DTC Controller Variable Speed Drive of Induction Motor with Signal Processing Technique

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***Abstract*—Induction motors (IMs) are very important components in industrial fields. This paper, variable speed actuator of induction motor (1M) with direct torque control (DTC) controller is proposed to control both flux and torque to increase the efficiency of a DTCIM in all period of operation due to adaptive algorithm. This adaptive algorithm set a large torque and flux at starting stage of operation to compensate instability while the small values of both torque and flux to control the steady state operation.**

Variable speed drive (VSDs) plays very essential role to control the speed and torque of IM by varying the voltage and frequency of IM supply. Simulation and experimental results through digital signal processor (DSP) ZQ28335 ensure accurate dynamic response in the torque and flux operations.

Keywords— DTC controller, 3-level inverter, IM, Speed control, Flux controller, VSD drive

I. Introduction

Computer control advances is essential issues in the enhancements of the human being life with the communications and control systems together with the power semiconductor electronics during the last 30 years. These advances leads to what is called smart technologies. One of the main device contributes this smartness is the VSD combined with the above technologies [1]. In the industry, the VSDs are played important role in different fields such as water pump station, filters and fault tolerant control systems. These devices are usually used with the medium voltage (MV) IMs, computer network, programmable logic controllers (PLCs), power electronics rectifiers inverters and supervisory control and data acquisition (SCADA) system.

The analogue devices is used to change the speed either manually or automatically in the intelligent or the smart VSD, according to a reference set up points.

The inverter is the main component to control the speed by changing the frequency. Hence, the new speed is obtained by changing the frequency to maintain a certain physical variable in the control system, such as the flow rate levels in the refineries. The main advantages of VSDs are good efficiency, low energy consumption, highly precision control [2].The smart actuator components can be shown in Fig.1.An IM with DTC is proposed in this work. Normally, the drawback of DTC is torque ripple, which is need special attention in the control system design. DTC performance has been improved through , a multi-band error status selection (ESS) method for the torque hysteresis controller in [3]. A neural network with sensorless five level DTC control using Extended Kalman Filter (EKF) applied to IM [4].Wavelet based three level inverter VSIM is presented in [5]. Speed control system in the low power IM by 2-level voltage source inverter has some difficulties mainly switching and insulation losses. A 3-level converter, with a fewer switching devices compared with the conventional 3-level inverters in the speed control of IMs is presented in [6].

A VSD with an active converter including a controller is new patent, which is similar to this paper [7].DTC applied to IM fed by 2-level voltage inverters and 3- level voltage inverters[8].

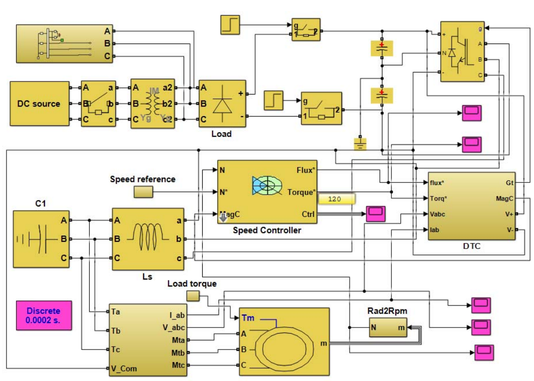

Fig.1. Main components of smart actuator

The control strategy of the smart actuator (SA) [9] is shown in shown in Fig.2.

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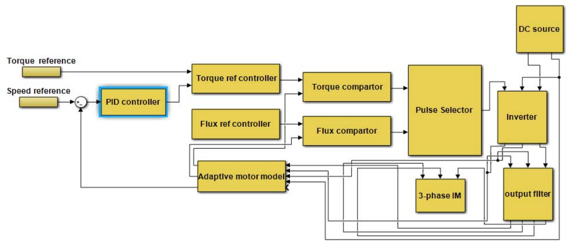

Fig.2. Control strategy used by smart actuator (VSD)

The computer technology is considered as the core of SA in the all range of utilization of the advantages of these advances and established in industrial development as new trend of control system and all aspect of engineering.

