

Analysis of Starting Current and Power Consumption of a Three-Phase Induction Motor Driving an Additional Air Compressor Using ETAP

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Abstract

Three-phase induction motors are extensively employed in industrial applications due to their high efficiency, robust construction, and reliable operation. Nevertheless, the Direct-On-Line (DOL) starting method produces a significant inrush current that may lead to temporary voltage dips, increased power demand, and reduced power system stability. Therefore, motor starting analysis is essential to ensure that industrial electrical systems operate within acceptable voltage and current limits. This study aims to analyze the starting current characteristics and electrical power consumption of the induction motor driving the Additional Air Compressor at PT Pupuk Iskandar Muda using Electrical Transient Analyzer Program (ETAP) version 19. The research methodology includes field data collection, electrical system modeling, load flow analysis, motor starting simulation, and validation using actual operational data. The simulation results indicate that the motor experiences a maximum starting current of approximately 180–185 A, equivalent to nearly six times the rated operating current of 29.94 A. During motor acceleration, the bus voltage temporarily decreases to 13.61 kV before recovering to the nominal operating condition of 13.80 kV. The calculated active power is 638.30 kW, while comparison with field measurements shows deviations below 5%, confirming the accuracy of the developed ETAP model. The results demonstrate that ETAP is an effective tool for evaluating induction motor starting characteristics and electrical power consumption in industrial electrical power systems.

Keywords: Three-Phase Induction Motor, ETAP, Direct-On-Line Starting, Motor Starting Analysis, Load Flow Analysis, Power Consumption

I. INTRODUCTION

Three-phase induction motors are widely used in industrial facilities because of their robust construction, relatively simple maintenance, and suitability for continuous operation. In process industries, motors drive compressors, pumps, fans, blowers, and other production equipment. Because large motors are directly coupled to essential process equipment, their starting behavior must be evaluated not only at the motor terminals but also at the supplying electrical network.

At PT Pupuk Iskandar Muda, the Additional Air Compressor is driven by a 596.6-kW, 13.8-kV three-phase induction motor operated with Direct-On-Line (DOL) starting. The engineering problem is whether the existing medium-voltage system can accommodate the motor-starting transient without producing an excessive bus-voltage reduction while maintaining the required operating condition of the compressor. This question is important because the motor is an additional industrial load and its starting current is substantially higher than its rated current.

DOL starting applies the supply voltage directly to the motor and therefore produces a high inrush current. Previous studies using ETAP and other simulation approaches have shown that DOL starting can produce several times the rated current

and can cause a temporary voltage dip whose magnitude depends on motor characteristics and the strength and impedance of the supplying network [1], [2], [15], [16]. The engineering significance of the starting event is therefore determined by the relationship between motor inrush current and the voltage response of the existing network, rather than by starting current alone.

ETAP provides load-flow and dynamic motor-starting functions that allow the steady-state and transient responses of an industrial power system to be represented in a common network model. Recent studies have used ETAP to investigate induction-motor starting, compare DOL with alternative starting methods, and evaluate voltage response and acceleration behavior [1], [2], [8], [15]. However, simulation-only studies do not necessarily establish how well the model represents an operating industrial network unless the simulated parameters are compared with field measurements.

The research gap addressed in this study is therefore methodological as well as application-specific. Previous work has frequently focused on comparing starting methods, assessing voltage dip, or modelling industrial networks with ETAP. In contrast, fewer studies integrate an ETAP model of an actual medium-voltage industrial network with

operational field data while simultaneously evaluating DOL starting current, transient bus-voltage reduction, and steady-state active-power demand for an additional compressor motor [1], [2], [15]. This integrated approach is important for engineering decisions because the suitability of a motor addition depends on both the transient response during starting and the operating demand after acceleration.

The novelty of this study lies in the field-validated assessment of an actual industrial electrical network supplying an additional 596.6-kW compressor motor. The study integrates ETAP load-flow and Dynamic Motor Starting analyses with operational measurements to quantify starting current, bus-voltage reduction, active-power demand, and simulation-to-field deviation. The objective is to determine the observed electrical response of the existing system to DOL starting and to provide an engineering basis for assessing similar additional motor loads.

