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Modulation of Five Level Inverter Topology for Open End Winding IM Drive using Fuzzy PID

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ABSTRACT

A Fuzzy PID controller based open end winding IM drive using v/f speed control fed by five level inverter is proposed in this paper. Five level inverter is fed such as three phase, three level, to the one end of the IM drive and three phase two level to the other end of the IM. So, combined result is getting five level motor phase voltage. Reverse-mapping based Space vector pulse width modulation technique is used in this paper. Controller is designed closed loop v/f speed control by fuzzy logic based. In constant v/f control variable speed IM drive, the controller is capable of reducing undesirable sustained oscillations which are commonly occurred at low frequencies. Results are presented for entire speed range during both light and high load condition, so complete drive is simulated in matlab.

Keywords:—*SVM; Fuzzy PID controller; Open-end winding induction motor; Multilevel Inverters; Induction motors drive*

I. INTRODUCTION

In recent years, industry has begin to demand higher power equipment, which now reaches the megawatt level. Controlled ac drives in the megawatt range are usually connected to medium voltage network. Today, it is hard to connect a single power semiconductor switch directly to medium voltage grids (2.3, 3.5, 4.16 or 6.9 KV). For these reasons a new family of multilevel inverters has emerged as the solution for working with higher voltages. Three classical topologies for multilevel Inverters are NPC (neutral point clamped), flying capacitor, CHB (cascaded H- bridge) inverter.

Multilevel inverters have gaining popularity most attractive features of multilevel inverter are:

1. They can generate output voltage with extremely low distortion and lower dv/dt.
2. They draw input current with very low distortion.
3. They generate smaller (CM) common mode voltage, thus reducing the stress in the motor bearings.

Three topology which gives common problem i.e with the increase in no. of levels in the output voltage, so structures becomes so complex and less reliable due to use of large no. of switching devices. H. Stemmler and P. Guggenbach proposed a new concept which is open end stator winding IM fed by two level inverter from both ends in 1993,to resolving above problems, newly research a technology which is open end winding IM drive.

Two level inverter is proposed by three level voltage space vectors generation for open end winding IM. To reduced the no. of DC sources and increased the reliability a hybrid topology which uses a single DC link and flying capacitor to generate five level voltage across the phase of open end winding IM is proposed in. By using only two no. of two level inverter and two capacitor fed H-bridge in each phase seven level voltage waveform generation is shown in this type of configuration increased the reliability because in case if any bridge fails the inverter can still be operated at reduced power level No clamping diodes are required and also for capacitor balancing hence no other circuit is required. The three main steps of implement of SVPWM are the sector identification, switching time calculation and switching vector determination. The no. of level increased identification of the sector where actual reference vector. A Nabae, I. Takashi and H. Akagi in 1981, he proposes on pwm generation scheme for any smoother than those of a two level inverter. The proposed method can be used for an inverter with an no. of level also. Even no. of levels can be implemented without any additional complexity.

As the number of level increased identification of the sector where actual reference vector lies, becomes very difficult. To overcome this problem a scheme is proposed in [15], in which the actual sector where the tip of the instantaneous reference space vector lies need not to be identified to generate switching signals. For speed control of induction motor constant V/f control scheme is widely used because of its low cost and simple implementation. But at the lower speed range the performance of drive get deteriorates due to voltage drops across stator resistances, which causes deterioration of air gap ux. In addition of this problem of sustained oscillation which also in varying nature depending upon load at lower speed range is also another issue to be addressed. Several compensation scheme to address these problems are reported in literature [16][18]. In this paper a fuzzy logic based closed loop V/f control open-end winding induction motor drive system is proposed. One side of the open-end winding stator is fed by three level inverter while other side is fed by two-level inverter. The combined effect of these two inverters is generation of five level in motor phase voltage. To generate control pulses for inverters space vector pulse width modulation (SVPWM) technique is used.