II. Induction Motor Model

The state space of the IM is:

$$X^{\cdot} = Ax + Bv_s$$
$$I_s = Cx \tag{1}$$

$x \in R^n$ is the state vector, $I_s \in Rm$ is the output vector,

$v_s \in R^r$ is the known input vector

A, B, C are the state space matrices of the IM according to the system shown in [10].The system matrix A is formulated as in (2)

$$A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \tag{2}$$

Where

$$A_{11} = \frac{1}{\sigma[1/\tau_s + (1-\sigma)/\tau_r]I} \tag{3}$$

Where

τ_r, σ, τ_s are rotor time constant ,the total leakage factor, stator time constant respectively.

$$A_{12} = \frac{L_m}{\sigma L_s L_r[(1/\tau_r)I - \omega_0 J)]} \tag{4}$$

Where

L_r, L_m, L_s is rotor inductance ,the magnetizing inductance, stator inductance respectively.

$$A_{21} = \frac{L_m}{\tau_s} I \tag{5}$$

$$A_{22} = -\frac{1}{\tau_r} I + \omega_0 j \tag{6}$$

j= [0 -1; 1 0] and I is an identity matrix. The input matrix B is calculated as in (7)

$$B = [B_1 \quad 0]^T \tag{7}$$
$$B_1 = (1/\sigma L_s)I \tag{8}$$

The output matrix C is calculated as in (9)

$$C = [I \quad 0] \tag{9}$$

Electrical model of IM implementation is shown in Fig.3

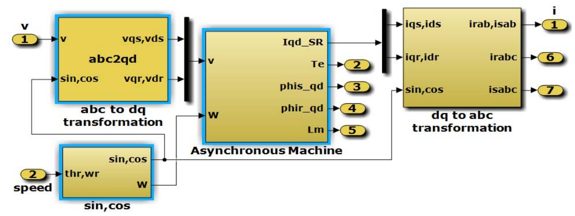

Fig.3. Electrical model of IM implementation

The rotor angle (Θ_m) computation in this paper uses Forward Euler (FE) integrator to ensure better reduction of the steady state error. This can be done according to mechanical model of the IM shown in Fig.4.

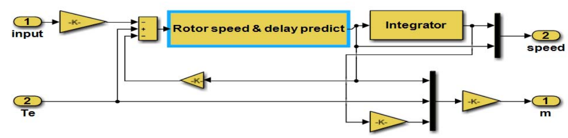

Fig.4. Mechanical model of IM implementation.

III. Speed Controller

Normally, the IM is considered as constant speed machine during all period of operation while the speed of a DC motor can be changed easily without and reduction of the efficiency as the IM operation [11].In the literature, there are many ways for the speed control of IM. One of the classification is rotor side control when using rheostat and cascade control. The stator side control carried out by changing the, input voltage, frequency, stator poles and the volt/ frequency control. The speed control is utilized PI controller and anti-wind up limiter, flux controller to maintain the flux in the range of operation. First order low pass filter is utilized for smoothing the output speed of IM. The speed controller block diagram is shown in Fig.5.

A adaptable motor model is matched with the speed controller as shown in Fig.2. The flux is sensed as the one output of the speed controller with to measure the speed operation and considered as input to the DTC controller with torque sensing as a second input for the DTC controller.

This technique improve the practical operation and will be considered as one type of the model predictive control [12].

