Implementation of Speed Control of Induction Motor with Eddy Current Dynamometer type Load Using Direct Torque Control Method through Digital Signal Processor

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Abstract---An induction motor and its dynamic model, torque – speed characteristics and high performance of Direct Torque Control (DTC) with Digital Signal Processor (DSP) for speed controlling of induction motor. The induction motor is most used in industrial application because of robustness and low maintenance. Using DSP speed control of induction motor obtain wide speed range of induction motor with smooth drive control, reduces torque ripples, noise and also reduces loss. So, that it will improve the efficiency of induction motor. Induction motor has wide speed range from 300 RPM to 1415 RPM or rated speed of particular induction motor. For the digital speed controlling, prepare simulation in MATLAB 2009 and with the help of F2812 target preference block and XDS510 emulator generating ‘C’ code in code composer studio. This ‘C’ code convert into .out file in code composer studio. Then after this .out file convert into .ASC file with the help of Vi DSP code composer. Then after this .ASC file down load in TMS320F2812 DSP. Test the induction motor for various speed drives with no load and also test induction motor for various speed under variation of eddy current dynamometer type load with the help of DTC method.

Keywords: Induction motor, DTC (Direct Torque Control), DSP (Digital Speed Control), CCS (Code Composer Studio)

I. INTRODUCTION

Electric Drive systems have huge area of applications, and list of applications such as fans, pumps, elevators, hybrid electric vehicles and subway transportations, servo & robotics, home appliances etc. Industrial drive applications are generally classified in to variable speed and constant speed drives. Mostly, AC motors with a constant sinusoidal frequency power supply have been used in constant speed drive applications. Whereas DC motors are mainly used for a variable speed drives. DC motor drive controls and converters are simple and also torque response is very fast. However DC motors have main disadvantage of higher rotor inertia, maintenance problem with brushes and commutator, and higher cost. However, recently we have seen research and development efforts for some advanced variable frequency and variable speed drive AC machine technology based on microcontroller, fuzzy system, ANN system, PLC system, DSP system etc. So, recently AC motors are also used for variable speed drive system replacing DC motors.

Many of some advanced methods, DSP based speed control of AC motor is most advance controller. DSP based speed control method is very flexible for wide range of speed and also high performance with low cost and maintenance. In addition, with the DSP controller improves the noise immunity efficiency of the system.

The torque control in various types of AC induction motors requires a greater understanding of the design and the characteristics of these motors.

II. DIRECT TORQUE CONTROL (DTC) METHOD

DTC method also known as direct torque and flux control method (DTFC) or direct self control method (DSC), which is introduce for voltage fed inverter drives. By using this method, get nearly comparable performance with vector controlled drives method.

At any other speed than synchronous speed of rotor, slip can be produced which causes rotor current and torque are developed in the rotor. So, that rotor moves in the same direction as that of the rotating magnetic field to reduce the induced current. If the rotor rotates at synchronous speed, there is no relative motion between the air gap flux and rotor. Hence, there is no induced voltage, current and torque in the rotor. Both the flux and torque are functions of frequency and voltage, respectively.

