COMPARATIVE ANALYSIS BETWEEN SCALAR CONTROL AND DIRECT TORQUE CONTROL METHODS FOR INDUCTION MOTOR DRIVES

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Abstract – This paper presents a comparative study on two control strategies for induction motor drives: Scalar Control Method and Direct Torque Control (DTC) Method. The comparison is based on various parameters like speed, torque and stator current THD. Based on that it can be concluded that Direct Torque Control (DTC) is better than Scalar Control Method. The study is done by simulation using the simulink power block set.

Index Terms- Scalar Control Method, Direct Torque Control Method, Induction Motor.

I. INTRODUCTION

Over the past years DC machines were widely used for variable speed drives application. Decoupled control of flux and torque can be achieved by field and armature control method respectively. DC machines have advantages like high starting torque, simple control. The biggest disadvantages of DC machines are the presence of commutator and brushes [1]. Today these drives are not much used because of various advantages of ac drives over DC drives. In industry, electric motor plays a very important role. It is a main part or the heart of the system. Today the performance of the system is considered in terms of efficiency, accuracy and smoothness of operation. Induction motor are widely used in industries and also widely used in high-performance drive. It is also used in commercial and domestic application of variable speed drives. It is robust in nature and also the absence of the commutator and brushes. The cost of the motor is very low. It has simple mechanical structure; more reliable and also low maintenance is required [1]. Scalar Control or v/f control method is very popular for induction motor drives. It is very simple method to implement. It only requires magnitude of the quantity. In this method, torque and flux are neither directly nor indirectly controlled. Also the flux variation is sluggish due to coupling. Control is provided by a frequency and voltage reference generator to get a constant volts per hertz output. Because of that it gives limited speed accuracy and poor torque response. It is normally used without speed feedback [3].

The main features of Direct Torque Control (DTC) method are as follows [7]:

- Direct control of flux and torque.
- Indirect control of stator currents and voltages.
- Approximately sinusoidal stator fluxes and stator currents.
- High dynamic performance.
- Inverter switching frequency depends on width of flux and torque hysteresis bands.

The advantages of this method are as follows [7]:

- Absence of co-ordinate transformation.
- Doesn’t suffer from parameter variation.
- No PWM modulator is required.
- No PI controller is required.
- No separate voltage modular block is required.
- Absence of voltage decoupling circuits.
- Minimum torque response time.

In the presented paper, section-II describes two control methods: Scalar Control Method and

Direct Torque Control Method (DTC). The simulation results are focused in Section-III. Section IV contains the conclusion.

II. DESCRIPTION OF SCALAR CONTROL AND DIRECT TORQUE CONTROL METHOD

SCALAR CONTROL METHOD

It is very important to control the speed of induction motors in industrial and engineering applications. Efficient control strategies are used for reducing operation cost. Scalar control involves controlling the magnitude of voltage or frequency of the induction motor. The relationship between rotor speed, synchronous speed, and slip is given by,

$$S = \frac{N_s - N}{N_s} \quad (1)$$

$$N_r = N_s(1 - S) \quad (2)$$

Rotor speed,

$$N_r = \frac{120f}{p}(1 - S) \quad (3)$$

Thus, speed of an induction motor can be varied by changing frequency (f), slip (S), or number of poles (P) for which the winding are wound [9].

The scalar control is based on changing any one parameter like frequency (f), slip(s) or pole (p). The speed can be changed by increasing or decreasing frequency but this results in the change of impedance. This in turn is the reason for change in current drawn by the motor. Reduction in supply frequency increase the air gap flux which results in saturation of the core. To avoid these problems, it is necessary to vary the frequency and the voltage at the same time keeping the v/f ratio constant. According to induced voltage equation (4) constant $V/_f$ control gives constant flux in the stator [10].

$$\frac{V_{rms}}{f} = 4.44N\varphi\zeta \quad (4)$$

Where,

V_{rms} = induced voltage in the stator

f = frequency of the supplied voltage

N = number of turns

φ = number of turns

ζ = constant of coil

The torque-speed equation (5) of induction motors reveals the voltage-torque-frequency relation, given by,

$$T_{air-gap} = \frac{3}{2\omega_m} I_r{}^2 \frac{R_r}{S} \quad (5)$$

From equation (5) it reveals that frequency and torque are inversely proportional, while voltage is directly proportional to torque.

