Jurnal Politeknik Caltex Riau
https://jurnal.pcr.ac.id/index.php/elementer
| ISSN: 2460 – 5263 (online) | ISSN: 2443 – 4167 (print)

Simulation of Voltage sagging mitigation with liquid starter for motor starter in PT Solusi Bangun Indonesia TQ 1 system using ETAP

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Abstract

Voltage stability is one of the main concerns in electric power systems. One of them is related to the problem of loose voltage. The cause of voltage stability disturbances in the electric power system is the motor starting event. The current way to start a motorbike that is often used is to use a VFD soft starter. However, using a VFD is quite expensive so there is another mitigation, namely a liquid starter. In this research, we will show how to model a liquid starter simulation and compare liquid starter vs direct online in terms of voltage mitigation. The results of the liquid starter modeling will be tested in a simulation using ETAP software where there is no liquid starter feature in ETAP. The simulation results obtained show that by using a liquid starter there is a minimal decrease in the voltage profile, low starting current, soft start, small impact on the network. This is proven in the application of liquid starter using etap and Matlab plotting software. The smallest voltage profile value is 90.35% and the starting current is 6 times lower than the direct online method. From its application, the liquid starter method has proven to be much more effective in overcoming high voltage and current sags when the motor is started.be much more effective in overcoming high voltage and current sags when the motor is started.

Keywords: *Rotor resistance method, motor starting Static and dynamic modeling, voltage sag.*

1. Introduction

Fulfilment of electricity needs today not only considers the availability of energy sources, but also must meet indicators of system reliability, economy and quality [1][2]. PT. Solusi Bangun Indonesia is a cement manufacturing company which is a subsidiary of the Semen Indonesia Group. SBI runs an integrated business of cement, ready-mix concrete and aggregate production. SBI operates four cement factories in Narogong (West Java), Cilacap (Central Java), Tuban (East Java), and Lhoknga (Aceh), with a total capacity of 14.5 million tons of cement per year. In carrying out production activities, PT. Solusi Bangun Indonesia utilizes electrical energy to drive all process equipment. Therefore, the electrical power supply at PT. Bangun Indonesia Solutions must be well maintained in order to maintain the reliability and continuity of factory operations. In terms of electric power quality, it includes aspects of continuity of power service and quality

Documents received on 18 April 2024
Documents published on 31 May 2024

of voltage and frequency waveforms. Interference is one of the factors causing instability in the electric power system. Disturbances on the supply side can cause the generator to trip, and this will result in an imbalance between the amount of power supply and the load power [1][2][3]. Apart from that, the effect of motor starting will result in an unstable system [1][2].

The motor starting process will cause the motor starting current to be 5 to 10 times the nominal current value and will cause a decrease in the voltage value on the buses [3][4]. At the PT Solusi Bangun Indonesia TQ 1 system there are several motors that have quite large capacities. If the motors with a large enough capacity are started, it could disrupt the stability of the electrical system at PT Solusi Bangun Indonesia TQ 1 system. The problem that often occurs during a motor starting event is a voltage sag which causes the under-voltage relay to work when voltage sagging happens in 0.8 pu value [4][5]. A lot of research to mitigate the normal starter motor is to use VFD, soft starter and Wye Delta connection [6][7]. But there is some method mitigate the occurrence of voltage sags when the motor starts, it is necessary to add rotor resistance, namely in the form of liquid resistance. This method is known as liquid starter [8] [9]. This research will compare the conventional starting method or what is called direct online starter (dol) and also liquid starter. The author purpose to mitigate voltage sagging when motor starting happen with liquid starter. In this research, a liquid starter will be modeled in the Matlab application to determine the amount of resistance used in the liquid starter, then the resulting resistance value will be input into the Etap application to be used to simulate motor starting using the liquid starter method. The addition of liquid starter will be tested and the results compared with the direct online method. The author tries to add a liquid starter feature in the modeling used in the Etap application to test the results of mitigating voltage sags that occur when motor starting happens.

1.1 Induction Motor

An induction motor has two construction parts, namely the stator and rotor. The stator coil functions to produce a rotating field that is used for motor rotation [1] [2]. The rotor coil is a part that moves due to magnetic induction from the stator coil which is induced into the rotor coil. Based on the form of rotor construction, induction motors can be divided into two types, namely: Cage type rotor (squirrel cage) and Wound rotor. Induction motors work based on electromagnetic induction from the stator coil to the rotor coil. When the stator coil is connected to a 3-phase source, a rotating field with speed will be formed

$$N_s = (120.f)/P \tag{1}$$

Where Ns = Synchronous speed, f = frequency system and P = Pole. After that, the rotating field will cut the conductor rod of the cage rotor or cut the windings of the coiled rotor so that it will cause an induced electromotive force (emf). In this condition the rotor coil is a closed circuit so the induced electromotive force (emf) will produce a current I. With the current in a magnetic field, it will cause a force F which will rotate the rotor in the direction of the stator rotating field.

