Simulation of Single Phase SPWM Full Bridge Inverter Using Different Control Techniques

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Abstract— this paper presents two control algorithms using two different feedback controls for a SPWM single phase inverter to obtain pure 50 Hz output sinusoidal voltage, the plan is to employ each controller with its particular features for controlling the SPWM single phase inverter. The first technique is done with a traditional Proportional-Integral (PI) controller and the second technique is done with the Fuzzy Logic Control (FLC), the efficiency of the offered scheme is tested under various operating conditions. The offered scheme has shown good performance regarding output voltage distortion, very good voltage chasing even under load inconstancy. This system is used with grid-solar energy systems; induction heating and uninterruptible power supplies (UPS).

***Keyword-* :** Membership functions M.F, Fuzzy Logic Controller (FLC), Sinusoidal Pulse Width Modulation (SPWM), inverters, Total Harmonic Distortion (THD).

محاكاة عاكس القنطرة المتكاملة ذي الطور الواحد باستخدام تقنيات تحكم مختلفة

احكام كامل ناجي

قسم هندسة تقنيات القدرة الكهربائية –الكلية التقنية الهندسية الكهربائية

الجامعة التقنية الوسطى

الخلاصة:

في هذا البحث تم استخدام تقنيتين للتحكم بعرض النبضه الجيبيه للعاكس ذو الطور الواحد للحصول على فولتية خرج ذات موجه جيبيه بتردد 50 هيرتز, التقنيه الأولى هي عباره عن تقنيه تقليديه حيث تم أستخدام طريقة تحكم (PI) و أما في التقنيه الثانيه فقد تم أستخدام نظام التحكم المضبب (FLC) , حيث تم أستخدام كل تقنيه على حده للتحكم بنفس دائرة العاكس ومراقبة سلوك الدائره والموجات الخارجه منها من ناحية التشوهات في موجة الفولتيه الخارجه وأستجابة الدائره للتغير المفاجئ للحمل وتعقب المنظومة لأشارة المرجع وبالتالي معرفة أذا كانت المنظومه تستجيب الى الأوامر التي يتم أدخالها لتعقب أشارات المرجع. تستخدم دائرة العاكس في العديد من التطبيقات مثل تطبيقات الطاقه المتجدده, مزود الطاقه اللامنقطعة (UPS) و, التسخين بالتيارات الحثيه.

I. Introduction

Inverters converts DC power to AC power by switching the input DC voltage in a pre-determined succession to produce AC output voltage. There are wide range of power inverters are available, though power handling capability is still a constraint for many applications [1].A voltage source inverter (VSI) is a device which has fixed dc voltage supply. VSI inverters are easy to control than that of current source inverter [2].VSI are mostly used in, uninterruptible power supplies (UPSs), adjustable speed drives (ASDs), static VAR compensators, voltage compensators, flexible ac transmission systems (FACTSs) and other industrial applications [3]. For economic and good performance purposes, VSI's are predominantly preferred over current source inverter (CSI).The transistors used in the bridge circuit of the inverter such as IGBTs, MOSFETs etc should have freewheeling diode built in as a part of entire integrated device convenient for voltage source inverter. For sinusoidal AC voltage, the phase, magnitude and frequency should be controllable. VSIs are at the heart of applications that demands to produce AC output voltage from a DC source voltage. So, it is important that VSI design should be efficient and robust, as inverter failure may cause damage in many production processes [4].

II. PI Controller

Proportional integral (PI) controllers have been exceedingly applied in industrial applications because of their ease of design, simplicity, efficiency, and low cost. There is a several of various method to apply a PI controller. Since various control systems that depend on the PI controller as the closed loop strategy, it has shown a good performance so the PI controllers are still used in industrial applications.

The mathematical equation of PI controller is:

$$u(t) = K_p\, e(t) + K_i \int_0^t e(\tau)d\tau \ldots\ldots (1)$$

Where the error signal is symbolized by e (e = r - y), and the proportional and integral signals are symbolized by *Kp* and *Ki* respectively, control signal is symbolized by u, the reference signal (the set point) is symbolized by r, So considering the summation of the two parts, the proportional part and the integral part, where the proportional part is only proportionate with error signal and the integral part which is proportionate with integral of the error signal, the proportional part *Kp* will drive any variation in the output signal that proportionate to the present error, The integral part K_i proportionates with both the magnitude of the error signal and the interval of the error signal. If added with the first part (proportional part), then it will accelerate the motion of the process across the set point and particularly minimizes or remove the residual of steady-state error that may appear with the proportional controller only [5]. Figure 1 shows the block diagram of PI controller.

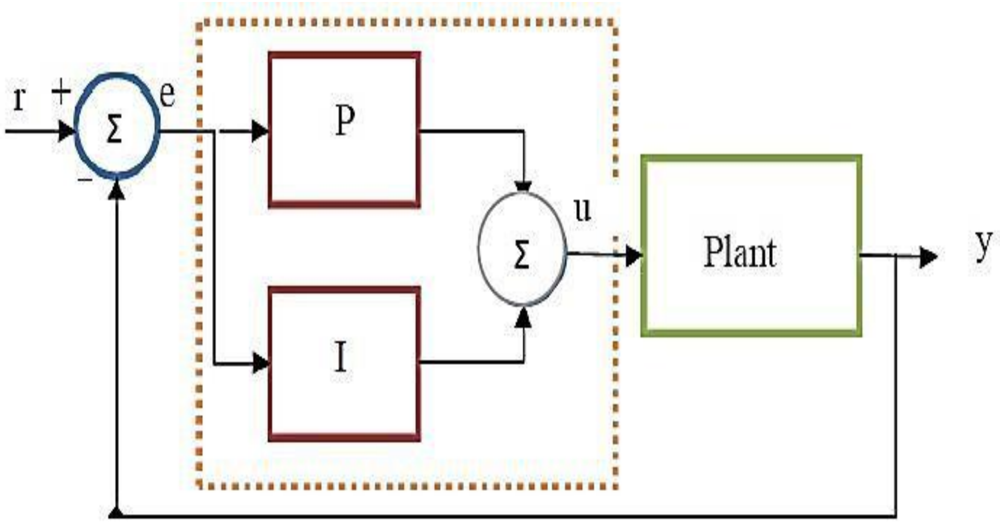

Fig.1 PI controller block diagram

The PI controller is designed by properly choosing K_i and K_P, The result suppose to have a a small overshoot, small rise time, a zero steady-state error and a small settling time. Such a response is surely almost typical. The difficulty in attaining such a response is the tuning (or selection) of the appropriate K_P and K_i, for any specific system under control. choosing the suitable K_P and K_i, depending on the experience of the design engineer, the suitable values of the parameters K_P and K_i of the PI controller may be chosen via trial and error.

III. The Fuzzy Logic Controller (FLC):

The fuzzy logic concept was introduced for the first time in 1965 and was discover by Lofti A. Zadeh. When the complexity of any system increases, it may become difficult to describe the behavior of the system, eventually coming to a complexity side where, as known the fuzzy logic technique has born in humans and this technique was the only technique so that a human could understand various problems. Theoretically, the fuzzy logic depends on the creation functions of membership. Dr. Zadeh, offered the notion of membership set to make appropriate resolve if the unbelieved occurs [6].

