A Proposed Strategy of Implementation for Load Shedding and Load Recovery with Dynamic Simulations

by

Chan Chee Ying

Dissertation submitted in partial fulfillment of the requirements for the Bachelor of Engineering (Hons) (Electrical & Electronics Engineering)

JUNE 2004

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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BACHELOR OF ENGINEERING (Hons)
(ELECTRICAL & ELECTRONICS ENGINEERING)

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June, 2004

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 of persons.

CHAN CHEE YING

ABSTRACT

Electric load shedding is basically the act of rapidly removing loads from a power system under certain predetermined conditions. It is implemented to maintain the generation power margin at nominated level when load demand is higher than electric supply. This prevents the widespread of system collapse when a fault occurs.

The objective of the project is to design and implement a load shedding and load recovery scheme for power system. The scope of study consists of system analysis, design and simulation. Dynamic simulations are performed using the ERACS Power Analysis Software.

Underfrequency load shedding is more popular compared to undervoltage due to its efficiency and robustness. The design of underfrequency load shedding scheme is strongly related to the system frequency and the amount of generation or load as system frequency will decline when overload occurs. When the frequency falls below preset level at a certain rate, a predetermined amount of load will be removed to restore the system frequency. Important design considerations for this scheme are the maximum anticipated overload, number of load shedding steps, size of load shed at each step and frequency relay settings.

Load restoration after load shedding can only be executed after the system has recovered completely and its normal frequency is restored. Loads should be restored in small blocks sequenced by time delay between successive restorations to allow frequency stabilization.

A case study is carried out on PETRONAS Penapisan Melaka, whereby a load shedding scheme is designed for its upcoming cogeneration plant. The maximum generation loss designed for by the scheme is 50% or 48 MW at system peak. There are four stages, removing 12.5% of load at each stage. The frequency relay settings are 49.5, 48.77, 48.22 and 47.86 Hz. Dynamic simulations performed indicate that the load shedding design is feasible and able to halt frequency collapse due to generation loss. The design strategy, calculations and justification are presented in this report.

ACKNOWLEDGEMENT

The author's heartfelt gratitude is forwarded to:

- her supervisor, Ir. N. Perumal, for his selfless imparting of knowledge and advice, which guided the author throughout her project;
- Software trainers, Dr. Morris Lockwood and Mr. Kevin Davey, for contributing ideas for the betterment of the project, especially in software simulation;
- Ipoh TNB senior engineer, Mr. Sugunan Pillai, foreman, Mr. Daud and OPP Mr. Danial Md Noor, for providing useful information and guidance to the author;
- her best of colleagues, D. Dimitri and Amir Khameis Kajo, ever encouraging and always there to lend a helping hand, the author promises to cherish their invaluable friendship which has enriched her life in all ways possible;
- her parents, Mr. and Mrs. Chan Fan On, brother, Siang Chak and sister, Chee Ming, for their unconditional love and support which constantly propelled the author to strive for excellence;
- and all the others whose names the author has failed to mentioned on this page, but has in one way or another contributed to the accomplishment of this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

1.1 Background of Study

Modern day society requires a large amount of energy for use in industry, commerce, agriculture, transportation, communications, domestic households, etc. In recent days, electrical energy has dominated the current world energy scene, due to its practicality and the existence of wide range of efficient electrical equipments.

Perhaps the most important and unique feature of an electrical power is that electrical energy cannot easily and conveniently be stored in large quantities. This means that at any instant in time, the energy demand has to be met by corresponding generation. Fortunately, the combined load pattern of a power system normally changes in a relatively predictable manner. Such a predictable system demand pattern goes some way towards allowing the daily generation schedule to be planned and controlled in a predetermined manner.

Since mankind has become more and more dependent on electricity, high supply reliability is of fundamental importance. Any interruption of supply will cause, at the very least, inconvenience to the consumer, can lead to life threatening situations, and for the industrial consumer, may pose severe technical and production problems.

High reliability supply can be ensured by high quality of installed elements, provision of reserve g eneration, employing large interconnected power systems capable of supplying each consumer via alternative routes and a high level of system security.

