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# Fuzzy Based Multi String Seven Level Inverter For Photovoltaic System

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Abstract: This paper presents a Fuzzy based single phase multi string seven level inverter for photovoltaic system with a PWM control scheme. Three reference signals are used which are identical to each other are going to compare with the amplitude of the triangular carrier signal to produce the switching pulses. This seven level inverter is capable of producing seven levels Vdc, 2Vdc/3, Vdc/3, 0, -Vdc, -2Vdc/3, -Vdc/3. Fuzzy logic controller has been used as a feedback controller with the load of 1-ph motor to improve the performance. The performance of the proposed system is verified through simulation using MATLAB/SIMULINK.
*Index Terms* — Grid connected photovoltaic system, single phase seven level inverter, pulse width modulation, total harmonic distortion, fuzzy logic controller.

## Introduction

As the world is concerned with fossil fuel fatigue and ecological issues brought about by the conventional power generation, renewable vitality sources especially sun based vitality and wind vitality have turn out to be exceptionally prevalent and demanding. PV sources are utilized today as a part of numerous applications as they have the benefits of being support and contamination free. Sun powered electric-vitality interest has become reliably by 20%-25% for each annum in the course of recent years, which is for the most part because of the diminishing expenses and costs. This decrease has been driven by 1) an expanding productivity of sun based cells; 2) assembling innovation upgrades; 3) economies of scale.

The PV framework changes over the sun radiation into power by sun oriented cells. These cells are made of some conducting materials. At the point when the sun radiation is consumed by the cells, the electrons from the molecules go into the materials and as it is a shut way it creates the power. This created power is the Direct current (DC). This DC will be changed over into AC by the seven level inverter.

## Inverter Topology

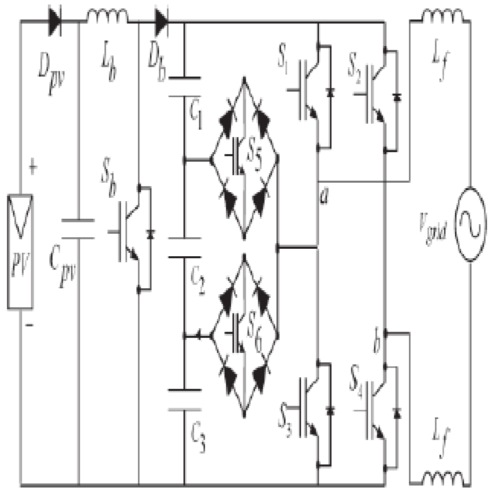



Fig.1.Proposed single phase seven level inverter for photovoltaic system.

The proposed single-phase seven-level inverter was produced from the five-level inverter in. It embodies a single phase conventional H-bridge inverter, two bidirectional switches, and a capacitor voltage divider framed by C1, C2, and C3, as indicated in Fig. 1. The altered H-bridge topology is essentially profitable over different topologies, i.e. less power switch, power diodes, and less capacitors for inverters of the same number of levels. Photovoltaic (PV) exhibits were associated with the inverter by means of a dc–dc boost converter. The power produced by the inverter is to be conveyed to the power network, so the utility grid, instead of a load, was utilized. The dc–dc boost converter was needed since the PV exhibits had a voltage that was lower than the grid voltage. High dc bus voltages are important to guarantee that power streams from the PV exhibits to the grid.

Proper switching of the inverter can create seven output voltage levels (Vdc, 2Vdc/3, Vdc/3, 0, −Vdc, −2Vdc/3, −Vdc/3) from the dc supply voltage. The proposed inverter's operation can be separated into seven exchanging states, as indicated in Fig. 2(a)–(g). Fig. 2(a), (d), and (g) demonstrates a conventional inverter's operational states in sequence, while Fig. 2(b), (c), (e), furthermore, (f) shows extra states in the proposed inverter integrating one- and two-third levels of the dc-bus voltage. The obliged seven levels of yield voltage were produced as follows.

