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Fuzzy Logic Closed Loop Control of 5 level MLI Driven Three phase Induction motor

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ABSTRACT

This paper deals about fuzzy logic control of closed loop controlled five level Multi Level Inverter (MLI) driven three phase induction motor. Three phase Induction motor is most widely used drive in Industries, so needs proper control of speed. Induction motor is fed from five level multilevel inverter which is controlled by fuzzy logic. The closed loop consists of two loops. First inner loop is current loop and second outer loop is speed loop. The torque is varied at different times and corresponding change in speed and Total Harmonic Distortion (THD) is observed. The MLI is controlled by Sinusoidal Pulse Width Modulation (SPWM) Technique.

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1. INTRODUCTION

Fuzzy logic is one of the most interesting fields where fuzzy theory can be effectively applied. Fuzzy logic techniques attempt to imitate human taught process in technical environments. So fuzzy logic techniques can be applied to complex problems such as closed loop control which reduces the time and cost [1]. While fuzzy control technique is being applied two things to be considered are i) selection of fuzzy control rules and ii) selection of appropriate membership functions.

Multilevel inverters are being used for dc to ac power conversions in high power applications such as utility and large motor drives. Multilevel inverters provide more than two voltage levels a desired output voltage waveform can be obtained from the multiple voltage levels with less distortion, less switching frequency, higher efficiency. [2] Multilevel Inverters have many advantages compared with and well known two level converters [3]. These advantages are fundamentally focused on improvements on the output quality and a nominal power increase in the inverter. Several Modulation and control Strategies have been developed for multilevel inverters including the following i) Sinusoidal Pulse Width modulation (SPWM) ii) Selective Harmonic Elimination (SHE) and iii) Space Vector modulation (SVM) [4]. Closed loop consists of inner current control loop and an outer speed control loop. In speed control loop fuzzy logic controller is used. In current control loop fuzzy logic controller is used. Tuning a control loop is the obtained by choosing appropriate fuzzy rules to the optimum value for the desired control response [5]. The torque input is varied at different instants of time and response of speed and THD'S are noted.

2. MULTI LEVEL INVERTERS (MLI)

Multi Level Inverters (MLI) includes an array of power semiconductor devices and capacitor voltage sources, the output of which generate voltages with stepped waveforms. The commutation of switches permit the addition of capacitor voltages, which results as high voltage at output, while the power semiconductor must withstand only reduced voltages. [6]

The Figure 1 shows a schematic diagram of one phase leg of inverters with different number of levels for which the action of semiconductors is represented by ideal switch with several positions. The term multi Level starts with the three level inverter introduced by Nabae (1981) [7]. By increasing number of levels in inverter, the output voltages have more steps generating a stair case waveform which has reduced harmonic distortion. However higher number of levels increase the control complexity and introduces the voltage imbalance problems. Hence in this paper five level inverter is considered for study.

