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Study Analysis of Three Phase Induction Motor Starting Using ETAP at PLN ULPL Indralaya, South Sumatera

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Abstract

Steam Generator of Electricity Power Plant at PT. PLN (Persero) UPDK Keramasan of ULPL Indralaya, South Sumatra Area. This power plant has 3-phase induction motors, which are the most commonly used motors because of their reliability. The 3-phase motor is directly connected to the supply at a high starting current of around 5 to 7 times the motor rating current (nominal current). This large starting current can cause a considerable voltage drop on the supply line, thus affecting other loads connected to the supply line. Because the large current flows for a long time, it causes the motor to heat up, which will damage the insulation. Therefore, when starting the motor, the motor bus voltage must be kept at around 80% of the voltage rating. This study investigates whether the motor could start successfully under the operating conditions. We used ETAP software to simulate motor starting and also analyze these motors is to obtain the values of starting current, starting torque, and voltage drop from the results of using VFD (variable frequency drive) on two motor units in LV Switchgear SUS-1 whose previous existing conditions were using DOL (direct on line). A result of our studies, we found that the system can still maintain a bus voltage of 99.94%, a small starting current when starting the motor of 0% FLA (1 second), and reaches 99% FLA (4 seconds) with a starting torque of 54% & 57% of the load torque.

Keywords: Motor starting, VFD, DOL, high starting current, 3-phase induction motor

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1. Introduction

Electric power plants rely heavily on 3-phase induction motors, which serve as vital components in various systems such as pumps, compressors, and fans. These motors are widely used due to their rugged construction, low maintenance requirements, and cost efficiency. However, one of the main challenges in operating 3-phase induction motors lies in the high starting current they draw—typically five to seven times the motor's nominal current—which can lead to significant voltage drops on the supply line. Such voltage drops may cause disturbances to other connected loads, reduce power quality, and even result in system instability. This issue becomes even more critical in industrial settings where multiple large-capacity motors are started simultaneously, placing considerable stress on the power system [1].

To minimize the impact of motor starting on the electrical network, various starting methods have been developed, including star-delta starters, soft starters, and Variable Frequency Drives (VFDs). Among these, VFDs are increasingly favored due to their ability to control the motor speed by adjusting the input frequency and voltage, thereby significantly reducing inrush current and mechanical stress during the start-up process. VFDs also offer energy-saving benefits and improved process control, making them ideal for applications where variable speed is required [2].

Understanding the behavior of induction motors during starting is essential for system planning and protection. Factors such as acceleration torque, voltage drop, slip, and starting time must be carefully analyzed to ensure reliable motor operation without compromising other parts of the system. This study utilizes ETAP software, a powerful simulation tool widely used for modeling and analyzing electrical power systems [3]. By using the dynamic motor acceleration module in ETAP, the entire motor start-up sequence can be simulated and observed. The goal is to determine whether the motor can start effectively under existing conditions, measure how long it takes to reach rated speed, and assess the performance improvements when using VFDs compared to traditional Direct-On-Line (DOL) starting methods [4]. Through this analysis, the study aims to provide insights into optimal motor starting strategies, enhance the reliability of power system operations, and support informed decision-making for motor control in industrial environments.

2. Methods

In theory, a 3-phase induction motor is self-igniting; the stator is made up of 3-phase windings, the magnetic field of which rotates when coupled to a 3-phase supply. This will link and disconnect the rotor conductors, causing current to flow through the motor wires and creating a rotor magnetic field. The revolving magnetic field of the distator will interact with the magnetic field generated by the rotor to induce rotation. The 3-phase induction motor utilizes a starting approach that does not deliver initial torque to the motor to lower the huge initial current and prevent excessive motor heat. Many ways [5], [6] are utilized to idle a 3-phase induction motor, and in this work, the variable drive method (VFD) is used to analyze the starting of a 3-phase induction motor, such as dynamic motor acceleration. In this study, motor starting is required if the:

a. Motor rating exceeds 30% of the kVA rating of the transformer (if there is no generator).
b. Starting the motor will cause disturbances to the motor, system, and locally connected loads, as well as the buses connected to it.
c. If the rating or capacity of the motor exceeds 10-15% of the kVA rating of the generator (if the system is supplied only by the generator).
d. Many motors are starting simultaneously.

2.1 Variable Frequency Drive (VFD)

VFDs are electronic motor operating devices (used commonly in fans, pumps, etc.). The principles of power electronics are controlled by this device by changing the frequency of the input power to the motor to control the motor speed. This, in turn, provides reduced motor starting current, reduced mechanical stress heat on the motor and belt during starting, and so on. VFDs are nowadays widely used all over the world when the load is required to be able to control the speed of the motor so that it will have many power-saving advantages while operating. The voltage on an alternating current (AC) power supply rises and falls in the form of a sine wave. When the voltage is positive, the current flows in one direction. When the voltage is negative, the current flows in the opposite direction. [7] described that VFDs convert incoming alternating power into direct current (DC) power.

2.2 Direct On-line (DOL)

The most basic and simple form of motor starter in an induction motor is the direct online starter (DOL). The stator winding of an induction motor is connected directly to the three-phase supply voltage so that the winding receives full line voltage. For DOL starters, this is suitable for motors with small ratings because the motor will draw 6-8 times its full rated current. When a motor with a very large capacity is started by direct-on-line, the system voltage will be disturbed (voltage dip in the supply network) due to the large starting current [8], [9]. This voltage disturbance can cause damage to other electronic equipment connected to the source. The definition of direct start is the motor that will be run directly switch-on to the mesh voltage source according to the nominal voltage of the motor. Other studies have illustrated that there is no need to adjust or lower the voltage when starting. Induction motors with large ratings can be started on the DOL starter if the power grid capacity allows. Large-rated transformers for 440V three-phase distribution and, large-rated motors up to 90 kW can be started with DOL starter[8], [10].

