Smart actuator for IM speed control with F28335 DSP application

Abidaoun H. Shallal[1], Assaad F. Nashee[2], Aws Ezzaldeen Abbas[3]
[1]Department of Communication, College of Engineering, University of Diyala, Baquba, Iraq
[2]Department of Information and Communications Technology, Institute of Technology, Middle Technical University, Baghdad, Iraq
[3]Al-zawraa Company, Ministry of Industry, Baghdad, Iraq

Article Info

Article history:

Received Feb 21, 2021
Revised Oct 7, 2021
Accepted Oct 12, 2021

Keywords:

3-level inverter
DTC controller
Flux controller
Speed control
VSD drive

ABSTRACT

In the industrial application, the induction motors (IMs) and the digital signal processing (ZQ28335) combination are very important in the scientific field. Two thirds of consumption of electricity is due to motor driven equipment. The direct torque control (DTC) is the standard of the industry and it has fast response control system applications. The drawback of DTC is the flux and torque ripples in the measurements. The scalar control can be considered as a solution to this drawback but with poor response. Torque and speed of IM are controlling individually, the variable speed drive (VSDs) is used. This occurs with variation of the voltage and frequency of IM supply. To decrease the levels of flux and torque ripples, 3-level inverters represent an attractive technique. The compromise of a huge flux and torque at the beginning level and low values at steady state of operation is crucial to ensure better stability with feedback linearization of the nonlinear behavior. In this paper, VSD with DTC IM with multilevel inverter with the newest version of ZQ28335 digital signal processor (DSP) is proposed. Emulation and the results of experiment through DSP ZQ28335 make certain correct dynamic response to the operations of torque and flux.

Corresponding Author:

Abidaoun H. Shallal
Department of Communication, College of Engineering
University of Diyala, Baquba, Diyala, Iraq
Email: abidaoun.hamdan@gmail.com

1. INTRODUCTION

A new development in industry has occurred in many aspects, such as a smart actuator. It can be defined as the merged acuter of all elements, for example, sensors, motor, controller and connection unit. Artificial intelligence is the workhorse of operation for the present and future research. In the past, direct current (DC) motors have been used in top execution of applications in variable speed drive (VSD) technique where fast torque is necessary [1]. They are considered as a main workhorse in the industry with freelance control of flux and torque in the motor. In direct torque control (DTC), the flux and torque ripples in the measurements should be avoided precisely to get sufficient functioning of induction motors (IM).

The maintenance of DC motor, sparking, difficulty in commutation at high current and voltage are confined to low power and low speeds, which are the main disadvantages [2]. During the last forty years, advances in computer control have contributed to improving the life of human beings with the connections and systems of control accompanied by the power semiconductor electronics. The future advances lead to near technologies inspiration. One of the major system sharing this cleverness is VSD along with the previous technologies [3]. Nowadays, VSDs play a significant function in missiles, medical applications, station of water pump, tolerant control systems of filters and spilt, computer connection, programmable system controllers (PLCs), power electronics rectifier's inverters and system of supervisory control and data acquisition (SCADA). They are commonly employed with medium voltage (MV) induction motors (Ims), direct controls for wind turbine with PMSG used on the real wind profile introduced by [4].

The TMS320F28335 digital signal processor (DSP) is a 32-bit floating-point digital signal controller. It improves system flexibility, accuracy, control performance, and performs more complex operations, saves code execution time, improves the system's response speed, and provides advantages for any control algorithm [5]. The main equipment is the inverter, which controls the speed by the frequent change in the circuit of IM.

The VSDs advantages include low energy consumption, better capacity, and highly precision control [6]. As mentioned earlier, the torque ripple is the drawback of DTC and requires observation in the layout of control system. It is controlled during the mistakes of multi-band status selection (ESS) procedure for the torque hysteresis controller in [7] with variable switching frequency [8]. A neural network with sensorless five level DTC control using extended Kalman filter (EKF) is designed by [9]. Wavelet based three level inverter voltage source inverter-fed induction motor (VSIM) is explained in [10].

The basic difficulties found in the system of speed control in the low power IM by 2-stage voltage source inverter are switching and dielectric losses. A 3-level converter, with a fewer switching devices compared with the conventional 3-level inverters in the speed control of IMs is explained in [11]. A VSD with an active converter in a new patent, which is similar to this paper, is introduced in [12]. DTC applied to IM fed by 2-level voltage inverters and 3- level voltage inverters is presented in [13]. A new trend of the actuator and sensors can be integrated in many fields, such as irrigation, as shown in Figure 1 [14]. The control strategy of the smart actuator (SA) [15] is presented in Figure 2.