1) Maximum positive output (Vdc): S1 is ON, joining the load positive terminal to Vdc, and S4 is ON, joining the load negative terminal to ground. All other controlled switches are OFF; the voltage connected to the load terminals is Vdc. Fig. 2(a) shows the present ways that are dynamic at this stage.

2) Two-third positive output (2Vdc/3): The bidirectional switch S5 is ON, joining the load positive terminal, and S4 is ON, joining the load negative terminal to ground. All other controlled switches are OFF; the voltage connected to the load terminals is 2Vdc/3. Fig. 2(b) demonstrates the present ways at this stage.

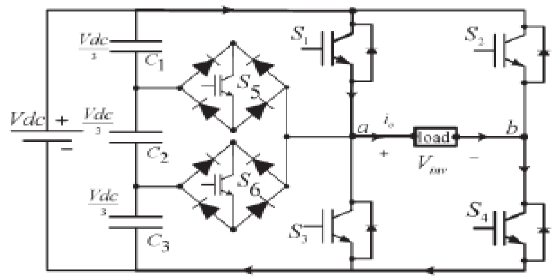
3) 33% positive output (Vdc/3): The bidirectional switch S6 is ON, interfacing the load positive terminal, and S4 is ON, uniting the load negative terminal to ground. All other controlled switches are OFF; the voltage connected to the load terminals is Vdc/3. Fig. 2(c) demonstrates the present ways that are dynamic at this stage.

4) Zero output: This level can be created by two switching combinations; switches S3 and S4 are ON, on the other hand S1 and S2 are ON, and all other controlled switches are OFF; terminal ab is a short out, and the voltage connected to the load terminals is zero. Fig. 2(d) shows the present ways that are dynamic at this stage.

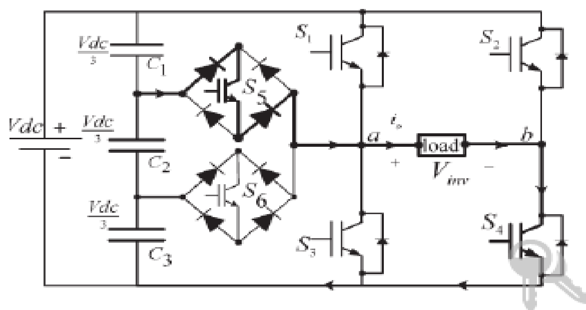
5) 33% negative load (−Vdc/3): The bidirectional switch S5 is ON, associating the load positive terminal, and S2 is ON, joining the load negative terminal to Vdc. All other controlled switches are OFF; the voltage connected to the load terminals is −Vdc/3. Fig. 2(e) demonstrates the present ways that are dynamic at this stage.

6) Two-third negative output (−2Vdc/3):The bidirectional switch S6 is ON, joining the load positive terminal, and S2 is ON, joining the load negative terminal to ground. All other controlled switches are OFF; the voltage connected to the load terminals is −2Vdc/3. Fig. 2(f) demonstrates the current ways that are dynamic at this stage.

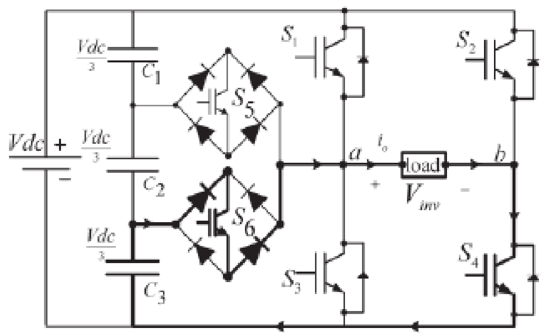
7) Maximum negative output(−Vdc): S2 is ON, joining the load negative terminal to Vdc, and S3 is ON, joining the load positive terminal to ground. All other controlled switches are OFF; the voltage connected to the load terminals is −Vdc. Fig. 2(g) shows the present ways that are dynamic at this stage.



