the modified SEPIC converter in a stable region. The inputs of error and change of error are divided into five groups; NB: Negative Big, NS: Negative Small, Z: Zero Area, PS: Positive small and PB: Positive Big and its parameter. The fuzzy rules are explained in the following table. Rules are derived from the analysis of behaviour of the modified SEPIC converter.

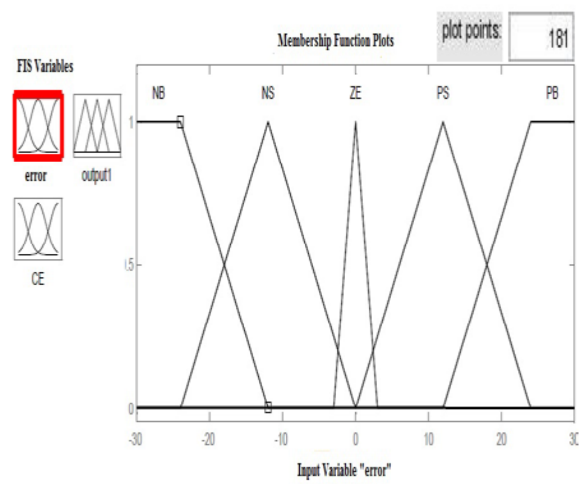
The output of this converter is have some distant from the set point (PositiveBig or Negative Big), the duty cycle should be close to zero or one so as to fetch to the set point as soon as possible. Because the converter output is impending to the set point(Negative Small or Positive Small), a small change of the duty cycle is needed. At the same time, if the output of the converter is approaching very near to the point which is set, duty cycle must be kept constant in order to prevent the overshoot.

To strengthen the fuzzy operational characteristics, those graphical results and model outputs will be compared with PI controller performance. Only the comparative analysis can prove the effectiveness of the best controller performance.

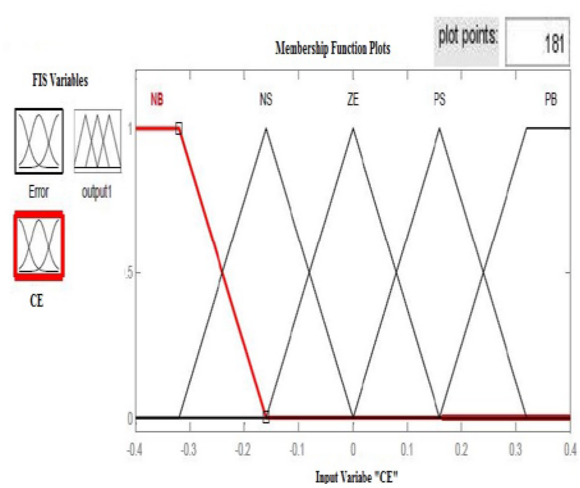
TABLE 1: FUZZY CONTROL RULES

eV_{out} \ $?eV_{out}$	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

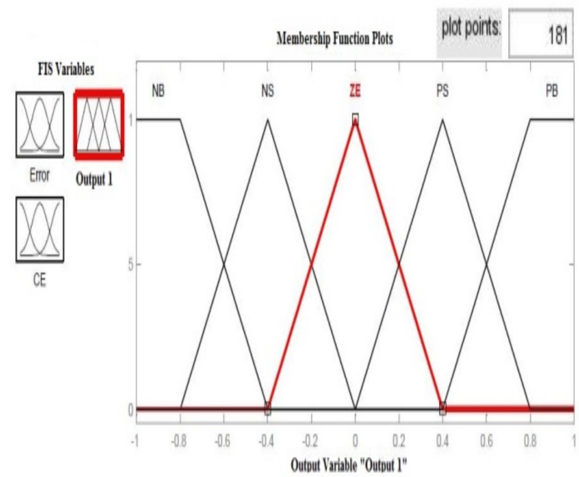
The membership functions for error, change in error and output are depicted in the following figure.



(a)



(b)



(c)

Figure 3 (a-c): The Membership function plots of error, change in error and output 1.