2. PROPOSED DRIVE SYSTEM

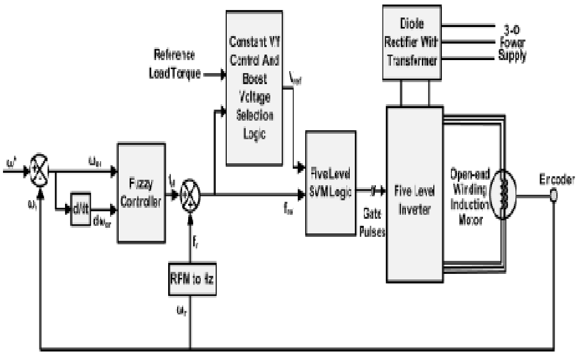

Figure 1: Proposed Drive System

In the proposed drive system speed control of open-end winding induction motor is carried out by maintaining V/f ratio constant. Proposed drive system is shown in Figure 1. The complete block diagram of the pulses generated by encoder used as feedback signal to computes the angular speed of the rotor r from these pulses. The rotor speed r is compared with reference speed and speed error er is generated. The speed error er and change in speed error d er are given to the fuzzy logic controller which generates the slip frequency fsl. V/f control and boost voltage selection logic which generate the reference phase voltage for five level space vector modulation (SVM) logic. The five levels SVM logic generates the appropriate gating signals for five level inverter depending upon reference voltage Vref and reference frequency fref. A reverse mapping based space vector pulse width modulation (SVPWM) technique is used to increase the DC link voltage utilization and reduced the switching losses. Now the reference frequency fref is generated by adding the slip frequency fsl to the rotor frequency for. This reference frequency is given to the constant.

A) Power circuit of five level inverter

The complete structure of five-level inverter along with open end stator winding induction motor is shown in Figure 2 One end of the open end winding(A2, B2, C2) is connected to three level inverter A while other end (A3, B3, C3)is connected to two-Level inverter B. The three- level inverter-A is realized by connecting two, two-levelinverter-1 and 2 in cascade so in total the complete structure uses three conventional two-level inverter. The DC link voltage of two level inverter-1 and 3 is (1/4)VDC each, whereas two-level inverter -2 is having DC link voltage of (1/2)VDC where VDC is the equivalent DC-link voltage required to operate conventional two-level inverter fed induction motor drive.

The DC link voltages for all the three, two-level inverters are generated by three phase rectifiers, REC.1-3 as shown in Figure 2. Pole voltages VA2O, VB2O or VC2O of three- level inverter-A can have any of three levels 0, (2/4) VDC or (3/4)VDC independently. Similarly two-level inverter -B pole voltages with respect to its own reference point O are VA3O,VB3O and VC3O can also have any of two levels either 0 or (1/4) VDC independently. The combine effect of inverter-A and B will be the generation of five different levels in the phase winding of induction motor. These levels are -(1/4)VDC,0,(1/4)VDC, (2/4) VDC, (3/4)VDC.

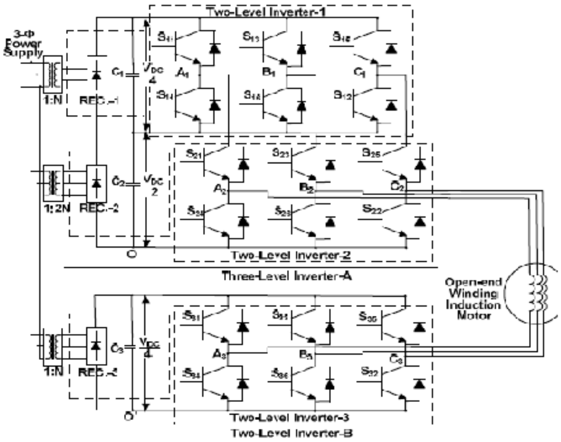

Figure 2: Power Circuit of Five Level Inverter with Open End Winding

Table1: Five Level Realized in Phase-A for Combinations of Pole Voltage of Inverter-B