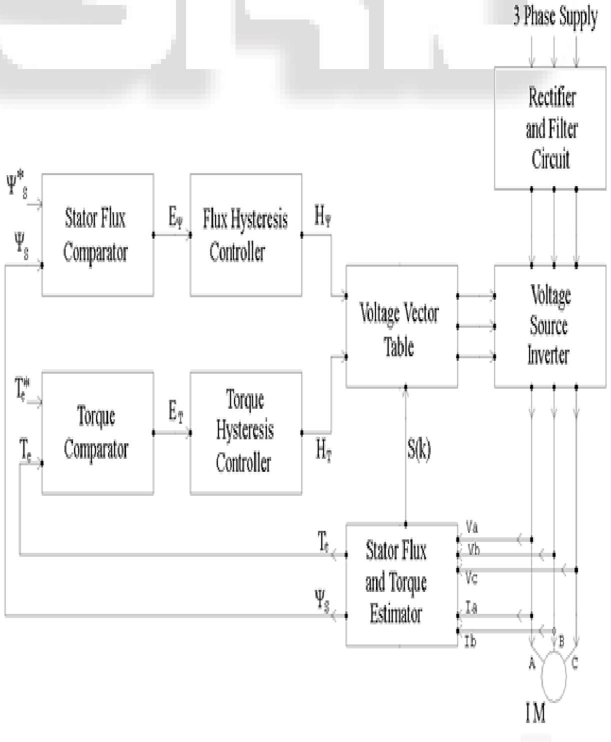

Fig. 1: Block diagram of DTC based speed control of induction motor

DTC method can provide fast instantaneous torque control of induction motor with simple control structure. So, that using vector DTC method increases its control sensitivity.

Also, by using this method torque ripple is high. In this method, receive signal of rotor speed from the speed sensor. Speed sensor introduces some noise. So, that accuracy and reliability are decreases due to appearances of noise. Furthermore, using this method, the expected performance is not met due to the load disturbance, motor saturation and thermal variation. Furthermore, using this method, filter is required for reducing torque ripple and noise. So, that system complexity is increased which cause cost and maintenance are also increased.

The basic concept of DTC method is to control directly both stator flux linkage and electromagnetic torque of induction motor. DTC method consists of two (flux & torque) error comparators, two (flux & torque) hysteresis band comparators, voltage vector table, voltage source inverter and flux & torque estimator. As the name indicates, direct control of torque and stator flux by inverter voltage space vector whose selection through voltage vector table. The use of voltage vector table for voltage vector selection provides fast torque response.

As shown in above figure 1, the reference stator flux (Ψ^*_s) and reference torque (T^*_{em}) magnitudes are compared with the respective estimated values by their respective comparators, and the errors are further processed through their respective hysteresis controllers. The selection of the switching voltage vector in order to maintain, flux and torque between lower and upper limits of their respective limits. So, that restricting the flux and torque band limits within flux and torque hysteresis band limits respectively using optimum selection being made. In DTC method, switching frequency is mainly affected by the width of hysteresis band of the flux and torque comparators.

The flux loop hysteresis controller has two levels of digital output, which have the following relations:

$H_\Psi = 1$ for $E_\Psi > +HB_\Psi$

$H_\Psi = -1$ for $E_\Psi < -HB_\Psi$

;Where $2HB_\Psi$ = Total hysteresis band width of the flux controller.

The circular trajectory of the reference flux vector Ψ^*_s with the band rotates in the anti-clockwise direction as shown in below figure 4. The actual stator flux Ψ_s is limited within the hysteresis band and it tracks the reference flux in a zigzag path.

The torque control loop has three levels of digital output according to the following relations:

$H_{Tem} = 1$ for $E_{Tem} > +HB_{Tem}$

$H_{Tem} = -1$ for $E_{Tem} < -HB_{Tem}$

$H_{Tem} = 0$ for $-HB_{Tem} < E_{Tem} < +HB_{Tem}$

;Where $2HB_{Tem}$ = Total hysteresis band width of the torque controller.

The torque & flux estimator block also calculates the sector number S(k) in which the flux vector Ψ_s lies. There are six sectors each wide by 60 degree. The voltage vector table block receives the input signals from H_Ψ, H_{Tem} and S(k). Therefore, voltage vector table generates the appropriate control voltage vector for the inverter as shown below table 1.

