MODELLING AND ASSESSMENT OF ENERGY LOSSES FOR MEDIUM VOLTAGE DISTRIBUTION NETWORK AT UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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in partial fulfillment of the requirements for the degree of
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2019

DECLARATION

I declare that this thesis entitled “MODELLING AND ASSESSMENT OF ENERGY LOSSES FOR MEDIUM VOLTAGE DISTRIBUTION NETWORK AT UNIVERSITI TEKNIKAL MALAYSIA MELAKA is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have checked this report entitled “MODELLING AND ASSESSMENT OF ENERGY LOSSES FOR MEDIUM VOLTAGE DISTRIBUTION NETWORK AT UNIVERSITI TEKNIKAL MALAYSIA MELAKA” and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

In preparing this report, I was in contact with many people, researchers, academicians and practitioners. They have contributed to my understanding and thought. I wish to express my sincere appreciation to my main project supervisor, Dr. Khairul Anwar Bin Ibrahim for encouragement, guidance critics and friendship. Without his continued support and interest, this project would not have been the same as presented here. I am also very thankful to Encik Mohd Faizuhar Bin Razali as electrical engineer at Pejabat Pembangunan UTeM for his guidance, advices and motivation.

My fellow undergraduate students who have made valuable comment and suggestion on this project which give me an idea to improve my project. I also want to express my deepest gratitude to all those who have directly and indirectly guided me in making this project. I really thank all the people for their help direct and indirect to finish this project. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

ABSTRACT

For energy planning and analytical purposes, information about losses and useful energy give a broader perspective on energy consumption and its harmful consequences for supplied energy consumption. When energy is consumed for end-use, some of the potential energy content is lost due to technical loss or non-technical loss. Technical losses (TL) in distribution network is causing substantial economic and financial losses annually to Universiti Teknikal Malaysia, Melaka. In this report, medium voltage actual feeders were developed using Digsilent Powerfactory Software and applied to energy flow model of Medium Voltage (MV) network to develop load flow graph to estimate energy inflow from 33/11 kV to 11/0.4 kV MV feeders and distribute to the load. The same MV actual feeders network also were applied to Quasi Dynamic Simulation of MV network to estimate its TL. Actual MV feeders were developed based on statistical analysis of MV feeders from Pejabat Pembangunan to categorize MV feeders according to their characteristics. The TL estimation approach and energy flow model is applicable to MV distribution network with energy meters at distribution interface substation, which register daily inflow energy and peak demand to the distribution networks. Feeder 7 has the highest energy consumption and energy losses because it has the most amount of load than other feeder. Feeder 7 estimated has 21,141.75 kWh energy consumption and 601.4636 kWh energy losses. Feeder 7 estimated cost for energy losses is RM222.54 per day. Feeder 4 and 5 has no load so its has no energy consumption but it has energy loss because of the leakage of electric flow. The TL estimation based on load flow over time can be developed into useful tool to evaluate TL of MV distribution network model in UTeM.

ABSTRAK

Untuk perancangan tenaga dan tujuan analisis, maklumat mengenai kerugian dan tenaga berguna memberikan perspektif yang lebih luas mengenai penggunaan tenaga dan akibat berbahaya untuk penggunaan tenaga yang dibekalkan. Apabila tenaga digunakan untuk kegunaan akhir, beberapa kandungan tenaga berpotensi hilang disebabkan kehilangan teknikal atau kehilangan bukan teknikal. Kerugian teknikal (TL) dalam rangkaian pengedaran menyebabkan kerugian ekonomi dan kewangan yang besar setiap tahun kepada Universiti Teknikal Malaysia, Melaka. Dalam laporan ini, feeder sebenar voltan sederhana dibangunkan menggunakan Perisian Digsilent Powerfactory dan digunakan untuk model aliran tenaga rangkaian Voltan Sederhana (MV) untuk membangunkan graf aliran beban untuk menganggarkan aliran masuk tenaga dari 33/11 kV ke 11 / 0.4 kV MV dan mengedarkan kepada beban. Rangkaian suapan sebenar MV yang sama juga digunakan untuk rangkaian Simulasi Dinamik Quasi untuk menganggarkan TLnya. Feeder MV sebenar telah dibangunkan berdasarkan analisis statistik feeder MV dari Pejabat Pembangunan untuk mengkategorikan feeder MV mengikut ciri-ciri mereka. Pendekatan anggaran TL dan model aliran tenaga boleh digunakan untuk rangkaian pengedaran MV dengan meter tenaga pada pencawang antara pengedaran, yang mendaftarkan tenaga aliran masuk harian dan permintaan puncak ke rangkaian pengedaran. Feeder 7 mempunyai penggunaan tenaga yang paling tinggi dan kehilangan tenaga kerana ia mempunyai jumlah beban yang paling banyak daripada feeder lain. Anggaran pengumpan 7 mempunyai 21,141.75 penggunaan tenaga kWh dan kehilangan tenaga 601.4636 kWh. Kos penganggar tenaga makanan 7 untuk kerugian tenaga ialah RM222.54 sehari. Feeder 4 dan 5 tidak mempunyai beban sehingga tidak mempunyai penggunaan tenaga tetapi ia mempunyai kehilangan tenaga kerana kebocoran aliran elektrik. Perkiraan TL berdasarkan aliran beban dari masa ke masa dapat dikembangkan menjadi alat yang berguna untuk menilai TL dari model jaringan distribusi MV di UTeM.

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LIST OF SYMBOLS AND ABBREVIATIONS

MV - Medium Voltage
TL - Technical Losses
LV - Low Voltage

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CHAPTER 1

INTRODUCTION

1.1 Background

Electricity losses occur at the power distribution process. Distribution reflects the overall operation to distribute electricity from power plants to consumer where it is utilized by homes, businesses and institutions. For more productive transportation of electricity, transformers are used to increase the voltage and decrease the voltage back to the suitable level for residential, commercial and industrial use. Power losses occur in both transmission and distribution lines and in transformers. It began from the step-up transformers that attach power plants to the transmission system and ending with the consumer wiring. [1]

Distribution losses refer to the dissimilarity between the amount of energy distributed to the distribution system and the amount of energy customer is charged. Distribution line losses consist of two types, which are technical losses and non-technical losses. Technical losses occur during transmission and distribution and involve substation, transformer and line related losses. Technical losses are due to a current flowing in the electrical network and generate the following types of losses:

i) Losses due to overloading and low voltage.

ii) Losses due to the poor standard of equipment.

iii) Unbalanced loading.

Load flow studies are important for planning the future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power flow study is the magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line. [3] [4]

1.2 Motivation

The purpose of power flow studies is to plan and account for various hypothetical situations. For example, if a transmission line is taken off line for maintenance, can the remaining lines in the system handle the required loads without exceeding their rated values. One of the ways to study power flow analysis in the distribution system was by calculate the electricity losses occur at the power distribution process.

In nature, during the process of transmitting and distributing electricity, the electricity loss was referred to as line losses. To reduce energy loss, electricity generated in power stations is raised to a very high voltage for transmission. A high transmission voltage means only a relatively small current flow through the transmission cables. The current produces a heating effect when flowing through the cables with resistance. Electricity has to be transmitted from large power plants to the consumers via extensive networks. The transmission over long distances creates power losses.

1.3 Problem Statement

Electricity loss during the transmitting and distributing electricity along the cable is one of the problems in the industry. This is because, the process to distribute electricity have a long distribution line, low power factor, overloading of lines and load imbalance among the phases. Load flow studies determine if system voltages remain within specified limits under normal or emergency operating conditions and whether equipment such as transformers and conductors are overloaded. Load flow studies are commonly used to optimize component or circuit loading. No research has been done in UTeM to analyze load flow analysis in UTeM.

The ability to understanding the technical losses and reduce its lead to having a stable and comfortable electricity at lower cost. Fighting non-technical losses leads to increase the income to the electrical company and make the company have an ability to make an improvement to the grid.

1.4 Project Objective

The main aim of this project is to propose a systematic and efficient methodology to estimate power losses in Medium Voltage (MV) distribution network with reasonable accuracy. The objectives are as follows:

i) To study the 33kV and 11kV network and load in UTeM.

ii) To model and perform load flow simulation 33kv and 11kv network model in UTeM using Digsilent Powerfactory software.

iii) To analyze energy losses of each medium voltage feeder and transformers in UTeM.

1.5 Project Scope

The project scopes included:

i) Design medium voltage model network in UTeM using Digsilent Powerfactory Software.

ii) Calculate energy losses in the cable for 33kV and 11 kV feeder and transformer from the main distribution substation in UTeM.

iii) Illustrate load flow simulation using Digsilent Powerfactory Software.

iv) Develop a systematic approach to estimating power losses for a medium voltage distribution network.

v) Analyze load flow profile in UTeM by electricity over time.

1.6 Project Report Summary

This report is arranged into five chapters and this section delivers a brief overview of the chapters.

Chapter 1: Introduction

This section will explain the main objectives of this report. It also consists of the introduction of load flow analysis and energy losses with project scopes.

Chapter2: Literature Review

This section provides the simple concept and explanation based on the previous work of related literature studies. Two categories of losses in power system which is technical and non-technical losses also been reviewed in this section

Chapter 3: Methodology

This section, the project flow and methodology to accomplish this project is stated. The load flow profile will be discuss in this section.

Chapter 4: Result and Discussion

This section shows the single line diagram of the medium voltage distribution network model in UTeM by using Digsilent Powerfactory Software. The technical losses were studied using load flow profile produced by the software by inserting the data that has been collected from Pejabat Pembangunan UTeM.

Chapter 5: Conclusion and Future Works

This section concluded the whole methodologies that have been used in this project. The suggestion of works that need to add on in this project is included in this section.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays, energy efficiency was identify as key strategies to address rising issues in rising fuel cost, market competition, tightening regulation, climate changed and energy crisis due to decreasing fossil fuels resources. Energy losses occur in the process of supplying electricity to consumers due to technical losses. The technical losses are due to energy dissipated in the conductors and equipment used for transmission, transformation, sub-transmission and distribution of power. These technical losses are essential in a system and could be reduce to an optimum level. Over extensive geographical areas, power distribution networks in each supply stretched and have large variety of characteristics. The losses in MV was group in Sub transmission losses, which are involving 33kV and 11kV. To analyze the power and energy flow its related technical losses for every distribution circuit normally need immense data input and precise computation effort. It is essential to develop an effective power losses estimation methodology, which is practically suitable for utilities.

2.2 Medium Voltage Network Model

Distribution substations connect to the transmission system and lower the transmission voltage to medium voltage ranging between 2 kV and 35 kV with the use of transformers. Primary distribution lines carry this medium voltage power to distribution transformers located near the customer's premises. Distribution transformers again lower the voltage to the utilization voltage used by lighting, industrial equipment or household appliances [5]. Voltages from 600 V to 69 kV are referred to as “medium voltage,”. Medium voltage fuses are those intended for voltage range from 2400 to 38000 VAC [6]. Medium voltage distribution implies a medium voltage or higher service voltage and will result in higher costs of equipment, installation, and maintenance than low voltage distribution. However, this must be consider along with the fact that medium voltage distribution will generally result in smaller conductor sizes and will take control of voltage drop easier [7].

When designing a Medium Voltage (MV) distribution system, special attention must be gave to equipment dimensions, ratings, and their tolerances. The equipment dimensions are greater for MV systems as compared with Low Voltage (LV) systems. Therefore, space dedicated to equipment becomes very important and should be allocate early in the design process.

MV equipment does not have the same flexibility as LV equipment. For LV systems, there are circuit breakers of all sizes, and larger breakers are equipped with easily adjustable trip units. For simple MV systems, fused switches can be using for protection, and these fuses come in many sizes as well. However, in complex MV distribution systems, such as in mission-critical facilities, using MV breakers becomes a necessity. The smallest circuit breaker for a nominal 13.8 kV system (15-kV switchgear) was rate at 1200 amps. The next size up is 2000 ampere, then 3000 amperes. The great advantage of MV systems is that the current is low, but there is currently no breaker small enough for these systems. [8]

2.3 Losses in Electrical Distribution System

Total power losses of distribution network was define as a difference between registered income energy from the transmission system and the sum of registered and supplied (output) energies to end-users. There are two categories of losses in the power system, which is technical and non-technical losses. It is very important to get the actual values of both losses forms to improve many activities in distribution network [6].

Energy losses occur in the process of supplying electricity to consumers due to technical and non-technical losses. Technical losses known as power dissipation in transmission lines due to the impedance of the line. These technical losses are inherent in a system and can be reduce to an optimum level. Technical losses can be determined by using various techniques such as load flow. Nontechnical losses are a phenomenon, which spread in all countries especially poor countries. Non-technical losses known as theft of the electricity this leads to economic damage in the electricity industry [9].

The losses in any system depend on the pattern of energy use, intensity of load demand, load density, and potential and design of the transmission and distribution system that vary for various system elements. A clear understanding of the magnitude of technical and non-technical losses is the first step to reduce transmission and distribution loss. This system helps the utility in bringing accountability and efficiency in its working. [10]

2.4 Load Flow Studies

A load flow study is a steady state analysis whose target is to determine the voltages, currents, and real and reactive power flows in a system under given load conditions. The purpose of load flow studies is to plan and account for various hypothetical situations [3].

A load profile defines how an electricity customer uses its electricity over time. It is created using measurements of a customer's electricity use at regular intervals, typically one hour, thirty or fifteen minutes, and provides an accurate representation of a customer's usage pattern [11].

Load flow analysis is the most important and essential approach to investigate problems in power system operating and planning. Based on a specified generating state and transmission network structure, load flow analysis solves the steady operation state with node voltages and branch power flow in the power system. The system can operate safely if there are equipment overloads, or some node voltages are too low or too high. [4]

Load-flow studies are probably the most common of all power system for analysis calculations. They used in planning studies to determine when specific elements will become overloaded. Major investment decisions begin with reinforcement strategies based on a load-flow analysis. In operating studies, a load-flow analysis was use to ensure that each generator runs at the optimum operating point; demand will be met without overloading facilities and maintenance plans can proceed without undermining the security of the system [12].

The objective of load flow analysis is to produce the following information:

- Voltage magnitude and phase angle at each bus.

- Real and reactive power flowing in each element.

- Reactive power loading on each generator.

2.5 Implementation of Load Profile

Load profile was use to improve operational efficiency and enhance power grid reliability. Consumers come from all type; completely have different electrical consumption patterns. Load profiling, which refers to an electricity consumption pattern for a customer over a given period, was perform. The Load Servicing Entities (LSEs) will emerge in large numbers and form a more competitive electricity market, especially on the demand side, thus challenging the current distribution and supply structures. In this context, LSEs would be need to make full use of detailed electrical power consumption data of individual customer obtained by Advanced Metering Infrastructure (AMI) to gain a better understanding of consumer behavior. [10]

Load profiling has many applications including demand response, load forecasting, and non-technical loss detecting, etc. Demand response is an effective way of promoting the accommodation of renewable energy and reducing the difference between peaks and valleys of electrical load [11] [12]. The electricity consumption data and load profiles extracted from these data are vital for demand response studies. [13–17].

This help both LSEs and electrical customers enhance the understanding of electrical consumption patterns for realizing personalized power management and activating the interaction between LSE and electrical customers in a competitive electric power retail market. [18]

2.6 Methodology to Evaluate Technical Losses.

To develop an effective way to manage technical losses in the distribution system is to identify the location, sources and level of technical losses in the system. This will assist utilities to determine the optimum selection of technical losses reduction options. A considerable amount of research was found to concentrate on the development of different methods to measure and evaluate the distribution of technical losses. [19]

In general, to determine technical losses in the distribution system is based on energy metering data [20]. Technical losses can be calculated as the difference between the energy input at the main substation and the sum of the power that is delivered to the destination nodes in the same period, as shown in Equation (**2-1** [21], [22]. Non-technical losses contribution was neglected. However, if non-technical losses (NTL) was considered, technical losses (TL) can be determined as a difference between E_{loss} and E_{loss}^{NTL}, as shown in Equation 2.2.

$$E_{loss} = E_{source} - \sum_{V_i} E_{destination}(i) \qquad (2\text{-}1)$$

$$E_{loss}^{TL} = E_{loss} - E_{loss}^{NTL} \qquad (2\text{-}2)$$

Where:

E_{loss} = Technical losses in the distribution network in MWh

E_{source} = Total energy delivered o the distribution network measured at source in MWh

$E_{destination}$ = Energy measured at the destination meters

i = Destination energy meter

E_{loss}^{TL} = Technical losses in MWh

E_{loss}^{NTL} = Non-technical losses in MWh

The main advantage is it does not require vast operational and network data as well as a complex and sophisticated computational model to calculate total distribution losses. Total distribution losses for each network and entire system are easy to obtain and widely used by utilities since energy inflow data from grid supply system and normally captured in real-time at the system level using data located at distribution interface substation, as well as the total energy billing data of the customer end [23].

Besides, technical losses can also be calculated using I^2R loss formulae in distribution feeder and transformer. In [23], Chang using I^2R formulation to determine annual technical losses which is for both active and reactive losses for primary feeder, transformer and considered technical losses reduction due to the capacitor bank. This method assumed constant voltage throughout feeder. The method also considered a combination of concentrated and uniformly distribution loads, which require load data at the start and end of each feeder. Furthermore, the validation and accuracy of the method are unknown. In [24], Schultz proposes an analysis of I^2R losses on idealized primary distribution system feeders.

The technical losses are calculated based on load density, which is calculated using extensive parameters, including feeder voltage, current, impedance, and length, the spacing between laterals, power factor, load density, and thermal limitations. The validation and accuracy are also unknown. Let us consider a simple three-phase radial transmission line between two points of source and load as illustrated in single line diagram of Figure 2-1, comprising the generated power (pg) line resistance, reactive (jx) and the load. [30]

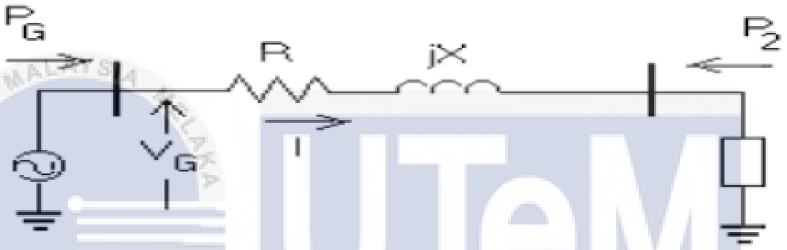

Figure 2-1: Single Line Diagram

We can deduce that the line loss is using Equation (**2-3**

$$P = I^2R \tag{2-3}$$

Where

I = the current

R = Resistance of the conductor

In 3 phase, we can calculate line loss using Equation (**2-4**:

$$P_{loss} = 3I^2R \tag{2-4}$$

Where:

R = Is the resistance of the line in ohms per phase.

The current I can be obtain by Equation 2.5:

$$|I| = \frac{Pg}{\sqrt{3}\, Vgcos\emptyset g} \tag{2-5}$$

Where;

P_g is the generated power (load power and losses)

V_g is the magnitude of the generated voltage (line-to-line)

$Cos\emptyset_g$ is the generator power factor

Combining the above two equations, we have Equation 2.6:

$$P_1 = \frac{R}{|V_g|^2 COS^2\emptyset_g} {P_g}^2 \tag{2-6}$$

Assuming fixed generator voltage and power factor, we can write the losses as Equation 2.7:

$$P_1 = B{P_g}^2 \tag{2-7}$$

Where in this case, Equation 2.8: [9]

$$B = \frac{R}{|V_g|^2 cos^2\emptyset_g} \tag{2-8}$$

In addition, technical loss for MV distribution can be determined using load flow simulation. This approach eliminates solving complex and non-linear equations through an iterative process. [25], [26]. With an advancement in computers software technologies, load flow simulation can be perform for large network model in a significantly short amount of time. The load flow simulations allow users to study technical losses performance of distribution network under different loading conditions and network configurations. By having a detailed network and load modelling, the technical losses can easily be evaluat as a total value or at every different part of the distribution network. The users can carry out load flow simulations where system element behavior varies with time due to the important features in load flow software capable to perform time interval solution to obtain the technical losses in MWh [27], [28] and [29].

