REDUCTION OF REACTIVE POWER LOSSES IN THE RADIAL DISTRIBUTION LINES AND ITS RELATIONSHIP WITH HARMONICS

By

AHMAD KAMIL BIN MD YUSOFF

FINAL REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

Ir. N. Perumal
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Ahmad Kamil bin Md Yusoff

ABSTRACT

The objective of this Final Year Project is to design and implement the real world problem as part of the preparation towards the future working experience in a specific area of Electrical Engineering field. Besides, this project is a requirement for the undergraduate students in order to complete their studies. The topic chosen for this project is "Reduction of Reactive Power Losses in the Radial Distribution Lines and its Relationship with Harmonics". The introduction part will elaborate the fundamental term and terminology of the topic. The project objective is to investigate the effectiveness of inserting capacitors to rectify the problem. Brief descriptions of the theory used are covered in the literature review. This report also states the methodology used during this project. The last part is the conclusion which describe the student's expectation from this project

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It is a pleasure for the author to sincerely gratitude to Allah the Almighty for giving the strength and chances to undergone the project. Without His permission, this report would not be realized.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

People life has become very dependent on electricity in every aspect. In order to cater for the needs, a proper and systematic system must be in place for the end-users to use electricity efficiently. This is to ensure the stability, quality and reliability of the power delivered to the end-users. Power is categorized into three main components which are generation, transmission and distribution.

But with the invention of sophisticated devices and machinery, the stability and quality of the power delivered has become a major concern. The terms such as active power, reactive power, apparent power and harmonics power have come into play. In single phase alternating current system; where the voltage and current increase and decrease in amplitude at the same time, only active power are transmitted. But when talking about 3 phase where there is a phase shift between voltage and current, both active power and reactive power are transmitted. This is where the major losses take place. Since that active power cannot be minimized, the only improvement that can be done is the reactive losses. This losses can be minimized by applying the reactive component to the system where needed.

Since the easiest method to improve the reactive power is by placing the capacitor that acts as the reactive power source, the method will be applied in this project. In some instance, the components addition cause two possible effects; improved reactive power as well as the real power or the additional harmonics effect in the power system network. So the project will observe and analyze the relationship of reactive power improvement with the harmonics within the same power system network.

1.2 Problem Statement

There are a lot of problems caused by harmonics to electrical and electronics equipments and appliances. These problems have increased with the introduction of power electronics equipment which pollutes the AC distribution system with the harmonic current which is very sensitive to the voltage distortion. This in turn affects the power quality and the power stability in the network.

In a system where the reactive power loss is high, the introduction of capacitor(s) in the affected circuit will reduce the losses. But the introduction of the capacitor(s) into the power system network may also introduce another problem as this might produce harmonics. As we know harmonics contribute to major power quality problem in any power system. Thus the investigation of harmonics content in a system is essential to stabilize and optimize the power quality of a power system network.

1.3 Problem Identification

The understanding of the different type of power transmitted is important in order to understand harmonics problems. The load flow analysis is done before inserting the capacitors. The system performance will be checked after the insertion. The effect will be compared through different approach of inserting capacitor, which is better than the other based on previous studies on the same power system network. The analysis can be done by simulation using the suitable power system analysis software applied to the available IEEE 34 bus standard distribution test system.

1.4 Objectives

The objectives of this project on the current topic are:

a) To review the power system especially the radial distribution system and its losses,
b) To understand the harmonics and its fundamental,
c) To understand the role of capacitor to the system,
d) To reduce reactive power losses and observe the harmonics implication and evaluate the system performance before and after insertion of the capacitors.

1.5 Scope of Study

The scope of study will emphasize on the radial distribution network which is used widely in Malaysia. For the project, the system network of IEEE 34 Bus Test System will be used (radial distribution lines). The project will only consider the loss of reactive power and its compensation which is then analyze from the harmonics perspective.

CHAPTER 2
LITERATURE REVIEW

The first thing to be done is to review the general information of power system particularly in distribution system. Then the focus goes to the characteristic of reactive power which also includes the reactive power losses. Lastly the knowledge of harmonics and its characteristics will be reviewed before the load flow analysis is done.

2.1 Electrical Power System

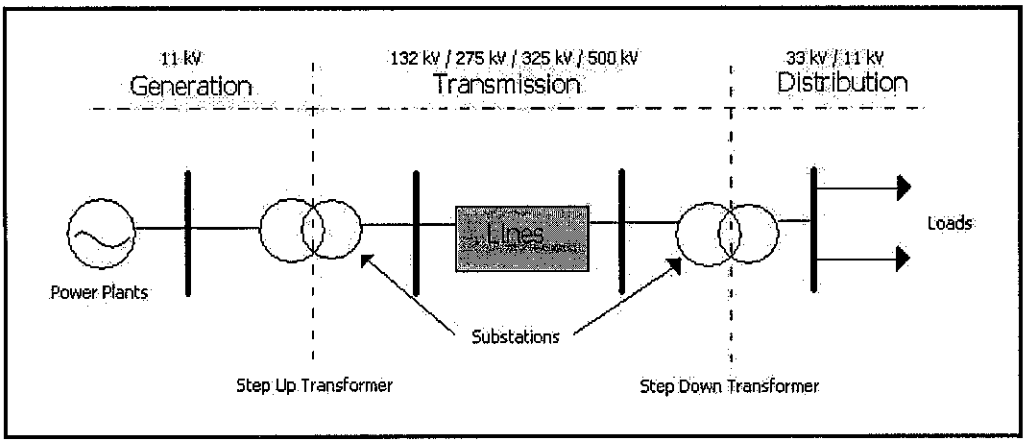

Figure 1 Major Components in Power System

In the figure above, the major components of a power system consists of generation, transmission and distribution. In Malaysia, the generation is done by Tenaga Nasional Berhad (TNB) and also the Independent Power Producers (IPPs) such as Teknik Janakuasa Sdn. Bhd, YTL Power and Genting Sanyen. TNB is then responsible to transmitted and distributed the power to the end-users. [7]

Transmission is where the high voltage is transmitted from one region to another. The voltage levels are stated in the figure above. Distribution is the part where the high voltage transmission will be stepped down before distributed to the end-users at low voltage. The end-users are the loads which consist of industrial consumers, commercial and infrastructures and lastly the residences that utilize typically 240 V single phase and 415 V three phase.

For distribution system, there are two common types of network configuration. They are ring distribution system and radial distribution network. [4]

2.1.1 Ring Distribution System

The ring distribution system can afford re-routing of power flow in the event of a breakdown as shown in the figure below. This can minimize the possible failure or power interruption to the customer. In turn of the better reliability, the cost of installation comes into play by which the cost is quite high compared to the radial distribution network. Below is the figure shows the network configuration of a ring distribution network. [7]

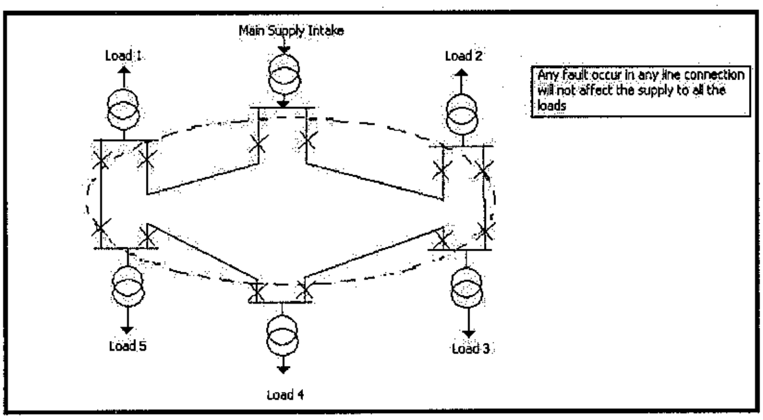

Figure 2 Ring Distribution System

2.1.2 Radial Distribution System

Radial distribution system only permits only one direction flow of power. In this network system, the supply is connected directly to the bus where the busses contained loads [7]. The disadvantage of utilizing this network system is when there is some problem in the middle of the bus, which also affects the supply continuity to the remaining loads after the interrupted bus. The next page shows the figure of how radial distribution system look like. But there is a solution for this type of system whenever there is power interruption or problem in any part of the system. The solution is done by making a circular radial distribution. In this network system, the lines are still maintain the basic as shown below except there will be another source of power for each types of loads/end-users which will be operated once the main source malfunction or having problems.

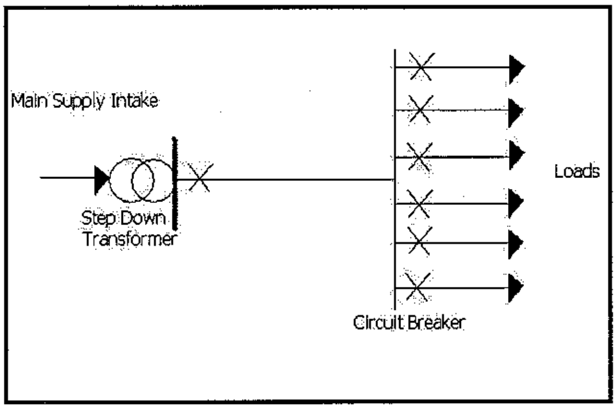

Figure 3 Radial Distribution System

2.2 Reactive Power and Losses

Reactive power is useful and important whenever there is a need of magnetic field for inductive elements and electric field generated by capacitive elements to operate. This can be the induction motors, electronics ballast, generators, transformers etc. Reactive power is stored and released by inductance and capacitance in a power system. If there is no loss or distortion, the loads are normally linear where voltage and current frequency rise and fall together. Therefore, it can be seen that there is an apparent value which is greater than the active and reactive values as shown in the figure below.

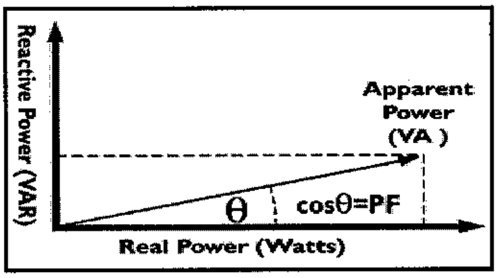

Figure 4 Power Relationship (Power Triangle)

Since that the reactive power is associated with power factor, the improvement of reactive power also means improving the power factor. This is because the power factor is defined as the ratio of active power to the reactive power [3].