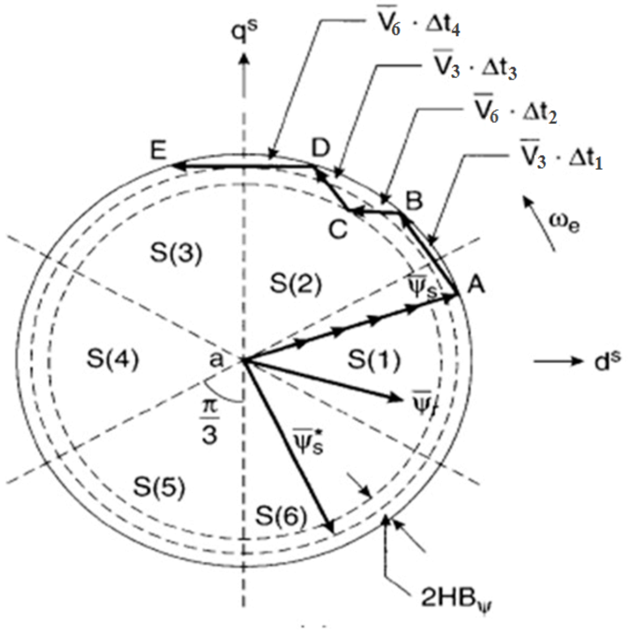

Fig. 2: Trajectory of stator flux vector in DTC control

The flux in the motor is initially established at zero frequency along the radial trajectory 'aA' as shown in above figure 4. With the rated flux, the reference torque is applied and the Ψ^*_s vector start rotating. Voltage vector table applies the selected voltage vector, which essentially affects both the torque and flux simultaneously. The flux trajectory segments AB, BC, CD and DE by the respective voltage vectors V_3, V_4, V_3 and V_4 are as shown in figure 4. Note that, the stator flux (Ψ_s) vector changes quickly by V_s but the rotor flux (Ψ_r) change is very sluggish due to large time constant T_r. Since rotor flux (Ψ_r) is more filtered. So, that its movement is uniformly where as stator flux (Ψ_s) movement is jerky. However, the average speed of both remains the same in the steady state condition.

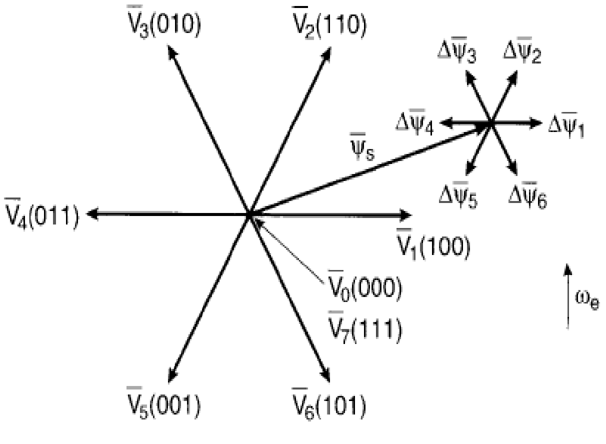

Fig. 3: Inverter voltage vectors & corresponding stator flux variation

DTC method selects one of the inverter's six voltage vectors and two zero voltage vectors, to keep stator flux and torque within a hysteresis band. Torque and flux are controlled by the six stator voltage vector defined in this reference frame, but the zero voltage vector (V_0 & V_7) short circuits the machine terminals and keep the torque and flux unaltered.

Due to finite stator resistance (R_s) drop, the flux and torque will slightly decreases during the short circuit condition.

Flux Error Status (H_Ψ)	**Torque Error Status(H_{Tem})**	**Sec tor I**	**Sec tor II**	**Sec tor III**	**Sec tor IV**	**Sec tor V**	**Sec tor VI**
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_6	V_1	V_2	V_3	V_4	V_5
-1	1	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_5	V_6	V_1	V_2	V_3	V_4

Table. 1: Switching table of inverter voltage vectors

Voltage Vector	**V_1**	**V_2**	**V_3**	**V_4**	**V_5**	**V_6**	**V_0 or V_7**
ψ_s	↑	↑	↓	↓	↓	↑	0
T_{em}	↓	↑	↑	↑	↓	↓	0

Table. 2: Flux and torque variations due to applied voltage vectors

The park transformation from abc to qd0 transformation is as below.

$$\begin{bmatrix} V_{qs}^{s} \\ V_{ds}^{s} \\ V_{os}^{s} \end{bmatrix} = \left(\frac{2}{3}\right) \begin{bmatrix} \cos\theta & \cos(\theta-120^\circ) & \cos(\theta+120^\circ) \\ \sin\theta & \sin(\theta-120^\circ) & \sin(\theta+120^\circ) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix}$$

The corresponding inverse transformation is dq0 to abc transformation is as below.

