Analysis of Compressor Motor Starting Current in a Block Ice Factory with Star-Delta Connection Using ETAP Software

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The abstract should be written as a the three-phase induction motor in a block ice factory compressor has a high starting current, which can cause voltage drops and disruptions in the electrical power system. This study aims to analyze the starting current of the compressor motor using the Star-Delta method with the aid of ETAP software. The research method involved collecting technical data on the motor, transformer, and electrical distribution system, followed by conducting Motor Acceleration Analysis simulations in ETAP. The results show that the Star-Delta method is able to reduce the starting current compared to the Direct On Line (DOL) method, resulting in more stable system voltage and reduced disruptions in the distribution network. Furthermore, switching from a Star to Delta connection results in momentary current surges that remain within safe limits according to electrical power system standards. This study demonstrates the effectiveness of the Star-Delta method in improving the reliability of the electrical system in a block ice factory.
Keywords: Induction motor, starting current, Star-Delta, ETAP, compressor

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1. Introduction

The development of the refrigeration industry and block ice production in Indonesia has experienced significant growth, particularly to support the needs of the fisheries, food distribution, and seafood storage sectors. In its operations, block ice factories utilize a refrigeration system driven by a three-phase induction motor as the primary compressor drive. Induction motors are widely used in the industrial sector due to their simple construction, high efficiency, and relatively low maintenance costs [1]. Furthermore, three-phase induction motors have the ability to operate continuously with high power capacity, making them highly suitable for use in industrial refrigeration systems [4].

Three-phase induction motors have a major weakness during the starting process, namely the very high starting current. The motor starting current can reach 5 to 7 times the nominal current, causing a voltage drop in the electrical distribution system and potentially disrupting other equipment on the same network [3]. This condition significantly impacts the refrigeration system in block ice factories, as voltage stability is essential for optimal refrigeration compressor operation. In addition to causing voltage drops, high starting currents can also increase conductor temperatures, increase power losses, and accelerate the lifespan of electrical equipment [8].

One common method used to reduce the starting current of an induction motor is the Star-Delta method. This method works by connecting the motor windings in a star configuration during starting, so that the motor phase voltage drops to 58% of the line voltage. With this voltage reduction, the motor starting current can be reduced to approximately one-third of the starting current used in the Direct On Line (DOL) method [12]. The use of the Star-Delta method is considered more economical and effective for medium to large capacity motors, which are widely used in the industrial sector [5]. Advances in electric power system technology allow motor starting analysis to be performed using simulation software. One widely used software is ETAP, which is capable of accurately simulating load flow, short circuits, and motor acceleration [2]. ETAP can display the characteristics of the motor's current, voltage, and acceleration during the starting process, making system analysis more effective and efficient. Research on motor starting analysis using the Star-Delta method was previously conducted by Putra and Syahputra, who demonstrated that the Star-Delta method can significantly reduce the starting current of induction motors compared to the DOL method [6]. Furthermore, other research has shown that reducing the starting current can improve power quality and maintain the stability of industrial power distribution systems [9]. Based on this description, this study was conducted to analyze the starting current of a compressor motor in a block ice factory using the Star-Delta method based on ETAP simulation to determine its effect on the stability of the industrial power system. This research is expected to serve as a reference in the development of three-phase induction motor starting systems in the refrigeration industry and help improve the reliability of the power distribution system.

2. Literature Review And Problem Statement

Three-phase induction motors are one of the most widely used types of electric motors in the industrial sector due to their simple construction, high efficiency, and relatively low maintenance costs. In refrigeration industries, such as ice block factories, induction motors are used as the main drive for refrigeration compressors, which operate continuously throughout the production process. However, induction motors have a major drawback during starting: the very high starting current. According to Fitzgerald et al. [3], the starting current of an induction motor can reach 5 to 7 times the nominal current, causing voltage drops, increased power losses, and disruption to the power distribution system. Stevenson [8] also stated that high starting current surges can degrade power quality and affect voltage stability in industrial power systems.

