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An Intelligent Hybrid Control System using ANFIS-Optimization for Scalar Control of an Induction Motor

Hasan A. Mohammed*, Ahmed Nasser B. Alsammak

Department of Electrical Engineering, College of Engineering, University of Mosul, Mosul 41001, Iraq

Corresponding Author Email: hasan82adnan@uomosul.edu.iq

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ABSTRACT

Recently, the three-phase induction motor (IM) has been widely used in AC motor drives and in industrial applications. The IM suffers from the accuracy of controlling the speed when it operates at different loads; this problem attracts the attention of many researchers in this field. This paper presents an Intelligent Hybrid Control System using ANFIS (Adaptive Neuro-Fuzzy Inference System)-Optimization for Scalar Control (SC) of an Induction Motor. In order to obtain optimum performance of the motor and to decrease the Total Harmonics Distortion (THD) of the motor current a Voltage Source Inverter (VSI) based on the Pulse Width Modulation technique (PWM) is used to drive the motor. To improve the speed response, accuracy and the motor's performance, an improved hybrid control system involves an optimization control method in addition to an Adaptive Neuro-Fuzzy Inference System used to adjust the amplitude and the Modulation Index (MI) of the reference signal. The proposed hybrid system improves the transient stability of motor speed and reaches a steady state much faster than the traditional controller. The Matlab-Simulink results proved the remarkable effectiveness of the proposed controller when comparing the results with two other controllers, the usual PI controller and the optimization controller.

1. INTRODUCTION

Asynchronous motors or induction motors are one of the most general motors used in industrial drives today, this is due to their advantages related to high power factor, high efficiency, high torque, high reliability and high stability. Different methods are used to control motor speed, and some take advantage of developments in power electronics components [1, 2].

The variable frequency drive (VFD) is used in the motor speed control system with the aim of ensuring that the motor operates in the linear region and that there is no saturation in the magnetic field within the air gap between the stator and the rotor. Both the voltage and the frequency are controlled simultaneously so that the ratio of (V/f) remains constant, where the source voltage of a constant value and frequency is converted into a voltage of a variable value and frequency, as shown in Figure 1 [3, 4].

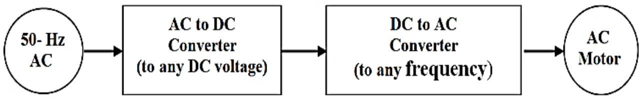


Figure 1. A block diagram of a variable speed control system

Conventional (scalar and vector) techniques are employed to manage the speed of IMs. Control systems are supposed as fast responses and exactly to variable speed and load situations and to offer stability control [5]. While SC is adequate for low-performance applications, vector control is suggested for high-performance applications with varying loads and speeds [6]. Literature reveals that it is used in conjunction with Proportional-Integral-Derivative (PID) control systems to improve the performance of conventional control systems [7]. It is recognized that the performance of these control systems will fail if the motor parameters change, necessitating an adaptation or modification in the PID controller factors i.e. K_p, K_i, K_d [8].

In addition, different approaches are proposed, which are used intelligent control techniques: Fuzzy Logic Controller (FLC), Artificial Neural Networks (ANN), Artificial Intelligence (AI), and Genetic Algorithms (GA) in combination with conventional approaches. Some studies employ both traditional and intelligent control methods, as well as studies that use exclusively intelligent control methods [9-11]. The control circuit represented by ANFIS and Optimization can significantly improve transient stability and reach a steady state quickly compared to traditional controllers [12].

All the methods mentioned above suffer from poor performance in the transient case of high overshoot and high settling time, which were addressed in this research, where the time for each was reduced significantly.

In this work, a SC of a three-phase IM using VSI based on PWM is used. In order to obtain optimum performance of the motor as well as to decrease the THD of the motor current, the switch pulses have been controlled using the PWM technique. This work used three methods to control the modulation factor (MI) and study its effect on the transient state of the speed of the three-phase induction motor. These methods are the conventional controller, optimization, and optimization-

ANFIS. The performance of the transient state of the motor speed for the three cases was also compared, and it was noted that the third method is the best of the three methods. The following paragraphs explain in detail the working principle of induction motors, methods of controlling the speed of the motor, the variable frequency driver, and a paragraph of the simulation results of the system. The results have been carried out using MATLAB/SIMULINK package. The simulation results proved the remarkable effectiveness of the proposed controller when comparing the results with the traditional PID controller and the optimization controller.

