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Enhance the performance of 3-phase induction motors with the utilization of a 9-phase winding design

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ABSTRACT

Because of its sturdy design, affordability, and convenience of use, the three-phase induction motor is a common kind of electric motor, especially in the industrial sector. This motor design is still being improved to make it work better. For example, permanent magnets are being added to the rotor, control systems are getting better, the number of phases is being increased, and motor winding designs are developing. Nevertheless, the creation of the motor winding design is the least expensive aspect of all these endeavors. By creating a nine-phase winding configuration with a three-layer design in the motor, this study aims to enhance the performance of a three-phase induction motor. This study examined output power, speed, mechanical torque, and motor efficiency in a 3-phase system operation. The study's results indicated that the new design motor worked better, with higher output power (4.27%), rotor speed (0.61%), and mechanical torque (3.47%), despite a minor reduction in efficiency relative to conventional 3-phase induction motors (-0.24%).

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1. INTRODUCTION

Because of their straightforward design, affordability, sturdy construction, dependability, and ease of maintenance, induction motors are widely used in a variety of industries [1]-[5], and they make up a sizable portion of modern motor applications [6]. Three-phase induction motors are alternating current electric motors frequently employed as drives, particularly in the industrial sector [7]-[9]. Despite their many benefits, 3-phase induction motors have a number of drawbacks, such as poorer performance in comparison to synchronous motors [1], [2], [7]-[9]. Numerous efforts have been made to date to enhance the performance of these motors [10], such as the use of permanent magnet rotors [11], [12], enhanced control systems [2], [13]-[27], more phases [28]-[35], and the creation of motor winding designs [36]-[39].

Research by developing the use of permanent magnets on the rotor, as in synchronous motors [11], [12], can enhance the power factor, torque, output power, and motor efficiency of induction motors. However, the use of permanent magnets on the rotor requires additional expensive costs to purchase high-quality, heat-resistant permanent magnets [11], [12]. Therefore, this technique is only suitable for induction motors with large output power capacities, as the increase in motor performance can offset the expensive cost of permanent magnets.

Research by developing a reliable control system on the motor [2], [13]-[27] can also improve the quality of output power, torque, and motor efficiency. But the more reliable the control system used, the greater the costs incurred [2], [13]-[27]. Therefore, the development of a very reliable control system is also very suitable for use on motors with very large power capacities so that the additional costs incurred are comparable to the increased performance provided.

Research by increasing the number of phases in the stator coil design to more than 3-phase can also improve motor performance by increasing torque, output power, and motor efficiency [28]-[35]. The more the number of stator coil phases, the better the motor will work. However, increasing the phases more than 3 phases requires additional costs to create a new power source using an inverter that must be adjusted to the number of motor coil phases supplied [28]-[35]. Since it must be modified to meet the power capacity of the motor, the expense of developing a new power source rises as the motor's power capacity does. Therefore, innovative methods are still needed to improve this motor's performance so that it can operate more efficiently and affordably.

Creating an induction motor's winding configuration was an alternate technique that might boost the motor's output power, torque, speed, and efficiency [36]-[39]. This procedure was the most economical in comparison to many alternative methods. To improve the performance of a 3-phase induction motor, this study designed a stator coil for a 3-phase induction motor using a 9-phase coil design arrangement. The three-layer motor coil was created to increase flux density, which enhances the torque and output power of the induction motor by taking into account the direction of the current passing through the coil. By utilizing the same stator, rotor, coil type, and number of coils per slot as a traditional 3-phase induction motor, this creative design does away with the need for costly additional motor expenses. Three-phase electricity is still used to operate the motor. Without needing a significant increase in cost, we are certain that the winding design presented in this work may be used to enhance performance in other three-phase induction motors.

2. THE COMPREHENSIVE THEORETICAL BASIS

Usually, a three-phase induction motor is built with three identical coils spaced 120 electrical degrees apart. It is designed to operate with a three-phase power source that is also out of phase by approximately 120 electrical degrees in order to function properly. The motor coils are designed with a specific number of poles to ensure that they operate at the required speed [40]. Figure 1 illustrates the design of a three-phase induction motor winding in its slot utilizing an 18-slot and 2-pole configuration. It is clear from Figure 1 that coil A (from A1 to A2) is the first phase coil, coil B (from B1 to B2) is the second phase coil, and coil C (from C1 to C2) is the third phase coil.