2.3 Motor Starting ETAP 19.0.01

ETAP software is the most complete solution for simulation, design, and analysis of power generation, transmission, distribution, and power systems in industry. In ETAP, each research project provides a set of users, user access controls, and databases spread across elements linked to stored data. Everything that is connected will be displayed in graphs and engineering properties, where each circuit element can be edited directly from this view. Under the network system, ETAP itself has three types of operations, namely: edit, AC, and DC. The AC mode consists of analyses such as power flow, short circuit, motor acceleration, transient stability, and relay coordination.

This study is working on motors, starting with power flow, where ETAP requires the selection of operating modes in the power source, such as swing mode, voltage control mode, power factor control mode, and Mvar control mode. After the mathematical modes of the source model, and load model with proper selection of operating modes, different power flow methods are used in order to get different electrical parameters and at different buses. In power flow and motor starting to get different parameters, the following methods are used: (a) accelerated gauss seidel; (b) Newton-Raphson method; (c) Fast-Decoupled method [11]. The Gauss-Seidel method is the simplest method and is used for small networks. The number of iterations required depends on the number of buses, so it takes a long time to complete. The Newton-Raphson method is used for large industrial networks and has some assumptions made to simplify the simplified version of the N-R method, which gives a close solution. In power flow analysis, there is a generator bus and also a load bus. In the generator bus, the parameters are determined such as power and voltage, while in the load bus the active power and reactive power are determined. In the fixed network, there is one bus that is a swing bus. To find out the better starting scenario in a motor starting analysis, it is carried out from 1 to 12 seconds in simulating motor starting.

In this study, the following steps are performed: (a) click the edit button and create the solution parameters for the VFD; (b) in the power flow study, click the mode bar and select the Newton-Raphson method. The one-line diagram and report manager can be displayed as a result of the power flow. (c) To study the results on the one-line diagram and also see the alert view [12] of dynamic motor acceleration, click the dynamic motor acceleration button in the toolbar. (d) To compare the results of 5 motors, click the plot button of motor starting, motor 3-5 with DOL (direct online), motor 1-2 with VFD. (e) and then click the report manager button [13] to see all parts of the report output.

3.Results and Discussion

The capacity data for each motor is different because the data used is real motor data at PLN ULPL Indralaya. **Figure 1** shows a one-line diagram for dynamic motor acceleration analysis of a 3-phase induction motor. Based on the parameter settings of circuit breakers [14] (CB1, CB2, CB3, CB4, CB5), cables (1, 2, 3, 4,5), and 3-phase induction motors (Motor1, Motor2, Motor3, Motor4, Motor5), are each has values that represent the actual state. The input data or parameter settings of the downstream and upstream one-line diagrams of this SUS-1 switchgear-related system are shown in **Table 1-7**.

The results of the study on the change in viscosity and density of used cooking oil biodiesel due to gradual heat treatment resulted in four sub-chapters of discussion. The sub-chapters of discussion are discussed in sub-chapters 3.1 to 3.4 as follows.

