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Study and Evaluation a New Predictive Control Method for Speed and Stator Current Control of Induction Motor

Faisal Ghazi Bashaw[1], *Intisar* Khalaf Salih[1] and *Ghanim* Thiab Hasan[2 *]

[1] Northern Technical College, Technical College, Kirkuk, Iraq Iraq
[2] Tikrit University, Al-Shirqat Engineering College, Iraq

ABSTRACT. It is clear that modern industries rely heavily on electric motors, especially induction motors. These motors convert electrical energy into mechanical energy. The distinction in the performance of the induction motor lies in that it is powerful when exposed to various operational and environmental variables, and it is also inexpensive. However, there are many traditional disadvantages that appear during the operation of the induction motor in its non-linear mechanical properties in addition to the difficulty in regulating the speed of the motor. In this paper , we present a new control method for controlling the stator current and speed of induction motor based on current control with speed control technique. The present model is based on conventional predictive controller development with a structure which is similar to rotor control and the direct torque control .It has double loops and both loops will use the prediction power. The inner loop controls the stator current based on Finite Control Set - Model Predictive Control (FCS-MPC) and the outer loop controls the speed to maximize the dynamic response of the loop. The MATLAB software has been used to implement the controller circuit. The obtained simulation results indicates that the presented control method has comparable performance to conventional controllers with some reduction in the overshoot and fast response interval.

1. INTRODUCTION

With the huge progress in the modern heavy industries, electric motors have an important aspect in modern industries through their effective ability to convert the applied energy from electrical to mechanical form. Factories use many types of electric motors in their production lines [1]. The induction motor (IM) is considered one of the most widely used engines due to its ease of operation, high flexibility in design, efficiency, low cost and maintenance [2]. Despite the available statistics, approximately 65% of the total motors used in industrial areas use induction motors (IMs) in various manufacturing applications [3]. However, one of the problems and challenges that designers face is the difficulty of controlling the speed of the induction motor compared to direct current motors, especially when there is a need to obtain high performance and high energy efficiency. Recently, there has been a focus on using the model called Predictive Control (MPC) as one of the most important and best ways to control instant messages. Therefore, it has become an area of interest for researchers in the topic of electrical power transformers and motors. Induction motors are increasingly used in industry and transport. This is mainly due to the mechanical suitability of these motors for loads such as electric vehicles, cranes, pumps and fans [4]. In addition, these motors have been improved and made more efficient by nonlinear and control methods using frequency converters to control the stator current and speed controllers [5]. So far, two ways demonstrated the field of high-power inverters. The first is field-centered control (FCC), which uses a linear regulator and a pulse width modulator to generate the gate signal of the power transistor [6-8]. Another widely used technique is incident torque control (ITC), which takes into account the extractive nature of the converter and uses a hysteresis comparator to generate pulses [9].

In recent years, prediction control become very important in implementation of the control of electronic and electrical devices [10-12]. This approach is useful in electrical engineering because it combines a reliable predictive model with a powerful microprocessor that can perform many computational operations. Predictive control is becoming increasingly popular in inverters, and the outcomes are very encouraging [13-15]. Model predictive control methods [16] are also used for speed loop control. These methods use a conventional cascade structure where an external speed controller feeds a torque into an internal current control loop [17],18].

* Corresponding author: ganimdiab@yahoo.com

Also, the model predictive control (MPC) has attracted much attention in the field of power electronics with the development of fast and powerful microprocessors [19]. The basic concept is to calculate the future behavior of a system in order to obtain optimal values for the driving variables. Using this basic concept, predictive control can be applied to a variety of methods where constraints and non-linearity can be easily added, multivariate situations can be investigated, and the resulting controllers can be easily implemented [20].

