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# An analysis of circuit breaker capacity according to IEC 60909 and IEC 60059 standards at the PT Borneo Alumina Indonesia electrical system

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**Abstract:** At PT Borneo Alumina Indonesia (PT BAI), the D01 Power Distribution System uses circuit breakers (CB) with a current rating capacity of 1250A for both incoming and outgoing 10kV busbars. Replacing outgoing CBs with the same capacity during maintenance leads to unnecessary waste. This study was conducted to examine the appropriate CB capacity as a substitute for the old CBs in the outgoing 10 kV busbars for loads of 10 kV induction motors and transformers so that recommendations can be made to improve efficiency during maintenance on the D01 Power Distribution System. The Electronic Transient Analyzer Program (ETAP) 19.0.1 software was used to perform short circuit simulations based on IEC 60909 and load flow simulations, which were then adjusted to IEC 60059 and CB products from Siemens. The results show that we can replace the current Siemens CB, which has a rated breaking current specification of 31.5kA, with 25kA during the maintenance period. We can also replace the rated peak value of 80kA with 63kA, and the rated current of 1250A with 630A. Replacement of CB specifications does not change/modify the switchgear panel because the replacement CB matches the brand, dimensions, and size of the currently installed CB. These findings would also help increase efficiency during maintenance on the D01 Power Distribution System. The discussion includes limitations and recommendations for future research.

***Keywords:*** *Circuit breaker, ETAP 19.0.1, IEC 60909, IEC 60059, Peak value, Rated breaking current, Rated current, Siemens, Switchgear.*

## 1. Introduction

PT BAI's bauxite processing industry is powered by electricity. Interruptions or power outages can reduce alumina production, making it hard to meet targets and causing financial losses. A reliable electrical system is crucial for alumina production. PT BAI operates a 3x25 Mega Watt (MW) steam power plant for self-use and supplies power to the alumina and coal gasification plants at 10kV. Within this system, CB ensures equipment safety by managing excess currents and short circuits.

At PT BAI, the D01 Power Distribution System for the alumina plant's medium-voltage network uses a 1250A CB on the incoming bus bar from the main 10 kV power distribution. However, the CB on the outgoing bus bars for 10kV induction motors and transformers also has the same 1250A capacity. If, during future maintenance, the outgoing bus bar CB needs replacement with a similar 1250A capacity CB for induction motors and transformers, it will result in waste. An evaluation is required to select the appropriate CB for these loads, enhancing maintenance efficiency in the D01 Power Distribution System's medium-voltage network at PT BAI. As per Kong and Nian [1] their study explores methods to select CB and fault current limiter (FCL) capacities for a reliable and cost-effective configuration in a mesh-type DC microgrid. They optimize CB breaking time, CB nominal breaking current, and FCL inductance. They use the Non-dominated Sorting Genetic Algorithm II (NSGA-II) to quickly configure CB and FCL

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capacities. The case study on a six-terminal DC microgrid confirms the method's accuracy in determining post-fault line currents and making cost-effective CB and FCL capacity choices.

In Gugale and Palazzo [2] the research aimed to accurately calculate short-circuit current disturbances for sizing generator circuit breakers (GCBs), using standards IEC 60909, IEEE C37.010, and IEC/IEEE 62271-37-013. Two key factors were computed: generator source short-circuit current and out-of-phase current disturbances. The ATP-EMTP software was used for simulations, concluding that the IEC/IEEE 62271-37-013 standard is recommended for precise GCB design and selection.

In Khattijit, et al. [3] the research evaluated and analyzed short-circuit faults in renewable energy-based (solar) electrical distribution networks. It used IEC 60909 calculations and IEEE 242 design standards for relay protection. ETAP software simulates short-circuit faults for optimal network design and reliable protection using relay systems. The findings highlighted that increased power from renewables could lead to higher short-circuit currents. Closed-loop configurations were more prone to faults than open-loop ones. The design should ensure power elements (Switchgear and CBs) can handle short-circuits under all conditions. Relay protection settings must be coordinated to safeguard the network effectively, activating backup protection if primary relays fail.

According to Makani and Daniel Chowdhury [4] their study focused on designing a stable electrical system for the Transnet Pipeline Terminal 2 (TM2) petroleum refinery in Heidelberg. They considered a variety of factors, including load lists, reliable protection, proper cable sizing, and equipment selection in hazardous areas. They used ETAP software for power flow studies, short-circuit analysis, and motor starting simulations. The study resulted in a well-designed electrical system that accounted for normal, emergency, and vital loads, ensured protection and efficiency, and included capacitor banks to improve power factor. In Pramudya, et al. [5] a study focused on modeling methods for selecting the right high-voltage AC circuit breaker capacity in circuits with varying voltage levels and capacities for commercial purposes. They used the Schwarz Black Box arc model (Schwarz-BB) for modeling and compared its performance to real CBs during fault events. The results showed a close match between actual and simulated conditions, indicating an accurate CB model. This modeling can be employed to analyze suitable circuit breaker choices in specific electrical circuits. The research aimed to determine the appropriate capacity of CBs by using IEC 60909 and aligning it with IEC 60059 standards and Siemens CB products. This would improve maintenance efficiency at PT BAI.

## 2. Theoretical Basis

### *2.1. Short-Circuit Simulation with ETAP*

As per Prabhu, et al. [6] calculating short-circuit currents is vital for system analysis, given the inevitability of short-circuit incidents in electrical systems. It guarantees that the system's selected electrical equipment can manage the potential maximum short-circuit currents. Short-circuit calculations (SCC) determine both maximum and minimum fault currents. Maximum short-circuit currents help size electrical equipment withstand capacity, especially for Line to Ground (LG) faults used in grounding system design. Minimum short-circuit currents are used to guide instantaneous overcurrent relay settings. ETAP software streamlines short-circuit simulations, significantly reducing calculation time in large electrical systems. ETAP's accuracy relies on precise input data. In ETAP, accurately modeling the electrical system is critical for calculating maximum short-circuit currents. This involves creating the appropriate configuration. For short-circuit calculations, common electrical equipment parameters used in ETAP modeling include:

#### *2.1.1. Grid Input*

Source impedance and network voltage values are necessary for short-circuit current calculations [7]. Network voltage values, three-phase short-circuit apparent power, and the X/R ratio are required for modeling the electrical network using ETAP. This information is extracted from the detailed engineering design documents [8, 9].

### 2.1.2. Transformer Data Input

Operating voltage, apparent power, positive and zero sequence impedances (in %) with X/R ratio, vector group, and grounding system type values are needed for modeling transformers in ETAP.

### 2.1.3. Motor Data Input

To model motors in ETAP, essential input parameters include motor power values, operating voltage values, power factor, efficiency, Locked Rotor Current (LRC), and starting power factor. The motor power value is contingent upon the load connected to the motor. It is recommended to assume LRC to be between 600% to 700%.

### 2.1.4. Busbar Data Input

The nominal busbar voltage stands as a crucial input for short-circuit current calculations. ETAP generates short-circuit currents based on the nominal busbar voltage. In projects adhering to IEC standards, the busbar voltage differs from the transformer secondary voltage. ETAP treats the busbar voltage (connected to the secondary transformer) as equivalent to the transformer secondary voltage. Thus, providing an accurate nominal busbar voltage is imperative.

Short circuit calculations (SCC) can be performed in ETAP by clicking the "Run LG, LL, and LLG 3-phase Faults" icon. ETAP calculates the initial symmetrical RMS current (I"k), steady-state RMS current (Ik), peak short-circuit current (ip), and the angle between current and voltage for 3-phase faults, Line to Ground (LG) faults, Line to Line (LL) faults, and Line to Line to Ground (LLG) faults. ETAP's output report displays the SCC results. To perform maximum short-circuit current calculations, select the specific case study and model the configuration status for maximum fault current, following the detailed engineering design documents [8, 9].