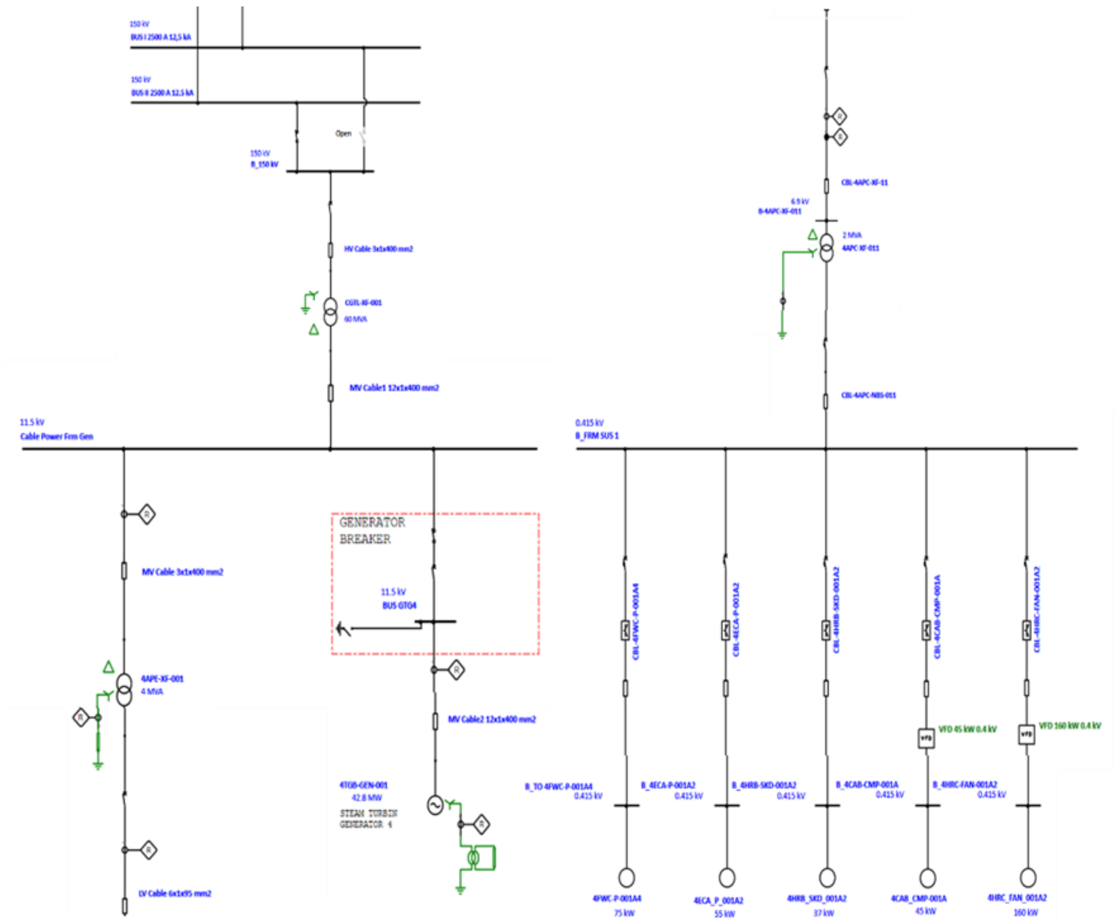

Figure 1. Viscosity Value Against Heat Treatment

Table 1. Generator data

ID	Type	Rating		Connected Bus	Bus Type
		MVA	kV		
4TGB-GEN-001	Gen	50.353	11.5	vB_4TGB-GEN-001	Swing

Table 2. Two-winding transformer data

Type	Rating			Stand	Attitude	%	%
	MVA	kV	Sec. KV		(m)	Z	X/R
4APC-XF-001	4	11.5	6.9	ANSI	1000	7.15	8.5
4APC-XF-011	2	6.9	0.415	ANSI	1000	6.25	6

Table 3. Three-phase motor induction data

ID	Type	Class	Model ID Revised	Rating		Load
				kW	kV	
4HRC_FAN_001A2	Motor	LV-LS-LT	LV200HP2P	160	0.4	Cooling Tower Fan
4CAB_CMP_001A	Motor	LV-LS-LT	LV75HP2P	45	0.4	Air Compressor A
4HRB_SKD_001A2	Motor	LV-LS-LT	LV50HP2P	37	0.4	Condenser Vacuum Pump Skid A
4ECA_P_001A2	Motor	LV-LS-LT	LV75HP2P	55	0.4	Aux Cooling Water Pump A
4FWC_P_001A4	Motor	LV-LS-LT	LV100HP2P	75	0.4	Condensate

Table 4. Circuit breaker data

ID	Stand	Mod.	Rating kV Max	Pole	Inter kA	Size (Amp)	Rated kV
ACB-4HRC-FAN-001A2	IEC	IZM	1	3	45	630	1
ACB_4CAB_CMP_001A	IEC	IZM	1	3	45	150	1
ACB_4HRB_SKD_001A2	IEC	IZM	1	3	45	150	1
ACB_4ECA_P_001A2	IEC	IZM	1	3	45	150	1
ACB_4FWC_P_001A4	IEC	IZM	1	3	45	250	1

Table 5. Cable data

ID	Library	Length (ft)	No. of Cond/ Phase
CBL-4HRC-FAN-001A2	XLPE	236.22	2
CBL_4CAB_CMP_001A	XLPE	186.35	1
CBL_4HRB_SKD_001A2	XLPE	96.12	1
CBL_4ECA_P_001A2	XLPE	173.22	1
CBL_4FWC_P_001A4	XLPE	104.65	1

Table 6. VFD Starting Device

ID	Motor	Type	Switching	Values %	V/HZ %	Ctrl Type
VFD 160 kW 0.4kV	4HRC-FAN-001A2	Frequency Ctrl	0	0	830	Ramp
			1	25	830	Ramp
			2	50	830	Ramp
			3	75	830	Ramp
			4	100	830	Fixed
VFD 45kW 0.4kV	4CAB_CMP_001A	Frequency Ctrl	0	0	830	Ramp
			1	25	830	Ramp
			2	50	830	Ramp
			3	75	830	Ramp
			4	100	830	Fixed

Table 7. VFD data

ID	kVA	kV	FLA	Hz	% Imax	% PF
VFD 45 kW 0.4 kV	48	0.415	66.78	50	150	100
VFD 160 kW 0.4 kV	168	0.415	233.72	50	150	100

The ETAP shown in **Figure 1**, where the power flow analysis uses the Newton-Raphson method. In Fig. 2 below is a one-line diagram of the results of the power flow analysis (Scenario 1) with 394 kW and 99.7 kVar used in this study. According to the nominal voltage value of 0.415 kV, a short circuit level of 30 kA has also been considered for all levels in the LV switchgear system [15].

Nomenclature Motor in **Figure 2**:

a). 4HRC_FAN_001A2 (Motor 1);

b). 4CAB_CMP_001A (Motor 2);

c). 4HRB_SKD_001A2 (Motor 3);

d). 4ECA_P_001A2 (Motor 4);

e). 4FWC_P_001A4 (Motor 5).