$$T \approx \frac{V^2}{2\pi f} \approx \frac{V}{f} \quad (6)$$

The torque developed by the induction motor is directly proportional to the ratio of the applied voltage and the frequency of supply. By varying the voltage and the frequency, but keeping their ratio constant, the torque developed can be kept constant throughout the speed range. This is exactly what $V/_f$ control tries to achieve [11]. Fig 1 stator voltage v/s frequency profile. Torque developed by induction motor remains constant if $V/_f$ ratio is constant up to the base speed. Beyond base speed torque is decreased in inverse proportion to increase in frequency because voltage can't be higher than rated value of equipment.

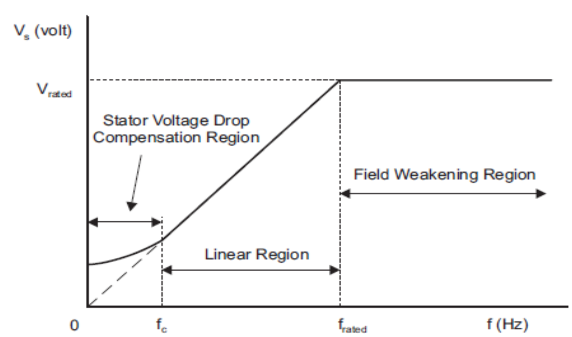


Fig 1: stator voltage v/s frequency profile.

Direct torque control method

The new control technique for induction motor drive was introduced by I. Takahashi as a Direct Torque Control (DTC) [2] and by M. Depenbrock as a direct Self Control (DSC). Using DTC, there is a possibility to obtain good dynamic control of torque without mechanical transducers on the machine shaft. The basic functional blocks used to implement the DTC scheme in an induction motor is shown in Fig. 2[6]. Three phase AC supply is given to the diode bridge rectifier which produces a DC voltage. A high value dc link capacitor is used to reduce the ripple content in the DC voltage. The filtered DC is the power supply to the inverter switches. The IGBT inverter switches are controlled by the direct torque control algorithm. The output of the inverter is connected to the stator terminals of induction motor.

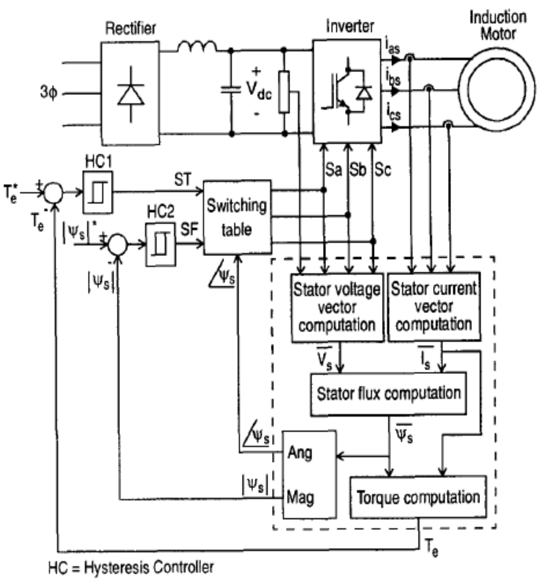


Fig 2: direct torque control of induction motor.

a. Flux and torque estimation

The feedback flux and torque are calculated from the machine terminal voltages and currents. The computation block also calculates the sector number in which the flux vector lies.

The stator flux of IM in stationary reference frame is written as [1]:

$$\varphi_s = \int (V_s - R_s i_s)\, dt \quad (7)$$

The flux vector can be obtained from the stator flux components. By using the flux components, current components and IM number of poles, the electromagnetic torque can be calculated by,

$$T_e = \frac{3}{2}\frac{p}{2}\left(\varphi_d i_q - \varphi_q i_d\right) \quad (8)$$

b. Torque and flux controller

The instantaneous values of flux and torque are calculated from stator variables by using flux and torque estimator. The command stator flux and torque magnitudes are compared with their respective estimated values and the errors are processed by the hysteresis band controllers. The flux loop controller has two levels of digital output according to following equations.