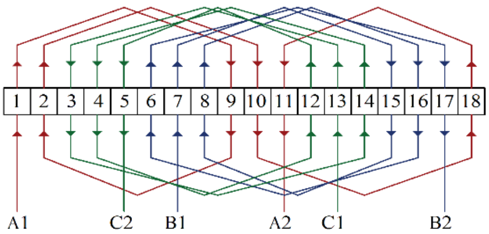


Figure 1. The shape of a three-phase induction motor's stator winding design in its 18-slot, 2-pole slot

To calculate the slots per pole number (Q_1), the slots per pole per phase number (q_1), and the electrical angle (α_{el}) between 2 adjacent slots in designing an induction motor winding, the (1)-(3) can be done [41].

$$Q_1 = {}^{s_1}/_{2p} \tag{1}$$

$$q_1 = {}^{s_1}/_{2p\, m_1} \tag{2}$$

$$\alpha_{el} = {}^{p\, 360^o}/_{s_1} \tag{3}$$

Where s_1 is the stator slots number, p is the pole pairs number, and m_1 is the stator coil phases number in the induction motor.

Multiphase induction motors are more dependable than 3-phase induction motors because of their reduced vibration and noise, their increased stability, their ability to increase flux density, and power [28], [31], their improved operating system [42], [43], their ability to increase torque [40], [44], and their ability to increase motor efficiency [30], [31]. A symmetrical 9-phase induction motor is a multiphase induction motor that is typically constructed with nine identical coils that are separated by 40 electrical degrees. To function properly, it requires a 9-phase power source that is approximately 40 electrical degrees out of phase. Figure 2 illustrates an example of the design representation of a 9-phase induction motor in its slot with an 18-slot and 2-pole design that is engineered with a 3-layer configuration.

From Figure 2, it can be explained that the 9-phase coil design consists of 3 layers of 3-phase coils, where the first layer consists of 3 coils, namely coil A (A1 to A2), coil D (D1 to D2), and coil G (G1 to G2), as seen in Figure 2(a). The second layer also consists of 3 coils, namely coil B (B1 to B2), coil E (E1 to E2), and coil H (H1 to H2), as seen in Figure 2(b). The third layer also consists of 3 coils, namely coil C (C1 to C2), coil F (F1 to F2), and coil I (I1 to I2), as seen in Figure 2(c). According to (3), the distance between two adjacent slots in a coil design with 18 slots and 2 magnetic poles is 20 electrical degrees. Therefore, if the 3-phase coil in the first layer starts at slot number 1, then the 3-phase coil in the second layer, for a distance of 40 degrees, starts at slot number 3, and the 3-phase coil in the third layer starts at slot number 5.

The ability of an induction motor to rotate its load is determined by the magnitude of the electrodynamic force (*F*) produced by the motor coil, resulting in mechanical torque (T_m) that can rotate its load. The magnitude of the flux density (B) generated by the coil and the size of this electrodynamic force (F) are likewise exactly related; this relationship can be expressed as (4) and (5) [45].

$$F = B.i.l \tag{4}$$

$$T_m = F.r \tag{5}$$

Where *i* is electric current (A), *l* is the effective length of the conductor on the rotor through which the electric current passes (m), and *r* is the rotor radius (m).

In addition, (6)-(11) can be used to determine the link between the mechanical torque (T_m), mechanical power (P_m), output power (P_{out}), and motor efficiency (E_{ff}) [46].

$$P_m = T_m.\omega_r \tag{6}$$

$$P_{out} = P_m - P_{rot} \tag{7}$$

$$E_{ff} = (P_{out} / P_{in}) x100\% \tag{8}$$

Where:

$$P_{in} = \sqrt{3}\, .V_{LL}.I_L.Cos\,\varphi \tag{9}$$

$$\omega_r = 2.\pi.Nr/60 \tag{10}$$

N_r is rotor rotation speed (rev/min), P_{rot} is rotational losses, and ω_r is angular velocity. In order to boost flux density, which raises torque, output power, and motor efficiency, the motor coil's number of phases can be increased to more than 3 phases [28]-[35].

