

ARC FLASH ANALYSIS STUDY IN INDUSTRY

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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To my beloved family and friends who keeps on supporting me throughout my
life.

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ABSTRACT

Nowadays, hazard that associated with arc flash incident is increasing every year by year. The increasing of the incident has been brought to our attention. This study proposed so that it can help the industries to eliminate or at least reduce those hazards. Through the analysis of this project, the limitation for the arc flash occurs will be proved through the stimulation of the short circuit calculation and the boundary calculation by using the ETAP software. There are few steps that will be included, which is data collection process, develop single line diagram, arcing short circuit calculations and also flash protection boundary calculations. The workers in industries should take the harm of arc flash as a serious matter and be aware of arc flash. The expected result from this project will be the limitation that will be gain in the end of this project. The limitations of the protective boundary to control the arc flash in industries. The limitations of the protective boundary from the result are also to control the usage of Personal Protective Equipment (PPE). For each distance form a system or work place there will be a certain suitable level of PPE. The result will help to reduce harm and accident that happens in industries. The analysis of this project basically will be based on industrial field, where the data that used to do the analysis will be involving the industry site.

ABSTRAK

Pada masa kini, bahaya berkaitan dengan kejadian 'arc flash' meningkat pada setiap tahun. Peningkatan bagi kejadian tersebut membawa kepada perhatian kami. Dalam kajian ini, dicadangkan bahawa ia boleh membantu industry untuk mengelakkan ataupun mengurangkan bahaya tersebut. Dengan, analisis bagi projek ini had bagi 'arc flash' yang terjadi akan dibuktikan melalui stimulasi dengan litar pintas dan pengiraan batas dengan menggunakan perisian ETAP. Beberapa langkah dimasukkan, iaitu mengumpul data, mengembangkan rajah single line, pencetusan litar pintas, dan juga pengiraan bagi flash perlindungan batas. Para pekerja di industri, sepatutnya mengambil perkara ini sebagai sesuatu yang serius dan juga berhati-hati. Keputusan dari projek ini adalah had yang akan dapat diakhir project ini. Had bagi perlindungan batas daripada keputusan juga mengawal kegunaan 'Personal Protective Equipment'. Bagi setiap jarak dari system ke tempat kerja, adanya peringkat yang sesuai bagi 'Personal Protective Equipment'. Keputusan tersebut akan mengurangkan bahaya dan kemalangan yang berlaku di industri. Analisis, bagi projek ini biasanya berdasarkan industri dimana data yang digunakan untuk analisis berkaitan dengan industri.

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CHAPTER 1

INTRODUCTION

1.1 ARC FLASH

Short circuit current flows across a gap which will create an arc. It does known as arc flash. It can be anything from minor embarrassing sparks to a deadly explosion. An arc flash is a result of a rapid release of energy due to an arcing fault that happen between phase bus bar and another phase bus bar neutral or a ground. During, an arc fault happen the air is the conductor, when conductor is energized accidently causes arc flash.

The air as a conductor during arcing fault can be energized when any tools dropped in the air. At the same time, an accidental contact with electrical system also causes an arc flash. Other factors that causes arc flash hazard are build up of conductive dust and also corrosion and improper work procedures. The result, from an arc flash can causes significant heating and burn injuries to occur.

1.2 PROBLEM STATEMENT

Electrical arcs produce some of the highest temperature known to occur on earth. This is four times the surface temperature of the sun. All known materials are vaporized at this temperature. When materials vaporize they expand in volume. The air blast can spread molten metal to great distance with force. Arc flash hazard that caused by pressure, normally the blast pressure waves have thrown workers across rooms and knocked them off ladders. Clothing can be ignited several feet away. Clothes areas can be burn more severely than exposed skin if clothing melts. Hearing loss from sound

blast is one of the harm caused by arc flash. The sound can have a magnitude as high as 140dB at a distance of 2 feet from the arc. Arc flash causes by dust and impurities, corrosion, condensation, spark discharge, overvoltage across narrow gaps, failure of insulating materials and also improper work procedures. To avoid the arc flash or to reduce harm to the worker from arc flash hazard analysis is done by categories the Personal Protective Equipment (PPE). PPE helps the workers to protect themselves from any accident.

1.3 OBJECTIVES

This project aims to implement an arc flash hazard analysis study on industrial test case scenario by using software. The output of software is to produce the arc fault current. The arc fault current for each bus in the system are used to calculate the value of incident energy, the suitable boundary for workplace and also suitable Personal Protective Equipment (PPE) level that can be use for each distance from the system.

The output from the software will be used to produce a technical report of analysis of arc flash. The analysis of arc flash will be depending on different scenario from the system that used.

1.4 SCOPES OF PROJECT

The scope of project for this study of arc flash hazard analysis is limited to certain limitation. In the case, the limitation of the study is limited to an industrial test case of a scenario based on the industrial. It means that, the calculation of short circuit, flash protective boundary and also Personal Protective Equipment (PPE) level only will be done based on the particular industries data or detailed that collected. Other than that, also produce a technical report of analysis of arc flash based on implementation of arc flash hazard analysis study that based on industrial test case.

1.5 SIGNIFICANT OF STUDY

An arc flash is one of the cause that explosion happens in industries. That explosion which is due to arc flash causes death and injury to workers. At the same time, it causes loss of in production and economically for country. Therefore, this study helps to reduce harm or fatality in industries. Arc flash studies should be used to determine the minimum level of PPE that workers must wear when they are near exposed energized equipment.

CHAPTER 2

ARC FLASH ANALYSIS STUDY IN INDUSTRY

2.1 ARC FLASH

Arc flash or known as arc blast is a type of electrical explosion that results from a low impedance connection to ground or another voltage phase in an electrical system. Normally arc flash occurs when a conductive object gets too close to a high ampere current source. Due to, arc flash burns the arc can heat to temperatures as high as 35000F and vaporized metal which will cause severe skin burns by direct heat exposure by igniting clothing. The impact from arc blast, is the heating of the air and vaporization of metal creates a pressure wave that can damage hearing and also cause memory loss and other injuries. At the same time, the flying metal parts are also a hazard.

2.2 ARC FLASH HAZARD ANALYSIS

An arc flash hazard analysis normally begins with a study of a facility based on methodology of the National Fire Protection Association (NFPA) 70E [1] and also IEE 1854 [2]. However, an arc flash hazard analysis is performed in conjunction with combination of other power system studies [3]. The power system studies that performed for arc flash hazard analysis are load flow, short circuit and also protective device coordination.

The result that gained from arc flash hazard analysis is the labels that used to be placed on equipment. The label will be consisting of information on the flash protection boundary, the distance within which a person must wear personal protective equipment (PPE). The risk category for classification of PPE that the person must wear is

indicating by a number 0 to 4. The protection boundary, must be reasonable to the people those who are not working on the equipment can still perform their functions.

In any case scenario, if the hazard or risk category is above level 4, there should be no approach is possible without deenergization of the equipment. This state is normally called as “danger” or even “extreme danger” on arc flash labels. It is desirable that the risk category be standardized so that all personnel working on a single project, or piece of equipment, that can wear the same gear.

An arc flash hazard level depends on the fault current magnitude and the duration, I^2t . The power flows into the arc resistance is a function of I^2R , where R is the arc resistance. When the function is multiplied by time, it is known as arc duration. Because of, arcs, current, and resistances are in constant variation; this is really a time-varying integral whose units are energy (calories). When this energy is radiated to a person’s skin, they experience an incident energy (in calories per square centimeter), which causes the burn.

There are few factors that can be control the time-current characteristic of the system protective devices, reducing I^2t by reducing t for any given I . The factors are, the minimum current at which a device actuates lower pickup provides arc fault protection for a greater range of fault current. Time delay also is consider as, one of the factor, where shorter time delay reduces time to trip and lowest I^2t . Last but not least, the instantaneous pick up also a factor to control the time-current characteristic. In this case, the operating time is typically the minimum possible for the circuit breaker being used. The lower instantaneous pickup setting will reduces arc flash [4].

2.3 ARC FLASH CALCULATION (IEEE STD 1584-2002)

IEEE STD 1584-2002 contains calculation methods that developed through testing by several sources to determine the boundary distance for unprotected personnel and the incident energy at the working distance for qualified personnel working on energized equipment. The incident energy level can be used to determine the suitable PPE that required for personnel.

The equation that developed in IEEE standard are to assess the arc flash hazard, which is based on fault or bolted current, voltage, clearing time, equipment type, grounding and also working distance. This method can be also used to determine the impact of certain current limiting low voltage fuses as well as certain types of low voltage breakers. It is an improvement over the previous work in that the calculations can be applied over a large range of voltage [5].

2.3.1 Determine Arcing Current

Usually, the system analysis determines the bolted or fault current at various points throughout the electrical system. In order to calculate free air short circuit arcing currents it's necessary to input the circuit parameters for the incident energy. The arcing current normally will be significantly less than the available bolted fault short circuit current. It does happen to be like that, because the arc will provide significant circuit impedance [6]. The equation that used for determining the arcing current from IEEE STD 1584-2002 are as follow:

For application under 1000V

$$\log I_a = K + 0.662 \log I_{bf} + 0.0966V + 0.000526G + 0.5588V(\log I_{bf}) - 0.00304G(\log I_{bf})$$

For applications 1000V and higher

$$\log I_a = 0.00402 + 0.983 \log I_{bf}$$

Convert from \log

$$I_a = 10^{\log I_a}$$

Where,

\log is the \log_{10}

I_a is arcing current (kA)

K is -0.153 for open configuration and -0.097 for box configuration

I_{bf} is the bolted fault current for three phase faults (symmetrical RMS) (kA)

V is the system voltage

G is the gap between conductors, (mm) (see Table 1)

Calculate a second arc current equal to 85% of I_a , so that a second arc duration can be determined [5].

2.3.2 Determine the Incident Energy

The following equations should be used for both values of I_a determined in the first step (2.2.1).

$$\log E_n = K_1 + K_2 + 1.0811 \log I_a + 0.0011G$$

$$E_n = 10^{\log E_n}$$

$$E = C_f E_n \left(\frac{t}{0.2} \right) \left(\frac{610^k}{D^x} \right)$$

For locations where the voltage is over 15kV the Lee method that used is:

$$E = 5.12 \times 10^5 V I_{bf} \left(\frac{t}{D^2} \right)$$

Where,

E_{in} is the incident energy (cal/m²) normalized for time and distance

K_1 is -0.792 for open configurations

is -0.555 for box configurations

K_2 is 0 for ungrounded or high resistance grounded system

is -0.113 for grounded systems

G is the gap between conductors, (mm) (see Table 1)

E is the incident energy (cal/cm²)

C_f is a calculation factor

1.0 for voltages above 1kV

1.5 for voltages at or below 1kV

t is the arcing time (seconds)

D is the distance from the possible arc point to the person (mm)

x is the distance exponent from table 1

I_{bf} is the bolted fault current for three phase faults (symmetrical RMS) (kA)

V is the system voltage

The arcing time t is the clearing time for the source-side protecting device that clears the faults first.

2.3.3 Determine the Flash Boundary

The flash boundary is the distance from an arcing fault where the incident energy is equal to 1.2 cal/cm².

For the IEEE STD 1584-2002 empirically derived model

$$D_B = \left[C_f E_n \left(\frac{t}{0.2} \right) \left(\frac{610^x}{E_B} \right) \right]^{\frac{1}{x}}$$

For the Lee method

$$\sqrt{5.12 \times 10^5 V I_{bf} \left(\frac{t}{E_B} \right)}$$

Where,

D_B is the distance of the boundary from arcing point (mm)

E_n is the incident energy (cal/cm²) normalized for time and distance

C_f is a calculation factor

1.0 for voltage above 1kV

1.5 for voltage at or below 1kV

t is the arcing time (seconds)

E_B is the incident energy in cal/cm² at the boundary distance

x is the distance exponent from table 1

I_{bf} is the bolted fault current for three phase faults (symmetrical RMS) (kA) [5]

Table 2.1: Factors for equipment and voltage classes

System Voltage (kV)	Equipment Type	Typical gap between conductors (mm)	Distance x Factor
0.208-1	Open Air	10-40	2.000
	Switchgear	32	1.473
	MCC and Panels	25	1.641
	Cable	13	2.000
>1-5	Open Air	102	2.000
	Switchgear	13-102	0.973
	Cable	13	2.000
>5-15	Open Air	13-153	2.000
	Switchgear	153	0.973
	Cable	13	2.000

2.4 ISSUES TO CONSIDER WHEN PERFORMING IEEE 1854 ARC FLASH CALCULATION

2.4.1 At what point in the system should arc flash hazard calculations be performed?

There could be multiple calculations performed depending on the particular task being undertaken.

- a) The value that used shall be calculated either at the incoming point to the enclosure.
- b) If the cable terminate immediately into the main device, and are not readily accessible, at the load terminals of an incoming over current protective device, OCPD.
- c) At the load side of OCPDs that are sensibly partitioned/separated from their line side.

2.4.2 Is the Over current Protective Device a fuse

For a certain specific low voltage fuses, and within a specific tested range of bolted fault currents, it is possible to input the fuse type, and also the calculation then automatically takes into account both current limiting effect of the fuse and the actual time of interruption. Thus both of the important parameters for arc flash, the arc current magnitude and arc current duration, are taken into account. This is the most accurate methods for these certain types of low-voltage fuses.

2.4.3 What if the fuse is not one of the specific ones stated?

If the fuse is not one of those specifically state, or when outside the model's tested bolted fault current range, input of the fuse's time/current curve information is required. If the manufacturer shows only the average melt time, add to that time 15% up to 0.003 seconds and 10% above 0.03 seconds to determined total clearing time [6].