1.2 Problem Statement

In electrical systems, electric loads do not comply with the ideal conditions, such as phase balance, zero harmonic content, constant voltage and frequency. Electrical generators themselves are not ideal devices and produce system conditions, which may have undesirable consequences in particular situations. When combined with the wide range of disturbance resulting from practical electrical loads, these problems can be very significant.

Under these unfavorable operating conditions, it is important to develop strategies to maintain a stable system. Fault in a power system includes sudden rapid increase in steady load, switching faults, which limit effectiveness of generation system and tripping of loaded generator set off bus bars.

Electric load shedding is one of the most crucial and effective strategy to retain the generation power margin at nominated level and prevent the widespread system collapse. The need to shed electric load occurs when electric demand (load) is higher that electric supply (generation). It involves rapidly reducing the stress on the electrical system by intentionally shutting off power to some electric circuits. To enhance the reliability and efficiency of the system, a load shedding scheme that is automatically activated to discard operators' response time delay, is desired.

September 1 Incident

On September 1, 2003, the entire Northern Region of Peninsular Malaysia suffered a severe electrical power system collapse, causing a loss of RM30M!

Concisely, the Northern Region electrical loads are supplied by two main substations, namely Batu Gajah [BGJH] and Kenyir [KNYR]. Each substation supplies 500MW and contains 2 feeders each. One of the two BGJH feeders was open for maintenance job. Unfortunately, the single feeder of BGJH could not handle the full load of 500 MW and tripped.

The effect of sudden loss of supply propagates rapidly. In no time, the sudden increase of load was detected by KNYR. Both feeders of KNYR tripped as a result of sudden enormous overload. Consequently, the blackout left the Northern States without electricity for two and a half hours before remedy actions took place.

An Underfrequency Load Shedding Scheme did exist to restore system generation load balance under severe generation loss contingencies. However, it did not function as expected during the contingency.

It is logical that, if an effective and efficient load shedding system existed, sufficient amount of load could have been removed when the BGJH feeder first tripped. By doing so, it was not impossible to restore the system supply-load balance before the system collapse spread to the entire region. At least 50% supply of the region [KNYR] could have been retained.

Hence, this project will be steered towards developing an effectual and proficient load shedding system in electric power systems to prevent recurrence of similar incident.

[See Appendix I-III for related diagrams]

1.3 Objectives and Scope of Study

Objectives

- To investigate the purpose and implementation of load shedding and load recovery.
- To design an automatic load shedding and load restoration scheme, where emphasis is placed on relay time settings and load priorities.
- To simulate the load shedding scheme using the ERACS Power System Analysis Software to gauge performance of the designed scheme

Scope of Study

Basically, the electric load shedding project takes on the form of system design, simulation and analysis. It spans over duration of two academic semesters and the scope of work covers exploring problems, building design objectives, applying appropriate methodology, producing and analyzing outcomes, as well as reporting the findings.

The first half of the project mainly involves research and study to acquire as much knowledge as possible to ease the design work later on. Research work for these 11 weeks of the first semester revolves around familiarization with existing load shedding schemes, typical parameters used to initialize load shedding in a power system, relay operation, load shedding design considerations, as well as designing a simple load shedding scheme.

For the second half of the project, also consists of 11 weeks, emphasis focuses on pure design work, whereby a case study is carried out on the power system of a real plant. An automatic load shedding system is designed for the plant and the scheme is verified by dynamic simulations using ERACS Power Systems Analysis Software. Dynamic simulations are performed to simulate the power system networks and investigate the dynamic behavior of the network under defined real life scenarios.

The area and scope of this project has been carefully planned, hence the project is feasible and could be completed within the allocated time frame. A project plan (methodology) and Gantt chart has been develop to guide the progress of the project. If the plans are strictly followed, the project will be a successful one.

[See project Gantt chart in Appendix IV]

2. LITERATURE REVIEW

2.1 Load shedding – Definition and purpose

Electric load shedding is basically removing loads from a power system under certain predetermined conditions, such as underfrequency and undervoltage, to retain the generation power margin at nominated level. Load shedding program has been used by many utilities, in distribution systems or major industrial loads.

When electric demand is higher than supply, electric load shedding needs to be implemented. It involves promptly cutting off power supply to some electric circuits, hence reducing the stress on the electric system.