### 2.2. Circuit Breaker (CB)

A CB, as per International Electrotechnical Vocabulary 441-14-20, is a mechanical switch that can close, carry, and interrupt current flow under normal and abnormal conditions, including short-circuit faults. It functions as a switch for electrical networks under load and can open or close in response to current faults (short circuits) in the network or electrical equipment [10]. Continuous Rated Current is the maximum current allowed to flow continuously through a CB. Pick-up current is the minimum current that activates a protection relay, typically ranging from 1.05 to 1.5 times its current settings, according to British Standard [11]. The CB's breaking capacity is defined as its ability to withstand short-circuit fault currents without damaging the breaker or connected electrical equipment. The balanced three-phase short-circuit current, determines its capacity [12].

### 2.3. IEC Standard Current Rating

The standard current values are based on IEC 60059 (IEC Standard Current Ratings) [13]. Electrical system design must apply this standard, which specifies the standard current values for electrical equipment. For any type of equipment, the standard current values should be selected from among the following options Table 1:

**Table 1.**
Standard current ratings.

| **Standard current ratings A** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1,25 | 1,6 | 2 | 2,5 | 3,15 | 4 | 5 | 6,3 | 8 |
| 10 | 12,5 | 16 | 20 | 25 | 31,5 | 40 | 50 | 63 | 80 |
| 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 |
| 1000 | 1250 | 1600 | 2000 | 2500 | 3150 | 4000 | 5000 | 6300 | 8000 |
| 10000 | 12500 | 16000 | 20000 | 25000 | 31500 | 40000 | 50000 | 63000 | 80000 |
| 100000 | 125000 | 160000 | 200000 | - | - | - | - | - | - |

**Source:** International Standard [13].

The choice of values to be used should be considered in each case based on their purpose, and it may be found that there are good reasons to select values such as 1.5 - 3 - 6 - 7.5 rather than choosing 1.6 - 3.15 - 6.3 - 8, and their multiples of $10^n$ (where n is a positive integer) [13].

### *2.4. Power Flow Analysis with ETAP*

In ETAP, all electrical equipment is represented in a single line diagram (SLD). This equipment requires specific input values for power flow calculations. ETAP identifies buses connected to loads as load buses and those connected to power sources as swing buses. Transformers, generators, and bus switchgear operate within their rated capacity. Parameters such as voltage, current, and power should not exceed the rated capacity. Power flow analysis helps determine the ratings of transformers, generators, and busbar switchgear [6].

## 3. Research Methodology

### *3.1. Research Location*

The research was conducted at PT Borneo Alumina Indonesia, located at Jl. Poros Bukit Batu, RT. 009/RW. 003, Dusun. Kembang Lada, Desa Bukit Batu, Kec. Sungai Kunyit, Mempawah district, West Kalimantan, Indonesia, 78971.

### *3.2. Tools*

A laptop was used for writing scientific papers and running ETAP 19.0.1 simulations. ETAP 19.0.1 software was used to create circuit simulations according to the single line diagram.

### *3.3. Research Materials*

Detailed engineering design documents obtained from PT BAI were used as references for simulations in modelling the system with ETAP 19.0.1.

### *3.4. Research Variables*

In this study, the 10kV induction motor and transformer loads at the D01 Power Distribution System's incoming 10kV busbar were looked at, along with the CB capacity, both when the system is working normally and when there is a fault.

### *3.5. Research Plan*

#### *3.5.1. Literature Review*

This research will start by gathering as many references as possible from books, journals, previous studies, and literature reviews. These references will serve as guidelines to support the theoretical framework used to address the research problem.

#### *3.5.2. Data Collection*

In this study, we will collect data by getting a single line diagram of the 10 kV medium-voltage D01 Power Distribution System, three-phase short-circuit current data for the 10 kV main bus, data on the capacity and reactance of the power transformer, data on the length and impedance of the cables, and data on the installed capacity.

#### *3.5.3. ETAP 19.0.1 System Modelling*

Using ETAP 19.0.1 and the data available from PT BAI, we will simulate the SLD of the electrical system based on the IEC 60909 standard.

#### *3.5.4. Analysis of ETAP Simulation Results*

The results of the ETAP simulation will be analysed in accordance with IEC 60059 standards and Siemens circuit breaker products.

### *3.6. Research Procedure*

The following flowchart illustrates the research procedure:

Figure 1 illustrates the research flowchart.

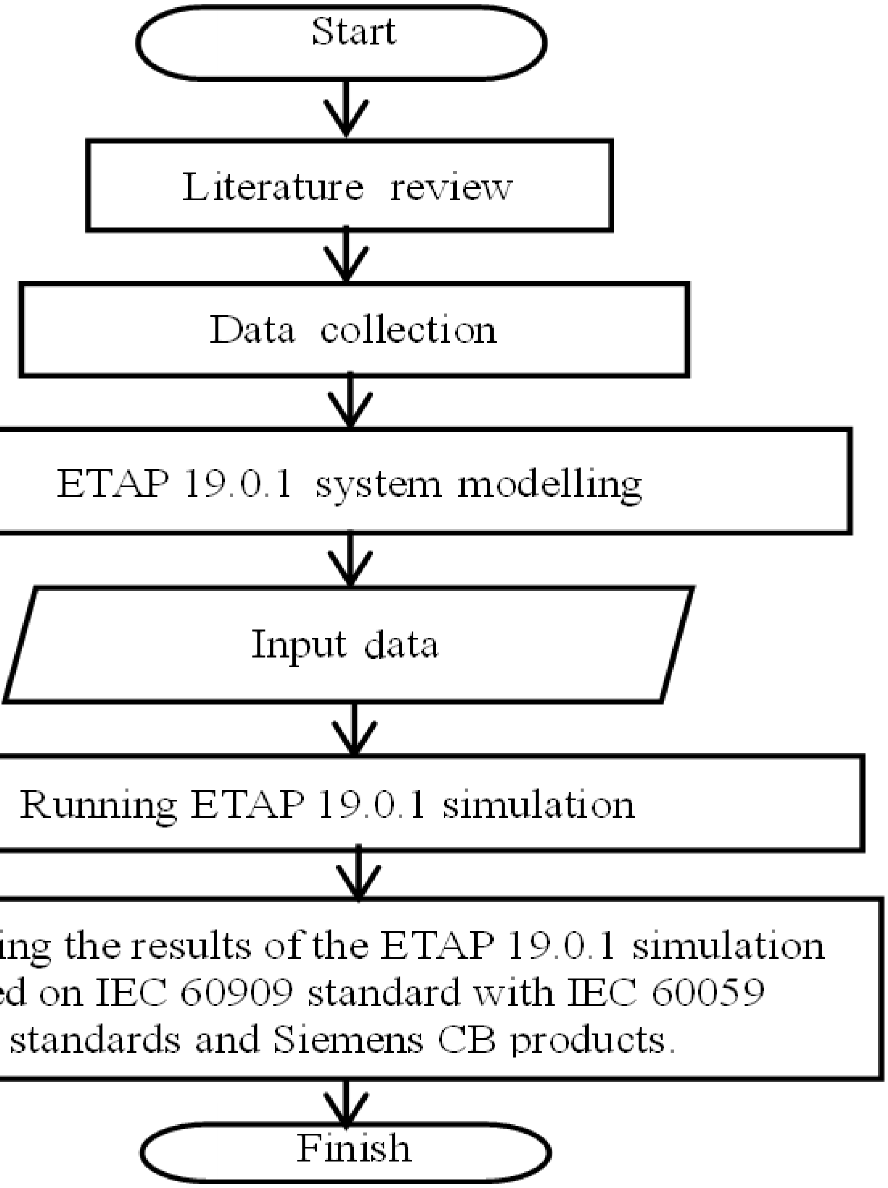

**Figure 1.**
Research flowchart.

According to the research flowchart:

1. Begin with a literature review.
2. Collect the necessary data.
3. ETAP 19.0.1 allows you to design and input data into the SLD.
4. To obtain results, perform simulations with ETAP 19.0.1.
5. Analyzing ETAP 19.0.1 simulation results based on IEC 60909, IEC 60059, and Siemens CB products.