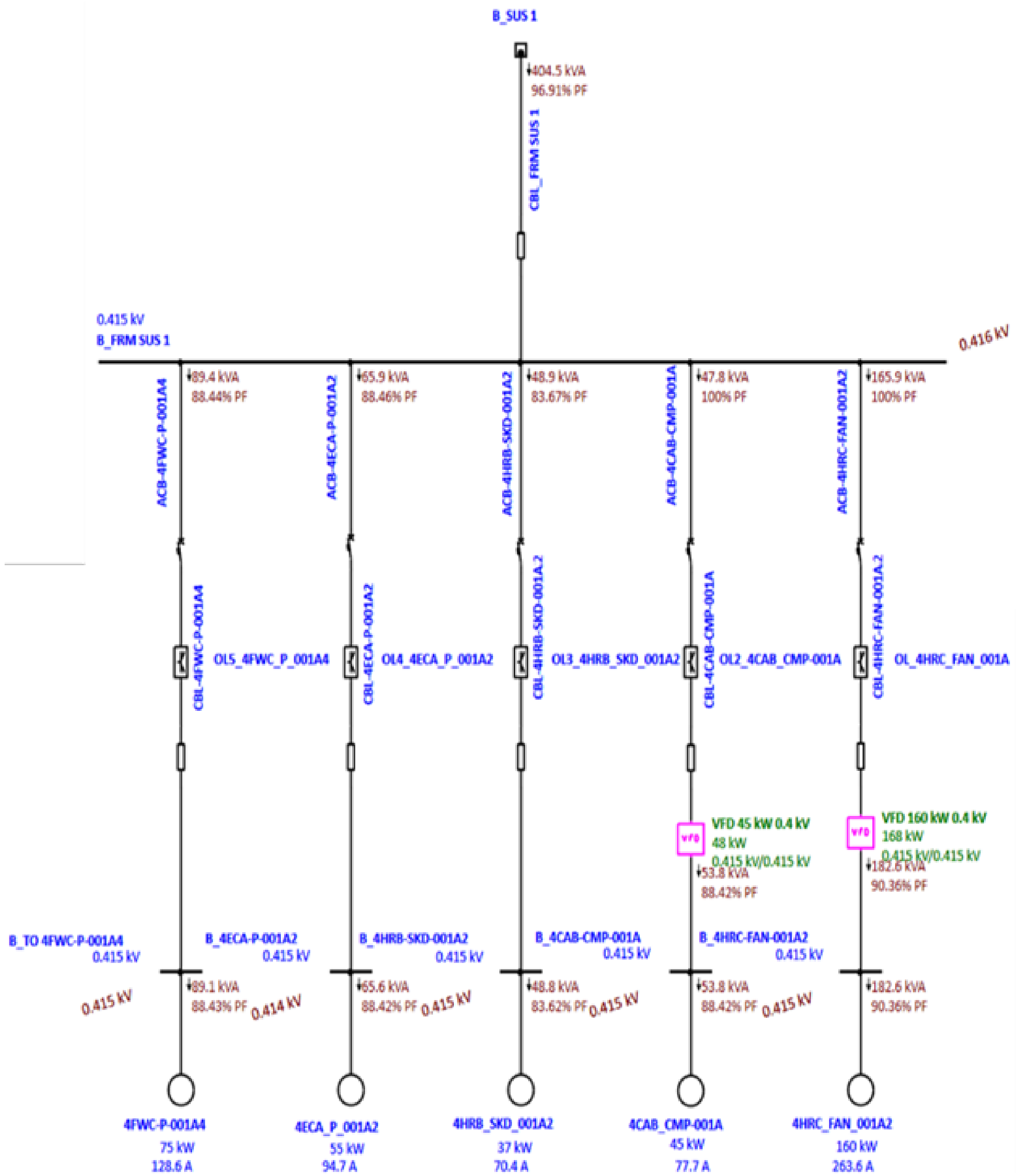

Figure 2. ETAP Single-Line Diagram For Power Flow

The study shows the results in **Figure 3-12** is a comparison of dynamic motor acceleration analysis for a 3-phase induction motor in DOL (direct online) and VFD modes on the same system.

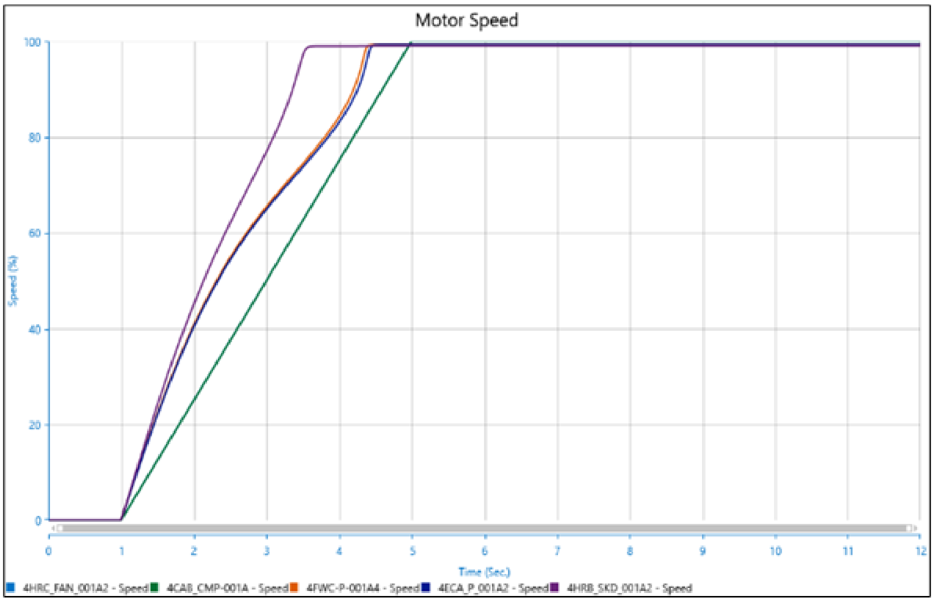

Figure 3. ETAP Single-Line Diagram For Power Flow

Figure 3 shows that the motor speed starts at 1 second with 0% of the speed rating for all motors, and rises to 100% of the speed rating of Motor No. 1 at 4.2 seconds, Motor No. 2 at 5 seconds with VFD, Motor No. 3 at 4.2 seconds, Motor No. 4 at 4.2 seconds, and Motor No. 5 at 3.3 seconds with DOL mode.