Level	Pole voltage of 2-level inverter-A (VA20)	Pole voltage of 3-level inverter-B (VA30)	Motor Phase voltage (VA2A3) =VA20-VA30
L1	0	(1\4)Vdc	-(1/4)Vdc
L2	0	0	0
L3	(2/4)Vdc	(1/4)Vdc	(1/4)Vdc
L4	(2/4)Vdc	0	(2/4)Vdc
L5	(3/4)Vdc	0	(3/4)Vdc

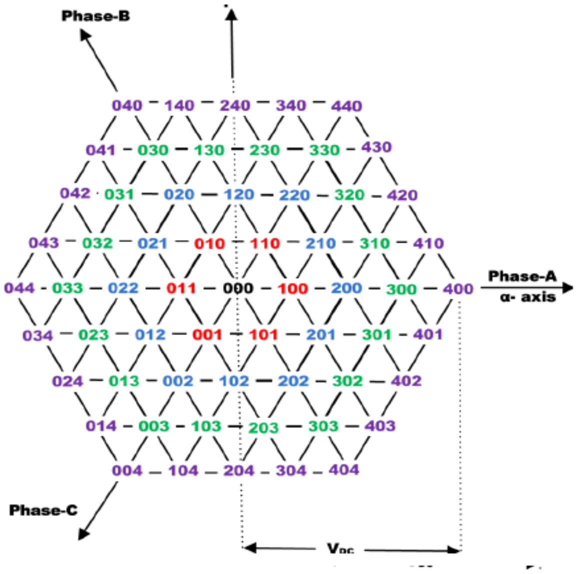

Figure 3 : Power Circuit of Five Level Inverter with Open End Winding

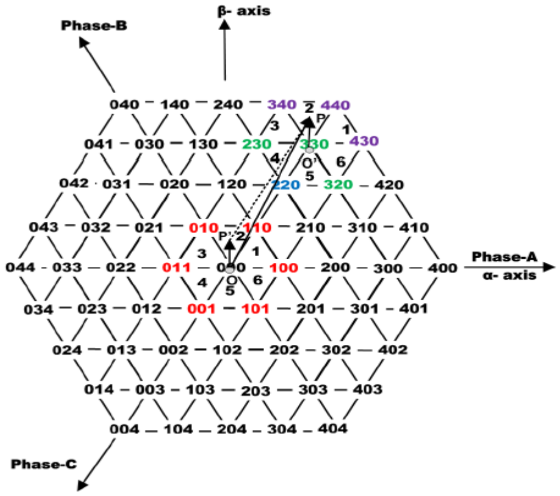

Figure 4: Power Circuit of Five Level Inverter with Open End Winding

Table 2: Switching States of Phase-A Related Switches of all the Three Inverters

Level	Motor phase –A vtg (VA2A3)	Switch inverter -1	Switchin-verter-2	Switch inverter-3
L1	-(1/4)Vdc	S14(ON)	S24(ON)	S31(ON)
L2	0	S14(ON)	S24(ON)	S34(ON)
L3	(1/4)Vdc	S14(ON)	S21(ON)	S31(ON)
L4	(2/4)Vdc	S14(ON)	S21(ON)	S34(ON)
L5	(3/4)Vdc	S11(ON)	S21(ON)	S34(ON)