2. OPERATING PRINCIPLE

When a three-phase power source is applied to the motor, an alternating current will pass through the stator coils, leading to the generation of an induced electromagnetic force (EMF) rotate at a synchronous speed (Ns). This force works to generate a magnetic flux within the air gap between the stator and rotor parts of the motor rotates at a synchronous speed (Ns).

This magnetic flux varies in value with time, and when this flux cuts the rotor's coils, it will generate an electromotive force induced in it. When the rotor circuit is closed, an electric current will pass inside the rotor. While the rotor of an IM rotates is a slower rate than Ns. Therefore, the stator's magnetic field varies relative to the rotor. This creates an EMF in the rotor when the rotor is short-circuited or closed by an impedance. The revolving EMF induces a current in the rotor's conductors. Similar to the induced secondary current of the transformer, the direction of the magnetic field in the rotor is the opposite of the direction of change in the rotor current.

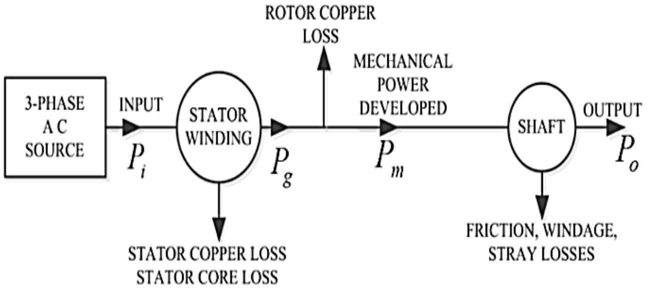


Figure 2. Power flow diagram of three-phase IM

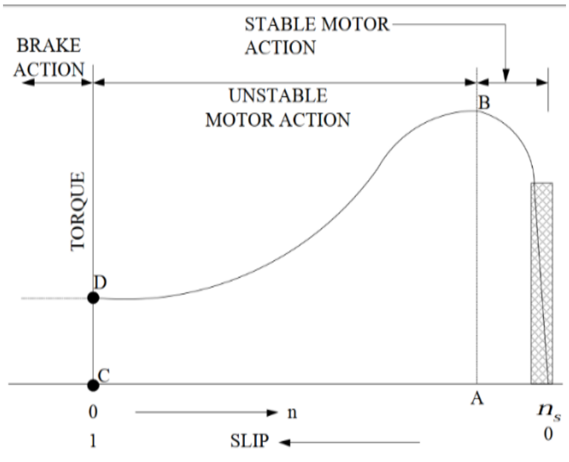


Figure 3. Torque-speed characteristic of three-phase IM

The magnetic field in the stator winding induces a current in the rotor windings; therefore, to counteract the change in rotor winding currents, the rotor will begin to rotate in the direction of the rotating stator magnetic field. The rotor accelerates until the magnitude of the induced rotor current and torque are proportional to the applied load. Since rotation at synchronous speed would not induce any rotor current, IMs always run slower than synchronous. As shown in Figure 2, the functioning of an IM results in losses and power output.

The torque-speed characteristic of the three-phase IM is shown in Figure 3. In contrast, the misleading region represents the active working region of the IM where it operates stably.

3. DIFFERENT SPEED CONTROL METHODS

The speed control of an asynchronous motor (AM) or an IM can be altered by adjusting the supply's slip (s), the number of poles (p), and frequency (F). The ability to modify any of the three parameters mentioned above provides ways to control an IM's speed. The constant flux approach is often utilized for constant and variable speed control of IMs. Scalar and vector control methods can broadly categorize the many IM speed control methods. Scalar methods of speed regulation can be classified as [13].

a. Rotor resistance control.
b. Distribution frequency control.
c. Supply voltage control.
d. Stator voltage and frequency control, or control of volts per hertz.
e. Pole changing.

The first method of controlling speed is by changing the rotor resistance, this method can control speed and torque, as well as the starting torque of the motor, without being affected by the value of maximum torque and synchronous speed.

The second method, the frequency control method, can control the speed and torque, starting torque of the motor, and both the maximum torque and the Ns change in this case.

The third method, represented by the voltage control method, can control the speed and torque, starting torque of the motor, as well as maximum torque also changes, while Ns remains without effect in this case.