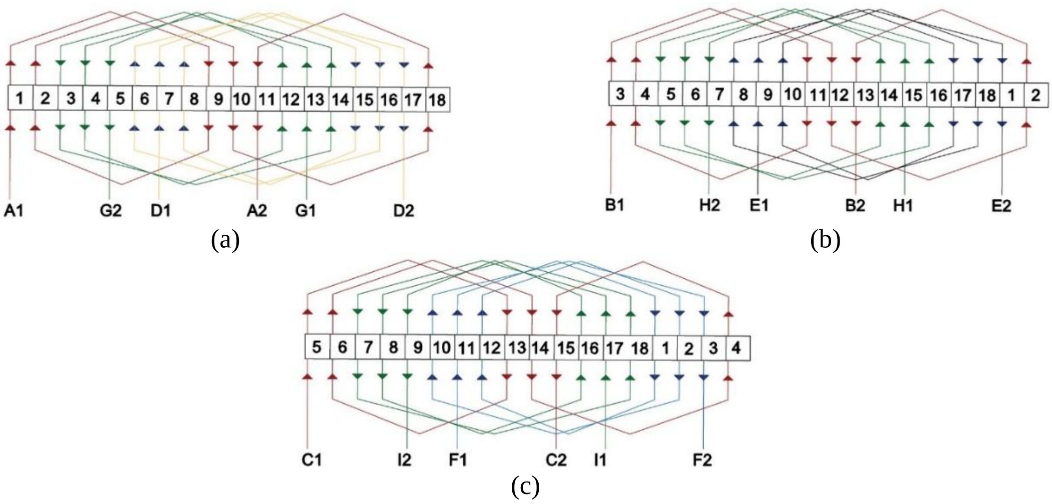


Figure 2. The shape of a symmetrical 9-phase induction motor's stator winding design in its slot, which has 18 slots and two poles, and is designed with three layers: (a) first layer, (b) second layer, and (c) third layer

3. METHOD

The study was carried out at the Electrical Engineering Laboratory of the Institute of Technology Padang. The performance of a newly developed three-phase induction motor was compared to that of a traditional three-phase induction motor. Both motors had the same rotor, stator, number of poles, coil type, number of coils per slot, and coil current characteristics. The primary objective of this study was to improve motor performance through the design of the stator winding for a three-phase induction motor. The new 3-phase induction motor's stator winding was constructed using a symmetrical 9-phase winding design, which is made up of three layers of coils made from three different 3-phase coil designs, as seen in Figure 2. Figure 3 shows how the coils of Figure 2 are connected to the three-phase power system that was connected on the winding in order to enhance the performance of the new design motor. Figures 2 and 3 show the beginning marks for each coil to enter the slot: A1, B1, C1, D1, E1, F1, G1, H1, and I1. On the other hand, each coil's final exit marks from the slot are A2, B2, C2, D2, E2, F2, G2, H2, and I2. 'R,' 'S,' and 'T' in Figure 3 indicate that the three-phase power system, which included phases 'R, S, and T,' was connected at this particular point. The stator winding architecture of a conventional three-phase induction motor used as a comparator motor is depicted in Figure 1. A conventional three-phase induction motor's performance was then contrasted with that of the newly designed motor. The motors' performance was evaluated by examining how changes in the load applied to them affected the motors' speed, mechanical torque, efficiency, and winding current.

Figure 4 depicts the type of equipment connection used to evaluate 3-phase induction motor performance in a lab setting. Figure 4 illustrates how the 3-phase induction motors were connected to a 1-phase induction generator that was gradually loaded with incandescent light bulbs. A three-phase electric power supply powered a three-phase induction motor that drove the generator. The motor's current, voltage, power factor, frequency, and input power were recorded using a digital power meter attached to it, and the generator's output voltage, current, power factor, frequency, and generator output power were recorded using a digital power meter on the generator. The rotor speed was measured in this test using a digital tachometer. The input power measured at the generator is used as the motor's output power, as the 3-phase induction motor and the 1-phase induction generator are intimately linked. The results of the motor's performance through the experiment were then presented in the form of a table and a graph of research results for analysis.

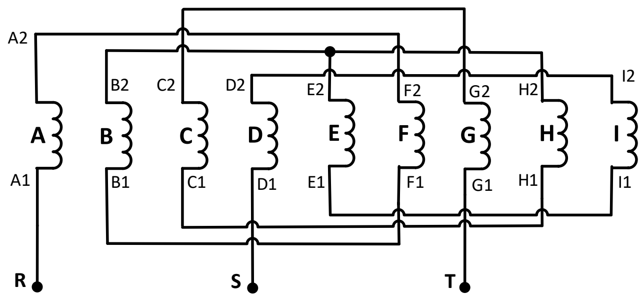


Figure 3. Connection between the coil and the 3-phase power system of the newly designed motor, referring to the motor coil design in Figure 2