2.5 USE OF OTHER EXISTING TECHNOLOGIES FOR REDUCING ARC FLASH.

When arc flash considerations are a significant factor in the selection of electrical distribution equipment, there are certain existing technologies that should be considered.

Zone Selective Interlocking (ZSI) – ZSI deactivates the preset delay on the circuit breaker which is closest to the fault, and then it trips with no intentional delay. The faster tripping reduces the amount of the time that current flows during a fault condition. Thus, zone-selective interlocking reduces the amount of arc flash and stress that the system encounters during fault conditions, resulting in improved personal protection and prolonged equipment life.

Ground Fault Detection – This technology used for reducing arc flash. The technology is known as ground fault detection, where it trips the circuit breaker during the early stages of fault development and prior to “bolted fault” conditions.

Finger-Safe Electrical Components – the use of finger-safe electrical component as much as possible. This can be used to reduce the chance that an arcing fault will occur.

Insulated Bus – When insulated bus for equipment such as motor control centre, switchboards, and also switchgear, this will reduce the chance that an arc fault may occur. However, it will increase the probability that an arc fault will self-extinguish.

2.6 ARC FLASH HAZARD ANALYSIS REQUIREMENT AND APPROACH

The most effective way is to protect workers from both shock and arc flash hazards is to de-energized circuits before performing any work on or near exposed conductors. NFPA 70E stressed this point in its coverage of safety related work practices. In this standard, stated that some tasks must be performed on energized circuits, such as trouble shooting.

Several basic concepts and definitions are keys to understanding hoe arc flash hazards which are measured. Somehow, the information can be used to help protect personnel. Arc flash hazards can be described in terms of energy and where energy is defined as the product of the power and time, such as in the unit kWatt-hours used to described electrical energy usage. An arc flash releases energy in several forms, including light energy and mechanically energy, but current analysis methods focus specifically on the thermal energy hazards workers. The term incident energy is used to describe as the thermal energy to which a worker is exposed in an arc flash incident, and it can be defined as the thermal energy impressed on a surface at some specified distance from the source of an arc flash. Incident energy is a function of several parameters that we can measure or calculated for a power system.

The approach that found in NFPA 70E, may not be applicable to some maintenance tasks, or on power system with available fault current or fault clearing times outside certain limits. Additionally, these simplified methods may yield unacceptably conversation PPE requirement. Another approach is to perform more comprehensive arc flash hazards calculations involving detailed power system parameters. This approach can be accurately quantify arc flash hazards on a wide range of power system, but such an analysis can be very time consuming and costly to perform. [7]

2.7 RISK CATEGORY OF PERSONAL PROTECTIVE DEVICE

Risk Category #0 – Arc Rating (not applicable)

Non-melting flammable materials with a fabric weight of 4.5 oz/yd.

Risk Category #1 – Arc Rating 4 cal/cm²

Fire resistant shirt & FR pants or FR coverall. Regular weight untreated blue jeans are acceptable in law of FR pants.

Risk Category #2 – Arc Rating 8 cal/cm²

Cotton underwear – conventional short sleeve and brief/short plus FR shorts & FR pants.

Risk Category #3 – Arc Rating 25 cal/cm²

Cotton underwear – conventional short sleeve and brief/shorts plus FR shirt & FR pants, plus coverall, or cotton underwear plus two FR coveralls.

Risk Category #4 – Arc Rating 40 cal/cm²

Cotton underwear – conventional short sleeve and brief/shorts, plus FR shirt & FR pants, multilayer flash suit. [1]

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The arc flash hazard analysis can be performed according various standard such IEEE 1584-2002 standard, NFPA 70E-2000, ANSI STD 242-2001 and many more. In this case, IEEE 1584-2002 standard is used has a guide to proceed with method of arc flash hazard analysis. The following are steps that will be used as a guide to proceed with the analysis study.

3.2 STEP 1: COLLECT THE SYSTEM AND INSTALLATION DATA

The largest effort in arc flash hazard study is the collecting the field data. The information that gathered are nominally up-to-date single line diagrams, time-current curves, and also short circuit study on a computer. The data required for the study is similar to data collected for typical load flow analysis, short circuit and protective device coordination studies. The basic data that need are shown in the table 2 below:

Table 3.1: Data required for equipment

Equipment	Required Data
Bus	a) Nominal Voltage (kV) b) Load Diversity Factor
Transformer	a) Rated voltage (kV) b) Size of transformer (kVA)
Cable	a) Length of the cable with unit b) Impedance for the cable R, X, and Y
Static Load	a) Rated voltage (kV) b) Power factor c) Loading Category d) Equipment cable data
Induction Motor	a) Rated power (kW) b) Power factor and efficiencies c) Loading category d) Equipment cable data

3.3 STEP 2: DETERMINED THE SYSTEM MODES OF OPERATION

Normally a site with a simple radial distribution system has only one mode but for more complex system can have modes, example of modes is included.

- a) One or more utility feeders in service
- b) Utility interface substation secondary bus tie breaker open or closed
- c) Unit substation with one or two primary feeders
- d) Unit substation with two transformers with secondary tie opened or closed
- e) MCC with one to two feeders, one or both energized
- f) Generators running in parallel with the utility supply or in standby

It's important to determine the available short circuit current for modes of operation. It provides both maximum and minimum available short-circuit current. In this case, the distribution system that used in this project is a complex system.

3.4 STEP 3: DETERMINED THE BOLTED FAULT CURRENTS

Input all data from the single line diagrams and the data collection into short circuit program. Determine bolted fault current for radial system and X/R ratio at each point of location where people could work by making each of these point of a bus. Before this programmed is run to determine the bolted fault current, make sure that the system is healthy enough. So that, the result for load flow or bolted fault current does not effect by any other problem.

3.5 STEP 4: DETERMINED THE ARC FAULT CURRENT

The arc fault current at the point and the portion of that current passing through the first upstream protective device must be found. Arc fault current depends on the bolted fault current. The bolted fault current in the protective device can be found from the short circuit study by looking at a one bus away run.

3.6 STEP 5: FIND THE PROTECTIVE DEVICE CHARACTERISTICS AND THE DURATION OF THE ARCS

Based on the field survey, time-current curves may have been found. It's best to create it. For a very simple study, it is possible to use protective device characteristics, which can be found in manufacturer's data. The manufacturer's time curves may include both melting and clearing time. So, the clearing time will be used.

3.7 STEP 6: DOCUMENT THE SYSTEM VOLTAGES AND CLASSES OF EQUIPMENT

The document for the system voltage and class of equipment are kept for each bus. It allow application of equations based on standard classes if equipment and bus-to-bus gaps.

3.8 STEP 7: SELECT THE WORKING DISTANCE

The arc flash protection is always based on the incident energy level of the person's face and body at the working distance. The working distance is choosing from the distance from the possible arc point to the person.

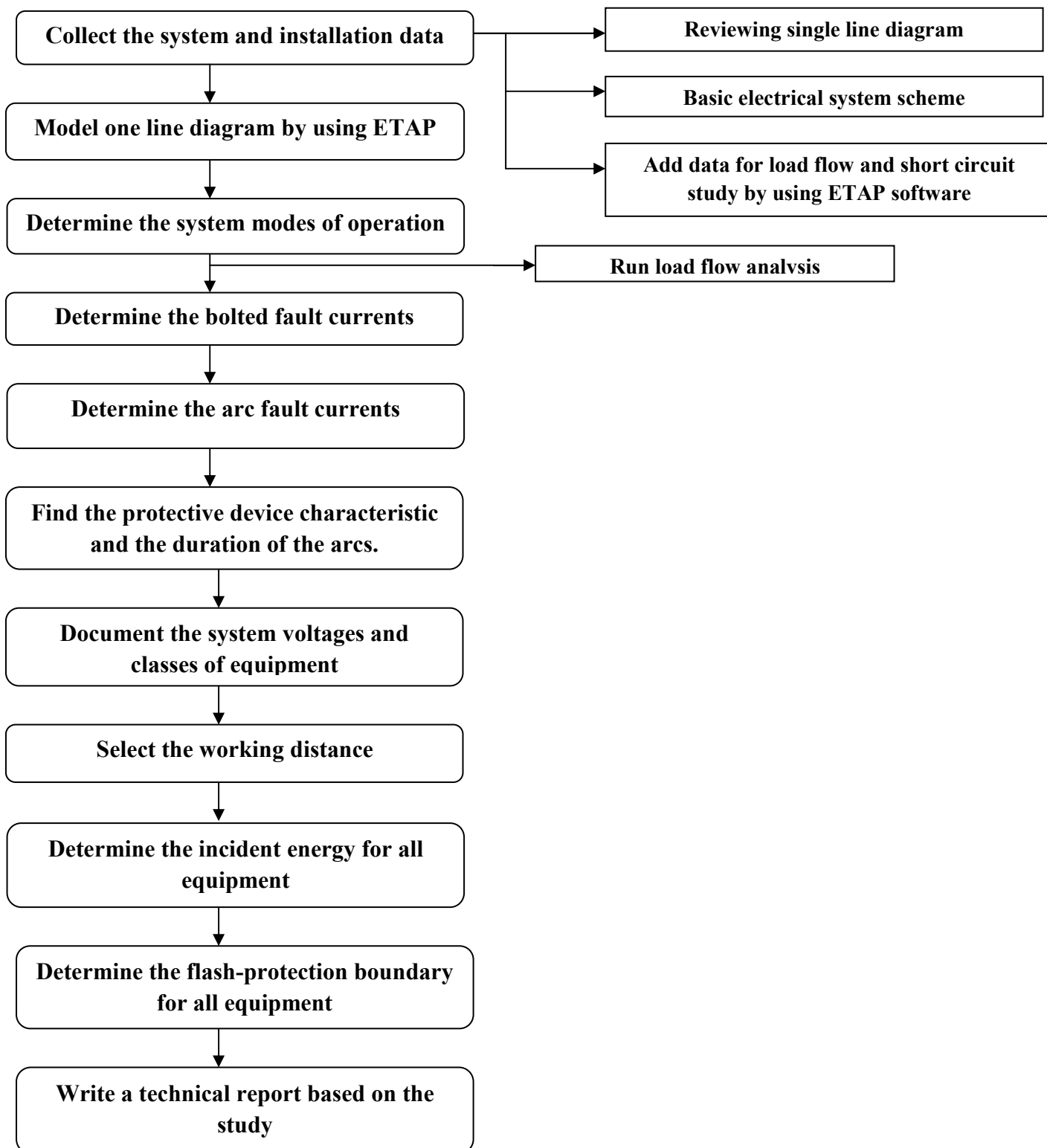
3.9 STEP 8: DETERMINE THE INCIDENT ENERGY FOR ALL EQUIPMENT

A software program for calculating incident energy must be selected. In some programs the problem is solved one bus at a time or hundreds or thousands of buses can be solved simultaneously.

3.10 STEP 9: DETERMINE THE FLASH PROTECTION BOUNDARY FOR ALL EQUIPMENT

To find the flash protection boundary, the equations for the finding incident energy can be solved for the distance from the arc source at which the onset of a second degree burn could occur. The programs include the flash protection boundary based on incident energy of 5.0 J/cm^2 . [2]

Flow Chart of the methodology



CHAPTER 4

RESULTS USING ETAP SOFTWARE

4.1 Collection and Installation Data

For this first step, all the data that required is already collected form industries system. The data that required can be referring at table 2. The installation data was done by using ETAP software. Installing data is considered as modeling the system with correct equipment at required data. After the modeling process, the system should key in with the data that collected for all equipment that used. In this case, there were 47 buses, 26 cables, 25 transformers, 21 static loads and also 3 induction motor.

4.1.1 Utility

Figure 4.1 shows the power grid editor for utility that used in load flow analysis by using ETAP software.

Power Grid Editor - U1

Info | Rating | Harmonic | Reliability | Energy Cost | Remarks | Comment

132 kV Swing

Rated kV: 132

Design Setting

% V	% V	Vangle
100	100	0

Rated kV Bus kVnom

Operating

% V	Vangle	MW	Mvar
0	0	0	0

var Limits

SC Rating

	MVAAsc	X/R	kAsc
3-Phase	0	0	0
1-Phase	0	0	0

SC Imp. (100 MVA base)

	% R	% X
Pos.	0	0
Neg.	0	0
Zero	0	0

< U1 > Undo Find Help OK Cancel

Figure 4.1: Power Grid Editor for utility

Figure 4.2 shows the power grid editor for utility for short circuit analysis.

Power Grid Editor - U1

Info | Rating | Harmonic | Reliability | Energy Cost | Remarks | Comment

132 kV Swing

Design Setting

Rated kV	% V	% V	Vangle
132	1.03	1.03	0
Rated kV	Bus kVnom		

var Limits

Operating

% V	Vangle	MW	Mvar
0	0	0	0

SC Rating

	MVAAsc	X/R	kAsc
3-Phase	20	30	0.09
1-Phase	15	30	0.07

SC Imp. (100 MVA base)

	% R	% X
Pos.	16.6574	499.722
Neg.	16.6574	499.722
Zero	33.3148	999.445

< U1 > Undo Find Help OK Cancel

Figure 4.2: Power Grid Editor for short circuit analysis

The power grid editors that shown in figure 4.1 are used only for load flow analysis, where there are certain data are not inserted. Those data are not necessary for the load flow analysis but will be important for short circuit analysis. The data that needed is already inserted as shown in figure 4.2. The data that used is design setting, Short circuit rating for three phase and single phase and impedance for the utility. Without those data or rating detail about the utility the short circuit analysis program does not run.