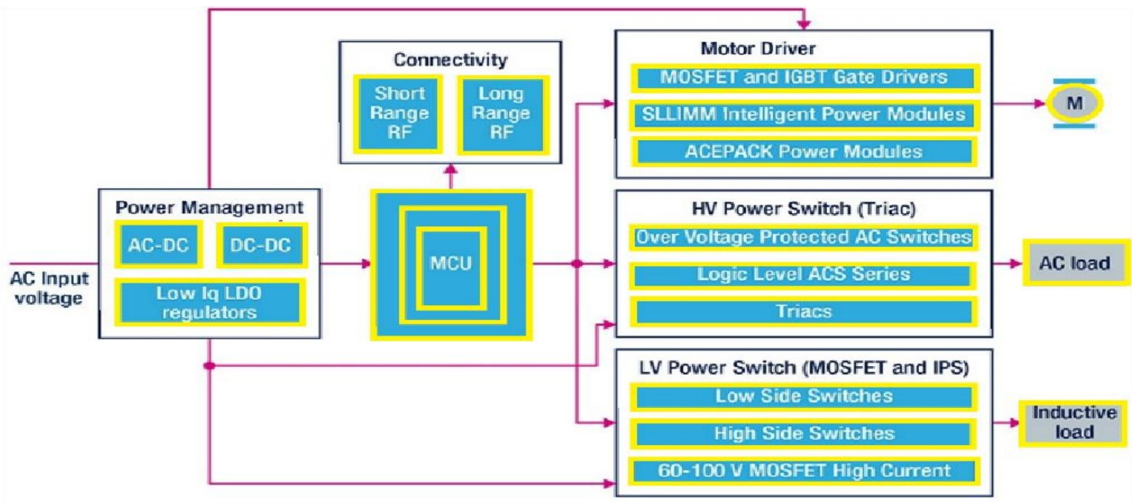

Figure 1. Integrated actuator and sensor components

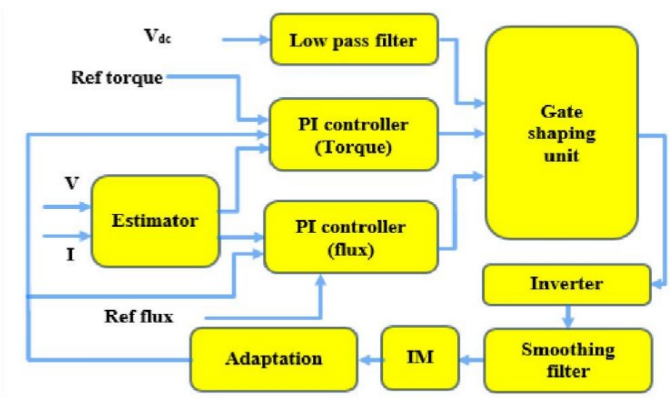

Figure 2. Control strategy used by smart actuator (VSD)

Nowadays and in future, the technology of computer is described as the SA core utilized in manufacturing evolution as a new method of control system. The actuators offer flexibility, cost efficiency, and intelligence.

2. INDUCTION MOTOR MODEL

The IM state space is expressed in (1):

$$X^{\cdot} = A * \begin{bmatrix} i_{sd} i_{sq} \\ \psi_{sd} \psi_{sq} \end{bmatrix} + B * \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix}$$
$$I_s = C * \begin{bmatrix} i_{sd} i_{sq} \\ \psi_{sd} \psi_{sq} \end{bmatrix} + D * \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} \quad (1)$$

x∈ Rn refers to the state vector; I_s ∈ Rm denotes the output vector; vs∈ Rr represents the known input vector [16]; A, B, C, D refer to the matrices of IM state space consistent with the system presented in [17]. The system matrix A is formed as in (2):

$$A = \begin{bmatrix} \frac{1}{\sigma\left[\frac{1}{\tau s} + (1-\sigma)\tau r\right] I} & \frac{Lm}{\sigma LsLr[(1/\tau r)I - \omega oj)]} \\ \frac{Lm}{\tau s} I - \frac{1}{\tau r} I + \omega oj & \end{bmatrix}$$
$$B = \begin{bmatrix} \frac{1}{\sigma Ls} I \\ 0 \end{bmatrix}, C = [10], D = 0 \quad (2)$$

where τr is rotor time constant; σ refers to the total leakage factor; τs indicates stator time constant; Lr is rotor inductance; Lm represents the magnetizing inductance; and Ls denotes stator inductance. The dynamics of the implementation of IM are presented in Figure 3.

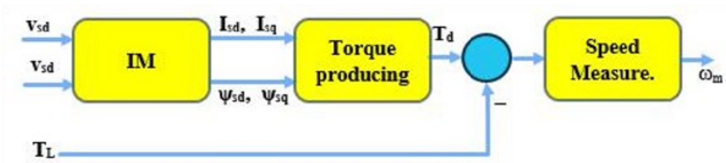

Figure 3. Dynamics fuction of the motor

In the work, the computation of rotor angle (Θm) is based on forward Euler (FE) integrator (explicit Euler) as one step integrator (β=0) in the general form of the linear multistep method (LMS) to ensure better decrease of the error of steady state and the stability [18].
The LMS equation is shown in (3).

$$y_{n+1} = y_n + h[\beta y^{\cdot}_{n+1} + (1-\beta) y^{\cdot}] \quad (3)$$

The criterion for the stability is that the amplification factor (z) does not exceed unity (4):

$$\left|z\right| = \left|\frac{1+(1-\beta)u}{1-\beta u}\right| \leq 1` \quad (4)$$

h, λ are the step size and Eigen value, respectively. The (4) is verified for all (h≥0) to ensure better stability of the system.

3. SPEED CONTROLLER

IM is considered as a constant speed machine; however, it is easy to change the DC motor speed without decreasing the IM operation activity [19]. The literature consists of many methods for the IM speed control including rotor side control when employing cascade and rheostat control. The input voltage, frequency, stator poles and the volt/ frequency control are changed to control the stator side.

