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Discrete SV PWM Simulation Based Speed Control Of Three Phase Induction Motor

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Abstract

Electric drives have a wide application in the industry and as well as other applications. Induction motors are the most rugged and widely used motors everywhere be it single or three phases. Pulse Width Modulation variable speed drives are increasingly applied in many new industrial applications where there is a need for superior performance. Recently, developments in power electronics and semiconductor technology have lead improvements in power electronic systems. Hence, different circuit configurations namely multilevel inverters have become popular and considerable interest by researcher are given on them. Variable voltage and frequency supply to ac drives is invariably obtained from a three-phase voltage source inverter. A number of Pulse width modulation (PWM) schemes are used to obtain variable voltage and frequency supply. One of the most widely used PWM schemes for three-phase voltage source inverters is Space Vector PWM (SV PWM). There is an increasing trend of using Space Vector PWM (SV PWM) because of their easier digital realization and better dc bus utilization. In this work with the method of SV PWM, lower order harmonics are minimized along with its output voltage control and also the higher order harmonics are filtered easily, so the filtering requirements are minimized. Simulation plays an important role in modelling and understanding of any work before they are actually being implemented on hardware. Simulation results are obtained using appropriate software environment by careful modelling and trial runs, which can be further used for the improvement in the work.

Keywords: *3phase induction motor, SVPWM, Speed control, Harmonics, SIMULINK/MATLAB.*

1- INTRODUCTION

Variable speed ac drives employing induction motors and converters have been developed in recent years to the point of meeting the high standards of performance set by dc drives. In earlier days separately excited dc motor were used extensively as the primary machine. But dc motors have some drawbacks like more weight to power ratio, frequent requirement of maintenance and, expensive and maintenance prone mechanical commutator. On the other hand, ac motors, especially induction motors with their simple, less expensive and more robust structure, are more suitable for industrial environments. However their control is quite complex. This is due to the fact that the rotor current in an induction motor, which is responsible for torque production, depends on stator current which also contributes to the air gap flux, resulting in a coupling between torque-producing flux and flux-producing components of stator current. In dc machines, the field current in stationary poles, producing the magnetizing flux and armature current, directly controlling the torque are independently accessible.

However, induction motors have generally been viewed as constant speed machines. Developments in static power controllers have made reliable and flexible variable- frequency supply available. This enables the use of robust induction motors in high- performance variable speed drives. It is possible to use the vector of the stator voltage or the vector of the stator current as the manipulated variable for the torque depending on whether the static converter supplying the motor provides a variable voltage or variable current.

The control of electric power is performed using power converters. The converter (inverters) transfers energy from a source in a switched operation mode that ensures high efficiency of the conversion. The algorithms that generate the switching functions are called Pulse-Width modulation techniques. One of the methods of PWM is Space Vector PWM (SVM or SVPWM). It is an advanced, computation-intensive PWM method and is possibly best among all the PWM techniques for variable frequency drive applications. SVM uses the concept of rotating space vector. In SVPWM scheme, a reference space vector is sampled at regular intervals to determine the inverter switching vectors and their time durations, in a sampling time interval. Three phase voltage-fed PWM inverters are recently showing growing popularity for multi-megawatt industrial drive applications. The main reasons for this popularity are easy sharing of large voltage between the series devices and the improvement of the harmonic quality at the output. In the lower end of power, GTO (Gate Turn off) devices are being replaced by IGBTs because of their rapid evolution in voltage and current ratings and higher switching frequency. This work focuses on SV PWM implemented on an Induction motor and the open loop speed control of the induction motor on various mechanical load conditions. Simulation results are obtained using MATLAB/Simulink environment for effectiveness of the study.