The main advantage of using load flow, it eliminates rigorous effect to individually measure and calculate the voltage, current and energy flow in each and every component of the network using complex non-linear equations. The accuracy of the technical losses obtained using load flow simulation is generally very high and more realistic and limited by the accuracy of input data and the tolerance of the iterative process.

2.7 Load Profile for Finding Energy Loss.

Some of the input energy is dissipate in the conductors and transformers along the delivery route. Losses increase the operating cost, estimated to add 10% to the cost of electricity and approximately 25% to the cost of delivery. These costs was levied on the consumers [36]. The losses in a distribution system contribute to a major part of losses in a power system. Therefore, the distribution system loss has become one and more of concern, because of the growth of load demand and the wide area it covers. It is important to estimate them accurately in order to take appropriate measures for reducing the losses. The loss factor can be use to calculate energy losses for those parts of the electric system where the current flowing is proportional to system load each hour, which would typically be the distribution and transmission system. [32]

In a power system, a load curve or load profile is a chart illustrating the variation in demand or electrical load over a specific time. A load profile will vary according to customer type examples residential, commercial and industrial, temperature and holiday seasons. Generation companies use this information to plan how much power they will need to generate at any given time. A load duration curve is similar to a load curve. The information is the same but presented in a different form. These curves are useful in the selection of generator units for supplying electricity.[33] The load profile of electricity usage is important to the efficiency and reliability of power transmission.

In retail energy markets, supplier obligations settled on an hourly or sub-hourly basis. For most customers, consumption measured on a monthly basis, based on meter reading schedules. Load profiles used to convert the monthly consumption data into estimates of hourly or sub-hour consumption in order to determine the supplier obligation. For each hour, these estimates are aggregated for all customers of an energy supplier, and the aggregate amount is used in market settlement calculations as the total demand that must be covered by the supplier.[34]

CHAPTER 3

METHODOLOGY

3.1 Introduction

In general, there are two requirements to evaluate technical losses for the power utility, which is accuracy and effectiveness. The more accurate the model, the higher the resources it requires. The ability of the model to estimate technical losses with the least resources but reasonable loss of accuracy was called effectiveness. The general concept behind the proposed model is that it provides the user with the ability to produce an accurate estimation of technical losses system in the distribution network.

Load flow studies provide a systematic mathematical approach for the determination of various bus voltages, phase angle active and reactive power flows through different branches, generators and loads under steady state conditions. It analyses the power systems in normal steady-state operation. A number of software implementations of power flow studies exist. Load flow study is important for planning the future expansion of the power system as well as in determining the best operation of existing systems. [31]

3.2 Project Design

The selected approach was based on the quantitative type, which aims to develop an analytical model to calculate and analyze the technical losses on medium voltage distribution network component, which is medium voltage feeders and transformers. The method is experimental, which utilize empirical modelling and statistical approach.

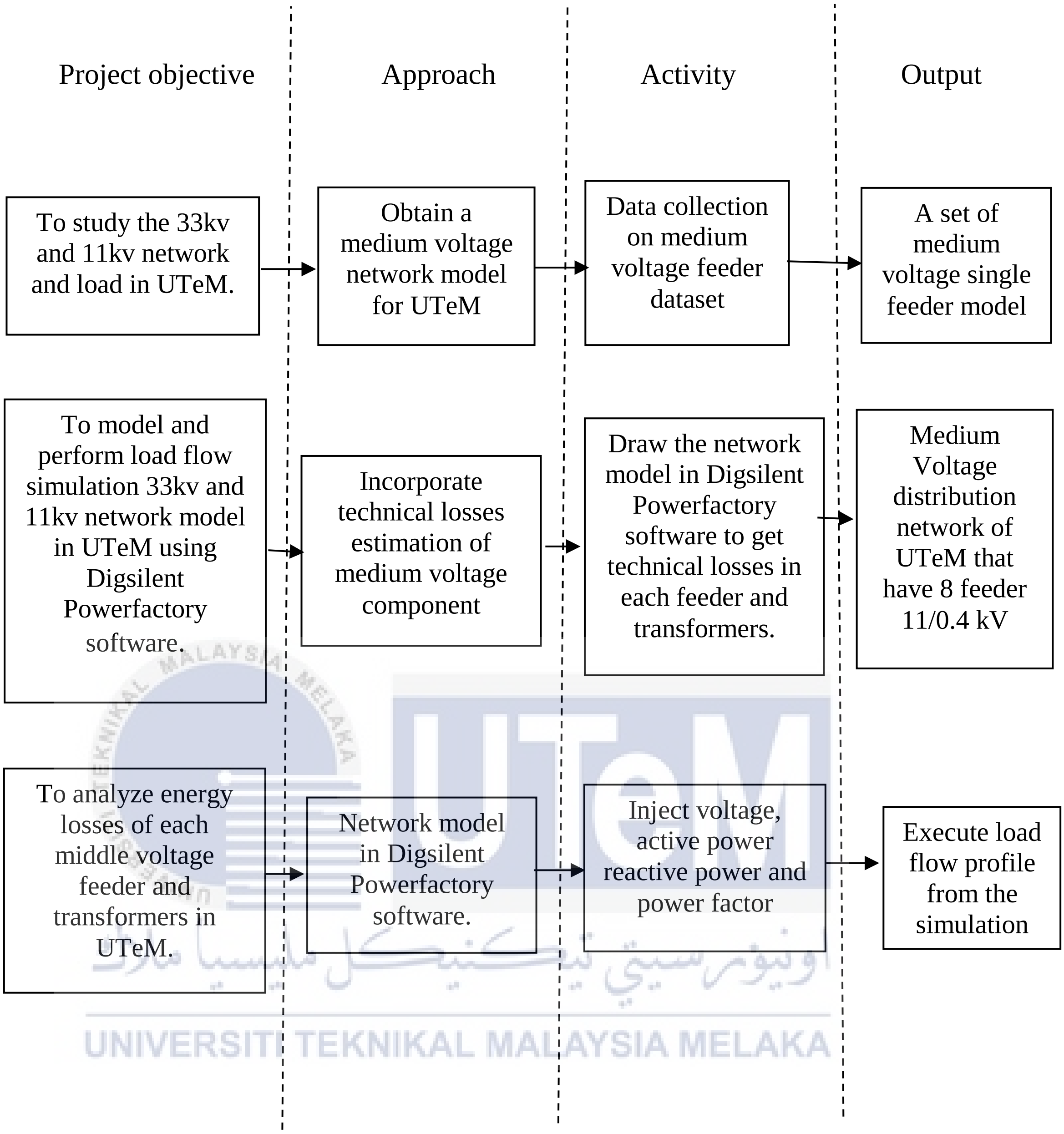

Figure 3-1: Experimentation Design

3.3 Proposed Implementation

The implementation of the experiment process is systematically organized into four main phase

a) Preliminary study
b) Data collection
c) Proposed model and methodology
d) Case study or application to validate the proposed method

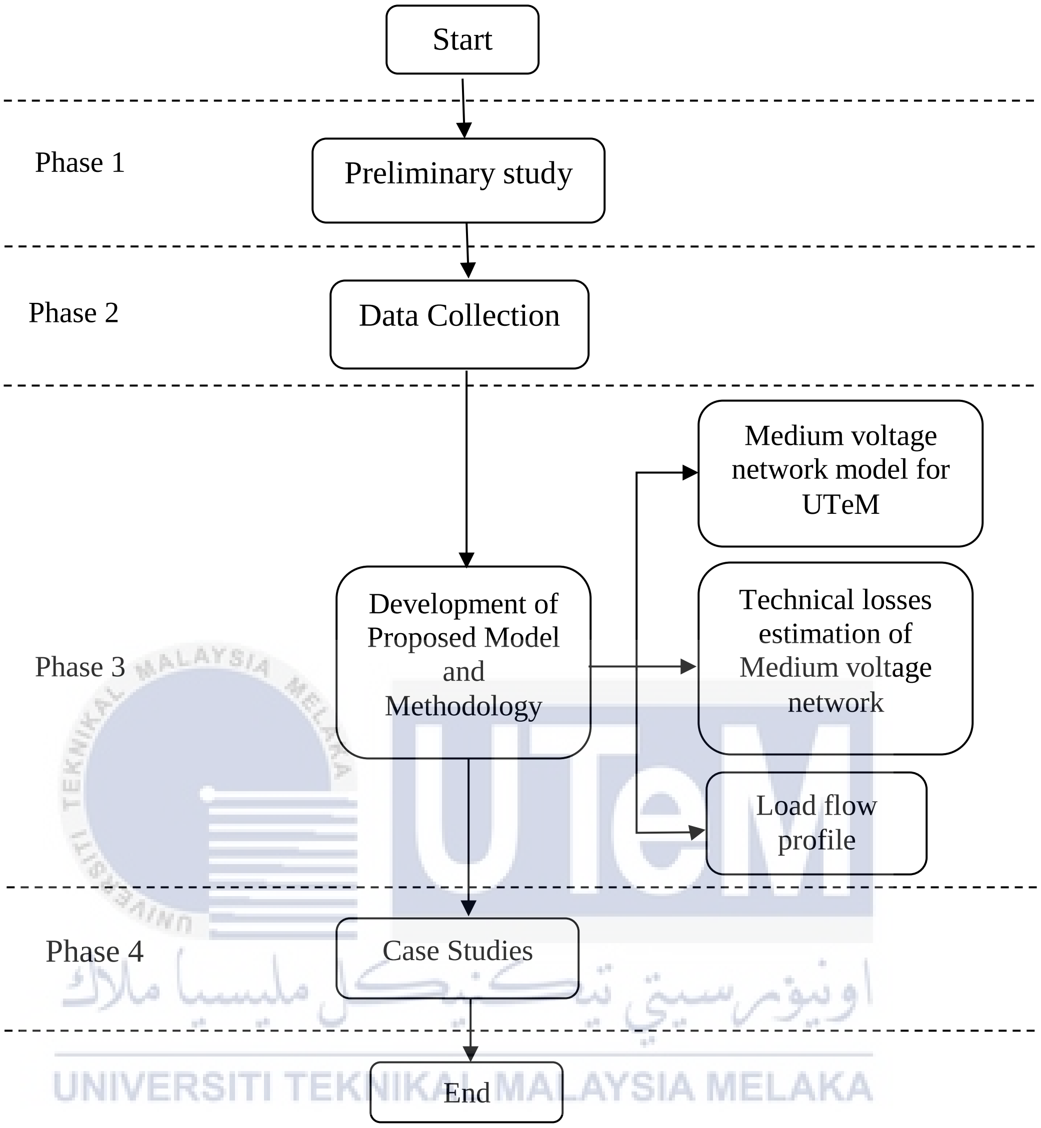

Figure 3-2: Flowchart of experimentation implementation

3.3.1 Phase 1: Preliminary Study

This phase involved on gathering information task, which is then analyzed and reviewed to generate the experiment specifications, which consists of problem statement, objectives and scope as, presented in Chapter 1. Figure 3.3 shows the overall preliminary study phase.

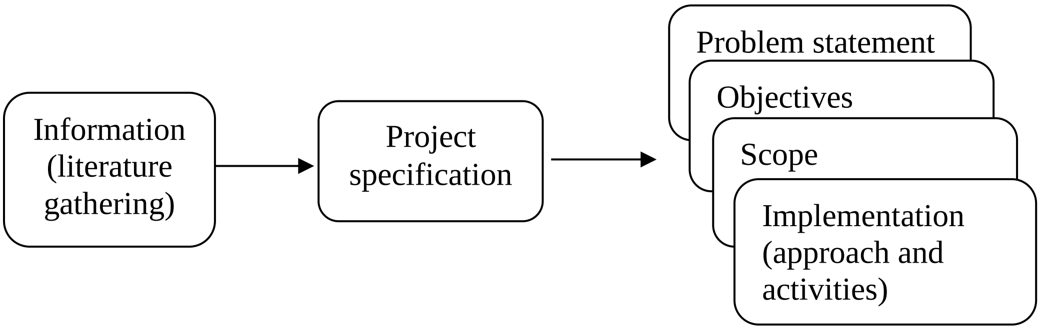

Figure 3-3: The preliminary study case

3.3.2 Phase 2: Data Collection

This phase obtained network data samples from Pusat Pembangunan UTeM and the energy data are based on typical substation operating values. Particularly the source of data including, shown in Figure 3.4:

i) Medium voltage feeder and transformer data

ii) Samples of real distribution network drawings and configuration

iii) Standard practice, guidelines and specifications of distribution network design and operation.

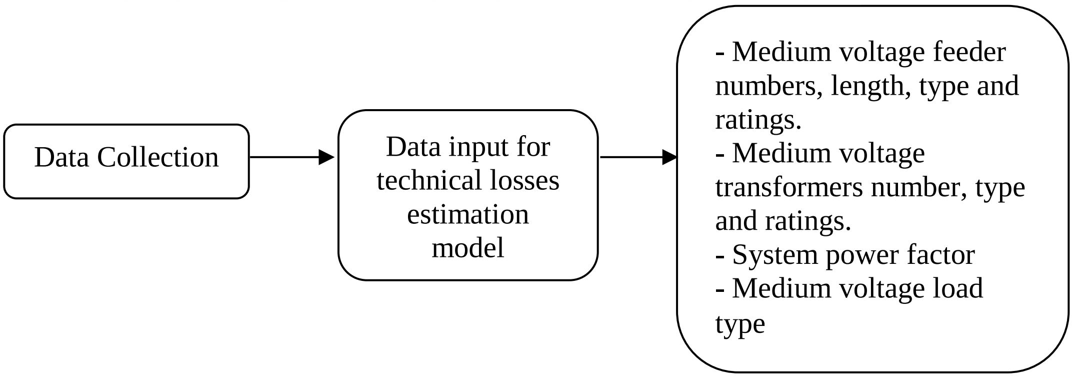

Figure 3-4: Data collection

3.3.3 Phase 3: Development of Proposed Technical Losses Estimation

This phase aim is to design and construct an efficient method to develop a medium voltage distribution network and estimate the technical loss. The proposed technical losses estimation model and method will be explain in detail. Figure 3.5 and Figure 3.6 shows the general technical losses estimation model.

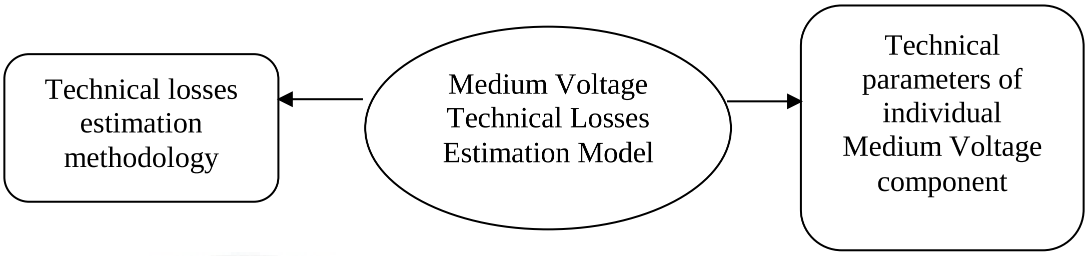

Figure 3-5: Technical losses estimation model

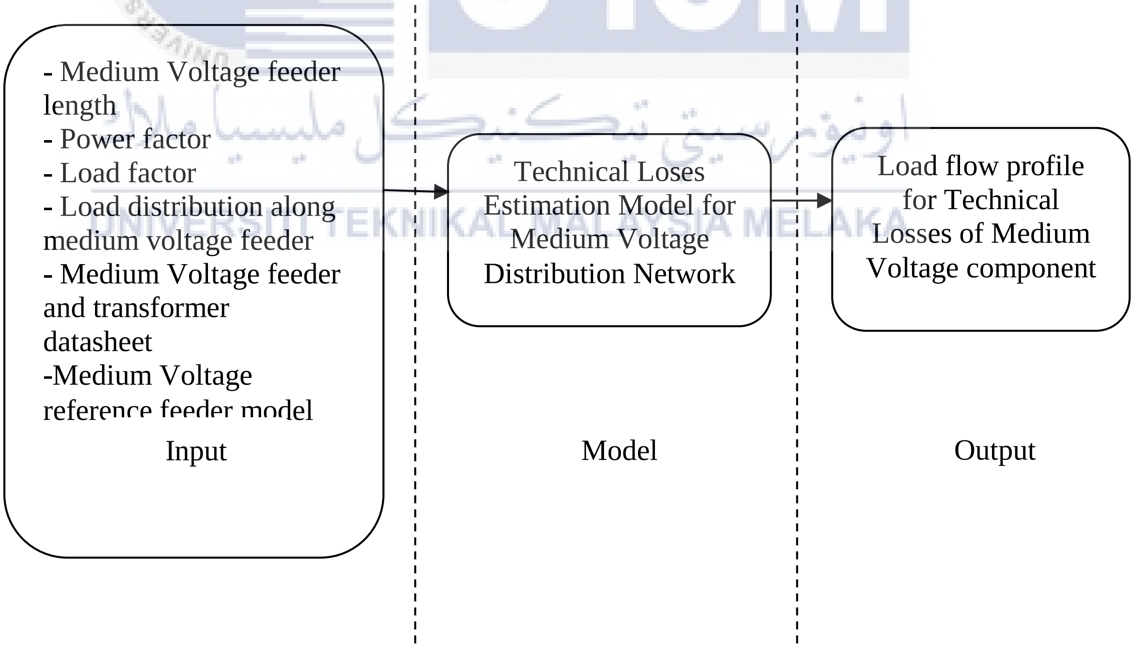

Figure 3-6: Data of the Technical Losses estimation model

3.3.4 Phase 4: Case Studies

Phase four aims to present the applicability of the proposed technical losses estimation model through case studies, as shown in Figure 3.7. The case study networks are based on real utility scale distribution network in Universiti Teknikal Malaysia, Melaka (UTeM), representing an eight feeder line of medium voltage network.