These features have made the technology attractive and successful in power electronic control systems, including drive control, especially in the area of Predictive Torque Control (PTC) [21], [22]. However, the synchronous speed between the flux currents in the rotor and the flux currents in the stator is never achieved because the flux from the rotating magnetic field is delayed. Control methods for induction motors are required in many industrial applications . The outer loop, which is the focus of our design, uses a dead loop to fully exploit the dynamic and steady state response of the inner loop [23].

The proposed present paper has therefore focused on the study and evaluation of a new method for speed and current control circuit.Firstly, we will develop a controller to predict stator current and speed. To evaluate the performance of the output solution, we evaluate and compare the simulation results in Finally, in the concluding section, we present our analysis, observations and suggestions for future research directions.

2. METHED

To develop a controller with speed and current prediction to drive the induction motor, we will go through some steps as follows:

- Create a system model including a 3-phase two stage inverter.
- Calculation of the l
- Current and speed prediction models at [k+1] and [k+2]times .
- Calculate the vector that acts as the lower cost function and apply this vector to the IGBT valve.

In the present work, the two-stage inverter used for the IC motor is translated into eight switching states to obtain the voltage vector.

2.1. Model for predicting current and magnetic flux

The stator flux equation in the stator coordinate system is given by the following equation [24].

$$\frac{di_s}{dt} = \frac{k_r}{r_\sigma \tau_\sigma} - \frac{1}{\tau_\sigma} i_s \left(jw + \frac{1}{\tau} \right) \gamma_r - \frac{1}{r_\sigma \tau_\sigma} u_s \tag{1}$$

Where : σ represent the total leacage factor $= 1 - \frac{L_{m^2}}{L_s L_r}$

τ_r represent the rotor time constant $= \frac{L_r}{R_r}$

τ_s represent the stator time constant $= \frac{L_s}{R_s}$

$\tau_\sigma = \frac{\sigma L_s}{r_\sigma}$, $K_r = \frac{L_m}{L_r}$ represent coefficient of calculations.

2.2. Stator current and speed controller model design

By using the Euler approximation for the sampling time Ts in equation (1) , the current and flux can be calculated as follows [24]:

$$i_s(k+1) = \frac{T_s k_r}{\tau_\sigma r_\sigma} \left(\frac{1}{\tau_r} - jw(k) \right) \gamma_r(k) v_s(k) + \left(1 - \frac{T_s}{\tau_\sigma} \right) \tag{2}$$

$$\gamma_r(k+1) = \frac{T_s L_m}{\tau_r} i_s(k) v_s(k) + \left(1 - \frac{T_s}{\tau_\sigma} \right) + jwT_s \, \gamma_r(k). \tag{3}$$

Where:

v_s represent the voltage.

T_s represent the stator tourqe.

γ_r represent the rotor flux.

2.3 Predictive speed controller model design

The aim of the speed controller is to achieve the correct vertical stator current in the shortest possible time according to the set speed.The change in the torque can be calculated as follows [25]:

$$\frac{d\omega}{dt} = \frac{1}{j}\,(T_e - T_L) \tag{4}$$

Where : T_e represent the elect tourque , T_L represent the load tourque.

If we apply the Euler approximation in case of sampling time T=Tds, we will have [25]:

$$\frac{\omega^{k+1} - \omega^{k}}{T_{ds}} = \left(\frac{3}{2}P\frac{L_m}{L_r}\gamma_{rd}i_{sq} - T_L\right)\frac{1}{j} \tag{5}$$

For implementing the speed predictive control loop, the value of the load torque $\mathbf{T_L}$ must be known. To achieve this task, the magnitude of the torque generated by the applied current must be calculated. For the evaluation within the loop, the load torque is only equal to the input disturbance. The load torque is equal to the input disturbance. Using the inverse Euler method, the load torque TL can be calculated as follows:

$$T_L = \frac{3}{2}P\frac{L_m}{L_r}\left(\gamma_{rd}^{k-1}\cdot i_{sq}^{k-1}\right) + \frac{1}{j}\left(\omega^{k} - \omega^{k-1}\right) \tag{6}$$

The modeling was carried out by using MATLAB-Simulink software with the simulation input data shown in Table 1. Motor parameter used in the simulation are indicated in Table 2.