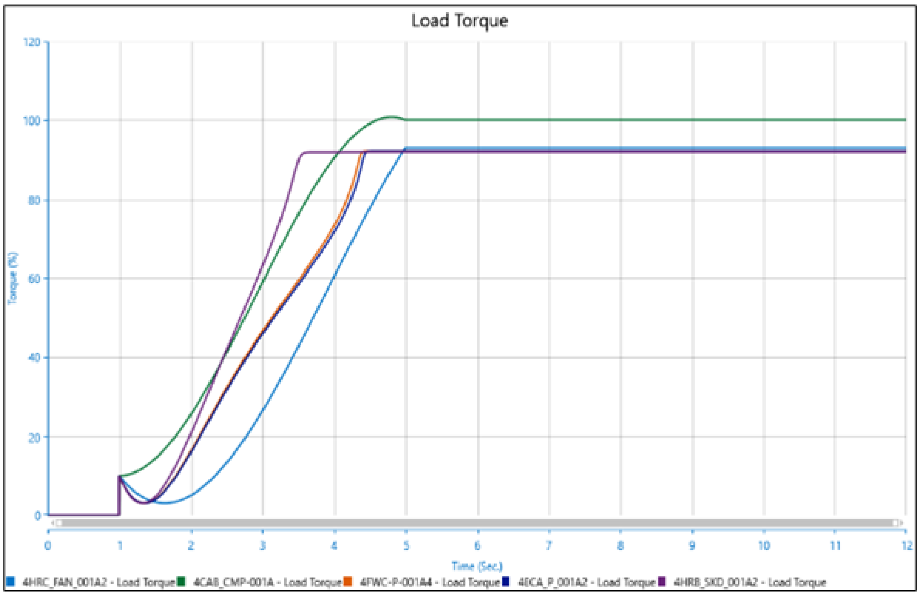

Figure 4. Percentage of Load Torque to Time

Figure 4 shows the load torque of all motors starts at 1 second with 10% of the rated load torque. The load torque becomes 93% and 100% of the rated load torque at 5 seconds for motors No. 1 and No. 2, the load torque for motor No. 3 is 92% at 3.5 seconds, and motor No. 4 No.5 at 4.5 seconds is 92%. Furthermore, motors No.1 and No.2 stable load torque values within 5 seconds by using variable frequency drives.

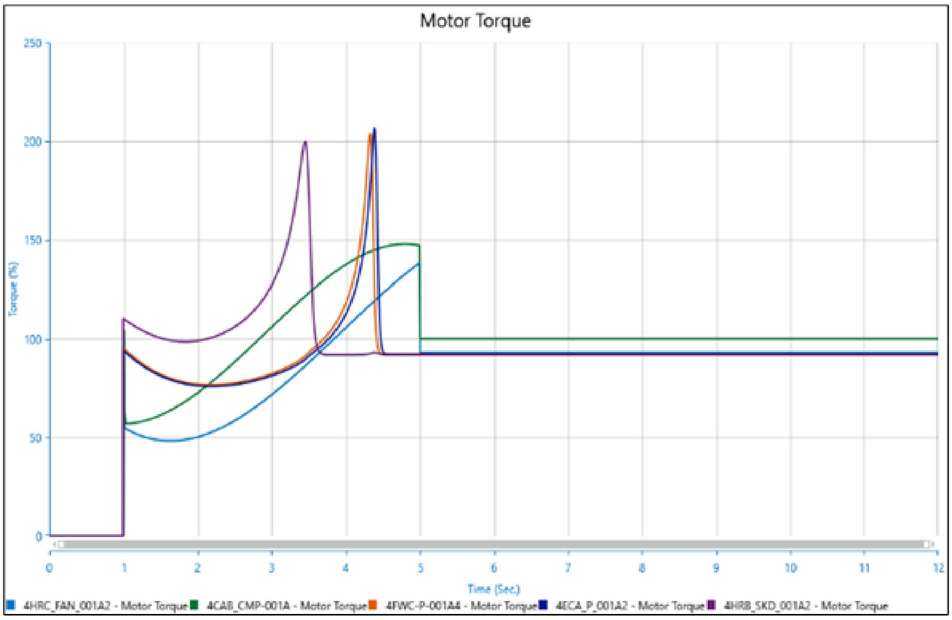

Figure 5. Percentage of Motor Torque to Time

Figure 5 shows that all motors can provide relatively the same torque value (93% of the load torque value) at steady-state time even though the initial value of motor torque is different.