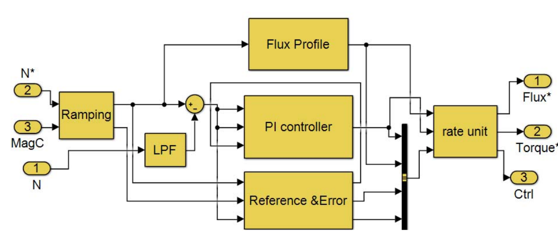

Fig. 5. Speed controller implementation

The complete speed matrix (w) in all frames of IM operation is shown as follows:

$$[w]=\begin{bmatrix} 0 & \omega & 0 & 0 \\ -\omega & 0 & 0 & 0 \\ 0 & 0 & 0 & \omega-\omega_r \\ 0 & 0 & \omega-\omega_r & 0 \end{bmatrix}$$

Where

□r, □ is the rotor speed and speed of the reference frame respectively.

IV. DTC CONTROLLER

In the industry, more than 60% of all the energy conversion is carried out by the rectification, smoothing and inversion combined the with the IM operation [13].

The main advantages of the DTC controller are[14]:

1. Maintain the motor stable operation without position feedback
2. Low cost due to sensorless speed estimation in many applications.
3. Accurate torque in a wide range of operation even in the zero or low speed.
4. Linear and high speed accuracy

DTC control system input /output variables can be shown in Fig.6.

Fig.6. DTC control system implementation

DTC control system implementation block diagram in Fig.6 can be shown as in Fig.7.

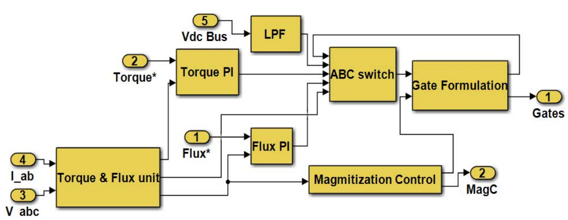

Fig. 7. DTC control system implementation

$$T_e=\varphi_{ds}I_{qs}+\varphi_{qs}I_{ds}$$
(10)

Where

$[\varphi_{ds}]=\begin{bmatrix} L_s & L_m \end{bmatrix}\begin{bmatrix} i_{ds} \\ i_{dr} \end{bmatrix}$, is the stator flux in the d-axis

$[\varphi_{dr}]=\begin{bmatrix} L_r & L_m \end{bmatrix}\begin{bmatrix} i_{dr} \\ i_{ds} \end{bmatrix}$, is the rotor flux in the d-axis

$[\varphi_{qs}]=\begin{bmatrix} L_s & L_m \end{bmatrix}\begin{bmatrix} i_{qs} \\ i_{qr} \end{bmatrix}$, is the stator flux in the q-axis

$[\varphi_{qr}]=\begin{bmatrix} L_r & L_m \end{bmatrix}\begin{bmatrix} i_{qr} \\ i_{qs} \end{bmatrix}$, is the rotor flux in the q-axis

One of the most important feature of the flux controller is to increase the efficiency of the DTC controller of IM [15]-[16].

This will completely depends on the switching signal controller which can be illustrated as in Fig.8.

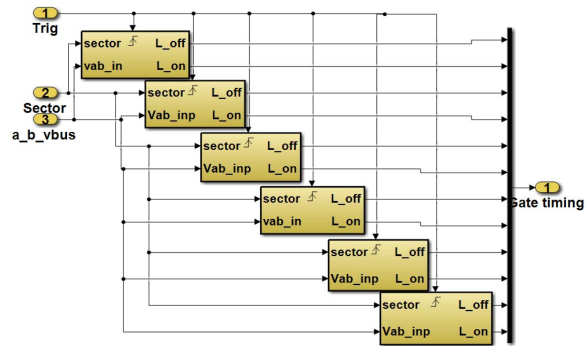

Fig.8. Switching signal formulation

V. INVERTER

The 3-ϕ inverters have gained great attention in the industry [17].The implementation 3-level in carried out with IGBT with RC snubber circuits in series and connected in parallel with each switch device.

