# Braking System for a 3-phase Induction Motor in Traditional Petroleum Mining

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**Abstract** – *A 3-phase induction motor prototype is designed for traditional petroleum mine, which is 48 kW for the capacity and 3000 rpm for rotational speed, to pull and insert a petroleum tube into a petroleum well. However, the braking system for the induction motor has not yet been designed. Consequently, the motor is unable stop immediately. Therefore, this study designed and tested the braking system that was suitable for this kind of induction motor by using the method of applying mechanical, dynamic and hybrid braking directly to the induction motor and then test the duration of the motor stopping. Based on the results of the analysis, it was found that the hybrid braking system, that was mechanical braking and dynamic braking configuration E, had the fastest braking duration, which only need time within 0.25 s for stopping the motor. Hence this hybrid braking system is the most suitable for 3-phase induction motors in a traditional petroleum mine.*

***Keywords***: *dynamic braking system, hybrid braking system, induction motor prototype, mechanical braking system, stator configuration*

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## I. Introduction

Induction motors are used in many industrial production processes because of their robustness, reliability, and high efficiency, as well as their low maintenance cost and good self-starting [1]-[3]. Some forms of induction motor settings that are often carried out in the industry are starting current setting, speed setting, and braking [4]-[5].

Braking is critical for immediately stopping the motor drive system when there is an interruption in operation in order to protect machine parts and personnel [6]. When the motor is turned off, the spinning of the motor does not stop instantly because there is still residual rotational energy in the shaft. The load served, rotation speed, and motor power have an effect in duration of motor to stop rotating. The greater the load on the motor, the faster the motor stops. The faster the motor rotates, the longer it will take the motor to stop [7].

In 2022, the researchers designed a 3-phase induction motor as substitute for diesel motor in Wonocolo traditional petroleum mining, Bojonegoro. The study resulted in the form of specification for the 3-phase induction motor capacity that is suitable for the traditional oil mine, which is 48 kW for the capacity and 3000 rpm for rotational speed [8]. This research produced a prototype of an induction motor for traditional petroleum mining with complete specification shown in Fig. 1. However, the induction motor design has yet to be completed with appropriate braking system so that the motor cannot stop immediately if it is stopped in a rotating state.

| | | | |
|---|---|---|---|
| LEYBOLD – DIDACTIC GMBH | | | VDE 0530 |
| Typ. | 73298 | | |
| 3 ~ Motor | Nr. 20065009 | | |
| Δ / Y 220/380 V | 4.32 /2.5 A | | |
| 1.0 kW | S1 | cos Φ 0.82 | |
| 1385 min$^{-1}$ | 50 Hz | | |
| ROTOR Y 100 V | 6.4 A | | |
| I . KL . B . IP 44 | | | |

Fig. 1. Name Plate of The Prototype

There are two ways to apply braking mechanism to an induction motor, namely mechanical and electrical braking. Mechanical braking is braking using physical brake to stop the rotor rotation, while electrical braking is done in various ways, namely regenerative braking, plugging braking, and dynamic braking [9]-[10]. Each braking method has its own advantages and disadvantages. Mechanical braking has the following advantages: (a) it can stop the motor rotation permanently; (b) it is easier to apply to all motor characteristics; and (c) the investment cost is relatively cheap. Meanwhile, electrical braking has advantages, including: (a) being maintenance-free; (b) being more flexible if you want to increase the motor speed; (c) being smoother than mechanical [11]-[12]. Based on research [13], the advantage of dynamic braking includes the ease of adjusting the speed of a 3-phase induction motor.

Previous researchers have carried out several studies on the braking design of 3-phase induction motors. Muhaimin in 2019 performed dynamic braking by injecting DC current so that the induction motor stops more quickly [13]. In 2017, Okazaki et al. proved that distributed dynamic braking was feasible and highly effective in induction motors [14]. Al-Barbarawi (2018) combined plugging braking and dynamic braking with the result that the combined braking system was reliable and fast [15]. Sattarov et al (2020) discussed mechanical braking when the induction motor stopped temporarily or completely stopped and the results were that mechanical braking worked well in both conditions [16]. In 2021, Wati et al. designed a dynamic braking system using DC voltage injection and capacitors, with the result that the greater the input DC voltage, the faster the braking occurs, while whatever value of capacitor is input, it will produce the same time in dynamic braking [17]. Research conducted by Ocoleanu, D. C. (2022) on dynamic braking which relies on redundancy in the power supply to stop the motor quickly and in a controlled manner concluded that the method worked well [18].