Several previous studies have been conducted to reduce the impact of induction motor starting current. Putra and Syahputra [6] conducted a study on the use of the Star-Delta method on three-phase induction motors and demonstrated that this method significantly reduced starting current compared to the Direct On Line (DOL) method. Furthermore, research by Suyanto [9] explains that reducing motor starting current can improve distribution system voltage stability and reduce the risk of disruptions to industrial electrical equipment. Simulation software such as ETAP is increasingly being used in power system analysis because it can accurately display motor current, voltage, and acceleration characteristics during the starting process [2]. With ETAP, evaluating power system performance can be carried out more effectively and efficiently without the need for direct testing on industrial systems.

Based on this literature review, the main problem encountered in block ice factories is the high starting current of the compressor motor, which has the potential to cause voltage drops and disrupt the stability of the power distribution system. If this condition is not properly controlled, it can affect the performance of the refrigeration system and accelerate damage to electrical equipment. Therefore, this study focuses on analyzing the starting current of the compressor motor using the Star-Delta method based on ETAP simulation to determine its effectiveness in reducing starting current and maintaining power system stability in block ice factories. This research is expected to provide a more optimal technical solution for implementing a three-phase induction motor starting system in the industrial refrigeration sector.

3. Method

This research was conducted using a quantitative method based on electric power system simulation using ETAP software. The quantitative method was used because the analyzed data were in the form of electrical quantities such as current, voltage, power, power factor, and motor acceleration characteristics expressed in the form of numbers and simulation result graphs. The simulation approach was chosen because it is able to provide safer, faster, and more efficient analysis results compared to direct testing on industrial electric power systems. In addition, simulation using ETAP can display the transient conditions of the motor in detail during the starting process, thus facilitating the analysis process. The research was conducted at the Ice Block Factory located at Jalan Mesjid No. 184, Sampali, Percut Sei Tuan District, Deli Serdang Regency, North Sumatra. The research object focused on a three-phase induction motor used as the main compressor drive in the refrigeration system of the ice block factory. The selection of the compressor motor as the research object was based on the magnitude of the motor power used and the high starting current that appears when the motor starts operating. In this study, the data used consisted of primary data and secondary data. Primary data was obtained directly through field observations and recording of technical data on the electric power system at the ice block factory. The data includes induction motor nameplate data, transformer capacity, cable data, system voltage, and electrical distribution panel configuration. Meanwhile, secondary data was obtained from various reference sources, such as power system books, scientific journals, SPLN and IEEE standards, and ETAP software user manuals related to motor starting analysis. The equipment used in the research consisted of hardware and software. A laptop or computer was used to run the ETAP simulation and process the research data. A printer and data storage media were also used to support the research report preparation process. The software used was ETAP as the primary software for the power system simulation, Microsoft Excel for processing the simulation results, and Microsoft Word for compiling the research report. The research phase began with a literature review to understand the basic theories regarding three-phase induction motors, the Star-Delta starting method, industrial power systems, and the use of ETAP software. The literature review was conducted by examining reference books, previous research journals, and electrical standards relevant to this research. This stage aimed to establish a strong theoretical foundation for the analysis and discussion. After completing the literature study, the next stage was field data collection. Direct observation of the ice block factory's electrical power system was conducted to determine the actual condition of the electrical distribution system and the characteristics of the compressor motor used. Technical data such as motor power, operating voltage, rated current, power factor, transformer capacity, and cable size were recorded for use in the ETAP simulation process. The obtained data was then used to create a single-line diagram of the power system using ETAP software. The modeling was carried out by depicting all the main components of the power distribution system, such as the power source, transformer, busbars, distribution panel, cable, and compressor motor. Creating a single-line diagram aimed to simplify the simulation process and the overall analysis of the power system. After the modeling was complete, the next step was to enter the technical parameters of each component into ETAP. The parameters entered included system voltage, transformer capacity, transformer impedance, motor power, motor power factor, motor efficiency, cable data, and star-to-delta switching time. All these parameters were entered according to actual data obtained from the field to ensure the simulation results were as close to reality as possible.