4.1.2 Bus

Figure 4.3 shows the bus editor for load flow analysis and short circuit analysis

The screenshot shows the 'Bus Editor - Bus1' dialog box. It features a tabbed interface with the following sections and controls:

- Info Tab:**
 - ID:
 - Nominal. kV:
 - In Service
 - Out of Service
- Initial Voltage:**
 - % V:
 - Angle:
- Operating Voltage:**
 - % V:
 - Angle:
- Connection:**
 - 3 Phase
 - 1 Phase 2W
 - 1 Phase 3W
- Equipment:**
 - FDR Tag:
 - Name:
 - Description:
- Load Diversity Factor:**
 - Min.:
 - Max.:
- Classification:**
 - Zone:
 - Area:

At the bottom, there is a dropdown menu showing 'Bus1', and buttons for '<', '>', 'Undo', 'Find', 'Help', 'OK', and 'Cancel'.

Figure 4.3: Bus editor for load flow and short circuit analysis

The bus editor that shown in figure 4.3 are used to run load flow analysis and short circuit analysis program, where this bus editor is only specified for bus 1. For the bus editor the only data that inserted is the nominal voltage for each bus. The amount of bus that used is 47 buses. Those buses consist of 132kV, 11kV and also 0.433kV as a nominal voltage. The bus that connected at utility, the nominal voltage is 132kV. The bus that connected to static load and induction motor, the nominal voltage is 0.433kV. The rest of load which is connected to primary side of transformer, the nominal voltage is 11kV.

4.1.3 Transformer

Figure 4.4 shows the rating for 2 winding transformer editor which used for both load flow analysis and short circuit analysis.

The screenshot displays the '2-Winding Transformer Editor - T10' window. It features several tabs: Info, Rating, Tap, Harmonic, Reliability, Remarks, and Comment. The 'Rating' tab is selected, showing the following data:

- 1000 kVA (Total Rating)
- 11 0.433 kV (Voltage Levels)
- Primary (Prim.): 11 kV, 1000 kVA, 1000 Max kVA, 52.49 FLA
- Secondary (Sec.): 0.433 kV, 1333 FLA
- Connected Bus: 11 (Nom. kV), 0.433 (Nom. kV)
- Impedance: Positive % Z = 5.75, X/R = 5.79; Zero % Z = 5.75, X/R = 5.79
- Z Variation: @ -5% Tap = 0%, @ +5% Tap = 0%
- Z Tolerance: +0%

At the bottom, there is a dropdown menu showing 'T10', and buttons for '<', '>', 'Undo', 'Find', 'Help', 'OK', and 'Cancel'.

Figure 4.4: Rating for 2 winding transformer editor

The two winding transformer editor that shown in figure 4.4, which are used in load flow analysis and short circuit analysis are rated as shown in the figure. For the rating part, the data that should be inserted is the nominal voltage for the primary and secondary part of the transformer. At the same time, the capacity or the size of transformer are used based on the table that given in appendix. Where else, for the impedance part for the positive and zero sequence value are used as a typical value of X/R and typical value of Z & X/R.

Figure 4.5 shows the tap for 2 winding transformer editor that used for load flow analysis and short circuit analysis.

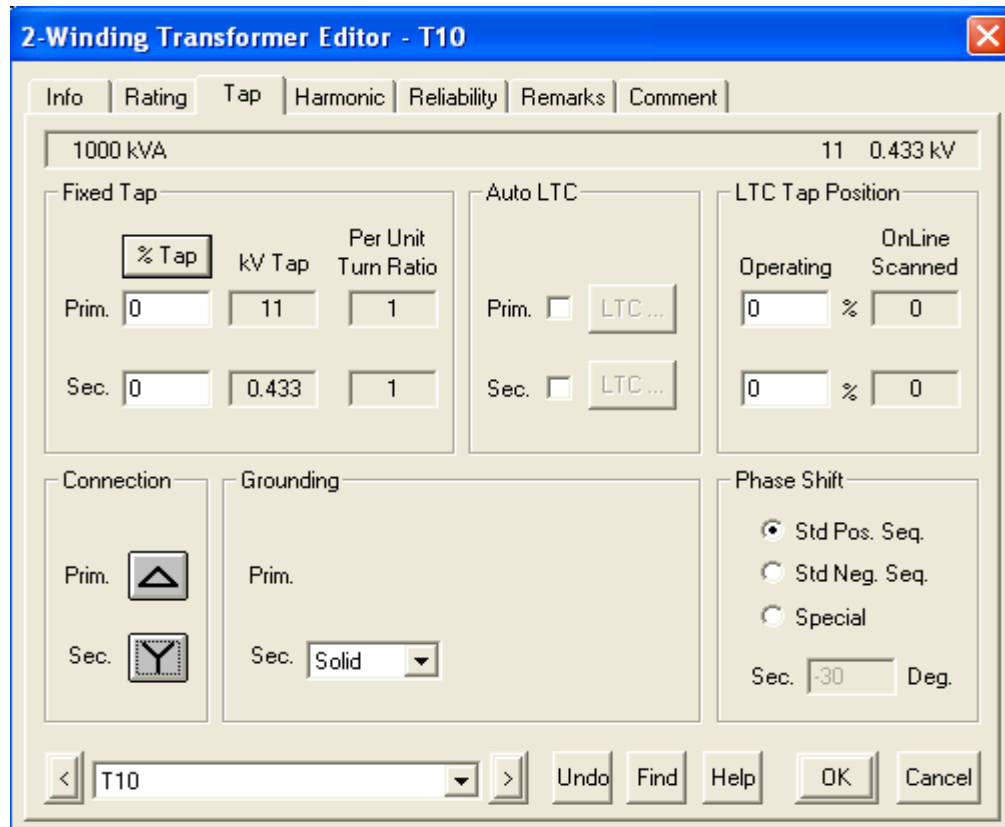


Figure 4.5: Tap for 2 winding transformer editor

For 2 winding transformer the tap that used is a fixed tap. Where, only the voltage for primary side and secondary side are inserted. The grounding and percentage tap is not inserted with any value. It's because, those part are not necessary for load flow analysis and short circuit analysis.

4.1.4 Cable

Figure 4.6 shows cable editor that used for both load flow and short circuit analysis.

Figure 4.6: Info about cable

The figure shows the info that should be used for load flow analysis and short circuit analysis. The info that used is the unit part. Where, the length of the cable should be inserted with the units neither in km nor meter. At the same time, the phase for cable should specify whether the cables used are for three phase or single phase. Before inserted the data, the library should be created to the standard for the cable that used.

Figure 4.7 shows the cable editor for cable impedance that used for load flow analysis and short circuit analysis.

The screenshot shows a software dialog box titled "Cable Editor - Cable10". It features a tabbed interface with the following tabs: Reliability, Remarks, Comment, Info, Impedance (selected), Physical, Routing, Loading, Ampacity, and Sizing. The "Impedance" tab is active, displaying the following settings:

- Impedance (per conductor):**
 - Pos. R: 0.1, X: 0.09, Y: 0
 - Zero R: 1.7, X: 0.4, Y: 0.4762
- Units:**
 - Ohms per 1000 ft
 - Ohms
- Cable Temperature:**
 - Base: 75 °C
 - Min.: 75 °C
 - Max.: 75 °C

At the bottom of the dialog, there is a dropdown menu showing "Cable10", and buttons for "<", ">", "Undo", "Find", "Help", "OK", and "Cancel".

Figure 4.7: Cable impedance

The figure shows the cable impedance for specific cable that used in the system modeling. The impedance for each conductor is consisting of resistance, reactance and admittance. For conductor, positive sequence only resistance and reactance value are inserted for load flow analysis. Whereas, the admittance value in positive sequence only should be inserted for short circuit analysis. For conductor, zero sequence, all the three value, which are resistance, reactance and also admittance are inserted for the both analysis.

4.1.5 Static Load

Figure 4.8 shows the static load editor for the load that used in the system for the load flow analysis and short circuit analysis.

Static Load Editor - Load8

Info Loading Cable/Vd Cable Amp Harmonic Reliability Remarks Comment

1 6.158 kW 751 kvar 0.433 kV Cable Info not available

Ratings

kV kVA kW kvar % PF Amps Grounding

0.433 751 6.158 751 0.82 1001

Calculator...

Loading

	Loading Category	Loading	Load		Feeder Loss	
			kW	kvar	kW	kvar
1	Design	100	6	751	0	0
2	Normal	100	6	751	0	0
3	Winter Load	0	0	0	0	0
4	Summer Load	0	0	0	0	0
5	Backup	0	0	0	0	0
6	FI Ld Rejec	0	0	0	0	0

Operating Load: 0 kW + j 0 kvar

< Load8 > Undo Find Help OK Cancel

Figure 4.8: Loading part for Static load editor

From the figure known that, the nominal voltage is inserted in the kV box. The value of the nominal voltage is depending on the transformer and the bus that connected to the certain static load. It means that, when the secondary transformer's nominal voltage will be the same with the bus that connected to the secondary part of the transformer. At the same time, the bus connected to the static load. Therefore, the voltage rating for the static load is same with the secondary transformer and also the bus, unless if there is any losses happen during the power flow.

Where else, for the capacity (kVA) and percentage of power factor of each static load is already given in the appendix. The power (kW) of the static load will be calculated automatically when the voltage and capacity of the load is inserted.

4.1.6 Motor

Figure 4.9 shows induction motor editor that specific for the nameplate for the induction motor.

Induction Machine Editor - Mtr1

Cable Amp	Reliability	Remarks	Comment
Info	Nameplate	Model	Start Dev
Start Cat	Cable/Vd		
1	1 kW 0.415 kV		Cable Info not available

Ratings

	100 %	75 %	50 %	
kW	1	0.75	0.5	SF 1
kV	0.415			
% PF	81.75	81.75	81.75	
kVA	1.6			Poles 4
FLA	2.21			
% Eff	76.96	76.96	76.96	
Library...	1 kW 0.415 kV MTR			RPM 1500

Loading

	Loading Category	% Loading	Motor Load		Feeder Loss	
			kW	kvar	kW	kvar
1	Design	100	1	1	0	0
2	Normal	90	1	1	0	0
3	Winter Load	0	0	0	0	0
4	Summer Load	0	0	0	0	0
5	Backup	0	0	0	0	0
6	FI Ld Rejec	0	0	0	0	0
7	Emergency	0	0	0	0	0

Operating Load: 0 kW + j 0 kvar

< Mtr1 > Undo Find Help OK Cancel

Figure 4.9: Nameplate for Induction motor editor

Figure 4.8 shows the nameplate for the induction motor that used for the load flow analysis and short circuit analysis. In this case, the rating for the power (kW) and voltage are inserted according the given data in the appendix. For the speed of the induction motor is chosen from the library. Click the library which was located at below the capacity (kVA) of the induction motor. From the library, the speed and poles for the induction motor can be chosen.

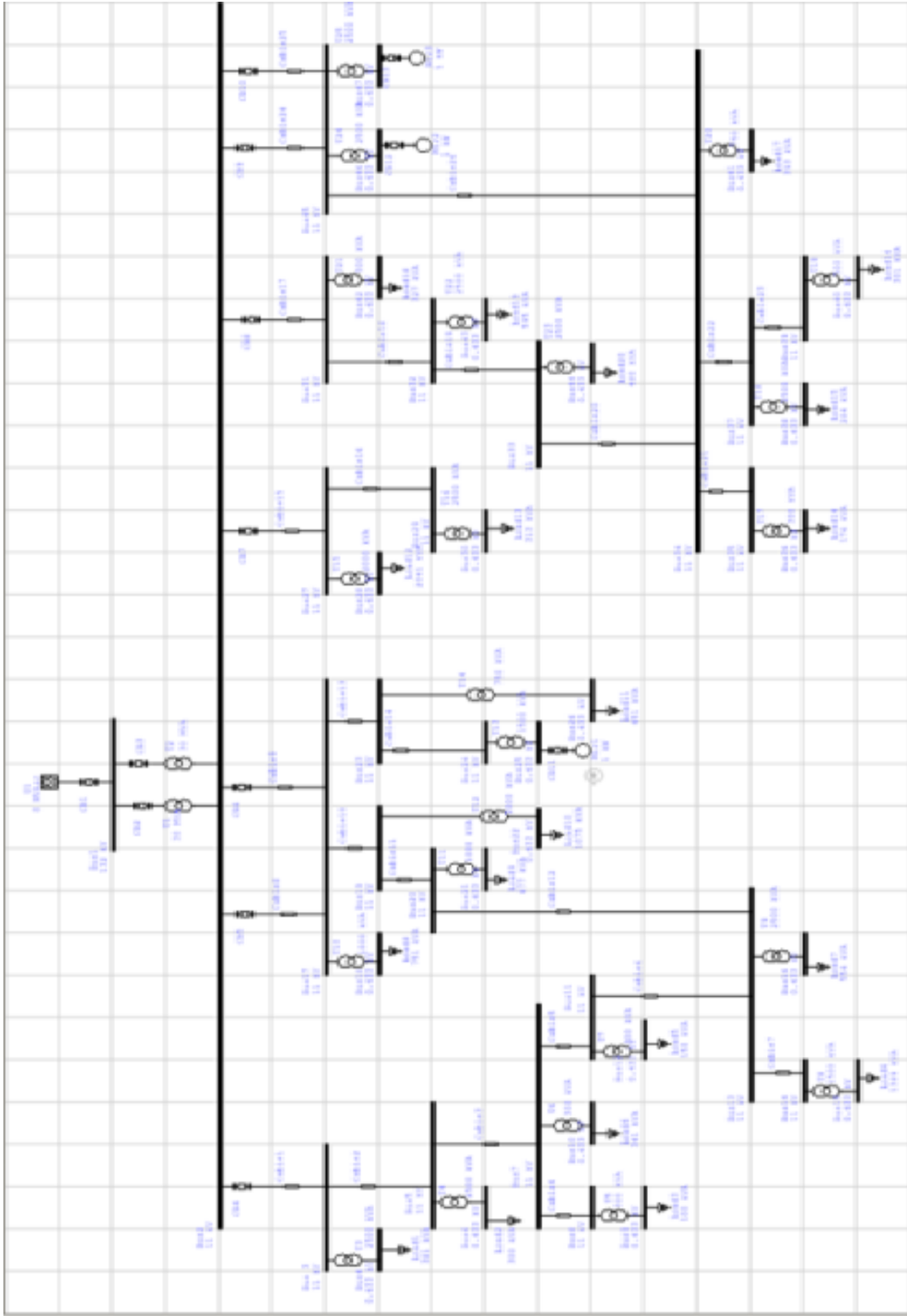


Figure 4.10 System modeled in ETAP

4.2 Load Flow Analysis

This process consists of 2 steps, where the first is run the program and make sure the system is perfect enough to run short circuit program. The next step will be analysis the result that gained from the program that runs earlier. Detect the problem whether the system is perfect