There are two types of inverter controllers either current control or voltage control source.The current control source has been utilized in this work. The error is obtained by comparison the load currents with reference currents to be as inputs to the SPWM circuit to minimize the error. Two techniques are used either PI control or hysteresis control [18].To compensate the error compensation, the DC side is composed of one current source and of two controlled current sources connected to static load and three controlled voltage source are obtained due to its fast dynamic response as in Fig.9[19].

The DC current source is calculated as in (11)[20].

$$I_{dc}=(P_{ac}+P_{loss})/V_{dc} \tag{11}$$

Where

P_{ac}, P_{loss}, V_{dc} is the instantaneous power, the power devices losses, the DC bus voltage respectively.

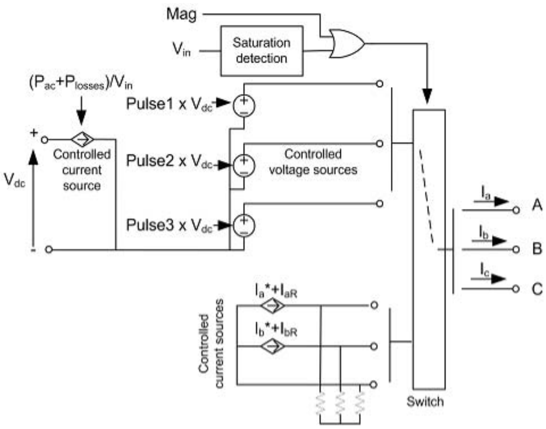

Fig.9. Current controlled inverter internal structure

According to the values of the pulses (1 or 0),voltage source outputs either V_{in} or 0, as can be shown in Fig.10.

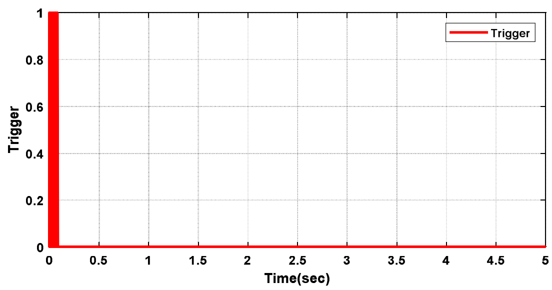

Fig. 10. Trigger response due DTC

This is detected uses a saturation detection block implemented in the Matlab/Simulink in the simulation results [21]-[22].

VI. Results

The DTC controller utilized to control motor flux and torque directly like the DC drives to obtain better accuracy. The torque and flux response of the IM during all period of operation can be shown as in Fig.11 and Fig.12 respectively.

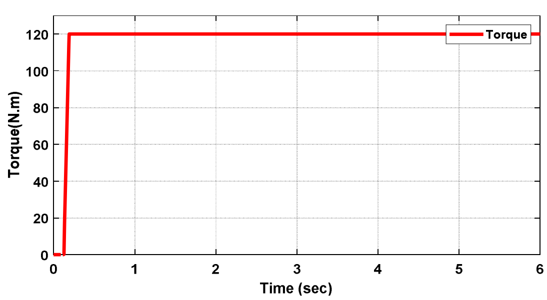

Fig.11.Torque response during the IM operation

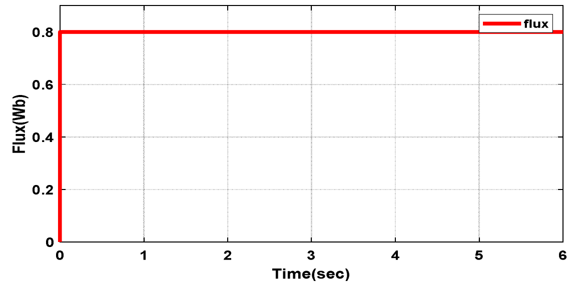

Fig.12. Flux response

The variable speed drive and the voltage output during the operation can be shown in Fig.13 and Fig.14 respectively.