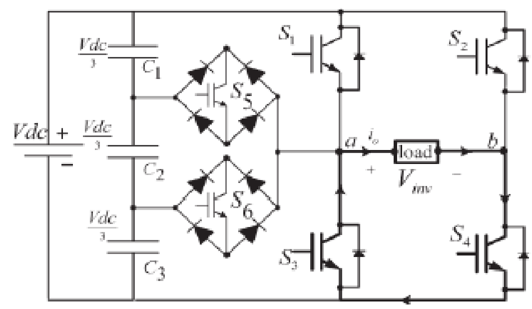
(a)



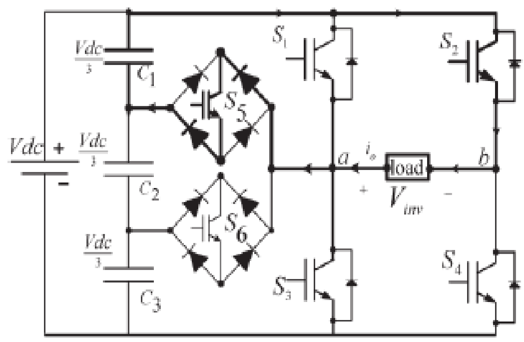
(b)



(c)



(d)



(e)

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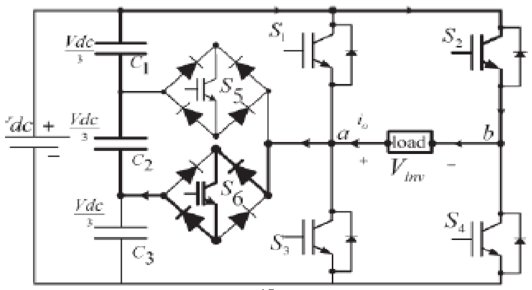
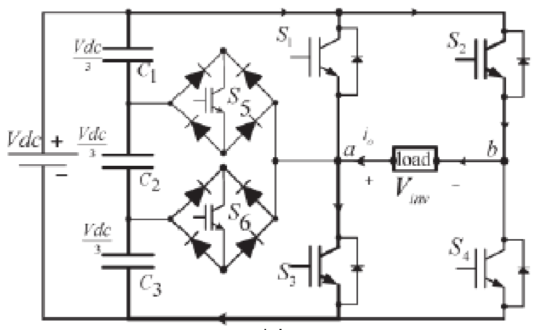



(f)




(g)

Fig. 2. Switching combination required to generate the output voltage ($V$ab)

(a) $V$ab = $V$dc. (b) $V$ab = 2$V$dc/3. (c) $V$ab = $V$dc/3. (d) $Vab$ = 0. (e) $V$ab = −$V$ dc/3. (f)$Vab$= − 2$V$dc/3. (g)$V$ab = −$V$ dc.

TABLE I

OUTPUT VOLTAGE ACCORDING TO THE SWITCHES' ON–OFF CONDITION

| $v_0$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ |
|---|---|---|---|---|---|---|
| $V_{dc}$ | on | off | off | on | off | off |
| $2V_{dc}/3$ | off | off | off | on | on | off |
| $V_{dc}/3$ | off | off | off | on | off | on |
| 0 | off | off | on | on | off | off |
| 0* | on | on | off | off | off | off |
| $-V_{dc}/3$ | off | on | off | off | on | off |
| $-2V_{dc}/3$ | off | on | off | off | off | on |
| $-V_{dc}$ | off | on | on | off | off | off |

Table 1 shows the switching combinations that generated the seven output-voltage levels (0, −$V$dc, −2$V$dc/3, −$V$dc/3, $V$dc, 2$V$dc/3, $V$dc/3).