## 4. Results and Discussion

### *4.1. System Data*

The collected data consists of component information within the SLD D01 based on the documents "Single Line Diagram Power Distribution System of Alumina Plant (D01 Power Distribution System)," "Electrical Calculation Report," and "Solitary Network System Steady-state & Transient Calculation and Analysis Report (Part I: Steady-state Analysis Report)" [8, 9, 14].

The single-line diagram of the system is shown in Figure 2.

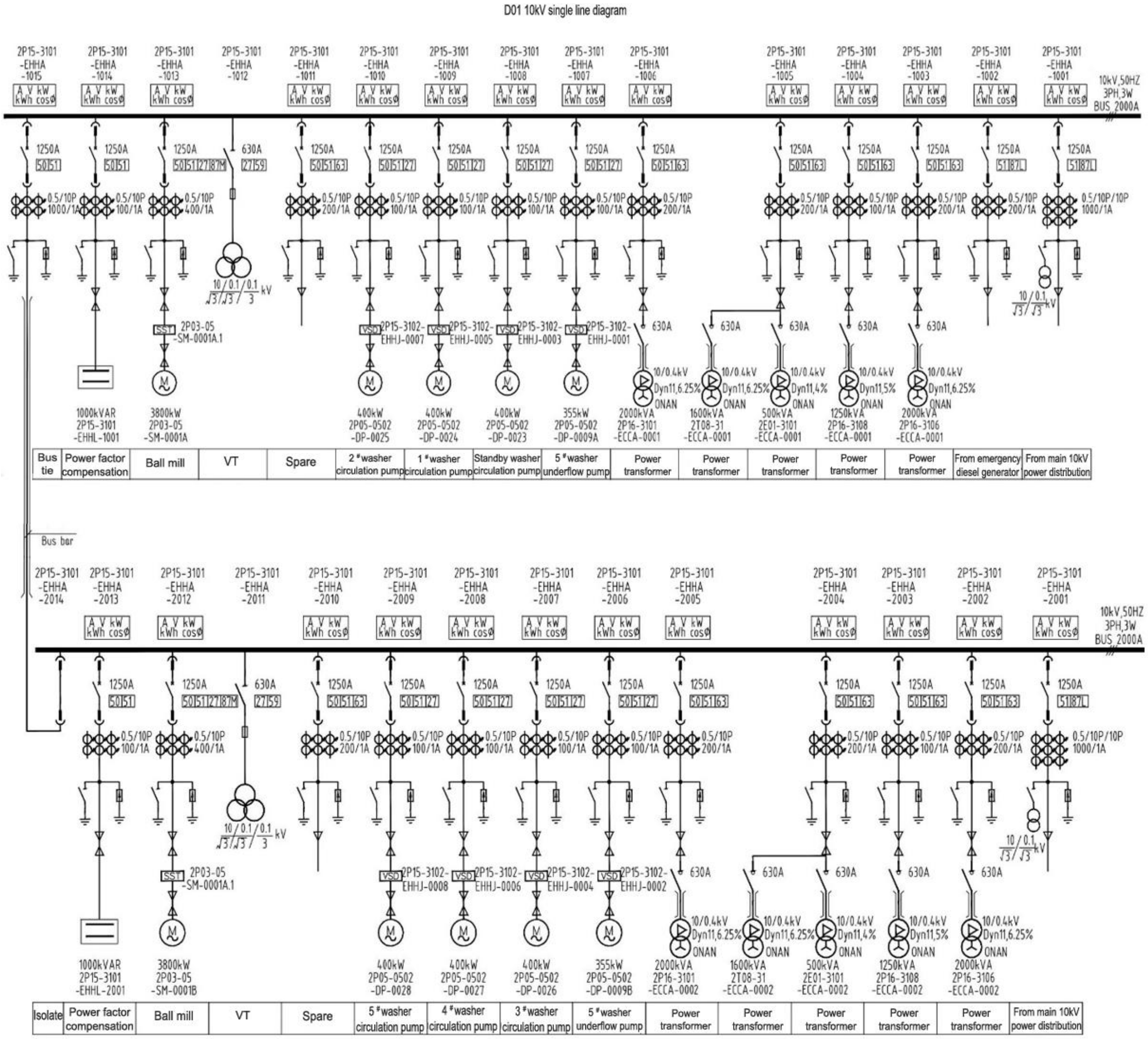

**Figure 2.**
Single line diagram of D01.
**Source:** Chao [9].

As for the system data, it can be observed in Table 2 to Table 3:

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**Table 2.**
Current limiting reactor as follows.

| No | ID CLR | Rated current | Z | X/R | Phase | Rated voltage |
|---|---|---|---|---|---|---|
| 1 | D01 CLR A | 800A | 0.577Ω | 61 | 3 | 10kV |
| 2 | D01 CLR B | 800A | 0.577Ω | 61 | 3 | 10kV |

**Note:** X = Reactance; R = Resistance; Z = Impedance.
**Source:** Xun and Wanya [8].

**Table 3.**
Motor induction.

| No | ID motor | V | Rated | FLA | PF (%) | EFF (%) |
|---|---|---|---|---|---|---|
| 1 | 2#WCP | 10kV | 400kW | 31A | 80 | 93 |
| 2 | 1#WCP | 10kV | 400kW | 31A | 80 | 93 |
| 3 | Standby WCP | 10kV | 400kW | 28.9A | 80 | 100 |
| 4 | 5#WUP A | 10kV | 355kW | 27.5A | 80 | 93 |
| 5 | 5#WCP | 10kV | 400kW | 31A | 80 | 93 |
| 6 | 4#WCP | 10kV | 400kW | 31A | 80 | 93 |
| 7 | 3#WCP | 10kV | 400kW | 31A | 80 | 93 |
| 8 | 5#WUP B | 10kV | 355kW | 27.5A | 80 | 93 |
| 9 | BALL MILL A | 10kV | 3800kW | 277.5A | 85 | 93 |
| 10 | BALL MILL B | 10kV | 3800kW | 277.5A | 85 | 93 |

**Note:** FLA = Full load ampere; PF = Power factor; EFF = Efficiency; WCP = Washer circulation pump; WUP = Washer underflow pump.
**Source:** Xun and Wanya [8].

The weight coefficient of the lumped load is considered to be 80% for the motor load and 20% for the static load Jian, et al. [14].

Table 4 Presents system data of lumped load.

**Table 4.**
Lumped load.

| ID Lumped load | Rated kVA | Rated kVA | PF (%) | Motor load (%) | Static load (%) |
|---|---|---|---|---|---|
| D01-2E01-3101-01 | 250 | 0.380 | 80 | 80 | 20 |
| D01-2E01-3101-02 | 250 | 0.380 | 80 | 80 | 20 |
| D01-2P16-3101-01 | 1000 | 0.380 | 80 | 80 | 20 |
| D01-2P16-3101-02 | 1000 | 0.380 | 80 | 80 | 20 |
| D01-2P16-3106-01 | 1000 | 0.380 | 80 | 80 | 20 |
| D01-2P16-3106-02 | 1000 | 0.380 | 80 | 80 | 20 |
| D01-2P16-3108-01 | 625 | 0.380 | 80 | 80 | 20 |
| D01-2P16-3108-02 | 625 | 0.380 | 80 | 80 | 20 |
| D01-2T08-31-01 | 800 | 0.380 | 80 | 80 | 20 |
| D01-2T08-31-02 | 800 | 0.380 | 80 | 80 | 20 |

**Note:** PF = Power factor.
**Source:** Xun and Wanya [8] and Jian, et al. [14].

Table 5 Presents system data of capacitor.