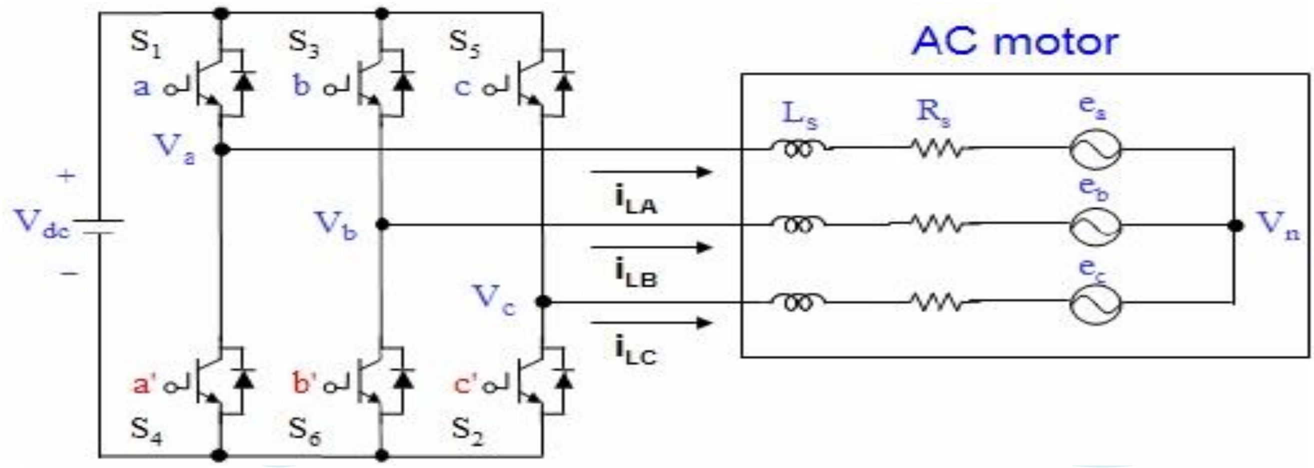

Fig 1. Three-phase voltage source PWM Inverter

2- PRINCIPLE OF SPACE VECTOR PWM

The circuit model of a typical three-phase voltage source PWM inverter is shown in Fig.1.S1 to S6 are the six power switches that gives the output, which are controlled by the switching variables a, a′, b, b′, c and c′. When an upper transistor is switched on, i.e., when a, b or c is equal to 1, the corresponding lower transistor is switched off, i.e., the corresponding a′, b′ or c′ is equal to 0.Therefore, the on and off states of the upper transistors S1, S3 and S5 can be used to determine the output voltage.

The relationship between the switching variable vector $[a, b, c]^T$ and the line-to-line voltage vector $[V_{ab}, V_{bc}, V_{ca}]^T$ is given below

$$\begin{bmatrix} Vab \\ Vbc \\ Vca \end{bmatrix} = Vdc \begin{bmatrix} 1-1 & 0 \\ 0 & 1-1 \\ -1 \quad 0 & 1 \end{bmatrix} \begin{bmatrix} ax \\ ay \\ az \end{bmatrix} \ldots(1)$$

Also, the relationship between the switching variable vector $[a, b, c]^T$ and the phase voltage vector $[V_a, V_b, V_c]^T$ can be expressed below.

As illustrated in Fig.1, there are eight possible combinations of switching (on and off) patterns for the three upper power switches. The on and off states of the lower power devices are opposite to the upper one and so are easily determined once the states of the upper power transistors are determined.

Space Vector PWM (SVPWM) refers to a special switching sequence of the upper three power transistors of a three-phase power inverter. It has been shown to generate less harmonic distortion in the output voltages and or currents applied to the phases of an AC motor and to provide more efficient use of supply voltage compared with sinusoidal modulation technique as shown in fig.2

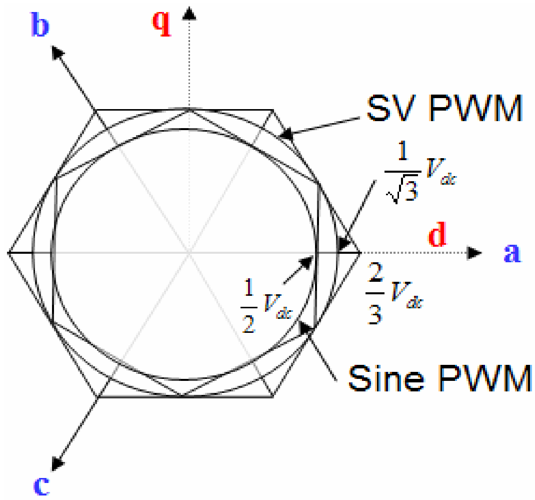

Fig. 2. Locus comparison of maximum linear control voltage in Sine PWM and SVPWM

To implement the space vector PWM, the voltage equations in the *abc* reference frame can be transformed into the stationary (*d-q)* reference frame that consists of the horizontal (d) and vertical (q) axes as depicted in Fig.3