4.2.1 Run Load Flow Analysis



Figure 4.11: Toolbar for ETAP analysis

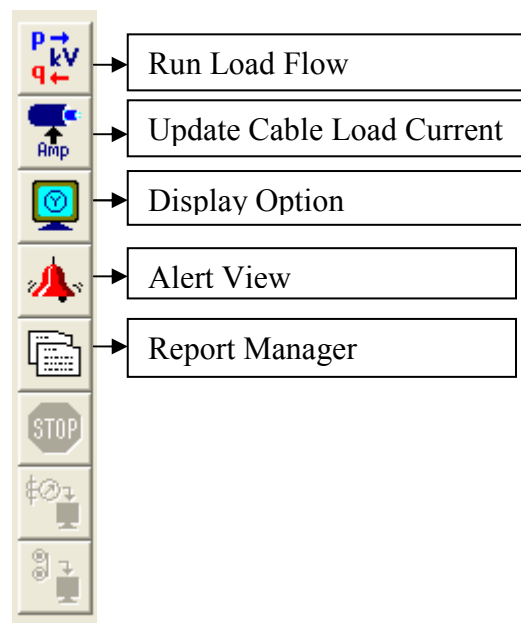


Figure 4.12: Load flow analysis toolbar

Once the modeling is completed then the software can be used to run load flow analysis. To run the load flow analysis, firstly click the load flow analysis icon that shown in figure 4.10. Later on, a tool bar will appear at right hand side of the software page in vertical form. The toolbar is already shown in the figure 4.11. Then, click the first icon at the toolbar, which is known as run load flow. Before get the report of the load flow analysis, click the display option icon to do the setting on the data that needed for the analysis in step 2. To gain complete reports for the analysis click the report manager. At the same time the icon alert view is also used for analysis as well. It's because it shows the stability of the voltage in the system. It also help to make sure the system is perfect. Check the voltage flow, form the bus to bus, bus to load and so on. It's because sometimes the voltage flow will have high voltage drop which causes the less voltage flowed to load. This makes the load not to work or may spoil the load.

4.2.2 Load Flow Analysis Results

4.2.2.1 Branch Loading (Transformer)

Through the result, the problem that detected was at transformer 5 and transformer 7. Where, the problem is, those transformer indicates a branch with operating load exceeding the branch capability. It means, the size of transformer is less than size of load that connected. In the case of transformer 5, the capacity of transformer was 300kVA but the capacity of the load was 642kVA. Same problem happens to transformer 7 which was connected to load 5. The transformer's capacity was also 300kVA and the load's capacity was 665kVA. So, it means the load capacity is higher than the capacity of transformer that connected at particular load. Therefore, the transformer does not support the load to run.

Figure 4.13 shows transformer 5 that connected to load 3 and also labeled with the size of the transformer which is 300kVA and also size of the load 643kVA.

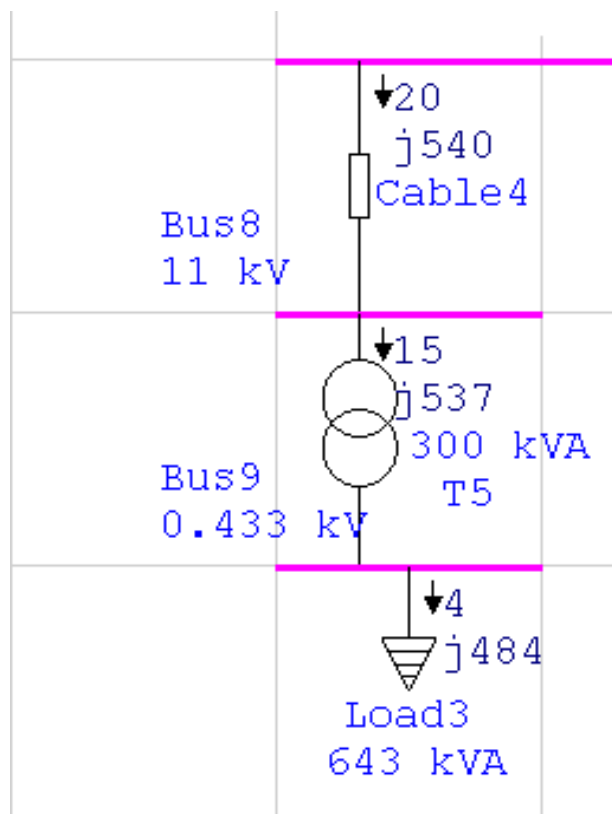


Figure 4.13: Transformer 5 connected to load 3

Figure 4.14 shows transformer 7 which is connected to load 5. Both transformer and load are already labeled with the size of equipment.

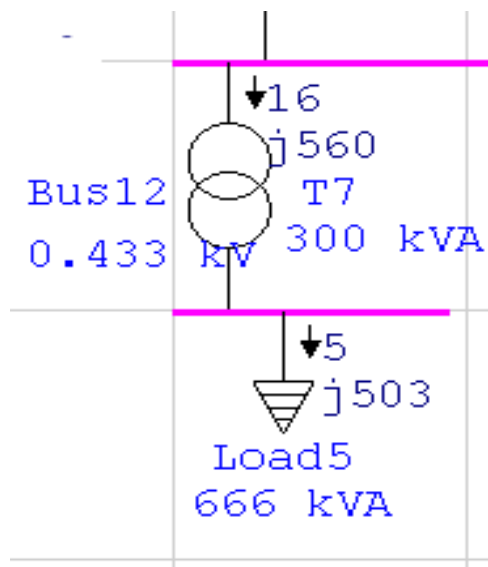


Figure 4.14: Transformer 7 connected to load 5

Table 4.1 shows that the loading input and loading output for transformer 5 and transformer 7. From the table, know that the transformer need the capability MVA that given in the table to run the load in stable condition. It means that to run the load 3, the suitable size of transformer 5 that needed is at least 0.537MVA. Whereas, to run the load 5, the suitable size of transformer 7 that needed is 0.561MVA. To avoid this problem arise again, the load that used should be in the size that can be supported by the transformer capacity.

Table 4.1: Extracted result for software

Transformer	Capability (MVA)	Loading (input)		Loading (output)	
		MVA	%	MVA	%
Transformer 5	0.300	0.537	179.0	0.484	161.3
Transformer 7	0.300	0.561	186.0	0.503	167.8

Figure 4.15 shows a part of the result of branch loading for load flow analysis that extracted directly from the report manager. The full report of this category had been attached in the appendix.

BRANCH LOADING Summary Report

CKT / Branch		Cable & Reactor			Transformer				
ID	Type	Ampacity (Amp)	Loading Amp	%	Capability (MVA)	Loading (input)		Loading (output)	
						MVA	%	MVA	%
T1	Transformer				30.000	5.660	18.9	5.564	18.5
T2	Transformer				30.000	5.660	18.9	5.564	18.5
T3	Transformer				2.500	0.363	14.5	0.359	14.4
T4	Transformer				2.500	0.283	11.3	0.281	11.2
* T5	Transformer				0.300	0.537	179.0	0.484	161.3
T6	Transformer				0.300	0.302	100.7	0.286	95.2
* T7	Transformer				0.300	0.561	186.9	0.503	167.8
T8	Transformer				1.500	1.210	80.6	1.149	76.6
T9	Transformer				2.500	0.515	20.6	0.509	20.4

Figure 4.15: Branch Loading (Transformer) report

4.2.2.2 Bus Voltage

For this part, the flow of voltage at bus is considered. Where, there is voltage drop occur at most of the buses. When the load flow program run there will be a percentage of voltage that will be drop, which is in the certain range. The voltage at bus drop at the range of 80% to 86%, it known as under voltage condition or the system is marginally stable. For overvoltage condition or the critical condition range percentage of voltage will be 105% to 102%. If the percentage of the voltage is out of the range for overvoltage and under voltage, the system in ETAP software will be show in different colour.

Figure 4.16 shows that the percentage of the voltage for under voltage and overvoltage is not in the range. Where, the range for under voltage is 80% to 87%. The range of the under voltage is less than the given value. Therefore the system bus is marginally stable. The range of the overvoltage is 105% to 102%. In this case, the range also exceeds the value. Where, this time the value is less than the higher value like shown in the figure below. It shows that, the system bus is in critical condition.

Load Flow Study Case [X]

Info | Alert

	Critical	<input checked="" type="checkbox"/> Marginal
Loading		
Bus	0 %	0 %
Cable	0 %	0 %
Reactor	0 %	0 %
Generator	0 %	0 %
Transformer	0 %	0 %
Protective Device	0 %	0 %
Bus Voltage		
OverVoltage	98 %	102 %
UnderVoltage	85 %	87 %
Generator Excitation		
OverExcited (Qmax)	0 %	0 %
UnderExcited (Qmin)	0 %	0 %

Auto Display Copy Online Alarms Copy Online Warnings

< LF > Help OK Cancel

Figure 4.16: Under voltage for bus voltage in out of range

Figure 4.17 shows that there are three buses coloured in red and also circled with green which are in critical condition. The buses that effected are bus 1, bus2 and bus 3. It's caused by the bus voltage, which is the value is less than 105%. So it cause the bus voltage at the red coloured bus is in overvoltage condition.

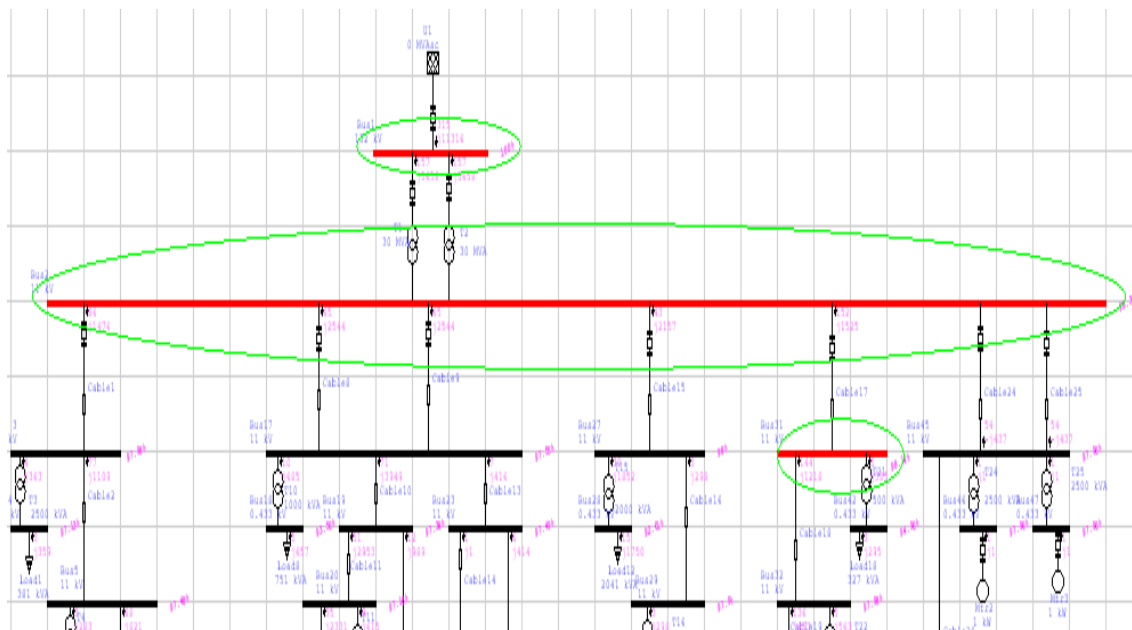


Figure 4.17: Buses that in critical condition

Figure 4.18 shows that there are two buses that effected with under voltage problem. The buses that effected are bus 9 and bus 8. It's caused by the bus voltage, where the values are in the range. Actually the value for under voltage should exceed the range of the bus voltage that given to avoid under voltage condition. Therefore, the pink coloured line shows that the bus in marginally stable condition.