Table 1. Simulation input data.

Sampling period(Ts)	Simulation time	Frequency period	Current (Isd)	Speed (ω)
200 s	5 s	5 KH	2.5 A	150 rad/sec

Table 2. Motor parameter used in the simulation.

Freq.	Rated power	Stator current	Inertia Moment	Stator resistance	Rotor resistance	Power factor
f	Pn	Isd	J	Rs	Rr	cosφ
50HZ	2.2 KW	2.5A	0.0018Kg.m^2	1.89 Ω	1.89Ω	0.8

The structure of the predictive control modeling is shown in Figure 1[26].

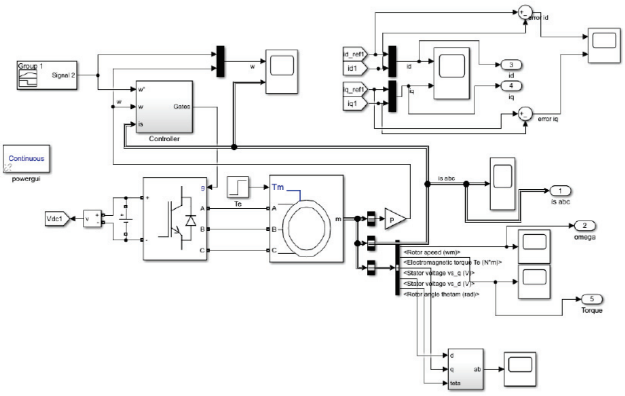

Fig. 1. Predictive control modeling [26].

3. RESULTS AND DISCUSSION

From the simulation results of the predictive control circuit in MATLAB software, we can see that the torque response is approximately achieved as shown in Figure 2. At the switch, however, it is aligned and has a large overshoot. The simulation results are shown in Figures 3, 4 and 5.

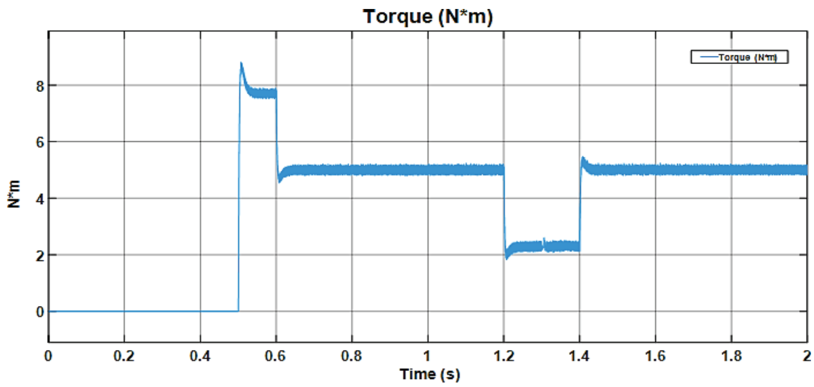

Fig. 2. Torque responses in case of using traditional controller (PI).

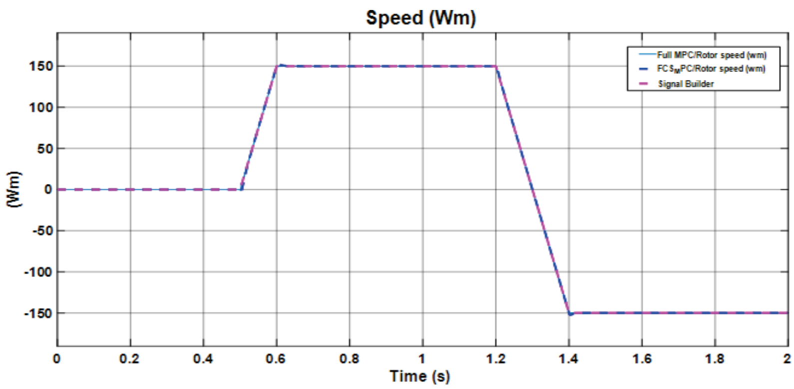

Fig. 3. Comparison between the responses of speed for the tradition (PI) and Model Predictive Control (MPC).