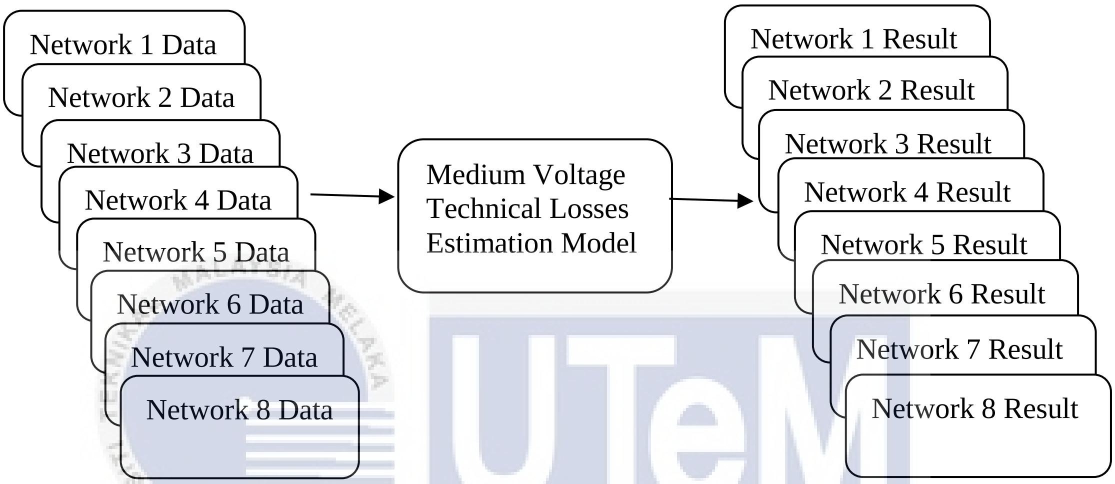

Figure 3-7: Case studies

From literature surveyed, the most accurate method to verify the results of any loss estimation methods is using actual field measurement of energy losses of a medium voltage feeder and compare it to estimated values. However, this is not reasonable in this work due to limited resources and difficulties to obtain the real medium voltage feeder energy measurement for the each of the load connected in each medium voltage feeder. So, in this project, the technical losses results obtained from the proposed method using one approach, which is time series load flow simulations. As shown in Figure 3.8,

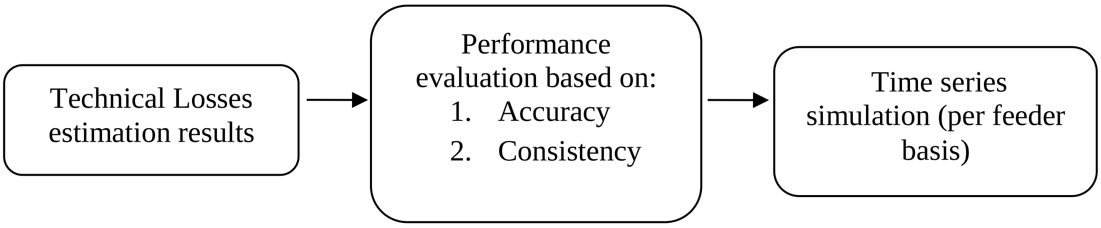

Figure 3-8: Performance evaluation of the time series simulation

The accuracy and consistency of the mathematical equation model to estimate technical losses of individual medium voltage feeders are test against the results obtained from load flow simulation of the same feeder. The medium voltage actual feeder was model in Digsilent Powerfactory software with different structure in terms of feeder type, peak demand, and length and load distribution. The load model connected to the feeders also consists of several type 24-hours load profile and a power factor of 0.85. The time series load flow is then simulated in each type of feeder structure on feeder per feeder basis to determine the daily energy infeed, energy losses and the percentage of energy losses

3.4 Gantt Chart and Key Milestone

3.4.1 Gantt Chart

Tasks	October				November				December				February				March				April				May			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Literature Review	■	■	■	■	■	■	■	■	■																			
Significant finding of Project Title	■	■	■	■	■	■	■	■	■																			
Developed Metthodology using Digsilent Powefactory Software				■	■	■	■	■	■																			
Collecting and Analyze Data					■	■	■	■	■	■																		
Writing Report			■	■	■	■	■	■	■	■	■	■																
Presentation PSM 1									■	■	■	■																
Collecting more data													■	■	■	■	■	■	■	■	■	■	■	■				
Do an analysis													■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Writing Report		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Presentation PSM 2																												■
Send Final Report																												■

Figure 3-9: Gantt Chart

3.4.2 Key Milestone

Table 1 : Key Milestone

Project Progress	Duration
Collect all of Journal and Literature Review	12 October 2018
Collect the initial data	19 October 2018
Perform analysis for data collected	26 October 2018
First seminar PSM 2018/2019	21 November 2018
Writte progress report draft	1 December 2018
Submit report	10 December 2018
Collect the data	15 February 2019
Do a final analysis	29 April 2019
Write progress report draft	1 May 2019
Submit Report	24 May 2019
Second Seminat PSM 2018/2019	29 May 2019

3.5 Development of Medium Voltage Network Model

Distribution feeders and its load characteristics are never the same for every feeder. So, making any type of assessment of power distribution network involves time-consuming and complex analysis due to a large number of network data sets and related criterion required. This simplified and actual feeder model could help to reduce the amount of data to be handle and simplify the estimating technical losses. Therefore, the aim of this section to establish a set of feeders that will be use to effectively estimate the technical losses of the entire medium voltage distribution system in UTeM.

There are only seven parameters were used for this project, which is:

i) Network location

ii) Type and the total number of 33kv feeders

iii) The total number of 33kv transformers, type and capacity.

iv) Total number and type of 11kv feeders

v) Total 33kv feeder length

vi) Total 11kv feeder length

3.6 Limitation of The Technical Losses Estimation Model

The primary focus of this work is to develop an effective methodology to estimate TL reasonably accurate results. Therefore, considering this, several assumptions and simplifications have to be made, described in the subsequent paragraph. It is also important to note that, these limitations and assumptions could potentially be the source of error in the accuracy of the estimation, hence, could be improve for future research work. The following lists out the current limitations and assumptions made during the development of the proposed model.

1. Limitations on the sources of TL

This work primarily calculates only the technical losses of medium voltage equipment. The losses calculated are only contributed by medium voltage feeders and transformers. All other losses in auxiliary medium voltage equipment are not considered in this work. Also, the non-technical losses are also not considered.

2. The assumption on loss reduction components

The model proposed does not consider the installation of any TL reduction components, such as capacitor bank.

3. The assumption on Load related - Peak Demand or Power factor

The load model for each MV feeder used is estimated based only on actual sample load profile of one day period and is not considering the effect due to different day seasons of the year. In addition, the load connected of all three phases in each feeder are assume balanced. If estimated values of phase loads are unbalanced, then, the feeder current in some phase will increases significantly, which is not consider here.

4. The assumption on equipment characteristics

The medium voltage losses estimation model assumed that there was no multiples taping of medium voltage feeders which all laterals and lines in the same feeders used cable size of similar physical and electrical characteristics. In addition, the medium voltage feeder and transformer type was assume the same for all network.

Further simplification is also introduce for the medium voltage network, as follows:

i) The power factor of all the loads is assume to be equal to the power factor of the feeder as measured at the transmission distribution interface substation.

ii) The unbalance between phases was neglected and a balanced 3-phase equivalent was used for load flow simulation.

iii) The voltage is considered constant for the feeders

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The chapter presents the results and analysis on the development of the medium voltage network model and power loss involving technical losses in the distribution network. The actual feeder was use to establish a methodology to estimate technical losses for medium voltage distribution system. Case studies are performe to demonstrate the applicability of the proposed system technical losses estimation method. The case studies was based on a real utility scale medium voltage distribution network in UTeM. It is important to note that, these case study aims at illustrating the proposed methodology, concerned of the location of area served by the network. Technical losses of medium voltage distribution network is estimated using actual sample load profile approach over a 1-day period. The results was validated based on the time series simulation results of the actual feeder as well as the technical loss estimation results, all the relevance information was provided by Pejabat Pembangunan UTeM.

4.2 Results of Medium Voltage Actual Feeder Model Development

This subsection discusses the work to generate a very general and descriptive mode of eight (8) medium voltage feeder for the UTeM medium voltage distribution network. Then, using medium voltage feeder characteristics, eight actual feeders a was constructed in Digsilent PowerFactory based on Appendices A. These eight feeders were distributed electricity to all substations in each building in UTeM. The incoming supply from Tenaga Nasional Berhad (TNB) is 33kV. The voltage that was supply from main substation was step down by transformers the voltage from 33kV to 11kV. The electricity was distributed to eight feeders and the transformers step down the voltage from 11kV to 0.4kV to distribute electricity to load

In general, characteristics of feeders in the distribution network can be classify based on its length, load distribution along the feeder, type of cable and feeder rating. In most cases, these parameters can used to estimate technical losses of the respective feeders accurate. The characteristics of the medium voltage feeder shown in Appendices B.

Consequently, based on the same analysis on the eight feeders, a set of medium voltage actual feeder is then develops, focusing on representing the actual individual feeders of different attributes such as load distribution along feeder, load power factor and load maximum demand. Although these feeders are quite general, they are reasonably accurate to represent the different classification of medium voltage feeders in UTeM. The characteristics of the medium voltage load shown in Table 2.

Table 2: Load Characteristics

From node	Component	Voltage (kV)	S (MVA)	Pf
S1	LOAD FTMK	11	1.18	0.85
S2	LOAD LIBRARY	11	0.29	0.85
S3	LOAD PBPI	11	0.31	0.85
S4	LOAD SATRIA	11	2.28	0.85
S5	LOAD PJBT KESELAMATAN	11	0.47	0.85
S6	LOAD DEWAN CANSELOR	11	0.103	0.85
S7	LOAD FKP	11	2.24	0.85
S8	LOAD LESTARI	11	0.588	0.85
S9	LOAD FKEKK	11	1.12	0.85
S10	LOAD FKE	11	1.53	0.85
S11	LOAD MVT	11	0.588	0.85
S12	LOAD PJBT PMBNGUNAN	11	0.11	0.85
S13	LOAD KOMPLEKS SUKAN	11	0.12	0.85
S14	LOAD CANSELOR	11	0.71	0.85

In the development of actual feeder for medium voltage distribution network, the transformer losses also considered to find the technical losses for the feeder. Therefore, transformer characteristics is shown in Table 3.

Table 3 : Transfromer Characteristics

Component	Load losses 100% load (W)	No load losses at rated voltage (W)	No load current (%)
T1, 33/11 kV Tx, 10/15 MVA	80000	11500	10
T2, 33/11 kV Tx, 10/15 MVA	80000	11500	10
T3, 11/0.4 kV , 2000KVA (FTMK)	13000	3800	0.6
T4, 11/0.4 kV , 1250KVA (LIBRARY)	11000	2600	0.7
T5, 11/0.4 kV , 2000KVA (PBPI)	13000	3800	0.6
T6, 11/0.4 kV , 1250KVA (SATRIA)	11000	2600	0.7
T7, 11/0.4 kV , 1250KVA (PJBT KSLMATAN)	11000	2600	0.7
T8, 11/0.4 kV , 2000KVA (DEWAN CANSELORI)	13000	3800	0.6
T9, 11/0.4 kV , 1250KVA (FKP)	11000	2600	0.7
T10, 11/0.4 kV , 2000KVA (LESTARI)	13000	3800	0.6
T11, 11/0.4 kV , 2000KVA (FKEKK)	13000	3800	0.6
T12, 11/0.4 kV , 2000KVA (FKE)	13000	3800	0.6
T13, 11/0.4 kV , 1500KVA (MVT)	12000	3100	0.7
T14, 11/0.4 kV , 1500KVA (PJBT PEMBANGUNAN)	12000	3100	0.7
T15, 11/0.4 kV , 2000KVA (KOMPLEKS SUKAN)	13000	3800	0.6
T16, 11/0.4 kV , 2000KVA (CANSELORI)	13000	3800	0.6

The extraction of dominant characteristics of feeder is based on the rule that each actual feeder is created by the actual value of the parameters associated with the real feeder allocated to the subdivide group. The length along the feeder is based on estimation. Statistical analysis is use to find the actual parameter relevant to the design.

The values of relevant network parameters under each feeder is shown in Appendices B. Figure shown the single line diagram of the medium voltage network.

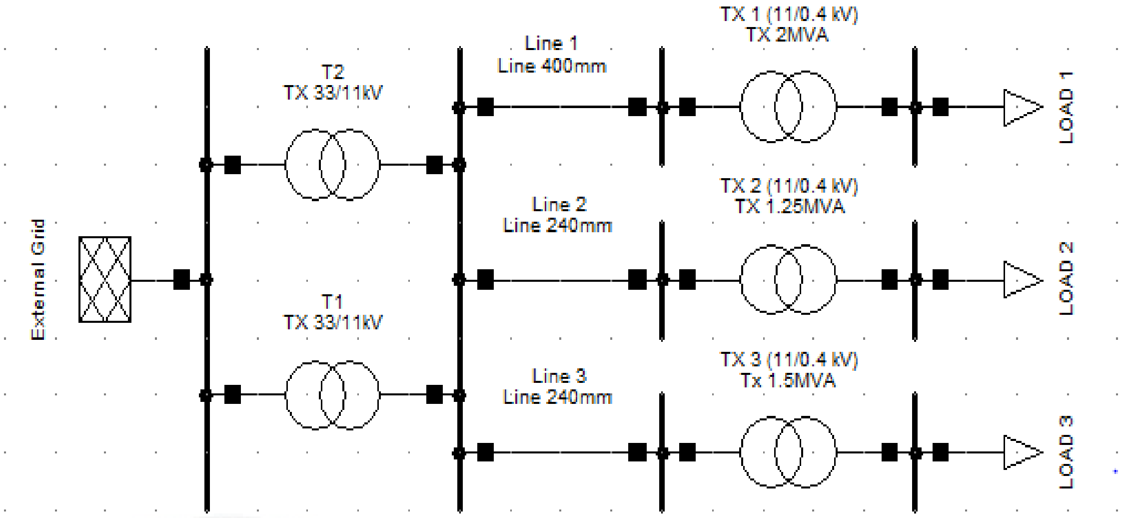

Figure 4-1: Single line diagram for network with 11/0.4 kV feeder

4.2.1 Actual Feeder Model

In general, characteristics of feeder in distribution network can be classified based on its length and, peak power demand, installed capacity and load profile. In most cases, these parameters can be used to estimate technical losses of the actual feeders accurately by comparing similar feeders with known technical losses [35]. Hence, the part of the work is established a set of actual feeder characteristics of medium voltage distribution network based on statistical analysis.

Based on, the same analysis on the eight actual feeder, a set of medium voltage actual feeder are the developed, focusing on representing he actual individual feeders of different attributes such as load segment composition, line length along the feeder and power demand. Although this actual feeder was quite general, there are reasonably accurate to represent the different classification of medium voltage feeders in UTeM for future. The characteristics of the medium voltage actual feeder are show in Appendices B and illustrated in Figure 4-1. In UTeM's medium voltage network, there are various type of load demand from different substation for different building as shown in Table 2

4.2.2 Estimating Network Technical Losses Based On Actual Feeder Characteristics.

By using medium voltage actual feeder characteristics, eight actual feeder MV distribution network for UTeM was construct in Digsilent PowerFactory based on Figure 4-1. Time interval for load flow simulation was set at 15 minutes are performed on all approximated actual feeder model to obtain the total estimated technical losses of each feeder in medium voltage distribution network at UTeM. The methodology, results and analysis can be found in the next section.

It is important to note that, these results only represent an overall value of technical losses for a complete network feeder by feeder. For effective and targeted approach of technical losses mitigation, it is important for utilities to be able ascertain which feeders and transformers that contributes the highest and lowest level of technical losses. Therefore, this model can be used to estimate technical losses for specific feeders found in actual network. This approximated actual network models configuration was in fact not much different from what is actually found in the system.

4.3 Load Flow Simulation Network Model

In this section, the aim to model and perform load flow simulation 33kV and 11kV network model in UTeM using Digsilent Powerfactory software. Technical losses can be simply calculated using load flow method of power system. The technical losses was computed using appropriate load-flow studies simulated using Digsilent Powerfactory software environment. Every feeder has a different amount of load. Therefore, each feeder has a different amount of losses. The list of load for each of feeder is show in Table 4. All the data for power inflow in each of 11/0.4 kV feeder was obtained from Pejabat Pembangunan for every 15 minutes in a day. The results of power inflow for each load that have been obtained is shown in Table 4. There was no load at feeder 4 and 5, so no power inflow to feeder 4 and 5.

Table 4: Total Power Inflow For Each Load

Feeder	Name of load	Total power inflow (kW)
1	FTMK	31,909.75
	Perpustakaan Laman Hikmah	19,816.99
2	PBPI	12,223.75
3	Satria	8,483.53
	Pejabat Keselamatan	929.97
4	-	-
5	-	-
6	Dewan Canselor	2,642.42
	FKP	7,159.06
7	Lestari	8,483.53
	FKEKK	31,909.75
	FKE	31,909.75
	Makmal Voltan Tinggi	4,405.95
	Pejabat Pembangunan	5,767.98
	Kompleks Sukan	2,090.05
8	Canselori	929.97

4.3.1 Result of Load Flow Simulation

The load flow simulation was obtain using DigSilent Powerfactory software by inserting all the data of power inflow for each load. Figure 4-2 to Figure 4-15 shown the graph of 24-hours load flow, captured every 15 minutes for each load, MW versus Minutes.