The objective is to prevent frequency and voltage decay and maintain equilibrium between generation and load when there is loss of generation. Load shedding can help in preventing interties from opening due to transmission overloads. It provides a low-cost means of preventing widespread system collapse.

2.2 Load recovery

Load recovery or load restoration is the reclosing of feeders, which have been tripped for load shedding. Normally, it is left to the discretion of system or station operators. Frequency relays can be used, however, either to supervise restoration or restore loads automatically.

One of the main requirements before load restoration is carried out is that the system frequency should return to normal before any load is restored. Load should be restored in small blocks and sequenced by time delay. This time delay is required to be increased as more loads are connected to the system.

2.3 Magnitude and sequence

All the expendable loads are pre-identified and given an order of priority. Thus, when the generation power margin decreases below nominated level due to sudden increase of load or trip of generator, the load shed system will switch off the expendable loads in sequence to maintain the margin.

For the determination of the magnitude, type and sequence of loads to be shed, PETRONAS Technical Standard[1] provides the following guidelines:

A fault over a fault, e.g., automatic load shedding shall not cater for the simultaneous shutdown of two supply units due to failure. The total amount of load to be shed therefore need not exceed the capacity of the largest supply unit.

Non-essential services shall be shed first. If further load shedding is required, some of the less important essential services, e.g., loading pumps, shall be tripped as a second stage; If the amount of load in the above cases is not sufficient, a choice has to be made by the principal as to which of the remaining essential services shall be tripped to safeguard supplies to the more important units. Utility plant and other vital services shall be considered as the most important units, and their electricity supply shall be safeguarded above all other consumers.

[1] PTS 33.64.10.10

2.4 Underfrequency Load Shedding

Severe system disturbance can result in cascading outstages and isolation of areas, causing formation of electrical islands. If such an islanded area is undergenerated, it will experience a frequency decline. Unless sufficient generation with ability to rapidly increase output is available, the decline in frequency will be largely determined by frequency sensitive characteristics of loads. In many situations, the frequency decline may reach levels that could lead to tripping of steam turbine generating units by underfrequency protective relays, thus aggravating the situation further. To prevent extended schemes of separated areas at lower than normal frequency, load-shedding schemes are employed to reduce the connected load to a level that can be safely supplied by available generation.