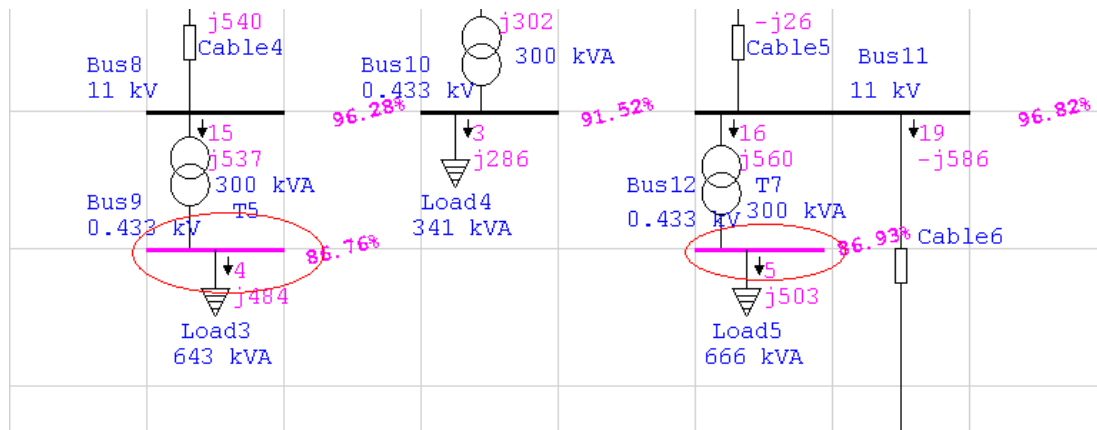


Figure 4.18: Buses that in marginally stable condition

4.2.2.3 Power flows and losses when the motor is connected

In this part, power flows and losses is also considered. Power flows occur at all buses, transformers, and also cables. But losses and voltage drop only happen at transformers and cable. At, some of the equipment there was no losses and voltage drop occur. This situation occurs at cable 14, transformer 13, transformer 24 and also transformer 25. The 3 transformer commonly connected to 3 different induction motor. It means that the entire transformer that connected to induction motor does not have any losses and voltage drop.

The losses that commonly occur are copper losses. Copper losses normally occur or produced by heat by the electrical current in conductors of transformer winding or other electrical devices. Copper losses contribute to the reduction of the efficiency in transformer, motors and generators. Through the results that obtain from the system, the copper losses happen at all cable and transformer except for cable 14, transformer 13, transformer 25 and also transformer 26. The equipment that stated was connected to three inductions motor respectively. This situation happens because the transformer that connected with induction motor has step down the voltage from 11kV to 0.433kV. Therefore the secondary part of those transformers is 0.433kV, whereas the rating voltage for the induction motor is 0.415kV. It shows that the induction motor need higher voltage to run the motor compare to load that connected to other transformer. The losses do not occur because of the any big difference on the voltage at transformer and also the induction motor. For cable 14, losses do not happen because of the size of the cable that used was 185 Sq.mm. It's because this cable is lined to induction motor through transformer. The length of the cable is shorter compare to other cable. Where, for example, the length of cable 24 and cable 25 which, are also linked to induction motor is 10.5km, whereas the length of cable 14 is 0.9km only. Losses at long distance transmission more compare to the short distance transmission.

Voltage drop also occur as electrical energy passes along a wire it loses a little "electrical pressure" or voltage the further that it travels. This is called as voltage drop. The factors that affect voltage drop are the power of the load (wattage), the length of the wiring run, the voltage at the transformer, and the size of the wire. Through the analysis that done, the voltage drops does not occur at transformer 13, transformer 24 and transformer 25 because the motor that connected has lower power (wattage). There is no voltage drop at the equipment that stated because the induction motor has 1kW power, where the power used is very lower. Whereas, when the induction motor's power is increased to 100kW for motor 1, motor 2 and motor 3 there is voltage drop happen at transformer 13, transformer 24 and also transformer 25. It means that, when the power or wattage of the motor increase the voltage drop will increase as well.

Figure 4.19a and **Figure 4.19b** shows that the changes that had done to three inductions motor, which is increased the wattage of the power rating to obtain difference in voltage drop between the 1kW and 100kW.

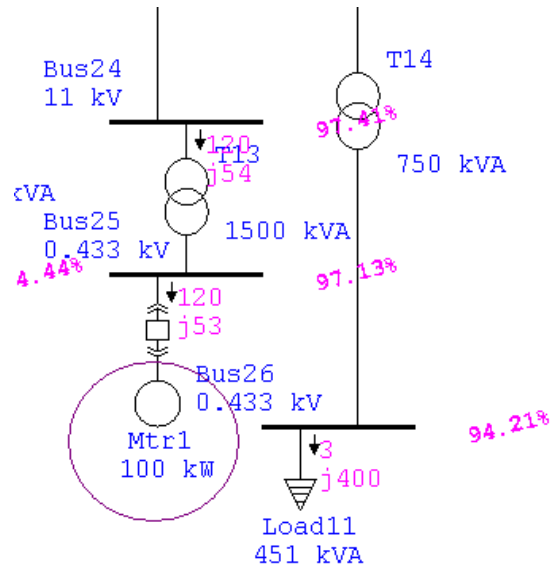


Figure 4.19a: Power of the Induction motor 1 is increased

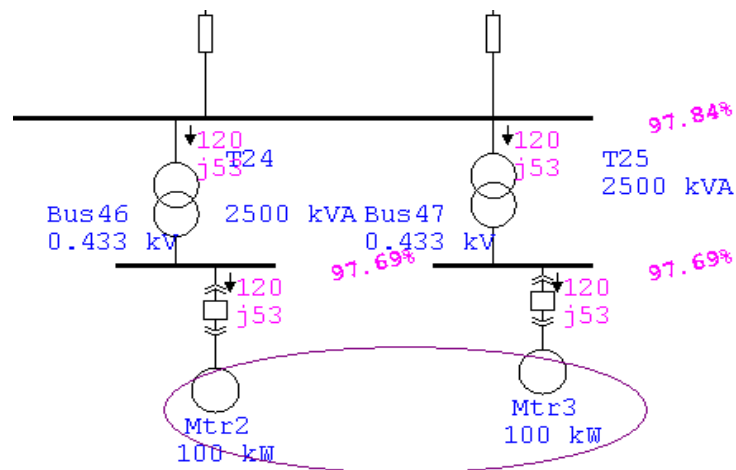


Figure 4.19b: Power of the Induction motor 2 and 3 is increased

Table 4.2 shows that the voltage drops that happen at the three transformers that discussed earlier. From the table, there is no voltage drop because of the motor that used a lower in wattage.

Table 4.2: Voltage drop at Motor with 1kW wattage

Branch ID	From to Bus Flow		To From Bus flow		Losses		% Bus voltage		%V _d
	MW	MVar	MW	MVar	kW	kVar	From	To	
T13	0.001	0.001	- 0.001	- 0.001	0.0	0.0	97.5	97.5	0.00
T24	0.001	0.001	- 0.001	- 0.001	0.0	0.0	98.0	98.0	0.00
T25	0.001	0.001	- 0.001	- 0.001	0.0	0.0	98.0	98.0	0.00

Table 4.3 shows that the voltage drops that happen at the three transformers that discussed earlier, which was connected to the induction motor that consist of higher wattage (100kW). From the table, there is voltage drop occur because of the motor that used a high in wattage. Whenever, the wattage at induction motor increase the voltage drop also increases. Same problem occur to losses, means that the losses also increases when the wattage of the motor increases.

Table 4.3: Voltage drop at Motor with 100kW wattage

Branch ID	From to Bus Flow		To From Bus flow		Losses		% Bus voltage		%V _d
	MW	MVar	MW	MVar	kW	kVar	From	To	
T13	0.120	0.054	-0.120	-0.054	0.1	0.7	97.4	97.1	0.27
T24	0.120	0.053	-0.120	-0.053	0.0	0.4	97.8	97.7	0.15
T25	0.120	0.053	-0.120	-0.053	0.0	0.4	97.8	97.7	0.15

4.3 Short Circuit Analysis

Short circuit analysis is the next step that done in this project. This step is proceeded to gain arc fault current at each bus. All the buses that used are faulted before run the short circuit program. Although all the buses are faulted, there won't be any effect to the fault current that obtained. Analysis that used is 3 phase short circuit analysis.

4.3.1 Three Phase Short Circuit Analysis

The purpose of a short circuit is to determine whether or not electrical equipment is rated properly for the maximum available fault current that the equipment obtain. There are essentially four types of fault, which are three phase fault, single line to ground fault, double line to ground fault and also line to line fault. In all the types there is a common element which is known as a low impedance path for current to flow, for a condition that can lead to extremely high current [8].

Short circuit analysis that used in this project is three phase short circuit. Three phase short circuit analysis is used because of the demand of the system. Where the system the minimum voltage that used is 415V at induction motor. The system cannot hit the demand with only single phase short circuit analysis. At the same time, for again or to proceed with arc flash analysis, this step is required to obtain bolted fault current. Bolted faulted current itself refer to three phase fault current. The faulted current that obtained is used to determined, arc fault current, incident energy for all equipment, protection boundary for the arc flash.

Before run the program of short circuit, all the bus is faulted together. So, each bus will have its own fault current value which does not affect the fault that happen at other bus at the same time.

4.3.2 Short Circuit Calculation

In this section short circuit calculation is shown in manually by using suitable equation for all the equipment that used.

Figure 4.20 shows that an example of a simple system which is used for short circuit calculation manually, for each equipment that used.

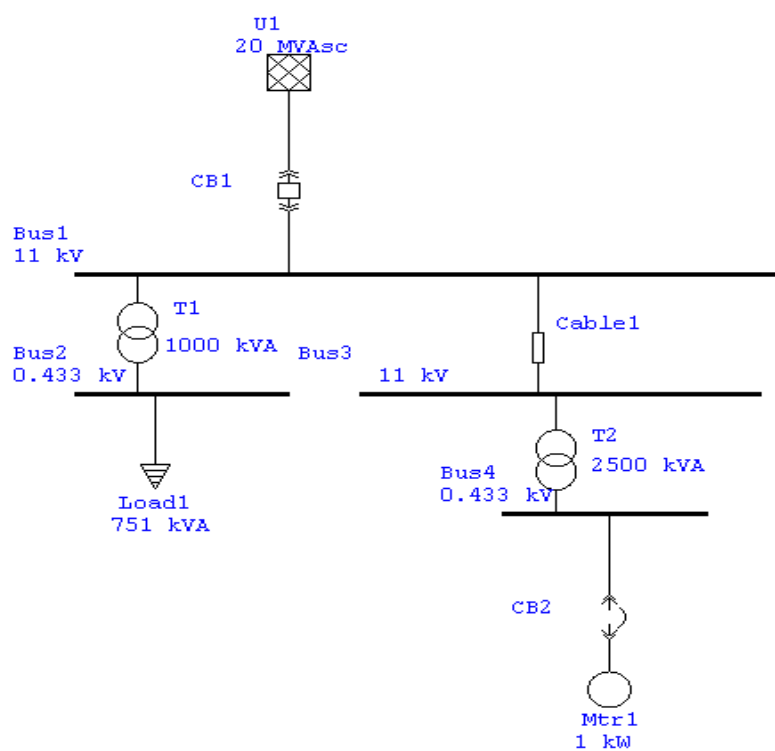


Figure 4.20: Example of a simple system

4.3.2.1 Utility

The data to calculate the short circuit for utility can be obtain from the power company supplier. The data that required are I_{SC} (short circuit current) and V_{LL} (line to line voltage). The short circuit for utility is calculated when only the bus 1 is faulted. The equation and calculation are as follow:

$$\text{Current Fault, } I_F = \frac{MVA_F}{(\sqrt{3})(V_{LL})}$$

MVA_F = Short circuit current in kA

V_{LL} = Line to line voltage in kV

Form the system, given that:

$$MVA_F = 20\text{kA}$$

$$V_{LL} = 11\text{kV}$$

$$\begin{aligned} \text{Current Fault, } I_F &= \frac{20\text{kA}}{(\sqrt{3})(11\text{kV})} \\ &= 1.049\text{kA} \end{aligned}$$

4.3.2.2 Transformer

Transformer are specified by output voltage (V), kVA rating, percentage of impedance (%Z), and X/R ratio. The X/R ratio is the ratio of resistance and reactance. This information, with the exception of X/R, is usually on the transformer nameplate. The equation and the calculation for both transformer 1 and transformer 2 are as follow:

$$SC\ MVA_F = kVA \times 10^{-3} / Z_{p.u}$$

$$\text{Current Fault, } I_F = \frac{MVA_F}{(\sqrt{3})(V_{LL})}$$

$$Z_{p.u} = \%Z / 100$$

Transformer 1: Bus 2 is faulted. Therefore the fault current will be at bus 2.

Given that:

$$kVA = 1000$$

$$Z_{p.u} = \%Z/100$$

$$= 5.75/100$$

$$= 0.0575$$

$$SC\ MVA_F = 1000 \times 10^{-3} / 0.0575$$

$$= 17.39\ MVA$$

$$Current\ Fault, I_F = \frac{17.39M}{(\sqrt{3})(433)}$$

$$= 23.2\ kA$$

Transformer 2: Bus 4 faulted. Therefore, the fault current represents the fault current at bus 4.

Given that:

$$kVA = 2500$$

$$Z_{p.u} = \%Z/100$$

$$= 5.75/100$$

$$= 0.0575$$

$$SC\ MVA = 2500 \times 10^{-3} / 0.0575$$

$$= 43.478\ MVA$$

$$Current\ Fault, I_F = \frac{43.478M}{(\sqrt{3})(433)}$$

$$= 57.97\ kA$$

4.3.2.3 Cable

The data that required calculating short circuit for cable is resistance, reactance and length. This data is available in cable standards and manufacturer's specification. Lengths may be measured, paced off and estimated. The cable short circuit MVA is determined from the equation below:

$$SC\ MVA = n \times kV^2 / Z$$

n = Number of cable in parallel

$$Z = (R^2 + X^2)^{1/2} \text{ Ohm}$$

Short circuit at cable is calculated when the bus 3 is faulted. It means that, the fault current will be at bus 3.

