*Research Article*

# Performance Evaluation of Symmetrical Current Source Multilevel Inverter

**Mr. A. Clement Raj[1], Dr.T.S.Sivakumaran[2], Mr. Reta Dengesu Haro[3],Mr. Abdi Abayneh Umer[4]**

[1]Lecturer, Dept. of Electrical and Computer Engineering, Bule Hora University, Ethiopia.
[2]Professor, power engineering, Dept. of Electrical and Computer Engineering, Bule Hora University, Ethiopia.
[3, 4]Lecturer, Dept. of Electrical and Computer Engineering, Bule Hora University, Ethiopia.
clementlecturer@gmail.com, Sivakumaran1969@gmail.com,retadengesu@gmail.com,umerabdi2018@gmail.com

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**Abstract:** In this paper proposes a Current Source Multilevel Inverter (CSMLI) with a single rating inductor topology. The multilevel inverters are generally acquainted with power converter's applications because of decreased dv/dt, di/dt stress, and extremely efficient for minimising harmonic distortion in the both output voltage and current. The proposed nine-level current source inverter has analyses under symmetrical operation, and their operation are compared using PI and Fuzzy PI controllers with multicarrier PWM topology. PV utilized as a DC source, photovoltaic energy is an environmentally friendly energy with high potential, simple construction, maintenance, dependability and long life. MATLAB/Simulink simulation has been made for the proposed converter to get its exhibition measures. Some test results are given to confirm the presented Current Source Multilevel Inverter.

**Keywords:** Current Source Inverter, Multilevel inverter, Multicarrier PWM, Total Harmonic Distortion, Fuzzy PI Controller, PV array.

## 1. Introduction

Multilevel inverters can offer substantial benefits for higher power applications, including reduced harmonics, and increased power ratings because of reduced switching device voltage and current stresses. Multilevel inverters have been shown more consideration [1], [2], [3]. Multilevel inverters comprise of power semiconductors and DC voltage sources, the output of which create voltages with stepped waveforms. The Multilevel inverter configuration can be categorized into the Voltage Source Multilevel Inverter (VSMLI) and Current Source Multilevel Inverter (CSMLI) [4], [5], [6]. Multilevel VSI has DC voltage power source and produces an AC output to the load. Whereas Multilevel Current Source Inverter delivers predetermined AC output from a single or more DC sources due to its high impedance DC power supply. The MCSI has the features of short circuit protection, lower voltage and current stress, and less THD in the output waveforms [7], [8], [9], [10]. The introduction of current source inverters (CSIs) into this field could lead to marketing advantages due to the advantageous characteristics of this currently less used converter topology. These advantages including: (i) a simple structure; (ii) short-circuit protection; (iii) bidirectional operation; (iv) nearly sinusoidal inputs and outputs; (v) the absence of electrolytic capacitors; and (vi) the possibility to connect in series GTO or GCT, make the use of CSI in high-power medium-voltage drives highly desirable [11].

Current Source Inverters with pulse width modulation strategies are employed to deliver a minimum distorted input and output waveforms. This inverter circuit is the double cascaded H-bridge multilevel Current Source Inverter. Tragically, the need for isolated DC sources, power devices, and their gating circuits are a few issues of this inverter circuit. Reference [12] introduced the multilevel CSI topology utilizing H-bridge and inductor-cell. This topology streamlines the necessity of isolated DC sources in the parallel H-bridge multilevel CSI. An alternate circuit design of multilevel CSI is made by using a multicell arrangement of multilevel CSI [13], [14], [15], which is the double flying capacitor multilevel VSI. Various control, strategies have been exhibited to control the voltage at intermediate levels and highlighted in [16], [17], [18]. However, the inverter still requires expensive larger size middle inductors (>100 mH). These inductors will result in more losses in the inverter circuits and the inverter circuits will have lower efficiency.

This paper presents a nine-level single phase single inductor current source inverter using multicarrier PWM strategy controlled with PI and Fuzzy PI Controller. The Fuzzy PI control algorithm that combines the fuzzy logic control results in suitable nonlinear characteristics as well as efficiently reduces the error in power extraction [19].