A novel PWM modulation technique was acquainted to produce the PWM switching signals. Three reference signals (Vref1, Vref2, and Vref3) were contrasted and a carrier signal (Vcarrier). The reference signals had the same frequency and amplitude and were in phase with an offset value that was identical to the sufficiency of the carrier signal. The reference signals were each contrasted and the carrier signal. On the off chance that Vref1 had surpassed the crest sufficiency of Vcarrier, Vref2 was contrasted and Vcarrier until it had surpassed the peak amplitude of Vcarrier. At that point, forward, Vref3 would assume responsibility and would be contrasted and Vcarrier until it came to zero. When Vref3 had come to zero, Vref2 would be analyzed until it came to zero.

At that point, ahead, Vref1 would be contrasted with Vcarrier. Fig. 3 demonstrates the subsequent switching pattern. Switches S1, S3, S5, and S6 would be switching at the rate of the carrier signal frequency, though S2 and S4 would work at a frequency that was proportional to the fundamental frequency. For one cycle of the fundamental frequency, the proposed inverter operated through six modes. Fig. 4 demonstrates the per unit output voltage signal for one cycle.

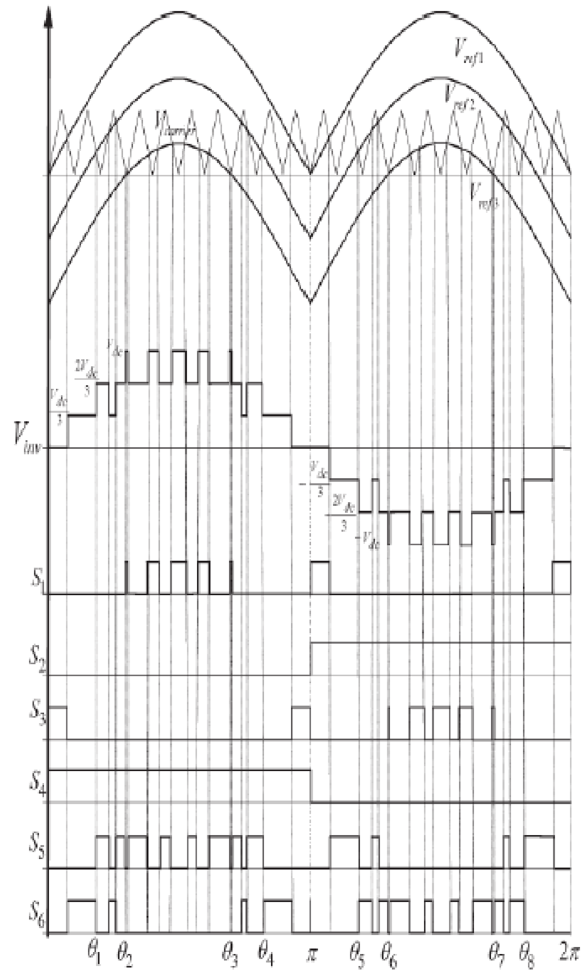



*Fig. 3. Switching patterns for single phase seven level inverter*

The six modes are described as follows:

Mode 1: $0 < \omega t < \theta 1$ and $\theta 4 < \omega t < \pi$

Mode 2: $\theta 1 < \omega t < \theta 2$ and $\theta 3 < \omega t < \theta 4$

Mode 3: $\theta 2 < \omega t < \theta 3$

Mode 4: $\pi < \omega t < \theta 5$ and $\theta 8 < \omega t < 2\pi$

Mode 5: $\theta 5 < \omega t < \theta 6$ and $\theta 7 < \omega t < \theta 8$

Mode6: $\theta 6 < \omega t < \theta 7$ *(1)*

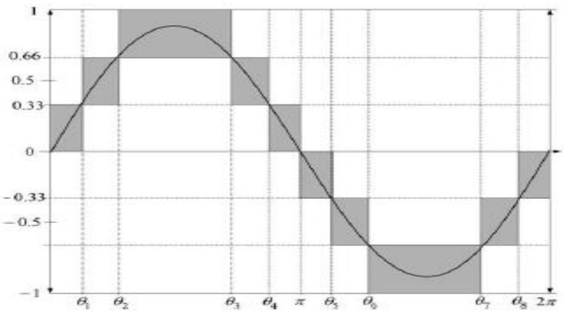



*Fig. 4. Seven level output voltage and switching angles*

The phase angle depends on modulation index *Ma*. Theoretically, for a single reference signal and a single carrier signal, the modulation index is defined to be