The next stage was the Motor Acceleration Analysis simulation using ETAP. In this study, two simulation conditions were created, namely starting the motor using the Direct On Line (DOL) method and starting the motor using the Star-Delta method. The simulation was conducted to determine the characteristics of the starting current, the system voltage profile, the motor acceleration time, and the effect of switching

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the Star to Delta connection on the stability of the electric power system. The simulation results obtained from ETAP were then analyzed to determine the performance comparison between the DOL and Star-Delta methods. The main parameters analyzed included the magnitude of the starting current, the percentage of current drop, the voltage drop on the busbar, and the stability of the electricity distribution system.

$$\% \text{ Penurunan} = \frac{I_{DOL} - I_{StarDelta}}{I_{DOL}} \times 100\%$$

Information:

I_{DOL} = Arus starting metode Direct On Line
$I_{StarDelta}$ = Arus starting metode Star-Delta

In addition to analyzing the magnitude of the starting current, this study also evaluates the stability of the system voltage based on the SPLN and IEEE standards. According to the SPLN standard, the permissible tolerance limit for voltage drops in the electric power distribution system is ±5% of the nominal system voltage. Therefore, the simulation results are compared with these standards to determine whether the electric power system in the ice block factory is still in a safe and reliable condition. The final stage of the study is drawing conclusions based on the results of the simulation and analysis that have been carried out. The conclusions are compiled to answer the research problem formulation regarding the effect of the Star-Delta method on the reduction of starting current and the stability of the electric power system. In addition, several suggestions are also provided that can be used as recommendations for further research and the development of motor starting systems in the ice block factory industry.

4. Results and Discussion

The electrical system in the ice block factory is used to supply various main equipment such as compressor motors, circulation pumps, cooling systems, control panels, and lighting loads. The largest load in this system comes from the three-phase induction motor used as a refrigeration compressor driver. The compressor motor runs continuously during the ice block production process so that the stability of the electrical power system is a very important factor [1]. In this study, an analysis was conducted on the main compressor motor using the Star-Delta starting method. Motor technical data was obtained directly from the motor nameplate and the results of field observations in the ice block factory's electrical power distribution system. The ice block factory's electrical power system simulation was carried out using ETAP software. In this study, a system model was created based on actual data obtained in the field. The compressor motor analyzed was a 3-phase induction motor with nameplate data in Table 1

Table 1. Compressor Motor Nameplate Data

Parameter	Value
Output Power	280 kW
Voltage	380 V
Current	534 A
Frequency	50 Hz
Speed	1485 rpm
Power Factor	0.85
Efficiency	95.1%
Connection	Delta
Service Factor	1.15
Number of Poles	4

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Based on the data above, the compressor motor has a nominal current of 534 A at a voltage of 380 Volts with a frequency of 50 Hz. This motor will be simulated using two starting methods, namely Direct On Line (DOL) and Star-Delta. The modeling of the electric power system is carried out using ETAP software by creating a single line diagram consisting of a PLN electric power source, distribution transformer, main distribution panel, Motor Control Center (MCC), conductor cables, and a compressor motor.