Based on several studies that have been carried out, no researcher has yet compared mechanical, dynamic, and hybrid induction motor braking systems, especially those that are suitable for application in traditional petroleum mining. Therefore, in this study, mechanical braking, dynamic braking, and hybrid braking will be applied to 3-phase induction motors for traditional petroleum mining system. The three braking system designs were analyzed and their performance were compared to one another in order to get the best braking system for this induction motor. The purpose of this study is to obtain the most suitable braking system design for 3-phase induction motors for traditional petroleum mining system.

## II. Methodology

### A. Design of Induction Motor for Traditional Petroleum Mining System

In the previous study, the rotation and capacity of an induction motor used in a traditional petroleum mine located in Wonocolo, Bojnegoro, Indonesia was calculated. This induction motor is used to replace the existing diesel motor. From the calculation results, the motor rotation speed was obtained at 640 rpm with a capacity of 48 kW.

### B. Design of The Prototype

As a research and testing object, a prototype of the induction motor was also designed with a smaller capacity of 15 kW with a rotation speed of 956 rpm.

### C. Induction Motor Braking

The induction motor will stop rotating when the supply connection from the three-phase ac source to the motor is disconnected. The time it takes for the motor to completely stop depends on the load and friction of the motor itself, and to regulate the motor stopping rotation, a braking method is required. Electrically braking, the braking torque is generated based on the value of the injection current given to the stator coil. Electric braking is done by providing a stationary magnetic field on the stator so that the rotor rotation will decrease by itself, electric braking is smoother and no pounding occurs. Stopping the motor is done by removing the source voltage so that the rotation speed is equal to zero. There are several braking methods, such as:

1. Mechanical braking method is that the kinetic energy of the rotating parts is disposed of on the rubbing parts as heat using the brake shoes found on the motor.
2. Plugging braking method is by reversing the direction of motion of the motor rotation, so that the motor can produce a balancing torque power and then form a slowing power.
3. Dynamic braking method is to inject dc current into the stator coil of the motor, so that it will generate a stationary field to reduce the voltage on the rotor.
4. Regenerative braking method is a braking system in which the induction motor is driven by a load above the synchronous speed.

### D. Stator Winding Configuration

As we all know, the induction motor stator winding can be connected in Y or delta connection. In the Y connection, the circuit of the stator winding can be varied into six configurations [20]-[21]. A list of the six configurations can be seen in Table I.

## III. Result and Discussion

### A. Testing without Braking System

Testing of a 3-phase induction motor prototype for traditional petroleum mine without a braking system was carried out to know the duration of the motor actually stopping from a rotating condition. In this test, a 3-phase induction motor was tested under Y-connection and delta-connection respectively. There was a difference in the duration of the motor stopping when it was in Y-connection or delta-connection as seen in Table II.

TABLE I
ROTOR CONFIGURATIONS

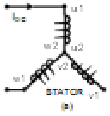
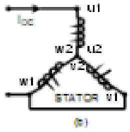
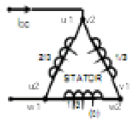
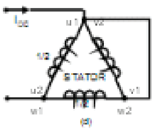
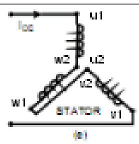
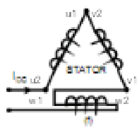
| | |
|---|---|
| **Configuration A** |  |
| **Configuration B** |  |
| **Configuration C** |  |
| **Configuration D** |  |
| **Configuration E** |  |
| **Configuration F** |  |

TABLE II
RESULTS OF TESTING WITHOUT BRAKING SYSTEM

| Connection | Motor Stoppage Duration (s) |
|---|---|
| Y | 1.36 |
| Delta | 1.62 |

Based on Table II, the motor completely stopped in 1.36 seconds when it was in star connection and 1.62 seconds when it was in delta connection. It is because Y-connected motors have smaller torque because they draw a smaller current. Meanwhile, a delta-connected motor has greater torque because it draws a greater current.

This test results can be compared in the form of a chart as seen in Fig. 2.