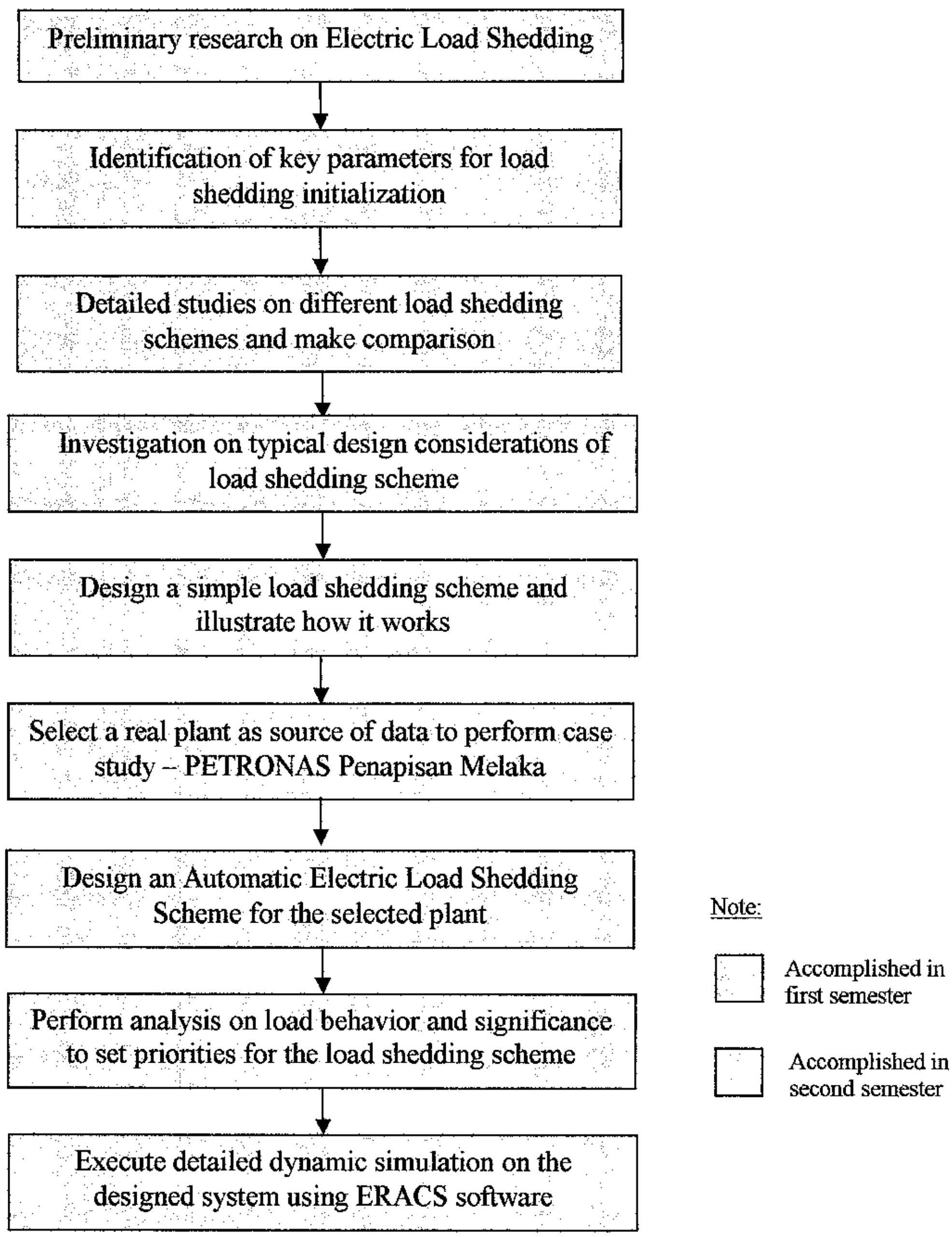
2.5 Undervoltage load shedding

Voltage monitoring of a power system is a means of detecting an overload condition that can predict a problem arising and preemptively shed loads before a chaotic system breakup occurs. Undervoltage load shedding schemes cater for these unplanned or extreme situations. Undervoltage load shedding is harder to apply to industrial facilities but still quite applicable. The characteristics and locations of the loads to be shed are more important for voltage problems than they are for frequency problems. Load shedding schemes should be designed so as to distinguish between faults, transient voltage dips, and low voltage conditions leading to voltage collapse. System voltage profile studies are run prior to implementation to determine settings and the best placement for the relaying. The studies are basically voltage stability and voltage profile studies.