The fourth method is the method of controlling voltage and frequency. In this method, the voltage and frequency are controlled at the same time so that the ratio remains constant, which leads to the flux inside the gap remaining constant without reaching a state of saturation. This method can control speed and torque, as well as the motor's starting torque and Ns of the motor, while the maximum torque remains constant without effect in this case.

The last method is to control the number of motor poles. In this method, the speed, torque, the starting torque and Ns are controlled.

4. VARIABLE FREQUENCY DRIVE

An AC motor may operate at various speeds with dependability and efficiency using VFD technology. The main function of the VFD drive is to obtain a voltage source with variable voltage and frequency, which can be used in many applications, including as AC motors drive, as is the case in the current research. The circuit topology consists of two main circuits. The first circuit is a three-phase bridge rectifier composed of 6 diodes; it works to convert the AC input voltage of a fixed value and frequency into a DC voltage of a fixed value and free of ripples due to the use of filters, as shown in Figure 4.

The second inverter is a three-phase voltage inverter that converts DC voltage into AC voltage of a controlled value and frequency. In order to improve the output voltage of the inverter and reduce the THD, the switches used in the inverter are driven by a PWM technique. In this research, three-speed control methods are used to control the modulation factor of PWM technology: the traditional method, the optimization method, and the hybrid ANFIS-Optimization method and by controlling the value of M [14, 15].

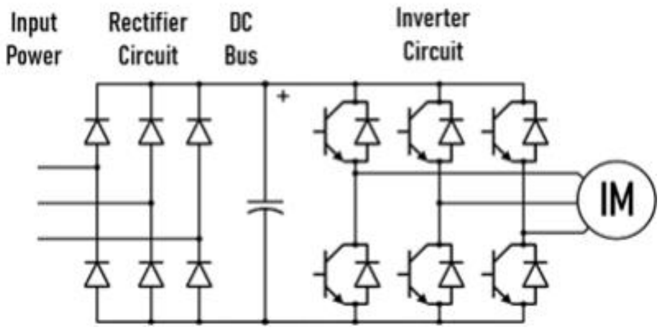


Figure 4. Three-phase IM with VFD

5. SIMULATION RESULTS

The circuit diagram of the three-phase IM supplied by three-phase VSI based on scalar control strategy is modelled and simulated by Matlab/Simulink package, as shown in Figure 5. In order to obtain the optimum performance of the motor and to decrease the THD of the motor current, the switch pulses have been controlled using PWM technique. An improved hybrid control system involves an optimization control method, and ANFIS is used to adjust the M of the reference signal to increase speed accuracy and improve the motor's performance. The results have been carried out for two loads (T_L) 10 N.m and 20 N.m, and different values of speeds from 1000 r.p.m to 2000 r.p.m using three types of controllers: classical PI controller, optimization method controller, and ANFIS-Optimization controller; the ratings of the motor parameters are shown in Table 1 [15].

The gain values resulting from the optimization process have been trained using ANFIS to obtain the best speed response. The input variables of the fuzzy circuit are the reference speed signal and the error signal, represented by the difference between the reference speed and the actual speed, while the output signal is the Modulation Index (M) as shown in Figure 6(a). The relationship between the inputs and output of the fuzzy circuit is a direct relationship with the M, and this is shown in the Figure 6(b).

Table 1 cleared the response of the three controllers regarding overshoot and settling time at load 20 N.m, and the motor speed has changed from 1000 r.p.m to 2000 r.p.m.

At each speed value, the transient response to the motor speed was studied by studying the overshoot results and the setting time (Ts) of the response using the three types of controllers separately and independently, as shown in Table 2. From the results, the best motor performance occurs when using the last hybrid mode, and the system performance has been improved significantly, where the value of settling time (Ts) has been reduced by 94% compared with the PI controller. The overshoot values decreased by about 90% compared to the PI controller.