The speed control utilizes PI observer and is against finish limiter, flux controller to monitor the flux in the operation extent. First arrangement low pass filter is employed to remove the IM output speed. Figure 2 presents matching adaptable model of motor with controller of speed. The flux is recognized as a speed controller output. For scaling the operation of speed considered as the input to the controller of DTC, the torque sensing is utilized as a second input to the controller of DTC. This method enhances the empirical process and is regarded as a kind of the sample fatal control [19]. The (5) presents the complete speed matrix (w) in all references frames of IM operation:

$$[\omega] = \begin{bmatrix} 0\omega 00 \\ -\omega 000 \\ 000\omega - \omega r \\ 00\omega - \omega r0 \end{bmatrix} \quad (5)$$

where ωr, ω are the rotor speed and speed of the reference frame, respectively.

4. DTC CONTROLLER

Over 60% of all energy conversion is executed by the rectification, inversion and smoothing in combination with the operation of IM [20]. Takahashi and Depenbrock first developed DTC as an infective to scope-oriented control. In DTC, an inverter with voltage source supplies the IM drive, it may control promptly the stator flux linkage (or the rotor flux or the magnetizing flux) and the electromagnetic torque through selecting an optimum inverter voltage vector.

Vector of the voltage source inverter is selected for restricting the mistake of torque and flux within their competent flux and torque hysteresis taps. In addition to obtain the fastest reply of torque and highest efficiency at each spot. DTC shows rapid torque reaction in the operation of transient and decrease of the harmonic losses and acoustic noise in steady state area. In DTC, modulator and a tachometer or position encoder are not required to estimate the speed or placement spear. The main advantages of the DTC controller are manifested in [21]. Figure 4 clarifies the DTC control system implementation.

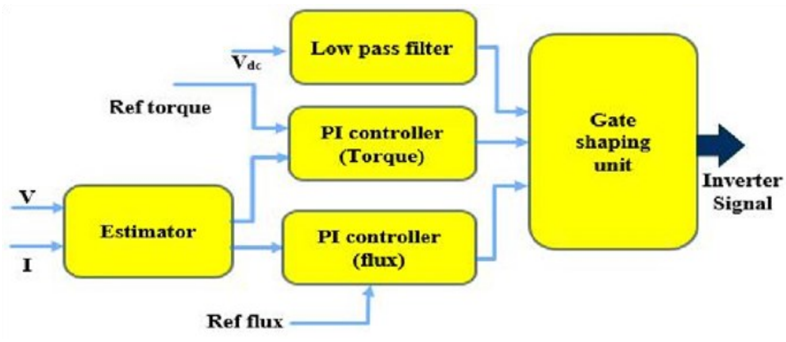

Figure 4. DTC control system implementation

The electromagnetic torque can be found as in (6):

$$T_e = \varphi_{ds} I_{qs} + \varphi_{qs} I_{ds} \quad (6)$$

where Φ_{ds} refers to the stator flux in the d-axis, and Φ_{qs} represents the stator flux in the q-axis. Among the most significant advantages of flux is the superfast effectiveness of the DTC controller of IM [22], [23], which will be very full on the switching indicative. In addition, speed estimators and sensors of flux, reducing the value and eliminating the need for regular maintenance represent advantages of DTC. It does not demand any match conversion, which would gain the computational schemes. Comparators of motor torque and flux hysteresis compare the real value with the reference value of torque and flux. The comparison between volt to frequency (v/f), DTC and field oriented control (FOC) can be illustrated in Table 1 for many parameters of operation.

Table 1. V/f, DTC and FOC comparison

Parameters	Controllers types		
	v/f	DTC	FOC
Torque reaction	Fair	Excellent	Good
Robustness	Low	Good	Good
PWM for closed loop control	Not	Needed	Needed
Construction	Simple	Simple	Not simple
Control of speed	Not	Good	Good
Steady state performance Low	Low	Good	Excellent

5. INVERTER

In the industry, the 3-ɸ inverters have a big notice [24]. The application 3-stage is performed in a chirred with insulated gate bipolar transistor (IGBT), resistor-capacitor (RC) snubber circuits in group and linked equally to each tool. Inverter controllers have two types: current control and voltage control source, as shown in Figure 5. This paper uses the current control source. Obtaining the mistake is achieved by comparing the currents of charge with those of reference to function as inputs to the sine pulse width modulation (SPWM) circuit to decrease the mistake.

There are two techniques of control used: hysteresis and proportional integral (PI) [25]. To improve the wrong compensation, the side of DC is collected from sources of: 1) current, 2) controlled current linked with static load, and 3) controlled voltage obtained because of its rapid dynamic response [26]. The traditional algorithm of DTC relies on the immediate values and is directly computed using the digital control signals for the inverter [27]. The current source of DC is computed using the (7) [28]:

$$I_{dc} = (P_{ac} + P_{loss})/V_{dc} \tag{7}$$

where P_{ac} refers to the instantaneous power; P_{loss} is the losses of power devices, V_{dc} represents the voltage of DC bus.

