PERFORMANCE COMPARISON OF PID AND PR CONTROLLER IN A DTC OF AN INDUCTION MACHINE

[1]F. R. ISLAM, [2]E. J. K. MAR

[1,2]School of Physics and Engineering, University of the South Pacific, Fiji
E-mail: [1]islam_f@ usp.ac.fj, [2]S11086154@student.usp.ac.fj

Abstract - Direct torque control (DTC) of an induction machine is used to control the torque and finally the speed with the usage of a variable frequency drive (VFD). By using the measured current and voltage of an induction machine the estimated magnetic flux can be calculated. DTC is assessed considering, space vector adjustment modulation, field oriented control (FOC), vector control and others. The main focus of DTC of an induction machine will be space vector modulation DTC (SVM–DTC), which is a common technique to control the induction machine with usage of the torque and flux of the machine. Controllers are utilized in the DTC scheme to reduce steady-state error and therefore improve induction performance. In this paper the comparison of a proportional integral (PI) controller and a proportional-resonant (PR) controller will be analyzed to find out the best performance of DTC. Simulations have been carried out and demonstrated that PR controller has significant advantages over PI controller in DTC.

Keywords - DTC, VFD, SVM-DTC, Scalar Control, PI Controller, PR Controller

I. INTRODUCTION

The implementation of DTC for induction motors have been around for more than two decades and were introduced as a method of effectively controlling the torque and stator flux of an induction machine. Depending on the reference and estimated error values of the torque and flux that are based on the measured current and voltage, the inverter states are directly controlled by the DTC [1], [2], [3], [4], [5]. The benefits of using this method of control are its robustness, low complexity, good dynamic torque response, high efficiency and low losses. But the main drawbacks of using DTC is its relatively high torque and flux ripples, and its inability to distinguish between large and small flux and torque errors causing the system to use the same vectors during startup, step changes, and steady-state [1], [6].

DTC is one of the drive control methods in VFD which adjusts the frequency, motor voltage magnitude and the angle from the reference. The other drive control method is vector control which is also called FOC and this can be seen in Fig.1. VFD has been a very important application in many industries as it provides a very important energy savings opportunity for many existing induction machines [7]. VFD's enable motors to change speed by varying the frequency and voltage of the power supplied to the motor and by maintaining the volts/hertz ratio of the motor, the power factor is be maintained and the amount of excess heat produced by the induction motor is reduced.

In Scalar Control, the drives give inferior performances compared to other control systems but an advantage of this system is that it is easy to implement [8]. Scalar control (V/Hz) is basically varying two quantities simultaneously to control the system [9] and mainly focuses on the steady state dynamics. In order to control the speeds of the motor, the stator voltage magnitude is used in the controlling of the torque and this is because the different changes in the stator voltage affect the torque more than the effects the stator flux on the torque [10]. The main idea of the scalar control is basically trying to keep the ratio at a constant value so that the developed torque is maintained over a wide range of different speeds. Keeping the flux constant enables the full load torque capability to be maintained under steady state conditions but not for low speed. For the scalar control method the motor improves in steady state but opposite on the transient state [8]. This method of control also maintains the decoupling between the flux and the torque.

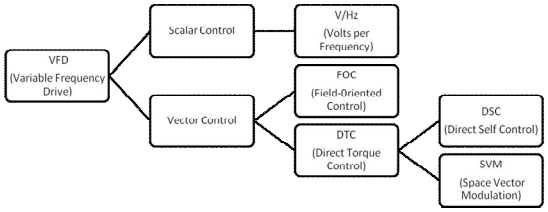


Figure 1: Overview of VFD control platforms

The basic idea of DTC is to choose the optimum vector of the supply voltage which causes the flux to rotate and produce the torque desired [11]. DTC is associated with the use of frequency drives to control the torque of three phase electrical drives. This method of controlling speed is well known because of the properties of the method which include fast dynamic responses compared with other control methods, for example the Field Oriented Control (FOC) [12]. In DTC the process of calculating and estimating the motor's magnetic flux and torque is

based on the outputs of the measured voltage and current. The stator current is decoupled so that it can obtain two independent components: flux and torque using Clarke's transformation [11]. Stator voltage is integrated to get stator flux linkage and using this flux linkages vectors and measured current, torque is estimated by the cross product of the two values. DTC enables quick torque response in the transient operations using stator Flux errors to generate the stator voltage and the frequency references [10].