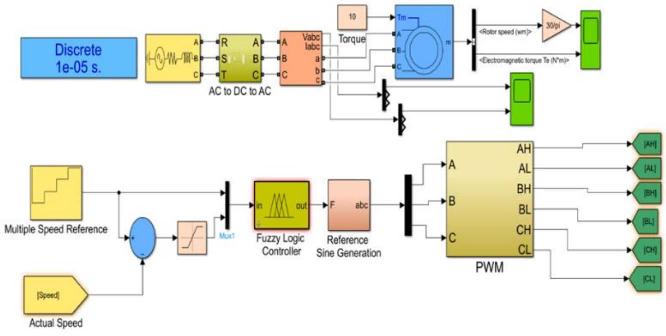
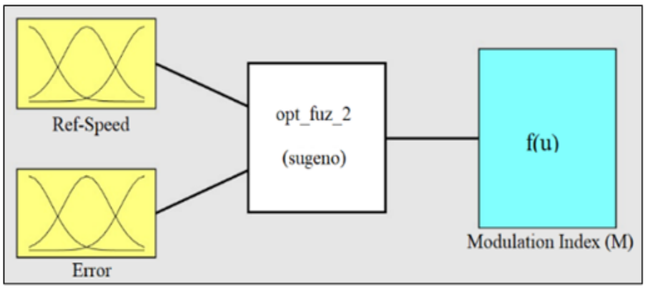
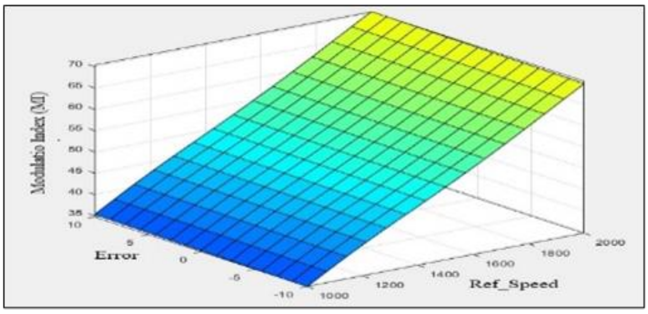


Figure 5. Simulink model of the three-phase IM with VFD



(a)



(b)

Figure 6. Proposed ANFIS where: (a) fuzzy circuit diagram, (b) the output vs inputs of the fuzzy circuit

Table 1. Induction motor ratings

Motor Parameters	Squirrel Cage Three-Phase Induction Motor
Nominal supply	460V, 60Hz.
Stator resistance and inductance	R_s=1.115Ω, L_s=0.005974
Rotor resistance and inductance	R_r=1.083Ω, L_r=0.005974
Mutual inductance	0.2037

Table 2. Comparison between the responses of PI, optimization, and ANFIS-optimization controllers

Speed (rpm)	Case	Ki	Kp	Settling Time (Ts) (sec)	Overshoot/Default Overshoot
1000	PI controller	0.12	0.01	1.3	100%
	Optimisation method	0.5	0.5196	0.7	25%
	ANFIS-optimization	0.5	0.5196	0.3	25%
1100	PI controller	0.12	0.01	1.5	100%
	Optimisation method	1	0.0066	0.5	80%
	ANFIS-optimization	1	0.0066	0.3	10%
1200	PI controller	0.12	0.01	1.5	100%
	Optimisation method	0.9491	0.0322	0.5	75%
	ANFIS-optimization	0.9491	0.0322	0.2	20%
1300	PI controller	0.12	0.01	1.5	100%
	Optimisation method	0.9646	0.0321	0.4	75%
	ANFIS-optimization	0.9646	0.0321	0.2	20%
1400	PI controller	0.12	0.01	1.5	100%
	Optimisation method	0.3038	0	0.4	100%
	ANFIS-optimization	0.3038	0	0.2	15%
1500	PI controller	0.12	0.01	1.5	100%
	Optimized gains	0.9494	0.0725	0.4	50%
	ANFIS-optimization	0.9494	0.0725	0.1	15%
1600	PI controller	0.12	0.01	1.5	100%
	Optimisation method	0.9989	0.0501	0.3	50%
	ANFIS-optimization	0.9989	0.0501	0.1	15%
1700	PI controller	0.12	0.01	1.5	100%
	Optimized gains	0.6276	0.0624	0.5	50%
	ANFIS-optimization	0.6276	0.0624	0.1	15%
1800	PI controller	0.12	0.01	1.5	100%
	Optimisation method	0.472	0.0139	0.3	90%
	ANFIS-optimization	0.472	0.0139	0.1	15%
900	PI controller	0.12	0.01	1.5	100%
	Optimisation method	0.4292	0.0144	0.5	85%
	ANFIS-optimization	0.4292	0.0144	0.1	15%
2000	PI controller	0.12	0.01	1.6	100%
	Optimisation method	0.5	0.05	0.5	50%
	ANFIS-optimization	0.5	0.05	0.1	15%