Stator flux error $\Delta\varphi_s = \varphi_{sref} - \varphi_s$

$|d\varphi_s| = 1$ if $|\varphi_s| \le |\varphi_{sref}| - |\Delta\varphi_s|$

: Flux is to be increased

$|d\varphi_s| = 0$ if $|\varphi_s| \ge |\varphi_{sref}| + |\Delta\varphi_s|$

: Flux is to be decreased

The width of the hysteresis band is$2\Delta\varphi_s$.

The actual stator flux is constrained within the hysteresis band and tracks the command flux. The torque control loop has three levels of digital output represented by the following equations.

Torque error $\Delta T_e = T_{eref} - T_e$

$|dT_e| = 1$ if $|T_e| < |T_{eref}| - |T_e|$

: Torque to be increased

$|dT_e| = -1$ if $|T_e| < |T_{eref}| - |T_e|$

: Torque to be increased

$|dT_e| = 0$ if $|T_{eref}| - |T_e| \le |T_{eref}| + |T_e|$: not changed

c. switching table

The switching selection block in fig.1 receives the input signals as shown in figure. The look up table for desired control voltage vector is shown in Table 1.

Table 1: Selected voltage Vector Switching Table

$d\varphi$	dT_e	$\alpha1$	$\alpha2$	$\alpha3$	$\alpha4$	$\alpha5$	$\alpha6$
	1	V_2	V_3	V_4	V_5	V_6	V_1
1	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_6	V_1	V_2	V_3	V_4	V_5
	1	V_3	V_4	V_5	V_6	V_1	V_2
0	0	V_0	V_7	V_0	V_7	V_0	V_7

-1	V_5	V_6	V_1	V_2	V_3	V_4

$$-30° < \alpha_1 < 30°$$
$$30° < \alpha_2 < 90°$$
$$90° < \alpha_3 < 150°$$
$$150° < \alpha_4 < 210°$$
$$210° < \alpha_5 < 270°$$
$$270° < \alpha_6 < 330°$$

The flux increment vector corresponding to each of six inverter voltage vectors are shown in fig.3.

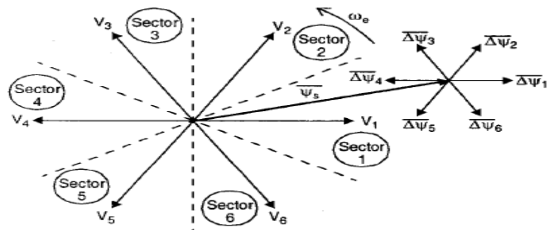


Fig 3: Inverter Voltage vectors and corresponding stator flux variation.

III. SIMULATION RESULTS

The comparison of the Scalar Control Method and Direct Torque Control (DTC) method of induction motor using the MATLAB/SIMULINK is given below.

A simulink model of scalar control is shown in fig 5.