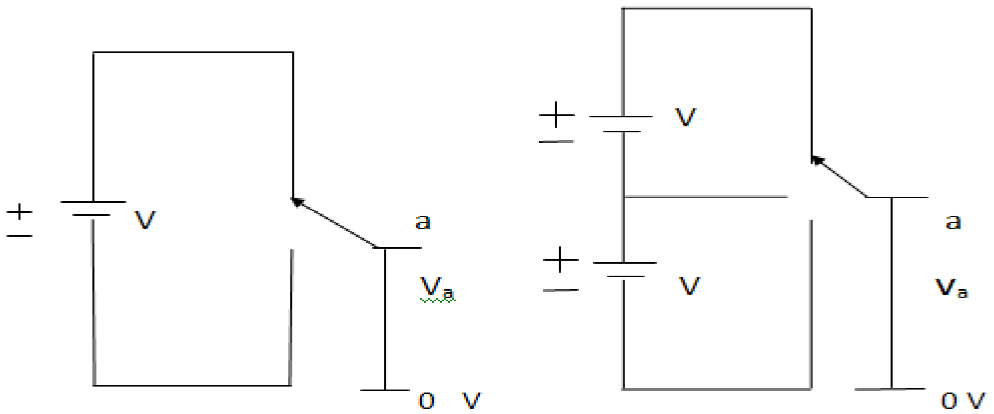

Figure 1. Two level and three level Inverter

The different Multi Level Inverter topologies are i) Diode clamped Inverter ii) Capacitor Clamped Inverter iii) Cascade full bridge Inverter. Out of this three topologies diode clamped inverters most widely used as it is well suited for drives directly connected to utility power system in the high and medium voltage ranges. Diode clamped topology needs only one power supply, so inverters with this topology is most suited for industrial adjustable speed drives. So Diode clamped Multi Level Inverter is considered for study.

Several modulation methods are used for Multi Level Inverters, few among them are a) Sinusoidal Pulse Width Modulation (SPWM) b) Selective Harmonic Elimination (SHE) and c) Space Vector Modulation (SVM). The Modulation technique used here is SPWM. In this modulation, a sinusoidal signal at power frequency is compared with Triangular Carrier wave with high frequency to generate pulses for switches in inverter to operate. The signal generated are shown in figure 2.

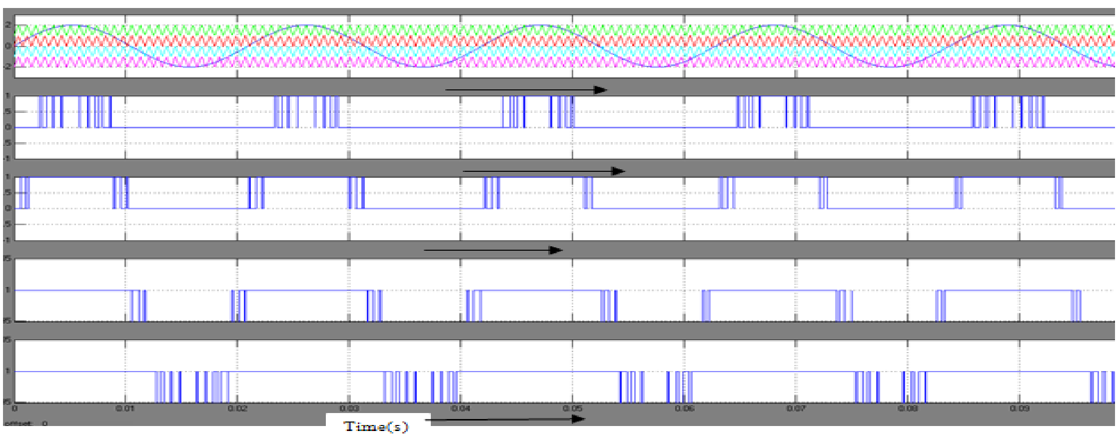

Figure 2. Sinusoidal Pulse Width Modulation Technique-Carrier signals and pulses to switches

3. FUZZY LOGIC

In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection. To understand why use of fuzzy logic has grown, you must first understand what is meant by fuzzy logic.

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multi valued logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of FL. Even in its more narrow definition, fuzzy logic differs both in concept and substance from traditional multi valued logical systems. Another basic concept in FL, which plays a central role in most of its applications, is that of a fuzzy if-then rule or, simply, fuzzy rule. Fuzzy logic is all about the relative importance of precision. Fuzzy logic is both old and new because, although the modern and methodical science of fuzzy logic is still young, the concepts of fuzzy logic rely on age-old skills of human reasoning.

Fuzzy logic starts with the concept of fuzzy set. A fuzzy set is a set without a crisp, clearly defined boundary. It can contain elements with only a partial degree of membership. In fuzzy logic, the truth of any statement becomes a matter of degree. Any statement can be fuzzy. The major advantage that fuzzy reasoning offers is the ability to reply to a yes-no question with a quite yes-or-no answer. A Membership Function (MF) is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is sometimes referred to as the universe of discourse, a fancy name for a simple concept.