B) Generation of optimizing switching sequence

A reverse mapping technique proposed in [15] is used to generate optimize switching sequence for inverter. When both the inverters are feeding simultaneously they can generate a total of 512 space phasors distributed over 61 locations as shown in Figure 3 for simplicity redundant switching states are not shown. There are four co-centric hexagons forming four layer of operating region. When the reference phasors Vs exist within the first layer, which is the region inside the innermost hexagon the inverter operates in two-level mode, reference phasor is in between first and second hexagon i.e. in layer two the operation is shifted from two-level to three-level similarly when reference phasor is in layer three mode of operation is four-level and finally where reference phasor is in layer four the operation reaches to its maximum level which is the five-level mode of operation. The reverse mapping technique can be easily understand by Figure 4.where the reference phasor OP is in layer four and the tip of reference phasor is in sector-2 of sub-hexagon whose center is 330. Now by subtracting there reference vector at the center of the sub-hexagon, the reference space vector can be mapped in to sector-2 of inner hexagon as OP'. The vectors 000, 010, and 110 are associated with sector-2 of the inner hexagon. Now by adding these inner vector to the center of sub-hexagon which is 330 the actual switching vectors 330 (330+000), 340 (330+010), and 440 (330+110)for the actual reference vector are generated. The advantage of this scheme is that the actual sector that contains the reference space vector needs not to be identified and apart from this the dwell time calculation is totally based on two-level operation hence it is fast. Below figure shows space phase distribution for five level inverter.

III. DESIGN OF FUZZY LOGIC BASED V/F CONTROLLER

A. V/f control design

The controller is design for 1.5 KW, 415V (L-L), 50Hz, 4 Pole open-end winding induction motor which is having maximum electromagnetic torque bearing capacity of 22n.m. The main objective of controller is to reduce the oscillation in rotor speed especially in lower speed range for light and high load condition. A load of 6 n.m and 15n.m. is considered for light and high load respectively. A speed range of 120 rpm-600 rpm correspond to 4Hz-20Hz is considered as lower speed range. The simulation is carried out to find appropriate boost voltage for light and high load condition. It is found in simulation that at 6 n.m load the motor is refuse to start below 2.6Hz at rated V/f ratio of 4.792 (rated phase voltage/rated frequency). Now the boost voltage Vboost which is to be added given by Vboost = Rs Is + 4.792

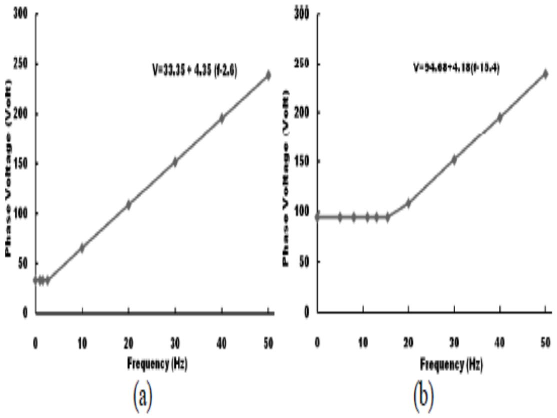

Figure 5: V/F Control Design for Light Load Figure(a) and (b) High Load

Where Rs and Is are per phase stator resistance and rated phase current respectively. From motor name plate rating and by doing experimentation the product of Rs and Is has been found 20.88, hence the value of the boost voltage Vboost is come out to be 33.35. Now the slope of V/f line is decided by joining the boost voltage Vboost at 2.6 Hz to the rated phase voltage at rated frequency. The final V/f design for light load is shown in Figure Adopting the similar procedure for high load condition the boost voltage Vboost is found to be 94.68 at 15.4 Hz. The corresponding design is shown in Figure (5)

B) Design of fuzzy logic based V/f controller

A fuzzy logic based controller is design to compensate slip speed. It is shown in simulation results that as compare to conventional PI controller response of proposed fuzzy controller in terms of overshoot and steady state oscillations, is better over a wide range of speed and load torque variation.

The complete block diagram of proposed fuzzy controller is shown in Figure 6 The proposed fuzzy controller uses speed error er and change in speed error der as input signals and generate slip frequency fsl. All the inputs and output of fuzzy controller are updated in every sample time step. The gains G1 and G2 are used to scaled inputs of fuzzy controller into a common discourse universe with values between [-1, 1] where as gain G3 is output gain.