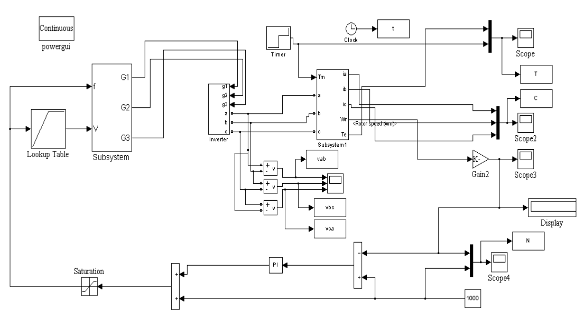


Fig 4: Simulink Model of Scalar Control Method

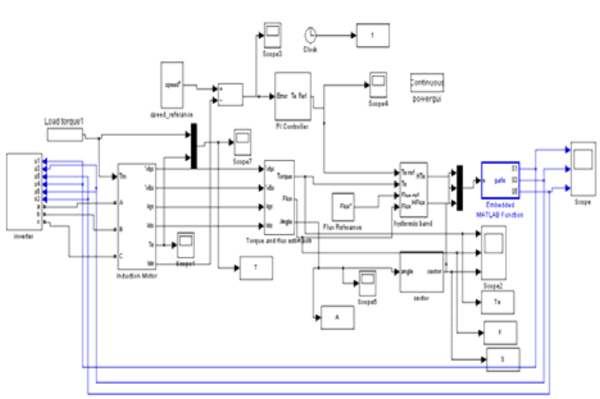


Fig 5: Simulink Model of Direct torque control Method

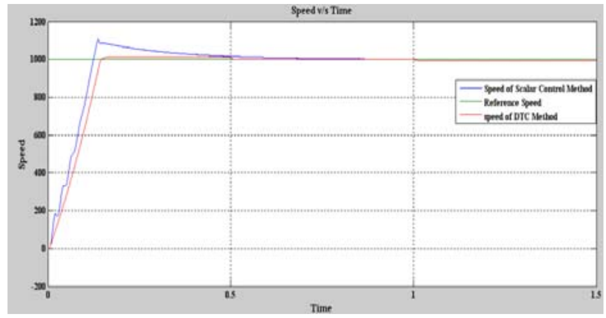


Fig 6: Speed of Induction motor (a) DTC and (b) Scalar

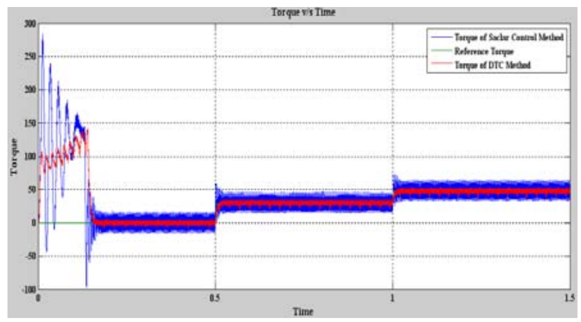
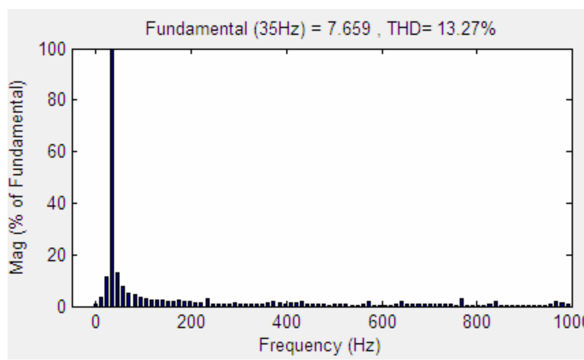
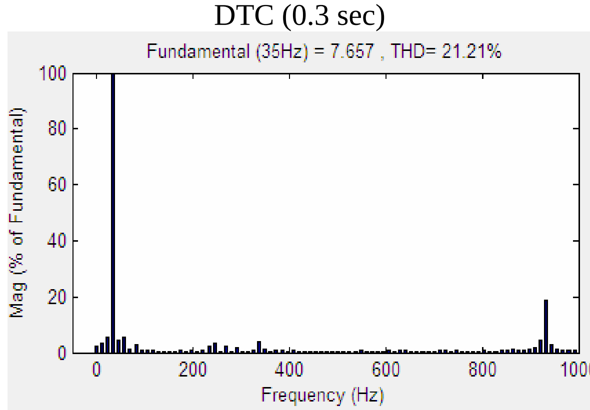


Fig 7: Torque of Induction motor (a) DTC and (b) Scalar

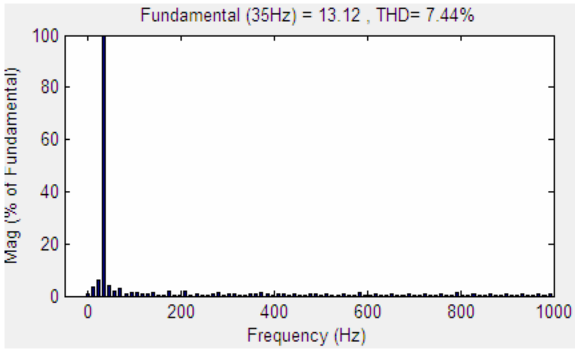


DTC (0.3 sec)