Control field is the master field of application in FLC, fuzzy logic control include complex aircraft machine, fans, train guidance, generator control, etc. The fundamental concept of FLC is to employ the experience and knowledge of the expert engineer for designing a system that controls a particular application process whose relevance between input and output is given by table of fuzzy control rules that utilize linguistic variables as an alternative of a dynamic model that possibly advanced. Fuzzy control rules are basically in the sort of "if- then" statment. In control system that uses fuzzy rules because of its linguistic variables which best employed for controller designing. The main parts of fuzzy controller are: fuzzification, fuzzy knowledge base, an inference components, the fuzzy rule base and a defuzzification. It includes of membership functions that assign the input variables to the fuzzy rule base as well as the output variable of the plant under control. The inference engine is considered as the head of the

FLC system, and it has the capability to mimic the human resolution by implementing sacrificial reasoning to get a desirable strategy for controlling [6].

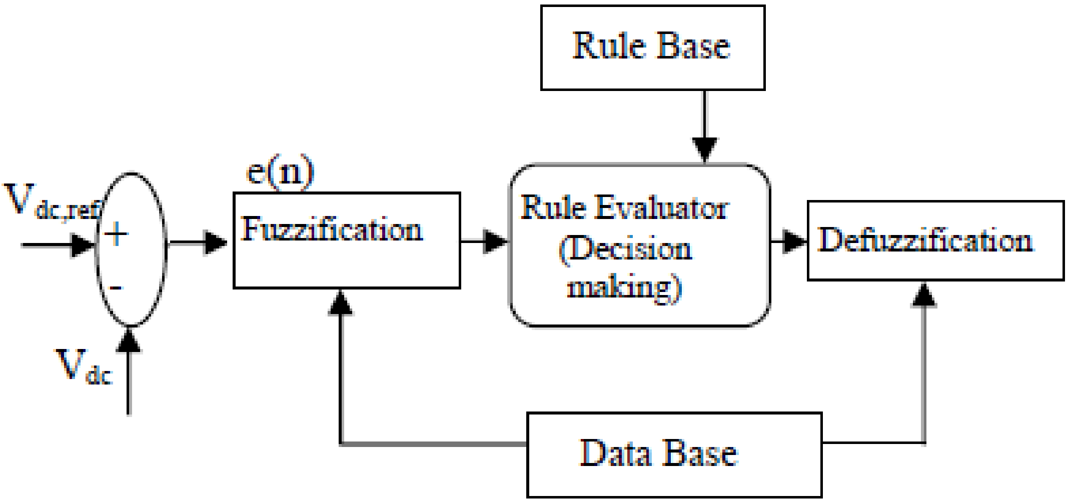

Fig.2 FLC system structure.

FLC is a set of several processes and procedures that are shown in Figure 2, It means a FLC involves several processes which are elaborate below.

1. The Fuzzification:

Fuzzy logic employs linguistic variables as an alternative of numeral variables. In control applications, the error that measured between the reference signal and the actual output signal could take one of the following linguistic variables "Positive Big (PB), Positive Medium (PM), Positive Small (PS), Zero (ZE), Negative Small (NS), Negative Medium (NM), Negative Big (NB)". a triangular membership functions are utilized in fuzzification procedure.

2. The Rule Elevator:

Basic controllers such as PI or PID controllers have a gain of control that are expressed in crisp values (numerical values). Fuzzy logic method does not used crisp values but uses linguistic variables instead. The linguistic variables for the error signal is represented as error input signal e_n and the fuzzy output is symbolize in the form of membership functions with a correction degree. The basic fuzzy set operations which are necessary for rules evaluation are AND (∩), OR (∪) and NOT (−).

3. The defuzzification:

The fuzzy logic produces the desired output in the form of a linguistic variable, according to the real world demands, linguistic variables must be transformed to crisp value. Therefore, the options of defuzzification are plentiful.

4. The data base:

The action of database is to store the definition of the membership function that related to both the defuzzifier and the fuzzifier. Storage arrangement is an arrangement between the available memory and the microprocessor step of the digital controller chip [7].

IV. FLC using SPWM single phase Inverter.

The fuzzy logic controller has been designed using the Matlab software utilizing the fuzzy logic toolbox [8]. This package will enable the designer to create the input membership functions, output membership functions and fuzzy control rules. There are two inputs will be applied to the fuzzy logic controller (FLC). The first one is an error signal (Ve) and the second is the change of error signal (Vce), these two inputs will be multiplexed and then fed to the fuzzy controller which produce a signal with a degree of correction. This degree of correctness will then be compared with one of the output variables which have the following linguistic variables Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), Positive Big (PB). Then the fuzzy logic controller (FLC) output is multiplied with modulation signal with a certain amplitude and then compared with triangular signal to produce the gating pulses to the inverter bridge. Seven membership functions in fuzzy logic controller (FLC) have been assigned for both input and output. A triangular membership functions are utilized to illustrate the variable related to the input and output. There will be 49 input linguistic variables because there is two input variables and each input variable have seven linguistic variables.

The rules table will link every of the 49 of the input pairs to the output respective label that is given in Table1.

Ve \ Vce	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Table 1: Membership Rules

V. Simulation of PI Controller Single Phase Inverter:

Figure 3 shows the simulation circuit using MATLAB/SIMULINK of single phase full bridge inverter which consists of 220V DC source, four IGBT transistors, LC filter of 25 mH and 0.25 μF respectively, resistive load of 400 ohm and PI controller with parameters of Kp=35 and Ki=70. The gains of PI controller are tuned so that the output voltage of the inverter is obtained with fast dynamic response. The root mean square block is added after the output sinusoidal voltage signal to obtain RMS voltage value and then scaled down and compared with the reference signal to obtain the error signal which is fed to the PI controller to which produce the correction signal. This correction signal will be multiplied with reference signal and then compared with triangular signal of 10 KHz to produce the gating signals that is fed to the bridge of the inverter.

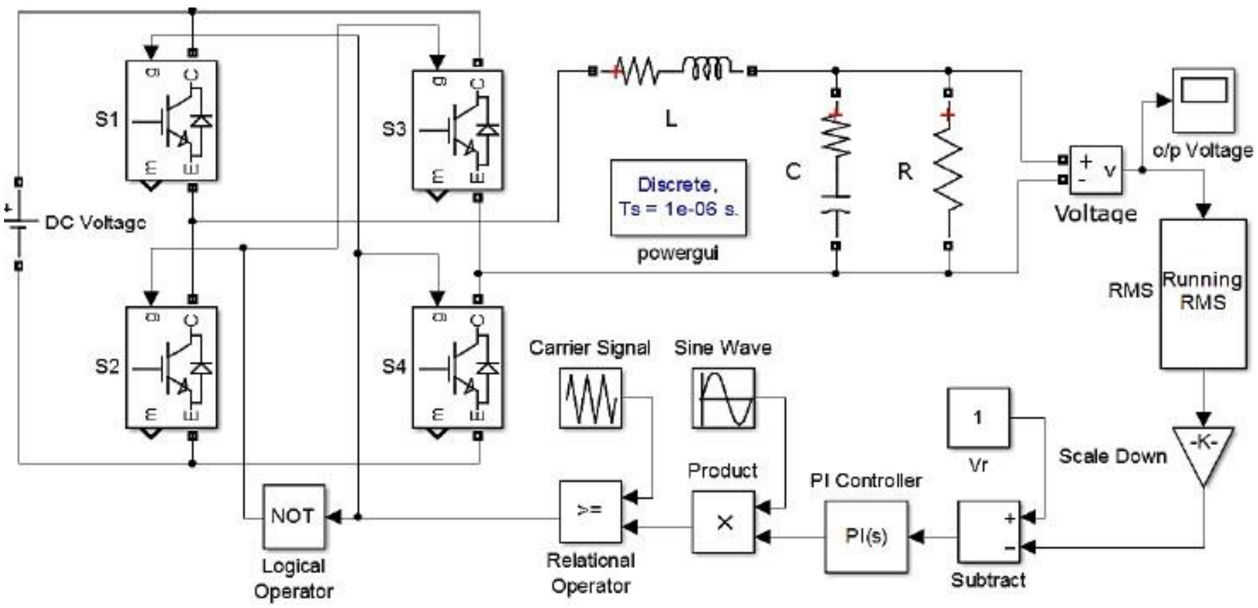

Fig.3 SPWM single phase inverter circuit using PI controller.