From the system, given that

$$n = 1$$

$$kV = 11kV$$

$$\begin{aligned} Z &= (R^2 + X^2)^{1/2} \text{ Ohm} \\ &= (0.08^2 + 0.09^2)^{1/2} \text{ Ohm} \\ &= 0.1204 \text{ Ohm} \end{aligned}$$

$$\begin{aligned} SC\ MVA &= 1 \times 11^2 / 0.1204 \\ &= 1004.98 \text{ MVA} \end{aligned}$$

$$\begin{aligned} \text{Current Fault, } I_F &= \frac{1004.98M}{(\sqrt{3})(11kV)} \\ &= 52.7477kA \end{aligned}$$

4.3.3 Short Circuit Analysis Result

Table 4.4 shows the bolted fault current that obtain through the short circuit current for all the buses that used, with the condition of all the buses is faulted at once.

Table 4.4: Result for bolted fault current

ID	Bolted Fault Current (kA)	ID	Bolted Fault Current (kA)
Bus 1	0.09	Bus 22	16.3
Bus 2	1.0	Bus 23	0.97
Bus 3	0.98	Bus 24	0.95
Bus 4	17.4	Bus 25	14.3
Bus 5	0.93	Bus 26	10.2
Bus 6	16.7	Bus 27	0.99
Bus 7	0.89	Bus 28	16.3
Bus 8	0.72	Bus 29	0.93
Bus 9	5.4	Bus 30	16.8
Bus 10	5.7	Bus 31	1.0
Bus 11	0.92	Bus 32	0.98
Bus 12	5.8	Bus 33	0.96
Bus 13	0.97	Bus 34	0.96
Bus 14	0.78	Bus 35	0.84
Bus 15	12.7	Bus 36	5.6
Bus 16	17.2	Bus 37	0.87
Bus 17	0.99	Bus 38	16.6
Bus 18	12.1	Bus 39	0.80
Bus 19	0.98	Bus 40	5.6
Bus 20	0.97	Bus 41	10.1
Bus 21	12.0	Bus 42	1.0

ID	Bolted Fault Current (kA)
Bus 43	17.5
Bus 44	17.2
Bus 45	0.96
Bus 46	17.2
Bus 47	17.2

From the table, the result for the fault current had already been obtained by short circuit analysis. The result shows that bus 1 which is connected to utility has the smallest fault current. The fault current that obtain from the utility is 0.09kA. It's because, the voltage that used are 132kV, where it's a high voltage (HV), so the current flow from the utility will less compare to flow of current at load and motor. Therefore, the fault current also will be smaller.

Those buses that were connected to transformer have bigger value of fault current. It's because the capacity of the transformer give an impact to the fault current. Whenever, the capacity of the transformer increased, the fault current at the bus that connected with transformer also increases. A transformer's impedance usually is expressed as a percentage of the primary voltage needed to circulate full load current in a short circuited secondary. 5% impedance is common. It means that only 5% of the normal primary voltage will produce full load current in the short circuited secondary. It follows that, at normal voltage, the three phase short circuit on the secondary side would result in a current twenty times as greater as the full load current flowing in the short-circuited secondary [9].

Whereas, for the buses that connected with load also have higher fault current. It's because the voltage that used are low voltage. So the current at the area where connected with low voltage will have high current. So it's possible have high current fault as well.

4.4 Arcing Fault Current

At this step, arcing fault current is determined by using the bolted fault current that obtain from the previous step, which is short circuit analysis. At the same time, the fault current also determined through application as shown below:

4.4.1 Application for under 1000V

Equation:

$$\log I_a = K + 0.662 \lg I_{bf} + 0.0966V + 0.000526G + 0.5588V(\lg I_{bf}) - 0.00304G(\lg I_{bf})$$

The equation above is only used for all the bus which rated the voltage under 1000V. In this, project the buses that rated the voltage is 0.433kV. There are 23 buses which were rated with 0.433kV. The value of constant K that used in this equation for the project is -0.153 for open configuration. Where it means that the equipment that used in open configuration does not cover with any protection equipment just like distribution board. The bus bar for distribution board is in close configuration. The variable that used in this equation is the voltage (V), Bolted fault current (I_{bf}) and gap between conductors (G).

Table 4.5 shows that, the result for arcing fault current for the buses that rated with 0.433kV and also in open configuration condition.

Table 4.5: Result of arcing fault current for buses with low voltage

Bus ID	Arcing Fault Current, I_a (kA)	Bus ID	Arcing Fault Current, I_a (kA)
Bus 4	8.06	Bus 28	5.24
Bus 6	7.80	Bus 30	7.64
Bus 9	3.13	Bus 36	7.84
Bus 10	3.28	Bus 38	3.23
Bus 12	3.32	Bus 40	7.76
Bus 15	6.25	Bus 41	3.23
Bus 18	7.99	Bus 42	4.52
Bus 21	6.01	Bus 43	8.10
Bus 22	5.97	Bus 44	7.99
Bus 25	7.65	Bus 46	8.41
Bus 26	7.22	Bus 47	8.41

4.4.2 Application for 1000V and Higher

Equation:

$$\lg I_a = 0.00402 + 0.983 \lg I_{bf}$$

The equation above is only used for the bus that rated voltage is 1000V and higher. In this case the rated voltage that the bus has is 132kV and 11kV. for those buses the equation used to obtain arcing fault current. The only variable that used is bolted fault current, I_{bf} .

Table 4.6, shows that the result for arcing fault current for all the buses that rated with 132kV and 11kV

Table 4.6: Result of arcing fault current for the buses the rated with high voltage

Bus ID	Arcing Fault Current, I_a (kA)
Bus 1	0.094
Bus 2	1.009
Bus 3	0.989
Bus 5	0.940
Bus 7	0.900
Bus 8	0.731
Bus 11	0.930
Bus 13	0.980
Bus 14	0.791
Bus 17	0.999
Bus 19	0.989
Bus 20	0.999
Bus 23	0.979

Bus ID	Arcing Fault Current, I_a (kA)
Bus 24	0.960
Bus 27	0.999
Bus 29	0.999
Bus 31	0.940
Bus 32	1.009
Bus 33	0.989
Bus 34	0.970
Bus 35	0.850
Bus 37	0.880
Bus 39	0.810
Bus 45	0.970

4.5 Protection Coordination

Protection coordination means that downstream devices should activate before upstream devices. This will minimize the portion of affected by a fault or other disturbance. All the substation level, feeder breakers should trip before the breaker at main trip. The protection device is done to help reduce unnecessary downtime and also to provides recommended settings for adjustable trip circuit breakers and relays.

4.5.1 Circuit Breaker with short-time-delay and Instantaneous override

Some electronic trip molded case circuit breakers (MCCB) and most insulated case circuit breaker (ICCB) offer short-time delay. This allows the circuit breaker the ability to delay tripping for a period of time, typically 6 to 30 cycles. However both circuit breakers, a built in instantaneous override mechanism is present. It known as instantaneous overrides function, and also will override the STD for medium to high level faults. The normal setting of instantaneous override for those device is 8 to 12 times rating of the circuit breaker and will kick in for faults equal to or greater than the setting. It's because, of this override, non-selective tripping can exist, similar to MCCB and ICCB without short-time delay. It will improve the coordination in the overload and low level fault regions; it also may not be able to assure coordination for medium and high level fault condition.

4.6 System voltage and classes of equipment and selection of working distance.

In this step, the voltage and also classes of equipment for each bus has selected for the table 2 of Standard IEEE 1584-2002. The table 2 that already attached in appendix shows that classes of equipment and also typical bus gaps. Whereas for the selection of working distance is stated in table 3 of Standard IEEE 1584-2002. The table also already attached in appendix. Both table 2 and table 3 are overlapped. It means that the working distance is selected based on the classes of equipment that already given in table 2.

Table 4.7 shows that the system voltage, classes of equipment and also the selection of working distance for each and every bus that used in this project's system.

Table 4.7: System voltage, classes of equipment and selection of working distance for all buses.

BUS ID	Voltage at Bus (kV)	Classes of Equipment	Typical bus gap (mm)	Typical working distance (mm)
Bus 1	132			
Bus 2	11	15kV switchgear	153	910
Bus 3	11	Cable	13	455
Bus 4	0.433	Low voltage switchgear	32	610
Bus 5	11	Cable	13	455
Bus 6	0.433	Low voltage switchgear	32	610
Bus 7	11	Cable	13	455
Bus 8	11	Cable	13	455
Bus 9	0.433	Low voltage switchgear	32	610
Bus 10	0.433	Low voltage switchgear	32	610
Bus 11	11	Cable	13	455
Bus 12	0.433	Low voltage switchgear	32	610
Bus 13	11	Cable	13	455
Bus 14	11	Cable	13	455
Bus 15	0.433	Low voltage switchgear	32	610
Bus 16	0.433	Low voltage switchgear	32	610
Bus 17	11	Cable	13	455
Bus 18	0.433	Low voltage switchgear	32	610
Bus 19	11	Cable	13	455
Bus 20	11	Cable	13	455
Bus 21	0.433	Low voltage switchgear	32	610
Bus 22	0.433	Low voltage switchgear	32	610
Bus 23	11	Cable	13	455
Bus 24	11	Cable	13	455
Bus 25	0.433	LV MCCs & Panel board	25	455

Bus 26	0.433	Low voltage switchgear	32	610
Bus 27	11	Cable	13	455
Bus 28	0.433	Low voltage switchgear	32	610
Bus 29	11	Cable	13	455
Bus 30	0.433	Low voltage switchgear	32	610
Bus 31	11	Cable	13	455
Bus 32	11	Cable	13	455
Bus 33	11	Cable	13	455
Bus 34	11	Cable	13	455
Bus 35	11	Cable	13	455
Bus 36	0.433	Low voltage switchgear	32	610
Bus 37	11	Cable	13	455
Bus 38	0.433	Low voltage switchgear	32	610
Bus 39	11	Cable	13	455
Bus 40	0.433	Low voltage switchgear	32	610
Bus 41	0.433	Low voltage switchgear	32	610
Bus 42	0.433	Low voltage switchgear	32	610
Bus 43	0.433	Low voltage switchgear	32	610
Bus 44	0.433	Low voltage switchgear	32	610
Bus 45	11	Cable	13	455
Bus 46	0.433	LV MCCs & Panel board	25	455
Bus 47	0.433	LV MCCs & Panel board	25	455

4.7 Determine the Incident Energy

To determine the incident energy value there are two equations that can be used. The first equation that stated below is used for low voltage and also medium voltage. In this case the buses that used are the buses that rated with 0.433kV and 11kV. Whereas, the second equation that stated below are used for high voltage bus. The bus that rated with high voltage bus is bus 1 in the project. Where, the bus was rated with 132kV.

First equation:

$$\lg E_n = K_1 + K_2 + 1.0811 \lg I_n + 0.0011 G \quad (1)$$

$$E_n = 10^{\lg E_n} \quad (2)$$

$$E = C_f E_n \left(\frac{t}{0.2} \right) \left(\frac{610^X}{D^X} \right) \quad (3)$$

Second equation:

$$E = 5.12 \times 10^5 V I_{bf} \left(\frac{t}{D^2} \right) \quad (3)$$

Table 4.8 shows that, the result of incident energy in cal/cm² for normalized for time and distance (E_n). This table also included with the converted normalized incident energy (E).

Table 4.8: Result for incident energy in cal/cm²

Bus ID	En (cal/cm ²)	E (cal/cm ²)	Bus ID	En (cal/cm ²)	E (cal/cm ²)
Bus 1	0.0097	2.637	Bus 27	0.1285	0.415
Bus 2	0.1852	0.225	Bus 28	0.1269	3.277
Bus 3	0.1271	0.410	Bus 29	0.1287	0.415
Bus 4	1.2883	3.469	Bus 30	1.2494	3.364
Bus 5	0.1203	0.388	Bus 31	0.1203	0.388
Bus 6	1.2429	3.347	Bus 32	0.1299	0.419
Bus 7	0.1148	0.370	Bus 33	0.1272	0.410
Bus 8	0.0916	0.296	Bus 34	0.1244	0.401
Bus 9	0.4644	1.250	Bus 35	0.1079	0.348
Bus 10	0.4868	1.311	Bus 36	0.4793	1.291
Bus 11	0.1189	0.384	Bus 37	0.1120	0.361
Bus 12	0.1248	0.336	Bus 38	1.2365	3.329
Bus 13	0.1258	0.406	Bus 39	0.1025	0.331
Bus 14	0.099	0.322	Bus40	0.4794	1.291
Bus 15	0.9789	2.636	Bus 41	0.8017	2.158
Bus 16	1.2753	3.434	Bus 42	0.6898	1.857
Bus 17	0.1285	0.415	Bus 43	1.2947	3.486
Bus 18	0.9385	2.527	Bus 44	1.2753	3.434
Bus 19	0.1272	0.410	Bus 45	0.1244	0.401
Bus 20	0.1258	0.406	Bus 46	1.3255	5.774
Bus 21	0.9317	2.509	Bus 47	1.3255	5.774
Bus 22	1.2169	3.277			
Bus 23	0.1258	0.406			
Bus 24	0.1230	0.397			
Bus 25	1.1236	4.894			
Bus 26	0.8086	2.177			

4.8 Determine the Flash Boundary

Flash boundaries for each bus are determined by using an equation. The equation is shown at below. This equation only used for all the buses that has rated voltage less than 15kV, or more specifically only used for low voltage and medium voltage. The variable that included in the equation are incident energy normalized for time and distance (E_n), time (t in seconds), calculation factor (C_f) and also distance exponent (x). The incident energy obtained from previous step which is determining the incident energy. The values of arcing time are also obtained from previous step, which is from protection coordination. For calculation factor are already given in the equation. Where there are two option, one for voltage above 1kV will be using 1.0 as calculation factor and the second option will be 1.5 for voltage at or below 1kV as calculation factor. The next variable is distance exponent (x), where the values for x can be obtain Table 1 from IEEE Std 1584-2002. The Table 1 is already attached in appendix

$$D_B = \left[C_f E_n \left(\frac{t}{0.2} \right) \left(\frac{610^x}{E_n} \right) \right]^{\frac{1}{x}}$$

The equation that given below is known as Lee method. This method only used for the bus that has rated voltage more than 15kV. In this project, the bus that has rated more than 15kV is bus 1, where the bus has rated voltage 132kV.

$$\sqrt{5.12 \times 10^5 V I_{bf} \left(\frac{t}{E_B} \right)}$$

Table 4.9 shows that, the result of the flash boundary that obtains from the both equation above.