1.2 Starting Inductor Motor Method

In starting an induction motor, there are several methods used for starting. Methods that can be used to start large induction motors are direct on-line, autotransformer, soft starter, wye-delta, primary resistor winding, and adjustable frequency drives [4] [6] [7]. This starting method uses the principle of controlling the input voltage and current which functions to reduce the starting torque which can also prevent damage to the load [7].

Wound type induction motors have stator windings similar to squirrel cage induction motors, but the rotor windings are connected out of the motor using slip rings and carbon brushes. The aim is to add resistance in series with the rotor windings during the starting process. After the starting process, the resistance is short-circuited using a contact. The advantage of adding this secondary resistance is that it reduces the motor starting current and will improve the torque during the starting process.

There are two types of resistance used, namely metal resistance and liquid resistance. Metal resistance has the principle of using metal contacts to adjust the resistance value. The farther the metal contact is from the input terminal, the greater the resistance value. Metal contacts are prone to melting due to large starting currents. Liquid resistance has the principle of an electrolyte liquid that soaks two conductor rods. The higher the electrolyte fluid, the smaller the resistance value. This liquid resistance has a negative temperature coefficient to the resistance value so that the higher the temperature, the resistance value will decrease. This will limit the starting current of the liquid resistance [9] [10]. The advantage of liquid resistance is that the liquid resistance resistance value setting is very smooth because it depends on the height of the electrolyte liquid immersion and there is no risk of contact melting.

1.2.1 Voltage Dip Standard

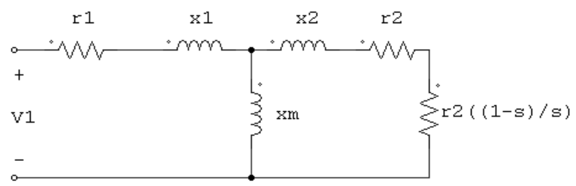
Voltage sag is defined as the phenomenon of decreasing the effective voltage magnitude relative to its nominal value during a time interval (t). Usually caused by system faults, energization of large loads or starting of large motors. The voltage standard used is IEC 61000-4-34.

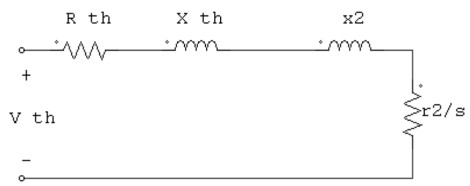
Table 1 Voltage Sagging Standard

VOLTAGE SAG DURATION			VOLTAGE SAG
Second (s)	**Cycles at 60 Hz**	**Cycles at 50 Hz**	**Percent (%) of Equipment Nominal Voltage**
< 0.05 s	< 3 cycles	< 2.5 cycles	Not specified
0.05 to 0.2 s	3 to 12 cycles	2.5 to 10 cycles	50 %
0.2 to 0.5 s	12 to 30 cycles	10 to 25 cycles	70 %
0.5 to 1.0 s	30 to 60 cycles	25 to50 cycles	80 %
>1.0 s	> 60 cycles	> 50 cycles	Not specified

1.2.2 Equivalent Circuit of Induction Motor with starting liquid

In starting using rotor resistance or liquid starter, a response between torque-slip, current-slip, and pf-slip is required [11]. To get this response, motor data is needed which includes: stator resistance and reactance, Rotor resistance and reactance, external resistance value, motor synchronous speed nominal power, nominal voltage, and nominal power factor. The calculation steps can be seen in through equation below to obtain the torque-slip response, current-slip, and power-slip factor. Apart from using the liquid starter method, this research will also discuss the differences between static and dynamic modeling:





The first thing that needs to be done is to get a Thevenin replacement circuit to determine these parameters so that the equation is used :

$$v\_th = v\_phase * (xm/\sqrt{(r12 + (x1 + xm)2)}) \tag{1}$$

$$z\_th = ((j * xm) * (r1 + j * x1)) / (r1 + j * (x1 + xm)) \tag{2}$$

with the information that r1 and x1 are the stator resistance and reactance, xm is the magnetization reactance while v_th and z_th are thevenin voltage and impedance. After the replacement circuit is obtained, then calculate the torque-slip response using the equation

$$T = \frac{1}{\omega s} \frac{q_1 V_{th}^2 \left(r2/s \right)}{\left(R_{th} + r2/s \right)^2 + \left(X_{th} + X_2 \right)^2} \tag{3}$$

With the information q1 for the number of phases, ωs is the synchronous speed (rps), Rth and The next step is to determine the current-slip response using the equation

$$i(A) = \left| V_{rating} / \left(\sqrt{3} * Z_{in} \right) \right| \tag{4}$$

$$Z_{in} = \left(r1 + jx_1 \right) + \left(\left(\frac{r2}{s} + jx_2 \right) \parallel \left(jx_m \right) \right) \tag{5}$$