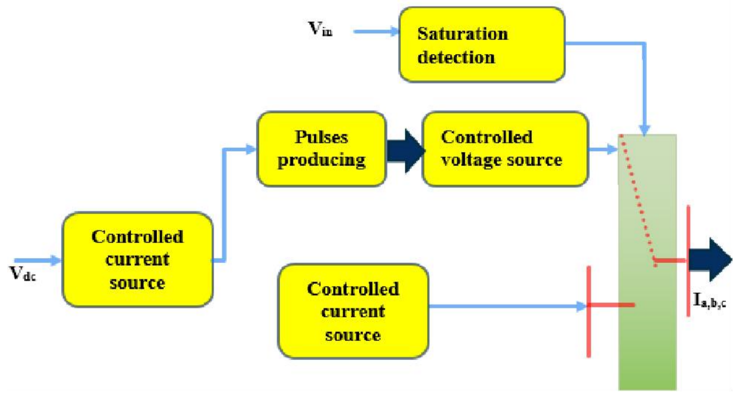

Figure 5. Internal structure of controlled current inverter

Consistent with the pulses values (1 or 0), outputs of voltage source (Vin or 0) are presented in Figure 6. A saturation revelation prevents executing this detected use in the Matlab/Simulink in the results of simulation [29], [30]. In real time applications, it is preferred to control a power converter using a DSP for the verification of SPWM control strategy. The block diagram of such a configuration is illustrated in Figure 7.

The family of C2000 includes the instruments required for the computation power to perform algorithms of complex control, such as digital motor control (DMC) [31], analog to digital converter (ADC), enhanced pulse width modulator (ePWM), and quadrature encoder pulse (QEP). IGBT control references are gained ship a DSP card, based on a processor dedicated to signal processing the TMS320F335 from Texas Instruments, which is controlled by computer. The F28335 DSP is shown in Figure 8.

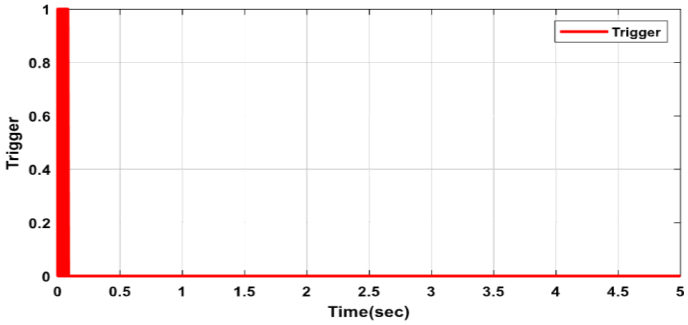

Figure 6. Trigger response due to DTC

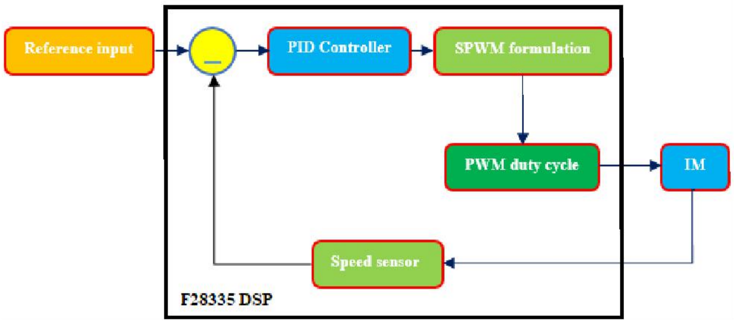

Figure 7. PWM generation block diagram

Figure 8. DSP28335

6. RESULTS

Controller of DTC is applied to regulate torque and motor flux frontally similar to the DC drives for obtaining the best accuracy. The flux and torque reply of IM during the whole process is presented in Figures 9 and 10, respectively. The voltage output through process and the changeable speed drive is shown in Figures 11 and 12, respectively.