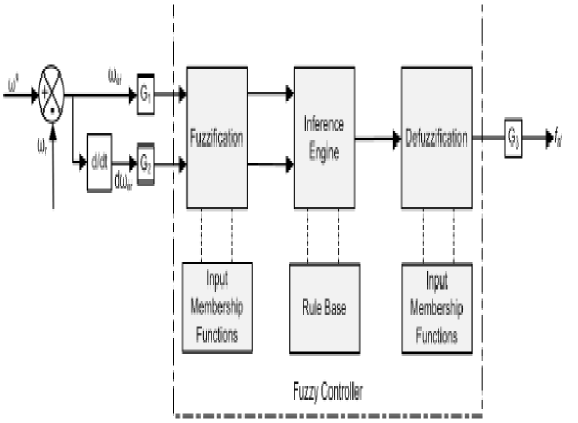

Figure 6: Block Diagram of Proposed Fuzzy Controller

Block diagram of proposed fuzzy controller the complete controller is design in three steps, the first step is fuzzification in which all the input and output variables are converted in to fuzzy set and a membership function is associated to each variable. Seven linguistic variables are chosen for input variables as: (1) negative big (NB), (2) negative medium (NM), (3) negative small (NS), (4) zero (ZZ), (5) positive small (PS), (6) positive medium (PM) and (7) positive big (PB), where as for output eleven linguistic variables are chosen which are as follows: (1) negative big (NB),(2) negative medium big (NMB), (3) negative medium (NM), (4) negative medium small (NMS),(5) negative small (NS), (6) zero (ZZ), (7) positive small (PS), (8) positive medium small (PMS), (9) positive medium (PM), (10) positive medium big (PMB), (11) positive big (PB).

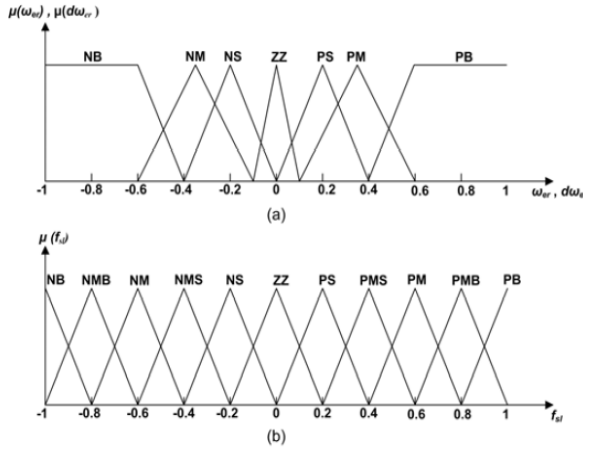

Figure 7 (a) Membership Functions for Inputs ωer and dωer (b) Membership function for Output fsl

The complete fuzzy set along with their membership function for inputs and output variable are shown in Figure 7 (a) and Figure 7(b).The second step is development of inference engine which generate the possible inference depending upon the input membership function and rule base. The rule base consist of IF-THEN statements which govern the input output Relationship like IF (er is positive small, PS) AND (der is negative small, NS) THEN (fsl is Zero).

IV. MATHEMATICAL MODELING

$$Wsl = (We - Wr) = \frac{Lm}{Tr\Psi r} \quad (1)$$

Where, Slip frequency (Wsl=We-Wr) is the difference between synchronous speed and rotor speed.

$$Tr\frac{d\Psi r}{dt}(\Psi r = Lmids) \quad (2)$$

Electromagnetic torque equation can be written as:

$$Te = \left[\frac{3PLm}{4Lr}\Psi rids\right] \quad (3)$$

Rotor angular speed Wr can be derived from mechanical dynamics of motor as:

$$\frac{dwr}{dt} = -\frac{B}{J}wr + \frac{1}{J}(Te - TL) \quad (4)$$

Where,

J=Moment of inertia

B=Viscous friction of motor

Tl=Load torque

Using slip frequency from equation (2) and rotor speed from equation (5), flux position can be obtained as:

$$\Theta e = \int Wedt = \int (Wr+Wsl)dt \quad (5)$$

$$Vs = (VA20 - VA30) + (VB20 - VB30)e^{j\left(\frac{2pie}{3}\right)} + (VC2 - VC30)\, e^{j\left(\frac{4pie}{3}\right)} \quad (6)$$

$$\begin{matrix} Vs(\alpha) \\ Vs(\beta) \end{matrix} = \begin{matrix} 1 & -\frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{matrix} \quad \begin{matrix} VA20 - VA30 \\ VB20 - VB30 \\ VC20 - VC30 \end{matrix} \quad (7)$$

Table 3: Rule Base of Proposed Fuzzy Controller

Wer	NB	NM	NS	ZZ	PS	PM	PB
NB	NB	NB	NMB	NM	NMS	NS	ZZ
NM	NB	NMB	NM	NMS	NS	ZZ	PS
NS	NMB	NM	NMS	NS	ZZ	PS	PMS
ZZ	NM	NMS	NS	ZZ	PS	PMS	PM
PS	NMS	NS	ZZ	PS	PMS	PM	PMB
PM	NS	ZZ	PS	PMS	PM	PMB	PB
PB	ZZ	PS	PMS	PM	PMB	PB	PB

In proposed design forty-nine rules are used to generate eleven possible inferences as shown in Table III. The third step of design is defuzzification of linguistic output variable to get the crisp value of slip frequency. In the proposed design centroid method is used for defuzzification and the slip frequency fsl is given as The control surface of proposed design which clearly shows that as the speed error and change in speed error move towards zero output slip frequency also tends towards zero.

V. SIMULATION RESULT AND DISCUSSION

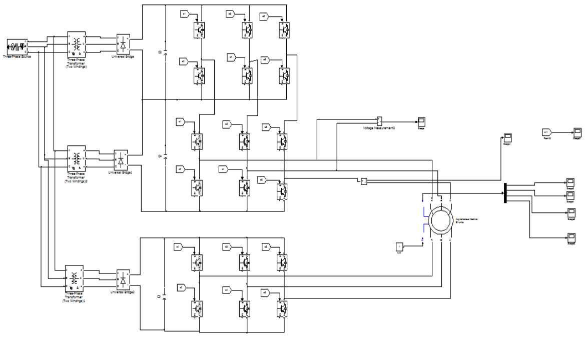

Figure 8: Simulink Diagram of Five Level Inverter

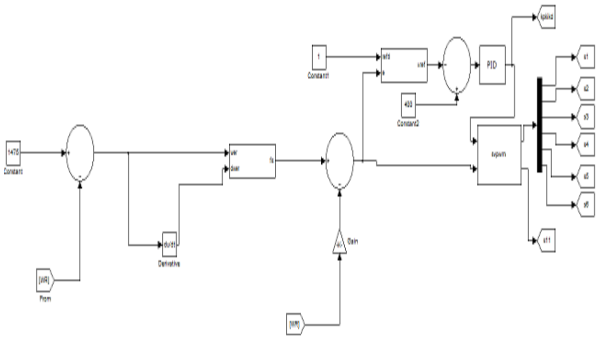

Figure 9: Simulation Diagram of Fuzzy PID System

This above Figure (8) shows the simulink diagram of five level inverter, and Figure (9) shows the simulation of fuzzy PID controller. Simulation result shows the Figure (10)is a output voltage of five level inverter. In this five level inverter operation is first level is clamped to zero, second level is zero to 200v, and third level is -200v,simillarly fourth level is -400v and last finally 400v is fifth level of five level inverter. Above fig(11)shows the output current of five level inverter which is 2.4 A Similarly fig(12)shows the Rotor speed response under light load condition 6 n.m. and fig(13) shows the Rotor speed response under high load condition which is 15 n.m. Fig(14) shows the Fuzzy PID speed response under light load and fig(15) shows the Fuzzy PID Speed response under high load.