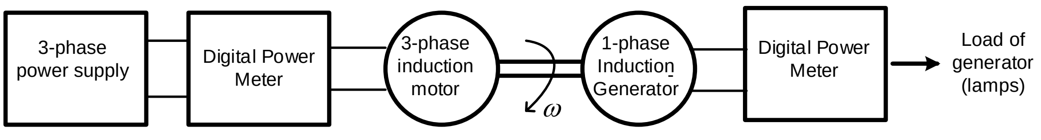


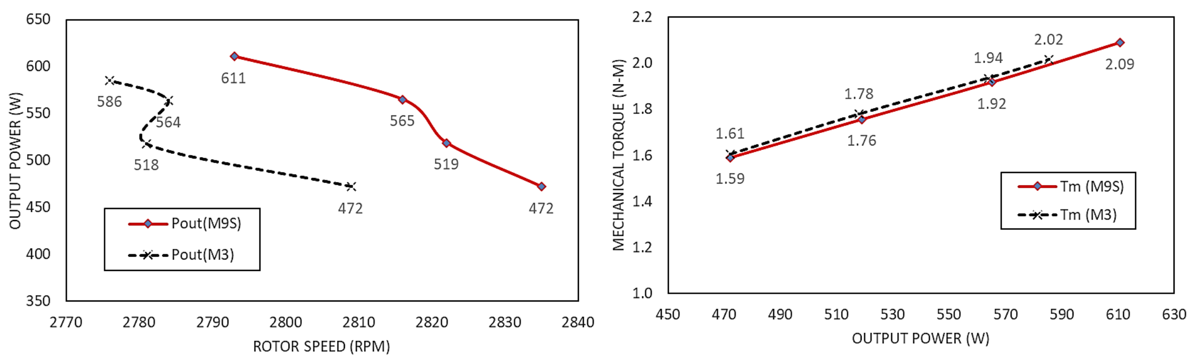
Figure 4. Connection of a 3-phase induction motor with equipment during testing in the laboratory

4. RESULTS AND DISCUSSION

Based on data from laboratory testing, Figures 5 and 6 show how well the two motors performed. The output power and mechanical torque of both motors are shown in Figure 5. According to Figure 5(a), the output power of the recently created 3-phase induction motor "Pout (M9S)" is higher than that of the traditional 3-phase induction motor "Pout (M3)". A normal three-phase induction motor's "Pout (M3)" is only 586 W, whereas the newly constructed induction motor's "Pout (M9S)" is 611 W, as shown in Figure 5(a). Newly designed induction motors typically have faster speeds and higher output power than conventional 3-phase induction motors, as seen in Figure 5(a). Additionally, as shown in Figure 5(b), the newly developed induction motor has a mechanical torque of 2.09 Nm, which is greater than the 2.02 Nm mechanical torque of a standard 3-phase induction motor. While the new 9-phase winding design for induction motors generates a flux density inside the 40 electrical degree region, the flux density of a conventional 3-phase induction motor is in the 120 electrical degree range. A greater flux density (B) in the new motor design will increase the electrodynamic force (F) around the rotor, as seen in (4). As demonstrated in (5), mechanical torque increases in tandem with a rise in electrodynamic force (F), and the motor's output power increases as well, as demonstrated in (6) and (7).

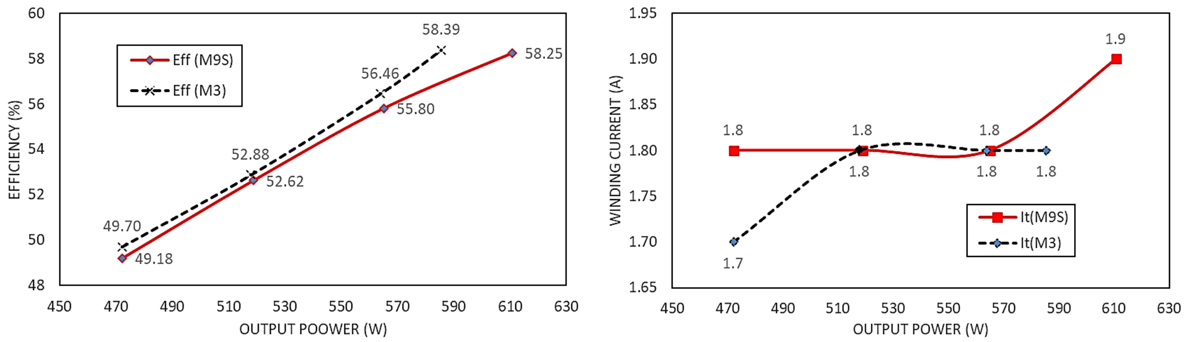
Figure 6 displays the winding current characteristics and efficiency of the motors. The efficiency of the newly developed 3-phase induction motor "Eff (M9S)" is marginally lower than that of the traditional 3-phase induction motor "Eff (M3)," as Figure 6(a) illustrates. Furthermore, as Figure 6(b) illustrates, the recently created 3-phase induction motor has a higher winding current. In comparison to the conventional 3-phase induction motor "Eff (M3)," the recently created induction motor has a little lower efficiency "Eff (M9S)," but it has a higher output power and speed. Thus, compared to the traditional three-phase induction motor, the newly developed induction motor is more powerful.