## 2. Current Source Multilevel Inverter (CSMLI)

A current source inverter converts the input DC to an AC at its output terminals. In these inverters, the input voltage is kept constant, and the amplitude of output voltage does not depend on the load. Nevertheless, the wave form of load current, as well as its magnitude, depends on the nature of the load impedance. In this inverter, the input current is constant, but adjustable. The amplitude of output current from CSI independent of the load. A DC source supplies current Source Inverter. In an adjustable speed drive (ASD), DC source is usually an AC/DC rectifier with a large inductor to provide stable current supply. Usually, a CSI has a boost operation function, its output voltage peak value can be higher than the DC-link voltage [20], [21].

A photovoltaic array used as DC source in the proposed Current Source Multilevel Inverter. The PV Array block implements an array of photovoltaic (PV) modules. The array is built of strings of modules connected in parallel, each string consisting of modules connected in series. The PV Array block is a five parameter model using a current source IL (light-generated current), diode, series resistance $R_s$, and shunt resistance $R_{sh}$ to represent the irradiance and temperature dependent I-V characteristics of the modules shown in Figs.1 and 2. The modelling of PV array is shown in Fig.3.

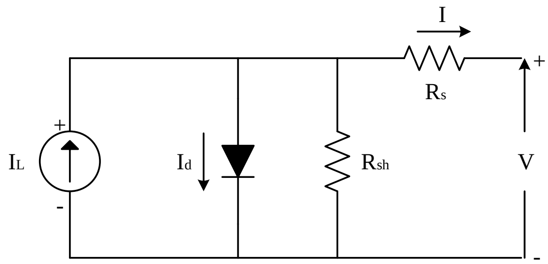



Fig. 1. Equivalent circuit of PV array

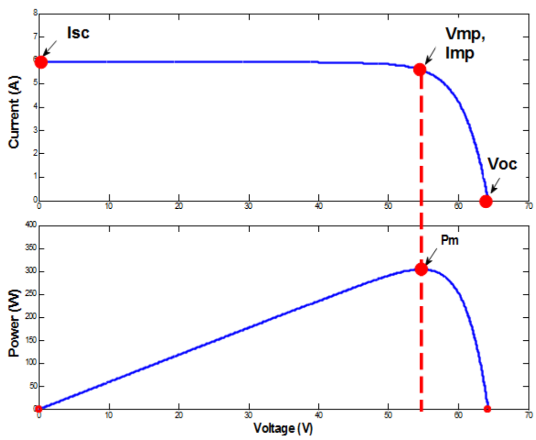
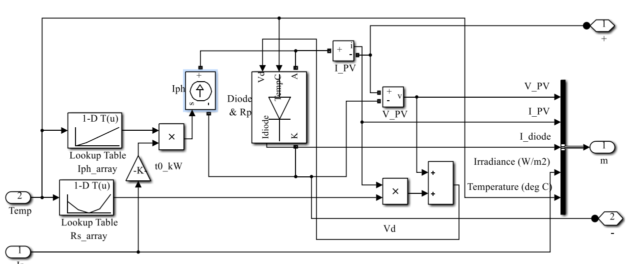
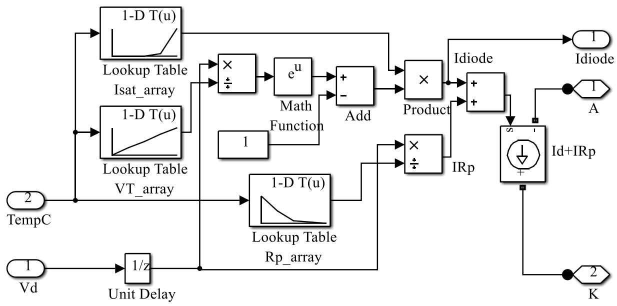



Fig. 2. V-I characteristics of PV




(a)




(b)