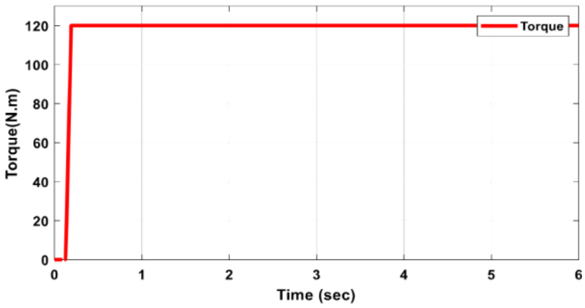

Figure 9.Torque reply through the IM process

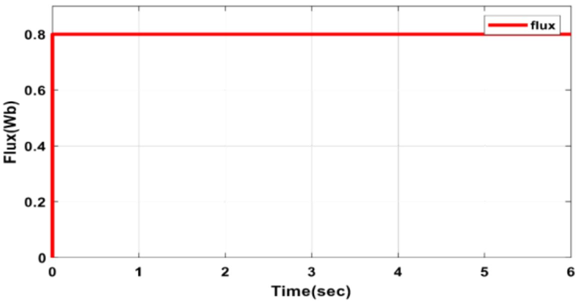

Figure 10. Flux response

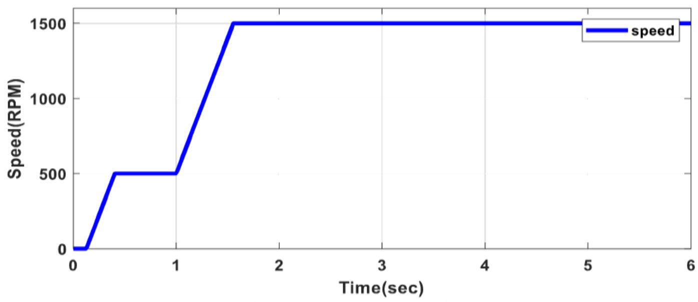

Figure 11. Variable speed response

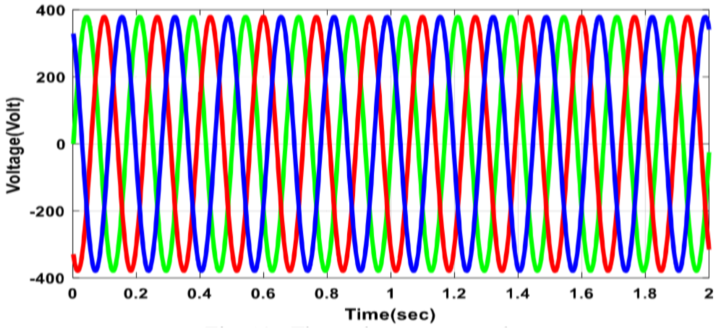

Figure 12. Three phase output voltage

A series of a multi cell, full bridge, and current source inverter feeding IM is performed. The experimental parameters of the inverter are characterized as:
- The supply voltage is 400V
- The values of the capacitor is 250µF
- The SPWM frequency is 5 KHz
- Three phase AC motor.

The three stage inverter wavefshape is shown in Figure 13. The periodic with the total harmonic distortion (THD) of the control signal is shown in Figure 14. The order of harmonics (1-7) of SPWM unit with the phase angle is shown in Table 2. The harmonics order of the control signal for (1-7) is presented in Figure 15.

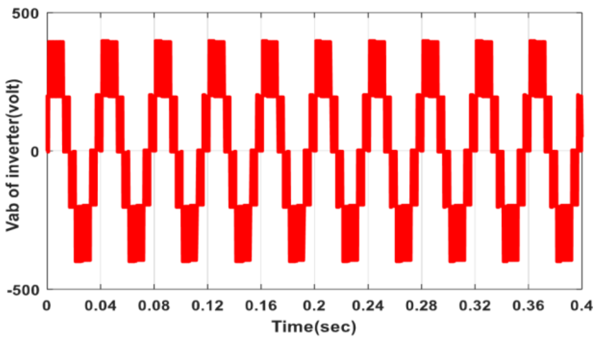

Figure 13. Waveform of the inverter

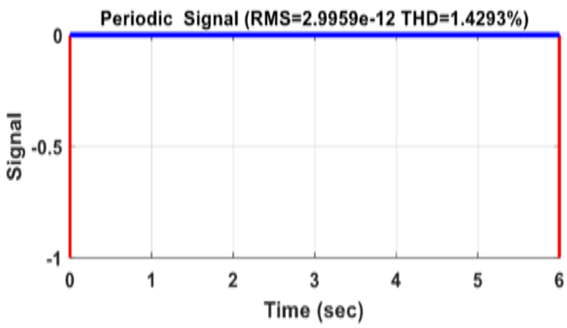

Figure 14. Periodic signal with THD

Table 2. Harmonic order and phase relationship for SPWM scheme

Order of harmonic phase (degree)	Value
1	-113.04
2	12.41
3	82.10
4	-129.31
5	54.30
6	117.26
7	-156.04

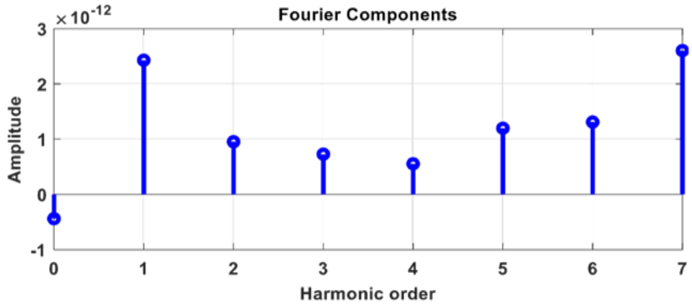

Figure 15. Fourrier components of the control signal

For showing the wrong measure of speed controller with the passage of time, a control table is employed as an observation instrument. An observation is an action happened frequently to point an unwanted, systematic turn in the procedure and to identify the difference. Hence, the compensation of process can decrease it as clarified in Figure 16. Figure 17 clarifies the wrong measure of the magnetization control in the controller of DTC. The signal of magnetization serves as a signal of feedback control for controller of speed. The duty cycle of SPWM to control the induction motor is shown in Figure 18.