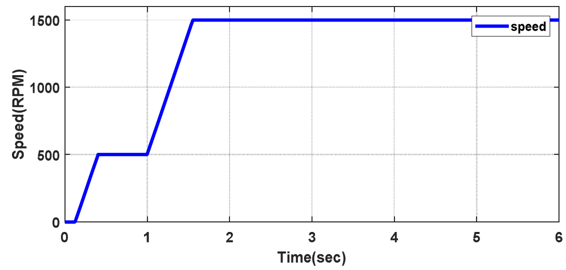

Fig.13. Variable speed output

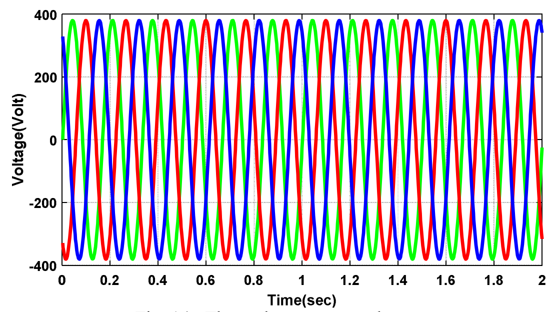

Fig. 14. Three phase output voltage

The three level inverter waveform is shown in Fig.15.

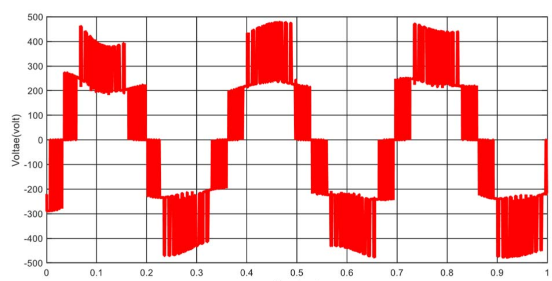

Fig.15. Waveform of the inverter

To displays the error measurements of speed controller over time, a control chart used for this purpose as monitoring tool [23]. A monitoring is an activity occur frequently to indicate an undesirable, systematic change in the process and identified the variation, so that the process can be compensated to reduce it as in the Fig.16.

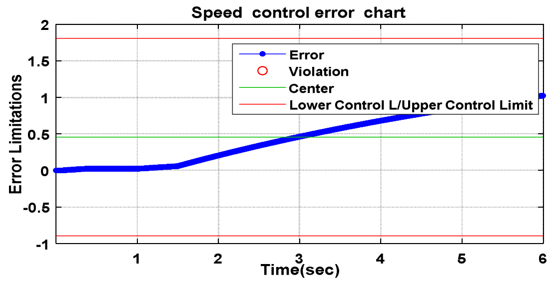

Fig. 16. Speed controller error limits

The error measurement of the magnetization control in the DTC controller is monitored as in Fig.17. The magnetization signal is used as feedback control signal for the speed controller.

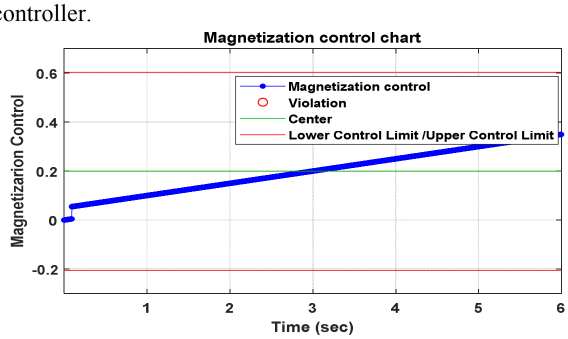

Fig. 17. DTC controller magnetization control limits.

The three sensors for the voltage (zmp101B), current (ACS712) and speed are used in this work as in Fig.18.

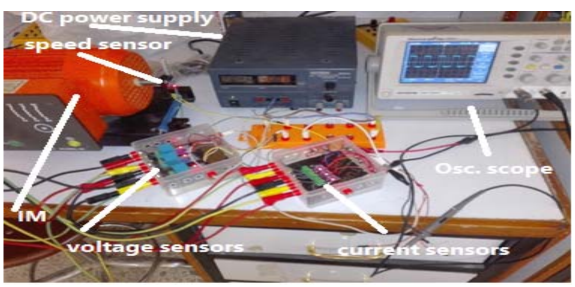

Fig. 18. Sensors used in this work

The ZQ28335 dsp used to control the proposed algorithm, The other part of the hardware is shown in shown in Fig.19.