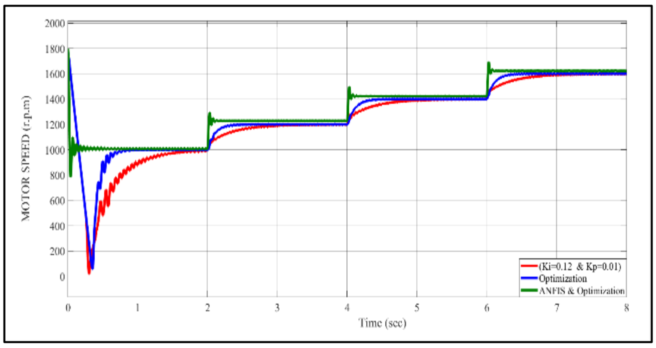


Figure 7. Speed response of PID, optimization and optimization-ANFIS controllers when T_L=10 N.m

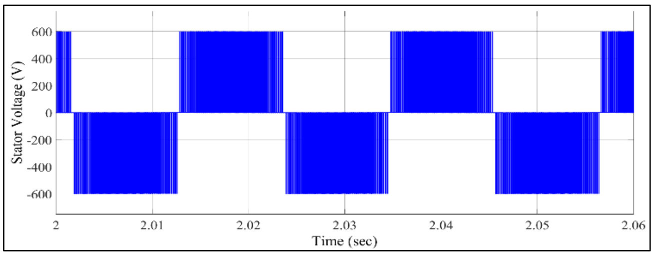


Figure 8. The output voltage of the VSI at T_L=10 N.m

The first case has been done by adjusting T_L to 10 N.m, the comparison between speed response for the three controllers and different types of speed is shown in Figure 7. Through this figure, it can be concluded that the best speed control method is ANFIS-Optimization.

The AC output voltage of the VSI or the input supply voltage of the motor is adjusted by the PWM technique, as cleared in Figure 8, while Figure 9 shows the electromagnetic torque of the motor.

The stator current waveform of motor at T_L of 10 N.m is shown in Figure 10 and the THD of this current is equal to 3% as shown in Figure 11.