VI. Simulation Results of PI controller.

After creating the simulation model of single phase inverter using PI controller, now it's time to test the circuit under different operating conditions as well as test the circuit robustness and effectiveness in terms of tracking performance and output voltage respond to load variations and voltage and current THD values.

1-Gating Signals.

Figure 4 shows the gating signals fed to the bridge circuit that consisting of four IGBT transistors.

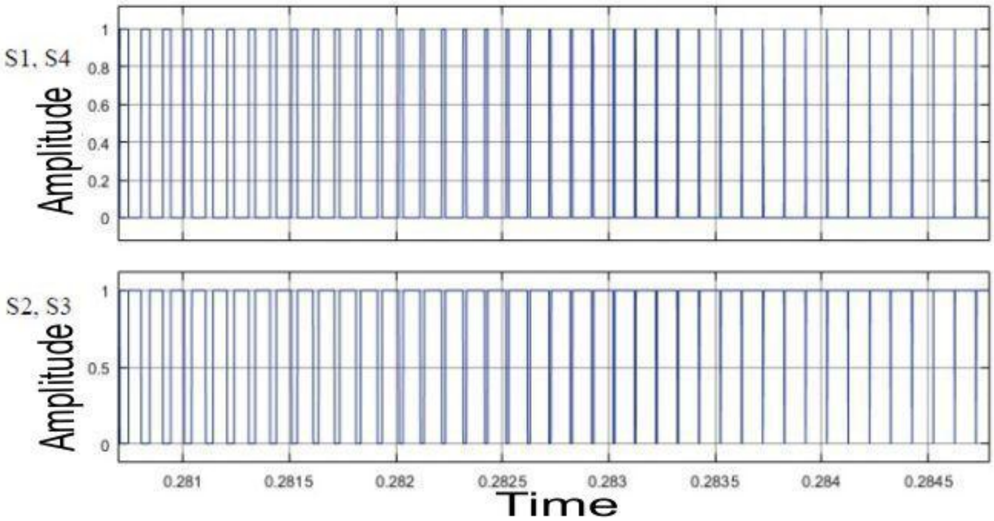

Fig.4 Gating signals fed to (S1,S4) and (S2,S3).

2-Output Voltage.

Figure 5 shows the inverter output voltage, the output waveform signal shows that the controller works efficiently and the controller keeps constant voltage amplitude.

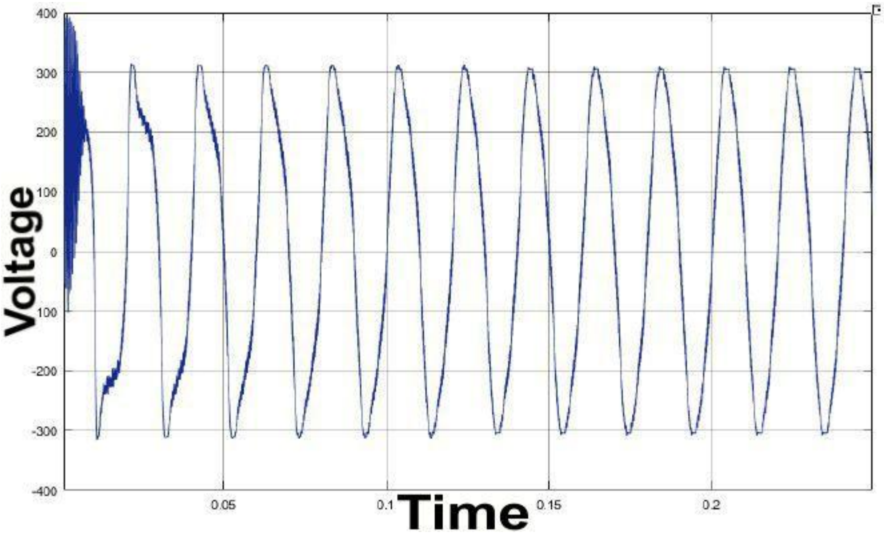

Fig.5 The output waveform of PI controller single phase inverter.

3-Total Harmonic Distortion of the Output Voltage.

Figure 6 shows the total harmonic distortion (THD) of the output voltage signal, the THD value is 4.26%, the inverter DC voltage is 220V with 400Ω resistive load, LC filter also used to block all higher order harmonics.

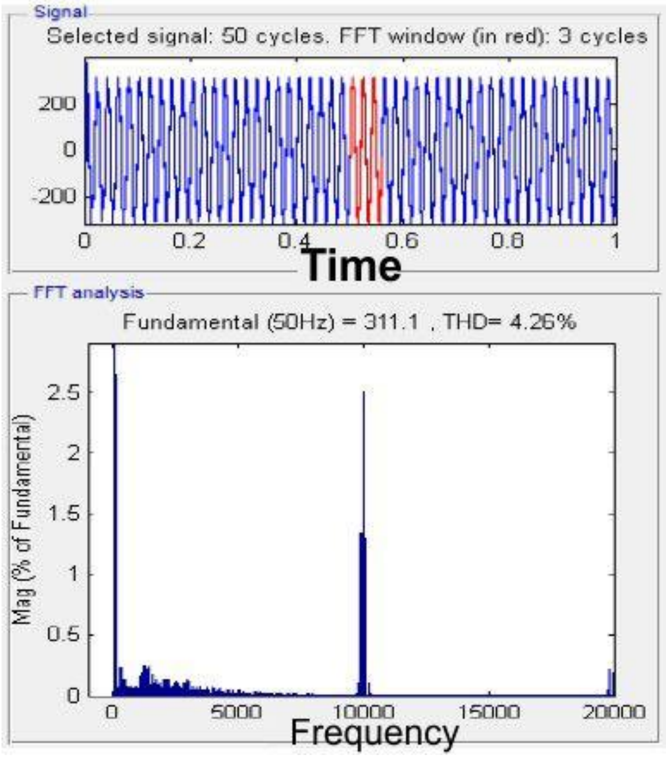

Fig.6 THD of single phase inverter using PI controller

4-Reference Signal Tracking.

Figure 7 shows the system response to a step change in reference signal, the initial value of the reference signal is 150V, at t=0.2sec a step change in reference signal is applied with amplitude of 230V, the system shows good tracking voltage performance with some overshoot noticed after t=0.2sec.