Information for i(A) is the starting current in units of Ampere and Zin is the input impedance in units of Ohms (Ω). The final step is to determine the pf-slip response using equation

$$Pf = Cos(\varphi) \tag{6}$$

1.3 Dynamic Model

The dynamic model is a method that represents the motor as a dynamic model to see the starting time of a motor until it reaches its nominal speed and is used to determine the effect of voltage sags on the system. The static model is a method that represents the motor as a locked rotor impedance during the starting time that will draw maximum current from the system. After the acceleration time of the motor is complete, the motor will be changed to a constant kVA load. The comparison between dynamic model and static model can be seen in figure Figure 1 based on reference etap modelling for motor starting [12].

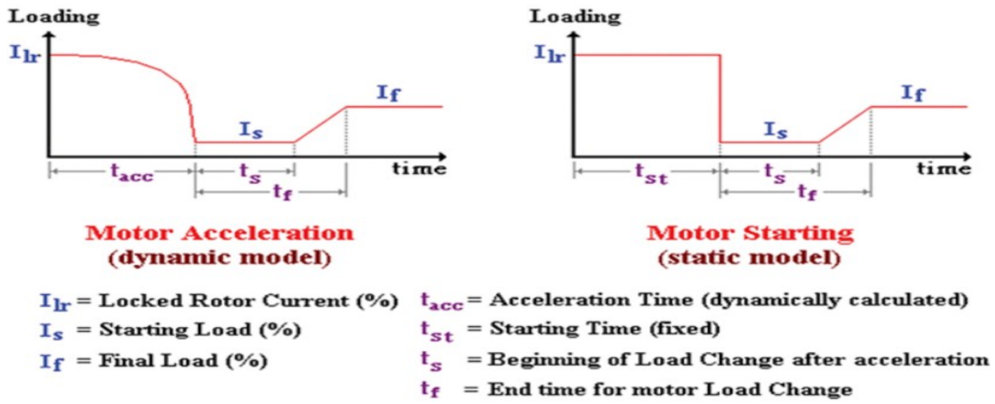


Figure 1 Comparison Between dynamic and static model motor starting

2. Research Methods

2.1 The research process

The research process begins with the process of collecting data inputs needed for simulation in ETAP. If the data requirements have been met then the motor starting simulation can be run. The first scenario is using the direct online method. After carrying out the analysis, it turns out that there is a weakness on the direct online side regarding voltage sagging. so that resistance is added for liquid starter modeling. Figure 2 is for reseaech flowchart

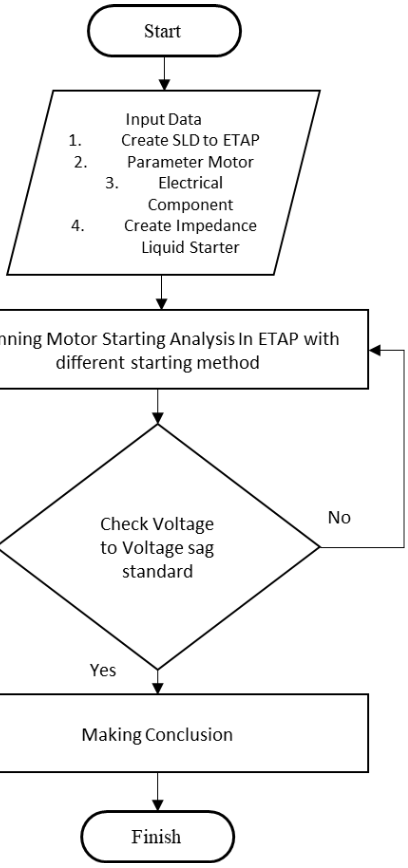


Figure 2 Research Flowchart

2.2 PT Solusi Bangun Indonesia TQ 1 system

In the Solusi Bangun Indonesia Tuban Plant TQ1 electrical system, there is one 40 MVA transformer which is used to meet the electricity needs of the production system which is obtained through the PLN GI Mliwang 150 kV network. Under normal circumstances, power distribution from PLN is distributed through 9 outgoing feeders to meet production operational needs. Apart from that, there is an emergency generator with a capacity of 1 MW which is used as backup power for loads which are categorized as essential for the company. An overview of the entire electrical system is visualized through.