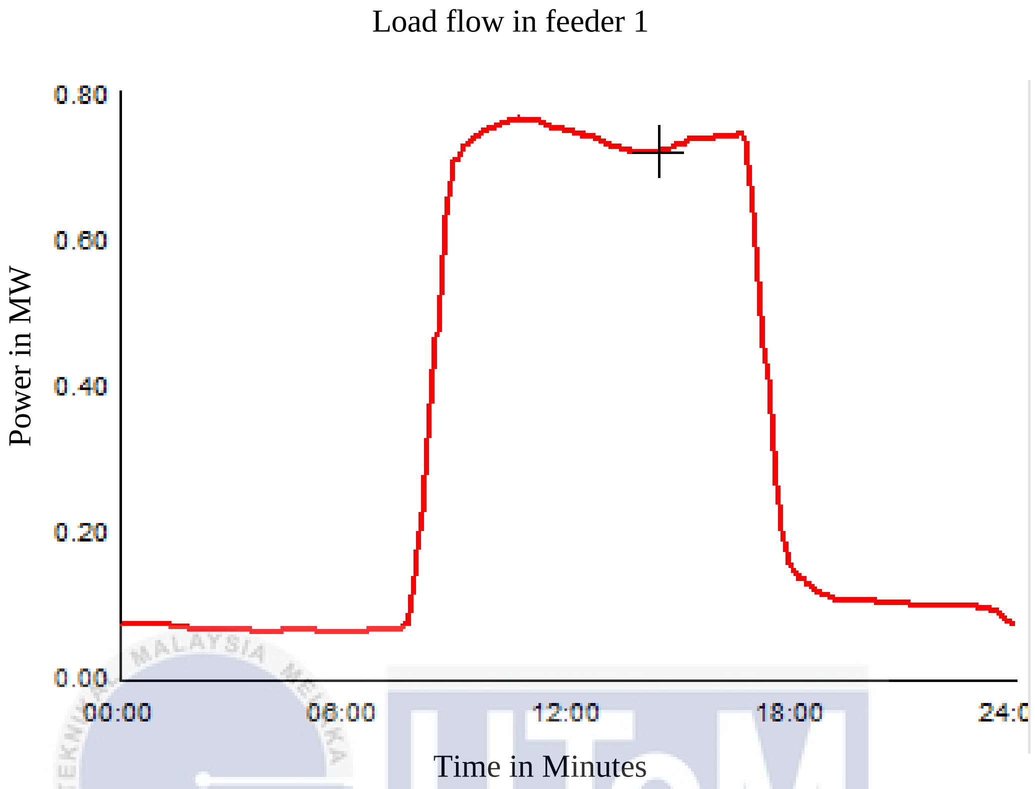

Figure 4-2 : Load Flow for FTMK

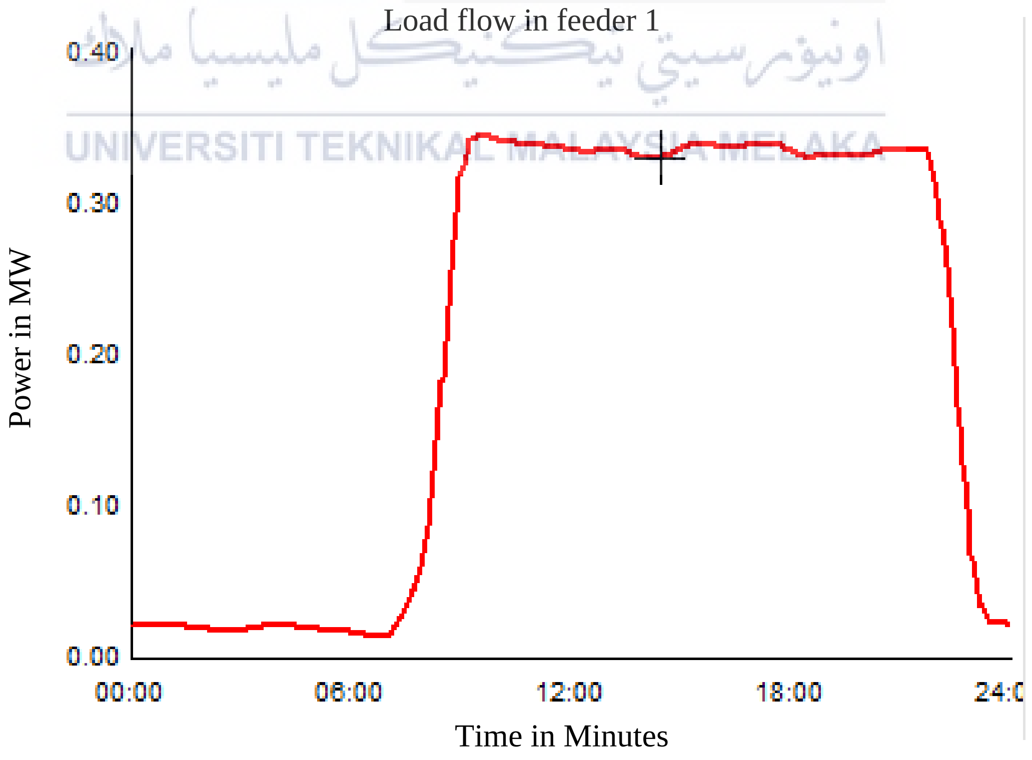

Figure 4-3: Load Flow for Perpustakaan Laman Hikmah

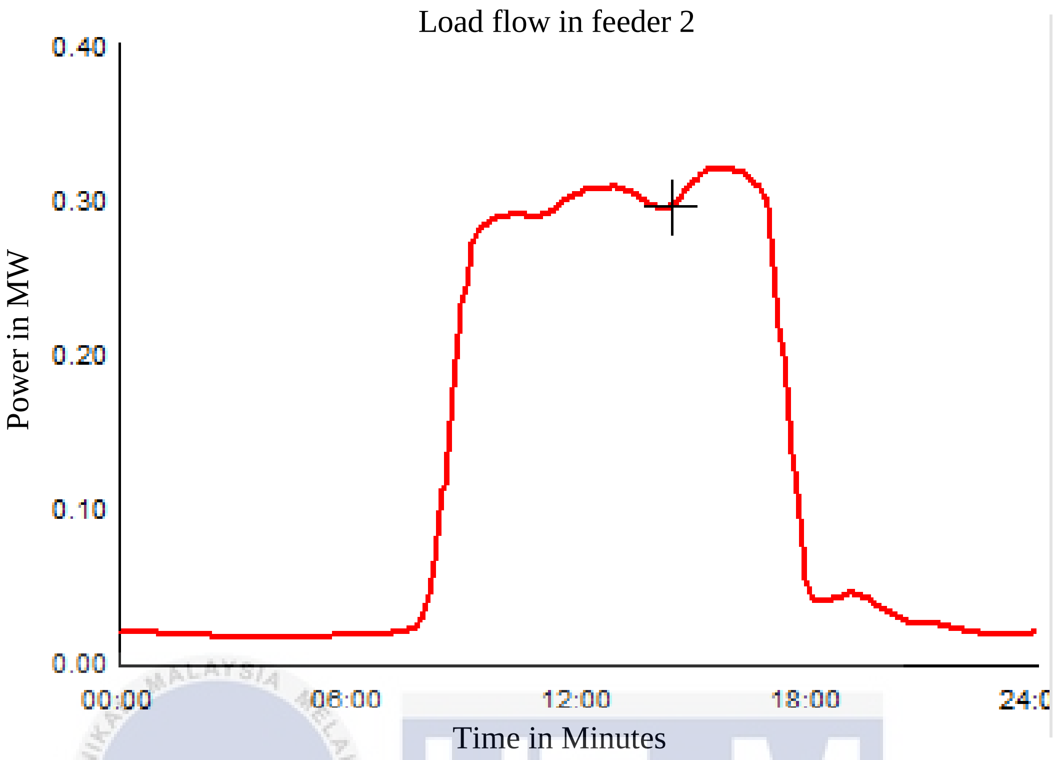

Figure 4-4: Load Flow for PBPI

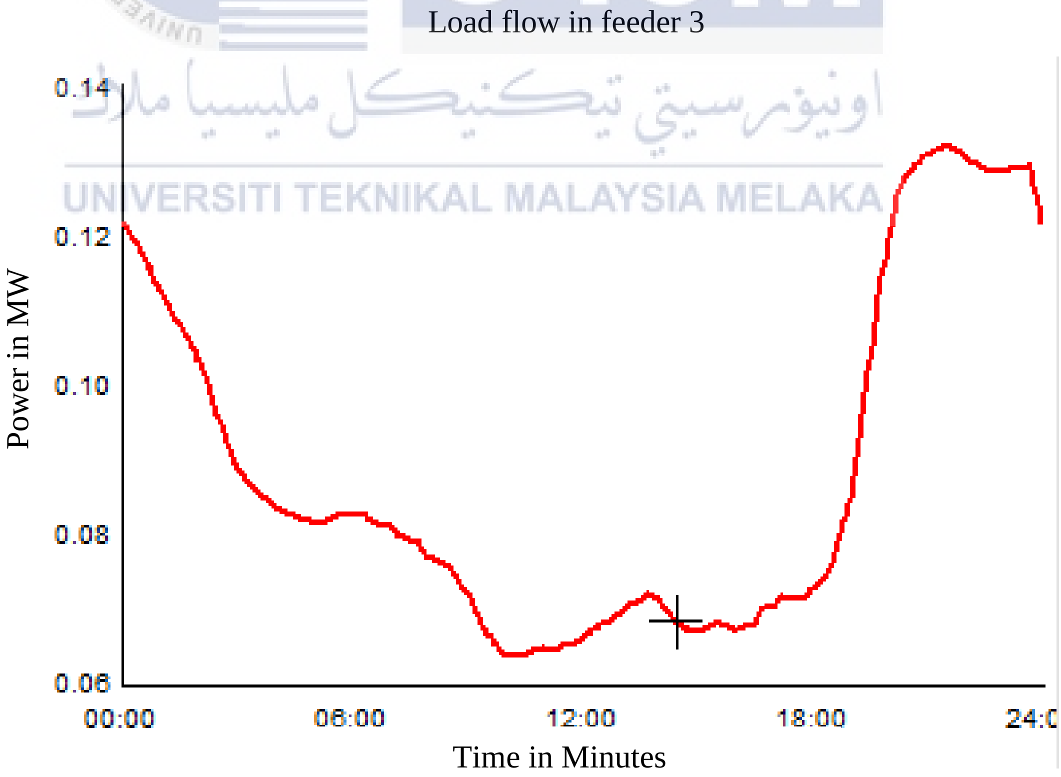

Figure 4-5: Load Flow for Satria

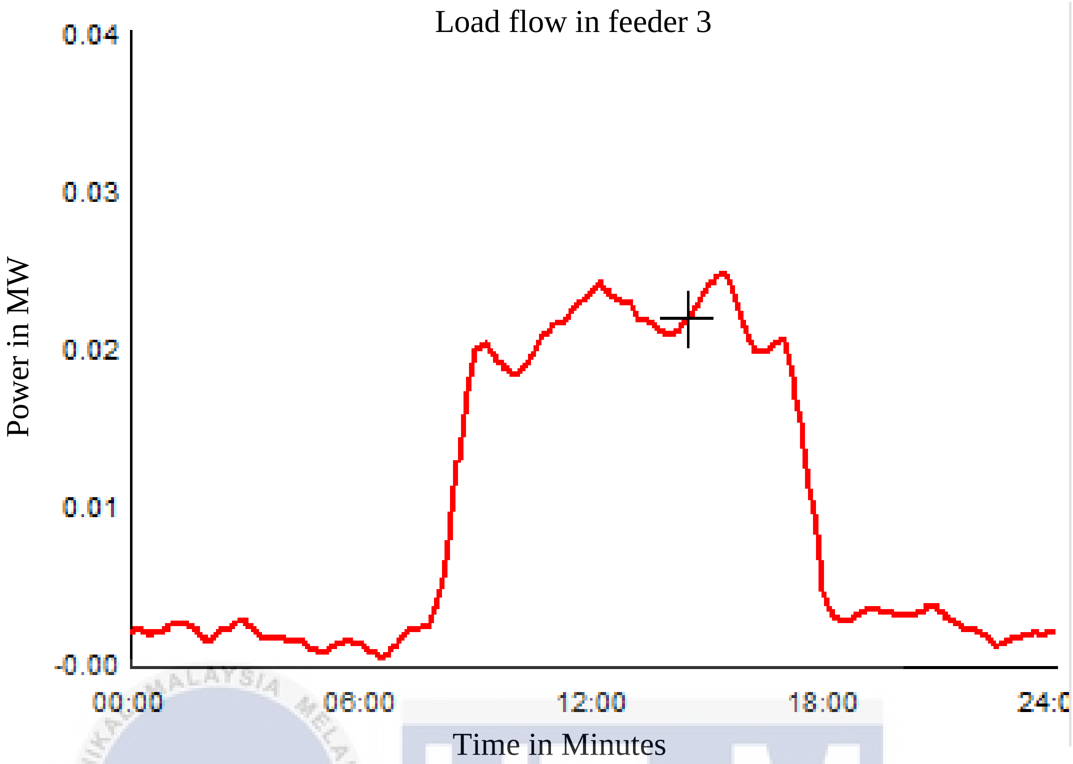

Figure 4-6: Load Flow for Pejabat Keselamatan

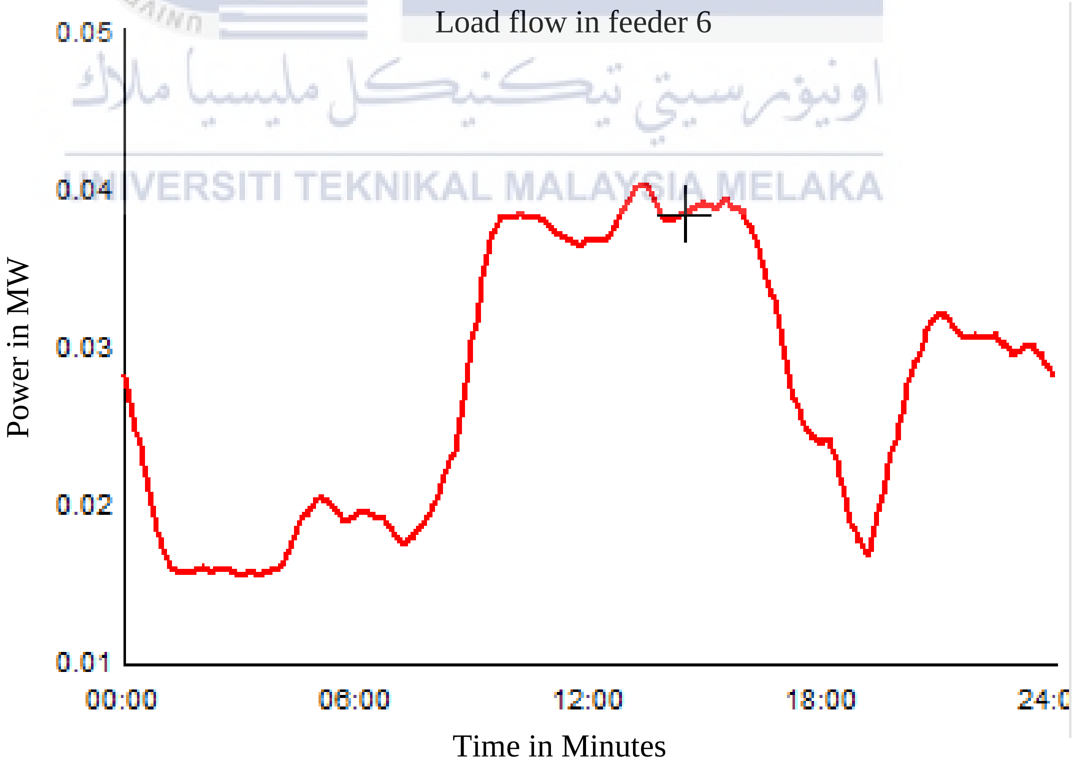

Figure 4-7: Load Flow for Dewan Canselor

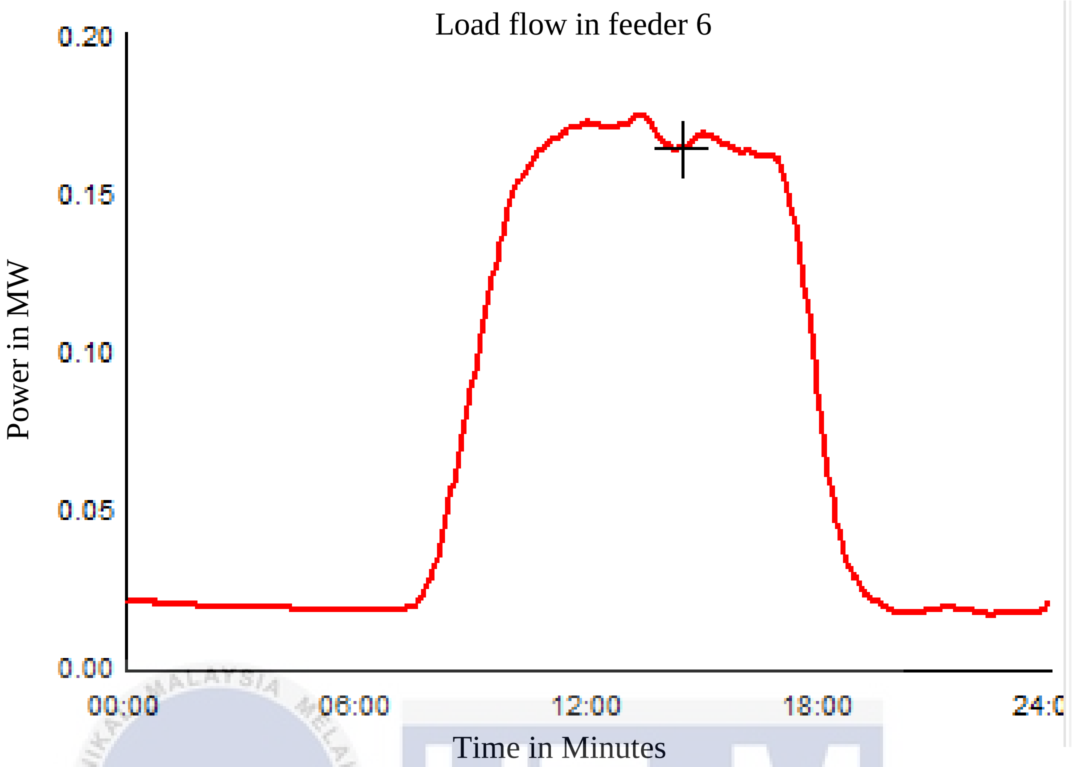

Figure 4-8: Load Flow for FKP

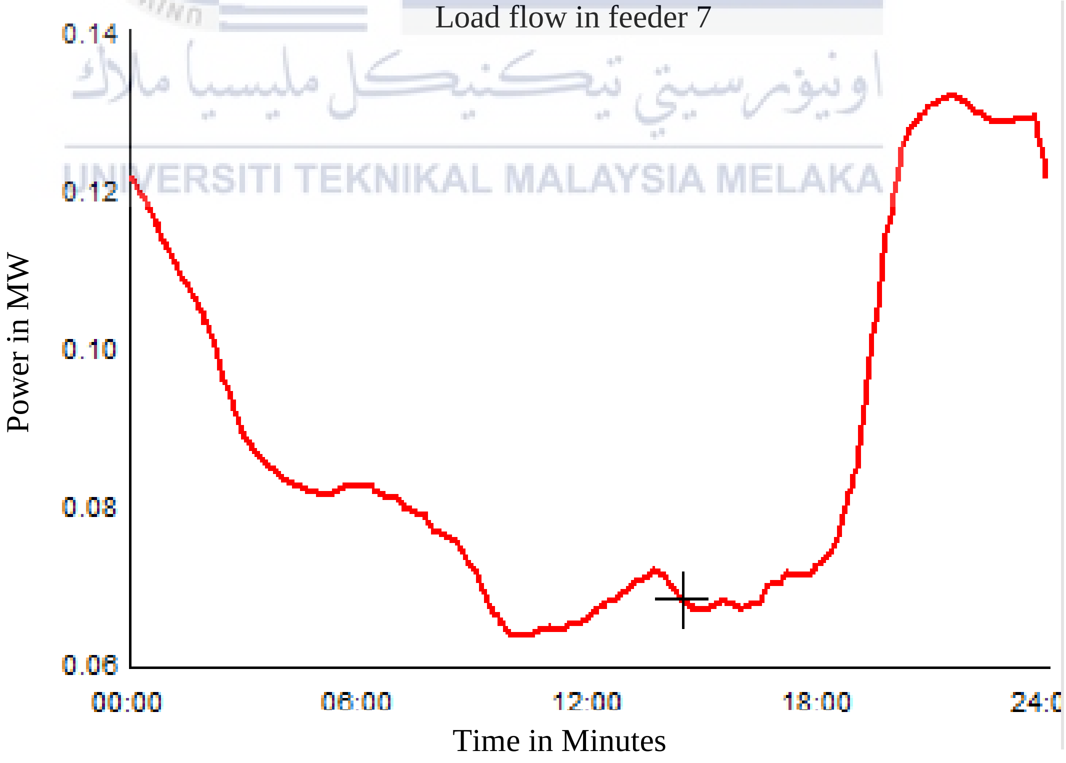

Figure 4-9: Load Flow for Lestari

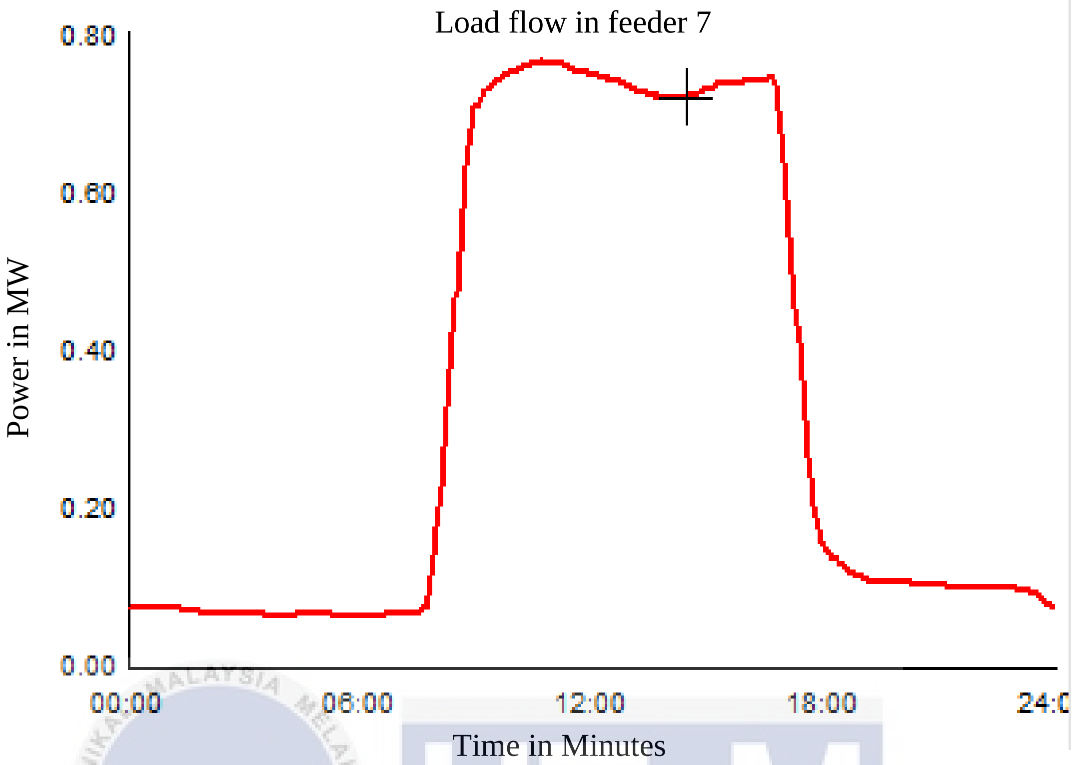

Figure 4-10: Load Flow for Fkekk

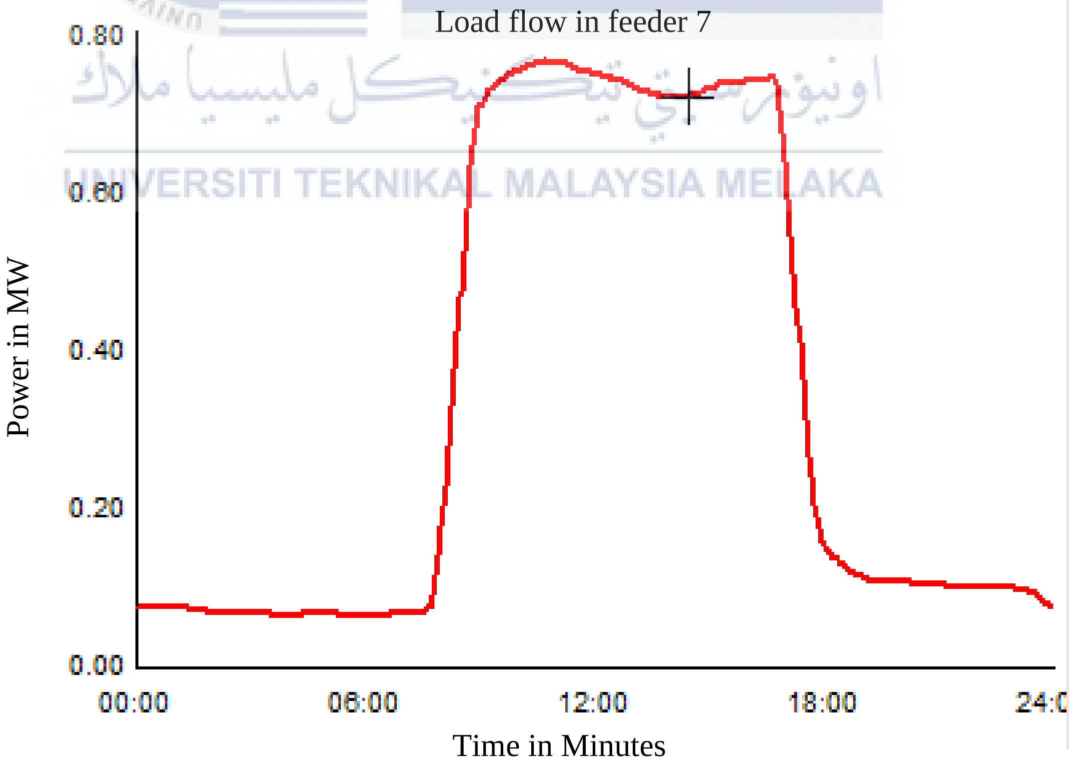

Figure 4-11: Load Flow for FKE

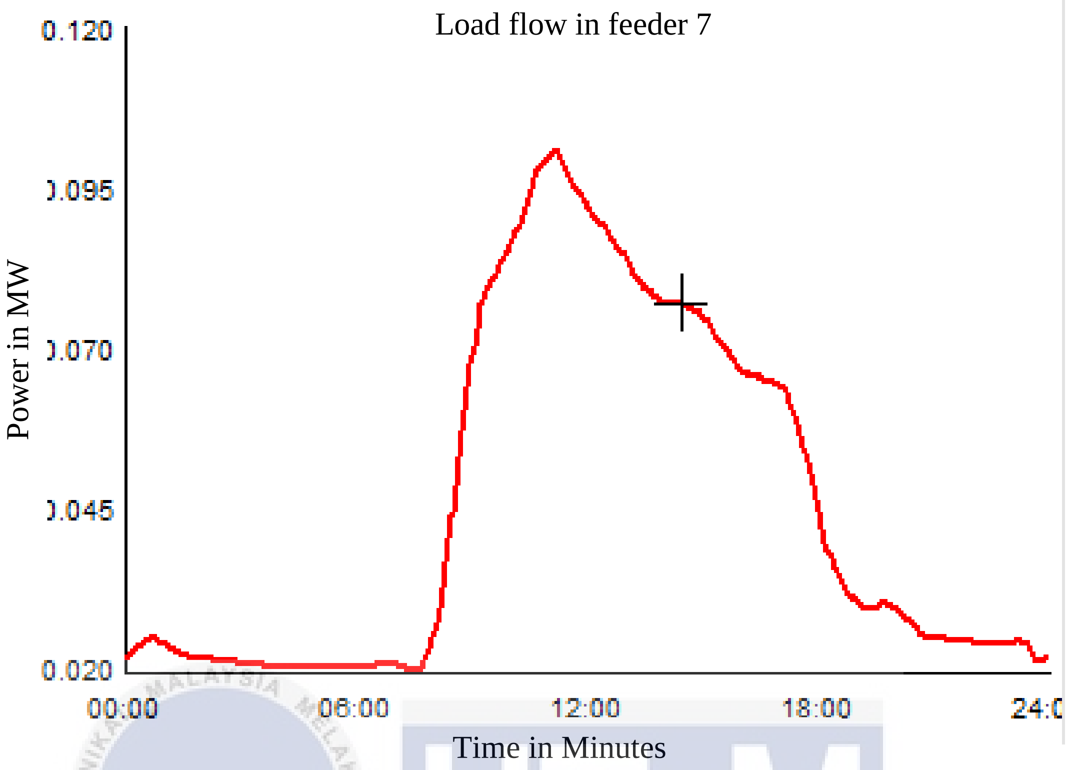

Figure 4-12: Load Flow for Makmal Voltan Tinggi

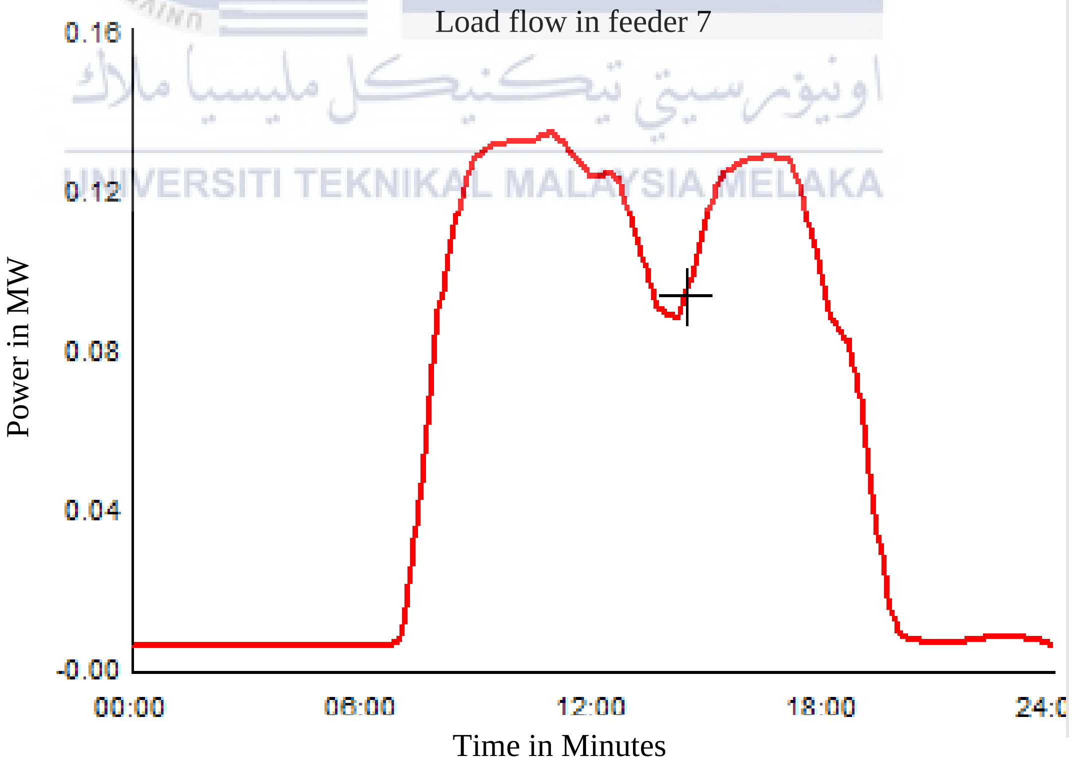

Figure 4-13: Load Flow for Pejabat Pembangunan

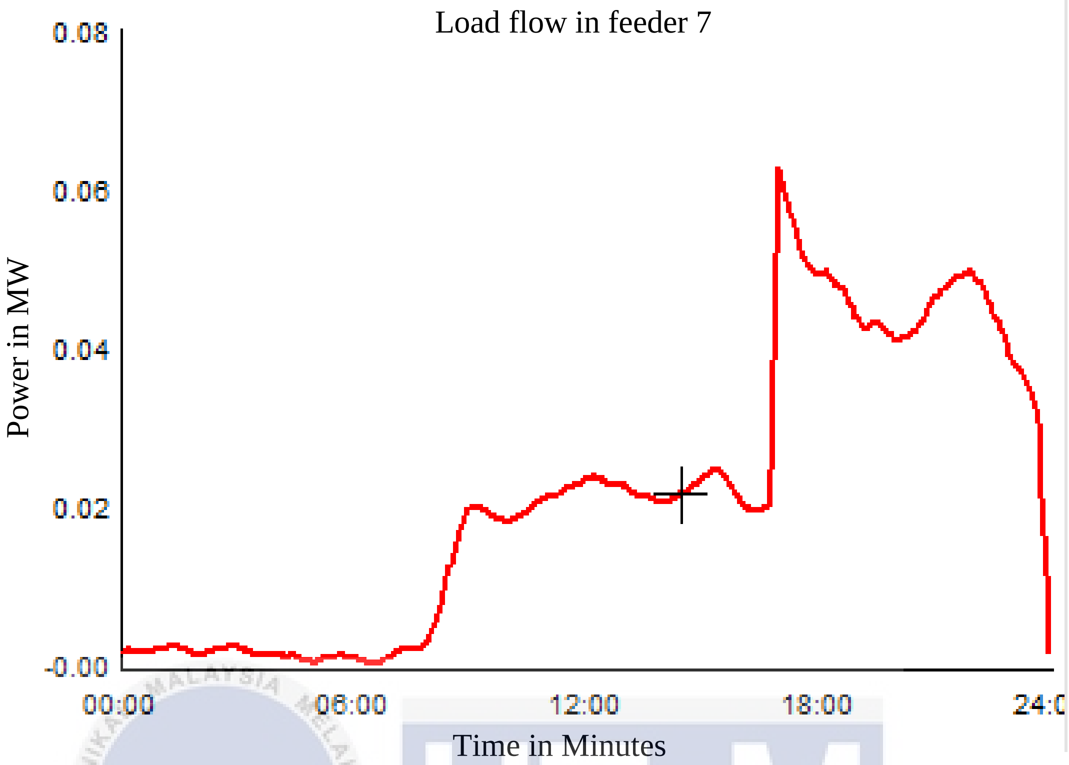

Figure 4-14: Load Flow for Kompleks Sukan

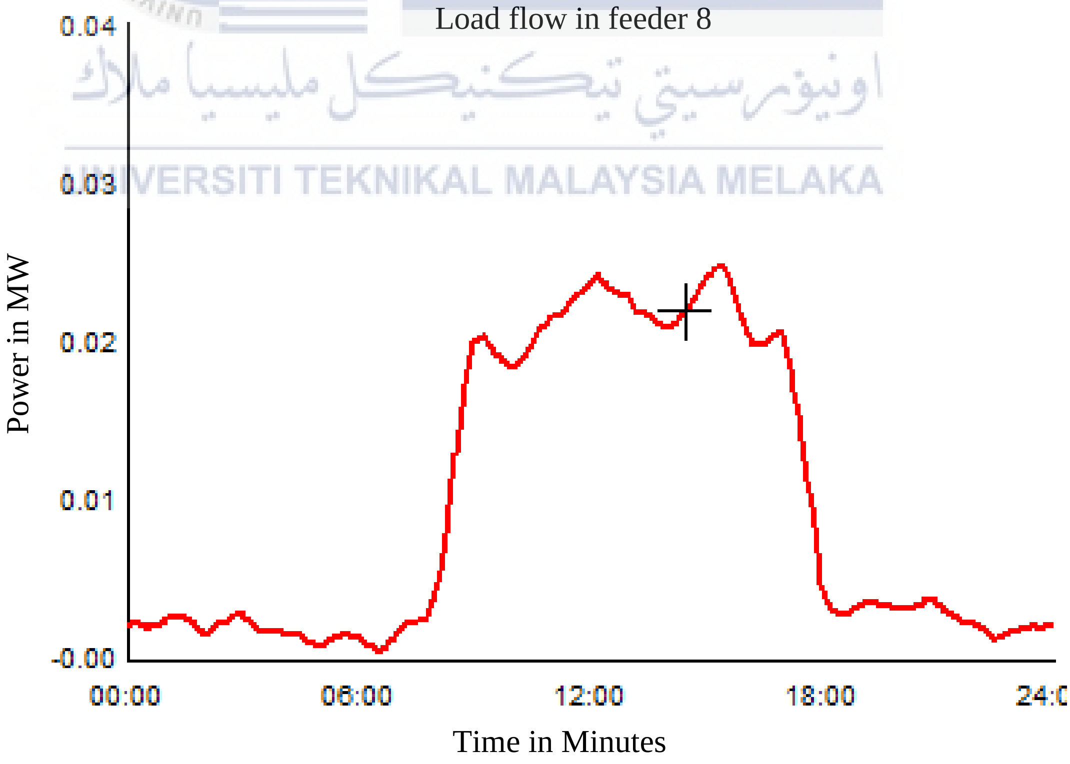

Figure 4-15: Load Flow for Canselori

Based on the load flow simulation, academic faculty and administration center have a quite similar load flow graph due to having a same operational time. Chiller operational time has been centralized which its operational time is from 8:00 a.m. to 5:p.m. only. Besides most of the class will start at 8:00 am and finished around 4:00 p.m. Therefore, between 8:00am to 4:00 p.m. is a peak power demand especially during weekdays due to academic program and lecturer working hour. On the contrary, at residential college have a different load flow from academic faculty. Residential college have a high-energy consumption at night due to a lot of student starting to spend their time in their own room instead at academic faculty. Library operate differently with other building, library's building load flow start to increase from 8:00 in the morning until 12:00 midnight. The energy inflow from main substation 33/11 kV distribute to each feeder 11/0.4 kV to meet demand of the load.

4.3.2 Total Energy Inflow for Each Feeder

In this step, the aim is to calculate the total energy inflow for each feeder to estimate the total losses feeder by feeder. By adding all the load per feeder, total energy per feeder can be plot in the graph kWh versus time. The graph of energy inflow for each feeder, kWh versus Time is shown in Figure 4-16 to Figure 4-21. For feeder 4 and 5 there was no energy flow because in feeder 4 and 5 has no load. The formula to calculate energy inflow as shown in Equation (4-1.