Both the conventional and the revolutionary motors have the same structure, with the same number of slots and windings in each slot, which enables them to have the same manufacturing costs. As a result, there are no extra financial requirements associated with the new motor. Table 1 lists each motor's specific performance metrics. The case demonstrates that the new design of the 3-phase induction motor has a greater capacity than the conventional 3-phase induction motor. In order to improve motor performance without increasing expenses, the motor winding design from this study can be applied to another three-phase induction motor winding design. We are certain that this developed winding design will enhance the performance of the other three-phase induction motors.



(a) (b)

Figure 5. Output power and mechanical torque characteristics of both motors: (a) output power versus rotor speed and (b) mechanical torque versus output power



(a) (b)

Figure 6. Features of both motors' efficiency and winding current: (a) efficiency versus output power and (b) winding current versus output power

Table 1. Specific performance achievements of motors

Object	Conventional design	New design	Enhancement (%)
The quantity of poles	2	2	0
The quantity of windings in each slot	114	114	0
The quantity of slots	18	18	0
Output power (W)	586	611	4.27
Rotor speed (r/min)	2776	2793	0.61
Mechanical torque (Nm)	2.02	2.09	3.47
Efficiency (%)	58.39	58.25	-0.24
Current (A)	1.8	1.9	5.56

5. CONCLUSION

According to the study's conclusions, the 3-phase induction motor's performance was enhanced by the proposed new winding design, which increased output power by 4.27%, rotor speed by 0.61%, and mechanical torque by 3.47%. This was achieved by redesigning the winding with a 9-phase winding design. But efficiency decreased by 0.24%. The proposed method does not necessitate costly additional expenditures for the motor because it still uses a three-phase power source and has the same stator, rotor, number of turns, and coil type as a traditional three-phase induction motor. We are certain that the other three-phase induction motors can be made to operate better by using this procedure.

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AUTHOR CONTRIBUTIONS STATEMENT

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Erhaneli				✓		✓	✓				✓		✓	✓
Zuriman Anthony	✓	✓		✓	✓		✓	✓		✓		✓		
Yusreni Warmi				✓		✓	✓			✓				
Arfita Yuana Dewi Rahman		✓	✓			✓	✓			✓	✓			✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article [and/or its supplementary materials].

REFERENCES

[1] S. Zhao, X. Huang, Y. Fang, and H. Zhang, "DC-link-fluctuation-resistant predictive torque control for railway traction permanent magnet synchronous motor in the six-step operation," *IEEE Transactions on Power Electronics*, vol. 35, no. 10, pp. 10982–10993, Oct. 2020, doi: 10.1109/TPEL.2020.2975497.

[2] S. Mahfoud, A. Derouich, N. El Ouanjli, N. V. Quynh, and M. A. Mossa, “A new hybrid ant colony optimization based PID of the direct torque control for a doubly fed induction motor,” *World Electric Vehicle Journal*, vol. 13, no. 5, p. 78, Apr. 2022, doi: 10.3390/wevj13050078.

[3] Z. Yang, Q. Ding, X. Sun, J. Ji, and Q. Zhao, “Design and analysis of a novel wound rotor for a bearingless induction motor,” *International Journal of Electronics*, vol. 106, no. 12, pp. 1829–1844, Dec. 2019, doi: 10.1080/00207217.2019.1625971.

[4] W. Pietrowski and K. Górny, “Analysis of torque ripples of an induction motor taking into account a inter-turn short-circuit in a stator winding,” *Energies*, vol. 13, no. 14, p. 3626, Jul. 2020, doi: 10.3390/en13143626.