The proposed drive system is simulated using simpower system and simulink toolbox of MATLAB-7. For doing simulation study the equivalent DC link voltage VDC is consider as 600 volt. The switching frequency is kept constant at 2 kHz throughout the operation. Firstly the simulated model is operated at no load for complete modulation range at rated V/f ratio to check the correctness of developed space vector pulse width modulation (SVPWM) logic. At lower speed of240 rpm modulation index is low and inverter operates in two level mode confirming the layer-1 operation, corresponding waveform of motor phase-A voltage VA2A3 and current are shown in Figure 7 (a). The pole voltage waveforms of phase-A for inverter-A & B are shown in Figure 7(b). It can be seen from pole voltage waveform Figure 7 (b), that in this mode inverter-B is switched between (1/4) VDC and zero while inverter -A is clamped at zero. When speed reference is increased from 240rpm to 600 rpm inverter operates in three-level mode confirming layer-2 operation, corresponding waveforms of motor phase-A voltage VA2A3 and current are shown in Figure 8a). In this mode inverter-B switched between (1/4)VDC and zero whereas inverter-A operates in two-level mode and takes the value (1/2)VDC and zero as shown in pole voltage waveforms Figure 8 (b), of phase-A for inverter-A & B. Similarly for higher speed reference of 1400 rpm inverter operates in five-level mode confirming layer-4 operation, corresponding voltage, current and pole voltage waveforms of phase-A are shown in Figure 9 (a) and (b) respectively. From phase voltage waveform it can be observed that as the inverter operation is shifted from two-level to five-level the motor phase voltage waveform becomes more and more sinusoidal and hence harmonic spectrum is also improved.

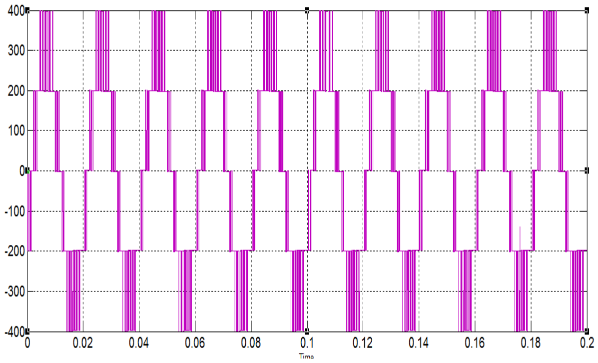

Figure 10: Output Voltage of Five Level Inverter

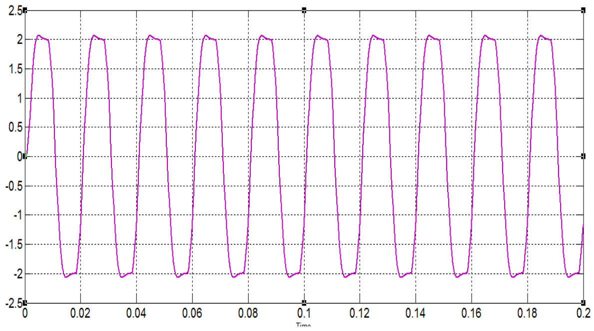

Figure 11: Output Current of Five Level Inverter

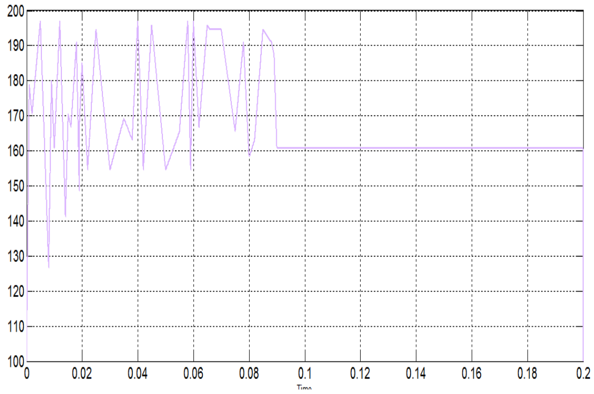

Figure 12: Rotor Speed Response Under Light Load for 6 n.m.