$$E = P \times T \qquad \textbf{(4-1)}$$

Where

E = Energy flow in the feeder, kWh

P = Power, W

T= Time, minutes

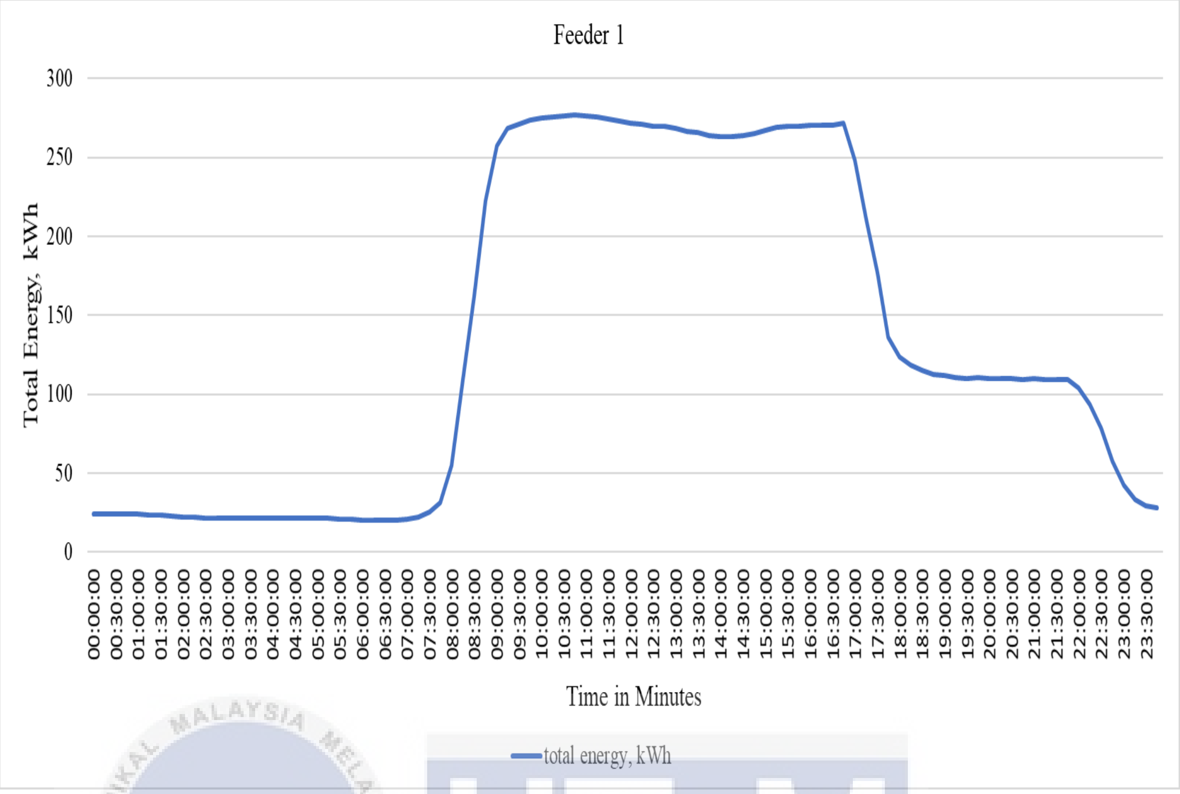

Figure 4-16: Total Energy flow in Feeder 1

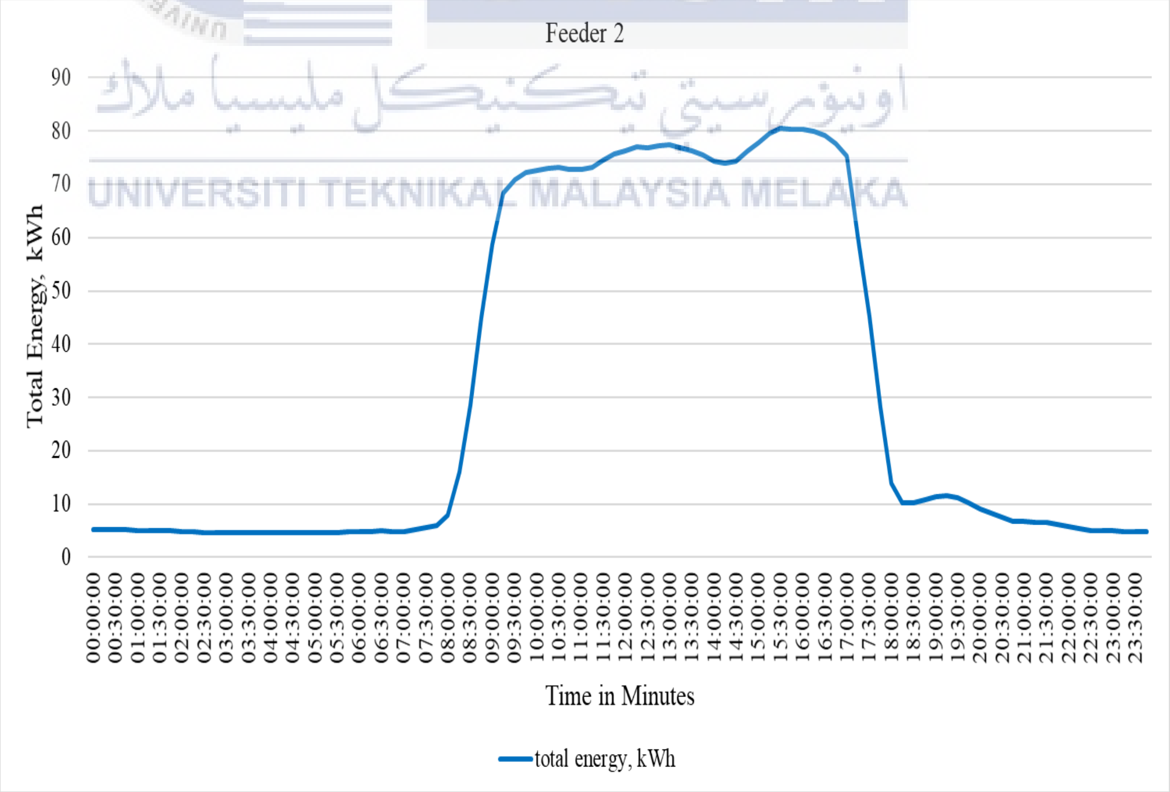

Figure 4-17: Total Energy Flow in Feeder 2

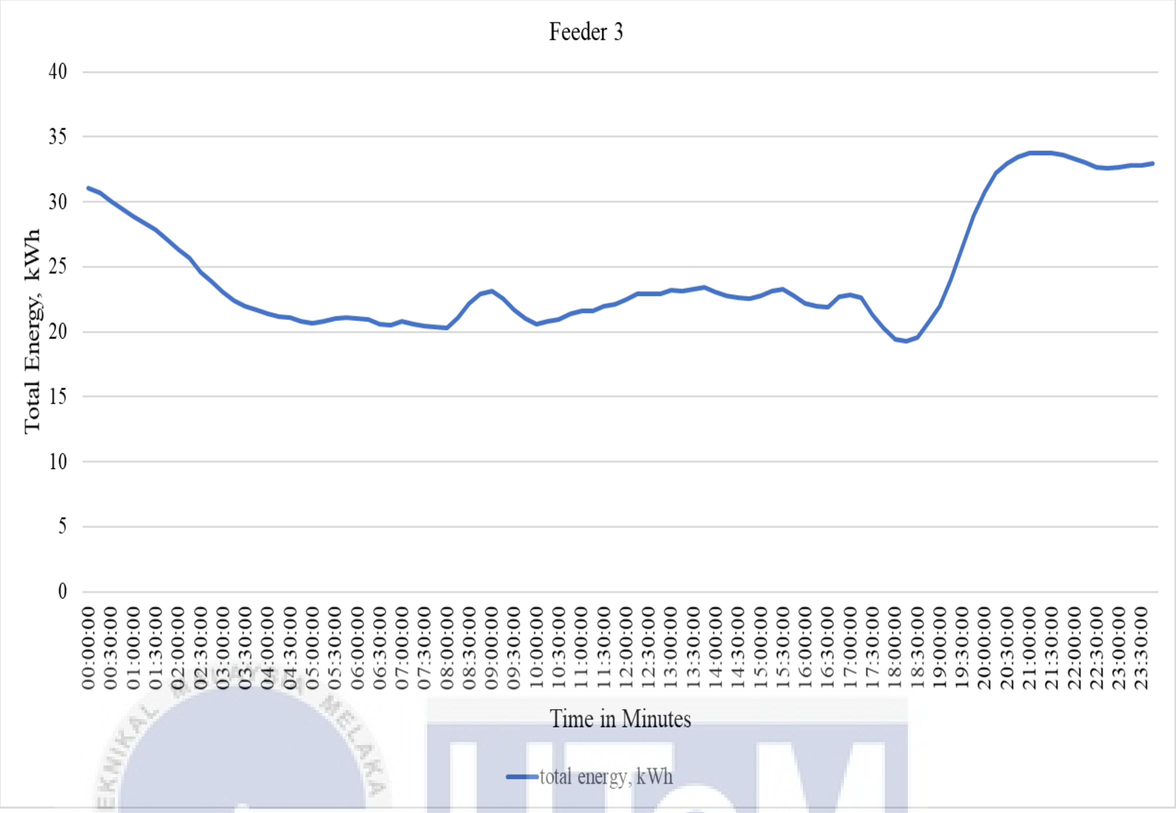

Figure 4-18: Total Energy Flow in Feeder 3

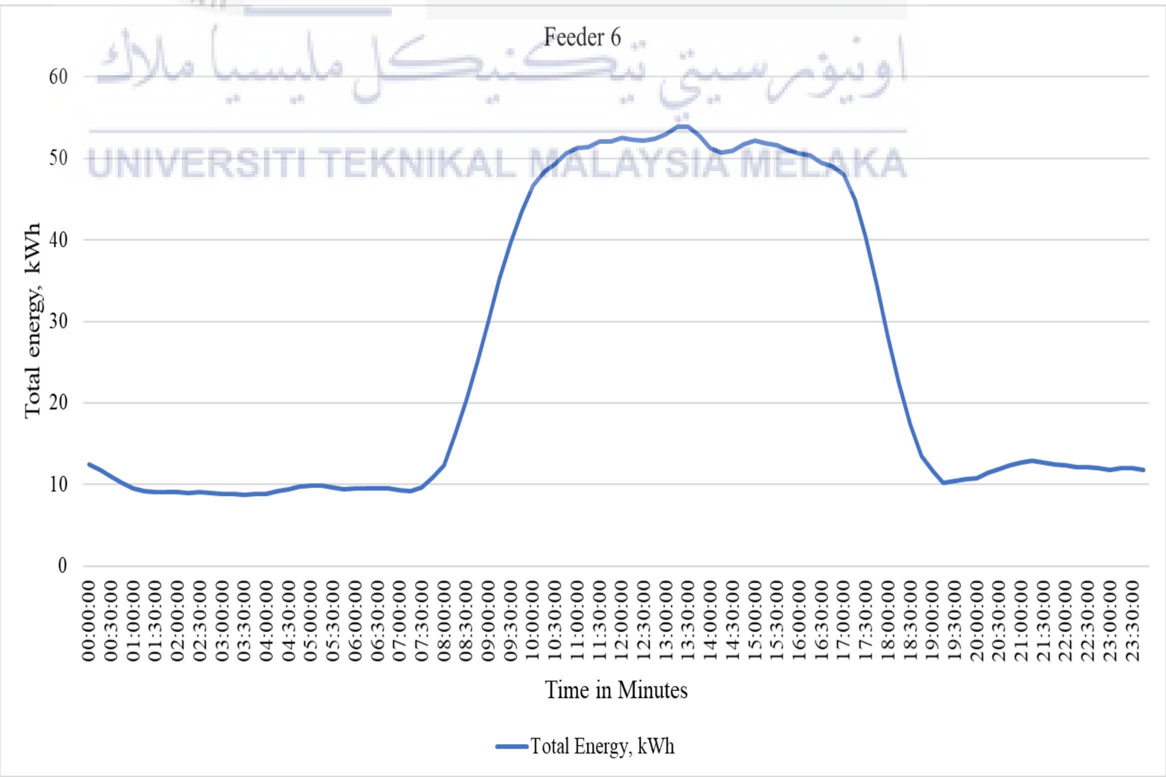

Figure 4-19: Total Energy Flow in Feeder 6

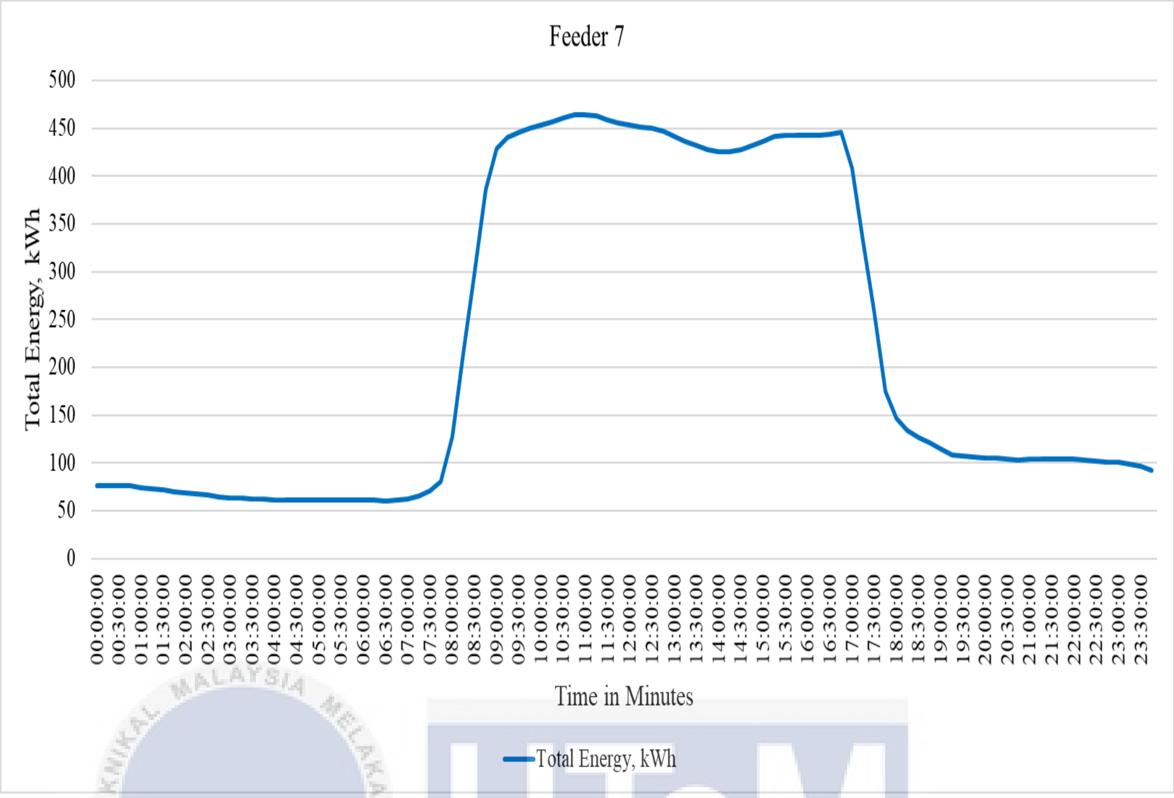

Figure 4-20: Total Energy Flow in Feeder 7

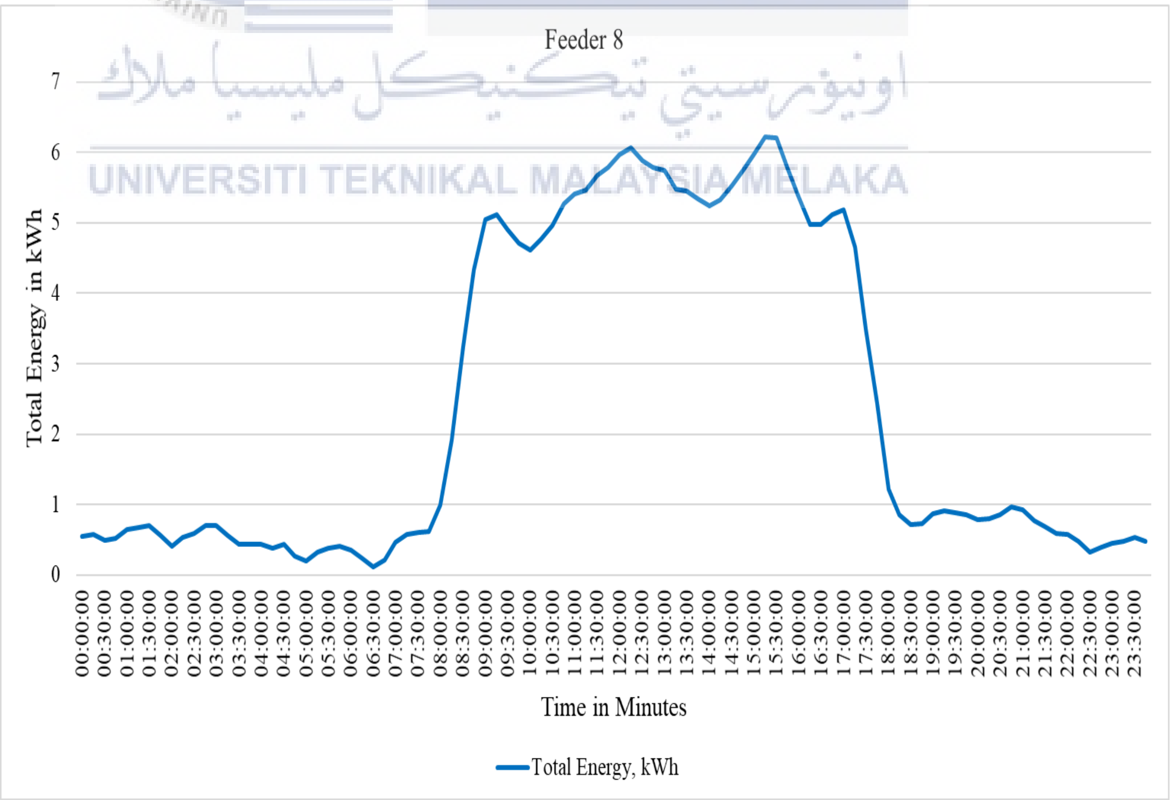

Figure 4-21: Total Energy Flow in Feeder 8

Feeder 7 has the highest energy flow because feeder 7 has the most amount of load. Feeder 7 estimating almost reach 500 kW at 10 am. Most of the energy flow will increase starting at 7:00 am until 6:30 pm. In feeder 3, the energy flow is quite consistent because in feeder 3 connected to Satria and Pejabat Keselamatan substation. Satria load flow has an increase only from night until midnight while Pejabat Keselamatan load flow has an increase during a working hour which is 8:00 am until 4:00 pm. Feeder 3 has consistent energy flow due to both load has a different operating hour. Feeder 8 has the lowest energy flow over time because feeder 8 load is only Canselori, which only operating during a working hour. Table 5 shown a total energy flow in each feeder.

Table 5: Total Energy Flow for Each Feeder

Name	**Energy input**	**Energy input**
	MWh	**kWh**
Feeders 1	12.8588675	12,858.87
Feeders 2	3.055938	3,055.938
Feeders 3	2.35338	2,353.38
Feeders 4	0	0
Feeders 5	0	0
Feeders 6	2.45037	2,450.37
Feeders 7	21.14175	21,141.75
Feeders 8	0.2324925	232.4925

4.4 Feeder technical losses estimation

In this part, the aim is to estimate 33kV and 11kV feeder 24 hour technical losses in kWh using Quasi Dynamic Simulation results with varied length of line, load demand and feeder characteristics. The losses was estimated using a 15-minutes load flow per feeder. Technical losses result from equipment inefficiency, the inherent characteristics of the materials used in the lines and equipment, and the sizes of lines and equipment. The three major contributors are the current squared losses through a resistance, transformer excitation losses, and line and insulation corona or leakage losses. The graph of power losses for each feeder, MW versus Time is shown in Figure 4-22 to Figure 4-29.