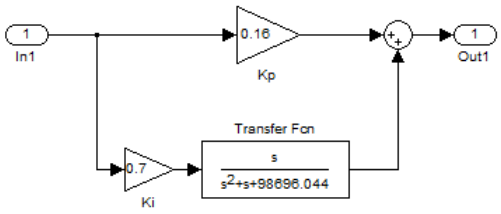


Figure 2: Block Diagram of PR Controller

The characteristics of a PI controller for the speed control of induction machines are characterized by the overshoot during the tracking mode and also the poor load disturbance rejections. It is commonly used in power systems as it is considered to be much steadier in steady state when noisy data is used. One disadvantage of the PI Controller is that, generally it is unable to follow a sinusoidal reference without the steady state errors due to the dynamics of the integral term [13].

The PR controller is a controller shown in Fig.2 provides a gain at a certain frequency (resonant frequency) and has almost no gain that exists at other frequencies. This controller does not suffer from the same problem as the PI controller whereby it has the inability to keep track of the sinusoidal reference but has a current controller which is more suitable at operating with the sinusoidal references.

II. SCALAR VERSUS VECTOR CONTROL

Scalar control involves the control of the magnitude of the target quantities. For the induction motor the technique used is referred to as VOLTS/HERTZ constant control as seen in Fig.3 with the downside being that scalar control cannot be used to control systems that are considered to be dynamic [14].
FOC is based on mathematical concepts for an easier to model and correlates to the structure of a DC machine which is well-controlled. The concept of field oriented control is that it deals with a complex coordinate system [14]. This method allows for the field components to be separated into two independent signaled controlled currents. These currents are components by which the flux and torque are derived. Thus, the torque and flux can be controlled independently.

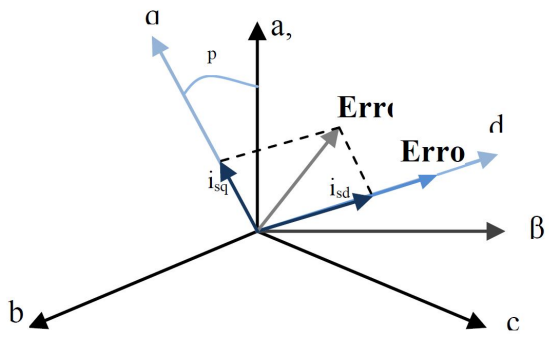


Figure 4: Rotating Reference Frame

The field oriented control consists of mathematically manipulating variables from one reference frame to the other. This involves bringing the vectors from the three phase reference frame 'abc' to the 'dq' synchronous rotating coordinate system. The rotating reference frame can be seen in Fig. 4. Here the directional component of the current can be utilized to control the rotor flux whereas the q directional component can be used to control the torque. Compared to the scalar control using the V/Hz constant model, the torque is controlled slowly. On the other hand the FOC provides a constant and steady torque response [13].

2.1. DTC versus FOC

With the usage DTC, it may be possible to establish a good dynamic control of the torque without the need of any mechanical transducers on the shaft of the machine thus this type of control technique can be considered to be 'sensor-less'. The DTC scheme is considered to be more suited within the small to medium power range applications [15]. Because DTC is sensor-less, for the purpose of comparison the Direct Field Oriented Control (DFOC) will be considered instead of just the scheme of FOC.

2.2. DTC using Space Vector Modulation

Common DTC drives makes use of the hysteresis comparators, and as a result tend to undergo relatively high variable switching frequency and torque ripple [16]. With the implementation of SVM this negative effect can be reduced.