II. LITERATURE STUDY

2.1 Three-Phase Induction Motor

A three-phase induction motor is the most widely used electrical machine in industrial applications due to its simple construction, high efficiency, low maintenance requirements, and reliable operation. The motor consists of two main components, namely the stator and rotor, separated by a small air gap. When a balanced three-phase voltage is supplied to the stator winding, a rotating magnetic field is generated at synchronous speed. This rotating field induces an electromotive force (EMF) in the rotor conductors, producing rotor current and electromagnetic torque that causes the rotor to rotate. Because the rotor speed is always slightly lower than the synchronous speed, a slip exists between the rotating magnetic field and the rotor speed. This slip is essential for the induction process and torque production [5].

The synchronous speed of an induction motor is expressed as:

$$N_s = \frac{120f}{P} \quad (1)$$

where N_s is the synchronous speed (rpm), f is the supply frequency (Hz), and P is the number of poles.

Rotor slip is calculated by

$$S = \frac{N_s - N_r}{N_s} \times 100\% \quad (2)$$

where N_r is the rotor speed.

2.2 Direct-On-Line (DOL) Starting

Direct-On-Line (DOL) starting connects the motor directly to the supply voltage. The method is simple and can provide high starting torque, but the motor initially presents a low effective impedance and consequently draws a high inrush current. The resulting current can produce a temporary voltage reduction at the supplying bus, particularly when the network has limited short-

circuit strength or relatively high upstream impedance [1], [2], [15], [16].

DOL starting is therefore commonly evaluated by examining the magnitude of the starting current, the minimum bus voltage, the duration of the transient, and the motor acceleration response. These parameters provide a more direct engineering basis for deciding whether the existing electrical network can support the starting event.

2.3 Starting Current Characteristics

The starting current of an induction motor is one of the most important parameters in power system analysis because it directly affects voltage stability and equipment performance. During the starting process, the rotor is stationary, resulting in maximum slip and minimum rotor impedance. Consequently, the motor draws a very large current from the power source until the rotor accelerates toward its rated speed.

As the rotor speed increases, the slip decreases, reducing the rotor current and consequently lowering the stator current until steady-state operating conditions are reached [7].

2.4 Active Power

The active power consumed by a three-phase induction motor can be expressed as

$$P = \sqrt{3}VI\cos\phi \quad (3)$$

Where:

- P = Active Power (W)
- V = Line Voltage (V)
- I = Line Current (A)
- $\cos\phi$ = Power Factor

The three-phase active power at the motor input can be expressed as $P = \sqrt{3} V_L I_L \cos\phi$. This relationship is used as a consistency check for the steady-state electrical demand. In this study, the ETAP-reported active-power value is compared with the field measurement; any discrepancy between nameplate-derived rated input power and simulated operating power is interpreted in relation to the actual operating condition rather than being treated as an energy-consumption value.

2.5 ETAP Software

Electrical Transient Analyzer Program (ETAP) provides power-system analysis functions including load flow and motor-starting analysis. Recent applications have used ETAP to examine induction-motor starting current, voltage response, and acceleration characteristics in industrial electrical systems [1], [2], [8], [15].

In this research, ETAP version 19 is used to represent the electrical network supplying the Additional Air Compressor at PT Pupuk Iskandar Muda. The model includes the generator, transformer, medium-voltage buses, cables, circuit breakers, reactor, and induction motor shown in

the plant single-line configuration. The model is evaluated using load-flow and Dynamic Motor Starting simulations and is subsequently compared with operational measurements.

III. SYSTEM DESCRIPTION AND METHODOLOGY

The research was conducted on the electrical power system supplying the Additional Air Compressor at PT Pupuk Iskandar Muda, Aceh, Indonesia. The workflow consisted of field-data collection, electrical-system modelling in ETAP 19, steady-state load-flow analysis, Dynamic Motor Starting analysis using DOL, comparison with operational measurements, and engineering interpretation of the resulting current and voltage responses.

Primary data were obtained from field observations and compressor operational records, while secondary data were obtained from the motor nameplate, plant single-line diagram, and available technical documentation. The analysed variables were bus voltage, motor current, active power, reactive power, apparent power, power factor, motor speed, and starting-current characteristics. The motor nameplate specifies 596.6 kW rated power, 13.8 kV rated voltage, 50 Hz frequency, 29.94 A rated current, 0.90 power factor, 95% efficiency, and 2981 rpm rated speed.