Fig. 3. PV array model

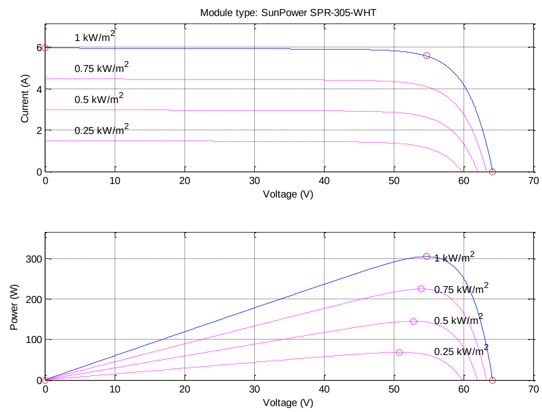



Fig. 4. V-I and P-V characteristics of PV array at 25ºC

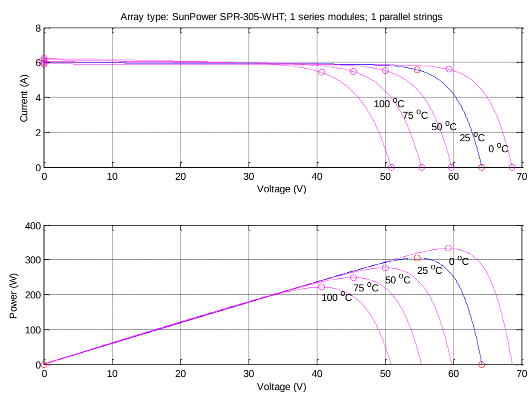



Fig. 5. V-I and P-V characteristics of PV array at 1000W/m$^2$

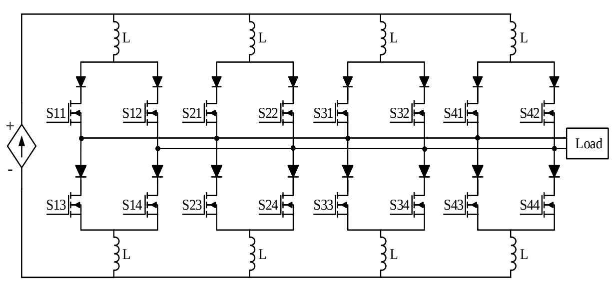



Fig. 6. Proposed nine level single rating inductor type symmetrical current source inverter.

## 3. Nine-Level Single Rating Inductor Type Symmetrical Current Source Inverter

Fig.6 shows the power circuit of the proposed nine level single rating inductor type symmetrical current source inverter. From this figure.3, it is observed that the circuit model is obtained by connecting four H-bridge unidirectional controlled power devices, and a DC source with equal inductors L. The DC module is working with different intermediate levels for nine-level output waveform generation. All DC sources connected at the common point, due to this the isolated DC sources are no longer necessary in the circuit. The switching sequences for nine level single rating inductor type symmetrical current source inverter shown in Fig.7 and

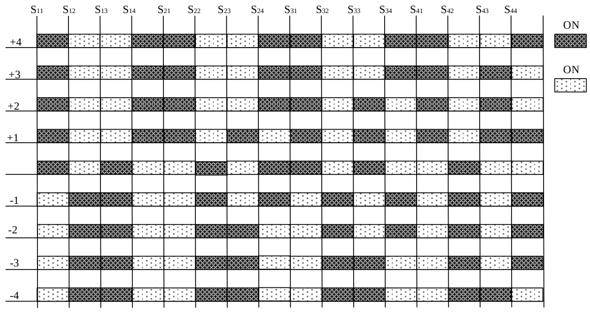



Fig.7. Switching sequence of nine level symmetrical current source inverter

For the designed PI controller suited for the multilevel CSI, error signal is as follows,

$$e(t) = I_d(t) - I_{act}(t) \qquad (1)$$

Where Id is the desired current or set point of the proposed current source inverter in amps, and $I_{act}$ is the actual current drawn by the proposed inverter.