3. SIMULATION AND EXPERIMENTAL RESULTS

The proposed FCBCS with Modified SEPIC converter structure is simulated using MATLAB Simulink and Sim Power Systems toolbox. The simulation results are drafted for the proposed system with closed loop control. The results of PI controller and Fuzzy logic controller for source and load variations are listed.

Kp and Ki values are obtained for the proposed modified SEPIC as 0.1205 and 0.00016 respectively as guided by the Ziegler-Nichols rules. The validation of the proposed FCBCS performance is done for Line variations and Load variations.

A) Line Variations

Fig.4 and Fig.5 shows the dynamic behaviour of the average output voltage of the modified SEPIC converter using a PI controller and a FLC for an increase in input voltage variation from Vin=24V to Vin=30V at 1s. The main point obtained from these results is that the output voltage of the modified SEPIC using FLC has a settling time at 0.8s, whereas the output voltage using PI controller has a severely affected longer settling time of 2.3s respectively.

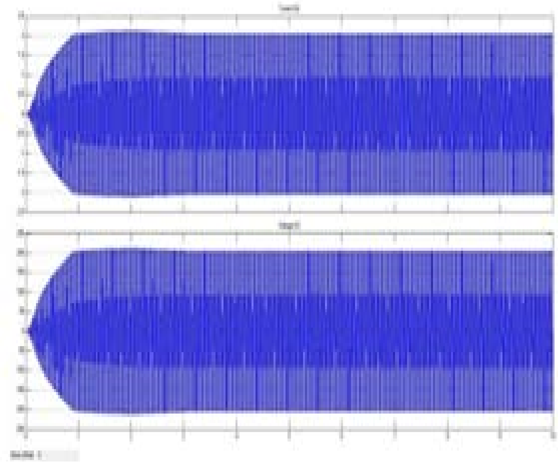


Figure 4: Response of the average output voltage of the Five-level inverter using FLC for the increase in Vin (from 24V-30V at time 1s).

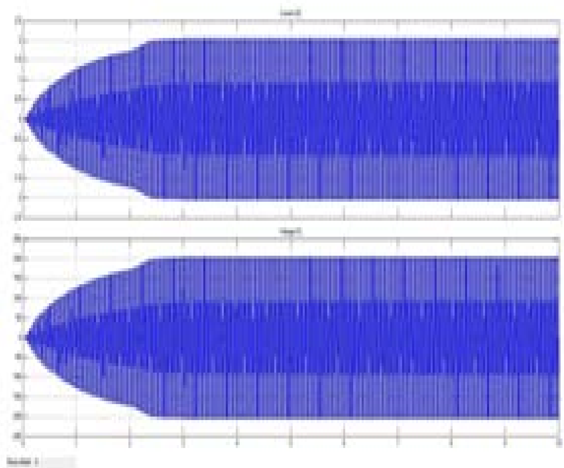


Figure 5: Response of the average output voltage of the Five-level inverter using PI Controller for the increase in Vin (from 24V-30V at time 1s).

Fig.6 and Fig.7 shows the dynamic behaviour of the average output voltage of the modified SEPIC converter using a PI controller and a FLC for a decrease in input voltage variation from Vin=24V to Vin=18V at 1s. The main point obtained from these results is that the output voltage of the modified SEPIC using FLC has a settling time at 1.3s, whereas the output voltage using PI controller has a severely affected longer settling time of 2.3s respectively.

Here at 1s when the input voltage is dropped from 24V to 18V immediately the battery comes into play supporting the input source. Thus the output is stabilized by enhancing the support to the input source.

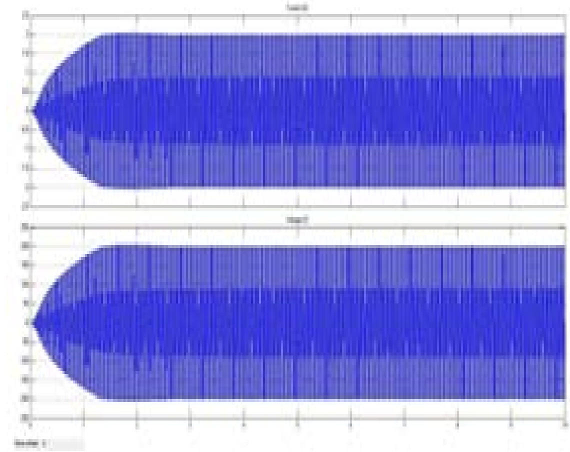


Figure 6: Response of the average output voltage of the Five-level inverter using FLC for the decrease in Vin (from 24V-18V at time 1s).