The reactive power can be express in mathematical expression which is a component of the total power representing as the vector sum of the real power and reactive power as shown below

$$\text{TOTAL POWER / APPARENT POWER} = \sqrt{(\text{REAL POWER})^2 + (\text{REACTIVE POWER})^2} \quad (2.1)$$

When considering the reactive power losses, a lot of factors affecting it which some of them are as follows;

a) Feeder Length – Longer distance increase the resistance and reactance lead to voltage drop and high current drawn.
b) Inadequate Conductor Sizing – Vary depending the locations of loads where at some bus branches, the loads are high and some are low where the conductors must have the capability for power flow efficiently.
c) Location of Distribution Transformers – Farther distance means lower voltage level as at each loads, there must have voltage drop until the last loads which might received a very low voltage level.
d) Low Voltage – Some of induction machine will be affected as low voltage will make to motor to drawn excessively high current at the same output.
e) Low Power Factor – Due to induction elements which in turn contribute to high losses.

Since that in the radial distribution system or any electrical system, the reactive power losses appear due to the loads characteristics. In order to improve it, a device that injects extra reactive power is essential and that is the capacitor. The capacitor provides the positive VAR which is then reduce the losses.

2.3 Harmonics

Harmonics is a component of a periodic wave having a frequency that is an integral multiple of the fundamental power line frequency of 50 Hz in Malaysia. The total harmonics distortion is the contribution of all harmonics frequency currents to the fundamental which is shown in the figure on the next page (employed American electrical fundamental frequency, 60Hz)

Harmonic	*Frequency*
1st	60 Hz
2nd	120 Hz
3rd	180 Hz
4th	240 Hz
5th	300 Hz
6th	360 Hz
7th	420 Hz
8th	480 Hz
9th	540 Hz
10th	600 Hz
11th	660 Hz
13th	780 Hz
:	:
49th	2940 Hz

The characteristic harmonics are based on the number of rectifiers (pulse number) used in a circuit and can be determined by the following equation:

$$h = (n \times p) \pm 1$$

where: n = an integer (1, 2, 3, 4, 5 ...)
p = number of pulses or rectifiers

For example, using a 6 pulse rectifier, the characteristic harmonics will be:

$h = (1 \times 6) \pm 1 \Rightarrow$ 5th & 7th harmonics
$h = (2 \times 6) \pm 1 \Rightarrow$ 11th & 13th harmonics
$h = (3 \times 6) \pm 1 \Rightarrow$ 17th & 19th harmonics
$h = (4 \times 6) \pm 1 \Rightarrow$ 23rd & 25th harmonics

Figure 5 Harmonics Characteristics

In 3 phase power system, the harmonics phase is categorized by its phase sequences. There are three types of phase sequences namely as positive sequences, negative sequences and zero sequences. A positive sequence is the angle displacement rotation which is anti-clockwise while the opposite direction for the negative phase sequences. This report will summarized the odd-harmonics phase sequence rotation as shown below.

- Harmonics order h = 1, 7, 13.... (positive sequence)
- Harmonics order h = 5, 11, 17...(negative sequence)
- Triplens (h = 3, 9, 15)....(zero sequence)[6]

Total harmonics distortion (THD) is a measure of the effective value of the harmonics components of a distorted waveform. It is the potential heating value of the harmonics relative of the fundamental. This index can be calculated for either voltage or current.

$$\text{THD} = \sqrt{\frac{\sum_{h>1}^{h\max} M_h^2}{M_1}} \tag{2.2}$$

Where M_h is the rms value of harmonic component h of the quantity M. The THD is a very useful indicator of how much the heat is realized when a distorted voltage is applied across a resistive load. THD is often referenced to the fundamental value of the waveform at the time of sample and to describe the voltage harmonic distortion. Shown below is the sample of recorded THD for an interval of time taken from an industry's load at a substation at rated voltage of 13.2 kV [2] [3].

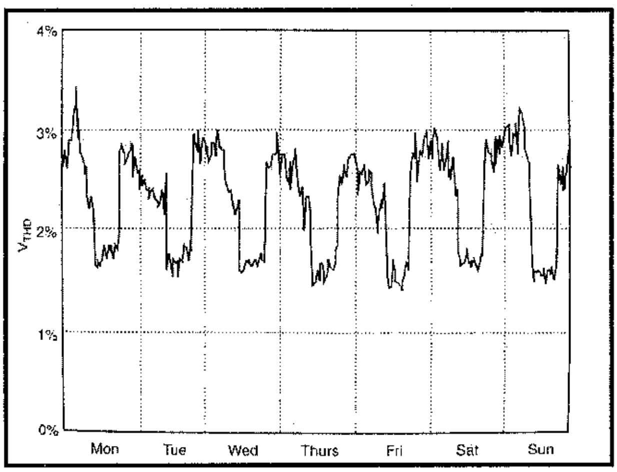

Figure 6 Variation of the voltage THD over a 1-week period

2.3.1 Harmonics Sources

Commercial facilities are the loads that have the harmonics injection to the power system network such as the offices complexes, department stores, hospitals which high-efficiency fluorescent lighting with electronics ballast, adjustable-speed drives for the ventilation, air-conditioning loads, elevator drives and sensitive electronics equipment supplied by single-phase switch-mode power supplies. Its depend on the types of loads whether these discrete small harmonics current produced may add in phase or cancel each other. The voltage distortion levels depend on both the circuit impedances and the overall harmonic current distortion.

Figure 7 below shows the harmonics content due to the usage of fluorescent lighting with electronics ballast.

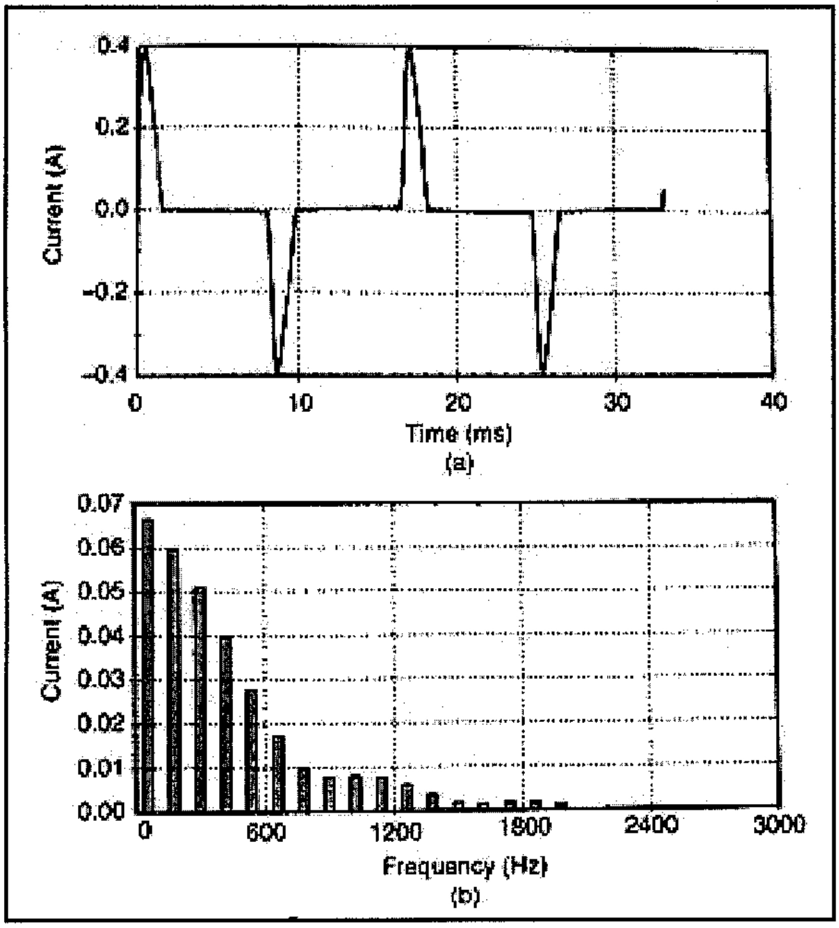

Figure 7 Fluorescent Lamp with (a) electronic ballast waveform and (b) its harmonic spectrum

2.3.2 Harmonics Effect

Harmonics can lead to power system inefficiency. In power system, odd harmonics will have a special attention rather than the other harmonics numbers. For the triplen harmonics, typical problem occurs especially for the grounded wye systems with the current flowing on the neutral conductor. In the balanced single-phase loads an assumption is made that the fundamental and triplens are present. For the fundamental component, the neutral current is found to be zero. But the triplens give a 3 times those of the phase currents because they naturally coincide in phase and time.

Some of the negative ways that harmonics may affect the equipment as an example in a plant are listed below:

a) Conductor Overheating – a function of the square RMS current per unit volume of the conduct", which increase with frequency and is similar to a centrifugal force.
b) Capacitors – can be affected by heat rise increases due to power losses and reduced life on the capacitors. If a capacitor is tuned to one of the characteristic harmonics such as 5^{th} or 7^{th}, over voltage and resonance can cause dielectric failure or rupture the capacitor.
c) Fuses and Circuit Breakers – Harmonics can cause false or spurious operations and trips, damaging or blowing components for no apparent reason.
d) Transformers – have increased iron and copper losses or eddy current due to stray flux losses. This causes excessive overheating in the transformer windings.
e) Generator – have similar problems to transformers
f) Utility Meters – may record measurement incorrectly, resulting higher billing to consumers
g) Drives/Power Supplies – can be affected by disoperation due to multiple zero crossings. Harmonics can cause failure of the commutation circuits, found in DC drives and AC drives with SCR
h) Computers/Telephones – may experience interference or failures.

2.3.3 Harmonics Problem with Capacitor

There are two type capacitor installations in the distribution network that are shunt capacitor and series capacitor. Both types of installation will yield the similar result that is providing the reactive power required and also improving the power factor.

Shunt capacitor compensate reactive power by improving power factor whereas series capacitor compensate reactive power by directly countering the lagging component of the inductive load current at the point of installation.
The project will utilize the shunt capacitor installation which the series capacitor has some disadvantage over the shunt capacitor. Series capacitor is generally costly to

install as well as its protection devices. Other than that, the capacitor may create certain disturbances such as Ferro-resonance in transformers, sub-synchronous resonance during motor starting, shunting of motors during normal operation and difficulties protection of the capacitors from system fault current.