Table 4.9: Result for Flash Boundary

Bus ID	Flash Boundary, D_B (mm)	Bus ID	Flash Boundary, D_B (mm)
Bus 1	1348.96	Bus 24	261.67
Bus 2	163.08	Bus 25	1071.61
Bus 3	266.03	Bus 26	914.04
Bus 4	1253.96	Bus 27	267.47
Bus 5	258.73	Bus 28	1206.40
Bus 6	1223.84	Bus 29	267.65
Bus 7	252.76	Bus 30	1228.17
Bus 8	255.83	Bus 31	258.73
Bus 9	627.27	Bus 32	268.90
Bus 10	647.67	Bus 33	266.03
Bus 11	257.25	Bus 34	263.13
Bus 12	256.99	Bus 35	245.11
Bus 13	264.58	Bus 36	640.92
Bus 14	235.64	Bus 37	249.72
Bus 15	1040.71	Bus 38	1219.50
Bus 16	1245.40	Bus 39	238.84
Bus 17	267.03	Bus 40	640.92
Bus 18	264.58	Bus 41	908.68
Bus 19	1006.36	Bus 42	820.52
Bus 20	1206.40	Bus 43	1258.22
Bus 21	264.58	Bus 44	1245.40
Bus 22	1206.40	Bus 45	263.13
Bus 23	264.58	Bus 46	1185.16
Bus 24	261.67	Bus 47	1185.16

4.9 Category of Personal Protective Equipment

The Personal Protective Equipment (PPE) has its category that already categories in NFPA 70E. The Personal Protective Equipment divided in five levels, starts from level 0 to level four. Each level has its own characteristic and also the range of required minimum arc rating. The category for the PPE is attached at appendix.

Table 4.10 shows that, the result of Personal Protective Equipment that should be categories for each and every bus that used in the system.

Table 10: Category of PPE

Bus ID	E (cal/cm ²)	Category of PPE	Bus ID	E (cal/cm ²)	Category of PPE
Bus 1	2.637	Class 1	Bus 28	3.277	Class 1
Bus 2	0.225	Class 0	Bus 29	0.415	Class 0
Bus 3	0.410	Class 0	Bus 30	3.364	Class 1
Bus 4	3.469	Class 1	Bus 31	0.388	Class 0
Bus 5	0.388	Class 0	Bus 32	0.419	Class 0
Bus 6	3.347	Class 1	Bus 33	0.410	Class 0
Bus 7	0.370	Class 0	Bus 34	0.401	Class 0
Bus 8	0.296	Class 0	Bus 35	0.348	Class 0
Bus 9	1.250	Class 1	Bus 36	1.291	Class 1
Bus 10	1.311	Class 1	Bus 37	0.361	Class 0
Bus 11	0.384	Class 0	Bus 38	3.329	Class 1
Bus 12	0.336	Class 0	Bus 39	0.331	Class 0
Bus 13	0.406	Class 0	Bus40	1.291	Class 1
Bus 14	0.322	Class 0	Bus 41	2.158	Class 1
Bus 15	2.636	Class 1	Bus 42	1.857	Class 1
Bus 16	3.434	Class 1	Bus 43	3.486	Class 1
Bus 17	0.415	Class 0	Bus 44	3.434	Class 1
Bus 18	2.527	Class 1	Bus 45	0.401	Class 0
Bus 19	0.410	Class 0	Bus 46	5.774	Class 2
Bus 20	0.406	Class 0	Bus 47	5.774	Class 2
Bus 21	2.509	Class 1			
Bus 22	3.277	Class 1			
Bus 23	0.406	Class 0			
Bus 24	0.397	Class 0			
Bus 25	4.894	Class 2			
Bus 26	2.177	Class 1			
Bus 27	0.415	Class 0			

4.10 ETAP Arc flash Calculator

Later on, arc flash calculator from ETAP software is used to determine the warning label and perfect working distance. The warning label consists of the required PPE level that should be used particular working distance. It also includes incident energy, limit approach boundary, restricted approach boundary and also prohibited approach boundary and so on.

To use the arc flash calculator, there are some data that should be used from previous result that determined from short circuit analysis. The data that needed to use is voltage (kV), faulted current (kAsc), and impedance (X/R) for source. Other than that, fault clearing time also needed to use the calculator. Data for transformer also is used, which are the capacity of the transformer (MVA) and impedance (%Z) this include with voltage and phase current at cable. Then, do the selection for the working distance. By key in all the data that required the warning label will be result for the calculator.

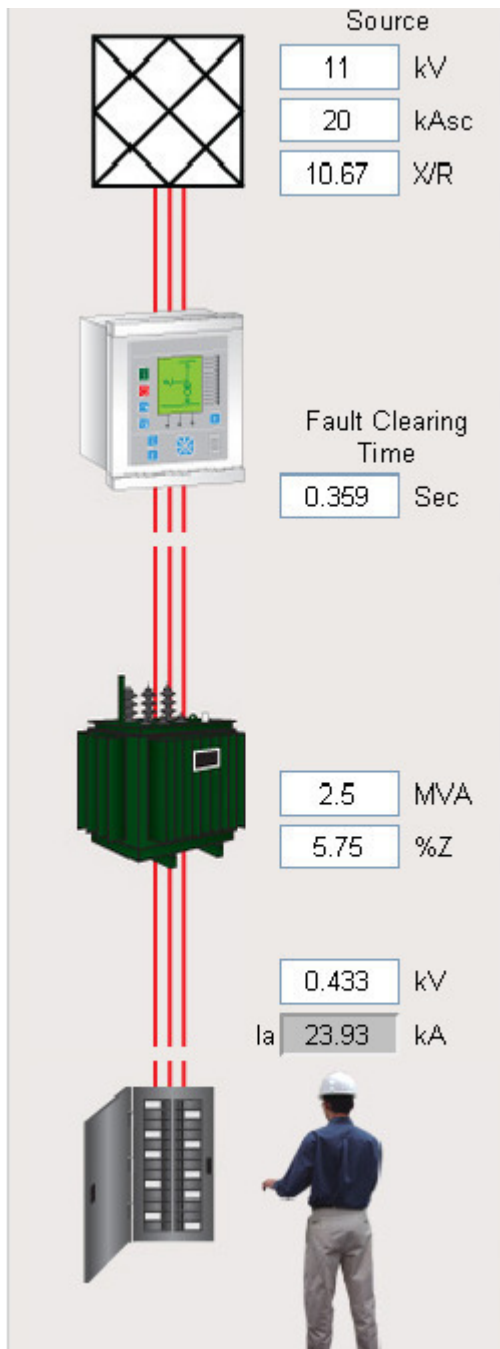


Figure 4.21: Arc Flash Calculator

Arc Flash and Shock Hazard Present		
Appropriate PPE Required		
Arc Flash Protection	Shock Protection	
Required PPE Level	3	Limited Approach Boundary 3.5 ft
Min. PPE ATPWE _{BT} Rating	11.7 cal/cm ²	Restricted Approach Boundary 1.0 ft
Incident Energy	9.8 cal/cm ²	Prohibited Approach Boundary 0.1 ft
@ Working Distance	36 in	
Arc Flash Hazard Boundary	10.8 ft	Shock Hazard Exposure 433 VAC
Arc Flash Analysis Date	11-21-2010	Insulating Glove Class 00
Equipment: Panelboard		

Figure 4.22: Result from arc flash calculator

4.11 Relationship between each procedure

This part mainly, will be discussed on the relationship of the procedure that was followed to precede arc flash hazard analysis. As known, the first step is the data collection and also modeling of the system in the software. Then, the procedure continues with load flow analysis. Where load flow analysis is import in this project so that the system does not effect by any other factor during the third step is proceeding. The third step is short circuit analysis. This step mainly will focus to obtain the fault current at each bus. The fault current at each bus will should be discussed to know the flow of the current at each bus or does it affect the other bus when all the bus is faulted at a time. The fault current that obtain will be used to obtain the arcing current. By determining the arcing fault current will the next step. Where, at this step the arcing current will be obtained manually through equation that took from the IEEE 1584 standard. To make easier for this calculation for 47 buses, Microsoft Office Excel is used to obtain the arcing current for each and every bus. The table form Microsoft Office Excel that already calculated the arcing fault current is attached at appendix. The result from the arcing fault current will be used in the next step. The following step will be protection coordination. Where during this step, the arcing fault current that obtain from previous step is used to rate the current transformer, circuit breaker and also over current relay. After the relay coordination is done, arc duration will be obtained for use for the next step. Where the next step is, select the working distance based on incident energy level. To calculate the incident energy level, arc duration is needed. The arc duration are obtaining from protection coordination. Then, the incident energy is used to determine the incident energy for all equipment that use in the system. Calculating incident energy must be selected. To find the flash protection boundary which is the final step for arc flash analysis calculation, the equation for finding incident energy can be solved for the distance from the arc source.

CHAPTER 5

CONCLUSION

5.1 Conclusion

As the tables shown and discussed, it clearly stated that to precede arc flash hazard analysis each step that undergoes are linked or related to the following step. The calculation that shown, in previous section are to obtain the Personal Protective Equipment for the use of workers at industry at each place of work.

In this project, the majority of the bus should uses level 0 of Personal Protective Equipment. The level of PPE is categories based on the incident energy that calculated earlier. Where, the minimum or required arc rating of PPE is $1.2\text{cal}/\text{cm}^2$ for level 0. The typical protective clothing systems for level 0 are, worker should use the non-melting and flammable material as clothes.

Other majority of the bus should uses level 1 of Personal Protective Equipment. This level's required arc rating is $4\text{cal}/\text{cm}^2$. These levels need more extra ordinary clothes, which is fire resistance pants and shirt to protect the human body.

In this system, the bus that required higher level of Personal Protective Equipment (PPE) is bus 25, bus 46 and also bus 47. Those buses are connected with motor. It's because, the induction motor that connected has low voltage rated. So, the current leakage during short circuit will be higher. Therefore the arcing current and also incident energy will higher too. The harm at this work place can reduce by increasing or further up the working distance. The level that should use is level 2. Where, this level's typical protective clothing system is cotton underwear, fire resistance pants and shirt.

REFERENCES

This guide is prepared based on the following references;

- [1] *Standard For Electrical Safety in the Workplace*, NFPA 70E, 2004.
- [2] *IEEE Guide for Performing Arc-Flash Hazard Calculations*, IEEE std. 1584-2002
- [3] *IEEE Recommended Practice for Industrial and Commercial Power System Analysis*, IEEE Std.399-1997.
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- [9] Department of Justice and Attorney-General, *High Fault Current*.

APPENDIX A
TABLES FROM IEEE Std 1584-2002

Table A1: Classes of equipment and typical bus gaps.

Table 2—Classes of equipment and typical bus gaps

Classes of equipment	Typical bus gaps (mm)
15 kV switchgear	152
5 kV switchgear	104
Low-voltage switchgear	32
Low-voltage MCCs and panelboards	25
Cable	13
Other	Not required

Table A2: Classes of equipment and typical working distance**Table 3—Classes of equipment and typical working distances**

Classes of equipment	Typical working distance ^a (mm)
15 kV switchgear	910
5 kV switchgear	910
Low-voltage switchgear	610
Low-voltage MCCs and panelboards	455
Cable	455
Other	To be determined in field

^aTypical working distance is the sum of the distance between the worker standing in front of the equipment, and from the front of the equipment to the potential arc source inside the equipment.

Table A3: Factor for equipment and voltage classes**Table 4—Factors for equipment and voltage classes^a**

System voltage (kV)	Equipment type	Typical gap between conductors (mm)	Distance x factor
0.208–1	Open air	10–40	2.000
	Switchgear	32	1.473
	MCC and panels	25	1.641
	Cable	13	2.000
>1– 5	Open air	102	2.000
	Switchgear	13–102	0.973
	Cable	13	2.000
>5–15	Open air	13–153	2.000
	Switchgear	153	0.973
	Cable	13	2.000

^aThe distance x factor is used in 5.3 as an exponent.