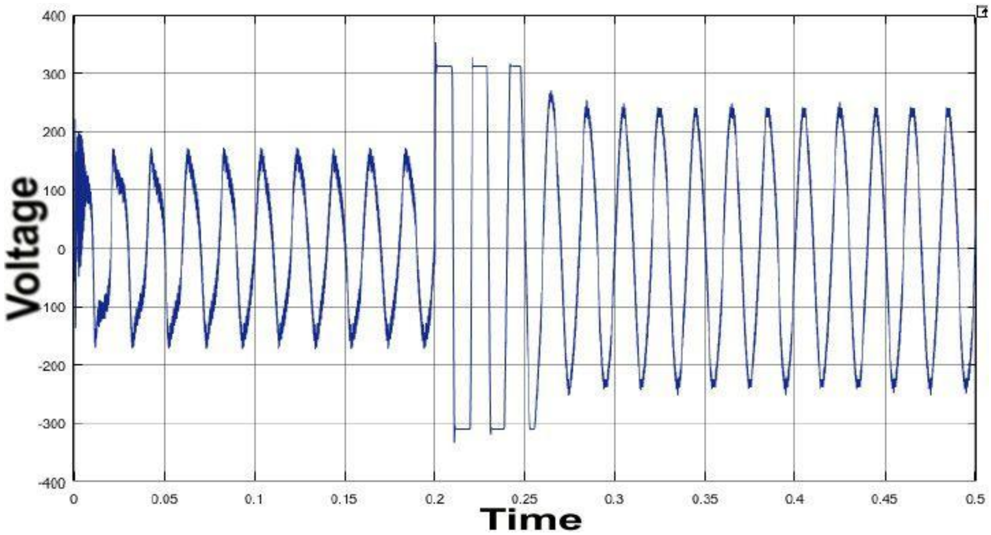

Fig.7 inverter output voltage waveform response after step change in reference signal is applied.

RMS voltage is also shown in figure 8 which shows good tracking performance when step change in reference signal is applied.

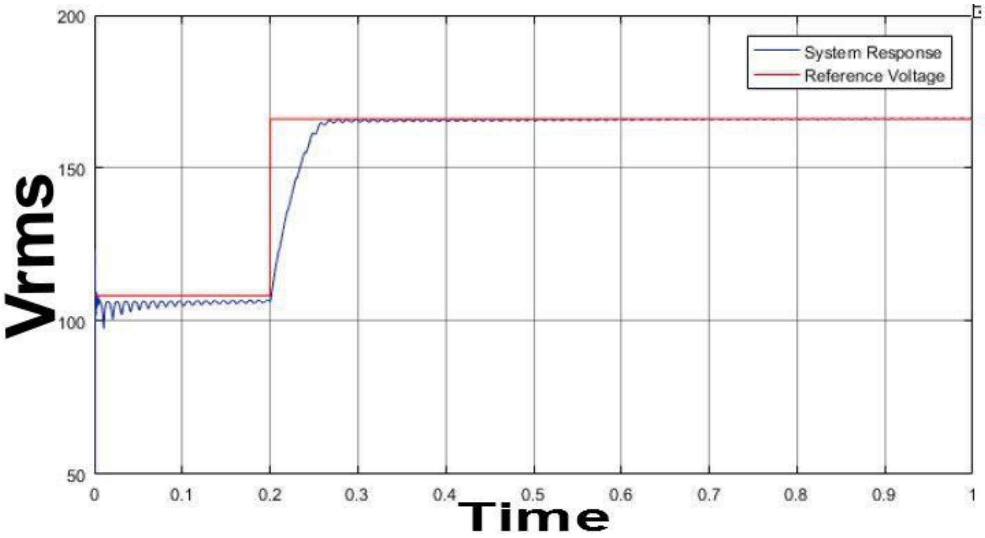

Fig.8 RMS voltage respond after step change is applied.

5- Load Current Response after Sudden Load Change is Applied.

Figure 9 and 10 show load current and output voltage signal response respectively after a sudden change in the load current which is applied at time t=0.2 sec, the initial value of the load is 200Ω, at t=0.2 sec a step change of 400Ω load is applied.

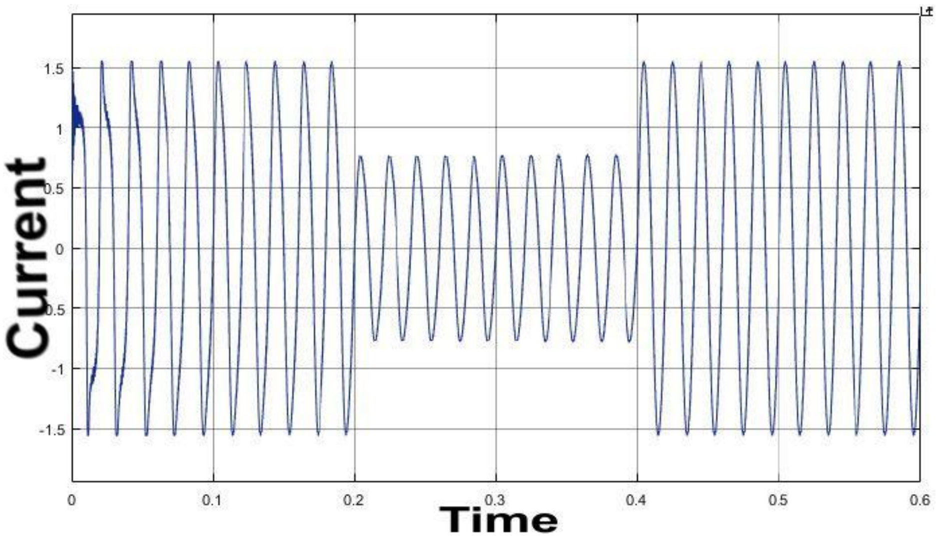

Fig.9 load current respond when sudden change is applied (200Ω to 400Ω).

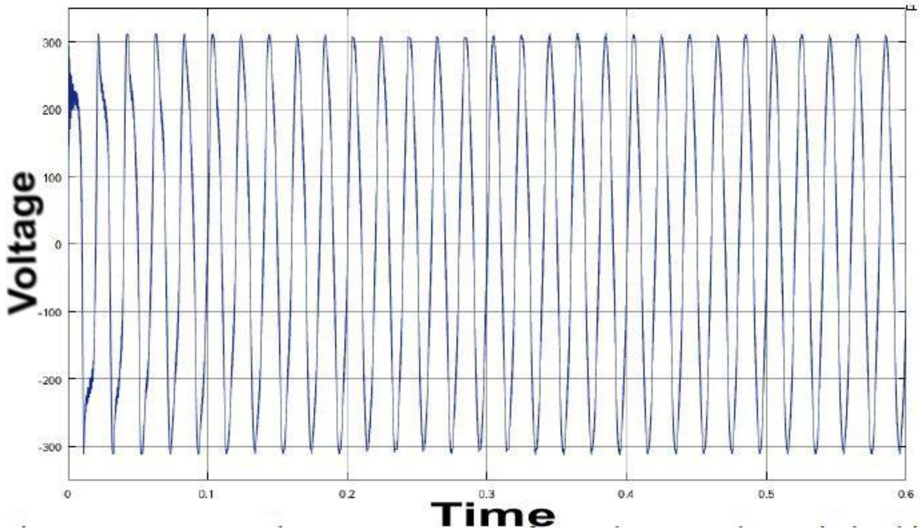

Fig.10 output voltage signal when step change in load current is applied.