The ETAP network follows the plant single-line configuration. The available system diagram identifies a 20-MW generator, a 25-MVA transformer, 13.8-kV buses, feeder cables, a reactor, switching devices, and the compressor motor. Component data were entered from the available plant technical records. The motor was configured for Direct-On-Line starting and connected to the compressor load represented in the ETAP model.

A Load Flow Analysis was first performed to establish the steady-state operating condition before motor starting. The resulting bus voltage, motor current, active power, reactive power, apparent power, and power factor were then compared with the corresponding field measurements. The steady-state results were kept separate from the transient motor-starting results so that the minimum voltage occurring during acceleration was not interpreted as a pre-start load-flow value.

A Dynamic Motor Starting analysis was subsequently performed with the DOL configuration. The principal transient indicators were the peak starting current, the initial bus voltage, the minimum bus voltage, and the duration of the starting event. The available ETAP output indicates a transient duration of approximately 2.98 s; because the supplied output does not explicitly label this value as the motor acceleration time, it is reported as the observed simulation-event duration rather than being

presented as an independently verified acceleration-time constant.

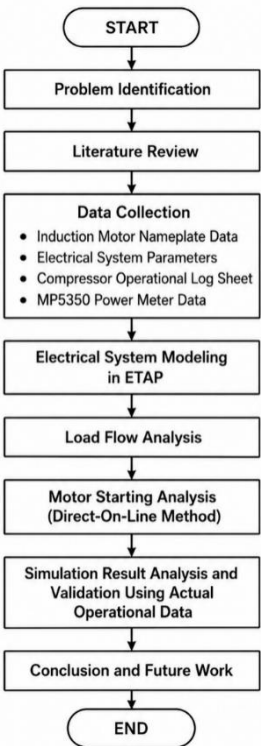


Figure 1. Research Flowchart

Table 1. Technical Specifications of the Induction Motor

Parameter	Specification
Motor Type	Three-Phase Induction Motor
Rated Power	596.6 kW
Rated Voltage	13.8 kV
Frequency	50 Hz
Rated Current	29.94 A
Power Factor	0.90
Efficiency	95%
Rated Speed	2981 rpm
Starting Method	Direct-On-Line (DOL)

The simulation-to-field deviation was calculated for each compared parameter using Deviation (%) = $|X_{sim} - X_{meas}| / X_{meas} \times 100\%$. In this study, the compared quantities were voltage, current, and active power. The resulting deviations were interpreted as measures of agreement between the model and the observed operating condition; they were not treated as a universal proof of model accuracy.

IV. RESULTS AND DISCUSSION

4.1 Electrical System Modeling

The electrical system supplying the Additional Air Compressor was modelled in ETAP version 19 from the plant single-line configuration. The model includes the 20-MW generator, 25-MVA transformer, 13.8-kV bus system, feeder cables, reactor, switching devices, and the 596.6-

kW three-phase induction motor. This configuration provides the network context required to evaluate both the steady-state operating condition and the transient response produced by DOL motor starting.

The model was used for two distinct analyses. First, load flow was used to establish the pre-start steady-state condition. Second, Dynamic Motor Starting was used to evaluate the transient current and bus-voltage response during DOL energization. Keeping these two analyses separate avoids assigning the transient minimum voltage to the steady-state load-flow condition.

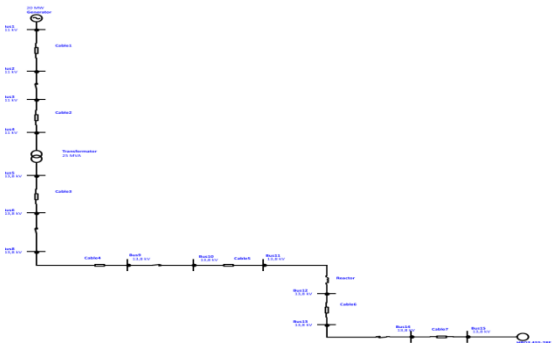


Figure 2. Single-Line Diagram of the Additional Air Compressor Electrical System in ETAP

4.2 Steady-State Load Flow Analysis

The load-flow results represent the electrical condition associated with normal operation before the starting transient. The ETAP model reports an operating current of 28.94 A and an active-power value of 638.30 kW for the compressor motor. The corresponding field values used for validation were 29.90 A and 644.00 kW. Because the original manuscript contained inconsistent combinations of voltage, current, reactive power, apparent power, and power factor, the numerical values of the ETAP output should be rechecked against the original ETAP load-flow report before final submission. The present revision therefore does not fabricate replacement values for parameters whose source output was not supplied.