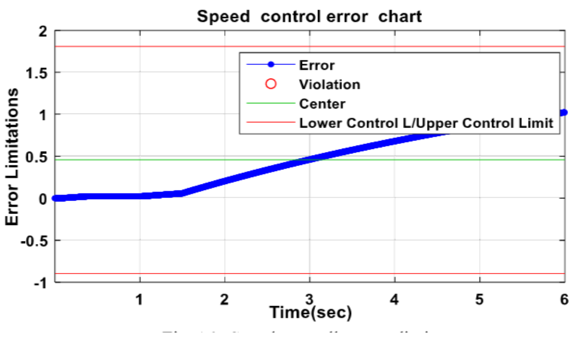

Figure 16. Error limits of speed controller

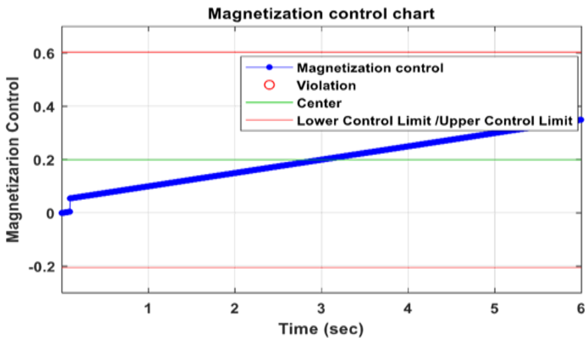

Figure 17. Limits of magnetization control of DTC controller

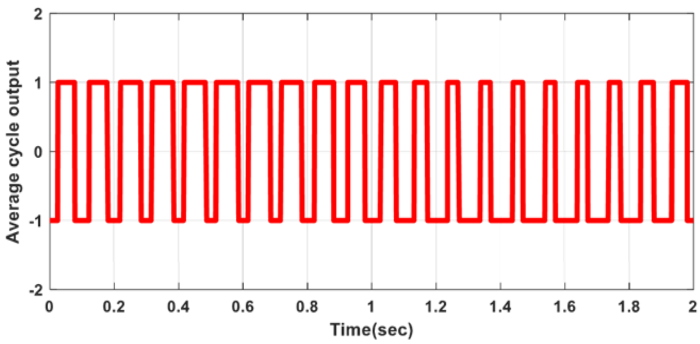

Figure 18. Duty cycle of SPWM

For nonlinear systems, a varying equilibrium, Jacobian linearization (JL) algorithm, is implemented to yield better linear operation. A fuzzy logic controller (FLC) algorithm is implemented for direct torque control induction motors (DTCIM). The speed-angle variation in Figure 19 shows that in (15), system response is fully controlled with increasing speed. In this paper, (3) sensors for the voltage (zmp101B), current (ACS712) and speed are employed. ZQ28335DSP is employed to control the suggested algorithm; the other small parts are presented in Figure 20.

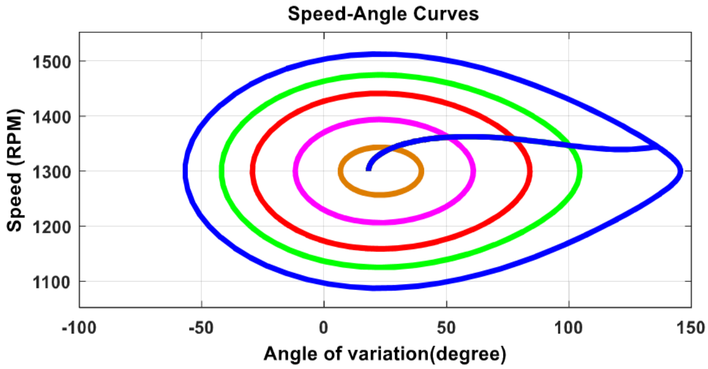

Figure 19. Equilibrium state of the system to ensure stability analysis

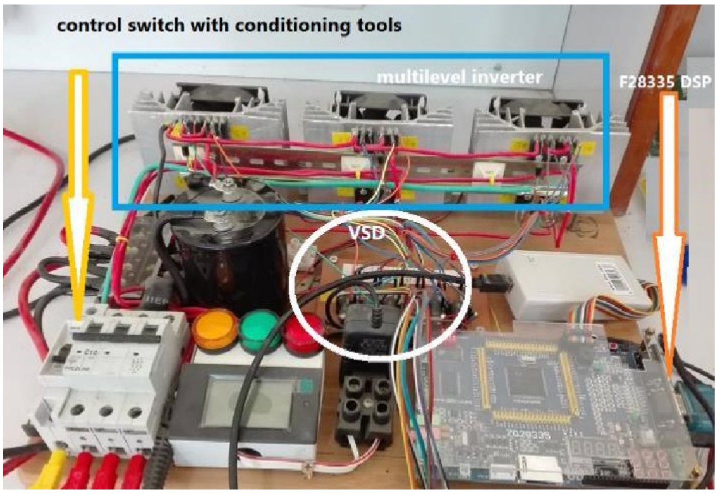

Figure 20. Hardware application of the suggested work

Two-phase voltage is recorded by using voltage sensor zmp101B. The sensor will show the analogue input and output voltage in the 0- 5V area. This will make it easy to use in observing enforcement connection the speed prospector (FC-03) on shift motor to observe the difference in speed. The FC-03 encoder or the FZ0888 encoder is an infrared speed sensor module with the LM393 comparator. It can be used with Arduino. The voltage of phase is defined by the duty cycle of the signals of PWM. Therefore, it is possible to change the frequency to confirm the different speed in the IM process. The key parameters utilized in speed controller of PI and torque controller include: Kp=23, Ki=10, the reference speed is 1900RPM, cut off frequency of the low pass filter is 100 Hz, switching frequency = 5000 Hz. The lockup table flux formation is shown in Figure 21.