The modeling of the electric power system of the ice block factory at ETAP is shown in the following single line diagram:

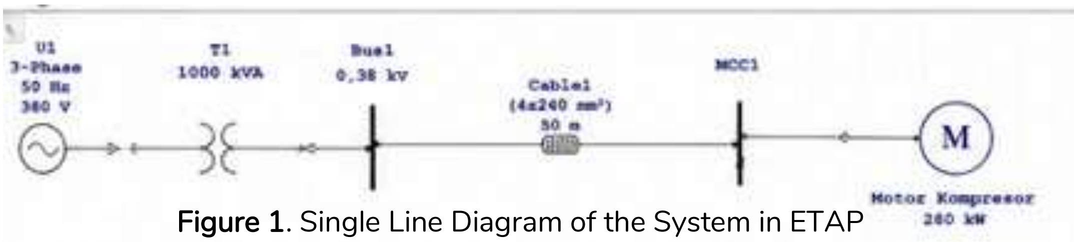

Figure 1. Single Line Diagram of the System in ETAP

The system consists of a 3-phase 380V power source, a 1000kVA transformer, 4 x 240mm2 cables 50m long, a Motor Control Center (MMC), and a 280 kW compressor motor. Simulation results using ETAP showed that starting the motor using the Direct On Line method results in a very high starting current. This occurs because the motor immediately receives full voltage upon starting, causing the rotor to draw a high current from the power source [3]. Simulation results show that the motor starting current reaches approximately 6 to 7 times the motor's nominal current. With a nominal current of 200 A, the motor starting current can be calculated as follows:

$I_{start} = 6 \times I_n$

$I_{start} = 6 \times 200$

$I_{start} = 1200$ A

While in maximum conditions:

$I_{start} = 7 \times 200$

$I_{start} = 1400$ A

The large starting current causes a voltage drop on the main busbar and increases the load on the electricity distribution system. According to Stevenson[8], high starting currents can cause significant voltage drops in industrial electricity distribution networks.

Table 2. DOL Method Starting Simulation Results

Parameter	Nilai (Value)
Maximum Starting Current (Imax)	3.280 A
Rated Current (In)	534 A
Imax / In Ratio	6.14 times
Minimum Voltage	323 V (0.85 pu)
Time to Reach 95% Speed	10.2 s
Final Speed	1475 rpm
Final Slip	1.0%

The simulation results show that the DOL method produces very large current surges so it is less effective for use in power distribution systems with limited capacity.

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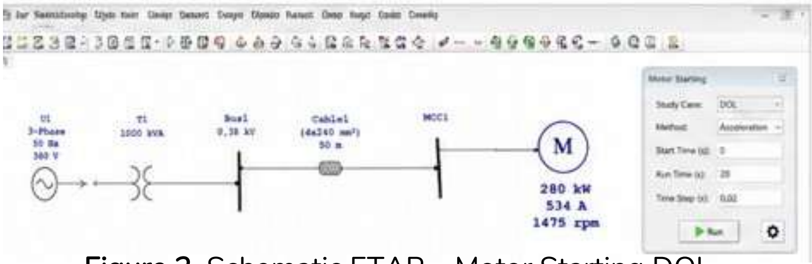

Figure 2. Schematic ETAP – Motor Starting DOL

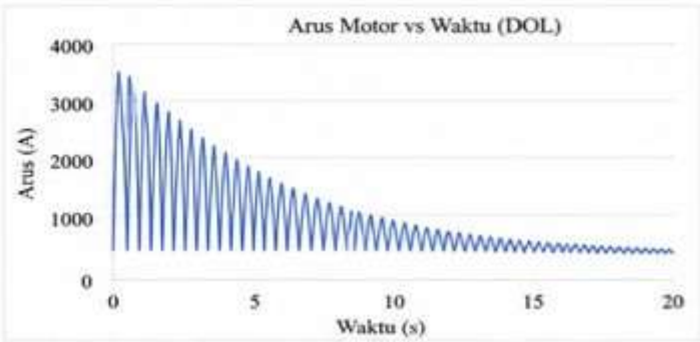

Figure 3. DOL Starting Flow Graph

The graph above shows that the maximum starting current using the DOL method reaches 3,280 A. The voltage drops to 323 V when the motor starts.