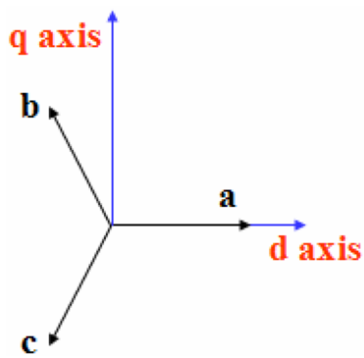

Fig. 3 The relationship of abc reference frame and stationary dq reference frame

SIMULINK model of proposed work

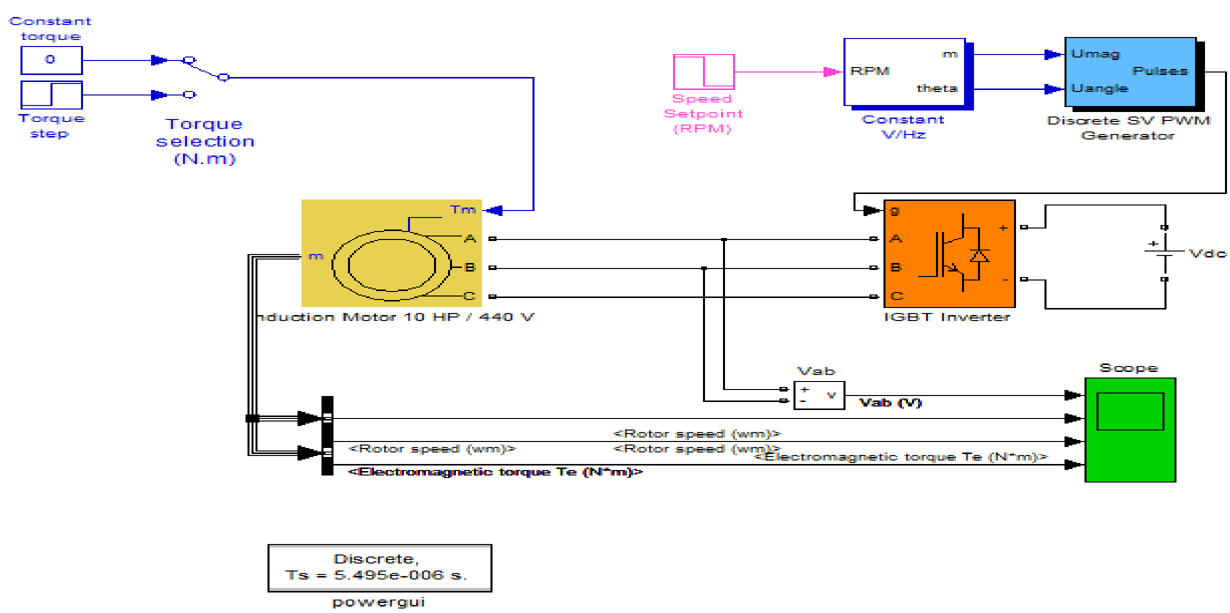

Fig.4 Simulink Model of IGBT inverter fed 3-phase induction motor

The detail model in the simulink is shown in Fig.4 It is “3ϕ induction motor” model and the “universal bridge inverter” (VSI type) which comprises of Three-phase bridge structure with six IGBT as switches and diodes anti-parallel to the IGBTs. Ports are provided to receive the switching signals for gating from the concerned controller. DC bus voltage “Vdc” is supplied to VSI to provide a variable frequency, PWM variable voltage to the motor. The triggering signal for inverter is generated from the “discrete SV PWM generator”. The input signal to this block is taken from the “constant V/Hz method”. The speed set point defines the upper and lower limits of speeds, i.e. 1725 rpm and 1300 rpm. The output from the motor denoted by ‘m’ is given to the “bus selector” switch, at which various parameters (like electrical, mechanical, frictional etc) can selected explicitly. The “scope” is used to display the signals while the simulation is being carried out.

The output from various blocks can be made to display in the scope and their transient and steady state response can be observed. The simulation is made to run to 3 decimation (or cycles) so as to obtain a stable and satisfactory output. The manual switch used in the upper left part of the diagram is used to provide “constant torque” or “torque in some definite increasing steps”. For the further analysis a “powergui” switch is given. Using this feature one can have the final output curves along with the harmonics involved.

In the block properties of the “Discrete SV PWM generator”, which can be seen by right clicking the block, we can select the type of ‘switching pattern’ from the two available options there. The pulses will be generated by both the blocks and feed the gate signal to the inverter, but the logic to select will determine which pattern will be selected.

3- SIMULATION RESULTS

The performance investigation is done of a three phase induction motor (squirrel cage) as per the following details given below:

1. Motor Rating: 10 HP
2. Stator voltage: 440 V (L-L)
3. Stator current: 16.9A
4. Stator connection: Y (star connected)
5. No. of Poles: 4
6. Stator and Rotor Resistance: Rs=0.6837 ohms, Rr=0.451 ohms
7. Stator and Rotor Inductance: Lls=0.004152 H, Llr=0.004152 H
8. Mutual inductance: Lm=0.1486 H
9. Friction Factor: 0.0018 Nms
10. Moment of inertia: J=0.05 Kgm^2

The reference parameter of speed is set to 142 electrical radian per second and the load torque is kept=0. We see that the starting current has increased due to the transient condition of the motor. After some time the motor attains a constant speed of 142 electrical radian per second. Once the speed error reduces to near about zero, then the current attains a stable value of amount 19 A and the developed torque is reduces to small near about 0 Nm as observed. The simulation results are depicted by all graphs of fig.5 (5.1-5.12) for various load condition.