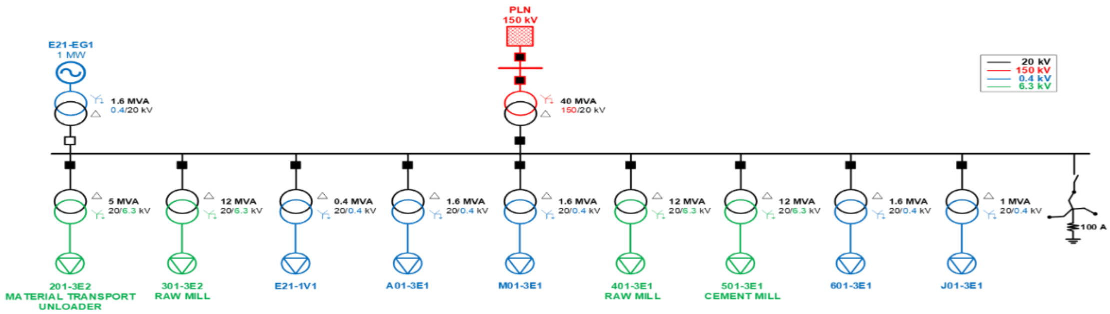


Figure 3 PT Solusi Bangun Indonesia TQ 1 system

2.3 Load Profile

In TQ 1 system, the load requirements at each substation have been met through PLN. The total load that must be met on the electricity system is 14.8 MW which is divided into each substation according to needs. The loading profile on each substation can be seen from Figure 4

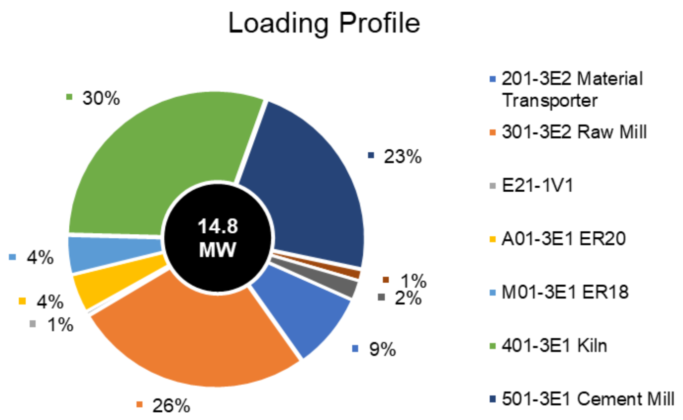


Figure 4 Loading Profile of Each Substation

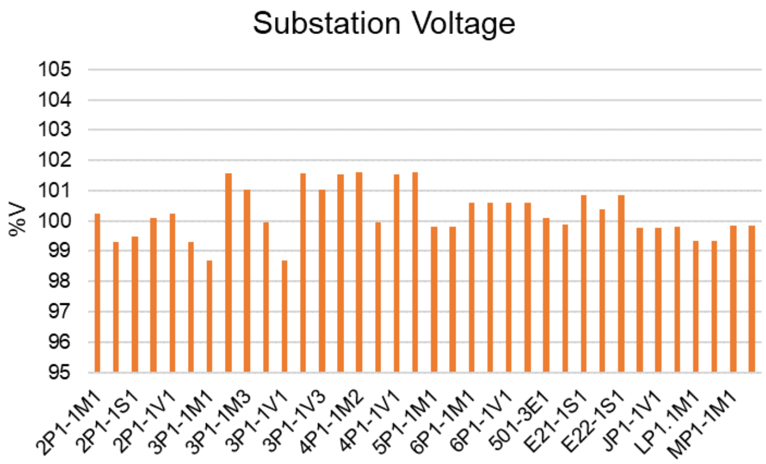


Figure 5. Substation Voltage

From Figure 4, it can be seen that the largest load is in the Kiln area, followed by the Raw Mill. These charges of course depend on the operational conditions of the plant which change according to production. The system operational voltage limitation criteria depend on the standards set by the company. If we refer to IEC 60038, the system operational voltage limit is ± 10%. However, if we refer to SPLN 1-1995, the permitted voltage variations are +5% and -10%. In the evaluation carried out, the stress evaluation will refer to the stress variation limits. Evaluation of the voltage profile at each substation which is visualized in Figure 5 shows that the operational voltage level at each substation within the range of ± 5% based on SPLN 1-1995 because we use source from PLN. For power flw condition all the bus voltage is within in range standard SPLN.