A series capacitor can be considered as a voltage regulator that provides for a voltage boost that is proportional to the magnitude and power factor of the through current. A series capacitor betters the system power factor much less than a shunt capacitor and has little effect on the source current. So the shunt capacitor is chosen for this project. [4]

The problem with the shunt capacitor is any energy storing devices will have one or more natural frequency. When one of these frequencies lines up with a frequency that is being produced on the power system, a resonance may develop in which the voltage and current at that frequency continue to persist at very high values.

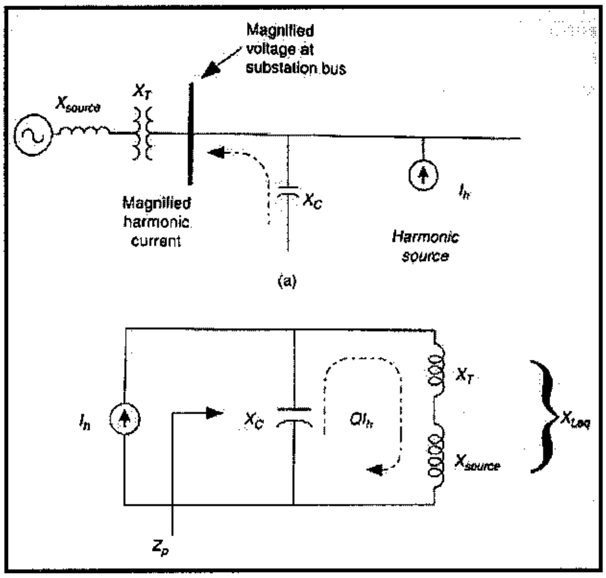

Figure 8 At Harmonics Frequencies, the shunt capacitor appears in parallel with the system inductance. (a) Simplified distribution circuit; (b) parallel resonant circuit seen from the harmonic source

At parallel resonant frequency, the quality factor of a resonant circuit that determine the sharpness of the frequency response will cause the current to be magnified which can lead to capacitor failure, fuse blowing or transformer overheating like shown in Figure 8 on the previous page.

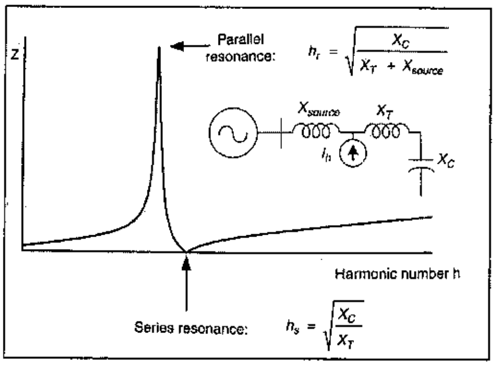

Figure 9 Frequency Response of a Circuit

In order to find the appropriate value of capacitor, the point where the highest harmonics distortion recorded will be the location of the capacitor. There, the capacitor's natural frequency must be shifted near the harmonic component so that the frequency does not coincide as to prevent the resonant. [2]

2.4 Standard

IEEE 519-1981, *"IEEE Guide for Harmonic Control and Reactive Compensation of Static Power Converters"*, originally established levels of voltage distortion acceptable to the distribution system for individual non-linear loads. With the rising increase usage of industrial non-linear loads, such as variable frequency drives, it became necessary to revise the standard.

The IEEE working groups of the Power Engineering Society and the Industrial Applications Society prepared recommended guidelines for power quality that the utility must supply and the industrial user can inject back onto the power distribution system. The revised standard was issued on April 12, 1993 and titled *"IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems"*. [5]

The revisions to IEEE 519-1992 establish recommended guidelines for harmonic voltages on the utility distribution system as well as harmonic currents within the industrial distribution system. According to the standard, the industrial system is responsible for controlling the harmonic currents created in the industrial workplace. Since harmonic currents reflected through distribution system impedances generate harmonic voltages on the utility distribution systems, the standard proposes guidelines based on industrial distribution system design. Table 1 from IEEE 519-1992 defines levels of harmonic currents that an industrial user can inject onto the utility distribution system. [1]

Table 1 Current Distortion Limit for General Distribution Systems (120V to 69kV)

Maximum Harmonic Current Distortion in % of I_L Individual Harmonic Order (Odd Harmonics)[1,2]						
I_{SC}/I_L	<11	$11 \le h \le 17$	$17 \le h \le 23$	$23 \le h \le 35$	$35 \le h$	TDD
<20[3]	4.0	2.0	1.5	.6	.3	5.0
20 < 50	7.0	3.5	2.5	1.0	.5	8.0
50 < 100	10.0	4.5	4.0	1.5	.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

[1] Even harmonics are limited to 25% of the odd harmonic limits above.
[2] Current distortions that result in a DC offset, e.g., half-wave converters, are not allowed.
[3] All power generation equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L, where I_{SC} = maximum short circuit current at PCC and I_L = maximum demand load current (fundamental frequency component) at PCC.

Table 2 of IEEE 519-1992 defines the voltage distortion limits that can be reflected back onto the utility distribution system. Usually if the industrial user controls the overall combined current distortion according to Table 1, this will help them meet the limitations set forth in the guidelines. [1]

Table 2 Voltage Distortion Limits

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Harmonic Voltage Distortion THD (%)[1]
69 kV and below	3.0	5.0
69.0001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

[4] High voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.

2.5 Harmonics Distortion

The harmonics distortion can be calculated in term of current and voltage. Both provide a good indicator of any power system network health in term of harmonics pollution. [6]

2.5.1 Calculation for Voltage Distortion

$$THD(\%) = \frac{1}{V_1}\sqrt{\left(\sum_{n=2}^{m} V_n^2\right)} \times 100$$

V_1 is the fundamental component of the voltage and V_n is the harmonic component. For this project, the harmonics characteristics are limited of up to 25^{th} harmonics number. [6]

2.5.2 Calculation for Current Distortion

$$TDD(\%) = \frac{1}{I_1}\sqrt{\left(\sum_{n=2}^{m} I_n^2\right)} \times 100$$

I_1 is the fundamental component of the current and I_n is the harmonic components. [6]

CHAPTER 3
METHODOLOGY

3.1 Project Flow Chart

The methodology used is very important in order to complete this project. The methodologies are identified as the flow of the project until the end. The project flow chart is shown below.

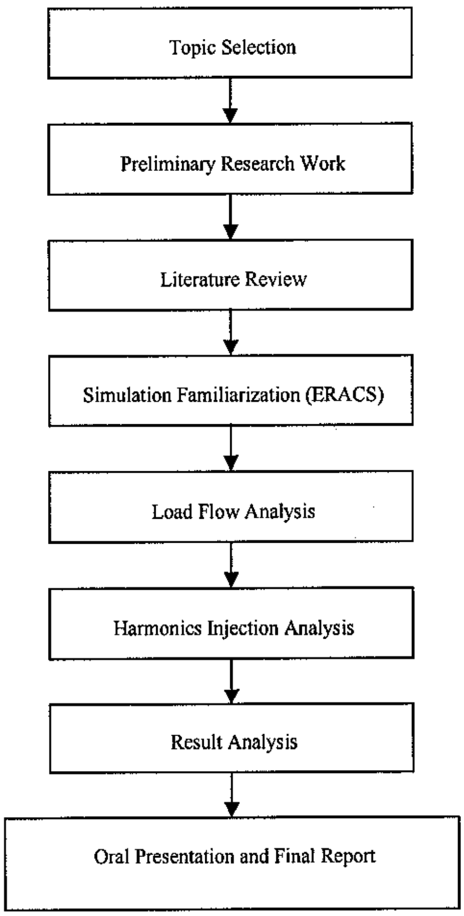

Figure 10 Project Flow Diagram

3.1.1 Preliminary Research Work

At the beginning of the project, finding information and explanation is done. This is to acquire the very fundamental knowledge of the topic which is essential in order to cater the future obstacle when implementation works are done. At this stage, the knowledge of the power system characteristics, reactive power and harmonics characteristics and mitigation will be observed and studied. The test system and also the tool needed in this project will also be clarified. The IEEE 34 Bus Test System will be the subject in accordance to the topic. In order to relate the reduction of reactive power losses, a tool named Load Flow Analysis in ERACS software will be used. A tool named Harmonics Injection Analysis within ERACS will be used to observe the harmonics effect. ERACS is specialized and user friendly software to Power System Engineering for precise and easy simulation.

3.1.2 Literature Review

A heavy and detail literature review is done at this stage to strengthen the knowledge in the related topic. It focuses more on the journals, product datasheets (capacitor bank), technical papers, internet discussion forum and books. The scope is limited to the mitigation of reactive power losses as well as the harmonics itself.

3.1.3 Software Familiarization (ERACS)

There are a number of tools provided by ERACS and for this project, it only utilized two tools that are; Load Flow Analysis and Harmonics Injection Analysis. During this stage, the software is explored and familiarized.

3.1.4 Load Flow Analysis

By running the Load Flow Analysis on any power system network, the important parameters such as the bus voltage profile, line currents, power flow and losses as well as other parameters can be obtained. The project will need those parameters to accomplish the objective.

3.1.5 Harmonics Injection Analysis

The Harmonics Injection Analysis in ERACS provides the penetration viewpoint and enables the level of harmonic distortion in electrical power system network to be predicted by assessing the injected harmonic current from the polluting sources.

3.1.6 Result Analysis

The result of those simulations of the integrated approaches (single capacitor placement and multiple capacitor placements) will be compiled and for easier public understanding, some figures will be produced to see the differences.

3.1.7 Oral Presentation and Final Report

The project will be presented to the supervisor and examiners (internal and external) to be evaluated and embedded to a report as a reference material.

3.2 ERACS

ERACS is one of the numerous power system analysis softwares available for industrial as well as for educational purposes. The user friendly interface makes it the powerful tool for its purpose.