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-120^\circ) & \sin(\theta-120^\circ) & 1 \\ \cos(\theta+120^\circ) & \sin(\theta+120^\circ) & 1 \end{bmatrix} \begin{bmatrix} V_{qs}^{s} \\ V_{ds}^{s} \\ V_{os}^{s} \end{bmatrix}$$

Whereas V_{os}^{s} is the zero sequence component, which may or may not be present.

V_{as}, V_{bs}, V_{cs} = stator voltages of phase A, B & C respectively

V_{qs} & V_{ds} = q and d axes stator voltages

We have considered voltage as the variable. The current and flux linkages can be transformed by similar equations. It is convenient to set θ = 0, so that the q^s axis is aligned with the as – axis. Ignoring the zero sequence components, the transformation can be simplified as V_{as}, V_{bs}, V_{cs} are following:

$$v_{as} = v_{qs}^{s}$$

$$v_{bs} = -\frac{1}{2} v_{qs}^{s} - \frac{\sqrt{3}}{2} v_{ds}^{s}$$

$$v_{cs} = -\frac{1}{2} v_{qs}^{s} + \frac{\sqrt{3}}{2} v_{ds}^{s}$$

Now, we show it how to calculate from the machine terminal voltages and currents which are sensed by machine. These equations are:

$$i_{qs}^{s} = \frac{2}{3} i_a - \frac{1}{3} i_b - \frac{1}{3} i_c = i_a$$

$$i_{ds}^{s} = -\frac{1}{\sqrt{3}} i_b + \frac{1}{\sqrt{3}} i_c$$

$$= -\frac{1}{\sqrt{3}} (i_a + 2i_b)$$

Since $i_c = - (i_a + i_b)$ for isolated neutral load.

$$V_{qs} = \frac{2}{3} V_a - \frac{1}{3} V_b - \frac{1}{3} V_c$$

$$V_{ds} = -\frac{1}{\sqrt{3}} V_b + \frac{1}{\sqrt{3}} V_c$$

$$\Psi_{ds} = \int (V_{ds} - R_s i_{ds}^{s})\, dt$$

$$\Psi_{qs} = \int (V_{qs} - R_s i_{qs}^{s})\, dt$$

$$\theta_f = \mathrm{Sin}^{-1}\left(\frac{\Psi qs}{\Psi s}\right)$$

Where

V_{qs} & V_{ds} = q and d axes stator voltages
Ψ_{ds} & Ψ_{qs} = d and q axes stator fluxes
i_{ds}^{s} & i_{ds}^{s} = d and q axes stator currents
Rs = stator resistance
Va, Vb, Vc = phase voltages of phase A, B, C respectively
ia, ib, ic = phase currents of phase A, B, C respectively
Vab, Vbc, Vac = line voltages
P = number of poles
θ_f = Flux angle
Ψs = Total stator flux

The feedback torque and flux are calculated from the machine terminal voltages and currents. The actual torque can be calculated from stationary variables as follows:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)(\psi_{ds}{}^{s} i_{qs}^{s} - \psi_{qs}{}^{s} i_{ds}^{s})$$

Similarly, actual stator flux can be calculated from stationary variables as follows:

$$\psi_s = \sqrt{\left(\psi_{ds}^{2} + \psi_{qs}^{2}\right)}$$

A. *EDDY CURRENT DYNAMOMETER TYPE LOAD*

The eddy current dynamometer type brake load is an independent foot mounted construction having an input shaft which is mechanically coupled to an induction motor. These induction motor and eddy current dynamometer are aligned on a common bed plate. Regulated D.C power supply (0 – 30 V & 0 – 2 Amp.) is used to energize the eddy current dynamometer brake coil. So, when the stationary field coil is energized by D.C input supply, a strong magnetic field developed around the stationary coil. When the armature core rotates which is mechanically coupled to induction motor shaft, it cuts the magnetic field. The magnetic flux path is through the air gap between the pole and armature core. Therefore, an e.m.f is induced in the armature core according to the electromagnetic induction law. However, due to this e.m.f and resistance of armature core, large current set up in the armature core. This current is known as eddy current. The direction flow of these induced eddy current, is perpendicular to the magnetic flow lines.