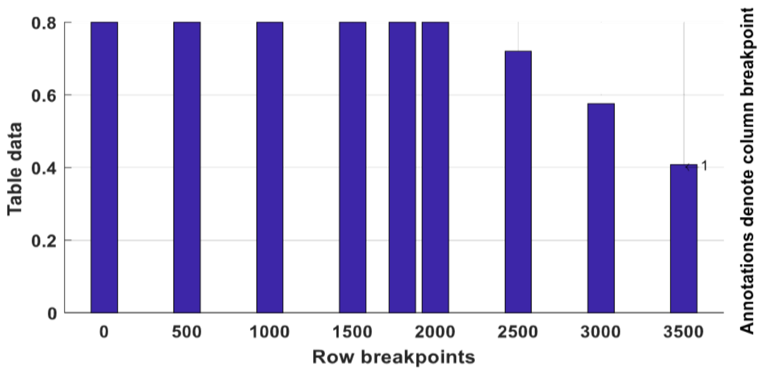

Figure 21. Flux data used

7. CONCLUSION

The intelligent or smart charging speed drives growth plays a significant role in improving our life. In industry, there are many applications involving actuators to connect with other actuators in intelligent ways, but we are well on the brink of something much bigger. DTC with multilevel inverter is better way to reduce the ripples of the flux and torque. This algorithm supplies an enough layout method due to the easily observation of the effects of parameters and the charge in system procedure and organizations of control. Program of Matlab/ Simulink is used for creating the models of subsystem and adjust the complete system of control easily. TMS320F28335DSP is a platform of the development board based on multi-carrier triangular SPWM control strategy. The stability analysis and equilibrium state proves the effectiveness of this algorithm.

REFERENCES

[1] A. Cagnano, E. De Tuglie, and P. Mancarella, "Microgrids: Overview and guidelines for practical implementations and operation," *Applied Energy*, vol. 258, 2020, doi: 10.1016/j.apenergy.2019.114039.
[2] O. Moradi, M. R. A. Pahlavani, and I. Soltani, "A Comparative Analysis of Field Oriented Control and Direct Torque Control of Induction Motor Drives," *MAGNT Research Report*, vol. 2, no. 5, pp. 22-31, 2014, doi: 14.9831/1444-8939.2014/2-5/MAGNT.3.
[3] J. K. Jain, S. Ghosh, and S. Maity, "Concurrent PI Controller Design for Indirect Vector Controlled Induction Motor," *Asian Journal of Control*, vol. 22, no. 1, pp. 130-142, 2020, doi: 10.1002/asjc.1911.
[4] D. Hammoumi, C. El Bekkali, M. Karim, M. Taoussi, N. El Ouanjli, and B. Bossoufi, "Direct controls for wind turbine with PMSG used on the real wind profile of Essaouira-Morocco city," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 16, no. 3, pp. 1229-1239, 2019, doi: 10.11591/ijeecs.v16.i3.pp1229-1239.
[5] H. Fu, W. Liu, and X. Du, "Hardware Design of Brushless DC Motor System Based on DSP28335," *International Journal of Science*, vol. 5, no. 3, pp. 265-270, 2018.
[6] U. R. Chinthakunta, K. K. Prabhakar, A. K. Singh, and P. Kumar, "Direct torque control induction motor drive performance evaluation based on torque error status selection methods," *IET Electrical Systems in Transportation*, vol. 9, no. 3, pp. 113-127, 2019, doi: 10.1049/iet-est.2018.5005.
[7] M. H. Lazreg and A. Bentaallah, "Sensorless Speed Control of Double Star Induction Machine With Five Level DTC Exploiting Neural Network and Extended Kalman Filter," *Iranian Journal of Electrical and Electronic Engineering*, vol. 15, no. 1, pp. 142-150, 2019, doi: 10.22068/IJEEE.15.1.142.
[8] S. A. A. Tarusan, A. Jidin, and M. L. M. Jamil, "The simulation analysis of torque ripple reduction by using optimal voltage vector in DTC fed by five-level CHB inverter," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 20, no. 3, pp. 1665-1676, 2020, doi: 10.11591/ijeecs.v20.i3.pp1665-1676.
[9] K. S. Gaeid, R. A. Maher, and A. J. Lazim, "Multilevel Inverter FaultTolerant Control with Wavelet Index in Induction Motor," *Journal of Electrical Engineering & Technology*, vol. 4, no. 13, pp. 1179-1191, 2019, doi: 10.1007/s42835-019-00086-0.
[10] S. G. Ardakani, M. Hosseinpour, M. Shahparasti, and M. Siah, "Direct Torque Control of Low-Voltage Three-Phase Induction Motor Using a Three-Level Eight-Switch Inverter," *Arab J Sci Eng.*, vol. 44, pp. 7121-7131, 2019, doi: 10.1007/s13369-019-03833-7.
[11] K. Borisov and J. Konstantin, "Variable speed drive with active converter," *patent no. US10187000B2*, 2019.
[12] L. Ouboubker, M. Khafallah, J. Lamterkati, and K. Chikh, "Comparison between DTC using a two-level inverters and DTC using a three level inverters of induction motor," *2014 International Conference on Multimedia Computing and Systems (ICMCS)*, 2014, pp. 1051-1058, doi: 10.1109/ICMCS.2014.6911167.
[13] ABB Switzerland Ltd., "ACS1000i air-cooled user manual," *Medium voltage AC drives*, Doc. No. 3BHS206977 E01 Rev H, 2020.
[14] STMicroelectronics, "Actuators, Valves and Pumps Control," *ST life augmented*, 2021. [Online]. Available: https://www.st.com/en/applications/smart-farming/actuators-valves-and-pumps-control.html
[15] K. S. Gaeid and H. W. Ping, "Induction motor fault detection and isolation through unknown input observer," *Scientific Research and Essays*, vol. 5, no. 20, pp. 3152-3159, 2010.
[16] S. E. Rezgui, H. Benalla, and H. Bouhebel, "Hybrid bacteria foraging-particle swarm optimization algorithm in DTC performance improving for induction motor drive," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 22, no. 2, pp. 660-669, 2021, doi: 10.11591/ijeecs.v22.i2.pp660-669.
[17] P. K. Ojha, E. Amiy, A. N. Bhagat, and S. Kumar, "Speed Regulation and Control of Inverter Fed Induction Motor Drives Using Controllers (PI, PID)," *Current Journal of Applied Science and Technology*, vol. 39, no. 9, pp. 7-14, 2020, doi: 10.9734/cjast/2020/v39i930601.
[18] A. Ibrahimbegovíc and B. Brank, "Engineering Structures Under Extreme Conditions: Multi-physics and Multi-scale Computer Models in Non-linear Analysis and Optimal Design," Amsterdam: IOS Press, 2005.
[19] Y. Zhang, Y. Bai, H. Yang and B. Zhang, "Low Switching Frequency Model Predictive Control of Three-Level Inverter-Fed IM Drives With Speed-Sensorless and Field-Weakening Operations," in *IEEE Transactions on Industrial Electronics*, vol. 66, no. 6, pp. 4262-4272, June 2019, doi: 10.1109/TIE.2018.2868014.
[20] I. Z. Ramirez, R. A. O. Rios, M. T. Hernande, R. de J. R.-Troncoso, and J. A. A.-Daviu, "Smart Sensors to Estimate Insulation Health in Induction Motors via Analysis of Stray Flux," *Energies*, vol. 12, no. 9, pp. 1658-1665, 2019, doi: 10.3390/en12091658.
[21] ABB, "DTC: A motor control technique for all seasons," 2019. [Online]. Available: https://new.abb.com/drives/dtc