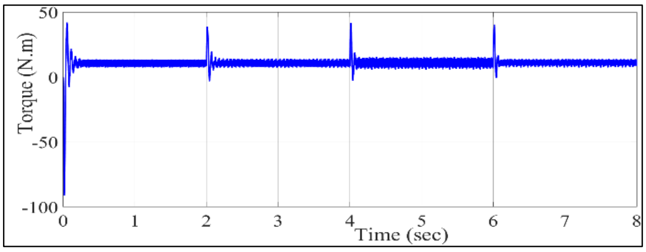


Figure 9. Electromagnetic torque at T_L=10 N.m

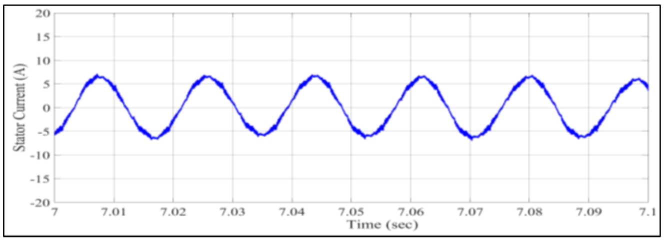


Figure 10. The stator winding current at T_L=10 N.m

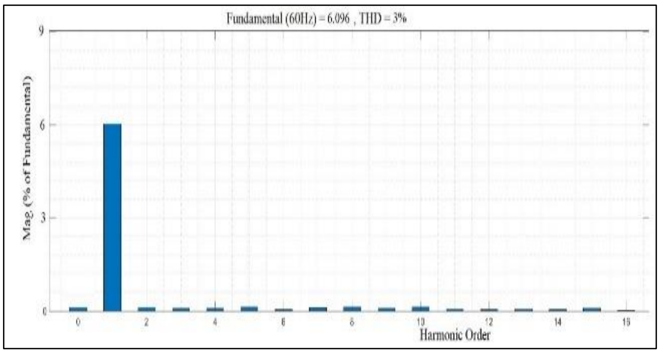


Figure 11. THD of the stator current at T_L=10 N.m

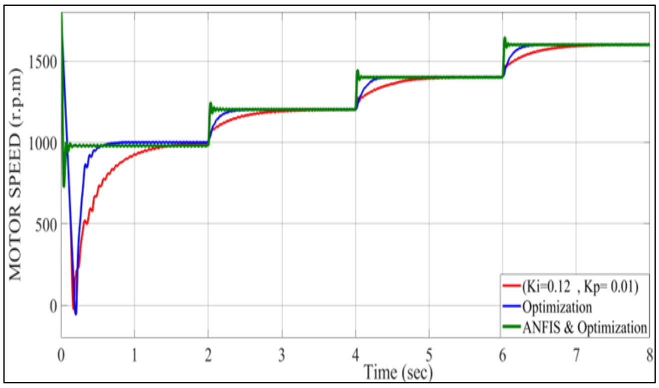


Figure 12. Speed response of PID, optimization and optimization-ANFIS controllers at T_L=20 N.m

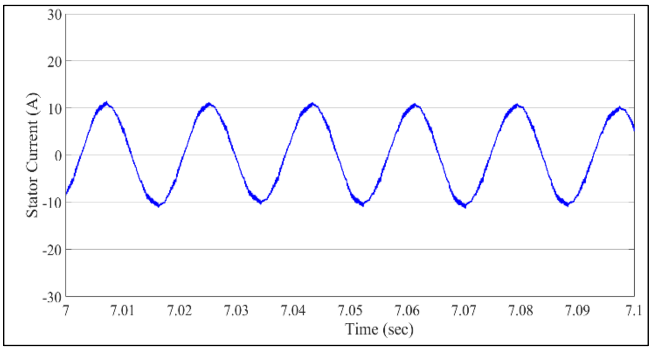


Figure 13. The stator winding current at T_L=20 N.m

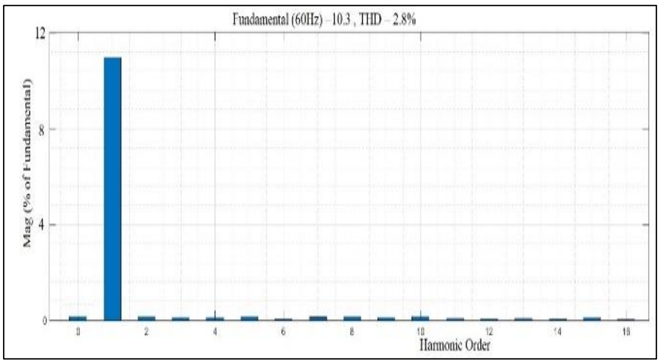


Figure 14. THD of the stator current at T_L=20 N.m

The second case has been done by adjusting the T_L to 20 N.m, the comparison between the speed response for the three controllers and different types of speed is shown in the Figure 12, through this figure, it can be concluded that the best method is the last method, ANFIS-Optimization to control the speed of the IM.

The stator current waveform of motor at T_L of 20 N.m is shown in Figure 13 and the THD of this current is less than 3% is shown in Figure 14.

6. CONCLUSION

One of the most important methods of controlling the speed of IMs is fixing the magnetic flux. This paper used the SC method based on three control strategies. In this research, three methods are used to control the modulation index (M) of PWM technology: the traditional method, the optimization method, and the hybrid ANFIS-Optimization method. From the results obtained, it can be concluded that in the second method, the overshot was reduced by up to (75%) and the settling time was reduced by up to (80%). While in the third method, the overshot was reduced by up to (90%), and the the settling time is about (94%).

This system can be exploited in the industrial induction motor drives and reach the required speed in a very short time (94%), less than motors that use traditional control circuits, and smoothly without disturbances due to reducing the overshot value by up to (90%) of the conventional case, as shown in the simulation results. The stator current has a THD less than (3%) due to using PWM technique to control the width of the pulses. The work tries to update the conventional V/f constant method previously used in many applications by combining optimization with neural networks to create ANFIS-Optimization control that gives transient dynamic and steady-state performance.