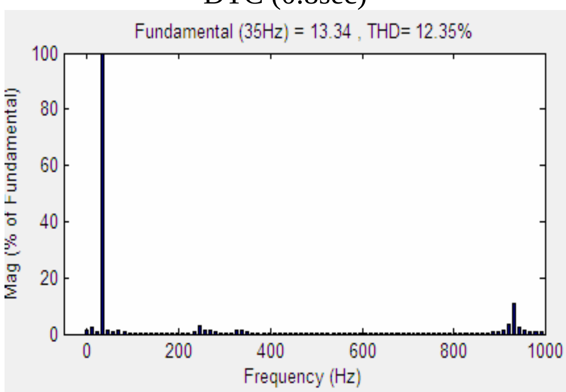


Scalar (0.3 sec)

Fig 8: FFT analysis at 0.3 sec (THD of stator current)

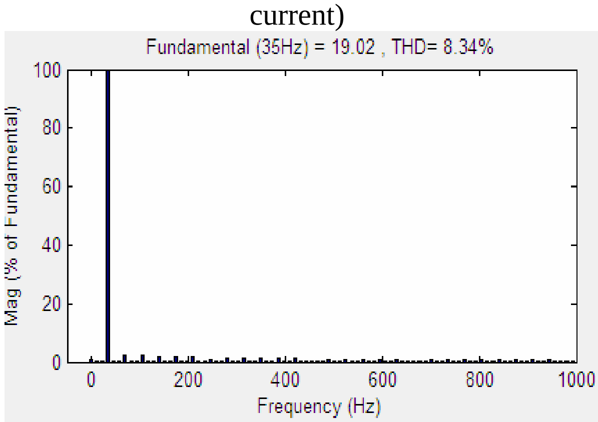


DTC (0.8sec)

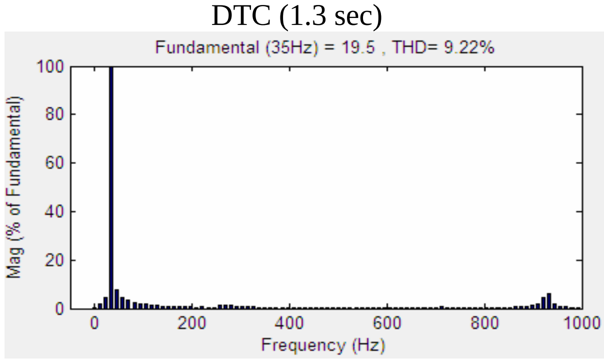


Scalar (0.8 sec)

Fig 9: FFT analysis at 0.8 sec (THD of stator current)



DTC (1.3 sec)



Scalar (1.3 sec)

Fig 10: FFT analysis at 1.3 sec (THD of stator current)

From the results, it is concluded that the speed response of direct torque control (DTC) method is faster than that of Scalar Control Method, torque of direct torque control method is within the hysteresis band and torque ripple is lower compared to scalar control method. From THD analysis, it is cleared that DTC has lower THD than the scalar control method.

IV. CONCLUSION

DTC is the control method for any IM drives. It does not require a co-ordinate transformation. It uses a stationary d-q reference frame where d-axis aligned with stator axis. Stator voltage vector defined in this reference frame control the flux and torque. It is concluded that speed response time of DTC is faster than Scalar Control Method also Stator current THD is lesser than Scalar Control Method. Torque ripple is also lower in DTC compared to Scalar Control Method.

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Appendix

Induction motor parameters

$R_s = 0.7384$	% Stator Resistance
$L_s = 0.003045$	%Stator Inductance
$R_r = 0.7402$	%Rotor Resistance
$L_r = 0.003045$	%Rotor Inductance
$L_m = 0.1241$	%Magnetizing Inductance
$p = 4$	%Number of Pole
$J = 0.14$	% Moment of Inertia
$f = 50$	%Frequency
$X_{ls} = 2 * pi * f * L_s$	%Stator Impedance
$X_{lr} = 2 * pi * f * L_r$	%Rotor impedance
$X_m = 2 * pi * f * L_m$	%Magnetizing Impedance

$$X_{m1} = 1 \Big/ [1/X_{ls} + 1/X_m + 1/X_{lr}]$$