[5] J. Srinivasan, K. Selvaraj, J. Chitrarasu, and R. R, “Induction motor in short pitch and full pitch winding configurations using FEA,” *2016 International Conference on Emerging Technological Trends [ICETT]*, pp. 1–10, 2016.

[6] G. Joksimović, J. I. Melecio, P. M. Tuohy, and S. Djurović, “Towards the optimal ‘slot combination’ for steady-state torque ripple minimization: an eight-pole cage rotor induction motor case study,” *Electrical Engineering*, vol. 102, no. 1, pp. 293–308, Mar. 2020, doi: 10.1007/s00202-019-00874-x.

[7] A. Dianov, F. Tinazzi, S. Calligaro, and S. Bolognani, “Review and classification of MTPA control algorithms for synchronous motors,” *IEEE Transactions on Power Electronics*, vol. 37, no. 4, pp. 3990–4007, Apr. 2022, doi: 10.1109/TPEL.2021.3123062.

[8] Y. Yang, Q. He, C. Fu, S. Liao, and P. Tan, “Efficiency improvement of permanent magnet synchronous motor for electric vehicles,” *Energy*, vol. 213, p. 118859, Dec. 2020, doi: 10.1016/j.energy.2020.118859.

[9] K. S. Mohammad and A. S. Jaber, “Comparison of electric motors used in electric vehicle propulsion system,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 27, no. 1, pp. 11–19, Jul. 2022, doi: 10.11591/ijeecs.v27.i1.pp11-19.

[10] Z. Anthony, R. Nazir, and M. I. Hamid, “A review of strategies for improving 3-phase induction motor performance,” *Andalasian International Journal of Applied Science, Engineering and Technology*, vol. 4, no. 1, pp. 01–12, 2024, doi: 10.25077/aijaset.v4i1.112.

[11] P. Sethupathi and N. Senthilnathan, “Comparative analysis of line-start permanent magnet synchronous motor and squirrel cage induction motor under customary power quality indices,” *Electrical Engineering*, vol. 102, no. 3, pp. 1339–1349, Sep. 2020, doi: 10.1007/s00202-020-00955-2.

[12] M. M. Tezcan and A. S. Akyurt, “Transforming of conventional type squirrel cage induction motor to permanent magnet synchronous motor for improving efficiency on industrial applications,” *International Scientific and Vocational Studies Journal*, vol. 6, no. 1, pp. 32–40, Jun. 2022, doi: 10.47897/bilmes.1129634.

[13] S. Hakami, I. Mohd Alsofyani, and K.-B. Lee, “Low-speed performance improvement of direct torque control for induction motor drives fed by three-level NPC inverter,” *Electronics*, vol. 9, no. 1, p. 77, Jan. 2020, doi: 10.3390/electronics9010077.

[14] M. A. Hannan *et al.*, “Role of optimization algorithms based fuzzy controller in achieving induction motor performance enhancement,” *Nature Communications*, vol. 11, no. 1, p. 3792, Jul. 2020, doi: 10.1038/s41467-020-17623-5.

[15] S. Mahfoud, A. Derouich, N. EL Ouanjli, M. EL Mahfoud, and M. Taoussi, “A new strategy-based PID controller optimized by genetic algorithm for DTC of the doubly fed induction motor,” *Systems*, vol. 9, no. 2, p. 37, May 2021, doi: 10.3390/systems9020037.

[16] H. Wang, Y. Yang, D. Chen, X. Ge, S. Li, and Y. Zuo, “Speed-sensorless control of induction motors with an open-loop synchronization method,” *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 10, no. 2, pp. 1963–1977, Apr. 2022, doi: 10.1109/JESTPE.2021.3050805.

[17] Q. H. Merdas, N. Yasin, M., and N. K. Alshamaa, “Comparison between modern optimization techniques to improve a 3-phase induction motor speed using V / f control with SVPWM,” *Techniques*, no. February, pp. 1–20, 2022.

[18] A. Ekim, A. I. Onyema, M. Olubiwe, N. O. Chikezie, P. N. F. Chiedozie, and E. E. Richard, “Design and modeling of PID system with controllability and observability test for three phase induction motor speed control using voltage / frequency,” *Scope*, vol. 13, no. September, pp. 1692–1701, 2023.