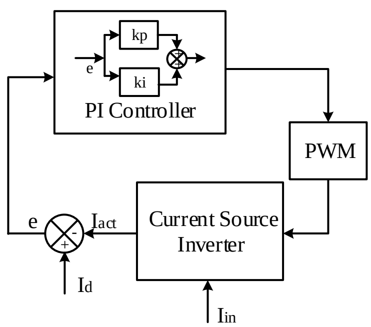



Fig.8. Nine level symmetrical current source inverter implemented with PI controller tuned PWM

## 4. Control Strategy

### *4.1 PI Controller*

A Proportional-Integral (PI) control is a particular case of the classic controller family known as Proportional – Integral-Derivative (PID). Till date, these controllers are the most common way of controlling industrial processes in a feedback configuration. More than 95% of all installed controllers are PID [22], [23]. Fig.8 shows the structure of proposed CSI using PI controller. The proportional part handles following the desired set-point while the integral part accounts for the accumulation of past errors. In spite of the simplicity, they can be used to solve even a very complex control problem, especially when combined with different functional blocks such as filters, selectors, etc.

### 4.2 *Fuzzy based Proportional Integral controller (Fuzzy PI)*

The designed Fuzzy Proportional Integral (Fuzzy-PI) controller is a hybrid controller that utilizes two sets of PI gains to achieve a suitable non-linear response. The switching of the controller accomplished with a fuzzy logic section that depends on the input $I_{in}(t)$. The PI gains utilize e(t) as input that highlighted in equation (1). Fig.9 shows a diagram of the proposed FuzzyPI controller. Fig.10 shows the Fuzzy Proportional and Integral gain response over error and change in error and the fuzzy rule table for proposed converter presented in Table.1.

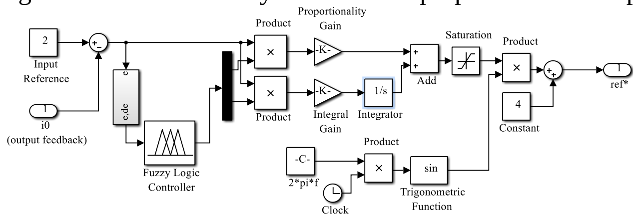



Fig.9 Fuzzy based PI controller for proposed current source Inverter

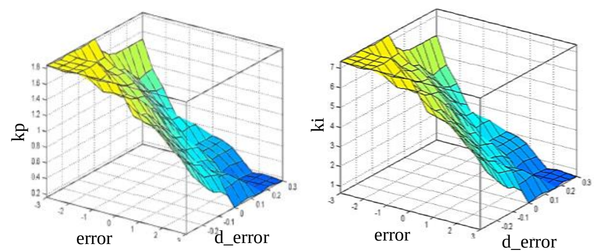



Fig.10. Fuzzy Proportionality and integral gain response over error and change in error

TABLE 1

FUZZY RULE TABLE FOR PROPOSED CONVERTER

| **e/Δe** | **NB** | **NS** | **Z** | **PS** | **PB** |
|---|---|---|---|---|---|
| **NB** | PB | PB | NS | PS | Z |
| **NS** | PB | NS | PS | Z | NS |
| **Z** | NS | PS | Z | NS | PS |
| **PS** | PS | Z | NS | PS | NB |
| **PB** | Z | NS | PS | NB | NB |

*4.3 Pulse Width Modulation (PWM)*

In the proposed CSI topology, a level based multicarrier PWM strategy implemented for firing the gate terminals of the MOSFET to obtain the current waveform of nine-level CSI. Multicarrier PWM strategy is a comparison of a reference waveform, with vertically shifted carrier signals. In multicarrier PWM technique, m-1 triangular carriers are used for m-level inverter output voltage or current. In this proposed nine-level topology, eight triangular carriers are preferred. In Phase Opposition Disposition (POD), the carriers above the sinusoidal reference zero points are 180 out of phase with those below the zero point. Fig.11 shows the gate pulse generation of proposed CSI with POD strategy with sine reference of modulation index ma = 0.9 and the carrier frequency of 2 kHz.