**Table 5.**
Capacitor.

| Capacitor ID | Rated capacity (kvar) | Power factor | Rated current (A) |
|---|---|---|---|
| SVC D01A | 1000 | 0.85 | 57.74 |
| SVC D01B | 1000 | 0.85 | 57.74 |

**Source:** Jian, et al. [14].

Table 6 presents system data of distribution transformer.

**Table 6**.
Distribution transformer.

| Transformer ID | Cap. (kVA) | Group con. | Rated voltage (kV) | | Rated current (A) | | Z (%) |
|---|---|---|---|---|---|---|---|
| | | | Prim | Sec | Prim | Sec | |
| TR.2P16-3101-PT-0001 | 2000 | Dyn11 | 10 | 0.4 | 110 | 2886.8 | 6.25 |
| TR.2T08-31-PT-0001 | 1600 | Dyn11 | 10 | 0.4 | 88 | 2309.4 | 6.25 |
| TR.2E01-3101-PT-0001 | 500 | Dyn11 | 10 | 0.4 | 27.5 | 721.7 | 4 |
| TR.2P16-3108-PT-0001 | 1250 | Dyn11 | 10 | 0.4 | 68.7 | 1804.2 | 5 |
| TR.2P16-3106-PT-0001 | 2000 | Dyn11 | 10 | 0.4 | 110 | 2886.8 | 6.25 |
| TR.2P16-3101-PT-0002 | 2000 | Dyn11 | 10 | 0.4 | 110 | 2886.8 | 6.25 |
| TR.2T08-31-PT-0002 | 1600 | Dyn11 | 10 | 0.4 | 88 | 2309.4 | 6.25 |
| TR.2E01-3101-PT-0002 | 500 | Dyn11 | 10 | 0.4 | 27.5 | 721.7 | 4 |
| TR.2P16-3108-PT-0002 | 1250 | Dyn11 | 10 | 0.4 | 68.7 | 1804.2 | 5 |
| TR.2P16-3106-PT-0002 | 2000 | Dyn11 | 10 | 0.4 | 110 | 2886.8 | 6.25 |

**Note:** Cap. = Capacity; Group con. = Group connection; Prim = Primary; Sec = Secondary; PT = Power transformer.
**Source:** Xun and Wanya [8] and Jian, et al. [14].

Table 7 Presents variable frequency drive (VFD).

**Table 7.**
Variable frequency drive (VFD).

| ID VFD | Rated AC | | | | | | | Output |
|---|---|---|---|---|---|---|---|---|
| | kVA | kV | | FLA | | Input | | |
| | Output | Input | Output | Input | Output | %EFF | %PF | Hz |
| 2P15-3102-MVVFD-0001 | 440 | 10 | 10 | 25.4 | 25.4 | 98 | 82.3 | 50 |
| 2P15-3102-MVVFD-0002 | 442 | 10 | 10 | 25.98 | 25.52 | 98 | 80.5 | 50 |
| 2P15-3102-MVVFD-0003 | 500 | 10 | 10 | 29.44 | 28.87 | 98 | 80.03 | 50 |
| 2P15-3102-MVVFD-0004 | 500 | 10 | 10 | 29.44 | 28.87 | 98 | 80.03 | 50 |
| 2P15-3102-MVVFD-0005 | 536.94 | 10 | 10 | 29.44 | 31 | 98 | 80.03 | 50 |
| 2P15-3102-MVVFD-0006 | 500 | 10 | 10 | 29.44 | 28.87 | 98 | 80.03 | 50 |
| 2P15-3102-MVVFD-0007 | 500 | 10 | 10 | 29.44 | 28.87 | 98 | 80.03 | 50 |
| 2P15-3102-MVVFD-0008 | 500 | 10 | 10 | 29.44 | 28.87 | 98 | 80.03 | 50 |

**Note:** FLA = Full load ampere; PF = Power factor; eff = Efficiency; MVVFD= Medium voltage variable frequency device.
**Source:** Xun and Wanya [8] and Jian, et al. [14].

Table 8 Presents system data of cable.

**Table 8.**
Cable.

| ID | Type | kV | Cond. /Phase | Cond./ Cable | Size (mm²) | Length (m) | Insulation type |
|---|---|---|---|---|---|---|---|
| Cable81 | CU | 10 | 1 | 3/C | 95 | 100.0 | CLP 90°C |
| Cable82 | CU | 10 | 1 | 3/C | 95 | 100.0 | CLP 90°C |
| Cable83 | CU | 10 | 1 | 3/C | 95 | 100.0 | CLP 90°C |
| Cable84 | CU | 10 | 1 | 3/C | 95 | 100.0 | CLP 90°C |
| Cable85 | CU | 10 | 1 | 3/C | 95 | 100.0 | CLP 90°C |
| Cable91 | CU | 10 | 1 | 3/C | 95 | 100.0 | CLP 90°C |
| Cable92 | CU | 10 | 1 | 3/C | 95 | 100.0 | CLP 90°C |
| Cable93 | CU | 10 | 1 | 3/C | 95 | 100.0 | CLP 90°C |
| Cable94 | CU | 10 | 1 | 3/C | 120 | 100.0 | CLP 90°C |
| Cable95 | CU | 10 | 1 | 3/C | 95 | 100.0 | CLP 90°C |
| Cable97 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |

| ID | Type | kV | Cond. /Phase | Cond./ Cable | Size ($mm^2$) | Length (m) | Insulation type |
|---|---|---|---|---|---|---|---|
| Cable98 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |
| Cable99 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |
| Cable100 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |
| Cable101 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |
| Cable102 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |
| Cable103 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |
| Cable109 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |
| Cable110 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |
| Cable111 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |
| Cable112 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |
| Cable113 | CU | 10 | 1 | 3/C | 95 | 50.0 | CLP 90°C |

**Note** CLP = Cross-linked polyethylene.
**Source:** Xun and Wanya [8].

### *4.2. Modeling Single Line Diagram (SLD) D01 in ETAP*

Modeling SLD D01 using the ETAP 19.0.1 by inputting collected data. Based on the Electrical Calculation Report [8] short-circuit current data ($I''_k$) for the 10kV main bus was obtained at 38.647kA with a voltage rating of 10kV. Therefore, by utilizing Equation 1 [15] the following results were obtained:

$$S = \sqrt{3}.V.I \quad (1)$$

$$S_{sc} = \sqrt{3}.V.I_k^{''}$$

$$S_{sc} = \sqrt{3}.10kV.38{,}647kA = 669{,}39MVA_{sc}$$

The result, Power Grid 1 (U1) and Power Grid 2 (U2) has a value of 669.39 $MVA_{sc}$. Therefore, the modeling of the SLD D01 is illustrated in Figure 3.