APPENDIX B1

Table B1: Result for Arcing current for application under 1000V

BUS ID	I _{bf}	log I _{bf}	Gap (mm)	log I _a	I _a
Bus 4	17.4	1.240549	32	0.906387	8.060956245
Bus 6	16.7	1.222716	32	0.892001	7.798322869
Bus 9	5.4	0.732394	32	0.496467	3.136660328
Bus 10	5.7	0.755875	32	0.515409	3.276492898
Bus 12	5.8	0.763428	32	0.521502	3.322784678
Bus 15	12.7	1.103804	32	0.796077	6.252830083
Bus 16	17.2	1.235528	32	0.902336	7.986130116
Bus 18	12.1	1.082785	32	0.779122	6.013419972
Bus 21	12	1.079181	32	0.776214	5.973297691
Bus 22	16.3	1.212188	32	0.883508	7.647293906
Bus 25	14.3	1.155336	25	0.85855	7.220217623
Bus 26	10.2	1.0086	32	0.719278	5.239354569
Bus 28	16.3	1.212188	32	0.883508	7.647293906
Bus 30	16.8	1.225309	32	0.894093	7.835970304
Bus 36	5.6	0.748188	32	0.509208	3.23004384
Bus 38	16.6	1.220108	32	0.889897	7.760631827
Bus 40	5.6	0.748188	32	0.509208	3.23004384
Bus 41	10.1	1.004321	32	0.715826	5.197879025
Bus 42	8.5	0.929419	32	0.655404	4.522763002
Bus 43	17.5	1.243038	32	0.908394	8.098306885
Bus 44	17.2	1.235528	32	0.902336	7.986130116
Bus 46	17.2	1.235528	25	0.924946	8.412913568
Bus 47	17.2	1.235528	25	0.924946	8.412913568

APPENDIX B2

Table B2: Result for arcing current for application 1000V and higher

BUS ID	I _{bf}	logI _{bf}	logI _a	I _a
Bus 1	0.09	-1.045757	-1.024064	0.09461
Bus 2	1	0	0.00402	1.009299
Bus 3	0.98	-0.008774	-0.004606	0.989451
Bus 5	0.93	-0.031517	-0.026964	0.9398
Bus 7	0.89	-0.05061	-0.045735	0.900047
Bus 8	0.72	-0.142668	-0.136236	0.730741
Bus 11	0.92	-0.036212	-0.03158	0.929865
Bus 13	0.97	-0.013228	-0.008985	0.979524
Bus 14	0.78	-0.107905	-0.102062	0.790566
Bus 17	0.99	-0.004365	-0.000271	0.999376
Bus 19	0.98	-0.008774	-0.004606	0.989451
Bus 20	0.97	-0.013228	-0.008985	0.979524
Bus 23	0.97	-0.013228	-0.008985	0.979524
Bus 24	0.95	-0.022276	-0.01788	0.959666
Bus 27	0.99	-0.004365	-0.000271	0.999376
Bus 29	0.93	-0.031517	-0.000271	0.999376
Bus 31	1	0	-0.026964	0.9398
Bus 32	0.98	-0.008774	0.00402	1.009299
Bus 33	0.96	-0.017729	-0.004606	0.989451
Bus 34	0.96	-0.017729	-0.013409	0.969596
Bus 35	0.84	-0.075721	-0.070421	0.850313
Bus 37	0.87	-0.060481	-0.055439	0.880159
Bus 39	0.8	-0.09691	-0.091252	0.81049
Bus 45	0.96	-0.017729	-0.013409	0.969596

APPENDIX B3

Table B3: Result for Incident Energy Normalized

Bus ID	log I_a	Gap (mm)	log E_n	E_n
Bus 1	-1.024064	153	-1.8437132	0.014331341
Bus 2	0.00402	153	-0.7323544	0.185201978
Bus 3	-0.004606	13	-0.8956791	0.127151332
Bus 4	0.906387	32	0.11000435	1.288262446
Bus 5	-0.026964	13	-0.9198481	0.120268506
Bus 6	0.892001	32	0.09445308	1.242948347
Bus 7	-0.045735	13	-0.9401395	0.114778479
Bus 8	-0.136236	13	-1.0379711	0.091628143
Bus 9	0.496467	32	-0.3331192	0.464387827
Bus 10	0.515409	32	-0.3126429	0.486807353
Bus 11	-0.03158	13	-0.924838	0.11889457
Bus 12	0.521502	32	-0.903938	0.124756166
Bus 13	-0.008985	13	-0.9004128	0.125772941
Bus 14	-0.102062	13	-1.001029	0.099763339
Bus 15	0.796077	32	-0.0092408	0.978947129
Bus 16	0.902336	32	0.10562522	1.275337753
Bus 17	-0.000271	13	-0.890993	0.128530752
Bus 18	0.779122	32	-0.0275691	0.938492664
Bus 19	-0.004606	13	-0.8956791	0.127151332
Bus 20	-0.008985	13	-0.9004128	0.125772941
Bus 21	0.776214	32	-0.0307127	0.93172411
Bus 22	0.883508	32	0.08527215	1.216948355
Bus 23	-0.008985	13	-0.9004128	0.125772941
Bus 24	-0.01788	13	-0.9100283	0.123018866
Bus 25	0.85855	25	0.05059255	1.123550378
Bus 26	0.719278	32	-0.0922605	0.808610764
Bus 27	-0.000271	13	-0.890993	0.128530752
Bus 28	0.883508	32	0.08527215	1.216948355

Bus ID	log Ia	Gap (mm)	log En	En
Bus 29	0.000271	13	-0.890407	0.128704269
Bus 30	0.894093	32	0.09671453	1.24943749
Bus 31	-0.026964	13	-0.9198481	0.120268506
Bus 32	0.00402	13	-0.8863544	0.129910909
Bus 33	-0.004606	13	-0.8956791	0.127151332
Bus 34	-0.013409	13	-0.9051951	0.124395558
Bus 35	-0.070421	13	-0.9668251	0.107938132
Bus 36	0.509208	32	-0.3193462	0.479351232
Bus 37	-0.055439	13	-0.9506296	0.112039314
Bus 38	0.889897	32	0.09217866	1.236455973
Bus 29	0.000271	13	-0.890407	0.128704269
Bus 30	0.894093	32	0.09671453	1.24943749
Bus 31	-0.026964	13	-0.9198481	0.120268506
Bus 32	0.00402	13	-0.8863544	0.129910909
Bus 33	-0.004606	13	-0.8956791	0.127151332
Bus 34	-0.013409	13	-0.9051951	0.124395558
Bus 35	-0.070421	13	-0.9668251	0.107938132
Bus 36	0.509208	32	-0.3193462	0.479351232
Bus 37	-0.055439	13	-0.9506296	0.112039314
Bus 38	0.889897	32	0.09217866	1.236455973
Bus 39	-0.091252	13	-0.9893434	0.102484123
Bus 40	0.509208	32	-0.3193462	0.479351232
Bus 41	0.715826	32	-0.0959921	0.801692657
Bus 42	0.655404	32	-0.1613083	0.689750024
Bus 43	0.908394	32	0.11217391	1.294714208
Bus 44	0.902336	32	0.10562522	1.275337753
Bus 45	-0.013409	13	-0.9051951	0.124395558
Bus 46	0.924946	25	0.12236663	1.32546
Bus 47	0.924946	25	0.12236663	1.32546

APPENDIX B4

Table B4: Result of Incident Energy after converted from normalized

BUS ID	En	Cf	t (second)	Distance	x	E
Bus 1	0.009727177	1	0.359	910	0.973	2.63693
Bus 2	0.185201978	1	0.359	910	0.973	0.22526
Bus 3	0.127151332	1	0.359	455	2	0.41023
Bus 4	1.288262446	1.5	0.359	610	1.473	3.46865
Bus 5	0.120268506	1	0.359	455	2	0.38802
Bus 6	1.242948347	1.5	0.359	610	1.473	3.34664
Bus 7	0.114778479	1	0.359	455	2	0.37031
Bus 8	0.091628143	1	0.359	455	2	0.29562
Bus 9	0.464387827	1.5	0.359	610	1.473	1.25036
Bus 10	0.486807353	1.5	0.359	610	1.473	1.31073
Bus 11	0.11889457	1	0.359	455	2	0.38359
Bus 12	0.124756166	1.5	0.359	610	1.473	0.33591
Bus 13	0.125772941	1	0.359	455	2	0.40578
Bus 14	0.099763339	1	0.359	455	2	0.32186
Bus 15	0.978947129	1.5	0.359	610	1.473	2.63582
Bus 16	1.275337753	1.5	0.359	610	1.473	3.43385
Bus 17	0.128530752	1	0.359	455	2	0.41468
Bus 18	0.938492664	1.5	0.359	610	1.473	2.52689
Bus 19	0.127151332	1	0.359	455	2	0.41023
Bus 20	0.125772941	1	0.359	455	2	0.40578
Bus 21	0.93172411	1.5	0.359	610	1.473	2.50867
Bus 22	1.216948355	1.5	0.359	610	1.473	3.27663
Bus 23	0.125772941	1	0.359	455	2	0.40578
Bus 24	0.123018866	1	0.359	455	2	0.39689
Bus 25	1.123550378	1.5	0.359	455	1.641	4.89416
Bus 26	0.808610764	1.5	0.359	610	1.473	2.17718
Bus 27	0.128530752	1	0.359	455	2	0.41468
Bus 28	1.216948355	1.5	0.359	610	1.473	3.27663

BUS ID	En	Cf	t (second)	Distance	x	E
Bus 29	0.128704269	1	0.359	455	2	0.41524
Bus 30	1.24943749	1.5	0.359	610	1.473	3.36411
Bus 31	0.120268506	1	0.359	455	2	0.38802
Bus 32	0.129910909	1	0.359	455	2	0.41913
Bus 33	0.127151332	1	0.359	455	2	0.41023
Bus 34	0.12439558	1	0.359	455	2	0.40133
Bus 35	0.107938132	1	0.359	455	2	0.34824
Bus 36	0.479351232	1.5	0.359	610	1.473	1.29065
Bus 37	0.112039314	1	0.359	455	2	0.36147
Bus 38	1.236455973	1.5	0.359	610	1.473	3.32916
Bus 39	0.102484123	1	0.359	455	2	0.33064
Bus 40	0.479351232	1.5	0.359	610	1.473	1.29065
Bus 41	0.80162657	1.5	0.359	610	1.473	2.15838
Bus 42	0.689750024	1.5	0.359	610	1.473	1.85715
Bus 43	1.294714208	1.5	0.359	610	1.473	3.48602
Bus 44	1.275337753	1.5	0.359	610	1.473	3.43385
Bus 45	0.124395558	1	0.359	455	2	0.40133
Bus 46	1.32546	1.5	0.359	455	1.641	5.77367
Bus 47	1.32546	1.5	0.359	455	1.641	5.77367

APPENDIX B5

Table B5: Result of Flash Boundary

BUS ID	C_f	E_n	t	x	D_B (mm)
Bus 1	1	0.009727177	0.359	0.973	1348.962268
Bus 2	1	0.185201978	0.359	0.973	163.075706
Bus 3	1	0.127151332	0.359	2	266.0307847
Bus 4	1.5	1.288262446	0.359	1.473	1253.955677
Bus 5	1	0.120268506	0.359	2	258.7303622
Bus 6	1.5	1.242948347	0.359	1.473	1223.839989
Bus 7	1	0.114778479	0.359	2	252.7561148
Bus 8	1	0.091628143	0.359	2	225.8322081
Bus 9	1.5	0.464387827	0.359	1.473	627.2657208
Bus 10	1.5	0.486807353	0.359	1.473	647.668302
Bus 11	1	0.11889457	0.359	2	257.2482617
Bus 12	1.5	0.124756166	0.359	1.473	256.9983295
Bus 13	1	0.125772941	0.359	2	264.5848948
Bus 14	1	0.099763339	0.359	2	235.6442932
Bus 15	1.5	0.978947129	0.359	1.473	1040.70652
Bus 16	1.5	1.275337753	0.359	1.473	1245.401122
Bus 17	1	0.128530752	0.359	2	267.4699292
Bus18	1.5	0.938492664	0.359	1.473	1011.312559
Bus 19	1	0.127151332	0.359	2	266.0307847
Bus 20	1	0.125772941	0.359	2	264.5848948
Bus 21	1.5	0.93172411	0.359	1.473	1006.355183
Bus 22	1.5	1.216948355	0.359	1.473	1206.401384
Bus 23	1	0.125772941	0.359	2	264.5848948
Bus 24	1	0.123018866	0.359	2	261.6720267
Bus 25	1.5	1.123550378	0.359	1.641	1071.614445
Bus 26	1.5	0.808610764	0.359	1.473	914.0444138
Bus 27	1	0.128530752	0.359	2	267.4699292
Bus 28	1.5	1.216948355	0.359	1.473	1206.401384

BUS ID	C_r	E_n	t	x	DB (mm)
Bus 29	1	0.128704269	0.359	2	267.650411
Bus 30	1.5	1.24943749	0.359	1.473	1228.174027
Bus 31	1	0.120268506	0.359	2	258.7303622
Bus 32	1	0.129910909	0.359	2	268.9021343
Bus 33	1	0.127151332	0.359	2	266.0307847
Bus 34	1	0.12439558	0.359	2	263.1321493
Bus 35	1	0.107938132	0.359	2	245.1087907
Bus 36	1.5	0.479351232	0.359	1.473	640.9171226
Bus 37	1	0.112039314	0.359	2	249.7219163
Bus 38	1.5	1.236455973	0.359	1.473	1219.496514
Bus 39	1	0.102484123	0.359	2	238.8359692
Bus 40	1.5	0.479351232	0.359	1.473	640.9171226
Bus 41	1.5	0.80162657	0.359	1.473	908.6772423
Bus 42	1.5	0.689750024	0.359	1.473	820.52473
Bus 43	1.5	1.294714208	0.359	1.473	1258.21563
Bus 44	1.5	1.275337753	0.359	1.473	1245.401122
Bus 45	1	0.124395558	0.359	2	263.132126
Bus 46	1.5	1.32546	0.359	1.641	1185.158866
Bus 47	1.5	1.32546	0.359	1.641	1185.158866