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REFERENCES

[1] Mohammad, K.S., Jaber, A.S. (2022). Comparison of electric motors used in electric vehicle propulsion system. Indonesian Journal of Electrical Engineering and Computer Science, 27(1): 11-19. https://doi.org/10.11591/ijeecs.v27.i1.pp11-19

[2] El Mrabet, M., Mekrini, Z., El Mesbahi, A., Boulaala, M. (2023). Comparative simulation study of electric motors for high performance of 3D printers. TELKOMNIKA (Telecommunication Computing Electronics and Control), 21(4): 935-948. https://doi.org/10.12928/telkomnika.v21i4.24210

[3] Shallal, A.H., Nashee, A.F., Abbas, A.E. (2021). Smart actuator for IM speed control with F28335 DSP application. Indonesian Journal of Electrical Engineering Computer Science, 24(3): 1421-1431. https://doi.org/10.11591/ijeecs.v24.i3.pp1421-1431

[4] Aljafari, B., Ashok Kumar, L., Indragandhi, V., Subramaniyaswamy, V. (2022). Analysis and implementation of sliding mode controller-based variable frequency drive using the scada system. International Transactions on Electrical Energy Systems,

2022. https://doi.org/10.1155/2022/7194119

[5] Alwadie, A. (2018). A concise review of control techniques for reliable and efficient control of induction motor. International Journal of Power Electronics and Drive Systems, 9(3): 1124-1139. https://doi.org/10.11591/ijpeds.v9.i3.pp1124-1139

[6] Asgari, S.H., Jannati, M., Sutikno, T., Idris, N.R.N. (2015). Vector control of three-phase induction motor with two stator phases open-circuit. International Journal of Power Electronics and Drive System, 6(2): 282-292. https://doi.org/10.11591/ijpeds.v6.i2.pp282-292

[7] Ibrahim, M.A., Alsammak, A.N.B. (2022). Switched reluctance motor drives speed control using optimized PID controller. Przeglad Elektrotechniczny, 98(11): 46-50. https://doi.org/10.15199/48.2022.11.07

[8] Ammar, H.H., Azar, A.T., Tembi, T.D., Tony, K., Sosa, A. (2018). Design and implementation of fuzzy PID controller into multi agent smart library system prototype. In the International Conference on Advanced Machine Learning Technologies and Applications (AMLTA), Springer International Publishing, 2018: 127-137. https://doi.org/10.1007/978-3-319-74690-6_13

[9] Otkun, Ö., Demir, F., Otkun, S. (2022). Scalar speed control of induction motor with curve-fitting method. Automatika: Časopis Za Automatiku, Mjerenje, Elektroniku, Računarstvo I Komunikacije, 63(4): 618-626. https://doi.org/10.1080/00051144.2022.2060657

[10] Alsammak, A.N.B., Al-Kaoaz, H.N.A. (2023). Design of a fuzzy distance relay taking into consideration the impact of using a unified power flow controller. Eastern-European Journal of Enterprise Technologies, 2(5(122)): 6-19. https://doi.org/10.15587/1729-4061.2023.277343

[11] Alhattab, A.S., Alsammak, A.N.B., Mohammed, H.A. (2023). An intelligent mitigation of disturbances in electrical power system using distribution static synchronous compensator. Indonesian Journal of Electrical Engineering and Computer Science, 30(2): 633-642. https://doi.org/10.11591/ijeecs.v30.i2.pp633-642

[12] Ghanim, A.S., Alsammak, A.N.B. (2020). Modelling and simulation of self-excited induction generator driven by a wind turbine. Eastern-European Journal of Enterprise Technologies, 6(8(108): 6-16. https://doi.org/10.15587/1729-4061.2020.213246

[13] Abbas, N.M., Mustafa, M.O., Shakor, A.M., (2022). Induction motor efficiency maximizing based on torque per power index. Indonesian Journal of Electrical Engineering and Computer Science, 25(3): 1266-1274. https://doi.org/10.11591/ijeecs.v25.i3.pp1266-1274

[14] Niazi, M.A., Hayat, Q., Khan, B., Afaq, M. (2020). Speed control of three phase induction motor using variable frequency derive control system. International Journal of Current Engineering and Technology, 10(1): 5-10. https://doi.org/10.14741/ijcet/v.10.1.2

[15] Gupta, A., Mathew, L., Chatterji, S. (2014). V/f-based speed controllers for an induction motor using AI techniques: A comparative analysis. In Proceedings of the Second International Conference on Soft Computing for Problem Solving (SocProS), Springer India, 2012: 1161-1171. https://doi.org/10.1007/978-81-322-1602-5_122