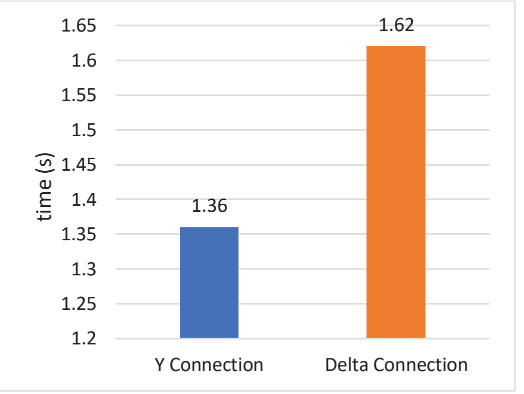



Fig. 2 Comparison of motor stopping duration in star and delta connection without braking system

*B. Testing with Mechanical Braking System*

Mechanical braking is standard braking on an electric motor. It generally uses brake shoes which provide frictional force to the disc so that the motor can stop [22].

In this test, the prototype motor for traditional petroleum mine was equipped with mechanical braking. The test results can be seen in Table III.

TABLE III
RESULTS OF TESTING WITH MECHANICAL BRAKING SYSTEM

| Connection | Motor Stoppage Duration (s) |
|---|---|
| Y | 1.2 |
| Delta | 1.5 |

From the test result, if the motor is stopped using a mechanical brake, from a rotating condition, in Y-connection, the motor stopped in 1.2 seconds. Meanwhile, if the motor is connected in delta, the motor stops within 1.5 seconds. Fig. 3 describes the comparison of motor stopping duration in wye and delta connection without braking system and with mechanical braking system. It can be seen that in Y connection, motor stopped faster than in delta connection at both conditions.

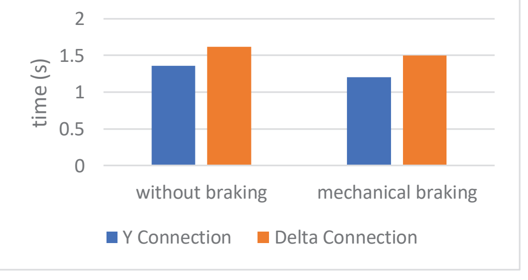



Fig. 3. Comparison of motor stopping duration in wye and delta connection for cases without braking system and with mechanical braking system

### C. Testing with Dynamic Braking System

Dynamic braking is a technique used to slow down an induction motor by introducing direct current (DC) into the stator. This method effectively controls the speed of the motor and brings it to a stop [23]. Direct current produces a static magnetic field so that the rotor is induced electromotive force which causes the flow of induced current. Electromotive force and induced current are directly proportional to the rotation. Because the rotor is short-circuited, there is a rotating magnetic field equal to the rotor speed but in the opposite direction. The magnetic force on the rotor creates a torque that is opposite to the motor torque so that braking can occur. The benefit of adopting dynamic brakes is the simplicity with which speed may be controlled and the decrease in mechanical losses [24]. In this dynamic braking test, the DC voltage used is 35 $V_{dc}$ to inject DC current into the stator. Six stator configurations, i.e. Configuration A to Configuration F, were tested to obtain the best braking duration time. The stator resistance value installed was 8.8 ohms with 1 kW for motor capacity. The total stator resistance value based on the calculation results of the six configurations and the injected DC current value in the stator coil based on the calculation and measurement results can be seen in Table IV. The calculation result was obtained by dividing $V_{dc}$ with $R_{tot}$.

Based on Table IV above, it can be seen that the $I_{dc}$ flowing on the motor stator winding in the star connection, that is, configuration B and in the delta connection, i.e., configuration C and D, exceeded the nominal current $I_{nom}$ of the motor and if this continues for a long time it will damage the motor stator winding.

TABLE IV
THE VALUES OF INJECTED DC CURRENT FOR SIX STATOR CONFIGURATIONS

| Configuration | $V_{dc}$ (V) | $R_{tot}$ (Ω) | $I_{dc}$ (A) | |
|---|---|---|---|---|
| | | | Calculation | Measurement |
| A (Y) | 35 | 17.6 | 1.99 | 1.5 |
| B (Y) | 35 | 13.2 | 2.65 | 2.4 |
| C (Δ) | 35 | 5.86 | 5.97 | 4.5 |
| D (Δ) | 35 | 4.4 | 7.9 | 5.7 |
| E (Y) | 35 | 26.4 | 1.3 | 1.1 |
| F (Δ) | 35 | 26.4 | 1.3 | 1.1 |

The test results for motor stopping duration, when the rotor is Y-connected in three different configurations are presented in Table V.