2.4 Motor Induction Profile with liquid starter

This induction motor with tag number MD1-1V1 is located in the Killn subsation 401-3E1 area. MD1-1V1 motor data can be seen in table 2

Table 2 Specification of Killn Motor Mill

Nominal voltage							6300 V
Nominal power							2500 kW
Synchronous speed							1200 rpm
Pf nominal							0.8
Stator resistance							0.580 Ω
Stator reactance							0.610 Ω
Rotor resistance							0.0176 Ω
Rotor reactance							0.610 Ω
Magnetization Reactance							16.8 Ω
Stator winding/rotor winding							1
External resistance level							
No.	Ω	No.	Ω	No	Ω	No	Ω
1	5.35	4	2.82	7	0.93	10	0.18
2	4.75	5	2.03	8	0.65	11	0.075
3	3.45	6	1.55	9	0.37	12	0

By using MATLAB software, the torque-slip, current-slip and pf-slip response results will be obtained which have been calculated based on equations 2-6 shown Determination of the torque-slip response, slip current, and pf-slip for starting a motor using the liquid method is carried out by considering that the rotor resistance reduction setting is carried out in stages with 12 levels of resistance for the case study so that 12 motor responses are obtained for each level of total rotor resistance. the sum of the rotor winding resistance with the external resistance, then combined for each level of motor speed from start to synchronous speed

Table 3 Liquid Starter parameter response

Slip	% Torque FL	% I FL	% PF	Slip	% Torque FL	% I FL	% PF
100.00	134.70	158.10	89.70	53.33	184.90	180.50	74.20
98.33	133.00	156.00	89.40	50.00	175.70	183.20	72.20
95.00	131.30	153.90	89.10	48.33	165.50	197.10	70.60
93.33	129.60	151.80	89.00	45.00	154.30	183.40	69.50
90.00	141.50	166.80	88.30	43.33	182.30	185.80	69.10
88.33	139.70	164.00	88.10	40.00	179.30	188.50	68.30
85.00	137.80	161.20	88.00	38.33	176.30	191.10	67.90
83.33	136.00	158.30	87.60	35.00	173.10	193.70	65.00
80.00	156.10	181.40	87.30	33.33	201.20	200.60	64.20
78.33	153.30	178.10	86.80	30.00	196.10	197.50	63.40
75.00	150.50	174.70	85.90	28.33	190.50	194.30	62.80
73.33	169.80	193.50	85.60	25.00	184.60	193.50	62.70
70.00	166.40	189.10	85.10	23.33	150.90	192.00	61.80
68.33	162.90	184.60	84.30	20.00	152.60	191.10	62.20
65.00	159.30	180.00	82.30	15.00	154.40	187.90	61.10
63.33	167.60	186.20	79.80	10.00	156.30	188.50	68.30
60.00	163.10	180.30	78.80	5.00	148.30	186.60	79.20
58.33	158.40	174.20	76.70	3.33	143.00	152.90	87.90
55.00	153.40	168.10	75.30	1.67	165.30	145.40	91.30
				0.00	10.00	53.60	70.60

3. Result and Analysis

3.1 Modelling response plot

After the response plot is obtained according to the existing Matlab program, Figures 6, 7, and 8 show the response graph plot of torque, current, and power factor vs slip from motor killn liquid starter