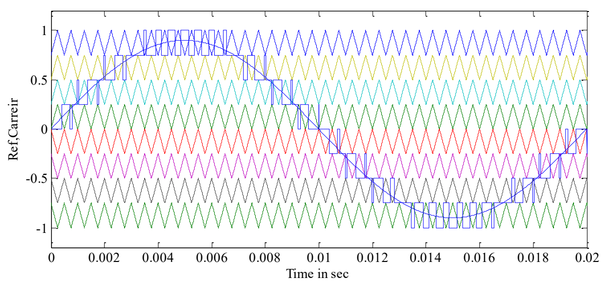



Fig.11. Gate pulse generation of proposed nine-level CSI

The carrier waveforms have same amplitude $A_c$ and frequency $f_c$. Similarly, the reference waveforms have frequency $f_{ref}$ and amplitude $A_{ref}$. At every instant, the response of the comparator is decoded to generate the correct switching sequences with respect to the output of the inverter. The frequency modulation index (mf) and amplitude modulation index (ma) calculated in equation (2) and (3) [24], [25]. In the level shifted multicarrier PWM, Phase Opposite Disposition (POD) strategy is used.

$$m_f = \frac{f_c}{f_{ref}} \qquad (2)$$

$$m_a = \frac{A_{ref}}{(m-1)A_c} \qquad (3)$$

## 5. Simulation Results

### *5.1 Simulation of nine level single rating inductor type symmetrical CSI*

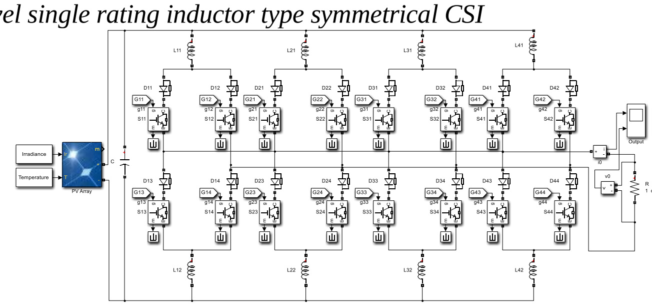


Fig.12 Simulink model of nine level single rating inductor type symmetrical current source inverter

Fig.12 shows the Simulink representation of nine level single rating inductor type symmetrical current source inverter, this power circuit consists of sixteen IGBT switches and eight identical inductors with rating of 100mH with a common current source generated from PV array. The current source shared by the four H-bridge inverter with suitable switching sequences generate the nine level output. Multi-carrier pulse width modulation is tuned with proposed PI and Fuzzy PI Controller.

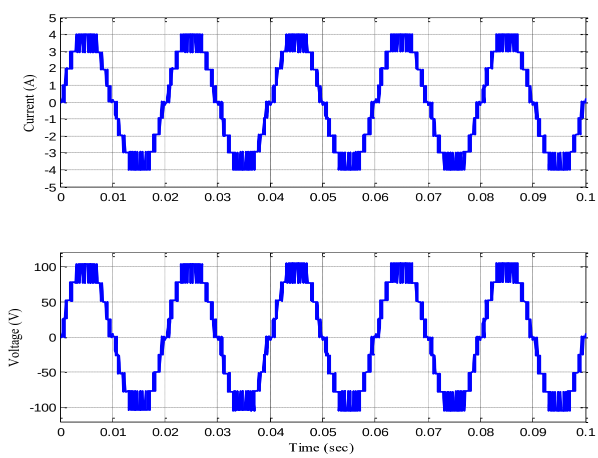



Fig.13. Open Loop Current and Voltage response of symmetrical CSI

Figs.13-19 shows the overall simulated responses of the nine level single rating inductor symmetrical current source inverter with PI and fuzzy PI controllers and their output responses obtained. Fig.8 shows the open loop current and voltage responses of symmetrical CSI. Fig.13 shows nine level current and voltage waveforms with significant current sharing. Fig.14 shows the current harmonic response of symmetrical nine-level CSI, which shows the total current harmonic distortion to be 14.31%.