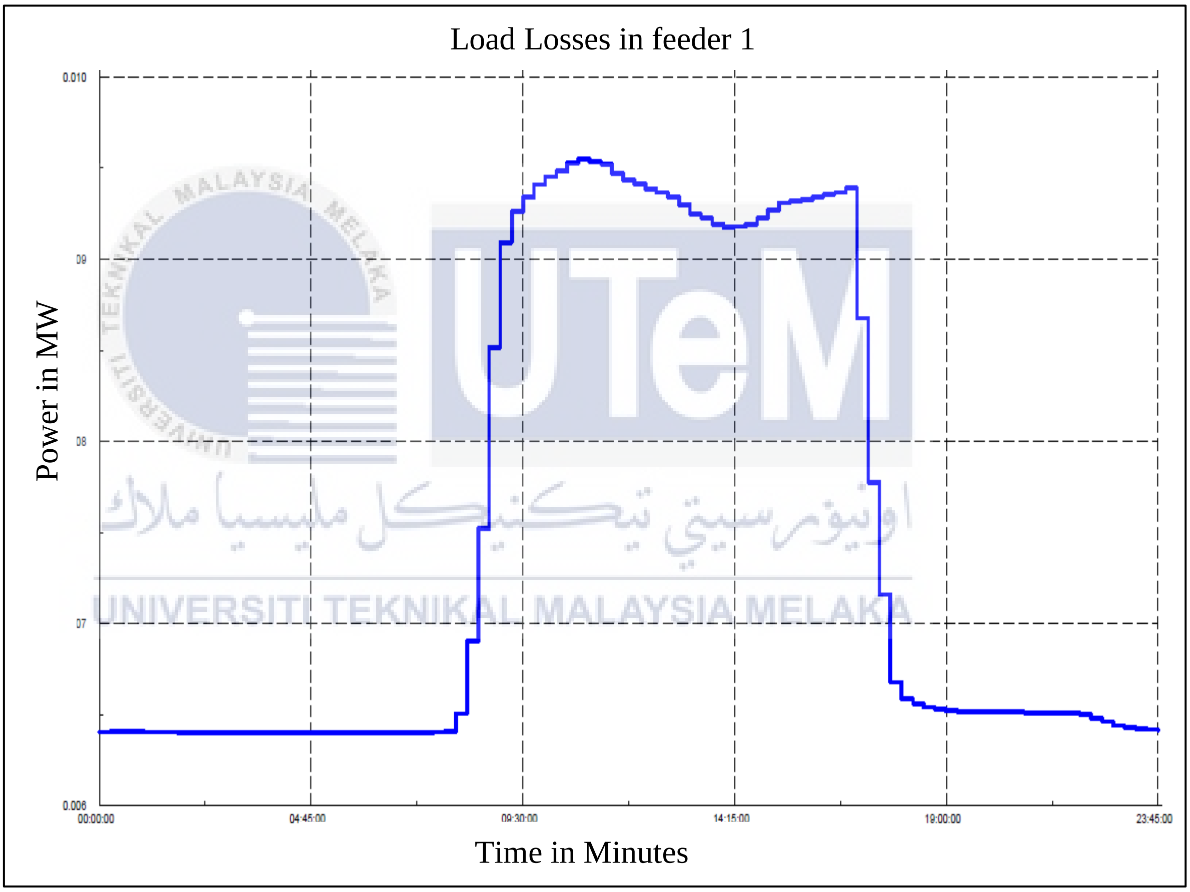

Figure 4-22: Power Losses in Feeder 1

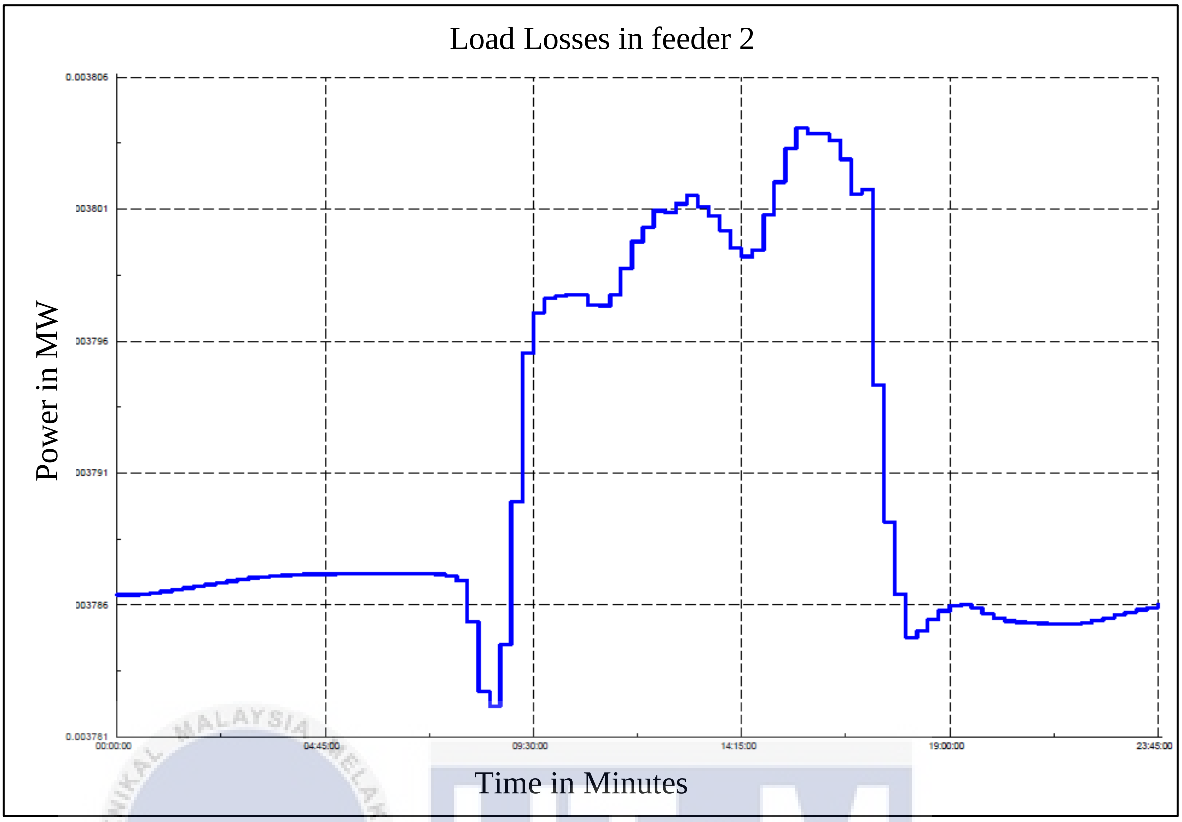

Figure 4-23: Power Losses in Feeder 2

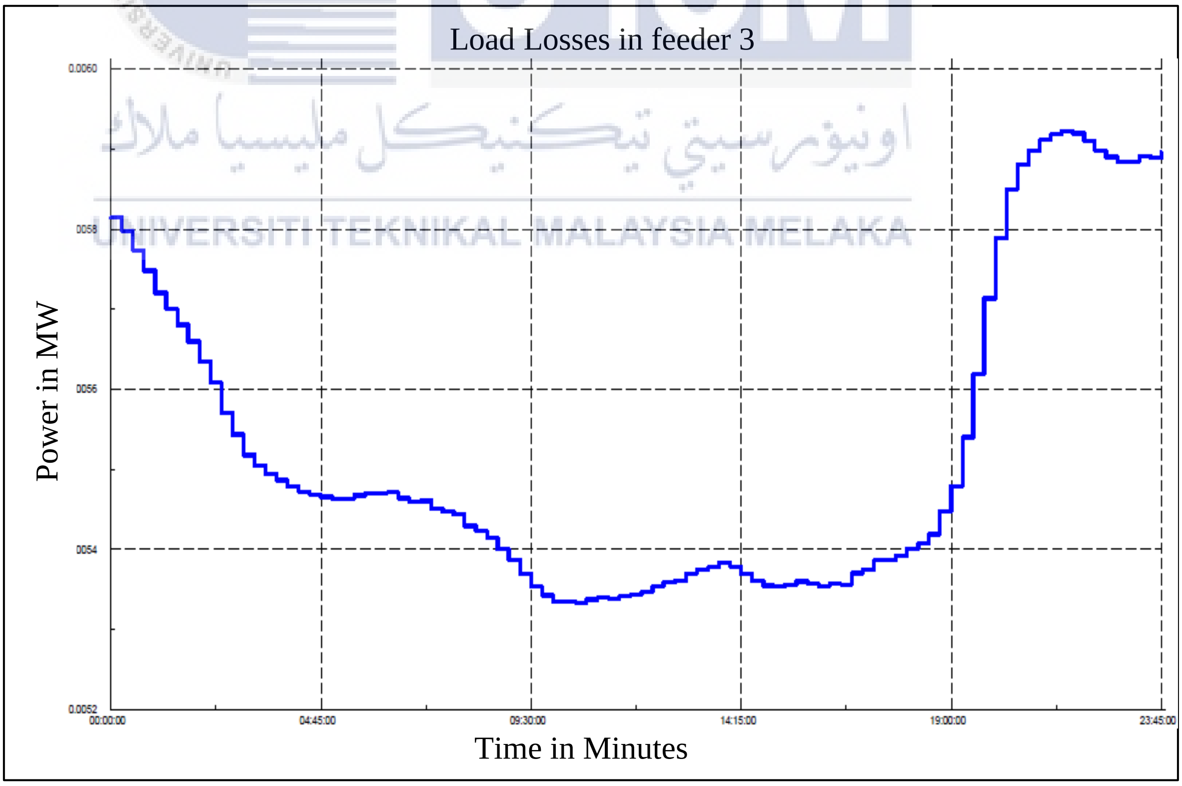

Figure 4-24: Power Losses in Feeder 3

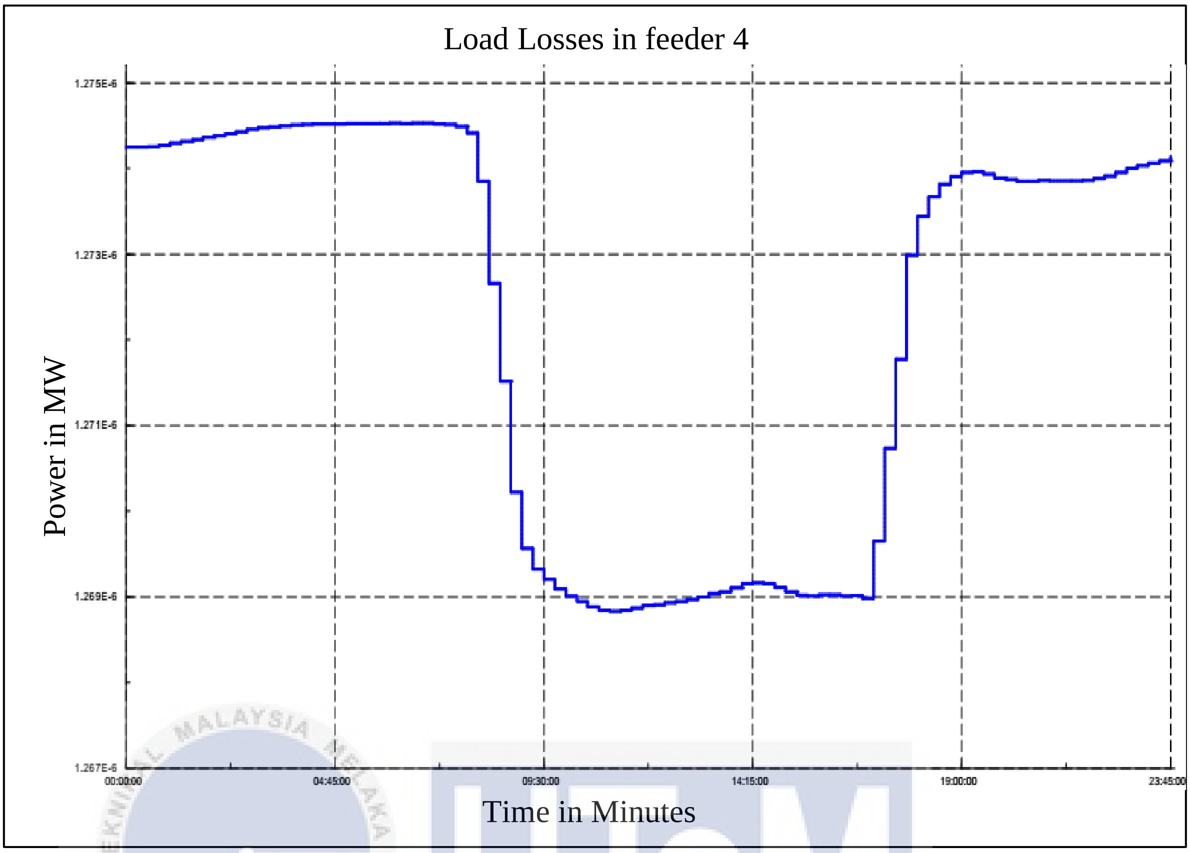

Figure 4-25: Power Losses in Feeder 4

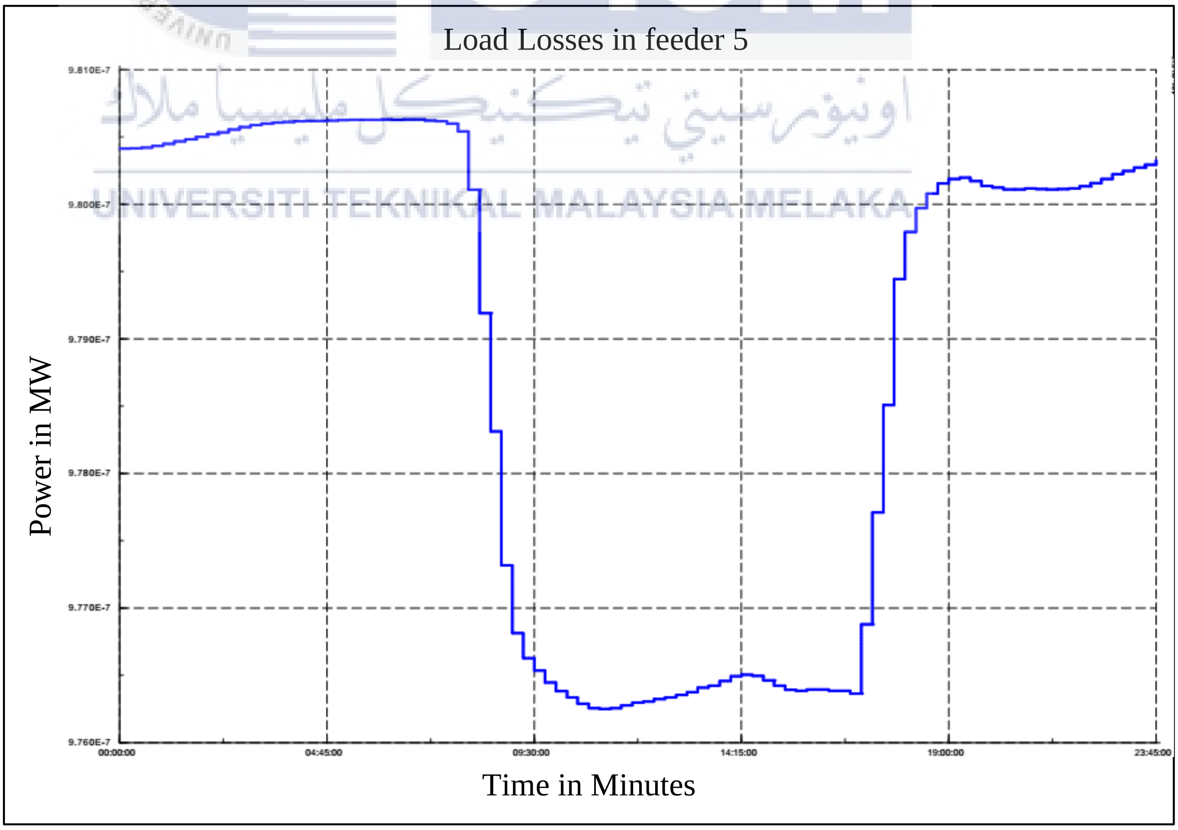

Figure 4-26: Power Losses in Feeder 5

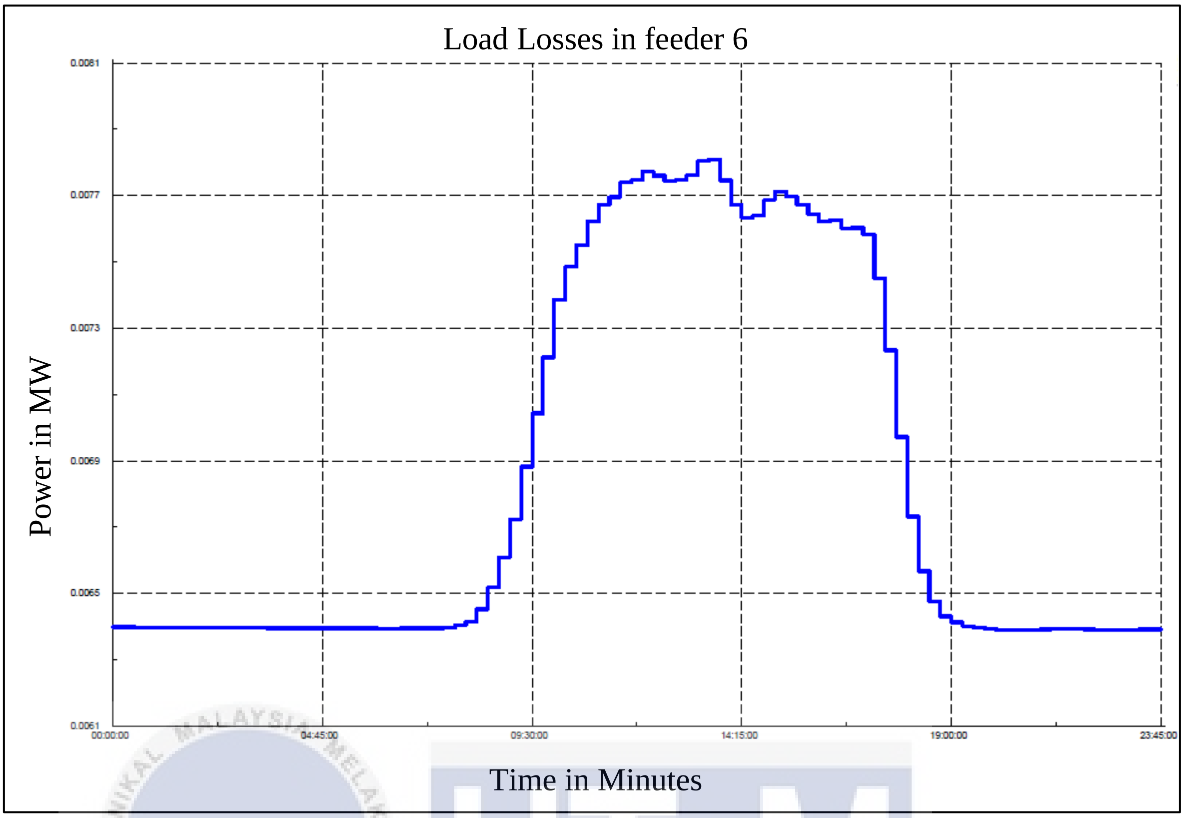

Figure 4-27: Power Losses in Feeder 6

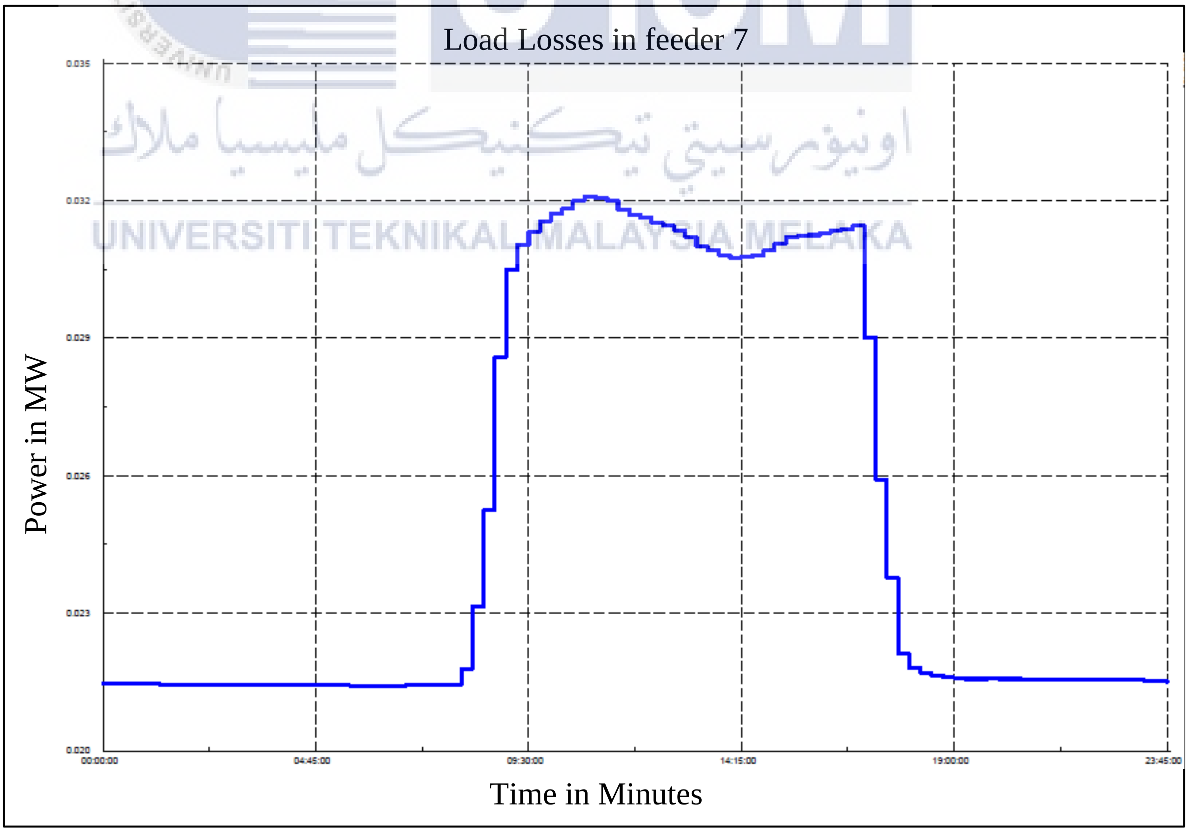

Figure 4-28: Power Losses in Feeder 7

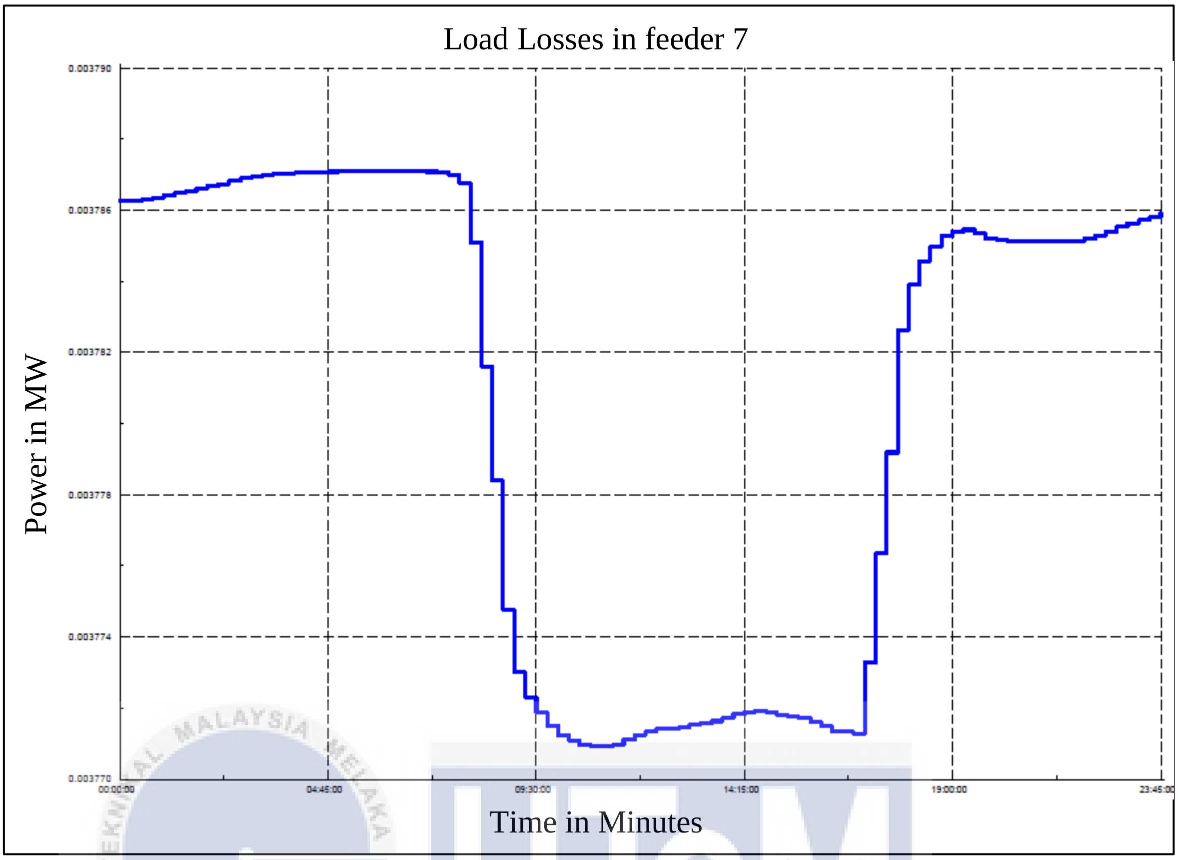

Figure 4-29: Power Losses in Feeder 8

Feeder 4 and 5 has a very small loss because feeder 4 and 5 has no load. Therefore, the losses are either line losses or leakage of power along the line. Most of the feeder has a higher loss at a same time as energy flow in the feeder, which is from 8:00 am until 4:00 pm. Therefore, the higher the energy flow, the higher the energy losses depends on the line and transformer in the feeder. Feeder 8 have a different condition than other feeders because it has low energy losses estimations during 8:00 am until 4:00pm but its energy flow in feeder is maximum during that hours contrary with the other feeders. As shown in Table 6 and Figure 4-30, feeder 7 has a higher energy losses because has a higher energy inflow to the feeder.