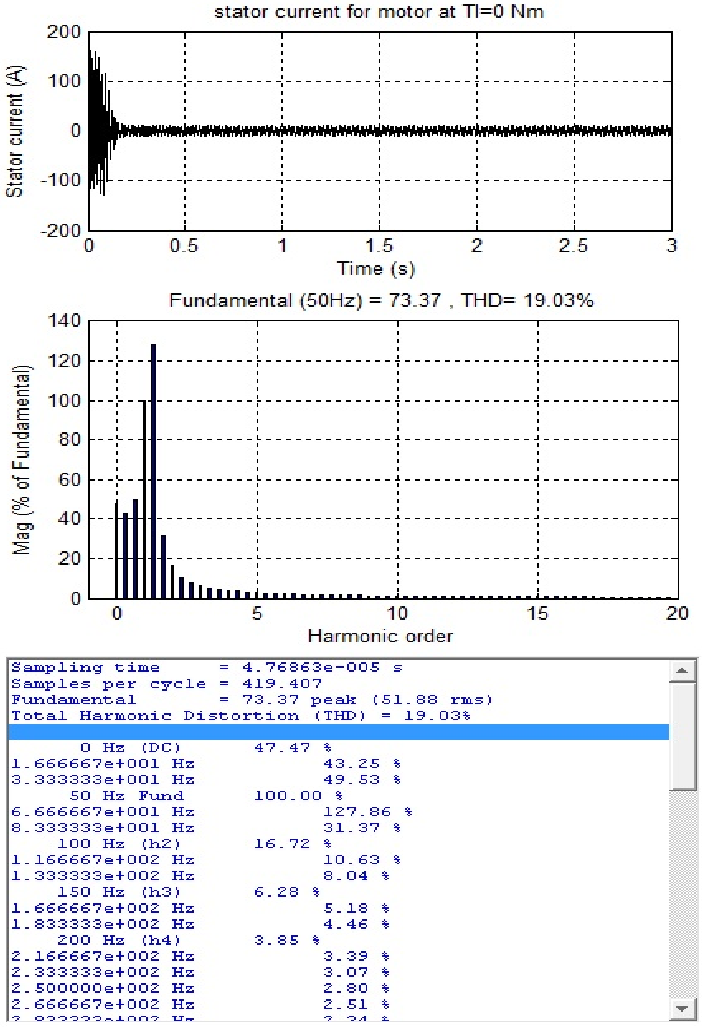

Fig. 5.1Stator current for motor at Tl=0 Nm

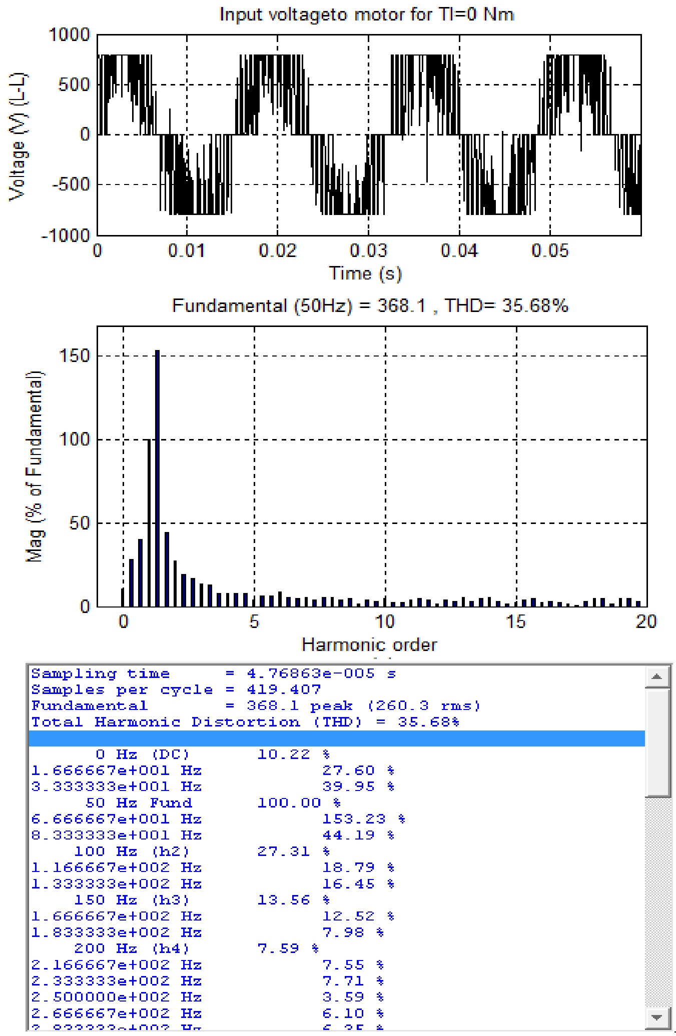

Fig. 5.2 Input voltage tomotor at Tl=0 Nm

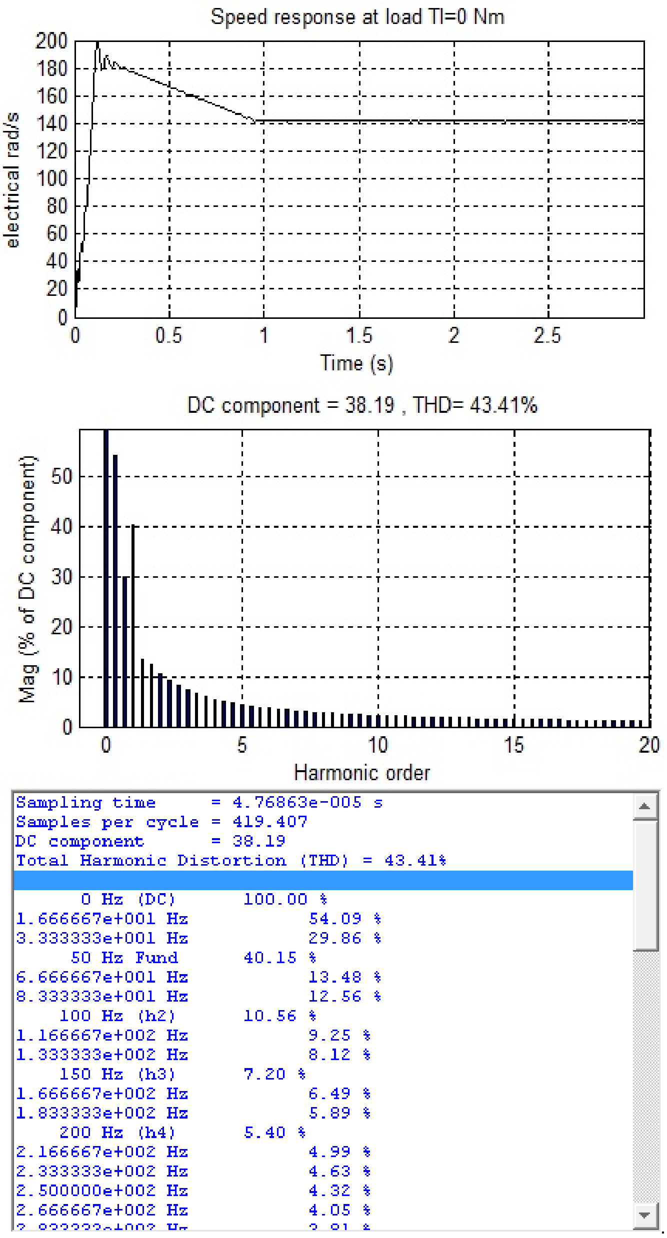

Fig. 5.3 Speed response for Tl=0 Nm

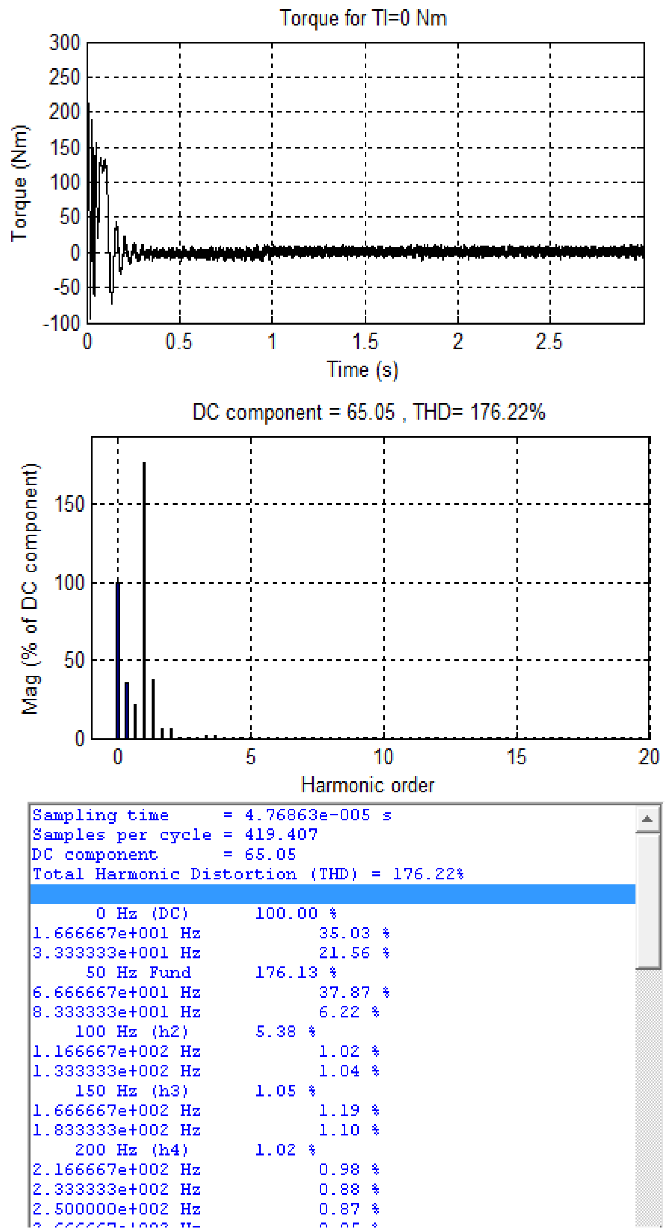

Fig. 5.4 Electromagnetic torque developed at T=0 Nm

With the speed at 142 electrical rad/sec. a step load torque Tl equals 10 Nm is applied to the shaft at the instant t=1.3s. With sudden application of load, there is a fall in the speed of the motor. The graphs are shown in figures 5.5, 5.6, 5.7 and 5.8.

With the help of manual selection switch at instants t=0s to t=1.2s, we apply a sudden step torque of Tl=15 Nm and then again remove the load at 2 seconds. Since, it is an open loop system, it can be seen in the speed response curve that till 1.2 s, the motor has achieved 142 electrical rad/s speed. After 1.2 s the speed of the motor falls near to 140 electrical rad/s. At the removal of the load at 2 s, the motor again attains the steady speed as was till 1.2s. The graphs are shown in figures 5.9, 5.10, 5.11 and 5.12.