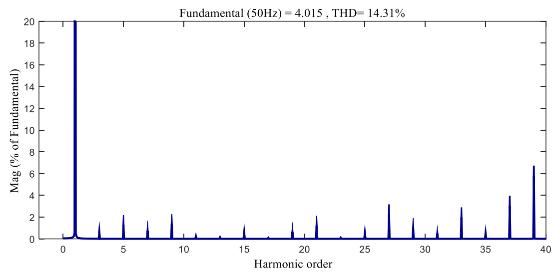



Fig.14. Current harmonic response of symmetrical CSI

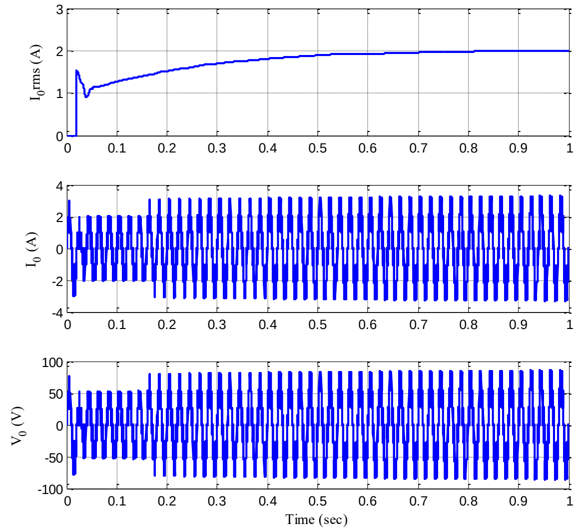



Fig.15. Closed loop PI controller I0rms, output current and voltage response of symmetrical CSI (set value of $I_{rms}$=2A)

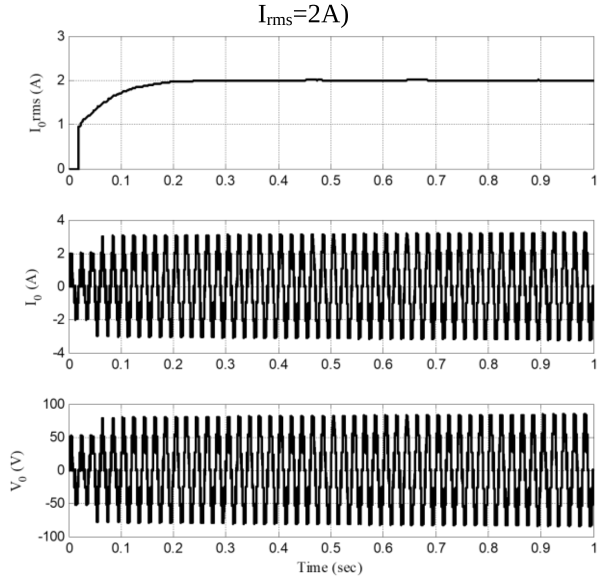



Fig.16. Closed loop Fuzzy PI Controller I0rms, output current and voltage response of symmetrical CSI (set value of $I_{rms}$=2A)

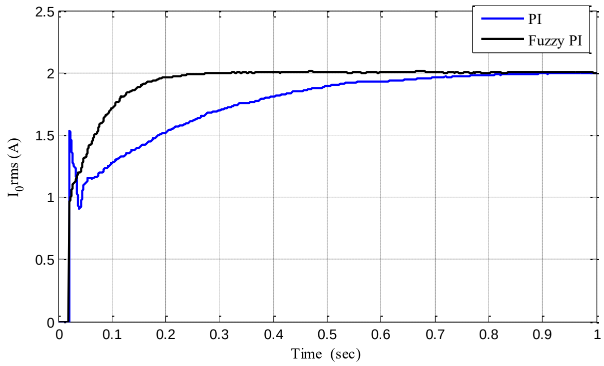



Fig.17. Current responses comparison of PI and Fuzzy Controller of symmetrical CSI