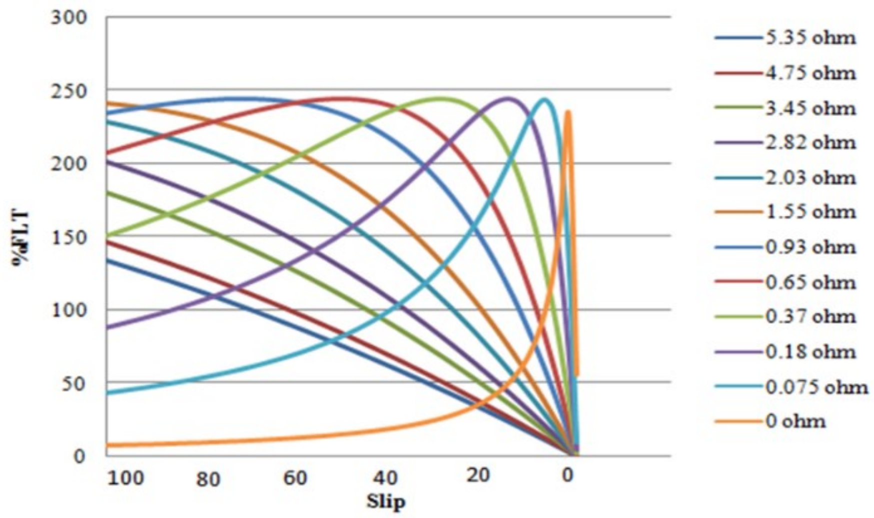


Figure 6 Response Torque VS Slip Liquid Starter

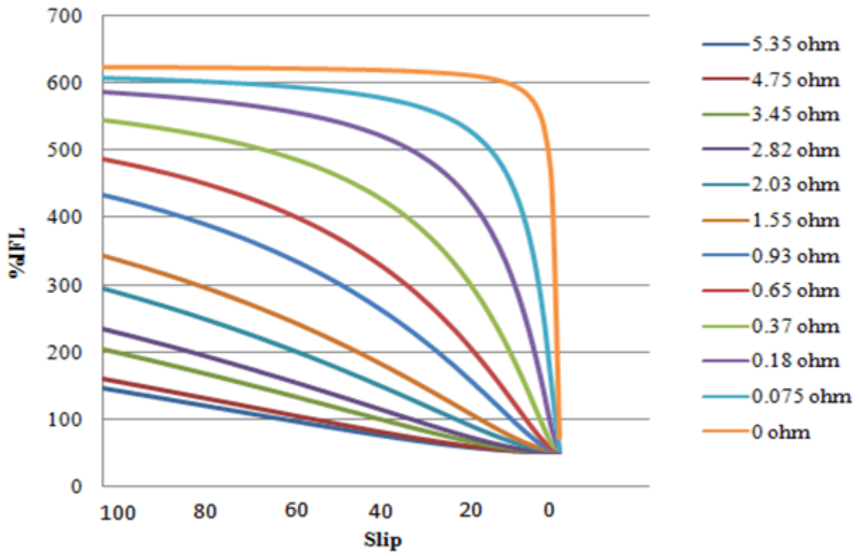


Figure 7 Response Current VS Slip Liquid Starter

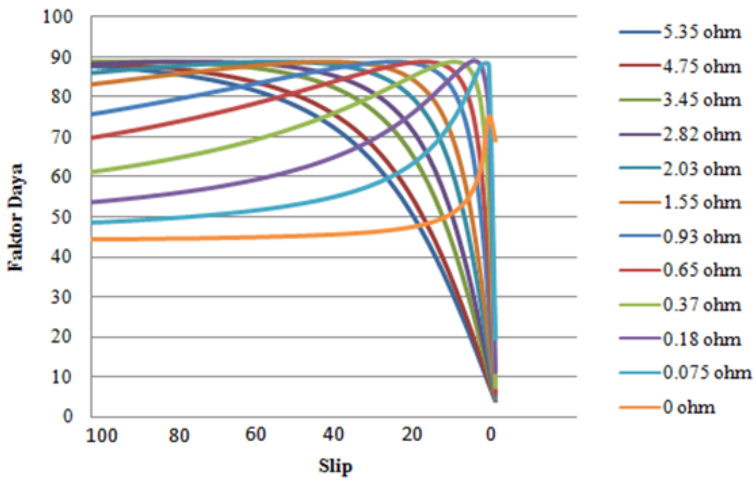


Figure 8. Response Power Factor VS Slip Liquid Starter

The torque, current and power factor response plots that have been obtained will be used to obtain the response from the motor using ETAP software. These responses are entered into the motor characteristic library in the ETAP software, then the motor starting analysis process is carried out to obtain the voltage curve resulting from the motor starting process. The motor starting process in the ETAP software consists of two types, namely static motor starting with direct online method and dynamic motor starting with liquid starter. The focus of the research topic this time is to reduce the impact of voltage sags and reduce high increases in motor starting current, so these 2 parameters will be compared between the direct online and liquid starter methods.

3.2 Response starting motor induction with direct online method

If a motor with a large capacity is started directly or using direct on-line, it will cause a very low voltage drop. The motor starting simulation was carried out by obtaining an electricity supply from PLN of 3886 MVAsc. The simulation results of motor starting with direct on-line can be seen in the table 4

Table 4 Voltage Operation Durimg starting motor wih direct online method

BUS observation	Starting Condition Direct Online Method			
	Before Starting	During Starting		After Starting
	(%)	(%)	Drop (%)	(%)
MD1-1V1	98.87	25.1421	73.7279	95.2177