VII. Simulation of single phase inverter using FLC.

As mentioned earlier the fuzzy logic controller has two inputs (the error signal Ve and change of error signal Vce), the change of error signal is obtained using two blocks, the memory block which generates the last error value and the subtractor block which produces the change of error signal from the error signal and the signal obtained from the memory block. Both signals are multiplexed and fed to the controller which contains input and output membership function and rules to decide how much of the signal needs to be corrected, the output signal from the controller will then be multiplied by sinusoidal signal as and then compared to triangular signal to generate the gating signals of the inverter bridge, figure 11 shows the simulation circuit which contains all the mentioned elements and blocks

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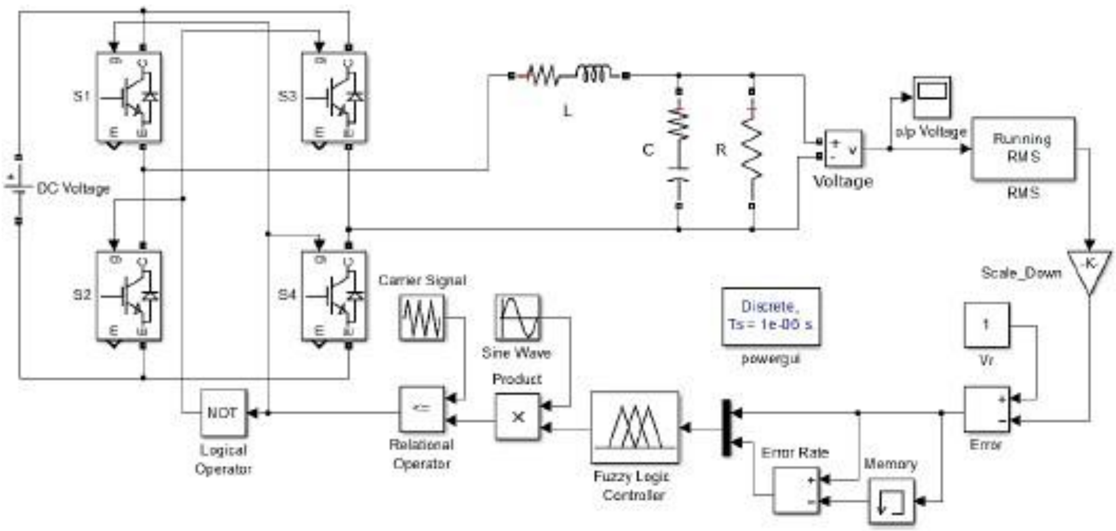

Fig.11 Simulation circuit of single phase inverter using fuzzy logic controller (FLC)

The harmonic distortion fuzzy model scheme is performed using the simulation software MATLAB/SIMULINK which contains the fuzzy logic toolbox. This tool enables the setting of both input/output membership functions as well as fuzzy control rules [9]. Fig.12 shows window of the FIS editor where the input/output membership function are formed as well as fuzzy rules that also can be formed using fuzzy logic toolbox, Fig.13 and 14 shows the signals of error and change of error which represent the error and change of error signals, Fig.15 shows the output membership function, In this paper, the fuzzification process have been applied using the Mamdani method, defuzzification process have been applied using centroid method, and all the used membership functions are triangular.

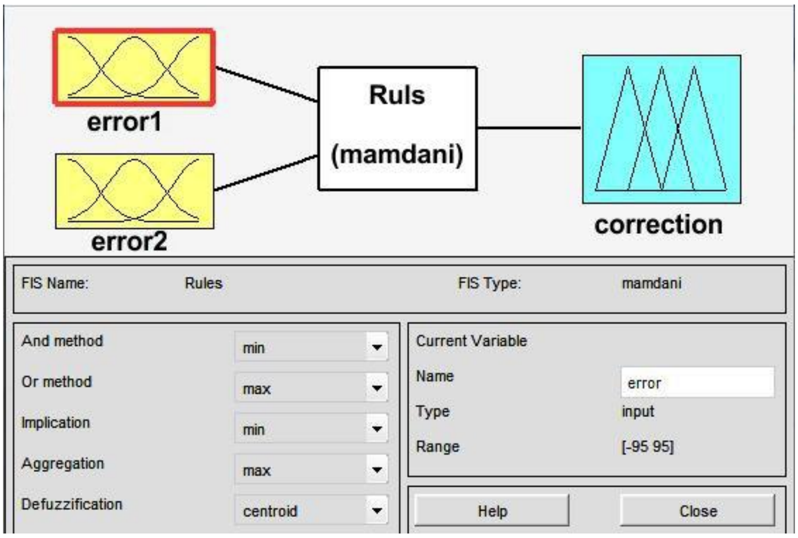

Fig.12 FIS editor window.

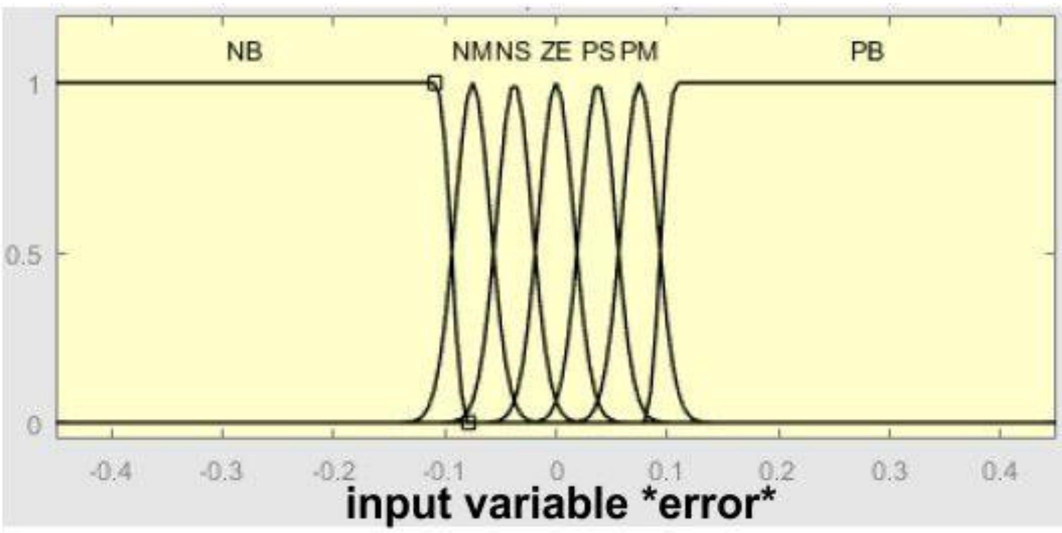

Fig.13 First input M.F (error).