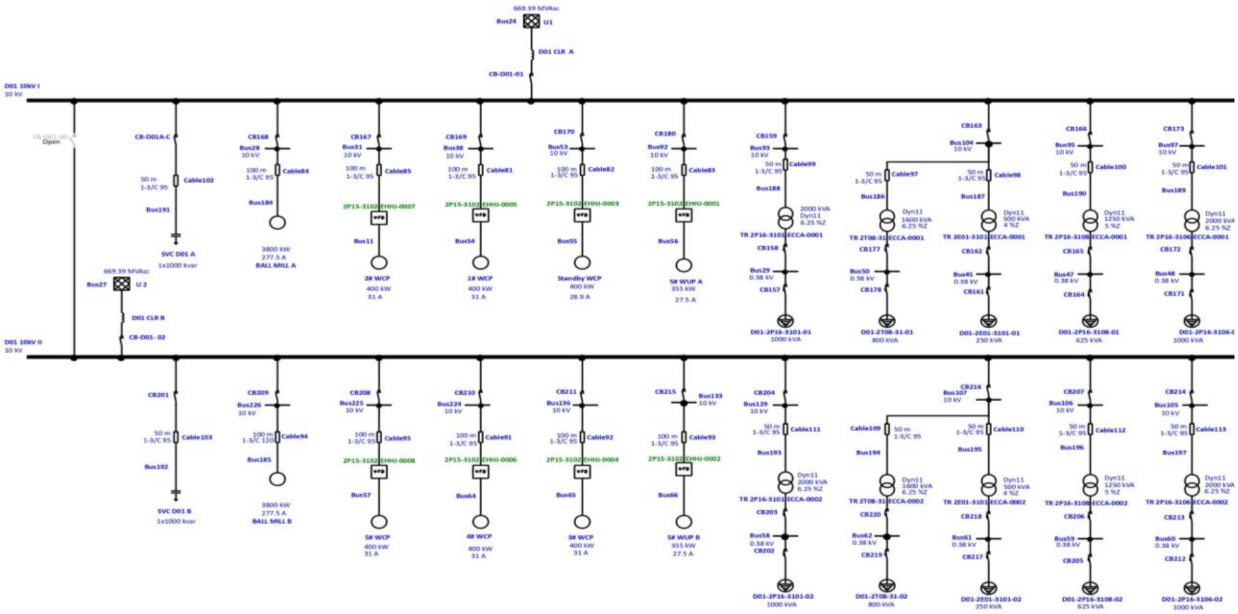

**Figure 3.**
D01 single line diagram modeling on ETAP.

### *4.3. Short-Circuit Simulation in ETAP*

After the completion of creating the SLD D01 in ETAP, the next step is to perform a short-circuit simulation within the ETAP 19.0.1 software, following the steps below:

a. Display the SLD D01.
b. Click on the "Short-Circuit Analysis Mode".
c. Click on "Run 3-Phase Device Duty" (IEC 60909).
d. ETAP will display the results of the short-circuit simulation as shown in Figure 4.

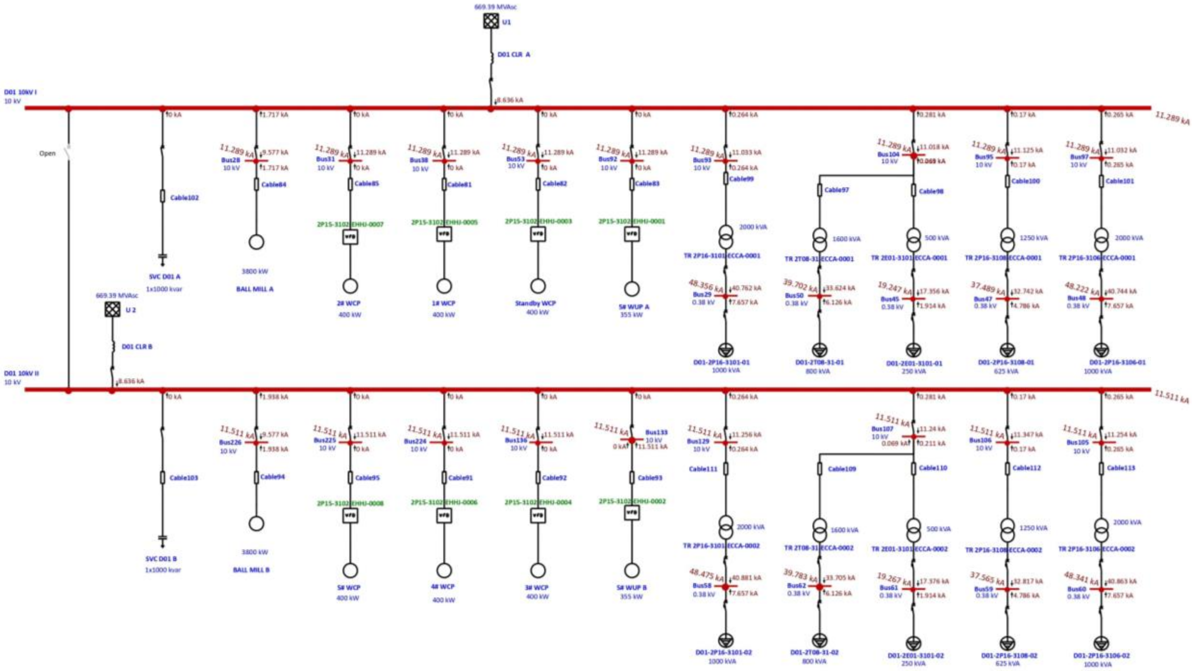

**Figure 4.**
Short-circuit simulation results in ETAP 19.0.1.

The results of the short-circuit simulation can also be found in Table 9 of The Short Circuit Summary.

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**Table 9.**
Short circuit summary report in ETAP 19.0.1.

| Bus | | Device | | Device capacity (kA) | | | | Short-circuit current (kA) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Making | | | | | | | | | |
| ID | kV | ID | Type | Peak | Ib Sym | Ib asym | Idc | I”k | ip | Ib sym | Ib asym | Idc | Ik |
| Bus28 | 10.000 | Bus28 | Bus | - | - | - | - | 11.289 | 27.365 | - | - | - | 8.636 |
| Bus29 | 0.380 | Bus29 | Bus | - | - | - | - | 48.356 | 98.650 | - | - | - | 39.207 |
| Bus31 | 10.000 | Bus31 | Bus | - | - | - | - | 11.289 | 27.365 | - | - | - | 8.636 |
| Bus38 | 10.000 | Bus38 | Bus | - | - | - | - | 11.289 | 27.365 | - | - | - | 8.636 |
| Bus45 | 0.380 | Bus45 | Bus | - | - | - | - | 19.247 | 32.209 | - | - | - | 17.093 |
| Bus47 | 0.380 | Bus47 | Bus | - | - | - | - | 37.489 | 76.420 | - | - | - | 31.704 |
| Bus48 | 0.380 | Bus48 | Bus | - | - | - | - | 48.222 | 107.666 | - | - | - | 39.155 |
| Bus50 | 0.380 | Bus50 | Bus | - | - | - | - | 39.702 | 80.748 | - | - | - | 32.544 |
| Bus53 | 10.000 | Bus53 | Bus | - | - | - | - | 11.289 | 27.365 | - | - | - | 8.636 |
| Bus58 | 0.380 | Bus58 | Bus | - | - | - | - | 48.475 | 98.868 | - | - | - | 39.207 |
| Bus59 | 0.380 | Bus59 | Bus | - | - | - | - | 37.565 | 76.557 | - | - | - | 31.704 |
| Bus60 | 0.380 | Bus60 | Bus | - | - | - | - | 48.341 | 107.936 | - | - | - | 39.155 |
| Bus61 | 0.380 | Bus61 | Bus | - | - | - | - | 19.267 | 32.234 | - | - | - | 17.093 |
| Bus62 | 0.380 | Bus62 | Bus | - | - | - | - | 39.783 | 80.894 | - | - | - | 32.544 |
| Bus92 | 10.000 | Bus92 | Bus | - | - | - | - | 11.289 | 27.365 | - | - | - | 8.636 |
| Bus93 | 10.000 | Bus93 | Bus | - | - | - | - | 11.289 | 27.365 | - | - | - | 8.636 |
| Bus95 | 10.000 | Bus95 | Bus | - | - | - | - | 11.289 | 27.365 | - | - | - | 8.636 |
| Bus97 | 10.000 | Bus97 | Bus | - | - | - | - | 11.289 | 27.365 | - | - | - | 8.636 |
| Bus104 | 10.000 | Bus104 | Bus | - | - | - | - | 11.289 | 27.365 | - | - | - | 8.636 |
| Bus105 | 10.000 | Bus105 | Bus | - | - | - | - | 11.511 | 27.929 | - | - | - | 8.636 |
| Bus106 | 10.000 | Bus106 | Bus | - | - | - | - | 11.511 | 27.929 | - | - | - | 8.636 |
| Bus107 | 10.000 | Bus107 | Bus | - | - | - | - | 11.511 | 27.929 | - | - | - | 8.636 |
| Bus129 | 10.000 | Bus129 | Bus | - | - | - | - | 11.511 | 27.929 | - | - | - | 8.636 |
| Bus133 | 10.000 | Bus133 | Bus | - | - | - | - | 11.511 | 27.929 | - | - | - | 8.636 |
| Bus136 | 10.000 | Bus136 | Bus | - | - | - | - | 11.511 | 27.929 | - | - | - | 8.636 |
| Bus224 | 10.000 | Bus224 | Bus | - | - | - | - | 11.511 | 27.929 | - | - | - | 8.636 |
| Bus225 | 10.000 | Bus225 | Bus | - | - | - | - | 11.511 | 27.929 | - | - | - | 8.636 |
| Bus226 | 10.000 | Bus226 | Bus | - | - | - | - | 11.511 | 27.929 | - | - | - | 8.636 |
| D01 10kV I | 10.000 | D01 10kV I | Bus | - | - | - | - | 11.289 | 27.365 | - | - | - | 8.636 |
| D01 10kV I | 10.000 | CB-D01-01 | CB | 100.000 | 40.000 | 42.167 | 13.343 | 11.289 | 27.365 | 101.161 | 10.407 | 2.245 | - |
| D01 10kV II | 10.000 | D01 10kV II | Bus | - | - | - | - | 11.511 | 27.929 | - | - | - | 8.636 |
| D01 10kV II | 10.000 | CB-D01-02 | CB | 100.000 | 40.000 | 42.167 | 13.343 | 11.511 | 27.929 | 10.270 | 10.517 | 2.270 | |