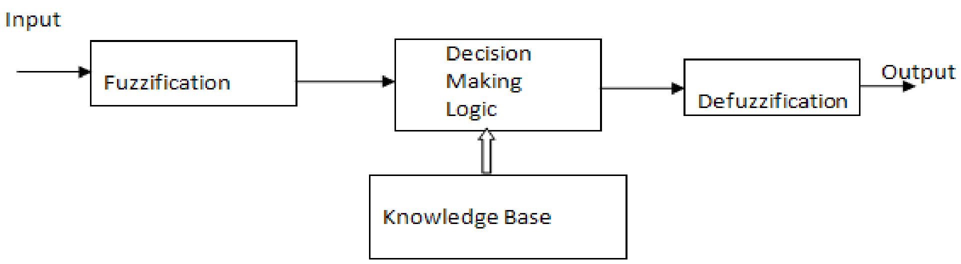

Figure 3. Fuzzy logic control system

Figure 3 Illustrates the four basic blocks of fuzzy control .In fuzzification block real world values are converted into values understood by fuzzy logic. In Decision making block decision is made on the rules we make and that are kept in Knowledge base. Finally in defuzzification block fuzzy values are converted into real world values. The following are some membership functions used in fuzzy logic i) Triangular ii) Trapezoidal iii) Gaussian and iv) Generalized bell. In this paper Triangular membership function is used.

4. CLOSED LOOP CONTROL OF INDUCTION MOTOR

The Induction motor speed can be controlled by varying torque input of the motor. The figure 4 shows the circuit for Fuzzy Logic Closed Loop Control of 5 level Multi Level Inverter Driven Three phase Induction motor. First the reference speed i.e. the rated speed of induction motor is compared with speed feedback. The angular speed obtained from motor is converted into speed using appropriate block. The feedback speed and reference speed are fed to fuzzy logic controller1 through fuzzification blocks. The fuzzy controller1 gives the output. The output of fuzzy controller1 and current feedback are fed to fuzzy controller 2 through fuzzification blocks. The table 1 and table 2 illustrate the fuzzy rules used for fuzzy controller1 and fuzzy controler2 respectively. Membership Function1 and Membership Function2 that are used in both fuzzy controllers is triangular, which are shown in figure 5. and figure 6 respectively. The output from fuzzycontroller2 is fed to control signal generation block through defuzzification block. The control signal generation block generates sinusoidal signal which is fed to PWM generation block. PWM signal is generated by comparing a sinusoidal signal with triangular carrier wave at high frequency. Then PWM signal for each leg of Inverter is generated and fed to appropriate switches in Multi Level Inverter. Then Multi

Level Inverter generates a.c. signal which is given as input to Induction motor. The rating of Induction motor is 3Phase, 4500 W, 415 V, 50 Hz.