Therefore, the eddy current will oppose the speed of armature core and thereby loading effect creates on induction motor. Thus, providing an easy electrical means to control the drive speed of an induction motor.

III. SIMULATION AND RESULTS QUADRATURE ENCODER PULSE CIRCUIT

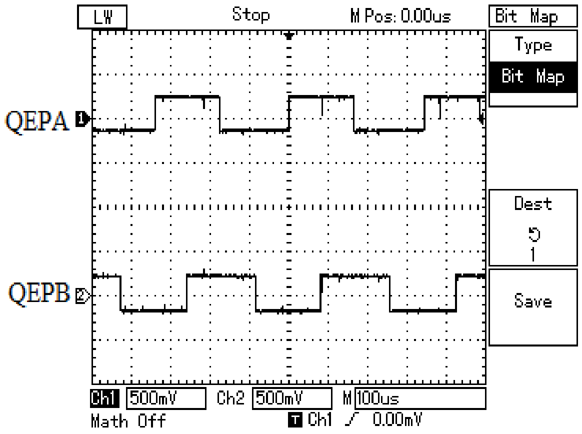

Fig. 4: QEP waveform on DSO (90° out of phase with each other)

The QEP module is used for direct interface with a linear or rotary incremental encoder to get direction, position and speed information from rotating machine for used in high performance motion system. Quadrature Encoder Pulses are two sequences of pulses which have a variable frequency and are 90° out of phase with each other whose phase relationship is used to determine direction of input rotor shaft.

A. Dead band generator

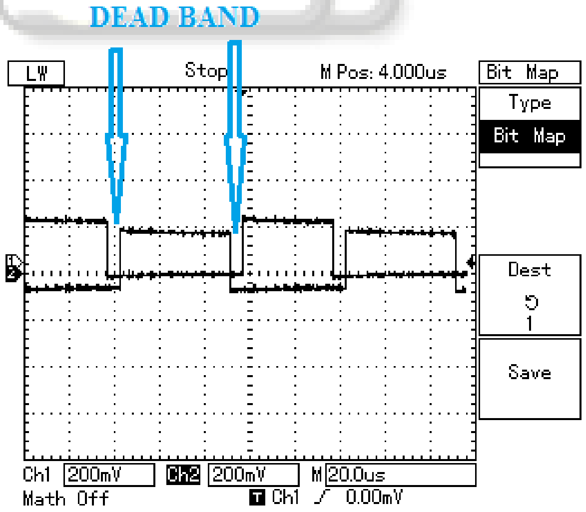

Fig. 5: Dead band between two PWM waveforms on DSO

The dead band generator generate the dead band delay between the toggling of the independently or dependently PWM outputs. The dead band generator solves the problem of PWM waveform leg short circuit. So, that upper and lower IGBTs cannot be turned on simultaneously.