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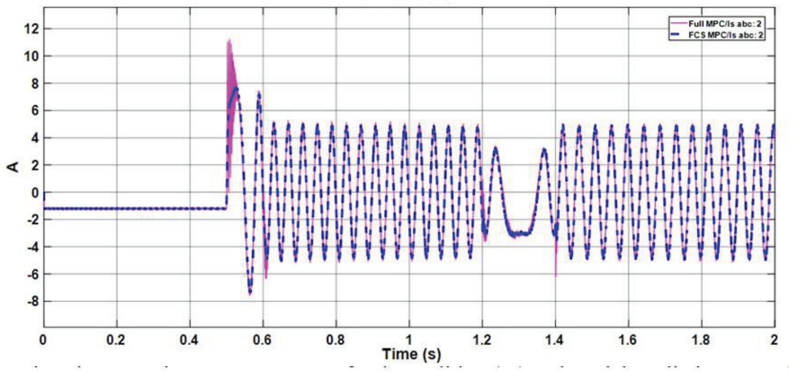

Fig. 4. Comparison between the current response for the tradition (IP) and model predictive control (MPC).

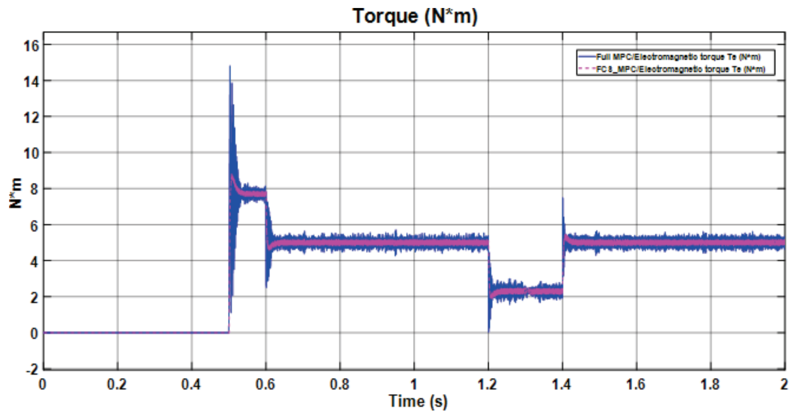

Fig. 5. Comparison between the torque response of the tradition (IP) and model predictive control (MPC).

The results show that when both controllers are used as predictive controllers, tracking is faster and overshoot is lower when MPC is used in the torque control loop and PI controller is used in the speed control .The torque and current characteristics are more stable and the impact ratio is lower when using a conventional predictive controller in both current and speed loop. Furthermore, both presented methods provide a sinusoidal current response.

In cooperation of the presented method of control with the similar predictive control models , we can see that the presented control method has comparable performance to conventional control methods with some reduction in the overshoot and fast response interval.

4. CONCLUSION

Model predictive control (MPC) in motors has become a factor of great interest in both academic and industrial fields because it contains important advantages in intuitive concept, in addition to rapid dynamic response, multivariate control, and the distinctive ability to deal with many nonlinear constraints that arise during induction motor working **.**In this paper ,the torque and speed controllers for induction motor has been successfully designed and implemented by using MATLAB simulation software. The speed, current,and torque responses are evaluated . The simulation obtained results indicate that this design achieve a fast and accurate in current and speed response. However, in the presented mathematical model, we do not include the problem in practical case such as nonlinearities that are evident in the case of a real system, for example, nonlinear magnetization, or nonlinear friction. These factors may lead to reduced speed performance in a certain situation, for example in a high-speed region. It is also possible that a similar problem may arise if the main operating parameters of the system are changed. So , to evaluate the validation of the proposed control solution, we may need to conduct experiments on faster controller with DSP or FPGA to evaluate the traditional predictive controller response for both current and speed loops. From the simulation results, it can be noted that the presented controller method provides an robust and effective motor speed from a low to high speed rating, with good accuracy.