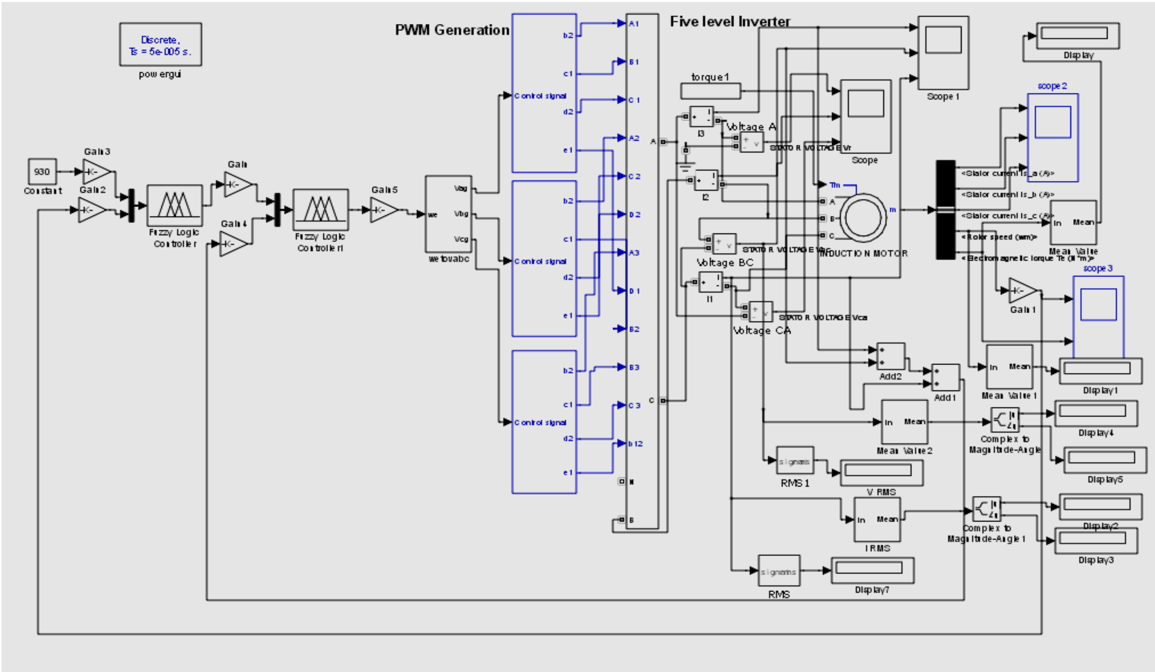

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Figure 4. Fuzzy Logic Closed Loop Control of 5 level Multi Level Inverter Driven Three phase Induction motor

Table 1. Fuzzy Controller 1

Speed Ref. → / ↓ Speed feedback	NL	NM	ZE	PM	PL
NL	NL	NL	NM	NM	ZE
NM	NL	NM	NM	ZE	PM
ZE	NM	NM	ZE	PM	PL
PM	NM	ZE	PM	PL	PL
PL	ZE	PM	PL	PL	PL

Table 2. Fuzzy controller 2

Fuzzy controller output → / ↓ Current feedback	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NM	NM	NS	NS	ZE
NM	NL	NM	NM	NS	NS	ZE	PS
NS	NM	NM	NS	NS	ZE	PS	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NS	NS	ZE	PS	PS	PM	PM
PM	NS	ZE	PS	PS	PM	PM	PL
PL	ZE	PS	PS	PM	PM	PL	PL