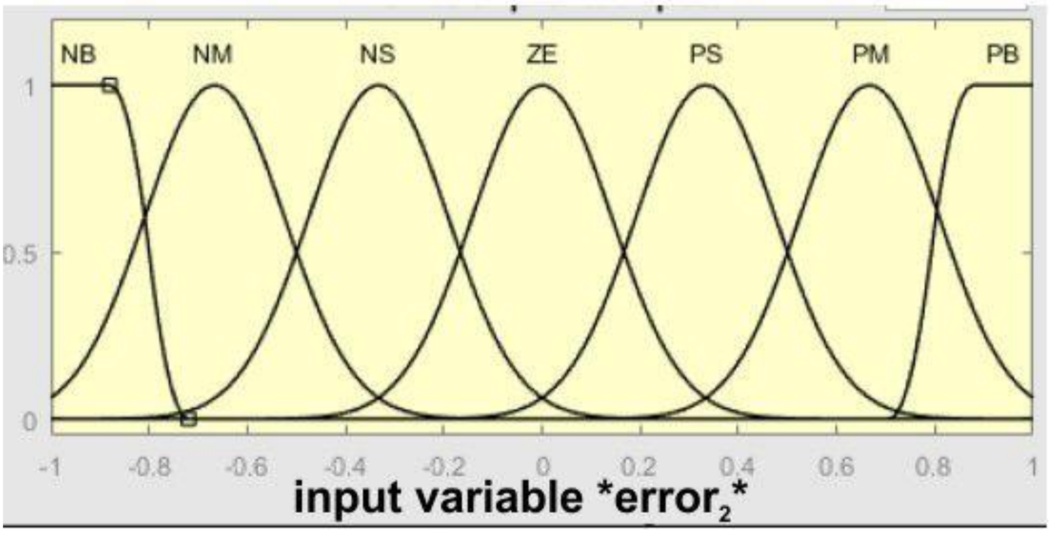

Fig.14 Second input M.F (change of error).

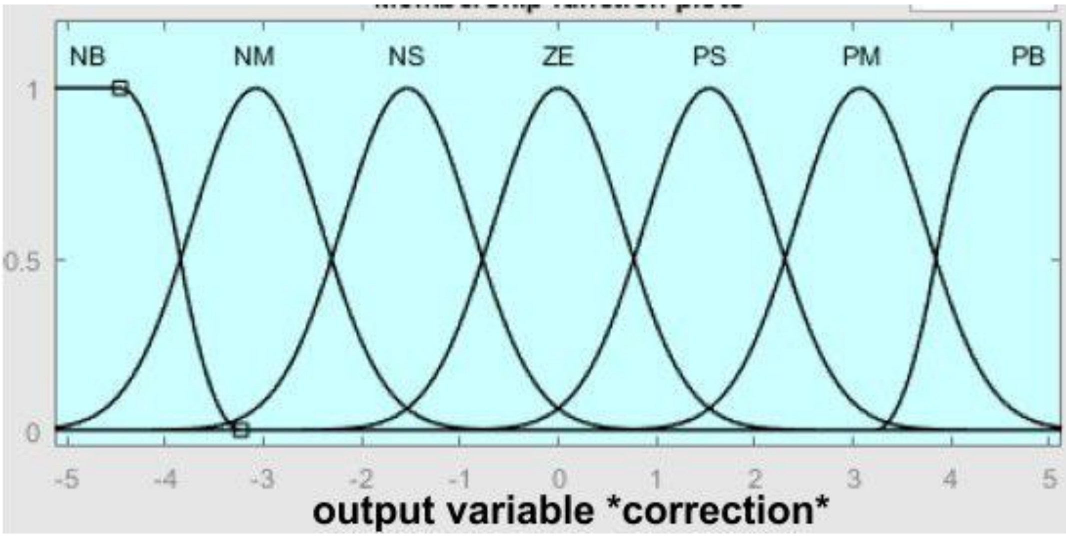

Fig.15 Output Membership Function.

I. The Results of Single phase inverter using FLC:

After finishing the simulation circuit of single phase inverter using fuzzy logic controller, it's time to test the circuit and obtain the waveforms and THD results, the same testing conditions will be applied on this circuit as done on the PI controller simulation circuit, at the end of the results, a THD comparison will be done on the output voltage under variation of the set point and load values.

1-Gating Signals.

Figure 16 shows the gating signals fed to the bridge circuit, the upper gating signals is sent to (S1 and S4) and the lower gating signal is sent to (S2 and S3).

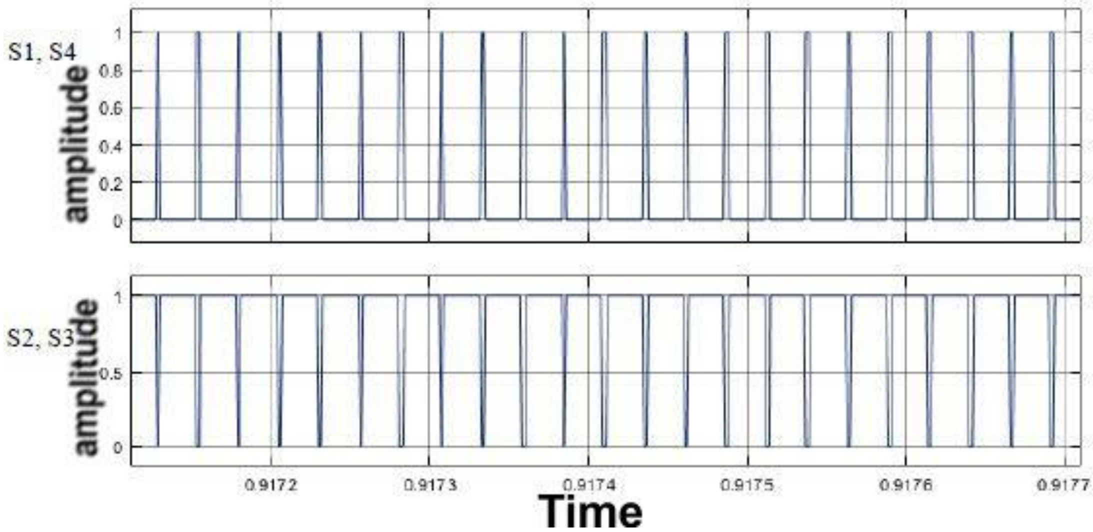

Fig.16 Gating signals fed to (S1, S4) and (S2,S3).

2-Output Voltage.

Figure 17 shows the output voltage waveform of single phase inverter using fuzzy logic controller (FLC), it is obvious that the waveform has some overshoots but the fuzzy controller acts efficiently and eliminates the overshoots and finally produce voltage waveform with reduced total harmonic distortion (THD).

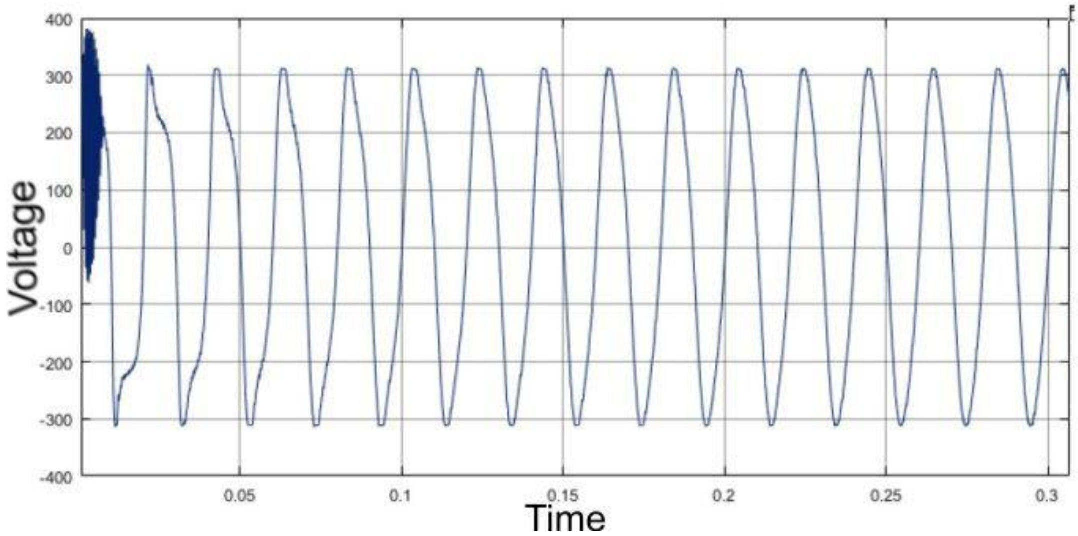

Fig.17 The output waveform of the inverter single phase with FLC controller

3- The Total Harmonic Distortion (THD):

Figure bellow shows the THD of the output voltage using FLC where the DC source voltage was 220V with load 400Ω.