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### *4.4. Load Flow Simulation in ETAP*

The steps to perform a load flow simulation in ETAP 19.0.1 are as follows:

a. Display SLD D01.
b. Click on the "load flow analysis mode".
c. Click "Run load flow calculation".
d. ETAP will display the results of the load flow simulation as shown in Figure 5, and Table 10 is the bus loading summary.

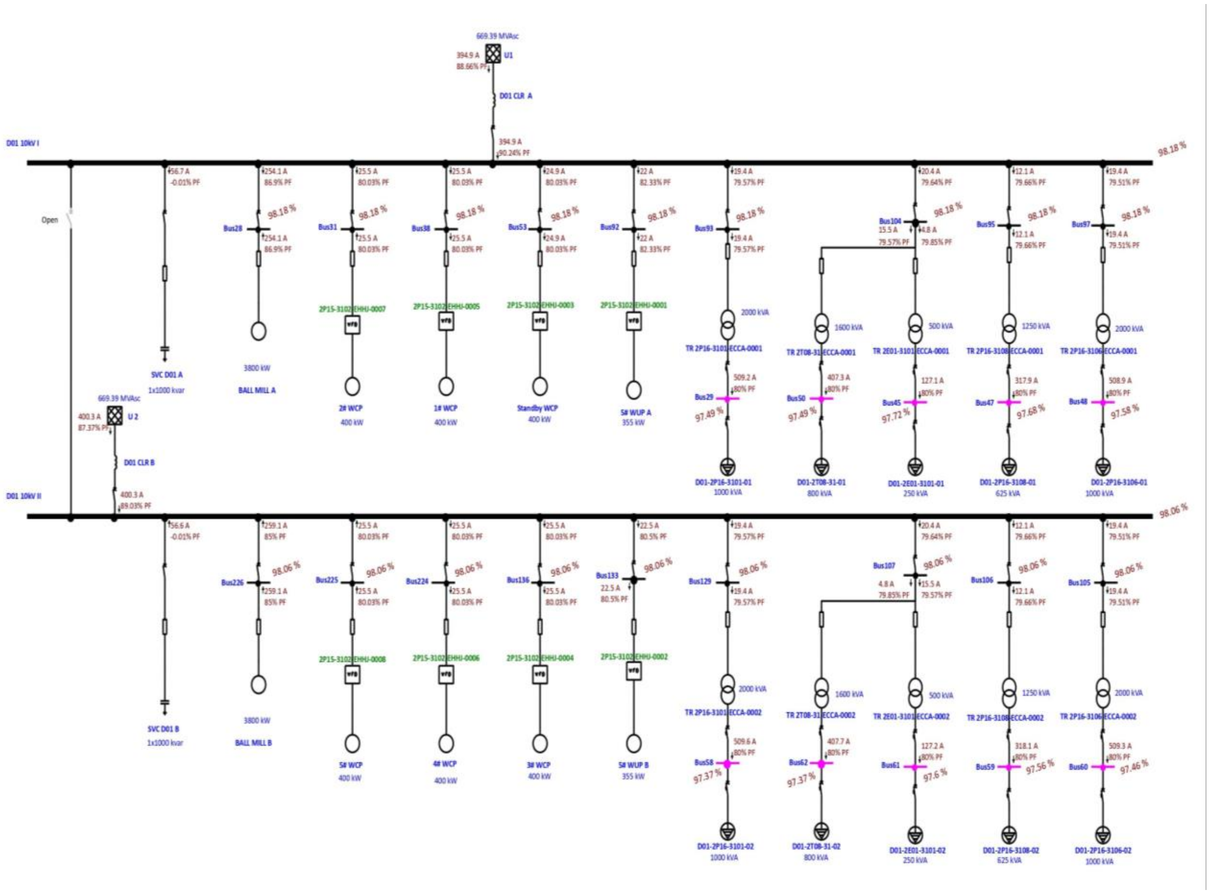

**Figure 5.**
Load flow analysis simulation results in ETAP 19.0.1.

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**Table 10.**
Bus loading summary report in ETAP 19.0.1.