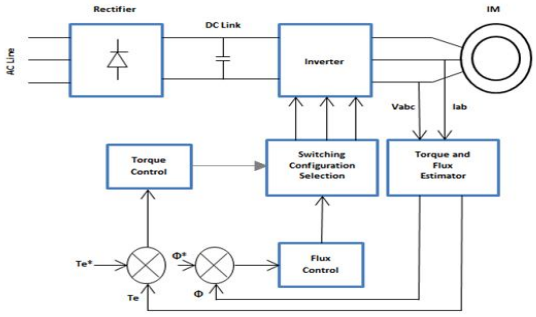


Figure 5: A Simplified Block Diagram of DTC via SVM

By using digital or analogue control electronics the PWM can be generated but it would require the significant computing time and this can only be calculated in real time. With the usage of SVM the calculations can be greatly simplified resulting in the required computing time to be reduced, therefore producing greater performance in the system [17].

SVM-DTC takes into account the torque and flux controller which is a three level comparator and a two level comparator respectively. The command torque T_e*and stator flux Φ* values are compared with the actual values of torque T_e and stator flux Φ in the hysteresis torque and flux controllers which can be seen in Fig.5.

A three-phase inverter converts the DC voltage source to AC voltage through a series of switches. This input voltage supply is maintained constant and periodically the switches are opened and closed in the appropriate sequence in order to produce the desired output.

The switching sequence of the inverter is determined by the six active vectors and depending the inverter switching pulses it is possible to achieve the PWM thus being able to control the stator current and voltage [18].

Essentially the switching pulses of the inverter gathered from the switching table will determine the error signals of the torque and flux. This error is vital in correcting the signal to perform more towards a desirable outcome. The end results show that the usage of space vector modulation in DTC ultimately provides a better control.

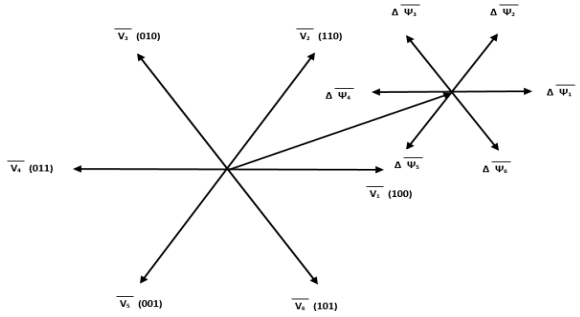


Figure 6: Inverter Voltage Vectors and Corresponding Stator Flux variation

IV. CONTROLLER DESIGN

Direct Torque Control Machines (DTCs) are sensor-less machines that do not require mechanical position sensors as required by Rotor Flux Oriented Control (RFOC). In fact, DTC machines estimate machine torque, stator and flux linkages using voltages and currents detected at the machine output terminals [19]. The stability of the output of a processing plant or in our case, a DTC machine, depends on the controller used. Controllers use error signals or actuating signals to adjust process output as seen in Fig. 6. These error signals are obtained by the addition of two signals for positive feedback system and subtraction for negative feedback system. Controllers are utilized in the DTC scheme to reduce steady-state error and therefore, improve induction motor performance. Two controllers are tested in the duration of this project, the PI and the PR controller. Comparisons are made between the two controllers by keeping the value of P constant while varying integral gain, the Load Current and Runtime, to determine the superior controller. All systems are expressed and analyzed in the Laplace domain (s-domain).

4.1. Proportional Integral (PI) Controller

Proportional Integral Derivative (PID) controller uses the error (actuating) signal to manipulate process variable and therefore minimizing the error signal. Within PID controller are three separate parameters, the proportional, integral and derivative values. PID controllers follow the general formula:

$$u(t) = G_{PI}(s) = K_P \cdot e(t) + K_I \cdot \int_0^{T_i} e(t) + K_D \cdot \frac{d}{dt} e(t) \quad (1)$$

Where $u(t)$ represents the input signal to the plant model,

K_P, K_I, K_D are the proportional, integral and derivative values respectively, and $e(t)$ is the error signal fed into the controller obtained by subtraction of feedback signal from reference input.

The implementation of the PI controller entails the exclusion of the derivative value, that is, $Kd \rightarrow 0$ [20]. System stability depends on the error signal, graphically referred to as steady-state error. The steady-state error percentage is determined by the plant output type or the plant designer. Zero steady-state error is generally preferred for its accuracy and stability in situations where the set-point tracks the reference value closely. For PI control strategy, $Kd \rightarrow 0$, and as a result, the PI controller function becomes:

$$u(t) = G_{PI}(s) = K_P \cdot e(t) + K_I \cdot \int_0^{T_i} e(t) \quad (2)$$

For example, given a plant transfer function in the continuous-time domain, $G(s) = 1/(s+1)^3$. Plots for the step response show the stability and accuracy (steady-state error) of the controller. K_P is held constant at 1 while K_i is varied .