[19] M. Medina-Sánchez, A. G. Yepes, Ó. López, A. S. Abdel-Khalik, and J. Doval-Gandoy, “A carrier-based overmodulation strategy with minimum voltage distortion for symmetrical nine-phase induction motor drives,” in *2023 IEEE Energy Conversion Congress and Exposition (ECCE)*, IEEE, Oct. 2023, pp. 4712–4719. doi: 10.1109/ECCE53617.2023.10362308.

[20] J. Listwan and P. Oleszczyszyn, “Analysis of the drive of the electric vehicle with six-phase induction motor,” *Power Electronics and Drives*, vol. 8, no. 43, pp. 252–274, Jan. 2023, doi: 10.2478/pead-2023-0017.

[21] S. Ghojoghnezhad, M. Ghanbari, R. Ebrahimi, and M. Jannati, “A novel control method for improving reliability of 3-phase induction motor drives under the stator winding open-circuit fault,” *IET Electric Power Applications*, vol. 17, no. 10, pp. 1347–1366, Oct. 2023, doi: 10.1049/elp2.12346.

[22] M. Zerdani, S. A. E. M. Ardjoun, H. Chafouk, and M. Denaï, “Experimental investigation of decoupled discontinuous PWM strategies in open-end winding induction motor supplied by a common DC-Link,” *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 11, no. 3, pp. 3087–3096, Jun. 2023, doi: 10.1109/JESTPE.2023.3258799.

[23] C. A. Ekim, I. O. Akwukwaegbu, A. Ubom, U. S. Ukommi, C. O. Jude-kennedy, and C. K. Joe-Uzuegbu, “Design and modeling of a proportional derivative controller for a three-phase induction motor speed,” *Nigerian Journal of Technology*, vol. 43, no. 2, pp. 338–344, Jul. 2024, doi: 10.4314/njt.v43i2.17.

[24] K. Laadjal, F. Bento, J. Serra, and A. J. M. Cardoso, “An integrated strategy for the real-time detection and discrimination of stator inter-turn short-circuits and converter faults in asymmetrical six-phase induction motors,” *IEEE Transactions on Industry Applications*, vol. 60, no. 1, pp. 37–387, 2024, doi: 10.1109/TIA.2023.3321266.

[25] R. Rinkeviciene and B. Mitkiene, “Design and analysis models with PID and PID fuzzy controllers for six-phase drive,” *World Electric Vehicle Journal*, vol. 15, no. 4, p. 164, Apr. 2024, doi: 10.3390/wevj15040164.

[26] M. A. Mossa, H. Echeikh, N. El Ouanjli, and H. H. Alhelou, “Enhanced second-order sliding mode control technique for a five-phase induction motor,” *International Transactions on Electrical Energy Systems*, vol. 2022, no. 1, Sep. 2022, doi: 10.1155/2022/8215525.

[27] S. El Daoudi, L. Lazrak, N. El Ouanjli, and M. Ait Lafkih, “Improved DTC-SPWM strategy of induction motor by using five-level POD-PWM inverter and MRASSF estimator,” *International Journal of Dynamics and Control*, vol. 9, no. 2, pp. 448–462, Jun. 2021, doi: 10.1007/s40435-020-00667-2.

[28] J. Laksar, R. Cermak, and K. Hruska, “Challenges in the electromagnetic design of multiphase machines: Winding and equivalent circuit parameters,” *Energies*, vol. 14, no. 21, p. 7335, Nov. 2021, doi: 10.3390/en14217335.

[29] A. Shawier, A. Habib, M. Mamdouh, A. S. Abdel-Khalik, and K. H. Ahmed, “Assessment of predictive current control of six-phase induction motor with different winding configurations,” *IEEE Access*, vol. 9, pp. 81125–81138, 2021, doi: 10.1109/ACCESS.2021.3085083.

[30] A. S. Abdel-Khalik, M. S. Abdel-Majeed, and S. Ahmed, “Effect of winding configuration on six-phase induction machine parameters and performance,” *IEEE Access*, vol. 8, pp. 223009–223020, 2020, doi: 10.1109/ACCESS.2020.3044025.