| Bus | | | Directly connected load | | | | | | | | Total bus load | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Constant kVA | | Constant Z | | Constant I | | Generic | | | | |
| **ID** | **kV** | **Rated amp** | **MW** | **Mvar** | **MW** | **Mvar** | **MW** | **Mvar** | **MW** | **Mvar** | **MVA** | **%PF** | **Amp** |
| Bus11 | 10.000 | - | - | - | - | - | - | - | - | - | 0.425 | 80.0 | 24.5 |
| Bus54 | 10.000 | - | - | - | - | - | - | - | - | - | 0.425 | 80.0 | 24.5 |
| Bus55 | 10.000 | - | - | - | - | - | - | - | - | - | 0.415 | 80.0 | 24.0 |
| Bus56 | 10.000 | - | - | - | - | - | - | - | - | - | 0.377 | 80.0 | 21.8 |
| Bus57 | 10.000 | - | - | - | - | - | - | - | - | - | 0.425 | 80.0 | 24.5 |
| Bus64 | 10.000 | - | - | - | - | - | - | - | - | - | 0.425 | 80.0 | 24.5 |
| Bus65 | 10.000 | - | - | - | - | - | - | - | - | - | 0.425 | 80.0 | 24.5 |
| Bus66 | 10.000 | - | - | - | - | - | - | - | - | - | 0.377 | 80.0 | 21.8 |
| Bus24 | 10.000 | - | - | - | - | - | - | - | - | - | 6.842 | 92.1 | 395.0 |
| Bus27 | 10.000 | - | - | - | - | - | - | - | - | - | 6.933 | 87.4 | 400.3 |
| Bus29 | 0.380 | - | 0.211 | 0.158 | 0.050 | 0.038 | - | - | - | - | 0.327 | 80.0 | 508.3 |
| Bus45 | 0.380 | - | 0.053 | 0.040 | 0.013 | 0.010 | - | - | - | - | 0.082 | 80.0 | 126.9 |
| Bus47 | 0.380 | - | 0.132 | 0.099 | 0.032 | 0.024 | - | - | - | - | 0.205 | 80.0 | 317.3 |
| Bus48 | 0.380 | - | 0.211 | 0.158 | 0.051 | 0.038 | - | - | - | - | 0.327 | 80.0 | 508.0 |
| Bus50 | 0.380 | - | 0.169 | 0.127 | 0.040 | 0.030 | - | - | - | - | 0.262 | 80.0 | 406.6 |
| Bus51 | 10.000 | - | - | - | - | - | - | - | - | - | 0.347 | 79.6 | 20.3 |
| Bus58 | 0.380 | - | 0.211 | 0.158 | 0.050 | 0.038 | - | - | - | - | 0.327 | 80.0 | 509.6 |
| Bus59 | 0.380 | - | 0.132 | 0.099 | 0.031 | 0.024 | - | - | - | - | 0.204 | 80.0 | 318.1 |
| Bus60 | 0.380 | - | 0.211 | 0.158 | 0.050 | 0.038 | - | - | - | - | 0.327 | 80.0 | 509.3 |
| Bus61 | 0.380 | - | 0.053 | 0.040 | 0.013 | 0.009 | - | - | - | - | 0.082 | 80.0 | 127.2 |
| Bus62 | 0.380 | - | 0.169 | 0.127 | 0.040 | 0.030 | - | - | - | - | 0.261 | 80.0 | 407.7 |
| Bus63 | 10.000 | - | - | - | - | - | - | - | - | - | 0.346 | 79.6 | 20.4 |
| Bus184 | 10.000 | - | 3.984 | 1.648 | - | - | - | - | - | - | 4.312 | 92.4 | 253.1 |
| Bus185 | 10.000 | - | 3.737 | 2.316 | - | - | - | - | - | - | 4.396 | 85.0 | 259.1 |
| Bus186 | 10.500 | - | - | - | - | - | - | - | - | - | 0.264 | 79.6 | 15.5 |
| Bus187 | 10.500 | - | - | - | - | - | - | - | - | - | 0.082 | 79.8 | 4.8 |
| Bus188 | 10.000 | - | - | - | - | - | - | - | - | - | 0.330 | 79.6 | 19.4 |
| Bus189 | 10.000 | - | - | - | - | - | - | - | - | - | 0.330 | 79.5 | 19.4 |
| Bus190 | 10.500 | - | - | - | - | - | - | - | - | - | 0.206 | 79.7 | 12.1 |

| Bus | | | Directly connected load | | | | | | | | Total bus load | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Constant kVA | | Constant Z | | Constant I | | Generic | | | | |
| ID | kV | Rated amp | MW | Mvar | MW | Mvar | MW | Mvar | MW | Mvar | MVA | %PF | Amp |
| Bus191 | 10.000 | - | - | - | - | -0.970 | - | - | - | - | 0.970 | - | 56.9 |
| Bus192 | 10.000 | - | - | - | - | -0.962 | - | - | - | - | 0.962 | - | 56.6 |
| Bus193 | 10.500 | - | - | - | - | - | - | - | - | - | 0.330 | 79.6 | 19.4 |
| Bus194 | 10.500 | - | - | - | - | - | - | - | - | - | 0.264 | 79.6 | 15.5 |
| Bus195 | 10.500 | - | - | - | - | - | - | - | - | - | 0.082 | 79.8 | 4.8 |
| Bus196 | 10.500 | - | - | - | - | - | - | - | - | - | 0.206 | 79.7 | 12.1 |
| Bus197 | 10.500 | - | - | - | - | - | - | - | - | - | 0.330 | 79.5 | 19.4 |
| D01 10kV I | 10.000 | - | - | - | - | - | - | - | - | - | 7.141 | 88.2 | 418.7 |
| D01 10kV II | 10.000 | - | - | - | - | - | - | - | - | - | 7.287 | 83.1 | 429.0 |

**Note:** MVA = Mega volt ampere.

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### *4.5. Analysis of the Load Flow Simulation Results in ETAP 19.0.1*

Based on Figure 5 and Table 10, the rating current passing through the CB is as follows:

**Table 11.**
The rating current passing through the CB at the outgoing 10kV Busbar that was analyzed.

| No | ID CB | From ID | To ID | Rated current (A) |
|---|---|---|---|---|
| 1 | CB168 | Bus D01 10kV I | Cable84 | 254.1 |
| 2 | CB167 | | Cable85 | 25.5 |
| 3 | CB169 | | Cable81 | 25.5 |
| 4 | CB170 | | Cable82 | 24.9 |
| 5 | CB180 | | Cable83 | 22 |
| 6 | CB159 | | Cable99 | 19.4 |
| 7 | CB163 | | Bus51 | 20.4 |
| 8 | CB166 | | Cable100 | 12.1 |
| 9 | CB173 | | Cable101 | 19.4 |
| 10 | CB209 | Bus D01 10kV II | Cable94 | 259.1 |
| 11 | CB208 | | Cable95 | 25.5 |
| 12 | CB210 | | Cable91 | 25.5 |
| 13 | CB211 | | Cable92 | 25.5 |
| 14 | CB215 | | Cable93 | 22.5 |
| 15 | CB204 | | Cable111 | 19.4 |
| 16 | CB216 | | Bus63 | 20.4 |
| 17 | CB207 | | Cable112 | 12.1 |
| 18 | CB214 | | Cable113 | 19.4 |

According to Table 11, the highest current ratings are CB168 = 254.1A and CB209 = 259.1A.

According to document [16] the voltage rating is 10kV with a normal voltage variation range of ±5%. The maximum normal voltage is 10.5kV (105%), and the minimum normal voltage is 9.5kV (95%). The voltage at Bus D01 10kV I is 9.818kV (98.18%) and the voltage at Bus D01 10kV II is 9.806kV (98.06%), therefore, the voltages at Bus D01 10kV I and Bus D01 10kV II still drop within the normal voltage variation range.

### *4.6. Analysis of ETAP 19.0.1's Short-Circuit Simulation Results*

The CBs that have been evaluated are only on the outgoing 10kV busbar D01 for 10kV induction motors and transformers. For faults on the 380V side, calculations are performed to obtain the short-circuit current values on the 10kV side by multiplying the short-circuit current values at 380V by the transformer ratio. Therefore, based on Figure 3, Figure 4, and Table 9, the CBs that have been analyzed are as shown in Table 12.

**Table 12.**
The CBs analyzed are those located on the outgoing 10kV busbar.

| No. | ID CB | From ID | To ID | Short-circuit current (kA) | | Peak current (kA) |
|---|---|---|---|---|---|---|
| | | | | Fault on *outgoing* CB | Fault on the 380v side | |
| 1 | CB168 | *Bus* D01 10kV I | *Bus28* | 11.289 | - | 27.365 |
| 2 | CB167 | | *Bus31* | | | |
| 3 | CB169 | | *Bus38* | | | |
| 4 | CB170 | | *Bus53* | | | |
| 5 | CB180 | | *Bus92* | | | |
| 6 | CB159 | | *Bus93* | | | |
| | | *Bus188* | *Bus29* | - | 40.762*0.38/10=1.549 | 98.65*0.38/10=3.749 |
| 7 | CB163 | *Bus* D01 10kV I | *Bus104* | 11.289 | - | 27.365 |
| | | *Bus186* | *Bus50* | - | (33.624*0.38/10) + (17.356*0.38/10) =1.278+0.66=1.938 | (80.748*0.38/10) + (32.209*0.38/10) =3.068+1.224=4.292 |
| | | *Bus187* | *Bus45* | | | |