REFERENCES

1. S. U. Raj and Tintu George T., “Speed sensor less induction motor drive with PCC in conveyor systems,” in Conference on Emerging Devices and Smart Systems (ICEDSS), 2016, pp. 97-112, doi: 10.1109/ICEDSS.2016.7587796.
2. Ghanim Thiab Hasan, Kamil Jadu Ali, Ali Hlal Mutlaq "Design of current controlled instrumental amplifier by using complementary metallic oxide semiconductor technology "Indonesian Journal of Electrical Engineering and Computer Science.Vol. 29, No. 2, February 2023, pp. 652~657. DOI: 10.11591/ijeecs.v29.i2.pp652-657 – 652.
3. J. Holtz, “Sensorless control of induction motor drives,” in Proceedings of the IEEE, vol. 90, no. 8, pp. 1359-1394, 2002, doi: 10.1109/JPROC.2002.800726.
4. G. T. Hasan, A. H. Mutlaq, and K. J. Ali, “Comparative evaluation of SiC/GaN “MOSFT” transistors under different switching conditions,” Bulletin of Electrical Engineering and Informatics, vol. 11, no. 2, pp. 681~690, April 2022, doi: 10.11591/eei.v11i2.3445.
5. V. T. Ha, L. T. Tan, N. D. Nam, N. P. Quang,”Backstopping control of two-mass system using induction motor drive fed by voltage source inverter with ideal control performance of stator current,” International Journal of Power Electronics and Drive System (IJPEDS), vol. 10, no. 2, 2019, pp. 720-730, doi: 10.11591/ ijpeds. v10.i2.pp720-730.
6. G. J. Rogers, J. Di Manno, and R. T. H. Alden, “An aggregate induction motor model for industrial plants,” IEEE Transactions on Power Apparatus and Systems, vol. PAS-103, no. 4, pp. 683-690, 1984, doi: 10.1109/TPAS.1984.318313.
7. V. T. Ha, N. T. Lam, V. T. Ha, and V. Q. Vinh, “Advanced control structures for induction motors with ideal current loop response using field- oriented control,” International Journal of Power Electronics and Drive System (IJPEDS), vol. 10, no. 4, 2019, pp. 1758-1771, doi: 10.11591/ijpeds.v10.i4.pp1758-1771
8. S. A. Asgari, M. Jannati, T. Sutikno, and N. R. N. Idris, “Vector control of three-phase induction motor with twostator phases open- circui,” International Journal of Power Electronics and Drive System (IJPEDS), vol. 6, no. 2, pp. 282-292, 2015, doi: 10.11591/ijpeds.v6.i2.pp282-292.
9. N. P. Quang, J. Dittrich, “Vector control of three-phase AC machines-System development in the practice 2nd edition,” Springer-Verleg Berlin Heidelberg, 2015.
10. M. Salo and H. Tuusa, “Vector-controlled PWM current-source-inverter-fed induction motor drive with a new stator current control method,” in IEEE Transactions on Industrial Electronics, vol. 52, no. 2, pp. 523-531, 2005, doi: 10.1109/TIE.2005.844243.
11. J. Rodriguez et al., “Predictive current control of a voltage source inverter,” in IEEE Transactions on Industrial Electronics, vol. 54, no. 1, pp. 495-503, Feb. 2007, doi: 10.1109/TIE.2006.888802.
12. S. M. Muslem Uddin, S. Mekhilef, M. Rivera and J. Rodriguez, “A FCS-MPC of an induction motor fed by indirect matrix converter with unity power factor control,” in Conference on Industrial Electronics and Applications (ICIEA), 2013, pp. 1769-1774, doi: 10.1109/ICIEA.2013.6566655.
13. K. Bándy and P. Stumpf, “Model predictive torque control for multilevel inverter fed induction machines using sorting networks,”IEEE Access, vol. 9, pp. 13800-13813, 2021, doi: 10.1109/ACCESS.2021.3052129.
14. M. Rivera, V. Yaramasu, A. Llor, J. Rodriguez, B. Wu and M. Fadel, “Digital predictive current control of a three-phase four-leg inverter,” IEEE Transactions on Industrial Electronics, vol. 60, no. 11, pp. 4903-4912, 2013, doi: 10.1109/TIE.2012.2219837.
15. M. Parvez, S. Mekhilef, N. M. L. Tan, and H. Akagi, “Model predictive control of a bidirectional AC-DC converter for V2G and G2V applications in electric vehicle battery charger,” in IEEE Transportation Electrification Conference and Expo (ITEC), 2014, pp. 1-6, doi: 10.1109/ITEC.2014.6861795.
16. J. Beerten, J. Verveckken and J. Driesen, “Predictive direct torque control for flux and torque ripple reduction,” IEEE Transactions on Industrial Electronics, vol. 57, no. 1, pp. 404-412, 2010, doi: 10.1109/TIE.2009.2033487.
17. M. Uddin, S. Mekhilef, M. Mubin, M. Rivera, and J. Rodriguez, “Model predictive torque ripple reduction with weighting factor optimization fed by an indirect matrix converter,” in IEEE Applied Power Electronics Conference and Exposition (APEC), doi: 10.1109/APEC.2019.8722124.