PI controller step response of was generated producing an output seen in Fig.9. Note that T_i value is varied to obtain different values of K_i. Varying the K_i value determines whether the error signal of the system decrease or increase. A stable system is one in which the error approaches zero which proven by Fig.7. According to the legend of the graph, the value of K_i which is at maximum T_i produces the least overshoot and settling time, hence, steady-state error is the least and stead-state is achieved in a short

period of time. Therefore the value of K_i has to be at minimum to decrease overshoot.

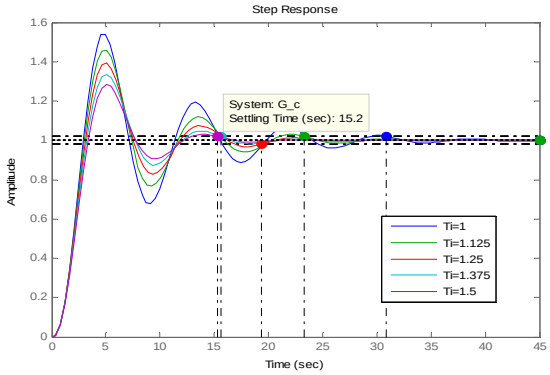


Figure 7: PI Step Response Curve for Selected Values of Ti

4.2. Proportional-Resonant (PR) Controller

A PR controller is a combination of proportional, integral and a notch filter to compensate the harmonics. The general formula for a PR controller is:

$$G_{PR}(s) = K_P + K_I \frac{2\omega_c s}{s^2 + 2\omega_c s + \omega_0^2} \quad (3)$$

Where ω_c represents the bandwidth around the ac frequency of ω_o = 0.5rad/sec. And ω_o represents the resonant frequency = 1/50rad/s = 314.2rad/sec

The plant transfer function used in the PI controller: $G(s) = 1/(s+1)^3$ was used in MATLAB simulation for comparison with the PR controller. Using the values for ω_o and ω_c, while K_P is held constant at 1 and K_i is varied, the MATLAB code for proportional plus resonant controller is stated as in Fig. 8.

There is major difference between the two controllers in shown in Fig. 7 and Fig. 8, the PR controller has no overshoot while PI controller shows overshoot at the same gain values. As result of 0% overshoot, the settling time is much faster and steady-state is achieved at a faster rate than PI controller. In addition, zero steady-state error is attained with the PR controller compared to the PI controller at the same values.

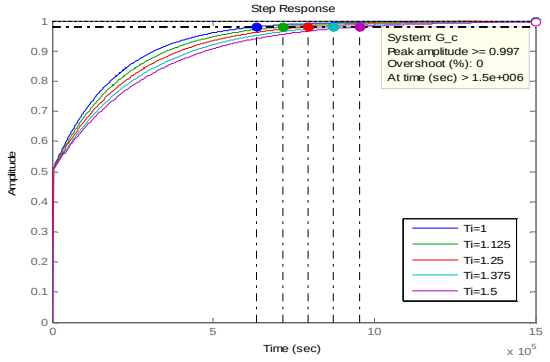


Figure 8: PR Step Response Curve for Selected Values of Ti

V. SIMULATION RESULTS

The PI and PR controller were both used in this DTC scheme and were simulated in order to obtain the different output waveforms with different loadings. The comparison between the output waveforms of the PI and PR controller will show which controller performs better under different load conditions.

5.1. Comparison Between PI and PR Controller

In order to compare a PI and PR controller the load of the system was varied from 0 to 15. This load is the torque load of the system that will change for different induction motors used, as different motors have different characteristics.

The parameters of the step input were adjusted to best suit the system. The step time was set to 0.5 seconds, it is the time taken to jump from the initial value to the final value. The initial value was left at 0 and the final value was adjusted for different load value ranging between 0-15.