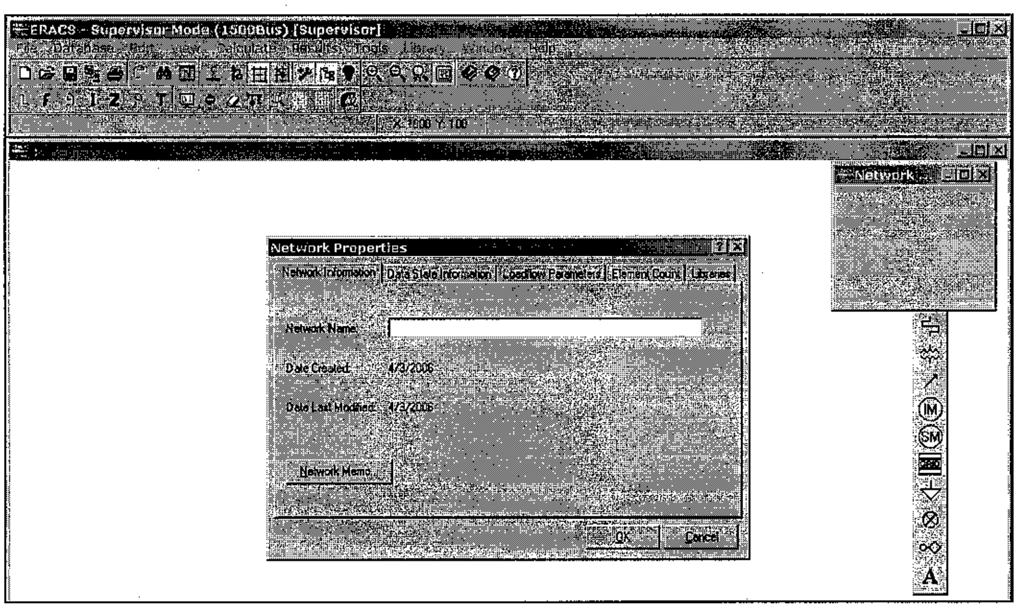

Figure 11 ERACS New Network Construction Interface

The interface consists of several parts (toolbars and windows) such as;

- Menu and General Function Toolbar (fig 12)
- ERACS Tools Toolbar (fig 13)
- Network Layout Window
- Element Toolbar (fig 14)

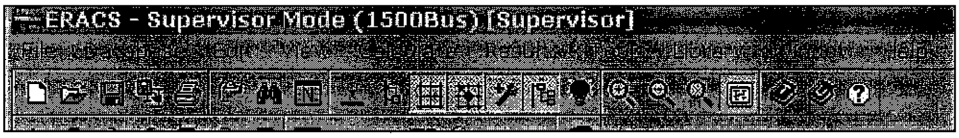

Figure 12 Menu and General Function Toolbar

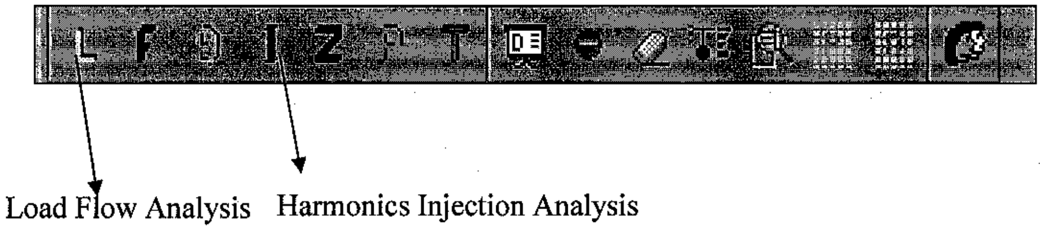

Figure 13 ERACS Tool Toolbar

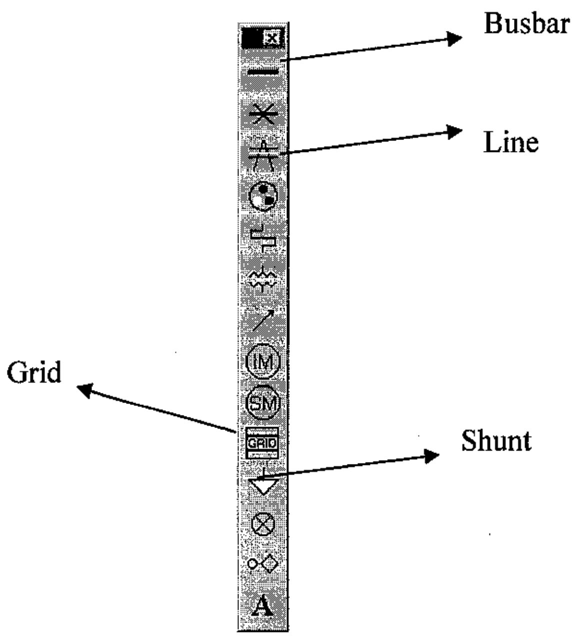

Figure 14 Element Toolbar

When creating new network, a pop-up window appear named Network Properties. This window must be filled with the appropriate things especially to the following field;

a) Network Information (give name to the network created)
b) Data State Information (give name to the data state of the network)
c) Libraries
   i) Working Library (setup user library for the elements used)
   ii) Reference Library (can use ERA Library as the reference library in the case where default element characteristics is needed or can be created by user alone)

The network can be created on the Network Layout Window using the Element Toolbar by click-and-drag the element onto the window. A pop-up window appears as depicted in the figure below. The bus identifier and the voltage rating must be filled when the busbar element to be established.

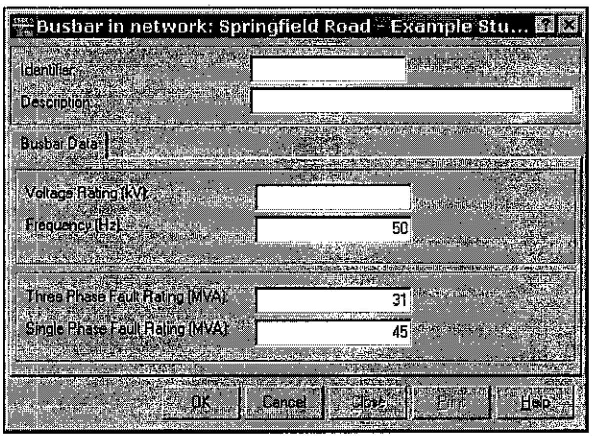

Figure 15   Busbar Data Entry

To establish an element, a specific data library must be chose or created specific to the particular element such as Line and Shunt. Figure 16 and 17 shows the pop-up windows of establishing the Line and Shunt elements. There are two common buttons in both figures which state the Library use. First, if the Library is not created yet, Figure 18 is where the library can be created by clicking the Library button. If the Library for the element is created, click Select to choose the library and fill in the values applicable to each elements.