Figs.15 and 16 show the individual responses of symmetrical nine-level current source inverter output current, voltage and $I_{rms}$ tuned with PI controller and fuzzy PI controller respectively with a set value of $I_{rms}$ as 2A. Figs.17 shows the output current responses of PI and fuzzy PI controllers. From this figure, it is observed that the fuzzy PI controller response has been converged very fast compared with conventional PI controller, without any overshoot. Figs.18 shows the current responses comparison of PI and Fuzzy Controller of symmetrical CSI for a step change in load current. From figure 18, it is observed that when the load current is suddenly incremented from 2A to 3A at t=1s and decremented from 3A to 2A with respect to time, t=2s. During this instant regulatory responses were obtained and it observed that the fuzzy PI controller response has been settled very fast with its reference current without any oscillation compared with PI controller. Similarly, the Fig.19 shows the current responses comparison of PI and Fuzzy Controller of symmetrical CSI for the same change in input. From the figure 19, it is noted that the input current has been suddenly increased from 4A to 5A at t=1s and back to 4A at t=2s. During this servo response, the fuzzy PI controller response has been converged quickly compared with PI controller, which has shown in Table.3.

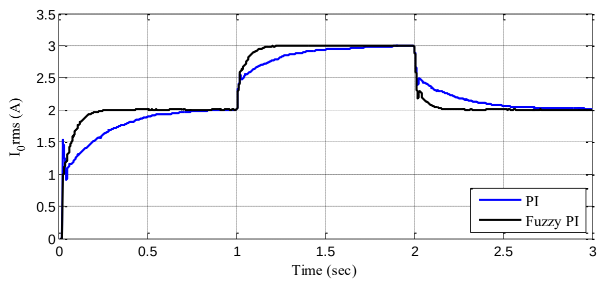



Fig.18. Current responses comparison of PI and Fuzzy Controller of symmetrical CSI for change in Load resistance (t=0s $I_{orms}$ = 2A; t=1-2s; $I_{orms}$ = 3A; t=2s; $I_{orms}$ = 2A)

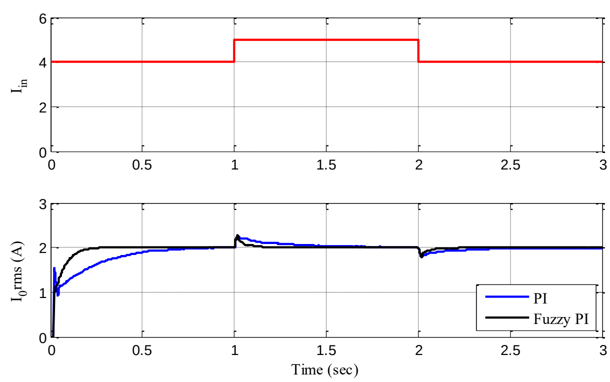



Fig.19. Current responses comparison of PI and Fuzzy Controller of symmetrical CSI for change in input current (t=0s $I_{in}$ = 4A; t=1-2s; $I_{in}$ = 5A; t=2s; $I_{in}$ = 4A)

Table 2Performance Evaluation of Symmetrical CSI with Resistive Load using MATLAB

| **Controller** | **Nominal Case** | | **Servo Response** | | | |
|---|---|---|---|---|---|---|
| | **Rise Time (sec)** | **Settling Time (sec)** | **Supply Increase 33%** | | **Supply Decrease 33%** | |
| | | | **Rise Time (sec)** | **Settling Time (sec)** | **Rise Time (sec)** | **Settling Time (sec)** |
| PI | 0.3027 | 0.7258 | 0.352 | 0.614 | 0.416 | 0.690 |
| Fuzzy PI | 0.1281 | 0.2306 | 0.181 | 0.119 | 0.093 | 0.212 |

## 6. CONCLUSION

In this work, a significant assessment of Current Source Staggered Inverter (CSMLI) has been introduced. It draws a lower ripple content current from the PV cells, in this manner maximizing its presentation. The inverter is worked with state-of-the-art power devices that have quick switching times. The general performance analysis of proposed symmetrical nine level single stagE inductor current source inverter tabulated in Table. 2. it is observed that the even CSI circuit gave a better %THD and steady state investigation controlled by PI and fluffy PI controllers at various working conditions. The switching and conduction lower losses because of the presence of less parts in the influence circuit of symmetrical CSI.

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