$Ma= A_m/A_c$ (2)

While for a single-reference signal and a dual carrier signal, the modulation index is defined to be

$Ma= A_m/2A_c$ (3)

Since the proposed seven-level PWM inverter utilizes three carrier signals, the modulation index is defined to be

$Ma= A_m/3Ac$ (4)

Where *Ac* is the peak-to-peak value of the carrier signal and *Am* is the peak value of the voltage reference signal *V*ref.

When the modulation index is less than 0.33, the phase angle displacement is

$\theta1 = \theta2 = \theta3 = \theta4 = \pi/2$ (5)

$\theta5=\theta6=\theta7=\theta8=3\pi/2$ (6)

On the other hand, when the modulation index is more than 0.33 and less than 0.66, the phase angle displacement is determined by

$\theta1=\sin^{-1}(A_c/A_m)$ (7)

$\theta2=\theta3=\pi/2$ (8)

$\theta4=\pi-\theta1$ (9)

$\theta5=\pi+\theta1$ (10)

$\theta6=\theta7=3\pi/2$ (11)

$\theta8=2\pi-\theta1$ (12)

If the modulation index is more than 0.66, the phase angle displacement is determined by

$\theta1=\sin^{-1}(A_c/A_m)$ (13)

$\theta2=\sin^{-1}(2A_c/A_m)$ (14)

$\theta3=\pi-\theta2$ (15)

$\theta4=\pi-\theta1$ (16)

$\theta5=\pi+\theta1$ (17)

$\theta6=\pi+\theta2$ (18)

$\theta7=2\pi-\theta2$ (19)

$\theta8=2\pi-\theta1$ (20)

For *Ma* that is equal to, or less than, 0.33, only the lower reference wave (*V*ref3) is compared with the triangular carrier signal. The inverter's behavior is similar to that of a conventional full-bridge three-level PWM inverter. However, if *Ma* is more than 0.33 and less than 0.66, only *V*ref2 and *V*ref3 reference signals are compared with the triangular carrier wave. The output voltage consists of five dc-voltage levels. The modulation index is set to be more than 0.66 for seven levels of output voltage to be produced. Three reference signals have to be compared with the triangular carrier signal to produce switching signals.

## Fuzzy Logic Controllers

Fuzzy control is a control system taking into account Fuzzy logic. Just a fuzzy logic can be depicted essentially as "processing with words as opposed to numbers"; fuzzy control can be portrayed just as "control with sentences instead of Mathematical statements". A fuzzy controller can incorporate empirical rules, and that is particularly valuable in administrator controlled plants. The target here is to distinguish and clarify plan decisions for engineers.

Fuzzy logic controllers are as of now utilized as a part of apparatuses washing machine, cooler, vacuum cleaner and so forth. PC subsystems (plate drive controller, power administration) buyer hardware (feature, camera, battery charger) C.D. Player and so forth thus on in last decade, fuzzy controllers have change over sufficient consideration in movement control frameworks. As the later have non-linear characteristics and an exact model is regularly unknown. Remote controllers are progressively being utilized to control a framework from a distant place because of unavailability of the framework or for solace reasons. In this work a fuzzy remote controller is produced for speed control of a inverter sustained single phase motor.

*A. Unique features of fuzzy logic*: The extraordinary elements of fuzzy logic that made it an especially great decision for some control issues are as follows, It is innately strong since it does not require exact, noise – free inputs and can be program to fall flat securely is a feedback sensor stops or is destroy. The output control is a smooth control function regardless of an extensive variety of input variations. Since the fuzzy logic controller procedures client characterize rules administering target control framework, it can be alter and takes easily to enhance or definitely adjust framework execution. New sensors can undoubtedly be joins into the framework just by creating proper representing rules.