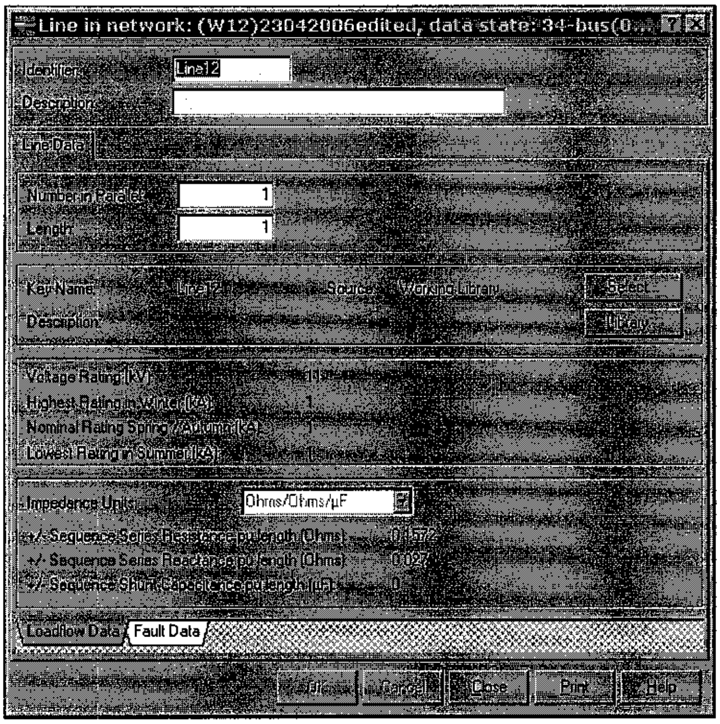

Figure 16 Line Data Entry

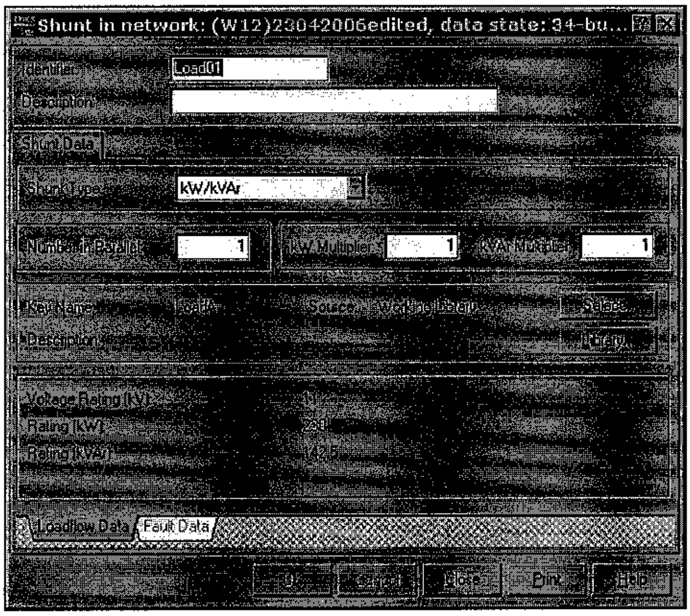

Figure 17 Shunt Data Entry

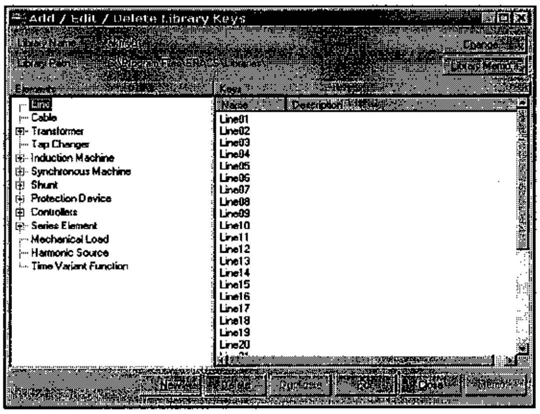

Figure 18 Library Keys Setup

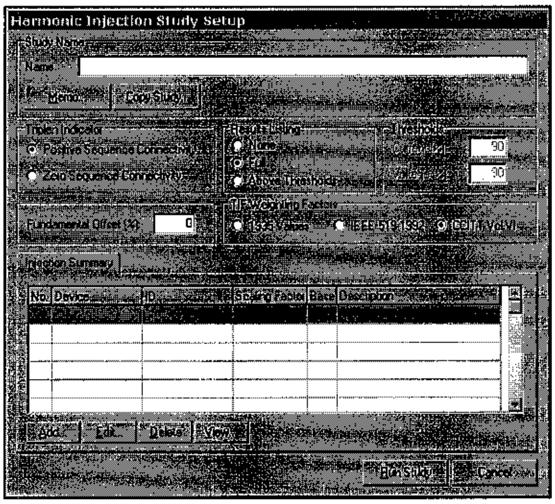

Figure 19 Harmonics Injection Analysis

For running the Load Flow Analysis just click the Load Flow Analysis button on the ERACS Tool Toolbar and for Harmonics Injection Analysis, click on the Harmonics Injection Analysis button on the same toolbar. For Harmonics Injection Analysis, a window will pop-up as in Figure 19 and harmonics injection source(s) must be chosen as well as its harmonics current data table which is in this project, the data is set to default which the harmonics current depends on the load current data by a certain multiplier for each harmonics component.

3.3 IEEE 34 Bus Test System

The test system is a model representing the practical distribution system which can be implemented in real scenario. The system will be created in ERACS and its data will be inserted as prescribed earlier. It has 34 busbars with and without loads (represent by shunt element consist of real power and reactive power) with 3 additional branches at its main radial line.

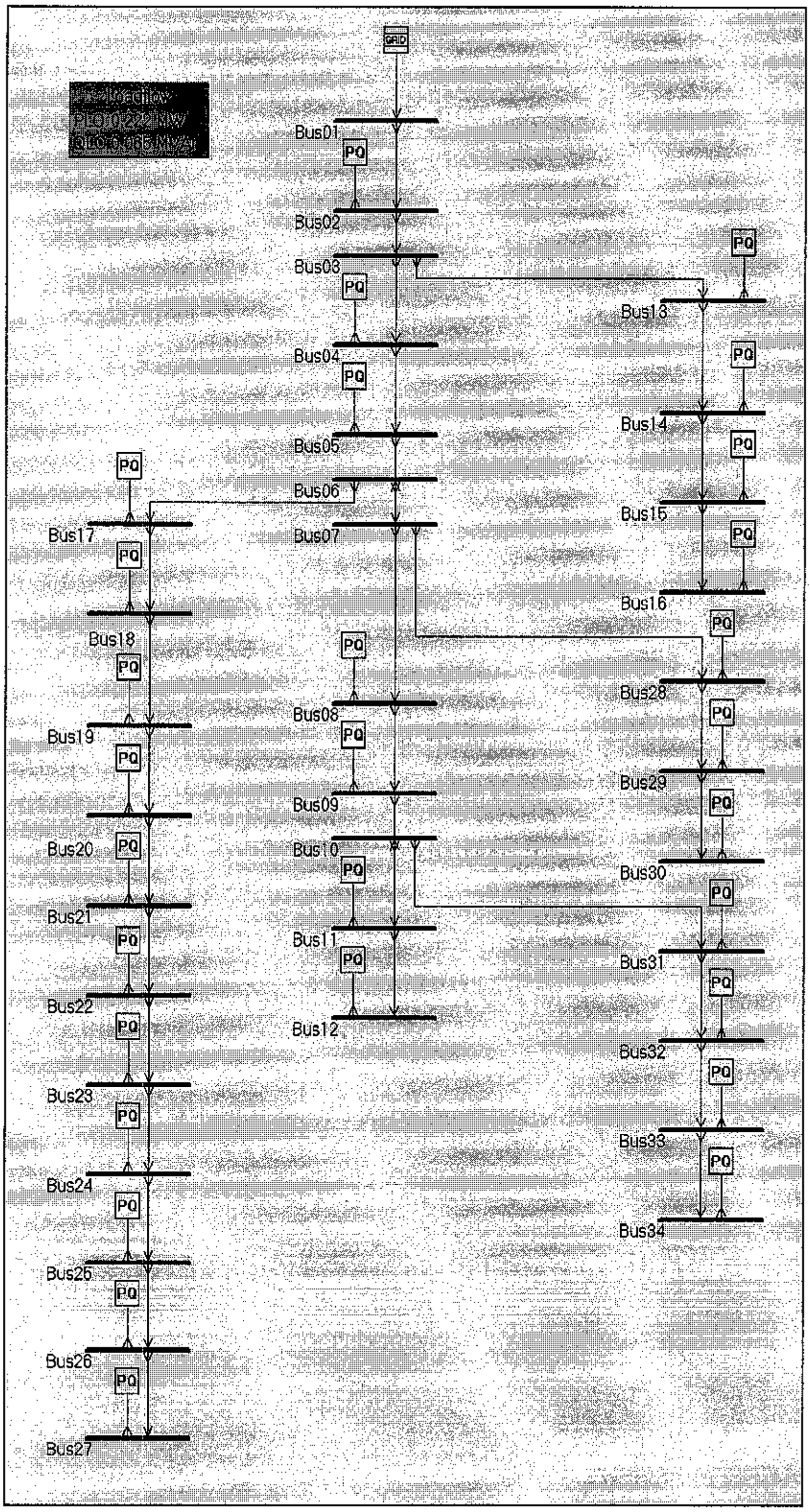

Figure 20 IEEE 34-Bus Test System Built in ERACS

Table 3 Line Data

No. of Nodes: 34 Base Voltage: 11 kV

No. of Branches: 33 Base Load: 5 MVA

Line	From	To	Resistance (Ω)	Reactance (Ω)
1	Bus01	Bus02	0.11700	0.04800
2	Bus02	Bus03	0.10725	0.04400
3	Bus03	Bus04	0.16445	0.04565
4	Bus04	Bus05	0.14950	0.04150
5	Bus05	Bus06	0.14950	0.04150
6	Bus06	Bus07	0.31440	0.05400
7	Bus07	Bus08	0.20960	0.03600
8	Bus08	Bus09	0.31440	0.05400
9	Bus09	Bus10	0.20960	0.03600
10	Bus10	Bus11	0.13100	0.02250
11	Bus11	Bus12	0.10480	0.01800
12	Bus03	Bus13	0.15720	0.02700
13	Bus13	Bus14	0.20960	0.03600
14	Bus14	Bus15	0.10480	0.01800
15	Bus15	Bus16	0.05240	0.00900
16	Bus06	Bus17	0.17940	0.04980
17	Bus17	Bus18	0.16445	0.04565
18	Bus18	Bus19	0.20790	0.04730
19	Bus19	Bus20	0.18900	0.04300
20	Bus20	Bus21	0.18900	0.04300
21	Bus21	Bus22	0.26200	0.04500
22	Bus22	Bus23	0.26200	0.04500
23	Bus23	Bus24	0.31440	0.05400
24	Bus24	Bus25	0.20960	0.03600
25	Bus25	Bus26	0.13100	0.02250
26	Bus26	Bus27	0.10480	0.01800
27	Bus07	Bus28	0.15720	0.02700
28	Bus28	Bus29	0.15720	0.02700
29	Bus29	Bus30	0.15720	0.02700
30	Bus10	Bus31	0.15720	0.02700
31	Bus31	Bus32	0.20960	0.03600
32	Bus32	Bus33	0.15720	0.02700
33	Bus33	Bus34	0.10480	0.01800

Table 4 Load Data

Busbar	PL	QL
Bus02	230.000 kW	142.500 kVAr
Bus04	230.000 kW	142.500 kVAr
Bus05	230.000 kW	142.500 kVAr
Bus08	230.000 kW	142.500 kVAr
Bus09	230.000 kW	142.500 kVAr
Bus11	230.000 kW	142.500 kVAr
Bus12	137.000 kW	84.000 kVAr
Bus13	72.000 kW	45.000 kVAr
Bus14	72.000 kW	45.000 kVAr
Bus15	72.000 kW	45.000 kVAr
Bus16	13.500 kW	7.500 kVAr
Bus17	230.000 kW	142.500 kVAr
Bus18	230.000 kW	142.500 kVAr
Bus19	230.000 kW	142.500 kVAr
Bus20	230.000 kW	142.500 kVAr
Bus21	230.000 kW	142.500 kVAr
Bus22	230.000 kW	142.500 kVAr
Bus23	230.000 kW	142.500 kVAr
Bus24	230.000 kW	142.500 kVAr
Bus25	230.000 kW	142.500 kVAr
Bus26	230.000 kW	142.500 kVAr
Bus27	137.000 kW	85.000 kVAr
Bus28	75.000 kW	48.000 kVAr
Bus29	75.000 kW	48.000 kVAr
Bus30	75.000 kW	48.000 kVAr
Bus31	57.000 kW	34.500 kVAr
Bus32	57.000 kW	34.500 kVAr
Bus33	57.000 kW	34.500 kVAr
Bus34	57.000 kW	34.500 kVAr

CHAPTER 4

RESULT AND DISCUSSION

From the early simulation, the total real and reactive power losses are 0.2218 MW and 0.065 MVAr respectively, which coincide with the result from the previous report. The loss can also be divided into two perspectives which are the loss incurred by the real components and also the loss incurred by the reactive components. The simulation data before the compensation is shown in the next page.

The next step is to look at the losses after the compensation. Utilizing both Single Capacitor Placement Method (Method 1) and Multiple Capacitor Placement Method (Method 2) the loss saving will be done. The results of utilizing both methods for losses compensation are showed in the following subsection of this chapter.

Then the harmonics distortion level in both methods can be obtained after running the Harmonics Injection Analysis within ERACS. The discussions for every sequence of task are explained after each particular subsection.