18. R. P. Aguilera and D. E. Quevedo, “Predictive control of power converters: designs with guaranteed performance,” in IEEE Transactions on Industrial Informatics, vol. 11, no. 1, pp. 53-63, 2015, doi: 10.1109/TII.2014.2363933.
19. M. Uddin, S. Mekhilef, M. Nakaoka and M. Rivera, “Model predictive control of induction motor with delay time compensation: An experimental assessment,” in IEEE Applied Power Electronics Conference and Exposition (APEC), 2015, pp. 543-548, doi: 10.1109/APEC.2015.7104402.
20. P. Correa, M. Pacas and J. Rodriguez, “Predictive torque control for inverter-fed induction machines,” IEEE Transactions on Industrial Electronics, vol. 54, no. 2, pp. 1073-1079, 2007, doi: 10.1109/TIE.2007.892628.
21. T. Geyer, “Model predictive direct current control: formulation of the stator current bounds and the concept of the switching horizon,” IEEE Industry Applications Magazine, vol. 18, no. 2, pp. 47-59, 2012, doi: 10.1109/MIAS.2011.2175518.
22. M. Abdelrahem, C. M. Hackl, and R. Kennel, “Simplified model predictive current control without mechanical sensors for variable- speed wind energy conversion systems,” Electrical Engineering, vol. 99, no. 1, pp. 367–377, 2017, doi: 10.1007/s00202-016-0433-y.
23. J. Rodriguez, J. Kolar, J. Espinoza, M. Rivera and C. Rojas, “Predictive torque and flux control of an induction machine fed by an indirect matrix converter,” in IEEE International Conference on Industrial Technology, 2010, pp. 1857-1863, doi: 10.1109/ICIT.2010.5472539.
24. A. A. Ahmed, B. K. Koh and Y. I. Lee, “A comparison of finite control set and continuous control set model predictive control schemes for speed control of induction motors,” in IEEE Transactions on Industrial Informatics, vol. 14, no. 4, pp. 1334-1346, April 2018, doi: 10.1109/TII.2017.2758393.
25. Vo Thanh Ha, Pham Thi Giang" Control for induction motor drives using predictive model stator currents and speeds control" International Journal of Power Electronics and Drive Systems (IJPEDS).Vol. 13, No. 4, December 2022, pp. 2005-2013. DOI: 10.11591/ijpeds.v13.i4.