Table 2. Steady-State Load Flow Simulation Results	
Parameter	ETAP Reported Result*
Pre-start bus voltage	13.80 kV
Motor current	28.94 A
Active power	638.30 kW
Reactive power	296.77 kVAR
Apparent power	709.21 kVA
Power factor	0.90

Table 2. Steady-state load-flow results reported by the ETAP model. *The P–Q–S–V–I–PF combination must be rechecked against the native ETAP load-flow output before final submission because the values in the original manuscript are not mathematically self-consistent. For the parameters directly compared with field measurements, the reported deviations were

3.21% for current and 0.89% for active power. Voltage deviation is treated separately in Section 4.4 because 13.61 kV is the minimum transient voltage reported during motor starting rather than the nominal pre-start bus voltage. This distinction is necessary for a technically consistent interpretation of the results.

4.3 DOL Motor Starting Analysis

The Dynamic Motor Starting analysis was performed using the DOL configuration. The manuscript reports a peak starting-current range of 180–185 A. Relative to the rated current of 29.94 A, this corresponds to approximately 6.01–6.18 times rated current. Because the supplied ETAP plot is displayed in percentage of full-load current and does not provide a single numerical peak label, the exact peak value should be taken directly from the original ETAP data export before final submission. The red-highlighted text therefore preserves the reported manuscript value while identifying the required source-data verification.

The reported transient voltage response shows a decrease from the nominal 13.80 kV to a minimum of 13.61 kV during motor acceleration, followed by recovery toward the normal operating level. The corresponding voltage reduction is approximately 0.19 kV, or 1.38% of the nominal voltage. This response is physically consistent with the increase in current demand during DOL starting and should be interpreted in relation to the impedance and short-circuit strength of the upstream generator-transformer network.

The magnitude of the starting-current response is consistent with recent ETAP-based studies of induction-motor starting, in which DOL operation produces several times the rated current and a corresponding bus-voltage reduction [1], [2], [15], [16]. The present case is distinguished by the relatively small reported bus-voltage reduction despite the high starting-current magnitude, which indicates that the observed transient response is strongly influenced by the electrical strength and impedance of the existing network.

Table 3. DOL Motor-Starting Characteristics and Transient Indicators	
Parameter	Value
Reported peak starting current	180–185 A
Rated current	29.94 A
Rated voltage	13.8 kV
Minimum transient bus voltage	13.61 kV
ETAP event duration	≈2.98 s (verify as acceleration time)
Voltage reduction	≈1.38%

The transient analysis indicates a high-current starting event accompanied by a limited temporary bus-voltage reduction. The available ETAP output shows an event duration of approximately 2.98 s;

this value should be verified against the motor speed/torque response before it is formally identified as acceleration time.

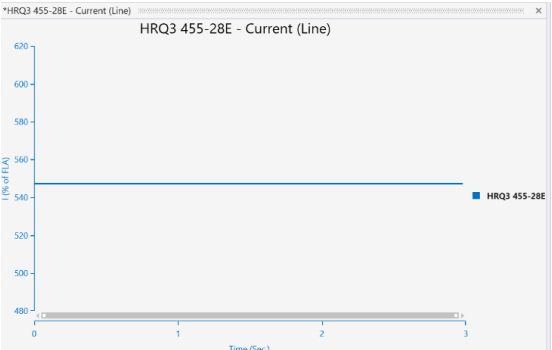


Figure 3. Starting Current Curve

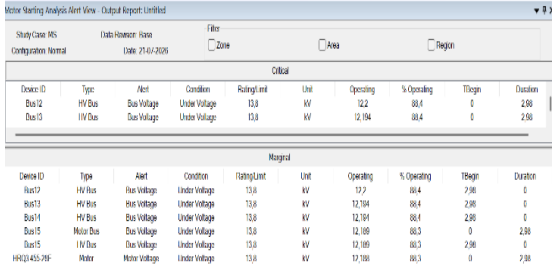


Figure 4. Voltage Profile During Motor Starting

4.4 Simulation–Field Validation

To evaluate the model representation of the operating system, the simulated steady-state current and active power were compared with the compressor operational data, while the nominal-to-minimum voltage change during starting was evaluated separately. This approach distinguishes model validation of steady-state quantities from assessment of the transient starting response.