Table 5 Voltage Profile and Power Losses

Busbar ID	pV (pu)	V (kV)	Line ID	Real Loss (MW)	Reactive Loss (MVAR)
Bus01	1.000000	11.000	Line01	0.0312	0.0128
Bus02	0.994137	10.936	Line02	0.0259	0.0106
Bus03	0.989020	10.879	Line03	0.0358	0.0100
Bus04	0.982053	10.803	Line04	0.0291	0.0081
Bus05	0.976061	10.737	Line05	0.0259	0.0072
Bus06	0.970414	10.675	Line06	0.0064	0.0011
Bus07	0.966586	10.632	Line07	0.0029	0.0005
Bus08	0.964483	10.609	Line08	0.0026	0.0005
Bus09	0.962015	10.582	Line09	0.0009	0.0001
Bus10	0.960829	10.569	Line10	0.0002	0.0000
Bus11	0.960371	10.564	Line11	0.0000	0.0000
Bus12	0.960235	10.563	Line12	0.0001	0.0000
Bus13	0.988687	10.876	Line13	0.0001	0.0000
Bus14	0.988381	10.872	Line14	0.0000	0.0000
Bus15	0.988298	10.871	Line15	0.0000	0.0000
Bus16	0.988292	10.871	Line16	0.0135	0.0037
Bus17	0.965953	10.625	Line17	0.0102	0.0028
Bus18	0.962244	10.585	Line18	0.0103	0.0024
Bus19	0.958149	10.540	Line19	0.0074	0.0016
Bus20	0.954856	10.503	Line20	0.0056	0.0013
Bus21	0.951993	10.472	Line21	0.0056	0.0010
Bus22	0.948723	10.436	Line22	0.0038	0.0006
Bus23	0.946037	10.406	Line23	0.0028	0.0005
Bus24	0.943513	10.379	Line24	0.0010	0.0002
Bus25	0.942298	10.365	Line25	0.0002	0.0000
Bus26	0.941831	10.360	Line26	0.0000	0.0000
Bus27	0.941692	10.359	Line27	0.0001	0.0000
Bus28	0.966250	10.629	Line28	0.0000	0.0000
Bus29	0.966026	10.626	Line29	0.0000	0.0000
Bus30	0.965914	10.625	Line30	0.0001	0.0000
Bus31	0.960488	10.565	Line31	0.0001	0.0000
Bus32	0.960148	10.562	Line32	0.0000	0.0000
Bus33	0.959977	10.560	Line33	0.0000	0.0000
Bus34	0.959920	10.559	***Total***	***0.2218***	***0.065***

4.1 Reactive Power

Reactive power is important for a certain purpose especially dealing with inductive equipments and capacitive equipments. An optimum reactive power usage is defined to be an effective use of power. The reactive power losses are expensive and inefficient. Due to this reasons, the compensation of reactive power loss is needed. Using the method of applying the shunt capacitors to the point where the highest power saving is, the location will depict from the previous report [4] where two approaches will be done as an extension analysis.

Table 6 Capacitor Rating for Both Approaches and Its Location

Approaches	Bus Location	Capacitor Rating (kVAR)
Method 1	21	1010.48
	8	691.44
	25	306.36
	11	*214.44*
Method 2	21	437.28
	8	567.71
	25	331.51

4.1.1 Load Flow Analysis for Method 1

In the first method, a capacitor will be inserted at the busbar where the highest loss saving can be achieved. Then the Load Flow Analysis is done again and the next highest loss saving can be achieved. It is done for several iterations. The capacitor rating is obtained from the MATLAB computation as done in previous report. The first three capacitors will be added for this method at busbar 21 followed by busbar 8 and 21. The reason of utilizing only three capacitors instead of four capacitors onwards is due to the cost benefit ratio where the loss saving is not significant by adding more capacitor. As we know, capacitor is not cheap to buy and it is to ensure the cost is suitable with the loss saving which means higher loss saving with minimum cost is preferable. The loss saving ratio (kW/kVAR) is 4.8067

Table 7 Loss Saving for Method 1

Losses	Before Compensation	After Compensation	Loss Saving
Real Power (kW)	221.8	164.6	57.2
Reactive Power (kVAR)	65	48.1	11.9

4.1.2 Load Flow Analysis for Method 2

The idea of multiple capacitor placement method is to calculate the capacitor current for each bus and from there, the highest achievable loss saving bus will be determined and its capacitor rating will be calculated. The second highest achievable loss saving bus will be the next busbar to be compensated same as the first one. After the calculation of loss saving, three capacitors are chosen for compensation which includes the cost benefit of how many capacitors to be inserted compared to how much loss can be compensated. The loss saving ratio for this method is 3.4015

Table 8 Loss Saving for Method 2

Losses	Before Compensation	After Compensation	Loss Saving
Real Power (kW)	221.8	175.2	46.6
Reactive Power (kVAR)	65	51.3	13.7

4.1.3 Comparison of Power Losses for Both Methods

From both methods, it is clear that method 2 compensate more reactive power compared to Method 1 by the difference of 1.8 kVAr. This is very close. To compare which one is better is then lies to the loss saving ratio which Method 1 and Method 2 are 4.8067 and 3.4015 respectively. Since by the insertion of capacitor purposes to reduce the loss, Method 1 is merely favorable to be implemented without considering the harmonics introduction by the capacitor insertion.

4.2 Harmonics Analysis

4.2.1 Harmonics Injection Analysis for Method 1 on THD Percentage

Numbers of Harmonics Injection Analysis are done for this method. This is to see the variation of harmonics effect to the network system for all iterations. Figure below shows the percentage of voltage THD for all iterations in each busbar.

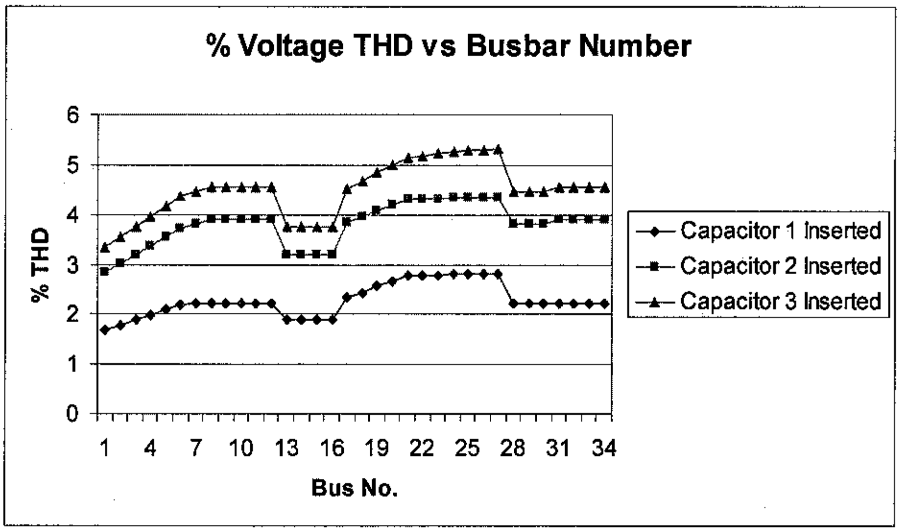

Figure 21 Percentage THD versus Busbar Number

4.2.2 Harmonics Injection Analysis for Method 2 on THD Percentage

Since the Load Flow Analysis for this method is done once, so as to the Harmonics Injection Analysis. The Harmonics Injection Analysis is done same as for the Method 1 after the insertion of all capacitors but for this method, the capacitor ratings for Method 2 are used.

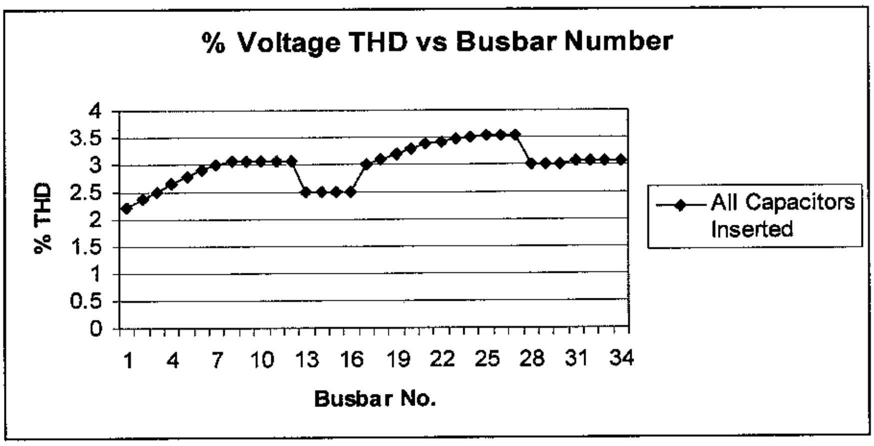

Figure 22 Percentage THD versus Busbar Number

4.2.3 Comparison of Harmonics Distortion for Both Method

It is clear that Method 1 will yield higher distortion compared to the Method 2. Not only it produces higher distortion, it also exceeds the IEEE 519-1992 Standard limit which state for system below 69 kV (test system employed 11 kV); the voltage THD percentage must not exceed 5%. Failure to abiding to the limit is severe. There are a lot of implications such as equipments failure, undesirable higher losses, less efficiency due to overheat. And power quality problem to the end users.