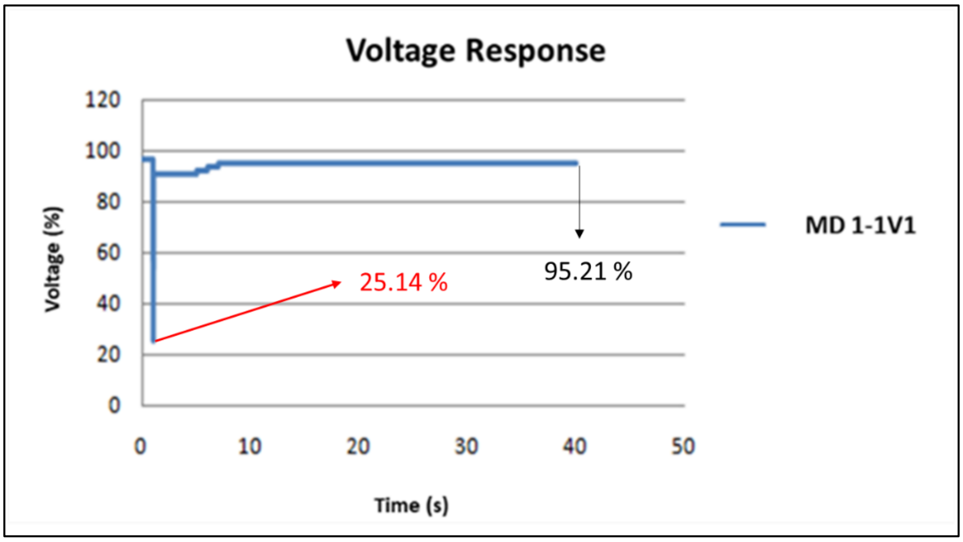


Figure 9. Voltage Respone with Direct Online method

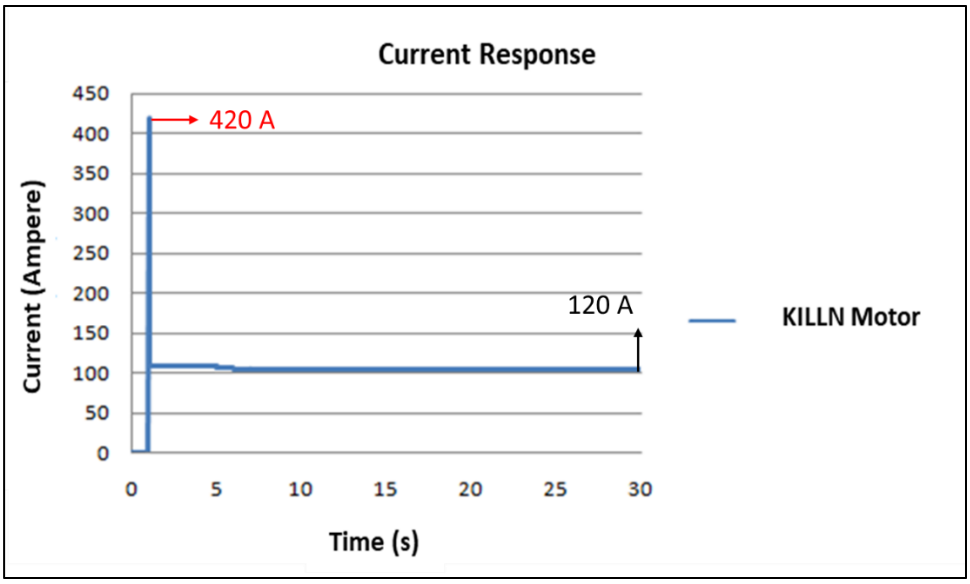


Figure 10 Response Current Direct Online Method

induction which uses a control system to close the contactor and apply full system voltage to the motor terminals. Motors with the direct online starting method will produce the highest starting torque which means the shortest rotor acceleration time. This method will cause a decrease in the capacity of the electrical system due to the high starting current which can reach 6 to 7 times the motor's full load. Based on table 4, when the KILLN Mill induction motor is started using the direct on-line type, the voltage on each bus will drop significantly and be below the existing standards. Figure 9 shows the voltage response of the MD1-1V1 motor bus when the Kiln Mill motor is started during the periode starting it will experience voltage sagging into 25.14 %. If the Kiln Mill motor is started using the direct on-line method periodically, the system will experience problems in voltage sagging and make under voltage relay will works during starting motor.

Apart from the motor bus voltage, another thing that needs to be considered when starting the motor is the motor starting current. When the roller mill motor is started with DOL, the starting current at the 1 second is 420 A and stady state at a nominal current of 102 A at the 9 second. Figure 10 shows the starting current response during direct online starting motor method. From the simulation results using the direct online method, it produces a voltage reduction of up to 73%. Apart from that, the direct online method increases the current up to 4 times the nominal current. This can cause the over current relay and over voltage relay to work. So the direct online method has weaknesses in the large nominal voltage drop and high starting current

3.3 Response starting motor induction with Liquid Starting method

The starting method used is a liquid starter which has been plotted and input into the ETAP library based on the characteristics in table 2. The motor starting simulation results for the Killn mill motor can be seen in table 5

Table 5

BUS observation	Starting Condition Liquid Starter			
	Before Starting	During Starting		After Starting
	(%)	(%)	Drop (%)	(%)
MD1-1V1	98.87	90.55	8.32	96.35