TABLE V
RESULTS OF TESTING WITH DYNAMIC BRAKING SYSTEM, Y-CONNECTION

| Configuration | Motor Stoppage Duration (s) |
|---|---|
| A (Y) | 0.8 |
| B (Y) | 0.6 |
| E (Y) | 0.5 |

The comparison of motor stopping duration, if there was no braking system (stator was connected both in Y and delta), equipped with mechanical braking system (stator was connected both in Y and delta), and equipped with dynamic braking system (stator was connected in Y only, including configuration A, B, E) can be seen in Fig. 4.

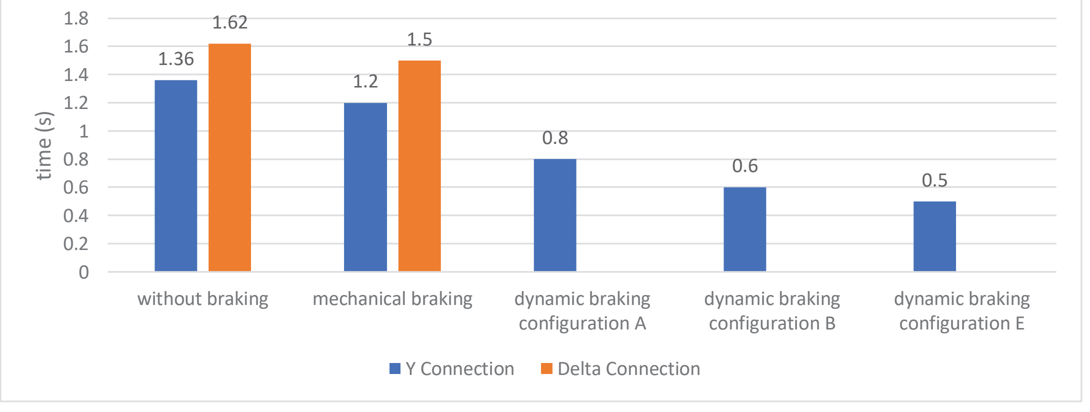



Fig. 4 Comparison of motor stopping duration for cases of without braking system and with mechanical braking system, connected in Y and delta, also with dynamic braking connected in Y connection

Based on Fig. 4, it can be seen from the dynamic braking test of the induction motor prototype for traditional petroleum mining, the fastest braking duration occurred if the stator coil was connected in Y, in configuration E (0.5 s), configuration B (0.6 s) and configuration A (0.8 s).

The test results for motor stopping duration, when the rotor is delta-connected in three different configurations, can be seen in Table VI. Furthermore, the comparison of motor stopping duration, if there was no braking system (stator was connected both in Y and delta), equipped with mechanical braking system (stator was connected both in Y and delta), and equipped with dynamic braking system (stator was connected in Δ only, including configuration A, B, E) can be seen in Fig. 5.

TABLE VI
RESULTS OF TESTING WITH DYNAMIC BRAKING SYSTEM, DELTA-CONNECTION

| Configuration | Motor Stoppage Duration (s) |
|---|---|
| C (Δ) | 0.47 |
| D (Δ) | 0.35 |
| F (Δ) | 0.86 |

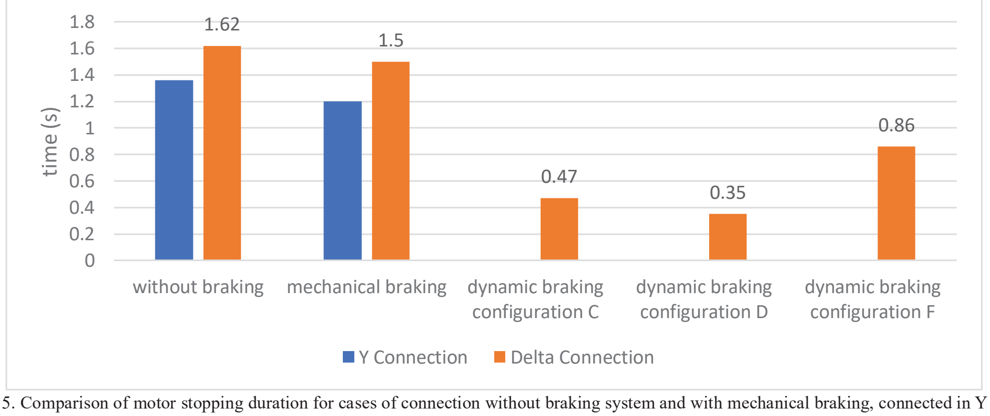



Fig. 5. Comparison of motor stopping duration for cases of connection without braking system and with mechanical braking, connected in Y and delta, also using dynamic braking connected in delta connection

Based on Fig. 5, it can be seen from the dynamic braking test of the induction motor prototype for traditional petroleum mining, the fastest braking duration consecutively occurred if the stator was connected in delta configuration D (0.35 s), configuration C (0.47 s) and configuration F (0.86 s).