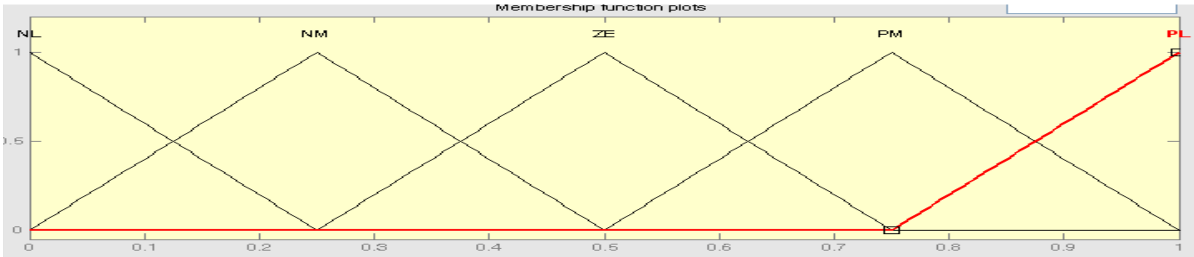

Figure 5. Triangular Membership Function 1

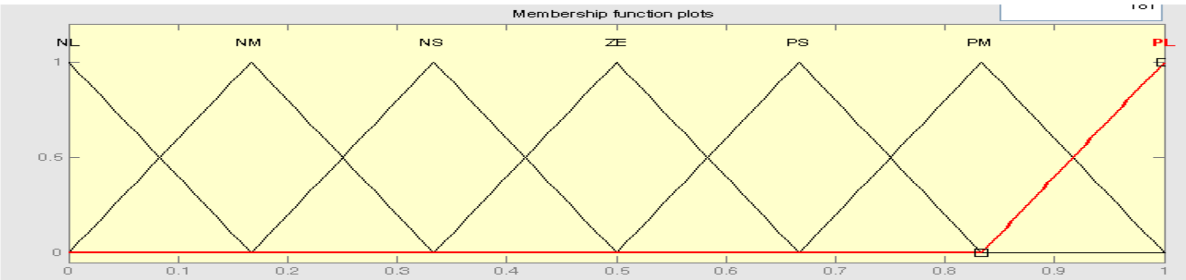

Figure 6. Triangular Membership Function 2

5. RESULTS

The Speed of Induction motor is varied by varying torques at different instants as shown in Table 3. The motor was started with no load, half load and full load and later with no load and load varied at different times as indicated in table. Even negative torque was applied. The carrier frequency is 1280 Hz. Table 4 illustrates the variation of torque ripple and d.c. current ripple with change in carrier frequency. Table 5 illustrates the variation of torque ripple and d.c. current ripple with change in carrier frequency as speed is reversed. The speed input is initially made positive, later speed input is negative and finally speed input is positive. Figure 7 and figure 8 shows d.c. current ripple and IGBT Current ripple. Figure 9 and Figure 10 shows the dc current and IGBT current ripple with current reversal Figure 11 gives stator voltage and Figure 12 shows Stator current. Figure 13 shows the variation of torque with time and speed with time. It is clear that as torque is increased speed has decreased. IGBT current value is 2.2082 mA, DC current is 6.5mA, stator current RMS value is 17.95 A, average torque is 40.35 N-m and average speed is 579.7 RPM.

Table 3. Current THD as torque is varied at different times

FUZZY CONTROLLER			
Torque Applied(N-m)	**Time(sec)**	**Voltage THD %**	**Current THD %**
0	0	6.37	**4.13**
20	0	6.37	7.17
40	0	6.66	**4.00**
0 20	0 2	6.66	7.57
0 40	0 2	6.29	**4.15**
0 20 40	0 2 4	6.54	**4.00**
0 -20 40	0 2 4	6.48	**4.10**
0 10 20 30 40	0 1 2 3 4	6.48	**4.10**
0 -10 -20 40	0 1 2 3	6.61	**4.12**

Table 4. Variation of d.c. current ripple and IGBT Current ripple with with carrier frequency

Carrier Frequency	DC Current Ripple(mA)	IGBT Current Ripple(mA)	Stator Current THD %
980	10	0.033	10.01
1120	10	0.033	11.01
1180	10	0.033	9.91
1220	10	0.033	10.21
1280	10	0.033	**4.13**
1320	10	0.033	10.21
1380	10	0.033	8.92
1420	10	0.033	9.09
1480	10	0.033	8.57
1520	10	0.033	8.94
4880	10	0.033	7.31
5880	10	0.033	6.15
6220	10	0.033	5.79
6880	10	0.033	5.79
7020	10	0.033	6.69
7220	10	0.033	6.39
7820	10	0.033	7.58
8000	8	0.033	8.49
8020	8	0.033	7.31
8880	8	0.033	7.19
9000	10	0.033	8.12