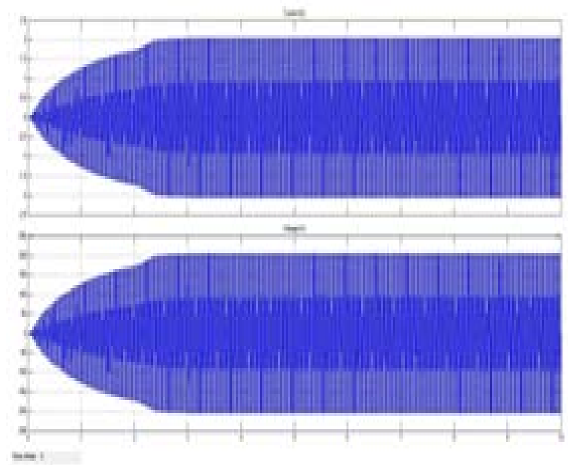


Figure 7: Response of the average output voltage of the Five-level inverter using PI Controller for the decrease in Vin (from 24V-18V at time 1s).

B) Load Variations

Fig.8 and Fig.9 shows the dynamic behaviour of the average output voltage of the modified SEPIC converter using a PI controller and a FLC for an increase in output load variation in terms of current from I_0= 2A to I_0=3Aof output AC voltage waveform at 1s. The observation validated from these results is that the output voltage of the modified SEPIC using FLC has a settling time at 0.8s, whereas the output voltage using PI controller has a severely affected longer settling time of 2.3s respectively.

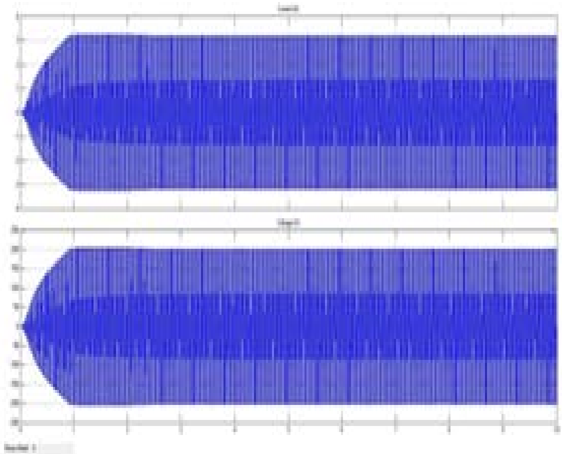


Figure 8: Response of the average output voltage of the Five-level inverter using FLC for the increase in I_0 (from 2A-3A AC at time 1s).

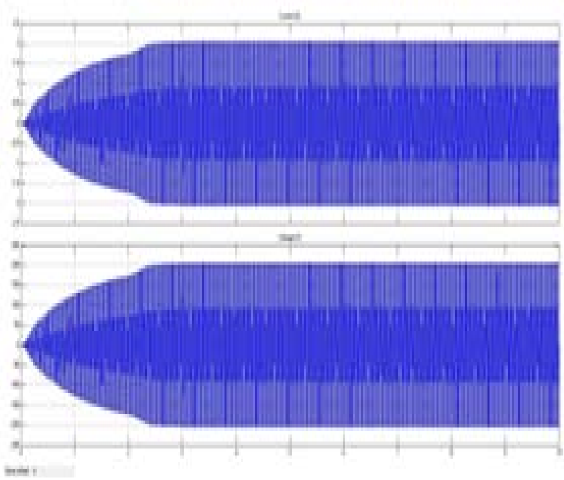


Figure 9: Response of the average output voltage of the Five-level inverter using PI controller for the increase in I_0 (from 2A-3A AC at time 1s).