### *D. Testing with Hybrid Braking System*

In this test, the braking system applied in the induction motor prototype for traditional petroleum mining was a combination of mechanical braking and dynamic braking. Configuration B, configuration C and configuration D were eliminated from this test because the current flowing from these three combinations was greater than the motor $I_{nom}$. The results of the test can be seen in Table VII.

TABLE VII
RESULTS OF TESTING WITH HYBRID BRAKING SYSTEM

| Configuration | Motor Stoppage Duration (s) |
|---|---|
| Mechanical braking + Dynamic braking Configuration A (Y) | 0.7 |
| Mechanical braking + Dynamic braking Configuration E (Y) | 0.39 |
| Mechanical braking + Dynamic braking Configuration F (Δ) | 0.25 |

The comparison of the motor stopping duration for each braking method tested on this motor prototype can be seen in Fig. 6.

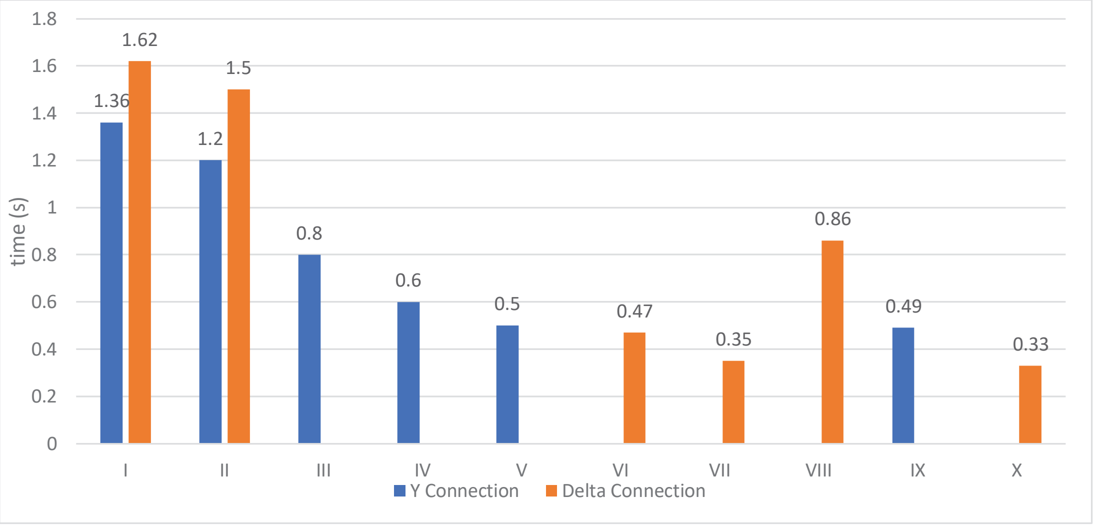



Fig. 6 Comparison of motor stopping duration at all tested methods

Information for Fig. 6:

I : without braking
II : mechanical braking
III : dynamic braking configuration A
IV : dynamic braking configuration B
V : dynamic braking configuration E
VI : dynamic braking configuration C
VII : dynamic braking configuration D
VIII: dynamic braking configuration F
IX : hybrid braking (configuration E)
X : hybrid braking (configuration F)

Based on Fig. 6, it can be seen that the fastest duration of motor stopping was obtained from the hybrid braking system or a combination of mechanical braking and dynamic braking configuration F, which was 0.25 seconds. Therefore, this type of braking system is used in the prototype motor for traditional petroleum mining.

## IV. Conclusion

Based on the results of this research, it can be concluded that the most suitable induction motor braking system used in the prototype motor for traditional petroleum mining is a hybrid braking system which is a combination of mechanical braking and dynamic braking connected in Y-connected configuration F. This is because it produces the fastest braking duration of 0.25 s.

## Conflict of Interest

The authors declare no conflict of interest in the publication process of the research article.

## Author Contributions

Harrij Mukti Kristiana initiated the research and carried out the experiments. Rohmanita Duanaputri conducted analysis and authored the publication. Imron Ridzki supervised the research. Muhammad Fahmi Hakim edited the manuscript.

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