B. How to create .ASC file of DTC code

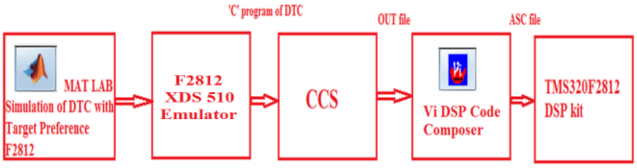

Fig. 6: Block diagram of .ASC conversion

C. Simulation of DTC method for generating C program using F2812 target preference

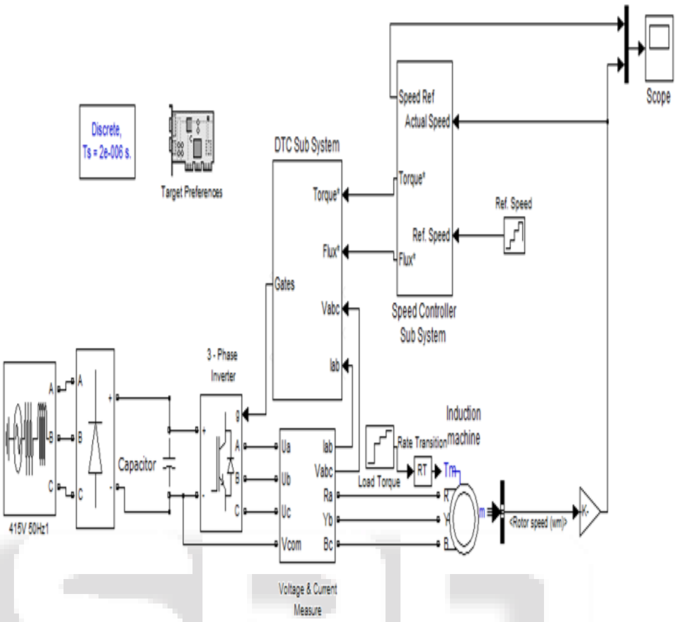

Fig. 7: DTC simulation

D. RESULT OF VARIOUS NO LOAD SPEED OF INDUCTION MOTOR ON MATLAB

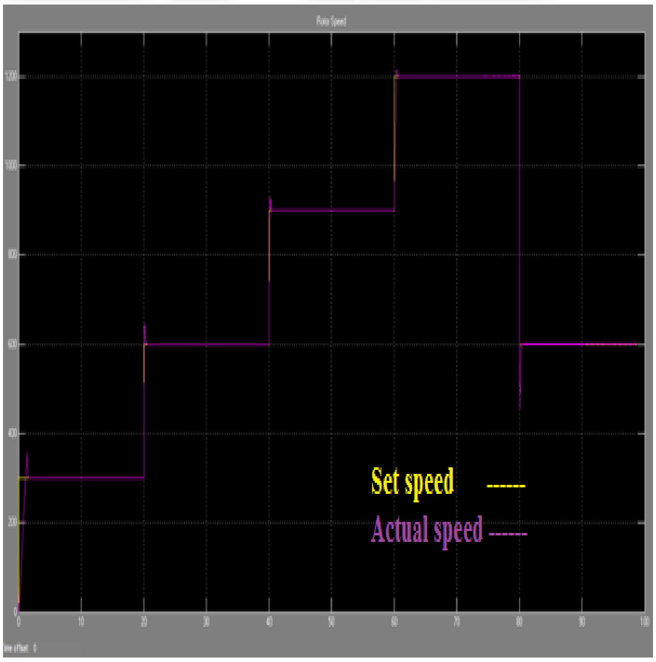

Fig. 8: Result of no load speed of induction motor

E. EXPERIMENT SET UP OF SPEED CONTROL OF INDUCTION MOTOR

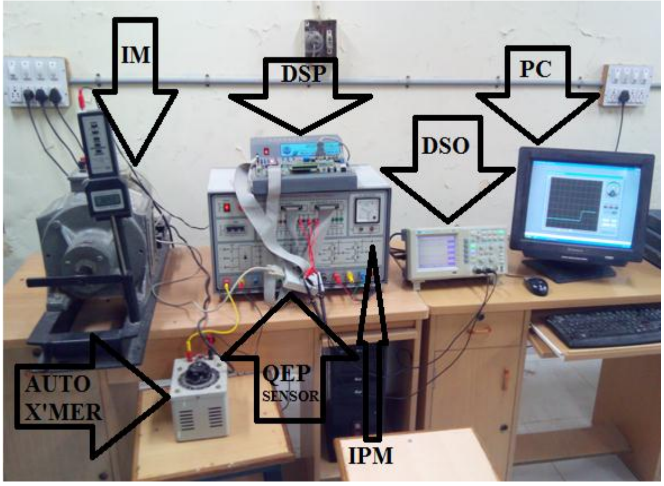

Fig. 9: Experimental Set up of speed control of Induction Motor

F. GRAPH FOR VARIOUS NO LOAD SPEED OF INDUCTION MOTOR

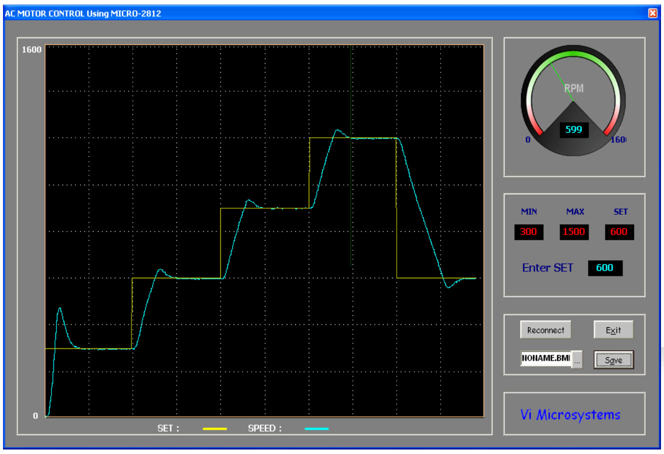

Fig. 10: Experimental Result of no load speed of induction motor

G. GRAPH FOR EDDY CURRENT DYNAMOMETER TYPE LOAD ON INDUCTION MOTOR

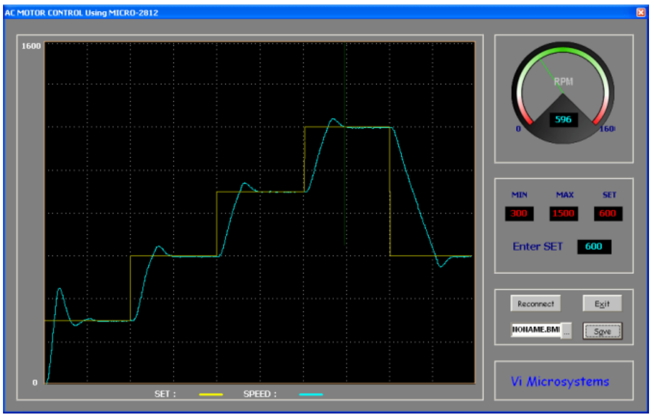

Fig. 11: Experimental result of various speed of induction motor with eddy current dynamometer type load with excitation 10 V and 0.42 A applied through regulated D.C power supply

IV. OBSERVATION TABLE

Here, Observation table is as given below for various excitations on eddy current dynamometer type load and various speeds of an induction motor

	Eddy current dynamometer type load		Motor Speed in R.P.M							
	Applied D.C voltage to eddy current dynamometer	Applied D.C current to eddy current dynamometer	Set speed	Actual speed	Set speed	Actual speed	Set speed	Actual Speed	Set speed	Actual speed
	5 V	0.23 A	300	296-301	600	596-601	900	897-901	1200	1196-1201