Graphs of tout vs. Ia

The following results were simulated with kp=0.16 and ki =0.7 for both PI and PR controllers

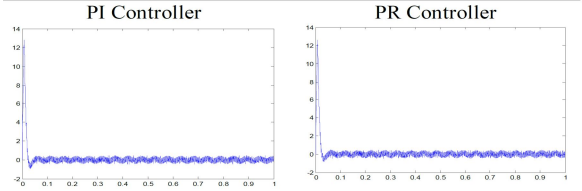


Figure 9: Current waveform with final load = 0
Max Amp ≈ 0.43
Min Amp ≈ -0.42
Wr = 120.1

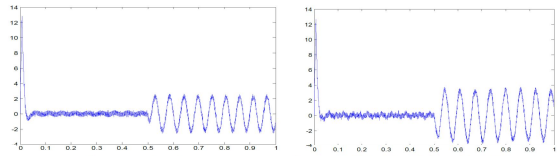


Figure 10: Current waveform with final load = 3
Max Amp ≈ 2.534
Min Amp ≈ -2.590
Wr = 117.9

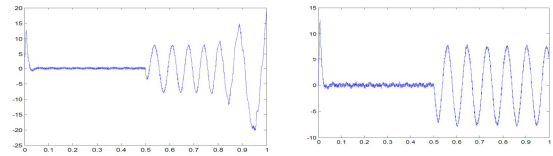


Figure 11: Current waveform with final load = 7
Max Amp ≈ 7.8
Min Amp ≈ -7.95
Wr = 72.69

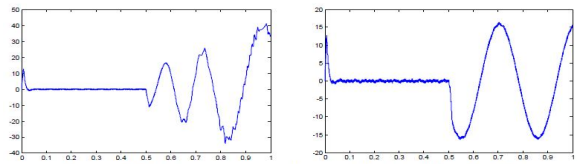


Figure 12: Current waveform with final load = 15
Max Amp ≈ 16.40
Min Amp ≈ -16.35
Wr = 20.41

Looking at the graphs above (Fig.9 – Fig.12), it can be seen that the PR controller can handle greater loads when compared to the PI controller. But there is one downfall to the PR controller when the proportional gain and the integral gain are the same for both systems, the output waveforms are noticeably noisier and needs further tuning to obtain a smoother output.

Also a major thing to notice is that as the torque load was increased the current of the system also increased, meaning that more current is needed to drive the system for greater torque loads.

5.2. PR Controller Fine Tuning

The output waveforms for the PR controller were considered to have more noise than in the PI controller when the proportional gain and the integral gain was the same for both controllers. Due to this fact the resonant part of the PR controller needed to be tuned to reduce to amount of noise produce by the system.

Graphs of tout vs. Ia

The following results shosw the comparsion between the original PR controller and the fine tuned PR controller

kp = 0.16
ki = 0.7

kp = 0.16
ki = 0.1

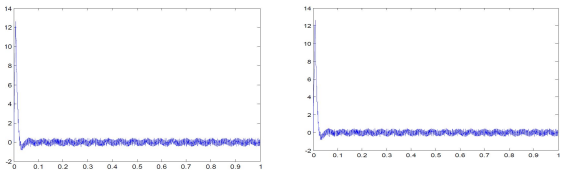


Figure 13: Current waveform with final load = 0
Max Amp ≈ 0.48
Min Amp ≈ -0.48
Wr = 119.2

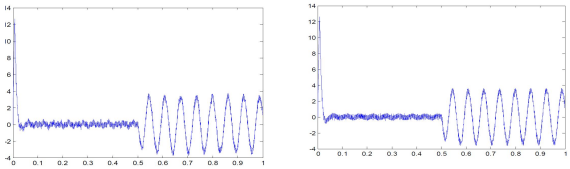


Figure 14: Current waveform with final load = 3
Max Amp ≈ 3.71
Min Amp ≈ -3.6
Wr = 99.31

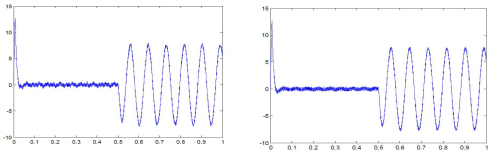


Figure 15: Current waveform with final load = 7
Max Amp ≈ 7.8
Min Amp ≈ -7.95
Wr = 72.69