Table 9 Comparison of Percentage Voltage THD for Both Methods in term of Highest Distortion

Method	Bus location	% Voltage THD	Remark
Method 1	27 (Highest)	5.30584	> 5%
	26	5.30535	> 5%
	25	5.30374	> 5%
	24	5.27164	> 5%
	23	5.22132	> 5%
	22	5.17769	> 5%
	21	5.13242	> 5%
Method 2	27 (Highest)	3.54162	Within limit

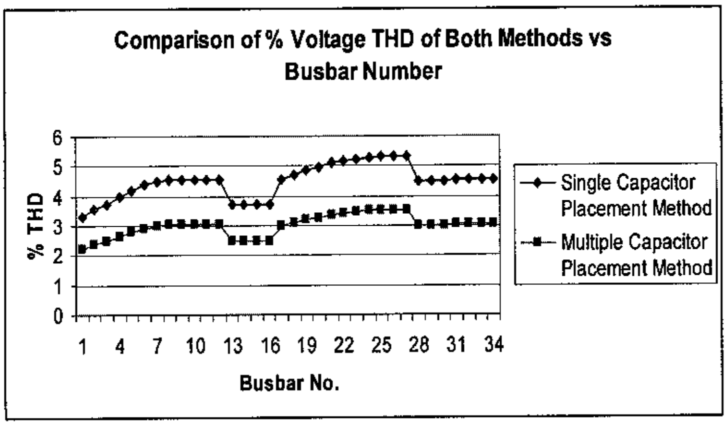

Figure 23 Comparison of % Voltage THD for Both Methods versus Busbar Number

4.3 Current Harmonics Distortion Level

The following table shows the percentage TDD for Method 1 where two busbars having highest percentage TDD are checked. It can be said that there are some areas where the Total Demand Distortion exceed the allowable percentage. From Figure 24, there are five busbars where the percentage TDD had exceeded. As known, this situation is not safe for the whole system especially those attached to the affected busbars.

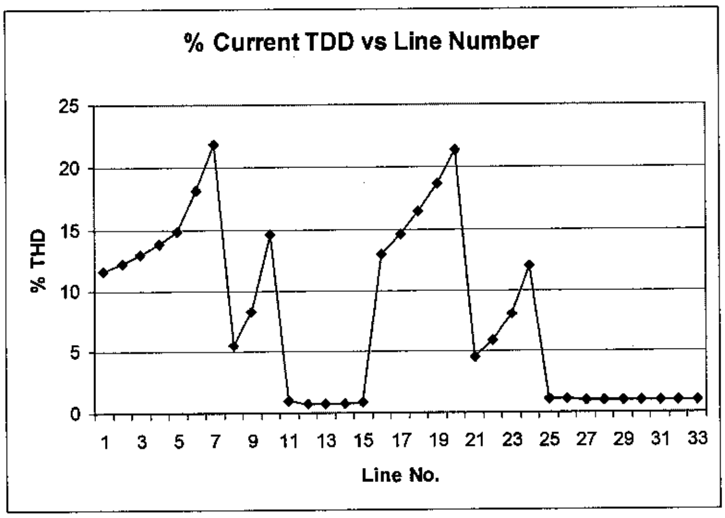

Figure 24 Percentage Total Demand Distortion versus Line Number for Method 1

Table 10 Percentage TDD for Method 1 Compared to IEEE 519-1992 Standard

PCC	I_{SC}	I_L	I_{SC} / I_L	Max %TDD	519-1992 (% TDD)	Remark
7	4187	15	279.133	16.774	<15	Exceed
20	3297	15	219.800	21.438	<15	Exceed

The Table 11 and Figure 25 shown are purposed to determine whether the harmonics exceed the standard limit or not. From the calculation taken from the simulation result, the harmonics do not affect the system much and it obeys the IEEE 519-1992 Standard.

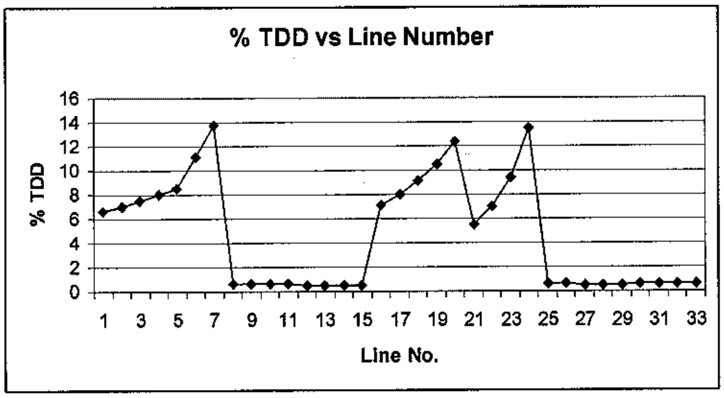

Figure 25 Percentage Total Demand Distortion versus Line Number

Table 11 Percentage TDD for Method 2 Compared to IEEE 519-1992 Standard

PCC	I_{SC}	I_L	I_{SC} / I_L	Max %TDD	519-1992 (% TDD)	Remark
7	4185	15	279.667	13.798	<15	Within limit
24	2183	15	145.556	13.551	<15	Within limit

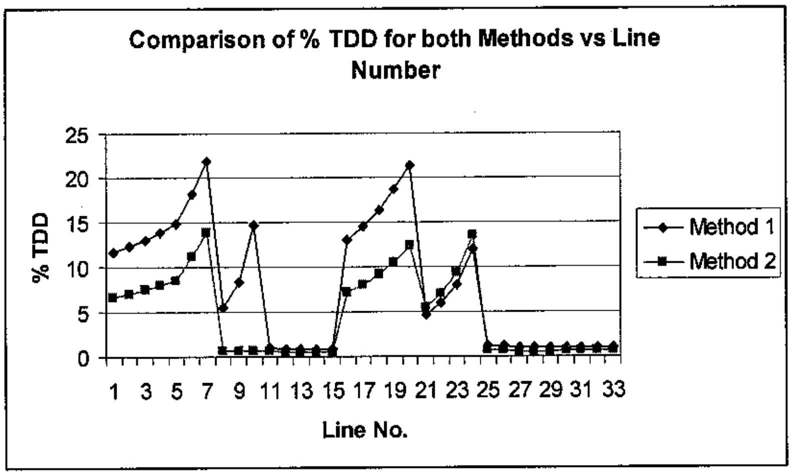

Figure 26 Comparison of Percentage TDD for Both Methods versus Line Number

From the comparison of the harmonics distortion for both voltage and current, it is clear that the Method 1 produce more harmful harmonics compared to Method 2. Thus it is very likely that Method 2 is preferable for implementation in the real world.

4.4 Effect of Harmonics Distortion on the Power Losses

From the data obtained after all the simulations, the Table 12 below shows the differences of power losses for both methods. These losses are due to the introduction of harmonics in the system after the capacitors insertion. From the table, it can be seen that Method 2 will make the system suffer less loss compared to Method 1. So as overall simulation on the system performance, Method 2 (Multiple Capacitor Placement Method) is recommended to be implemented compared to Method 1 (Single Capacitor Placement Method). Even though the total losses (due to harmonics) for both methods barely contributed to the total system losses, the reasons to choose Method 2 lies to the harmonics level which the distortion level for Method 2 obeys the IEEE 519-1992 Standard to preserve the system from future damage.

Table 12 Comparison of Power Losses Due to Harmonics for Both Methods

Method	Real Power Loss (W)	Reactive Power Loss (VAR)
Method 1	839.2443	237.519
Method 2	298.4454	83.25376

CHAPTER 5
CONCLUSION AND RECOMMENDATION

Power quality phenomenon especially on harmonics must be observed seriously. This is due to the catastrophic impact to the power system done by the harmonics. The project expected to meet the objectives set forth at the beginning of FYP1.

The project focused on the power system characteristic that is the radial distribution lines through the analysis on the IEEE 34 bus test system. From which the losses and characteristics associated to the system had been analyzed and understand. Two methods are implemented which are single capacitor placement method (Method 1) and multiple capacitor placement method (Method 2). Multiple capacitor placement method can saved more reactive power but compare to the kW/kVAR ratio, single capacitor placement method is a better choice due to higher loss compensation.

From the harmonics analysis, even though the losses due to harmonics for both methods are less than 1 kW and 1 kVAR, but due to the harmonics content for single capacitor placement as some of the lines and busbars are exceeding the IEEE 519-1992 allowable limit, multiple capacitor placement method is a better choice for implementation to preserve the equipment.

The project managed to implement the compensation of reactive power losses and also evaluating the harmonics implication. This is done through the introduction of capacitors. And for future research, it is good to evaluate such a power quality phenomenon to the real system rather than the test system. By comparing the real and practical data and also the simulation data, the improvement can be implemented for a better system practically.

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[3] Power Quality, C. Sankaran, CRC Press, 2001

[4] An Intergrated Approach to the Reduction of Reactive Power Losses in Radial Distribution System, Than Khong Hon, Final Year Report, Universiti Teknologi Petronas, December 2004

[5] A Study on Power Factor Improvement and Its Relationship With Harmonics, Nur Azra Azmi, Final Year Report, Universiti Teknologi Petronas, December 2004

[6] Understanding Power System Harmonics, W. Mack Grady, Surya Santoso, September 2004

[7] Power System Foundation, Mustafar Kamal Hamzah, Universiti Teknologi MARA, Mc Graw Hill, 2004

APPENDICES

APPENDIX A : LOSSES DUE TO HARMONICS FOR METHOD 1

Line ID	P(W)	Q(VAR)
Line01	85.33083	35.18797
Line02	78.84130	31.89086
Line03	121.37000	33.91221
Line04	111.5395	30.58341
Line05	112.47500	30.83992
Line06	41.14973	7.122068
Line07	27.96298	4.849073
Line08	1.813129	0.313811
Line09	1.339595	0.23230
Line10	0.924471	0.162638
Line11	0.000642	0.000111
Line12	0.001639	0.000277
Line13	0.001031	0.000179
Line14	0.000154	2.65E-05
Line15	2.02E-06	3.29E-07
Line16	45.52700	12.61221
Line17	42.49738	11.87427
Line18	54.62079	12.38495
Line19	50.36872	11.62355
Line20	51.23277	11.82295
Line21	2.686008	0.457983
Line22	2.936023	0.500612
Line23	3.834363	0.66364
Line24	2.773794	0.481005
Line25	0.007513	0.001322
Line26	0.000843	0.000145
Line27	0.002323	0.000393
Line28	0.001035	0.000175
Line29	0.000259	4.38E-05
Line30	0.00268	0.000454
Line31	0.002009	0.000348
Line32	0.00067	0.000113
Line33	0.000112	1.93E-05
Total Loss	***839.2443***	***237.519***