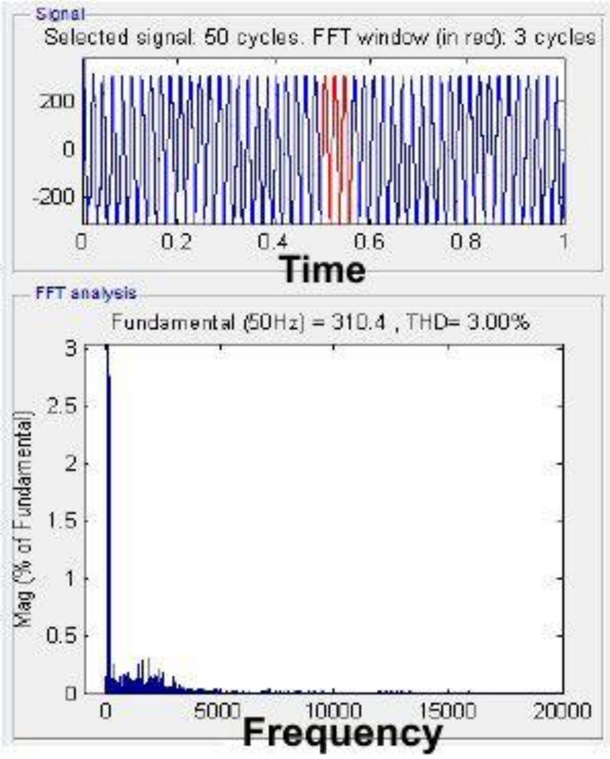

Fig.18 THD of single phase inverter using FLC controller

From the THD results seen previously, it can be seen that the output voltage controller using fuzzy logic controller (FLC) has less THD percentage, the PI controller has THD percentage of 4.26%, but fuzzy logic controller outperformed this value with a THD percentage of 3% only.

4- Reference signal Tracking.

Figure 19 shows the voltage signal when step change in reference signal is applied, the initial value of the set point was 150V, at time t=0.2sec a step change of 230V in the reference signal is applied.

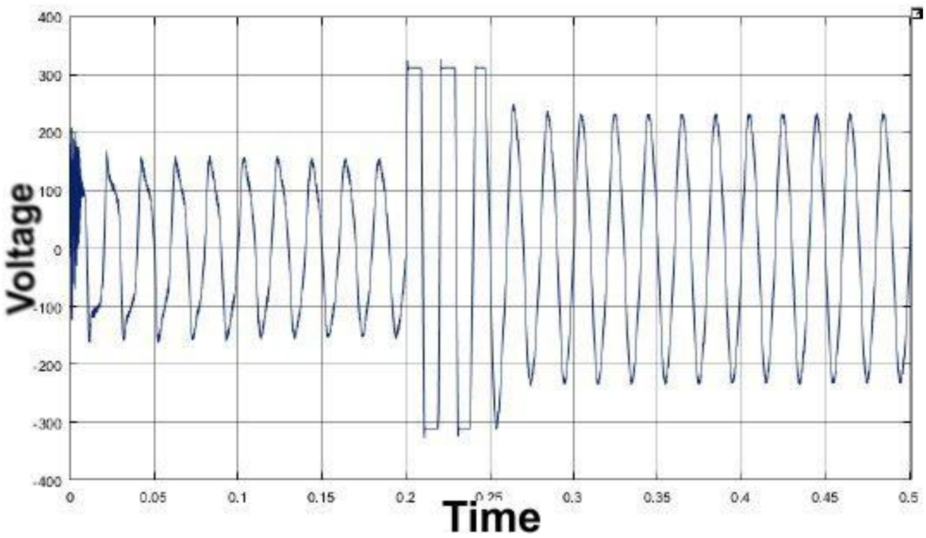

Fig.19 inverter output voltage waveform response after step change in reference signal is applied. **figure 20** show the RMS value acts when applying the step change in reference signal.

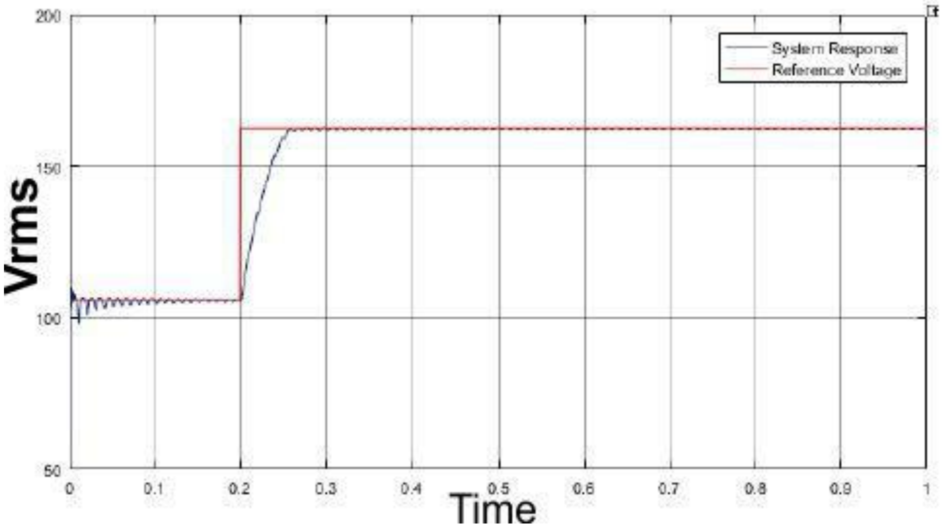

Fig.20 RMS voltage response versus step change signal.

From the simulation results, fuzzy logic controller shows better performance regarding set point tracking. In comparison with PI controller, the fuzzy logic controller has outperformed the rise time, overshoot and steady state error.

5- Load Current Response after Sudden Load Change is Applied.

Figures 21 and 22 shows the load current signal and output voltage signal when a step change in the load is applied (200Ω to 400Ω).