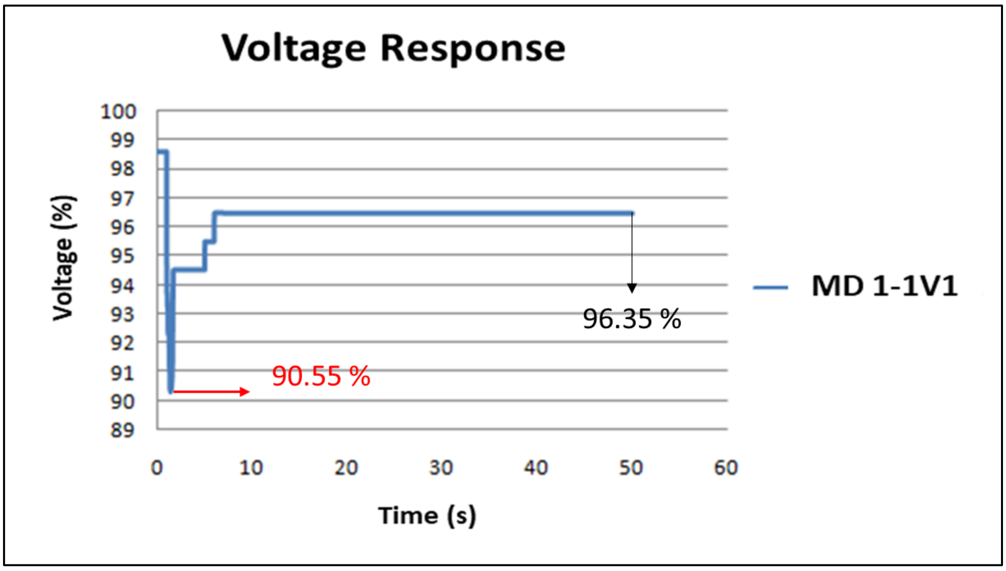


Figure 11 Voltage Respone with Liquid Starter method

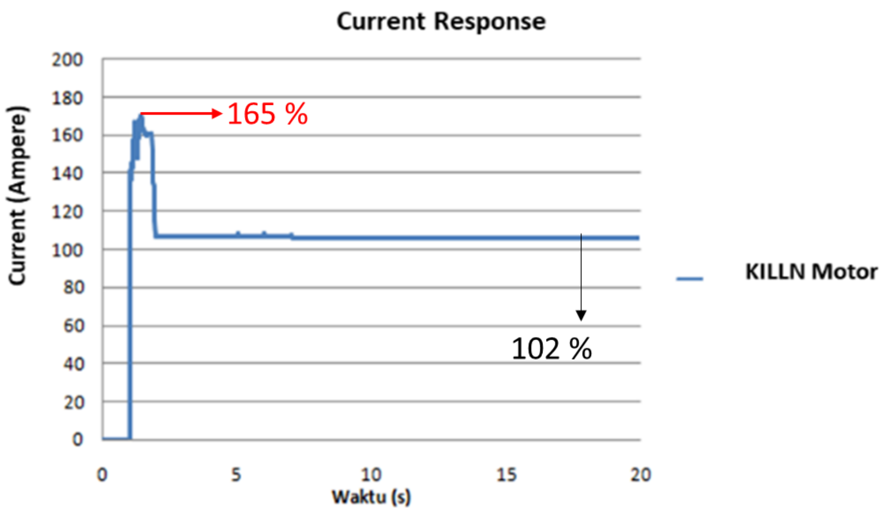


Figure 12 Current Response with Liquid Starter method

Based on table 4, you can see the bus voltage before the motor starting, the bus voltage during the starting process, and the bus voltage after the motor starting with liquid starter method. Figures 11 and 12 show the voltage and current response of bus where the voltage response has been seen. Figure 11 is the voltage response of the bus MD 1V1-1 where on the bus Killn Mill motor is started at the 1st second to the 4.54th second so that the motor starts for 5.04 seconds. The voltage sag when the Killn Motor is started is 8.32% with minimum voltage during operation in9 90.55% and the steady state voltage is 96.35%. Figure 12 shows that in the 1st second the starting current was 165 after that in the 5.04th second the motor reached normal speed with a current of 102%. We can see that method of liquid starter can reduce sagging when starting operation and the current is not higher 6 times than direct online method. The simulation results using the liquid starter method show a significant impact where voltage sags can be overcome. The nominal voltage at starting is 90.55 which is almost 4 times different compared to the direct online method. whereas if we compare it in terms of starting current, using the liquid starter method the increase in current only reaches 1.3 times compared to the nominal current, whereas if we compare the starting current with the direct online method the comparison increase is up to 5-6 times with the liquid starter method

4. Conclusion

After modeling the motor by statically and dynamically modeling the motor starting using a liquid starter type at the PT Solusi Bangun Indonesia TQ 1 System, the results of the simulation and analysis can be drawn as follows Using a starting method in the form of a liquid starter will smooth out the voltage drop on the motor bus so that it is still within safe limits. This research shows the impact of mitigation due to motor starting events seen from the voltage side and also the current side. Apart from this, the starting time required for an induction motor is also relatively fast if the liquid starter method is used**.** Dynamic modeling using the liquid starter method will mitigate the voltage sagging on the motor bus when starting periode also the increase current during starting will not higher than direct online method. as we can see in the simulation results and discussion, using the liquid starter method will reduce the voltage drop by up to 4 times compared to the direct online method. Meanwhile, the occurrence of inrush current or the increase in current that occurs during the motor starting event is 5-6 times different between the liquid starter method and the direct online method.

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