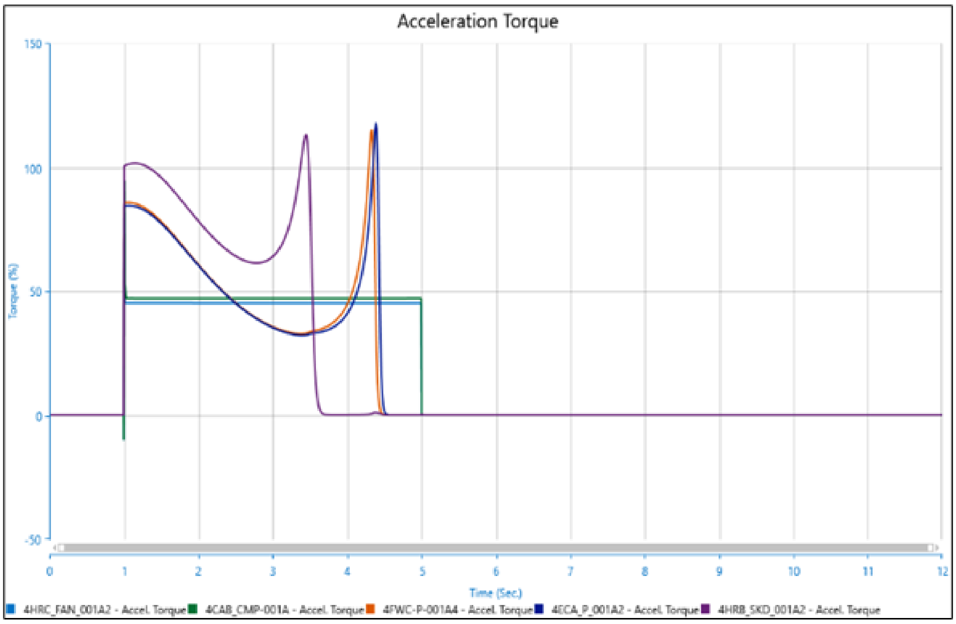

Figure 6. Percentage of Acceleration Torque to Time

Figure 6 obtained that the acceleration torque of motor No.1 and motor No. 2 is less than motor No. 3, motor No. 4, and motor No. 5 at the starting time. However, all motors can operate with a load torque value of 93% because all motors have zero acceleration torque at steady-state time.

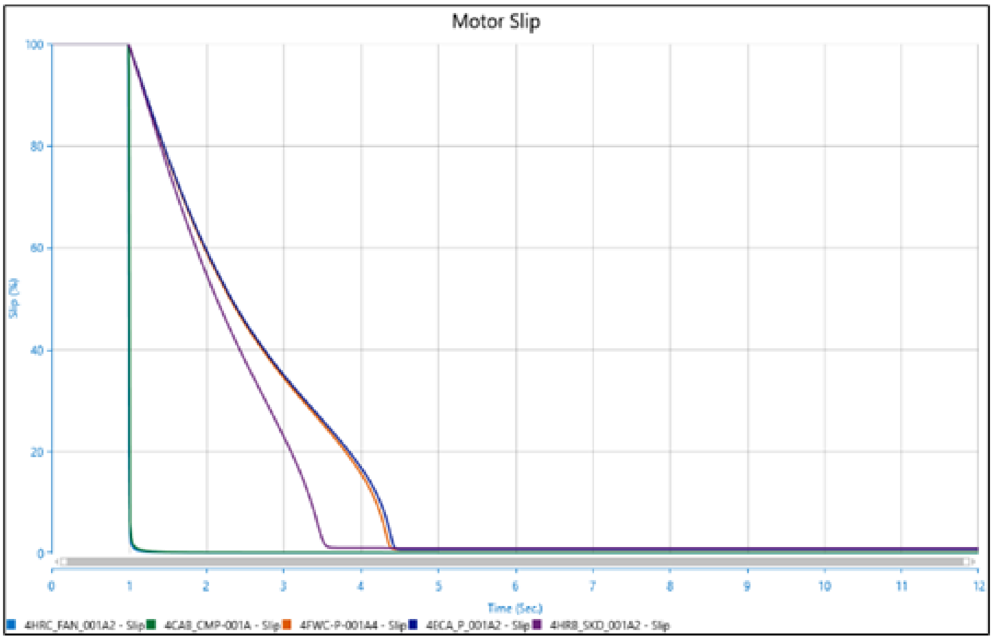

Figure 7. Percentage of Slip Motor to Time

Figure 7 shows that the slip of all motors is 100% (S = 1) at start time. Then the slip of each motor appears at 0% (S = 0). So the induction machine operates in motor mode (1 ≥ S ≥ 0). Slip is the difference between the rotor speed and the synchronous speed of the rotation.