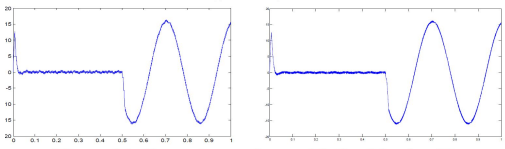


Figure 16: Current waveform with final load = 15
Max Amp ≈ 16.15
Min Amp ≈ -16.15
Wr = 20.41

RESULTS AND DISCUSSION

The performance of the system was done and observed by using MATLAB Simulink. This shows that the reference speed of the system goes up to 120 rad/s and is constant from values of time from 0 to 1. Simulation results shown above reputes two controllers used in comparison with each other. The figures show different performances of the system regarding the current, torque, speed and voltage with each being associated with time response of the system. The values of the proportional gain, integral gain and resonant gain are being changed in order to check for system response as well as system errors.

In comparison of the PI controller and the PR controller, it is found and observed that there is not much change in response between the two controllers except that varying the loads of the torque affects the system for both the PR controller and the PI controller. As described above for each set of graphs (Fig. 13 to Fig. 26) in correspondence to values of the proportional gain and the integral gain for both the PI controller and the PR controller that the stability of each controller is depended upon the load values applied to the torque. The reference speed remains the same throughout the system heedlessly to the values of the gain being changed run by trials. The PI controller has different responses to the different trials ran, with changes varying from negative to positive for the overshoot in current as well as changes in the amplitude. There are also instability problems as the proportional gain and the integral gain experiences higher loads applied. The system is also found to be more responsive to larger torque loads than in lesser torque loads for both systems of PR controller and PI controller.

The problem with PI controller is that it has a shorter delay and eliminates the steady state error but it is noticed that the overshoot or its transient response increases with increasing values of trials for both the Proportional gain and the Integral gain. Thus, the PI controller is less responsive. As this problem we faced using the PI controller, we also face instability problems with PR controller. Since PR controller has no limitations to its gain, this has likely to introduce stability problems when the values of the gains become too large for the system regarding this reason being, a transfer function is introduced as a damping factor in order to make the PR controller non-deal thus avoiding instability problems. Another problem is caused when the proportional gain, and the integral gain are the same as the resonant gain, tuning them to be of the same value makes the PR controller nosier, considering this factor, we have to use a different set of values for resonant gain in order to tune our PR controller correctly.

CONCLUSION

In this paper we have presented our findings and our analysis which shows the performance of the DTC of the Induction Machine in Comparison to a Scalar Control. The findings and the report are based on simulated results as done in MATLAB Simulink. The main aim of this experimented project is compare how Induction Machine Torque is being directly controlled compared to another controller called the Scalar Method. Induction motors could be controlled using various different controllers and are also classified under two main categories but choosing the right controller could lead to a better performance with an expected output.

The PR controller was studied in comparison with the PI controller as shown in our simulation in order tune the system. The system was analyzed, designed and the outcome performances were studied comprehensively by results of simulations in order to validate the theoretical concept for both controllers.
By using the PI controller in the system some problems were faced and encountered some disadvantages, such as high ripples in current and torque, variable switching frequency and less responsive to noise as well low operation conditions and also instability states when using values beyond limitation values of the proposed gain. These effects have led to another controller called the PR controller.
The PR controller used here has advantage regarding the gain, since PR only takes into consideration the resonant frequency, therefore only gain exist is the resonant gain and there are no other gains exist at any other frequencies. The only problem with the PR controller is that it does not work with the same values of proportional gain and integral gain as it is very sensitive and noisy, thus needed new set of values for tuning.

REFERENCES

[1] D. Ocen, "Direct Torque Control of a Permanent Magnet synchronous Motor," Stockholm, Sweden, 2005.

[2] A. A.H and A. Z.A, "Design of Direct Torque Controller of Induction Motor (DTC)," International Journal of Engineering and Technology (IJET), vol. 4, no. 2, pp. 54-70, 2012.