Fig.10 and Fig.11 shows the dynamic behaviour of the average output voltage of the modified SEPIC converter using a PI controller and a FLC for a decrease in output load variation from I_0= 2A to I_0=1Aof output AC voltage waveform at 1s. The observation validated from these results is that the output voltage of the modified SEPIC using FLC has a maximum overshoot of 18V and a settling time of 0.05s, whereas the output voltage using PI controller has a severely affected longer settling time and overshoot of 0.07s and 22V respectively.

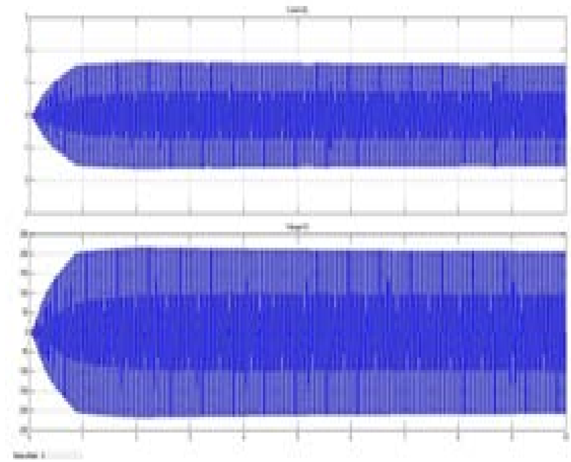


Figure 10: Response of the average output voltage of the Five-level inverter using FLC for the increase in I_0 (from 2A-1A AC at time 1s).

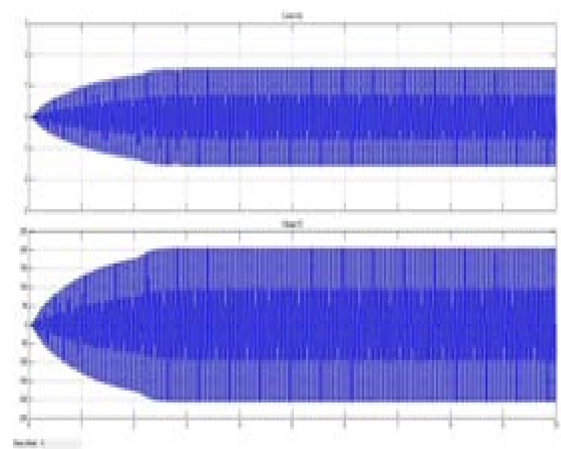


Figure 11: Response of the average output voltage of the Five-level inverter using PI controller for the increase in I_0 (from 2A-1A AC at time 1s).

TABLE 2: SIMULATED RESULTS OF THE OUTPUT VOLTAGE AND CURRENT FOR VARIOUS SOURCE/LOAD VARIATIONS

Controller	Settling time	Vin	Vo	Io
Fuzzy	0.8	24-30	200	2.1
	1.3	24-18	200	2.1

Controller	Settling time	Vin	Vo	Io
PI	2.2	24-30	200	2.1
	2.4	24-18	200	2.1

Controller	Settling time	Vin	Vo	Io
Fuzzy	0.9	24	200	3.2
	0.8	24	200	1.5

Controller	Settling time	Vin	Vo	Io
PI	2.3	24	200	3.2
	2.4	24	200	1.5

From the results listed in Table II, it is clear that the fuzzy logic controller performance is better compared to the PI controller. The steady state settling time of the FLC is less than that of the PI controller. It also shows that when the source variation is occurs whether the voltage goes up or down the output remains constant. Whenever the voltage sets down 24V the secondary battery comes into play enhancing the voltage profile thus there is no variations shown in the waveforms.

V. CONCLUSION

The closed loop control analysis for modified SEPIC converter coupled FCBCS with battery backup is successfully studied. FLC and PI controller operation under various supply variations and load variations was verified. Both FLC and PI controller results have only slight differences in peak overshoot and settling time. FLC has advantages over PI controller in terms of wide variations of line and load variations. With this design, features such as stability, parameter variations and change in controller parameter values can be deeply analysed. During line and load variations, the controller aims to make the AC output voltage waveform be in a stable region, for providing smooth output voltage waveform to the various residential loads which are connected to this FCBCS. Thus the proposed converter is suitable for residential applications for providing uninterrupted power supply to the connected loads with low cost and high efficiency.

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