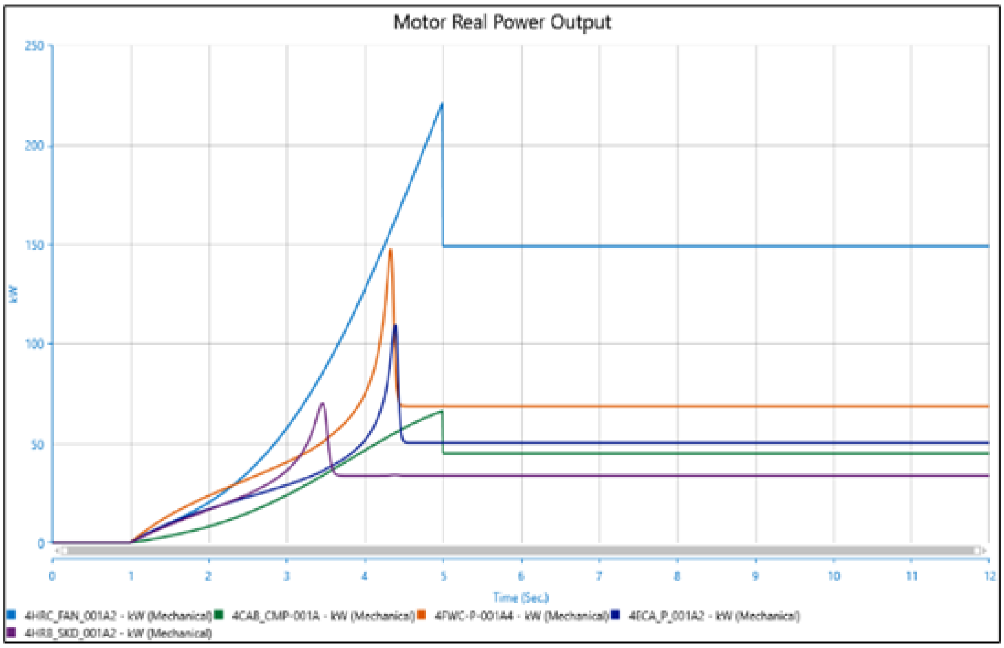

Figure 8. Real Power Output to Time

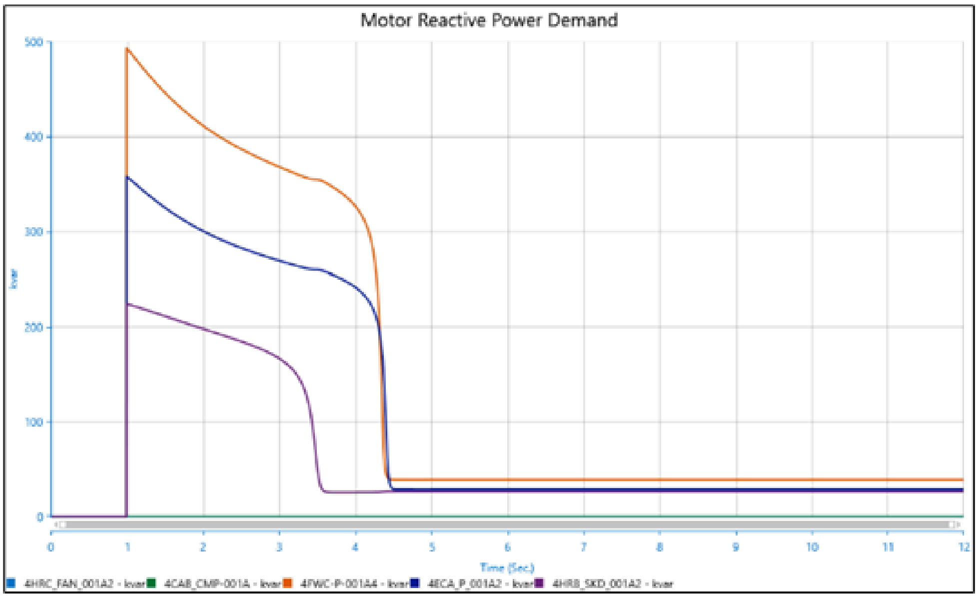

Figure 9. Motor Power is Reactive to Time

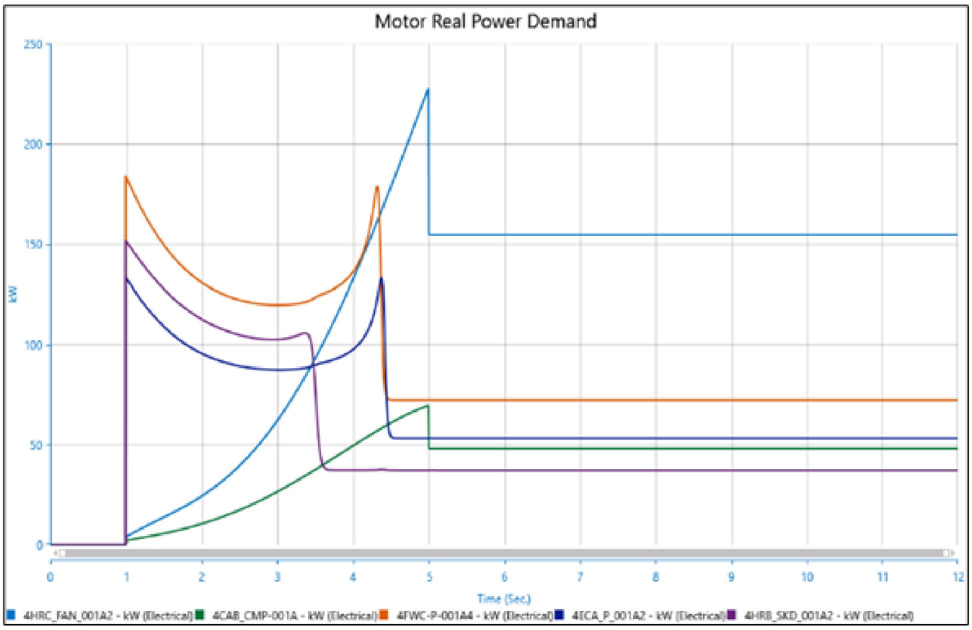

Figure 10. Active Motor Power to Time

In **Figure 8-10** the active power consumption of all motors in steady-state is the same, but **Figure 9** shows no reactive power demand for motors No.1 and motor No. 2. It can also be seen that the reactive power demand for starting motor No. 5 is less than motor No. 3, and motor No. 4 (DOL). Significantly, the total energy of the system can be saved during motor starting by using the VFD.

Figure 11 shows that the bus voltage drop of motor No.1 and motor No. 2 were was 0.061% of the normal bus voltage, the bus voltage of motor No. 3 and motor No.5 decreased by 0.074%, and for motor No. 4, it was about 0.08% of the normal bus voltage at the time of starting. The result shows that the bus voltage on all motors can be maintained at around 99.92% of the normal bus voltage (0.415 kV) at the motor start time (1 second).