[3] T. Geyer and G. Papafotiou, "Direct Torque Control for Induction Motor Drives: A Model Predictive Control Approach Based on Feasibility," pp. 274-290, 2005.

[4] . Essadki, M. Douiri, T. Nasser and C. M, "Direct Torque Control of Induction Motor Based on Artificial Neural Networks with Estimated and Regulation Speed using the MRAS and Neural PI Controller," Journal of Theoretical and Applied Information Technology, pp. 15-21, 2010.

[5] S. Gdaim, A. Mtibaa and M. F. Mimouni, "Direct Torque Control of Induction Machine based on Intelligent Techniques," International Journal of Computer Applications, pp. 29-35, 2010.

[6] "Direct Torque Control Principles and Generaliies," [Online]. Available: http://www.tdx.cat/bitstream/handle/10803/6317/07Chapter1.PDF?sequence=7.

[7] V. Dahiya and S. Saurabh, "Sensorless Speed Control of 3-Phase Induction Motors by using Several Techniques," International Journal of Enhanced Research in Science Technology & Engineering , vol. 3, no. 9, pp. 71-78, 2014.

[8] P. K. Behera, M. K. Behera and A. k. Sahoo, "Speed Control of Induction Motor Using Scalar Control Techniques," international Journal of Computer Applications, vol. 1, no. 1, pp. 37-39, 2014.

[9] K. G and F. D, "Comparision of Scalar and Vector Control Strategies of Induction Motors," Hungarian Journal of Industrial Chemistry VESZPREM, vol. 39, no. 2, pp. 265-270, 2011.

[10] N. Pimkumwong, A. Onkrong and T. Sapaklom, "Modeling and Simulation of Direct Torque Control Induction Motor Drives via Constant Volt/Hertz Techniques," in International Conference on Advances in Computational Modeling and Simulation, Thailand, 2012.

[11] F. Korkmaz, I. Topaloglu and H. Mamur, "Fuzzy Logic Direct Torque Control of Induction Motor with Space Vector Modulation," International journal on Soft Computing, Artificial Intelligence and Applications, vol. 2, no. 5/6, pp. 31-40, 2013.

[12] A. Chourasia, V. Srivastava, A. Choudhary and S. Praliya, "Comparison study of vector Control of Induction Motor Using Rotor Flux Estimation by Two Different Methods," International Journal of Electonic an Electrical Engineering, vol. 7, no. 3, pp. 201-206, 2014.

[13] Z. D, S. S. C and A. M, "Comparison Between PI and PR Current Controllers in Grid Connected PV Inverters," International journal of Electrical, Computer, Energetic, Electronic and Communication Engineering, vol. 8, no. 2, pp. 221-226, 2014.

[14] G. Kohlrusz and D. Fodor, "Comparison of Scalar and Vector Control Strategies of Induction Motors," Hungarian Journal of Industrial Chemistry Vesprem, vol. 39, no. 2, pp. 256 - 270, 2011.

[15] D. Casadei, F. Profumo, G. Serra and A. Tani, "FOC and DTC: Two Viable Schemes for Induction," IEEE TRANSACTIONS ON POWER ELECTRONICS, vol. 17, no. 5, pp. 1 - 9 , 2002.

[16] A. Manuel and J. Francis, "Simulation of Direct Torque Controlled Induction," International Jornal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 2, no. 9, p. 1, 2013.

[17] H. Kantari, "K Direct Torque Control of Induction Motor Using Space Vector," International Journal of Modern Engineering Research (IJMER), vol. 2, no. 5, pp. 3750 -03757, 2012.

[18] A. S. Bhugul and A. G. Thosar, "Simulation of Direct Torque Control of Induction motor using Space Vector Modulation in Methodology," International Journal of Modern Engineering Research (IJMER), vol. 4, no. 5, pp. 10-17, 2014.

[19] F. Giri, "Part Five: Industrial Applications of AC Motors Control," in AC Electric Motors Control Advance Design Techniques and Applications, New Jersey, John Wiley & Sons, Inc, 2013, pp. 465-486.

[20] D. Xue, Y. Chen and D. P. Atherton, "Linear Feedback Control," Society for Industrial and Applied Mathematics, 2007.

★★★