[31] J. Paredes, B. Prieto, M. Satrustegui, I. Elosegui, and P. Gonzalez, "Improving the performance of a 1-MW induction machine by optimally shifting from a three-phase to a six-phase machine design by rearranging the coil connections," *IEEE Transactions on Industrial Electronics*, vol. 68, no. 2, pp. 1035–1045, Feb. 2021, doi: 10.1109/TIE.2020.2969099.
[32] I. Gonzalez-Prieto, M. J. Duran, F. Barrero, M. Bermudez, and H. Guzman, "Impact of postfault flux adaptation on six-phase induction motor drives with parallel converters," *IEEE Transactions on Power Electronics*, vol. 32, no. 1, pp. 515–528, Jan. 2017, doi: 10.1109/TPEL.2016.2533719.
[33] A. S. Abdel-Khalik, A. M. Massoud, and S. Ahmed, "Application of standard three-phase stator frames in prime phase order multiphase machine construction," *IEEE Transactions on Industrial Electronics*, vol. 66, no. 4, pp. 2506–2517, Apr. 2019, doi: 10.1109/TIE.2018.2840497.
[34] A. Shawier *et al.*, "Effect of winding design on the performance of predictive current control of six-phase induction machine-based propulsion systems," *IEEE Access*, vol. 10, pp. 80587–80599, 2022, doi: 10.1109/ACCESS.2022.3194893.
[35] H. Chen *et al.*, "Multi-objective optimum design of five-phase squirrel cage induction motor by differential evolution algorithm," *Energy Reports*, vol. 8, pp. 51–62, Nov. 2022, doi: 10.1016/j.egyr.2022.09.098.
[36] Z. Anthony, S. Bandri, E. Erhaneli, Y. Warmi, Z. Zulkarnaini, and F. Firdaus, "A simple way to increase the performance of the 3-phase induction motor," *Journal of Pharmaceutical Negative Results*, vol. 13, no. 7, pp. 4975–4983, 2022, doi: 10.47750/pnr.2022.13.S07.615.
[37] J. Chen, Y. Fujii, M. W. Johnson, A. Farhan, and E. L. Severson, "Optimal design of the bearingless induction motor," *IEEE Transactions on Industry Applications*, vol. 57, no. 2, pp. 1375–1388, Mar. 2021, doi: 10.1109/TIA.2020.3044970.
[38] S. I. Suriano-Sánchez, M. Ponce-Silva, V. H. Olivares-Peregrino, and S. E. De León-Aldaco, "A review of torque ripple reduction design methods for radial flux PM motors," *Eng*, vol. 3, no. 4, pp. 646–661, Dec. 2022, doi: 10.3390/eng3040044.
[39] S. M. S. H. Rafin, Q. Ali, S. Khan, and T. A. Lipo, "A novel two-layer winding topology for sub-harmonic synchronous machines," *Electrical Engineering*, vol. 104, no. 5, pp. 3027–3035, Oct. 2022, doi: 10.1007/s00202-022-01531-6.
[40] Y. Demir and M. Aydin, "A novel asymmetric and unconventional stator winding configuration and placement for a dual three-phase surface PM motor," *IEEE Transactions on Magnetics*, vol. 53, no. 11, pp. 1–5, Nov. 2017, doi: 10.1109/TMAG.2017.2710424.
[41] J. F. Gieras, *Electrical machines: fundamentals of electromechanical energy conversion*. London, New York, 2016. doi: 10.1201/9781315371429.
[42] M. A. Fnaiech, F. Betin, G.-A. Capolino, and F. Fnaiech, "Fuzzy logic and sliding-mode controls applied to six-phase induction machine with open phases," *IEEE Transactions on Industrial Electronics*, vol. 57, no. 1, pp. 354–364, Jan. 2010, doi: 10.1109/TIE.2009.2034285.
[43] H. S. Che, M. J. Duran, E. Levi, M. Jones, W.-P. Hew, and N. A. Rahim, "Postfault operation of an asymmetrical six-phase induction machine with single and two isolated neutral points," *IEEE Transactions on Power Electronics*, vol. 29, no. 10, pp. 5406–5416, Oct. 2014, doi: 10.1109/TPEL.2013.2293195.
[44] Y. Demir and M. Aydin, "A novel dual three-phase permanent magnet synchronous motor with asymmetric stator winding," *IEEE Transactions on Magnetics*, vol. 52, no. 7, pp. 1–5, Jul. 2016, doi: 10.1109/TMAG.2016.2524027.
[45] A. Fleitas *et al.*, "Winding design and efficiency analysis of a nine-phase induction machine from a three-phase induction machine," *Machines*, vol. 10, no. 12, p. 1124, Nov. 2022, doi: 10.3390/machines10121124.
[46] J. Pyrhönen, T. Jokinen, and V. Hrabovcová, *Design of rotating electrical machines*. John Wiley & Sons, 2013. doi: 10.1002/9781118701591.

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