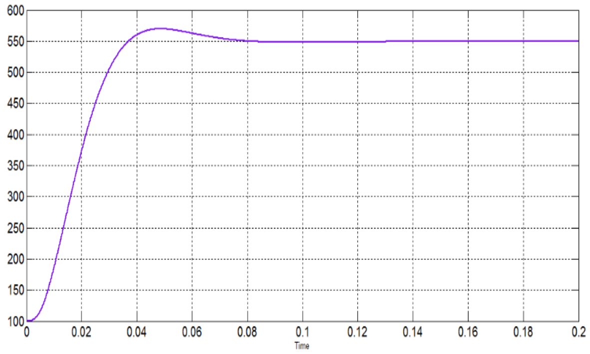

Figure 13: Rotor Speed Response Under High Load of 15 n.m.

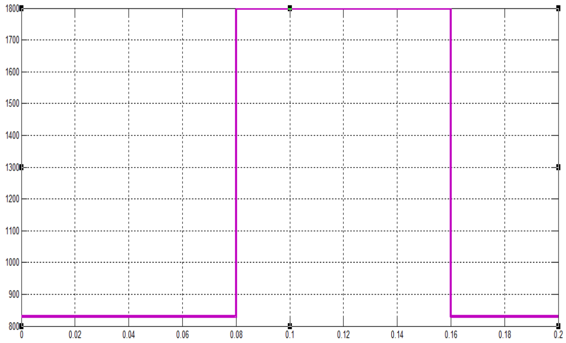

Figure 14: Fuzzy PID Speed Response Under Light Load Condition

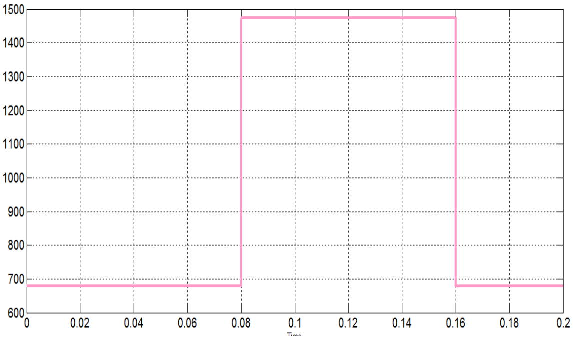

Figure 15: Fuzzy PID Speed Response Under High Load Condition

Table.4: Comparison Between Fuzzy and Fuzzy PID Output Results:

Sr. no	Parameter	Fuzzy controller	Fuzzy PID controller
1	Voltage	400V	400V
2	Current	2.2A	2A
3	Rotor speed for light load	80rpm	198rpm
4	Rotor speed for high load	390rpm	550rpm
5	Fuzzy Speed response for light load	600rpm	1490rpm
6	Fuzzy Speed response for high load	1400rpm	1800rpm

VI. CONCLUSION

In this paper fuzzy PID based closed loop constant V/f control scheme is proposed for five-level inverter fed open-end winding induction motor drive. A new method is proposed to design appropriate V/f ratios and boost voltages that can start the motor below the minimum starting frequency at various loading condition. Simulation results depicted that the proposed scheme drastically reduced the steady state oscillations in rotor speed which are very common at low speed in constant V/f control induction motor drive. The comparative analysis of proposed Fuzzy PID controller with conventional Fuzzy controller shows that the proposed method achieves better result in terms of overshoot and steady state oscillation. By using Fuzzy PID controller instead of Fuzzy we getting improved voltage, reduced current increase the rotor speed, and reduces harmonics, so when the harmonics reduces means output getting more sinusoidal with better results comparative Fuzzy controller. The complete drive system is simulated in MATLAB and simulation results satisfactory validate the design of Fuzzy PID controller and feasibility of drive system.

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