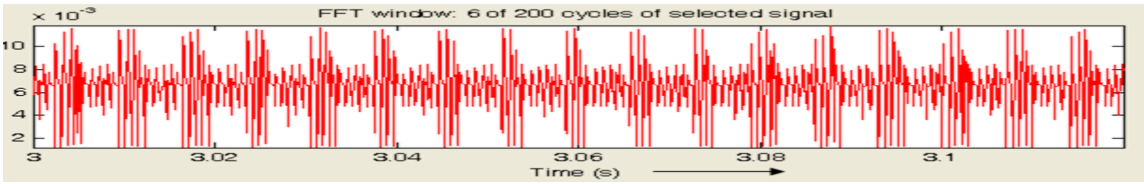

Figure 7. D.C. Current Ripple

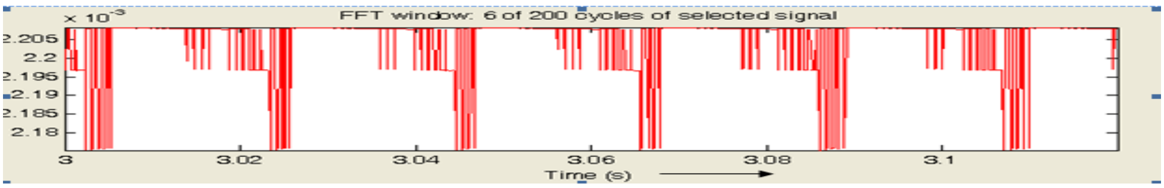

Figure 8. IGBT Current ripple

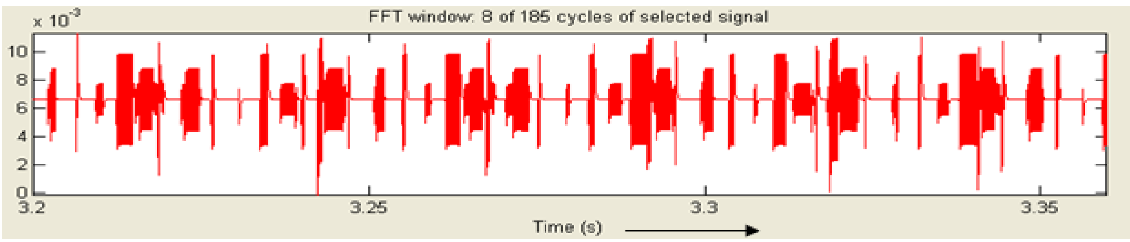

Figure 9. D.C. Current Ripple with speed reversal

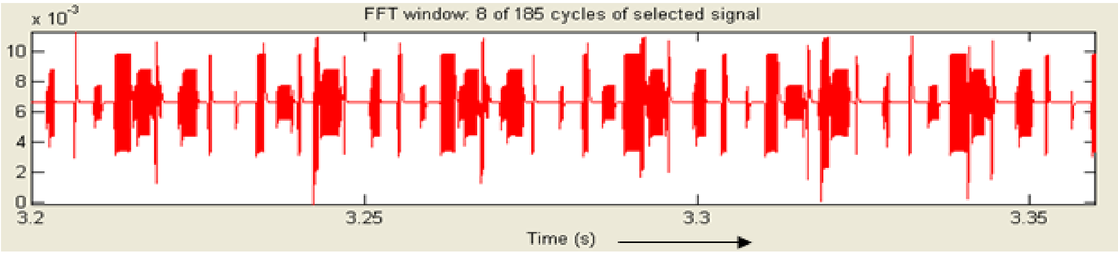

Figure 10. IGBT Current ripple with speed reversal

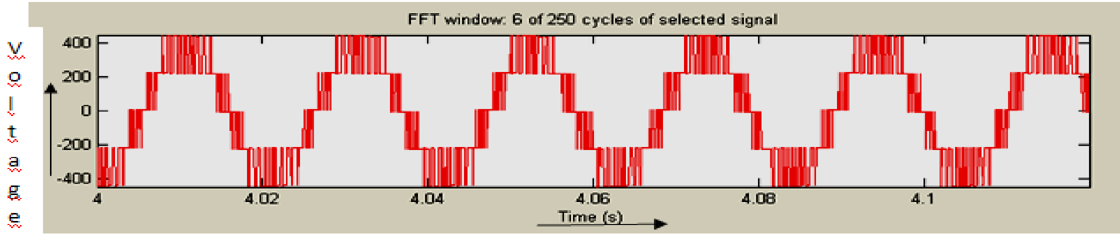

Figure 11. Stator voltage

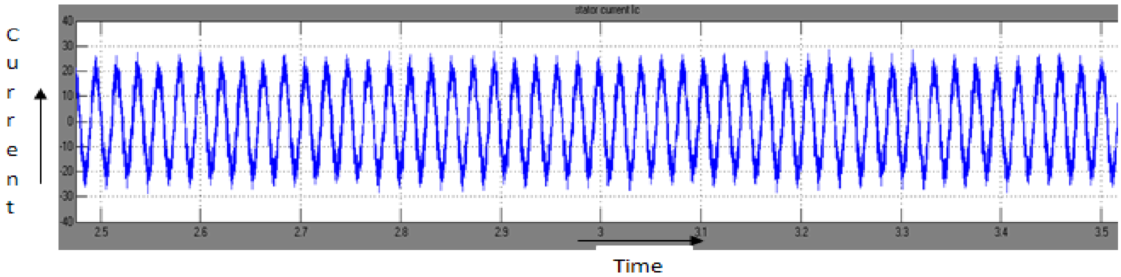

Figure 12. Stator current

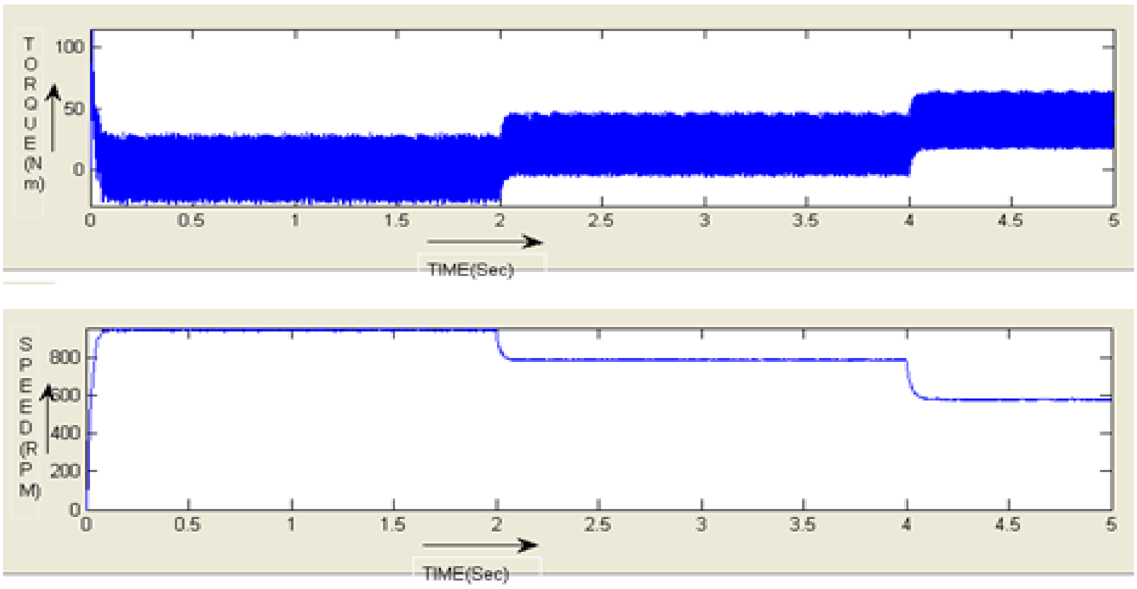

Figure 13. Speed vs time and Torque vs Time plot

6. CONCLUSION

It is clear from table 3 that although load is varied the THD at full load is around 4.00% which is within IEEE standards (5%). But the voltage THD is slightly above the 5% which is to be reduced. It is found that the carrier frequency of 1280 Hz is ideal for the circuit so it is used. DC current ripple is around 12 mA. This can be reduced using proper tunning of fuzzy controller. IGBT current ripple is around 0.225 mA.The torque ripple is slightly high which can be reduced using proper triggerring of inverter.As THD of current is less than 5 % it is ideal.

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