*B. Fuzzification and Normalization:* Fuzzification is identify with the dubiousness and imprecision in a common language. It is a subjective valuation, which changes estimation into a valuation of a objective input space to fuzzy sets in certain information universes of discourse. In fuzzy control applications, the observed information are normally crisp. Since the information control in a fuzzy logic controller is in light of fuzzy set hypothesis, fuzzification is essential in a prior stage.

*C. Membership functions:* Fuzzy system uses '4' different shapes of MF's., those are Triangular, Gaussian, Trapezoidal, sigmoid, etc.,

i. Triangular membership function: The most straightforward and most generally used membership functions are triangular membership functions, which are Symmetrical and asymmetrical in shape, Trapezoidal membership functions are likewise symmetrical or asymmetrical has the shape of truncated triangle.
ii. Gaussian membership function: Two membership functions Triangular and Trapezoidal are built on the Gaussian curve and two sided composite of two different Gaussian curves.

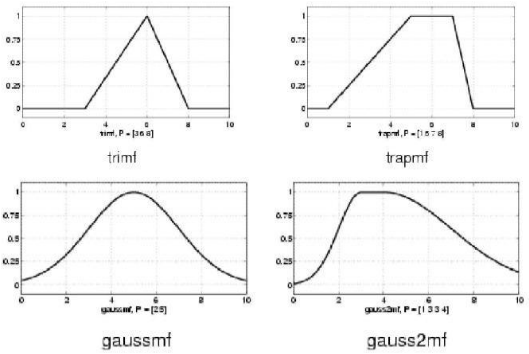



*Fig.5. Membership functions*

*D. Fuzzy system:* The fuzzy interface system Fuzzy system basically consists of a formulation of the mapping from a given input set to an output set using Fuzzy logic. The mapping process provides the basis from which the interference or conclusion can be made.

*E. Steps for A Fuzzy interface process*

i. Fuzzification of input variables.
ii. Application of Fuzzy operator.(AND, OR, NOT) In the IF (antecedent) part of the rule.
iii. Implication from the antecedent to the consequent (Then part of the rule).
iv. Aggregation of the consequents across the rules.
v. Defuzzification.

*F. Implication method:* The implication step introduces to evaluate the individual rules.
The implication methods are,
1) MAMDANI
2) SUGENO
3) LUSING LARSON.

i. Mamdani: Mamdani, one of the pioneers in the application of 'FL' in control systems, proposes this implication method. This Mamdani method is most commonly used method. The outputs of the Mamdani method is truncated Signals of the inputs; this output is depending on the minimum values in the
inputs.
Ex: If X is zero (ZE) AND y is positive (PS) Then Z is negative.

ii. Sugeno: The sugeno or Takgi-Sugeno-Kang method of implication was first introduced in1985. The difference here is that unlike the Mamdani and Lusins Larson methods, the output MFS are only constants or have linear relations with the inputs with a constant output MF (Singleton); it is defined as the Zero-order
Sugeno method whereas with a linear relation, it is known as first order Sugeno method. The outputs of the sugeno method have a constant minimum value in the input.

*G. Defuzzification and Denormalization:* The function of a defuzzification module (DM) is as follows: Performs the so-called defuzzification, which converts the set of modified control output values into single point – wise values.
Performs an output denormilization, which maps the point wise value of the control output onto its physical domain. This step in not needed if non normalized fuzzy sets is used.
A defuzzification strategy is producing a non-fuzzy control action that best represents the possibility of an inferred fuzzy control action. Seven strategies in the literature, among the many that have been proposed by investigators, are popular for defuzziffying fuzzy output functions:
i. Max-membership principle
ii. Centroid method
iii. Weighted average method
iv. Mean-max member ship
v. Centre of sums.
vi. Centre of largest area
vii. First (or last) of maxima.
The best well-known defuzzification method is Centroid method.