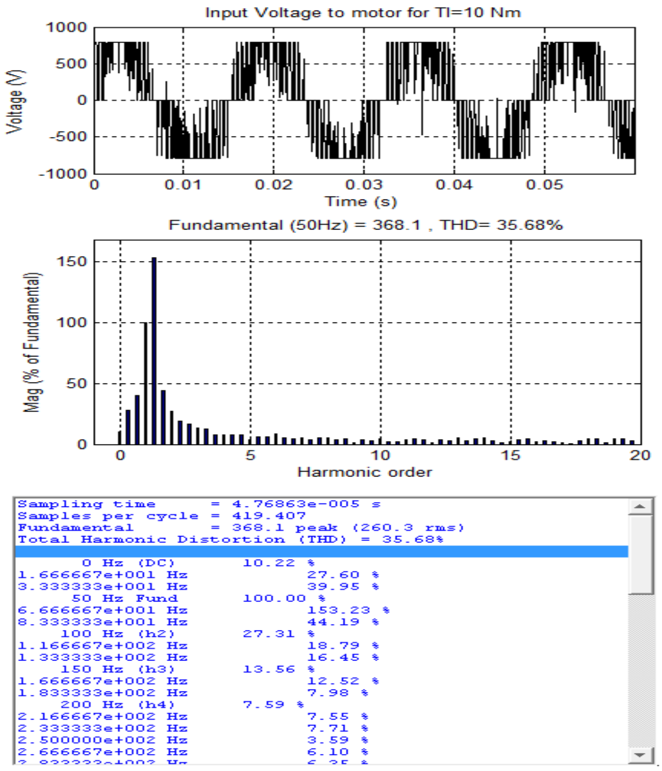

Fig. 5.5 Input voltage to motor for Tl=10 Nm

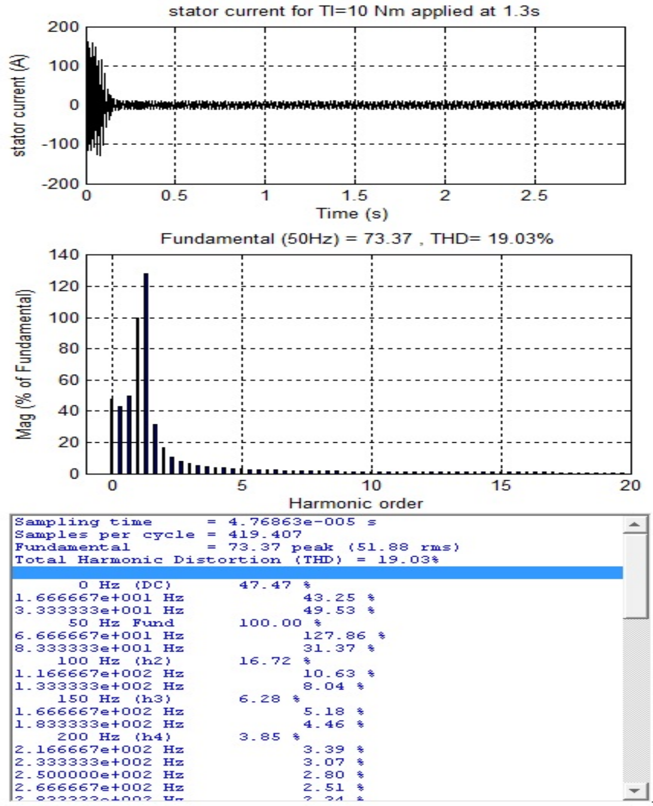

Fig. 5.6 Stator current for motor at Tl=10 Nm

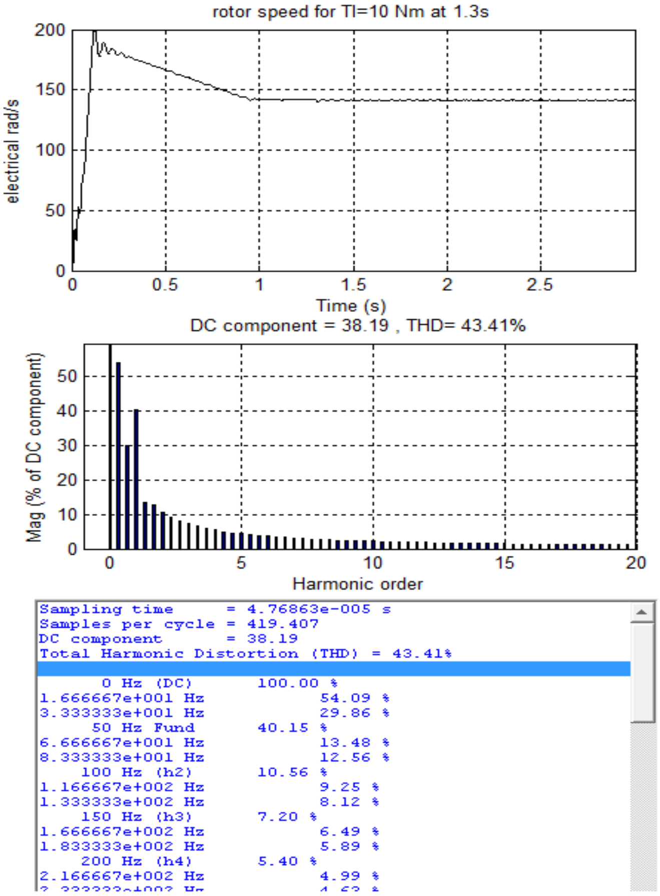

Fig. 5.7 Speed response for Tl=10 Nm

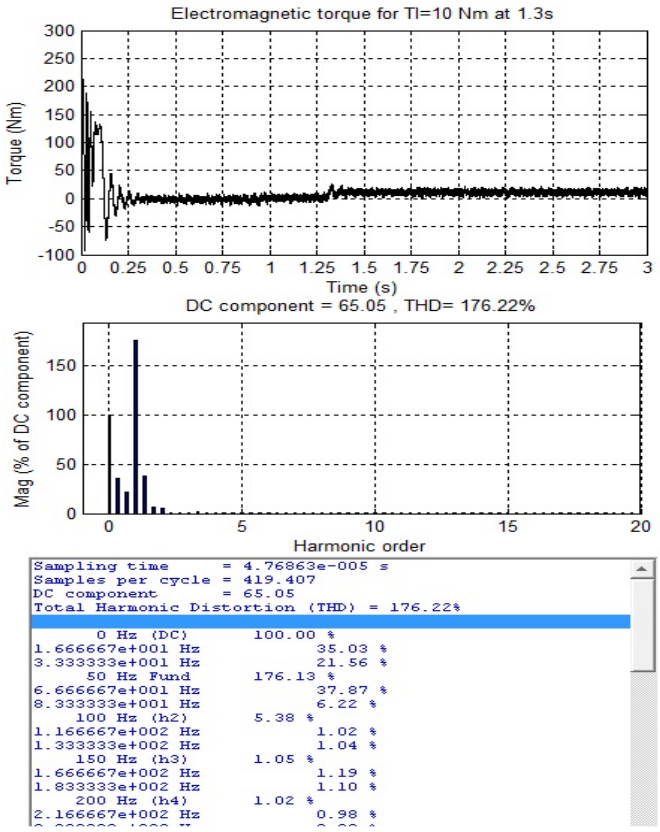

Fig. 5.8 Electromagnetic Torque developed for Tl=10Nm

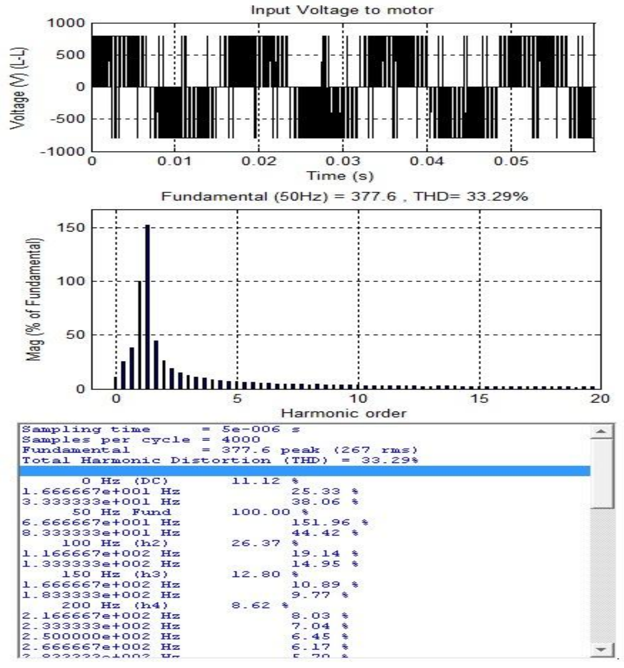

Fig. 5.9 Input voltage to motor for load perturbations

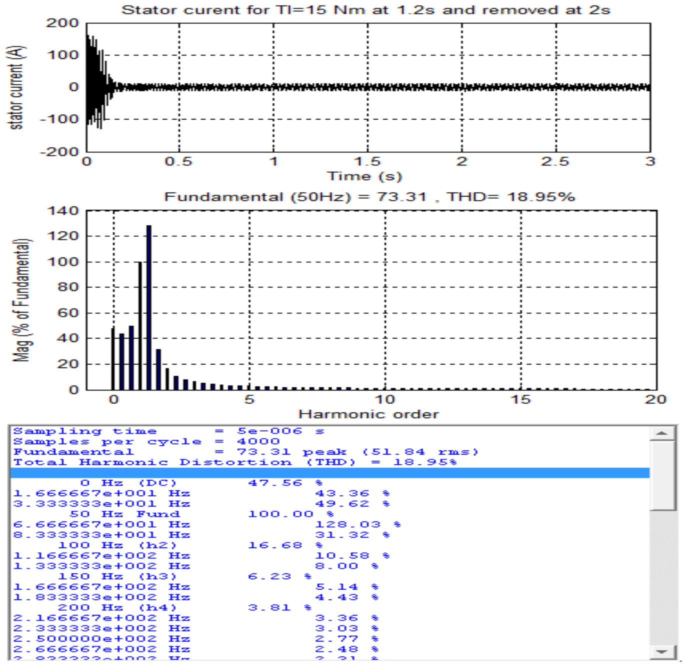