APPENDIX B : LOSSES DUE TO HARMONICS FOR METHOD 2

Line ID	P(W)	Q(VAR)
Line01	29.62108	12.21488
Line02	27.36896	11.07059
Line03	42.13372	11.77266
Line04	38.72256	10.61748
Line05	39.04923	10.70705
Line06	15.68290	2.714348
Line07	10.64856	1.846571
Line08	0.023971	0.004149
Line09	0.008329	0.001444
Line10	0.001968	0.000346
Line11	0.000222	3.83E-05
Line12	0.000576	9.75E-05
Line13	0.000361	6.27E-05
Line14	5.43E-05	9.36E-06
Line15	7.17E-07	1.17E-07
Line16	14.73933	4.083192
Line17	13.76772	3.846864
Line18	17.70718	4.015001
Line19	16.33991	3.770749
Line20	16.63129	3.83799
Line21	3.74407	0.63839
Line22	3.918034	0.668052
Line23	4.911257	0.850025
Line24	3.417908	0.592701
Line25	0.002749	0.000484
Line26	0.000308	5.31E-05
Line27	0.00082	0.000139
Line28	0.000364	6.17E-05
Line29	9.13E-05	1.54E-05
Line30	0.000928	0.000157
Line31	0.000694	0.00012
Line32	0.000233	3.95E-05
Line33	3.89E-05	6.71E-06
Total Loss	***298.4454***	***83.25376***

APPENDIX C : VOLTAGE THD FOR BOTH METHODS

Bus ID	Method 1 (%)	Method 2 (%)
Bus01	3.33088	2.22149
Bus02	3.54646	2.36533
Bus03	3.74651	2.49886
Bus04	3.96549	2.64511
Bus05	4.16753	2.78010
Bus06	4.37209	2.91685
Bus07	4.47537	2.99923
Bus08	4.54361	3.05392
Bus09	4.55077	3.05875
Bus10	4.55423	3.06108
Bus11	4.55556	3.06198
Bus12	4.55596	3.06225
Bus13	3.74729	2.49939
Bus14	3.74801	2.49987
Bus15	3.74821	2.50000
Bus16	3.74822	2.50001
Bus17	4.53346	3.01241
Bus18	4.68217	3.10040
Bus19	4.84155	3.19491
Bus20	4.98690	3.28098
Bus21	***5.13242***	3.36706
Bus22	***5.17769***	3.41176
Bus23	***5.22132***	3.45553
Bus24	***5.27164***	3.50687
Bus25	***5.30374***	3.54022
Bus26	***5.30535***	3.54130
Bus27	***5.30584***	3.54162
Bus28	4.47634	2.99988
Bus29	4.47699	3.00031
Bus30	4.47731	3.00053
Bus31	4.55521	3.06174
Bus32	4.5562	3.06241
Bus33	4.55670	3.06274
Bus34	4.55686	3.06285

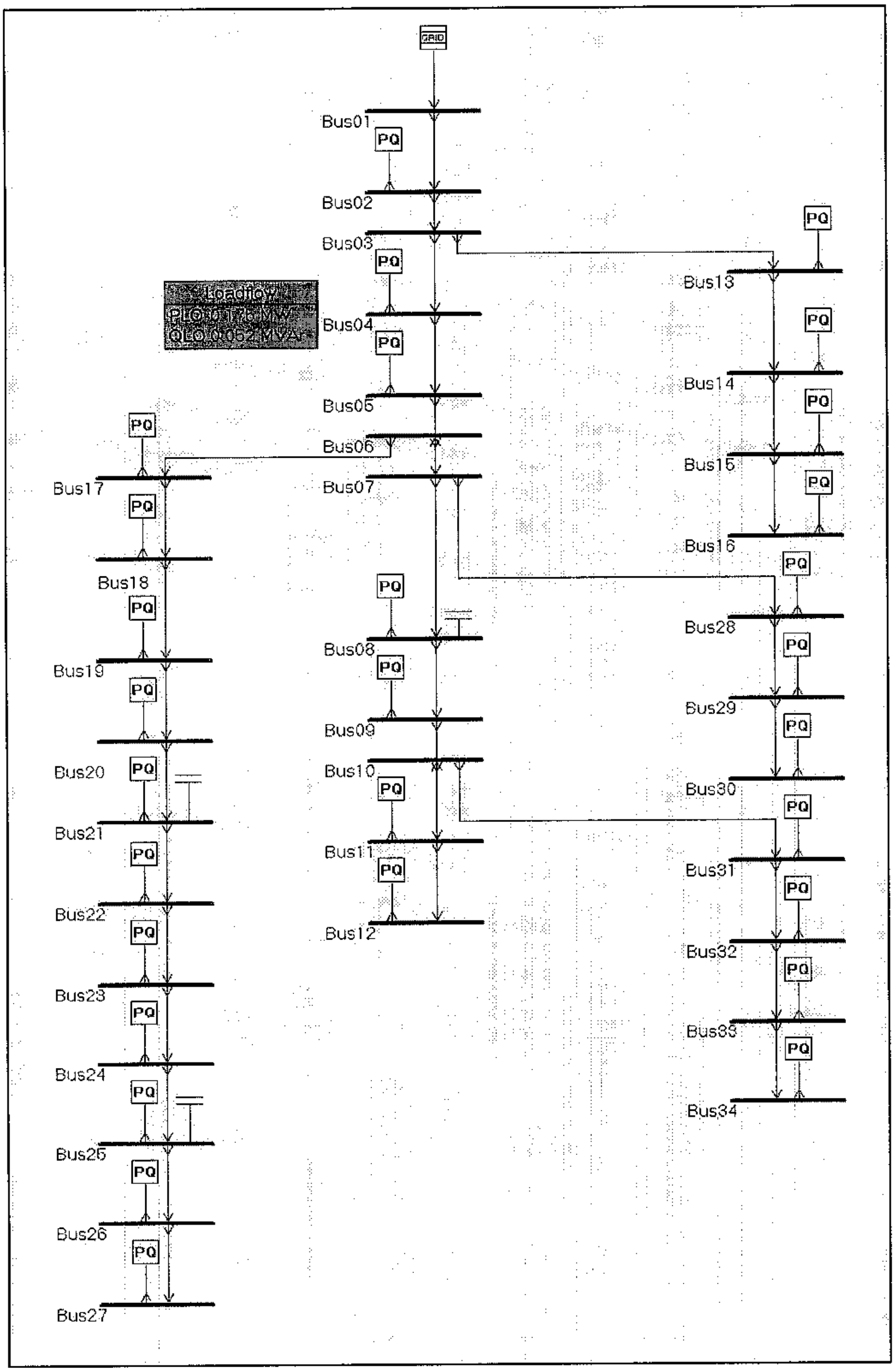
*Exceeding IEEE 519-1992 limit are bolded

APPENDIX D : TDD FOR BOTH METHODS

Line ID	From	To	Method 1 (%)	Method 2 (%)
Line01	Bus01	Bus02	10.36440	6.63466
Line02	Bus02	Bus03	10.97132	7.02314
Line03	Bus03	Bus04	11.64801	7.45873
Line04	Bus04	Bus05	12.40965	7.95220
Line05	Bus05	Bus06	13.26846	8.51361
Line06	Bus06	Bus07	13.57876	11.10859
Line07	Bus07	Bus08	***16.77473***	13.79826
Line08	Bus08	Bus09	0.87110	0.58575
Line09	Bus09	Bus10	0.87320	0.58712
Line10	Bus10	Bus11	0.86888	0.58427
Line11	Bus11	Bus12	0.87282	0.58678
Line12	Bus12	Bus13	0.70878	0.47268
Line13	Bus13	Bus14	0.71028	0.47366
Line14	Bus14	Bus15	0.71433	0.47620
Line15	Bus15	Bus16	0.76551	0.51340
Line16	Bus16	Bus17	13.1088	7.18708
Line17	Bus17	Bus18	14.63054	8.05728
Line18	Bus18	Bus19	***16.47435***	9.14443
Line19	Bus19	Bus20	***18.72001***	10.53494
Line20	Bus20	Bus21	***21.43766***	12.35953
Line21	Bus21	Bus22	4.68430	5.52870
Line22	Bus22	Bus23	6.02354	6.99085
Line23	Bus23	Bus24	8.16945	9.32898
Line24	Bus24	Bus25	12.07184	13.55082
Line25	Bus25	Bus26	1.01522	0.67758
Line26	Bus26	Bus27	1.01398	0.67707
Line27	Bus27	Bus28	0.83310	0.55837
Line28	Bus28	Bus29	0.83302	0.55851
Line29	Bus29	Bus30	0.83371	0.55837
Line30	Bus30	Bus31	0.88031	0.59188
Line31	Bus31	Bus32	0.88039	0.59191
Line32	Bus32	Bus33	0.88055	0.59207
Line33	Bus33	Bus34	0.87892	0.59211
Line ID	Bus34	Bus02	10.3644	6.63466

*Exceeding IEEE 519-1992 limit are bolded

APPENDIX E : IEEE 34 BUS STANDARD TEST SYSTEMS WITH CAPACITORS INSERTION



APPENDIX F
GANTT CHARTS

Milestone Chart for the First Semester of 2 Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic assigned to students	▒													
		→	→												
2	Preliminary Research Work		▒	▒	▒										
	-Project planning		→	→	→	→									
	-List of references/literature														
3	Project Work					▒	▒	▒	▒	▒	▒	▒	▒		
	-Reference Literature Review					→	→	→	→	→	→	→	→		
	-Review on Papers and Previous Reports														
	-Review on Distribution System														
	-Review on Reactive Power														
	-Review on Harmonics and Effects														
	-Review on Technique of Reactive Power Improvement														
	-Review on Capacitor Compensation														
	-Simulation														
	-ERACS Familiarization														
4	Submission of Progress Report								●						
5	Submission of Interim Report Final Draft												●		
6	Oral Presentation													●	
7	Submission of Interim Report														●

● Suggested Milestone

→ Actual Progress

▒ Projected Progress

Milestone Chart for the Second Semester of 2 Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Literature Review														
2	Submission of Progress Report 1			●											
3	Project Work														
	-ERACS Simulation														
	-Loadflow analysis on IEEE 34-bus system														
	-Harmonics Analysis (Before and After Capacitor Insertion)														
	-Data and Result Gathering														
4	Submission of Progress Report 2							●							
5	Project Work														
	-Evaluate Loss and Harmonics Distortion														
6	Submission of Dissertation Final Draft													●	
7	Submission of Project Dissertation														●
8	Oral Presentation														●
7	Submission of Interim Report														●

● Suggested Milestone

→ Actual Progress