## Simulation Results

MATLAB SIMULINK simulated the seven level inverter and switching pulses were generated by comparing the three sinusoidal reference waves (Vref1,Vref2,Vref3) with triangular carrier wave. The three reference and carrier signals and the generated PWM switching pulses S1-S6 are shown in figs 6 and 7.

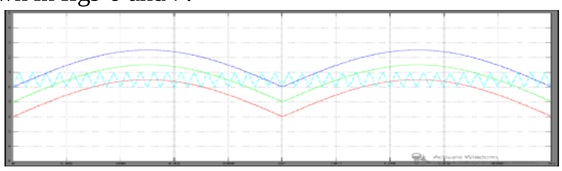


*Fig. 6.Sinusoidal references and triangular carrier wave*

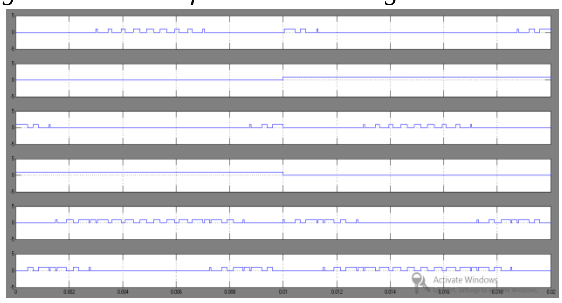


*Fig.7.Switching pulses for switches S1-S6*

The simulink diagram for seven level inverter with R-load is shown in fig 8 and the output voltage and THD performance is shown in figs9 and 10.

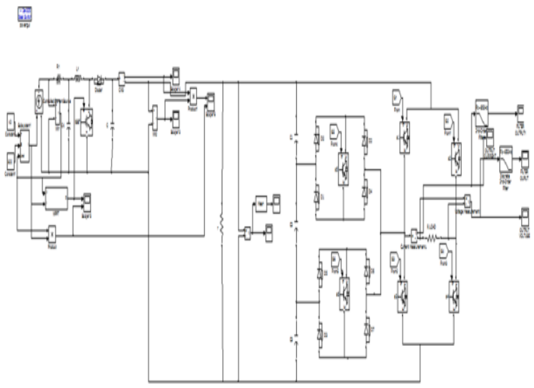


*Fig.8.Seven level inverter with R-load*

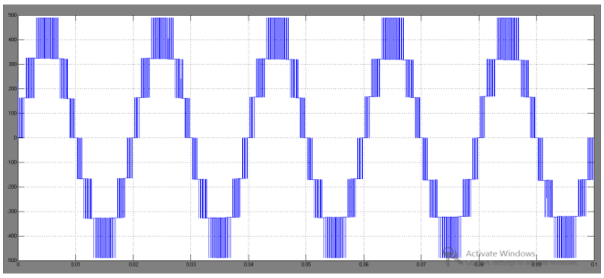


*Fig.9. output voltage waveform*

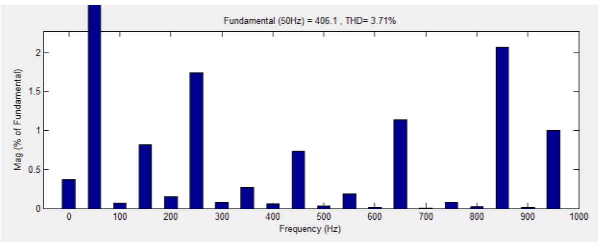



*Fig.10. THD of seven level output voltage*

The seven level inverter with 1-ph asynchronous motor as load using PID as the feedback controller is shown in fig 10. The speed characteristics are shown in fig 11 which has settled at 0.15 secs.