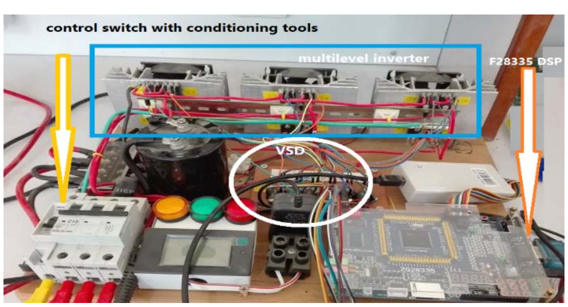

Fig. 19. Hardware implementation of the proposed work

Two phase voltage is captured with voltage sensor zmp101B. the sensor will sample the input and output an analogue voltage, in the region of 0- 5V[24]-[25]. This makes it easy to use in power monitoring applications is shown in Fig.20.

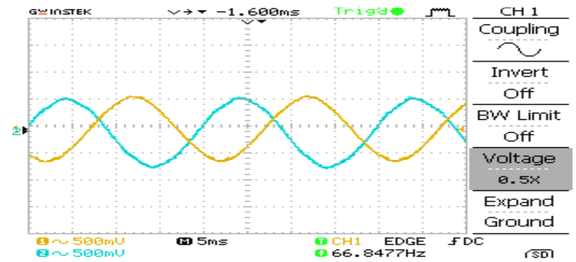

Fig. 20. Two phase voltage waveform

Connecting the sped sensor (FC-03) on shift of motor to monitor the speed variation as in Fig.21 and it is also clear on the oscilloscope shown in Fig.18. The FC-03 encoder or the encoder FZ0888 is an infrared speed sensor module with the LM393 comparator and it can be used with arduino [26].

The phase voltage is determined by the duty cycle of the PWM signals [27]. Hence, the frequency will be changed to prove the variable speed in the operation of IM.

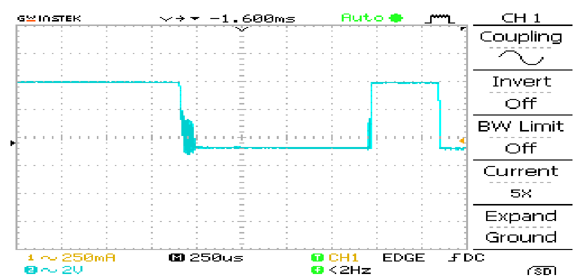

Fig. 21. Variable speed waveform.

The main parameters used in the PI speed controller, torque controller and flux controller can be listed as in table 1.

TABLE I. THE MAIN PARAMETERS IN THIS WORK

Controller	*Kp*	*Ki*	*Speed ref Ramp(rpm/s)*	*Hz*	*Ts*
Speed controller	23	10	-1900 +1900	100 cutoff	16e-6
Torque controller	80	1		50 cutoff	25e-6
Flux controller	8	4			
Switching frequency				5000	

VII. CONCLUSION

Smart or intelligent variable speed drives development is crucial in the enhancement of the life. Electronics devices is the state of the art for the VSD to provide sophisticated, efficient and accurate performance specifications in the control system. Induction motors is very important in the electromechanical energy conversion. The IM is started at no load with constant frequency and voltage. When the steady state has been reached, the control voltage is reduced in amplitude and frequency and after full load is applied as a step function.

This algorithm provides a sufficient design way because of the ease of sensing the monitoring of the parameter effects and the changes in system configurations and control strategies. Using Matlab/Simulink program to build the subsystem models and modify the complete control system easily.

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