Motor Load current				0.130		0.292		0.400		0.480
	6 V	0.27 A	300	295-301	600	595-601	900	896-901	1200	1195-1201
Motor Load current				0.160		0.330		0.455		0.555
	7 V	0.30 A	300	295-301	600	594-601	900	896-901	1200	1195-1201
Motor Load current				0.200		0.379		0.520		0.637
	8 V	0.34 A	300	294-301	600	594-601	900	895-901	1200	1194-1201

Motor Load current				0.261		0.446		0.604		0.742
	9 V	0.38 A	300	294-301	600	594-601	900	895-901	1200	1194-1201
Motor Load current				0.345		0.534		0.732		0.893
	10 V	0.42 A	300	292-301	600	593-601	900	894-901	1200	1194-1201
Motor Load current				0.444		0.655		0.897		1.055

Table 3: Various excitations on eddy current dynamometer type load and various speeds of an induction motor

V. CONCLUSION

An implementation of speed control of induction motor drive with eddy current dynamometer type load using digital signal processor has been presented for speed control of induction motor using direct torque control (DTC) method. The scheme has been shown to provide wide speed range. Also, manually change from DSP kit and from personal computer (PC). Using DSP based speed control method, to build a high precision controlling system. With the DSP controller it is possible to reduce the overall system cost and losses, to improve the reliability of the drive system. DSP controllers are less susceptible to aging and environmental variations. In addition, DSP controllers have the better noise immunity efficiency of the system.

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