| No. | ID CB | From ID | To ID | Short-circuit current (kA) | | Peak current (kA) |
|---|---|---|---|---|---|---|
| | | | | Fault on *outgoing* CB | Fault on the 380v side | |
| 8 | CB166 | *Bus* D01 10kV I | *Bus95* | 11.289 | - | 27.365 |
| | | *Bus190* | *Bus47* | - | 32.742*0.38/10=1.244 | 76.42*0.38/10=2.904 |
| 9 | CB173 | *Bus* D01 10kV I | *Bus97* | 11.289 | - | 27.365 |
| | | *Bus189* | *Bus48* | - | 40.744*0.38/10=1.548 | 107.666*0.38/10=4.091 |
| 10 | CB209 | *Bus* D01 10kV II | *Bus226* | 11.511 | - | 27.929 |
| 11 | CB208 | | *Bus225* | | | |
| 12 | CB210 | | *Bus224* | | | |
| 13 | CB211 | | *Bus136* | | | |
| 14 | CB215 | | *Bus133* | | | |
| 15 | CB204 | | *Bus129* | | | |
| | | *Bus193* | *Bus58* | - | 40.881*0.38/10=1.553 | 98.868*0.38/10=3.757 |
| 16 | CB216 | *Bus* D01 10kV II | *Bus107* | 11.511 | - | 27.929 |
| | | *Bus194* | *Bus62* | - | (33.705*0.38/10) + (17.376*0.38/10) =1.281+0.66=1.941 | (80.894*0.38/10) + (32.234*0.38/10) =3,074+1,225=4,299 |
| | | *Bus195* | *Bus61* | | | |
| 17 | CB207 | *Bus* D01 10kV II | *Bus106* | 11.511 | - | 27.929 |
| | | *Bus196* | *Bus59* | - | 32.817*0.38/10=1.247 | 76.557*0.38/10=2.909 |
| 18 | CB214 | *Bus* D01 10kV II | *Bus105* | 11.511 | - | 27.929 |
| | | *Bus197* | *Bus60* | - | 40.863*0.38/10=1.553 | 107.936*0.38/10=4.102 |

**Note:** "*" is the multiplication sign.

In document Agreement on 10kV [17] there is a technical data sheet for the CBs used in the *Power Distribution System of the Alumina Plant (D01 Power Distribution System)*, as shown in Table 13:

**Table 13.**
The technical data sheet of CBs in the D01 power distribution system.

| No. | Specification | Information |
|---|---|---|
| 1 | Type | Vacuum circuit breaker |
| 2 | Model | 3AE8-12kV |
| 3 | Rated voltage (kV) | 10 |
| 4 | Maximum working voltage (kV) | 12 |
| 5 | Rated current (A) | 1250 |
| 6 | Rated frequency (Hz) | 50 |
| 7 | Rated breaking current (kA) | 31.5 |
| 8 | Full capacity breaking times | Not less than 20000 |
| 9 | Peak value (kA) | 80 |
| 10 | Rated short circuit duration (s) | 4 |
| 11 | Rated withstand voltage 1 min power-frequency (kV) | 42 |
| 12 | Rated withstand lightning impulse (kV) | 75 |
| 13 | Opening time (ms) | ≤ 60 |
| 14 | Closing time (ms) | ≤ 75 |
| 15 | Mechanical life | Not less than 20000 |

If the specifications of the CBs in Table 13 are analyzed using IEC 60909, IEC 60059, and Siemens products [18], the results can be seen in Table 14.

**Table 14.**
The selection of circuit breakers based on IEC 60909, IEC 60059, and siemens products.

| No | ID CB | ***Rated breaking current*** | | | ***Rated peak value*** | | | | | ***Rated current*** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Data sheet (kA)** | **ETAP IEC 60909 (kA)** | **IEC 60059 (kA)** | **Siemens (kA)** | **Data sheet (kA)** | **ETAP IEC 60909 (kA)** | **IEC 60059 (kA)** | **Siemens (kA)** | **Data sheet (A)** | **ETAP (A)** | **IEC 60059 (A)** | **Siemens (A)** |
| 1 | CB168 | 31.5 | 11.289 | 12.5 | 25 | 80 | 27.365 | 31.5 | 63 | 1250 | 254.1 | 315 | 630 |
| 2 | CB167 | | | | | | | | | | 25.5 | 31.5 | |
| 3 | CB169 | | | | | | | | | | 25.5 | 31.5 | |
| 4 | CB170 | | | | | | | | | | 24.9 | 25 | |
| 5 | CB180 | | | | | | | | | | 22 | 25 | |
| 6 | CB159 | | | | | | | | | | 19.4 | 20 | |
| | | | 1.549 | 1.6 | | | 3.749 | 4 | | | | | |
| 7 | CB163 | | 11.289 | 12.5 | | | 27.365 | 31.5 | | | 20.4 | 25 | |
| | | | 1.938 | 2 | | | 4.292 | 5 | | | | | |
| 8 | CB166 | | 11.289 | 12.5 | | | 27.365 | 31.5 | | | 12.1 | 12.5 | |
| | | | 1.244 | 1.25 | | | 2.904 | 3.15 | | | | | |
| 9 | CB173 | | 11.289 | 12.5 | | | 27.365 | 31.5 | | | 19.4 | 20 | |
| | | | 1.548 | 1.6 | | | 4.091 | 5 | | | | | |
| 10 | CB209 | | 11.511 | 12.5 | | | 27.929 | 31.5 | | | 259.1 | 315 | |
| 11 | CB208 | | | | | | | | | | 25.5 | 31.5 | |
| 12 | CB210 | | | | | | | | | | 25.5 | 31.5 | |
| 13 | CB211 | | | | | | | | | | 25.5 | 31.5 | |
| 14 | CB215 | | | | | | | | | | 22.5 | 25 | |
| 15 | CB204 | | | | | | | | | | 19.4 | 20 | |
| | | | 1.553 | 1.6 | | | 3.757 | 4 | | | | | |
| 16 | CB216 | | 11.511 | 12.5 | | | 27.929 | 31.5 | | | 20.4 | 25 | |
| | | | 1.941 | 2 | | | 4.299 | 5 | | | | | |
| 17 | CB207 | | 11.511 | 12.5 | | | 27.929 | 31.5 | | | 12.1 | 12.5 | |
| | | | 1.247 | 1.25 | | | 2.909 | 3.15 | | | | | |
| 18 | CB214 | | 11.511 | 12.5 | | | 27.929 | 31.5 | | | 19.4 | 20 | |
| | | | 1.553 | 1.6 | | | 4.102 | 5 | | | | | |

According to Table 14, the appropriate specification selection for Siemens CB products is as follows:

- The rated breaking current of 31.5kA can be replaced with 25kA.
- The rated peak value of 80kA can be replaced with 63kA.
- The rated current of 1250A can be replaced with 630A.

Based on the 3AE8 Vacuum Circuit Breaker [18] the replacement of the CB specifications does not affect D01 Power Distribution System switchgear panel because the recommended specifications of CB match the brand, model, dimensions, and size of the original.

## 5. Conclusion

We can draw the following conclusions from simulations and analyses of the CBs in the D01 Power Distribution System for 10kV induction motor loads and transformers: To improve maintenance efficiency in the medium-voltage network system, the current CBs can be replaced with Siemens Model 3AE8-12kV with these specifications: a rated breaking current of 25 kA, a rated peak value of 63 kA, and a rated current of 630 kA.

## 6. Recommendations

Based on this research, the following recommendations are provided:

- During maintenance periods, PT BAI may consider replacing the CBs in the D01 Power Distribution System for 10kV induction motor loads and transformers with Siemens circuit breakers, Model 3AE8-12kV, which have the following specifications: a rated breaking current of 25kA, a rated peak current of 63kA, and a rated current of 630A.
- The focus of this research is on selecting the appropriate specifications for the CBs on the outgoing busbar of the D01 Power Distribution System. Further research can be undertaken to calculate the economic value of replacing the CBs with the recommended capacity.

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## Transparency:
The authors confirm that the manuscript is an honest, accurate and transparent account of the study that no vital features of the study have been omitted and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

## Competing Interests:
The authors declare that they have no competing interests.

## Authors' Contributions:
All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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