Table 4. Comparison Between Field Measurements and ETAP Results

Parameter	Actual	ETAP	Deviation
Voltage (nominal → minimum transient)	13.80 kV	13.61 kV	1.38%
Current	29.90 A	28.94 A	3.21%
Active power	644.00 kW	638.30 kW	0.89%

The available comparison gives deviations of 1.38% for voltage, 3.21% for current, and 0.89% for active power. These values indicate good agreement between the simulated and measured operating quantities under the investigated condition. They should be interpreted as validation results for the specific operating point and data set, rather than as a universal statement of ETAP model accuracy.

Small differences between measured and simulated values may arise from operating-load variation, parameter uncertainty, instrument accuracy, and differences between the time of field

measurement and the ETAP model condition. The original data set does not report a formal instrument uncertainty budget; therefore, no numerical measurement-uncertainty value is introduced in this revision.

4.5 Discussion

The principal engineering finding is that DOL starting produces a starting current several times higher than the motor rated current. The reported 180–185 A starting-current range corresponds to approximately 6.0–6.2 times the 29.94-A rated current. Such a current increase is expected during DOL energization because the motor initially draws a large current before reaching its normal operating speed [1], [15], [16].

The associated bus-voltage response is more informative for system assessment than the starting-current magnitude alone. The bus voltage decreases from 13.80 kV to 13.61 kV, a reduction of approximately 1.38%. The relationship is consistent with the general voltage-drop mechanism in which increased current through the upstream system impedance produces a transient reduction in bus voltage. The magnitude of the reduction depends on generator capacity, transformer impedance, feeder impedance, and the short-circuit strength of the network [15], [16].

The field comparison further shows that the simulated current and active-power values are close to the measured operating values, with deviations below 5% for the reported validation parameters. The practical implication is that the developed model can be used as a representation of the investigated operating condition for engineering assessment of the additional compressor load. However, a formal acceptance decision should be based on the plant's applicable voltage-dip, motor-stall, protection, and equipment-operating criteria; the present data set does not provide sufficient evidence to assign a universal acceptance threshold.

4.6 Study Limitations

The main limitation is that the available manuscript package does not include the complete numerical ETAP output for generator short-circuit data, transformer impedance, cable length and impedance, motor inertia, torque-speed characteristics, detailed simulation time-step settings, or instrument uncertainty. These parameters should be documented from the original plant/ETAP records in the final submission. In particular, the numerical consistency of the load-flow table and the exact peak starting current should be verified directly from the native ETAP output.

V. CONCLUSION

1. This study evaluated the DOL starting response and steady-state active-power demand of the 596.6-kW three-phase induction

motor driving the Additional Air Compressor at PT Pupuk Iskandar Muda using ETAP version 19 and field operating data. The revised analysis separates the steady-state load-flow condition from the transient motor-starting condition to avoid mixing nominal and minimum transient voltage values.

2. The reported DOL starting current was 180–185 A, equivalent to approximately 6.0–6.2 times the 29.94-A rated current. During starting, the bus voltage decreased from 13.80 kV to 13.61 kV, corresponding to an approximately 1.38% temporary voltage reduction. The ETAP-reported steady-state active power was 638.30 kW, compared with 644.00 kW in the field data.
3. The reported simulation-to-field deviations were 1.38% for voltage, 3.21% for current, and 0.89% for active power, indicating good agreement for the investigated operating condition. These findings show that the observed starting event produced a limited temporary bus-voltage reduction in the investigated network. Before final publication, the ETAP source files should be used to verify the exact load-flow P–Q–S–V–I–power-factor combination and the exact peak starting-current value.
4. Future work should include a complete parameter disclosure of the generator, transformer, cable, motor inertia, compressor torque-speed characteristic, and simulation settings, together with formal assessment against the plant's applicable technical criteria. Additional scenarios involving varying system loading, alternative starting methods, harmonics, and repeated motor-starting events can then be evaluated.

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