[22] D. Ahmed, B. Mokhtar, and B. Aek, "DTC-ANN-2-level hybrid by neuronal hysteresis with mechanical sensorless induction motor drive using KUBOTA observer," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 1, pp. 34-44, 2020, doi: 10.11591/ijpeds.v11.i1.pp34-44.

[23] Noelp and Rebhan, "Advantages of variable speed actuators," 2019. [Online]. Available: https://www.valve-world.net/pdf/vw10xx_actuation_sipos.pdf

[24] C. Xie, K. Li, J. Zou, D. Liu, and J. M. Guerrero, "Passivity-Based Design of Grid-Side Current-Controlled LCL-Type Grid-Connected Inverters," in *IEEE Transactions on Power Electronics*, vol. 35, no. 9, pp. 9813-9823, Sept. 2020, doi: 10.1109/TPEL.2020.2971380.

[25] C. Harkare and P. Kapoor, "Study and Simulation of Current Controlled PWM Inverters and their applications," *International Journal on Recent and Innovation Trends in Computing and Communication*, vol. 3, no. 2, pp. 138-142, 2015.

[26] A. Milczarek, K. Możdżyński, M. Malinowski, and S. Styński, "Effective and Simple Control of Grid-Connected Three-Phase Converter Operating at a Strongly Distorted Voltage," in *IEEE Access*, vol. 8, pp. 12307-12315, 2020, doi: 10.1109/ACCESS.2020.2965727.

[27] B. K. Bose, "Modern Power Electronics and AC Drives," NJ: Prentice Hall, 2002.

[28] F. Mehedi, R. Taleb, A. B. Djilali, and A. Yahdou, "SMC based DTC-SVM control of five-phase permanent magnet synchronous motor drive," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 20, no. 1, pp. 100-108, 2020, doi: 10.11591/ijeecs.v20.i1.pp100-108.

[29] G. S. Tomar and A. Bagwari, "Fundamentals of Electronic Devices and Circuits, Part of the Algorithms for Intelligent Systems," book series (AIS), *Springer Publishers*, 2020, doi: 10.1007/978-981-15-0267-5.

[30] MathWorks, "Statistics and Machine Learning Toolbox," 2020. [Online]. Available: https://www.mathworks.com/help/stats/control_charts.html

[31] M. Schaefer, "Direct Current Control for Grid Connected Multilevel Inverters," *PhD thesis*. University Polytechnic. Catalonia. Department of Electrical Engineering, Spain, 2017.

BIOGRAPHIES OF AUTHORS

Abidaoun H. Shallal received a Bachelor's and Master's degree in Electrical and Electronic Engineering from Al-Rasheed College of Engineering and Science, University of Technology. Iraq. 1992 and 2001, respectively and PhD in electrical and electronic engineering. Control engineering from Altinbas University, Istanbul, Turkey in 2019. He taught many subjects in his field of expertise. He has a lot of research publications in international journals, his research interests in the field of control and robots.

Asaad F. Nashee received a Bachelor's and Master's degree and in Electrical Engineering/ Control from Al-Rasheed College of Engineering and Science, University of Technology. Iraq. 1993 and 2005 respectively. He is assistant lecturer information and communications Technology Department/Institute of Technology/MTU/ Iraq. His research interests of control and machine learning.

Aws Ezzaldeen Abbas, born in Baghdad- 1975, he received a Bachelor of Science in Communications Engineering-University of Technology 2000.