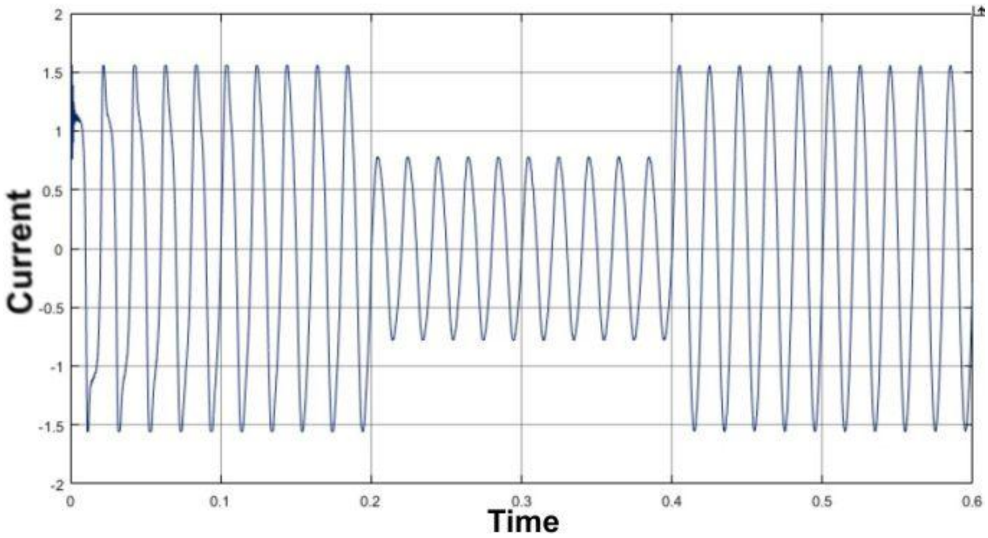

Fig.21 load current respond when sudden change is applied (200Ω to 400Ω)

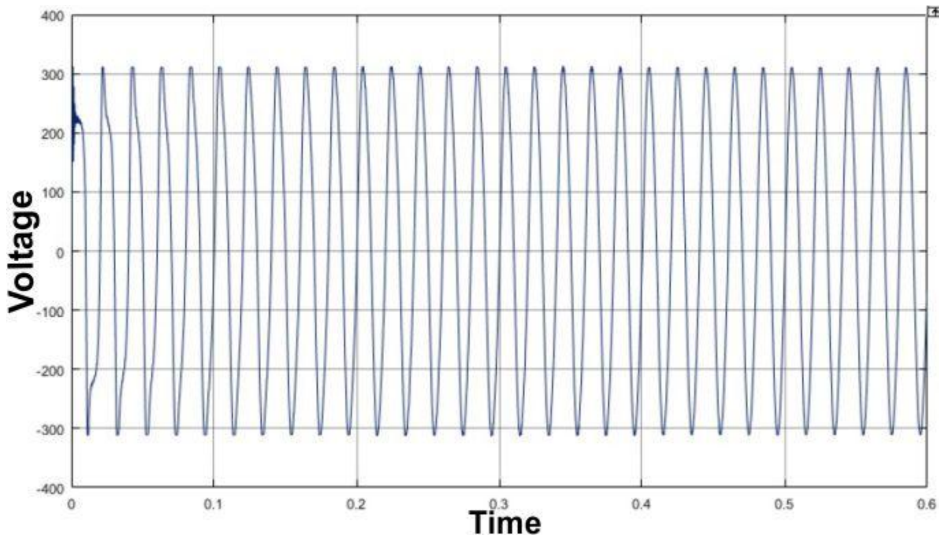

Fig.22 output voltage signal when step change in load current is applied.

VIII. THD percentage comparison using PI controller and fuzzy logic controller (FLC)

Different set points and load values are tested and the THD values for the output voltage signal is compared.

1-THD percentage of the PI controller and fuzzy logic controller (FLC) under variation of reference signal.

Under fixed load resistance of 400Ω, the simulation circuit of the both controllers is tested with different set point values, the following table shows the THD value of the output voltage with reference signal taken from (250V to 320V).

Table 2. The THD of the output voltage under reference signal variation

V_r (V)	THD % V	
	PI	Fuzzy
250	5.52	3.64
260	5.21	3.52
270	4.95	3.43
280	4.77	3.25
290	4.64	3.23
300	4.48	3.05
310	4.26	3.01
320	4.19	2.90

2-THD percentage of the PI controller and fuzzy logic controller (FLC) under variation of resistive load.

Under fixed reference voltage of 220V, a variation of the load resistance has been done (300Ω to 460Ω) and the THD results of the output voltage are obtained as shown in table 3 for both controlling schemes.

Table 3. The THD of the output voltage under resistive load variation

R_{load} (ohm)	THD % V	
	PI	Fuzzy
300	4.19	2.95
320	4.20	2.96
340	4.21	2.97
360	4.23	2.98
380	4.24	2.99
400	4.25	3.00
420	4.26	3.02
440	4.27	3.02
460	4.28	3.05

From the results of the tables shown above, it is clear that the THD percentage of the output voltage is mitigated using fuzzy logic controller (FLC) scheme under set point and load variation.

In the paper named, "**Use of PWM Techniques for Power Quality Improvement (2009)**", the author discussed different PWM techniques, and show that the result of modified SPWM technique is best. The THD of such technique is about 3.76 %.

In the paper named "**Fuzzy Logic Controller for MPPT SEPIC Converter and PV Single-Phase Inverter (2011)**", four IGBTs were used to implement the single phase inverter, 4.5% THD was achieved, and tracking for the maximum power using SEPIC was attained, all via optimization for PID controller.

Conclusion

In this paper both controller schemes (PI controller and fuzzy logic controller (FLC)) have been presented and explained and simulation circuits has been done using MATLAB/SIMULINK, MATLAB also has very useful tool which calls FIS editor which was very useful in creating input/output membership functions as well as the fuzzy rules which all have been formed to decide how much of the error signal should be corrected, , THD percentage of both controllers are compared and presented in tables, also the simulation circuit is tested in terms of step change in reference signal and sudden step change in load, the fuzzy logic controller has better performance in terms of rise time, steady state error and overshoot as well as the THD percentage which has outperformed using FLC as shown in tables 2 and 3.

References

[1] V. K.. Kishan., P. P. Puthra, and K. N. Reddy, "Paralleling of inverters with dynamic load sharing", Power India International Conference (PIICON), IEEE 7th,2016.

[2] G. N. Jadhav, and D.D. Changan, Modelling of inverter for stability analysis of microgrid ", Power India International Conference (PIICON), IEEE 7th,2016.

[3] Muhammad H. Rashid, "Power Electronics", 3rd Edition, BH Publications.

[4] Wing-Chi ***So,*** Chi K. Tse, and Yim-Shu Lee, "Development of a Fuzzy Logic Controller for DC/DC Converters: Design, Computer Simulation, and Experimental Evaluation," IEEE Trans. Power. Electron. vol. 11, NO. 1, pp. 24-32, 1996.

[5] S. M. Cherati N. A. Azli S. M. Ayob and A.Mortezaei, "Design of a Current Mode PI Controller for a Single-phase PWM Inverter" Power Electronics and Drive Research Group IEEE, 2011.

[6] Sivanandam, S. N., and S. N. Deepa. PRINCIPLES *OF SOFT COMPUTING.* John Wiley & Sons, 2007.

[7] Michael Negnevitsky "**Artificial Intelligence**" Second edition 2005.

[8] Halpin S.M., "Harmonics in Power Systems", in *the Electric Power Engineering Handbook*, L.L. Grigsby, Ed. Boca Raton: CRC Press, 2001.

[9] The MathWorks. [Online]. Fuzzy Logic Toolbox.Available : http:// www.mathworks.com / products /fuzzylogi