Fig. 5.10 Stator current in case of load perturbations

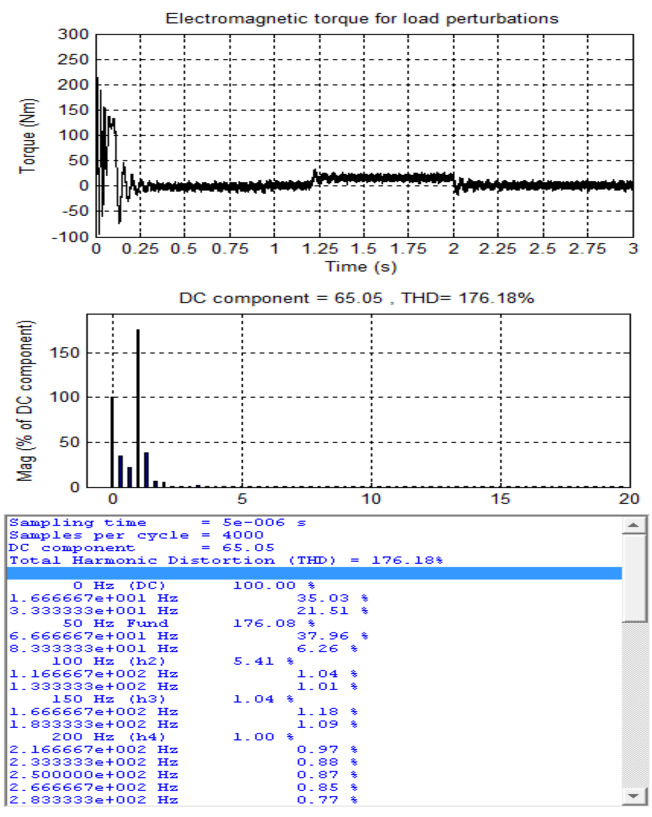

Fig. 5.11 Electromagnetic Torque for load perturbations

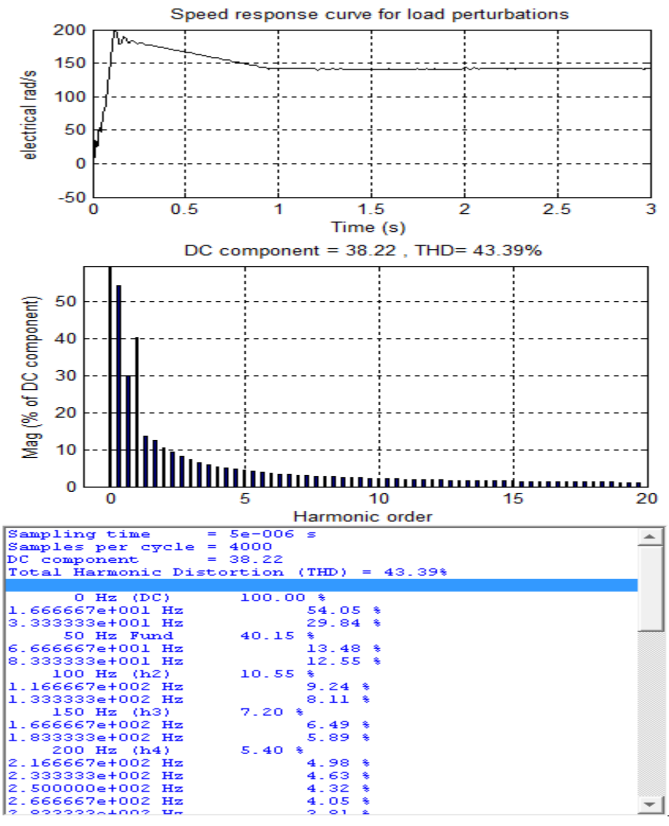

Fig. 5.12 Speed response for load perturbations

4- CONCLUSION

In the open loop speed control of the induction motor as carried out in the simulation, it was observed that there was a decrease in the speed of motor as some mechanical load on it was applied. We had seen three cases in the above results mentioned. There was also more current drawn by the motor on increasing the mechanical load on its shaft, which may also lead to its overheating, more losses during its operation or burning of the windings. Table-1 shows various results of the simulation on the three phase induction motor.

Table-1

S. No.	Load Applied (Nm)	Input Voltage (L-L) (Volts)	Rotor Speed (Electrical rad/s)	Stator current (A)	Electromagnetic Torque (Nm)
1	0	792	142	19	0
2	10	792	141	20	10
3	15	792	140	22	15

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