The second simulation used the Star-Delta starting method. In this method, the motor is connected in a Star configuration during starting, resulting in a lower phase voltage. This voltage drop also reduces the motor's starting current [10]. The phase voltage in a Star connection is formulated as follows:

$$V_{ph} = \frac{V_L}{\sqrt{3}}$$

Table 3. Star-Delta Starting Simulation Results

Parameter	Value
Maximum Starting Current (Imax)	1,720 A
Nominal Current (In)	534 A
Imax / In Ratio	3.22 times
Minimum Voltage	358 V (0.94 pu)
Time to Reach 95% Speed	12.4 s
Final Speed	1,475 rpm
Final Slip	1.0%

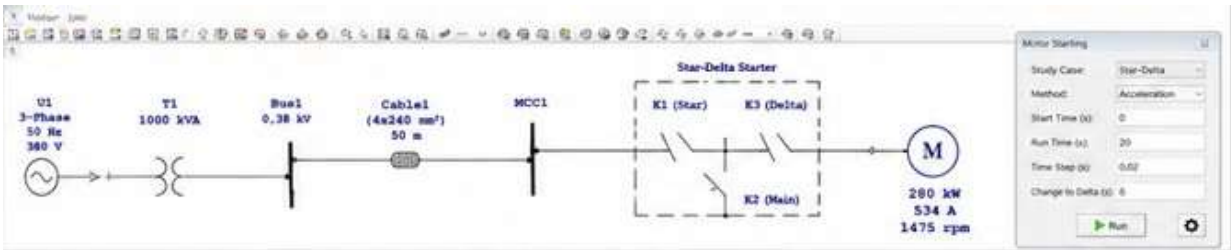

Figure 4. Schematic ETAP – Motor Starting Star-Delta

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Figure 5. Starting Current Graph – Star-Delta

With the Star-Delta method, the maximum starting current is only 1,720A. The minimum starting voltage is 358V, resulting in a smaller voltage drop than with DOL. Simulation results using ETAP software show that the Star-Delta method is effective in reducing the starting current of compressor motors in block ice factories. The 65.38% reduction in starting current has a positive impact on the power distribution system by reducing voltage drops and maintaining system stability. Furthermore, the Star-Delta method can reduce the load on transformers and conductors, thus extending the lifespan of electrical equipment. According to Stevenson [8], reducing starting current can improve power quality and reduce the risk of disruptions in industrial power distribution systems. Although there is a momentary current surge when switching from a Star to Delta connection, this condition is still within safe limits and does not cause serious disruption to the power system. This is in accordance with the IEEE standard, which states that momentary transients are permissible as long as they do not disrupt the stability of the power grid [11]. Overall, the research results show that the Star-Delta method provides better performance than the Direct On Line method in terms of reducing starting current, controlling system voltage, and increasing the stability of the electric power distribution network in the ice block factory.

5. Conclusion

Based on the results of research, simulations, and analysis conducted using ETAP software on the compressor motor starting system in a block ice factory, the following conclusions were obtained:

a. The use of the Star-Delta starting method has been proven to significantly reduce the compressor motor starting current. Based on the ETAP simulation results, the motor starting current dropped to approximately 400 A to 500 A, or approximately 200% to 250% of the motor's nominal current. The percentage reduction in starting current achieved reached 65.38% compared to the DOL method. These results indicate that the Star-Delta method is very effective in reducing initial current surges in three-phase induction motors.
b. The reduction in starting current using the Star-Delta method has a positive impact on power system stability. Simulation results show that the system voltage during starting using the DOL method decreased by up to 12.5%, compared to only 3.75% with the Star-Delta method. This value is still within the SPLN standard tolerance limit of ±5% of the system's nominal voltage, making the Star-Delta method considered safer and more reliable for use in industrial power distribution systems.
c. Overall, the Star-Delta method is highly suitable for application to ice block factory compressor motors because it can improve power system reliability, reduce voltage disturbances, and maintain operational continuity in the refrigeration industry.

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