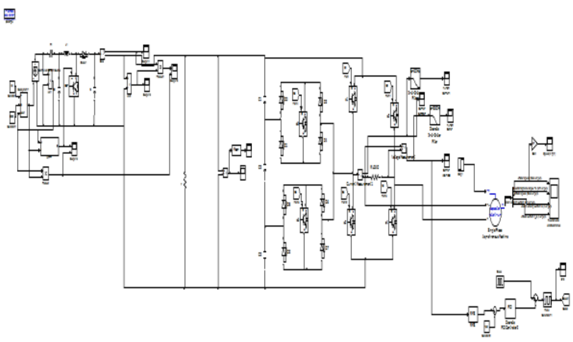


*Fig. 10 .seven level inverter with 1-ph asynchronous motor load using pid feedback controller*

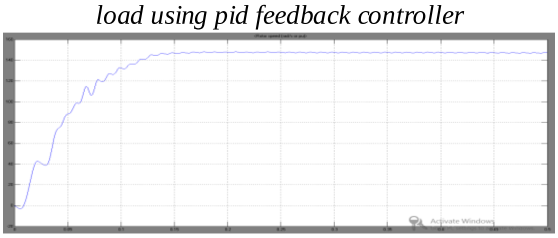


*Fig.11.Speed characteristics*

The seven level inverter with 1-ph asynchronous motor load using fuzzy feedback controller with 49 rules is shown in fig 12. The motor speed characteristics are shown in fig 15 which has settled at 0.1 secs.

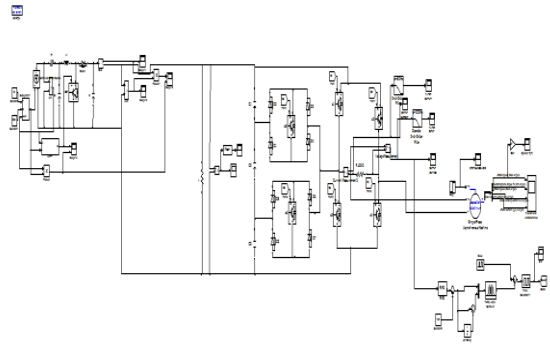


*Fig. 12.Seven level inverter with 1-ph asynchronous motor load using fuzzy feedback controller*

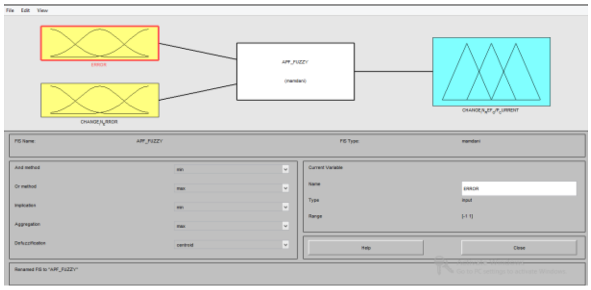


*Fig. 13.Fuzzy interface system*

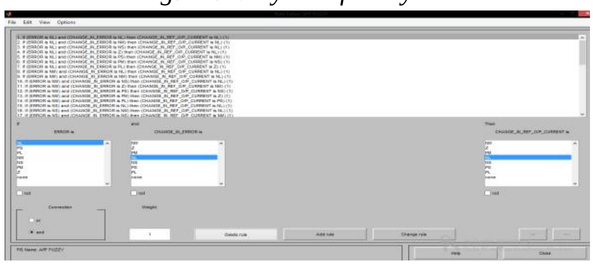


*Fig. 14.Fuzzy rule viewer*

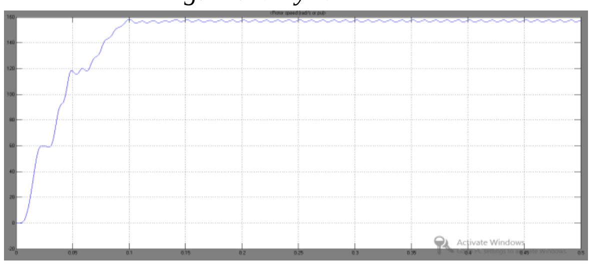


*Fig. 15.Speed characteristics*

## Conclusion

The fuzzy logic controller to seven level inverter with 1-ph asynchronous motor load improves the speed characteristics. This paper has presented with the three reference signals and one carrier signal to generate the switching signal and the desired levels of output voltage has achieved. The THD performance has also improved with the seven level inverter.

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