Table 6: Energy Losses in Each of the Feeder

Name	**Energy (Losses)**	**Energy (Losses)**
	MWh	**kWh**
Feeders 1	0.1798968	179.899
Feeders 2	0.09098407	90.984
Feeders 3	0.1326335	132.634
Feeders 4	0.00003053	0.031
Feeders 5	0.00002349	0.023
Feeders 6	0.1641713	164.171
Feeders 7	0.601457	601.457
Feeders 8	0.0907355	90.736
Total	0.001259	1,259.935

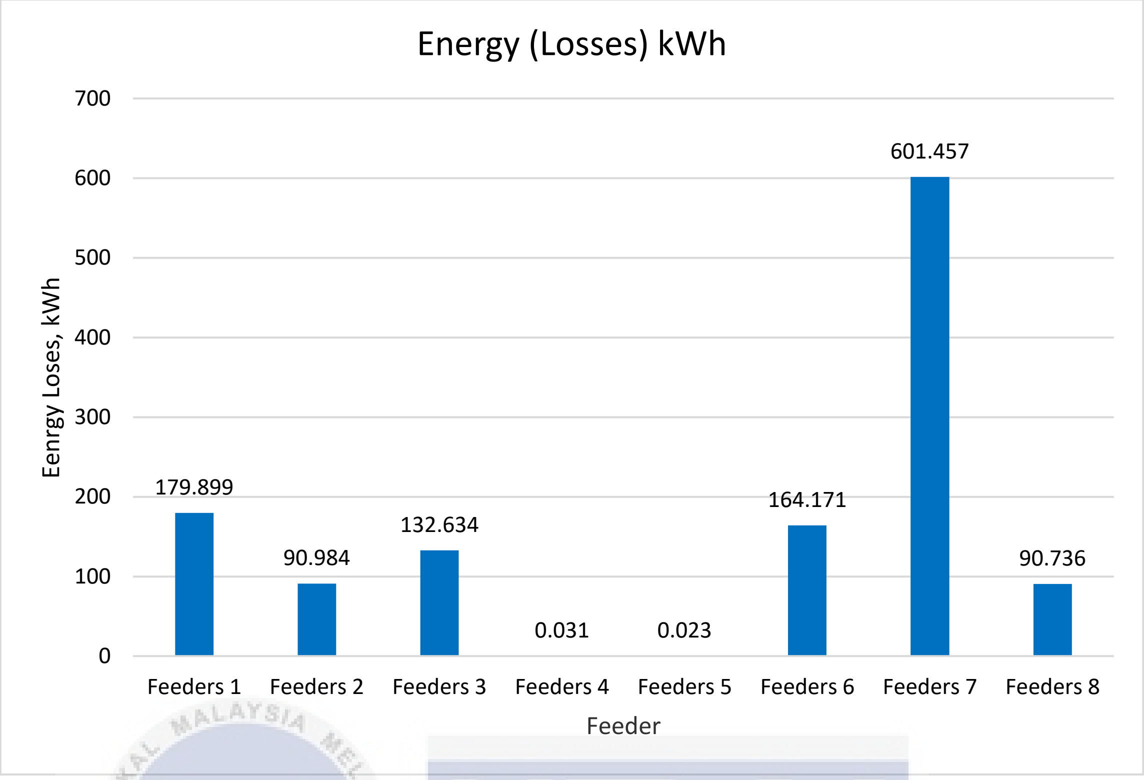

Figure 4-30: Energy Losses in kWh

Table 7: Energy Efficiency and Energy Losses Cost Per Feeder In One Day

Name	**Energy input**	**Energy (Losses)**	**Energy (Losses)**	**Cost of energy loss (RM)**
	kWh	**kWh**	**%**	**0.37 cents/kWh**
Feeders 1	12858.8675	179.899	1.40	66.56
Feeders 2	3055.938	90.984	2.98	33.66
Feeders 3	2353.38	132.634	5.64	49.07

Name	Energy input	Energy (Losses)	Energy (Losses)	Cost of energy loss (RM)
	kWh	kWh	%	0.37 cents/kWh
Feeders 4	0	0.031	The value too small	0.01
Feeders 5	0	0.023	The value too small	0.01
Feeders 6	2450.37	164.171	6.70	60.74
Feeders 7	21141.75	601.457	2.84	222.54
Feeders 8	232.4925	90.736	39.03	33.57
Total	42,092.80	1,259.935	2.99%	466.16

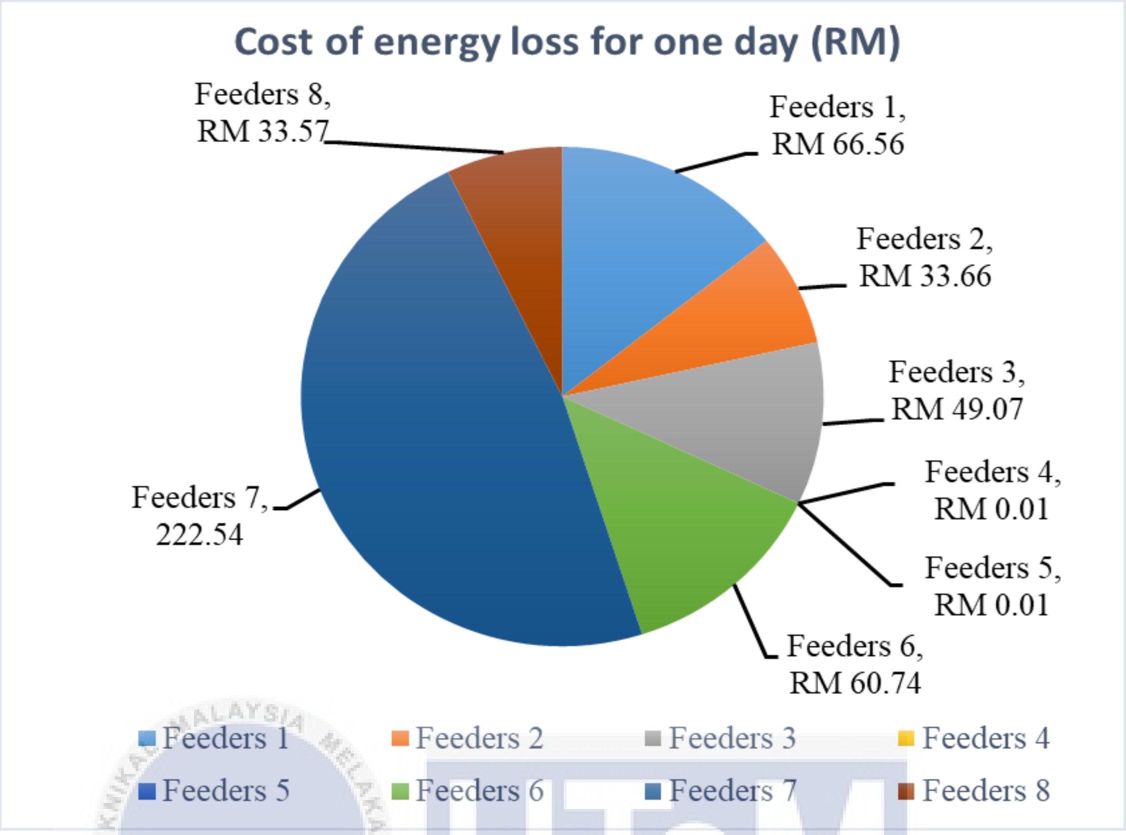

Figure 4-31: Cost of energy loss for every feeder in one day

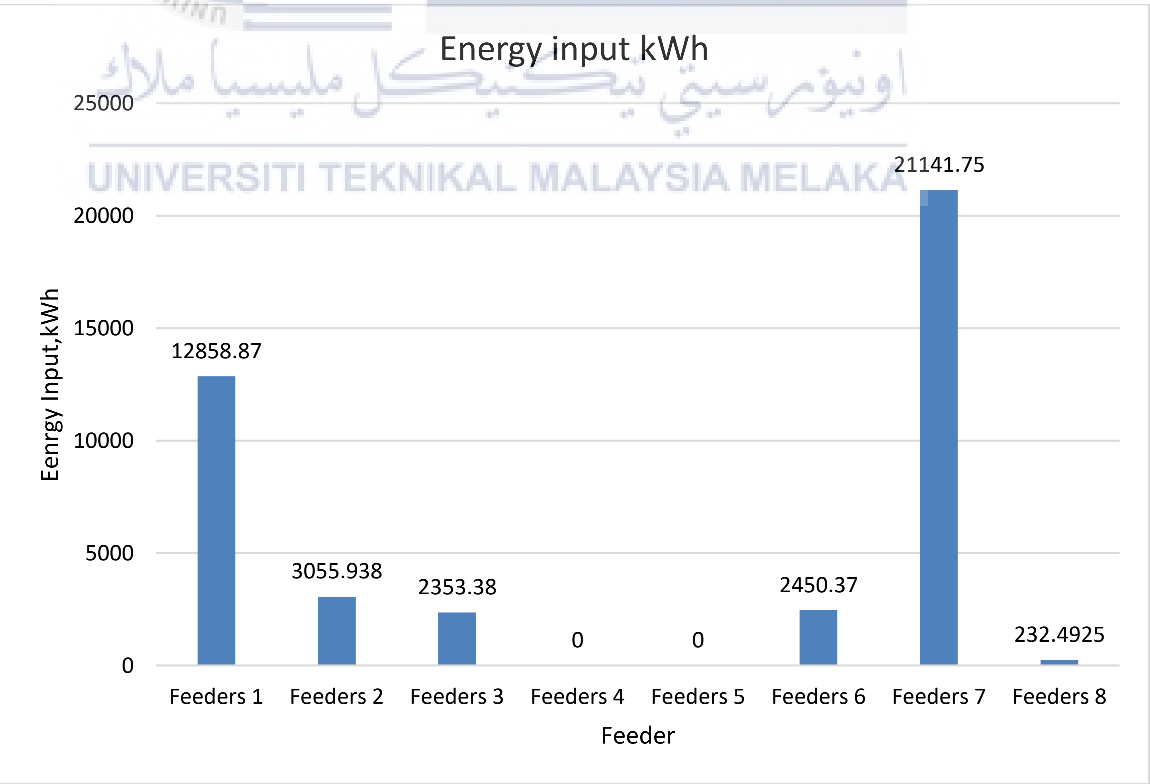

Figure 4-32: Energy input for every feeder

Table 7 shows how the energy losses can affect in financial. If estimated 0.37 cents per kWh based on TNB tariff, feeder 7 only will cost RM 222.54 per day. This value considered only during working days. In 1 month, medium voltage of feeder 7 only estimated would cost RM 4,895.88 during working days, which have 22 days per month. Energy losses can be reduce by improved the line length or transferred some of the load in feeder 7 to the other feeder. Figure 4.31 shows the cost of energy losses for every feeder in one day. Therefore, estimation of total of energy loss cost for all feeder in one day is RM 466.16. If 1 month, energy losses cost RM 10,255.52 during working days, which have 22 days per month. The total cost of energy lost maybe less than mentioned because the total cost of energy lost only considering working day and ignored weekend, public holiday and semester breaks. The value maybe varied following the energy usage in a day. Figure 4-32 shows energy input for every feeder in one day at UTeM. The total energy input for all the feeder in one day at UTeM is 42,092.80 kWh. . If estimated 0.37 cents per kWh based on TNB tariff, the total of energy input for all feeder will cost RM 15,574.34 per day at UTeM. Therefore, the overall estimated percentage for energy losses is 2%. This value is small for energy losses but it will effect in financial.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This report presents a method for estimating a TL in MV distribution network for UTeM. The proposed methodology is effective in order to obtain good results utilizing only accurate information and with a minimum network measurement information. The proposed analytical approach of using actual feeder to estimate TL in MV network of UTeM. The development of MV distribution network was analysed using Digsilent Powerfactory software. This study also proves that TL can be analyse using time series load flow simulation. Data input for TL estimation model has been analysed to ensure it is accurate and consistent. The data was used to model medium voltage actual feeder in Digsilent Powerfactory software with different structure in terms of feeder type, length and load demand.

This study also used Quasi Dynamic Simulation to approach the developed actual feeder MV model network in order to establish an effective and simplified system for TL estimation for MV distribution network in UTeM. In addition, this model can be easily programmed and used repeatedly to estimate daily TL for feeder by replacing the load flow data only. The proposed MV distribution TL estimation model is presumed to be simple enough to enable the utility and regulator to understand the main parameters to establish a reasonable estimation on the MV distribution TL in UTeM. It is envisaged that the proposed method can be very useful in the practical distribution network planning strategies and to evaluate the foreseeable network TL in MV distribution network at UTeM.

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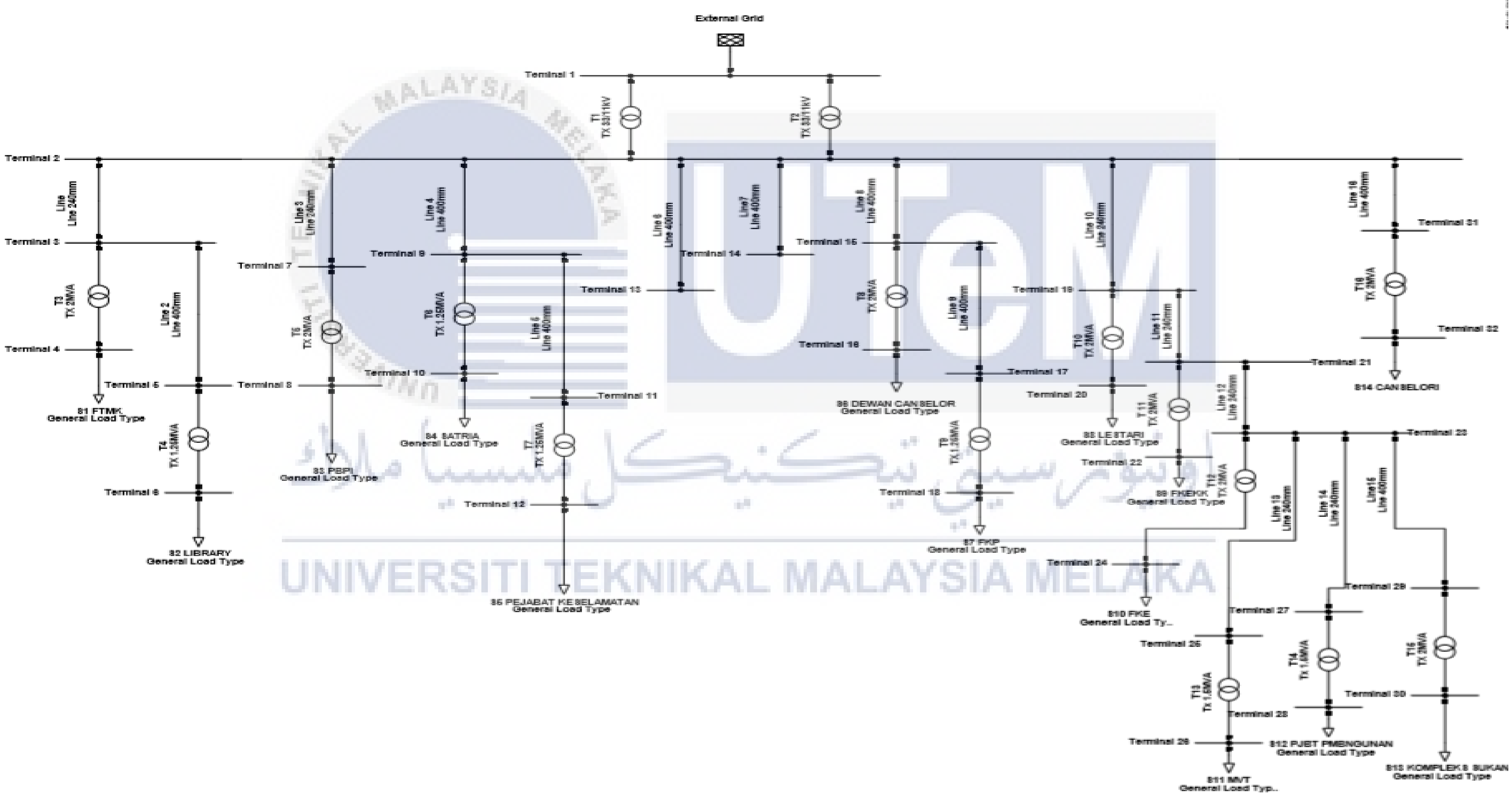
APPENDICES

APPENDIX A MEDIUM VOLTAGE DISTRIBUTION NETWORK MODEL



APP ENDIX B MEDIUM VOLTAGE DISTRIBUTION NETWORK DATA

From node	To node	Component	Voltage (kV)	R1 dc at 20℃ (Ω/km)	X1 at 50 Hz (Ω/km)	Capacitance (μF/km)	Length (km)
1	2	T1, 33/11 KV Tx, 10/15 MVA	33/11	-	-	-	-
1	2	T2, 33/11 KV Tx, 10/15 MVA	33/11	-	-	-	-
2	3	U/G cable XLPE/SWA/PVC, 3C 240mm sq. Cu	11	0.0754	0.089	0.48	0.6
3	4	T3, 11/0.4 KV , 2000KVA (FTMK)	11/0.4	-	-	-	-
3	5	U/G cable XLPE/SWA/PVC, 3C 400mm sq. Al	11	0.0778	0.083	0.59	0.45
5	6	T4, 11/0.4 KV , 1250KVA (LIBRARY)	11/0.4	-	-	-	-
2	7	U/G cable XLPE/SWA/PVC, 3C 240mm sq. Cu	11	0.0754	0.089	0.48	0.24
7	8	T5, 11/0.4 KV , 2000KVA (PBPI)	11/0.4	-	-	-	-
2	9	U/G cable XLPE/SWA/PVC, 3C 400mm sq. Al	11	0.0778	0.083	0.59	1.73
9	10	T6, 11/0.4 KV , 1250KVA (SATRIA)	11/0.4	-		-	-
9	11	U/G cable XLPE/SWA/PVC, 3C 400mm sq. Al	11	0.0778	0.083	0.59	1.15
11	12	T7, 11/0.4 KV , 1250KVA (PJBT KSLMATAN)	11/0.4	-	-	-	-
2	13	U/G cable XLPE/SWA/PVC, 3C 400mm sq. Al	11	0.0778	0.083	0.59	2.51

From node	To node	Component	Voltage (kV)	R1 dc at 20℃ (Ω/km)	X1 at 50 Hz (Ω/km)	Capacitance (μF/km)	Length (km)
2	14	U/G cable XLPE/SWA/PVC, 3C 400mm sq. Al	11	0.0778	0.083	0.59	2.3
2	15	U/G cable XLPE/SWA/PVC, 3C 400mm sq. Al	11	0.0778	0.083	0.59	2.61
15	16	T8, 11/0.4 KV , 2000KVA (DEWAN CANSELORI)	11/0.4	-	-	-	-
15	17	U/G cable XLPE/SWA/PVC, 3C 400mm sq. Al	11	0.0778	0.083	0.59	1.0
17	18	T9, 11/0.4 KV , 1250KVA (FKP)	11/0.4	-	-	-	-
2	19	U/G cable XLPE/SWA/PVC, 3C 240mm sq. Cu	11	0.0754	0.089	0.48	0.76
19	20	T10, 11/0.4 KV , 2000KVA (LESTARI)	11/0.4	-	-	-	-
19	21	U/G cable XLPE/SWA/PVC, 3C 240mm sq. Cu	11	0.0754	0.089	0.48	0.3
21	22	T11, 11/0.4 KV , 2000KVA (FKEKK)	11/0.4	-	-	-	-
21	23	U/G cable XLPE/SWA/PVC, 3C 240mm sq. Cu	11	0.0754	0.089	0.48	0.6
23	24	T12, 11/0.4 KV , 2000KVA (FKE)	11/0.4	-	-	-	-
23	25	U/G cable XLPE/SWA/PVC, 3C 240mm sq. Al	11	0.0754	0.089	0.48	0.63
25	26	T13, 11/0.4 KV , 1500KVA (MVT)	11/0.4	-	-	-	
23	27	U/G cable XLPE/SWA/PVC, 3C 240mm sq. Cu	11	0.0754	0.089	0.48	1.21
27	28	T14, 11/0.4 KV , 1500KVA (PJBT PEMBANGUNAN)	11/0.4	-	-	-	-

From node	To node	Component	Voltage (kV)	R1 dc at 20℃ (Ω/km)	X1 at 50 Hz (Ω/km)	Capacitance (μF/km)	Length (km)
23	29	U/G cable XLPE/SWA/PVC, 3C 400mm sq. Al	11	0.0778	0.083	0.59	0.26
29	30	T15, 11/0.4 KV , 2000KVA (KOMPLEKS SUKAN)	11/0.4	-	-	-	-
2	31	U/G cable XLPE/SWA/PVC, 3C 400mm sq. Al	11	0.0778	0.083	0.59	1.013
31	32	T16, 11/0.4 KV , 2000KVA (CANSELORI)	11/0.4	-	-	-	-