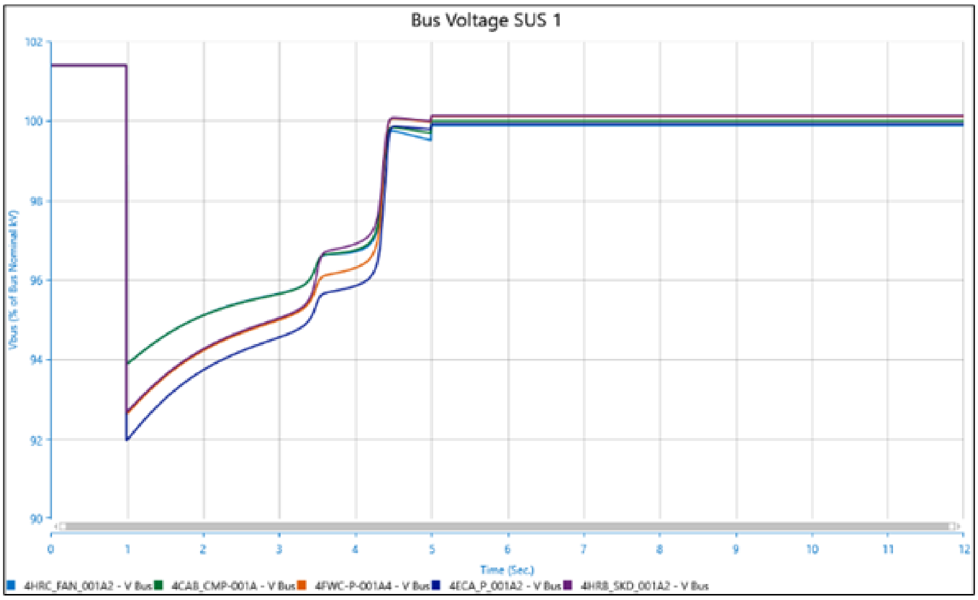

Figure 11. Percentage of Bus Normalized Voltage to Time

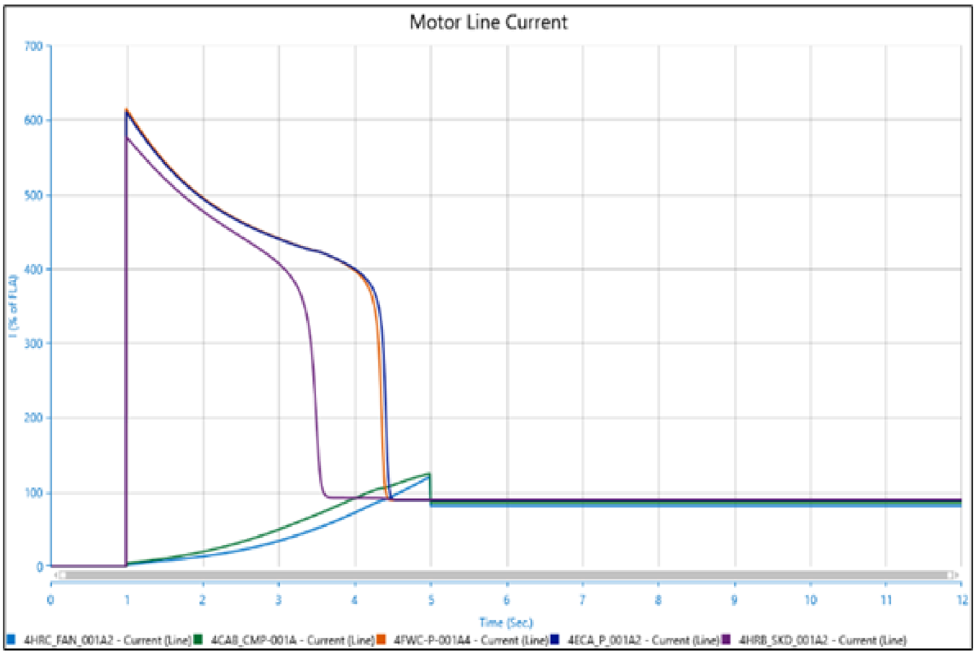

Figure 12. Percentage of Motor Line Current to Time

In **Figure 12** illustrates that the current at motor No. 5, motor No. 4, and motor No. 3 is 570%, 610%, and 610% of FLC (full load current) at 1 second, and the line current decreases until it reaches a steady state value of about 99.99% of FLC. The line currents at motor No. 1 and motor No. 2 are drawn at 0% of FLC at 1 second. The line current of motors No. 1 and motor No. 2 were rises gradually until it reaches about 130% of FLC and then immediately decreases until it reaches a steady state value of 99% of FLC at 5 seconds.

4. Conclusion

To avoid overheating of the motor and excessive voltage drop in the system network, it is necessary to keep the starting current small. The starting torque should be about 50-100% greater than the load torque to ensure that the motor runs for a short enough time. ETAP software was used to study the analysis of the motor acceleration for 3-phase induction motors for pump, fan, and compressor loads in the SUS 1 low-voltage switchgear system. In this motor starting analysis, two conditions are explained; normal operation (DOL) and VFD. Through this research, it was found that motors 1 and 2 can be started with three conditions; a small current (0% FLA for 1 second) and a high current (reaching 99% FLA at 4 seconds). Secondly for the voltage drop that occurs is 0.061% (can maintain the bus voltage close to the nominal voltage which is 99.94% and last results is obtained for small starting torque which is 54% to 57% of the load torque so that it can save energy during the starting period.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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