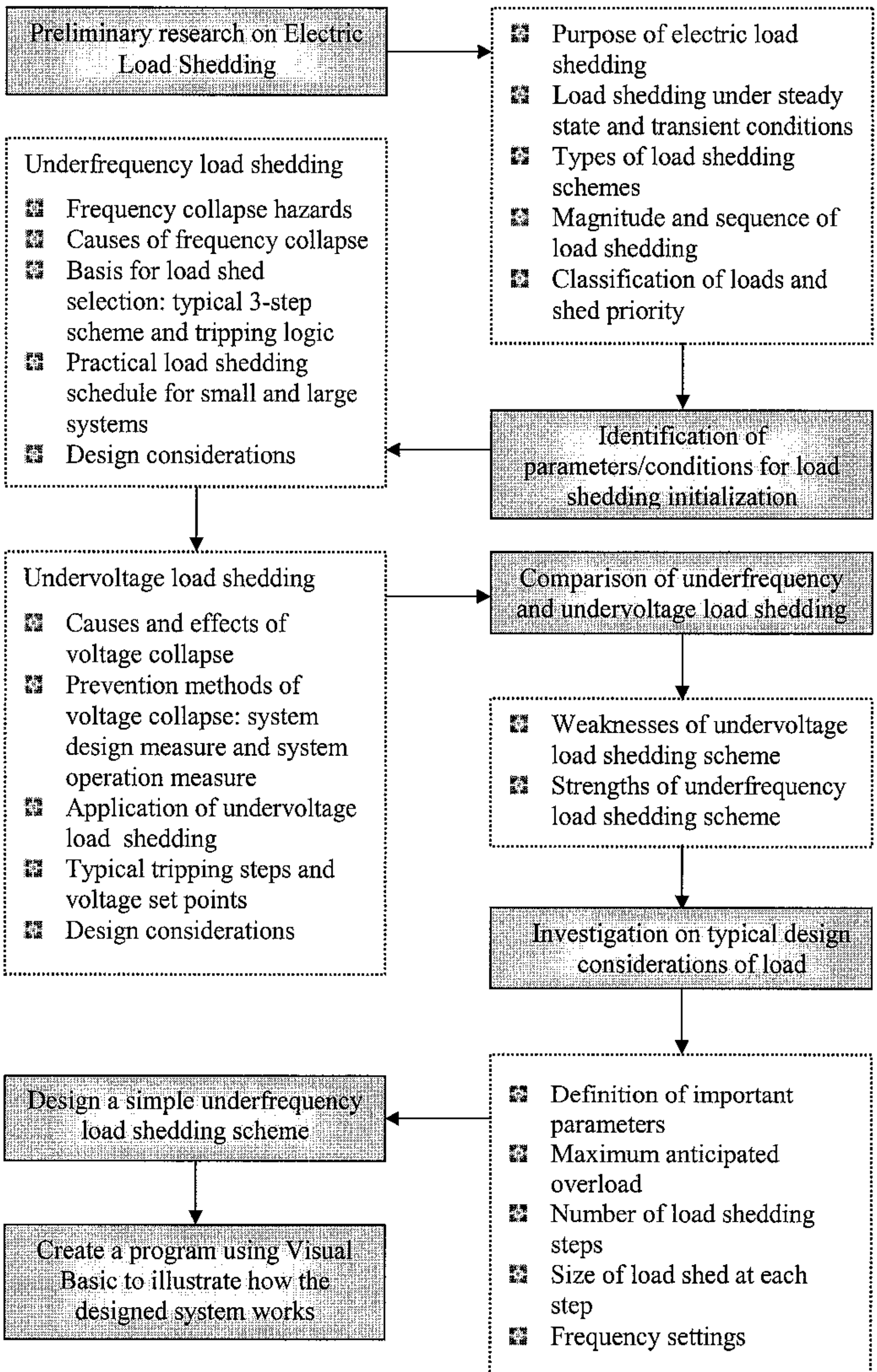
3. METHODOLOGY

3.1 Procedure Identification

The execution of project is divided into several stages and is illustrated in the flow chart below.



3.2 Breakdown of tasks for first semester



3.3 Breakdown of tasks for second semester

Select a real plant as source of data to perform case study – PETRONAS Penapisan Melaka

- Choose a suitable plant of desirable size, where load shedding is applicable
- Study the power generation and distribution of the selected plant
- Acquire information regarding number of generators, number of incoming lines, peak load, stand-by supply etc.

Design an Automatic Electric Load Shedding Scheme for the selected plant

Determine all criteria of formulating a load shedding scheme through load flow study and calculations:

- Maximum anticipated overload
- Number of load shedding steps
- Size if load shed at each step
- Frequency settings
- Time delay
- Location of the frequency relays

Also look into load restoration service after load shedding is completed.

Perform analysis on load behavior and significance to set priorities for the load shedding scheme

- Identify significant and important loads, which cannot be removed from the system
- Determine the load shedding priorities

Execute detailed dynamic simulation on the designed system using ERACS software

- The purpose is to gauge the performance of the proposed scheme with due regard to power plant and network protections/ controls and to system voltages
- Perform case studies for different generation loss contingencies
- Compare system frequency plots for systems with and without load shedding scheme
- Conclude if load shedding scheme designed is feasible and effective

3.4 Presentation of expected results

The underfrequency load shedding scheme designed is presented using Visual Basic 6.0 in a prompt-and-do manner. The single line diagram of the power system is displayed (as shown in *Figure 3, Page 33*). For demonstration purposes, underfrequency fault can be introduced manually by a click. A display panel indicating the initialization of load shedding scheme will appear. The display panel contains important parameters, such as:

- Load shedding frequency for each step
- Pick-up time (fault)
- Actual trip time
- Amount of load to be shed
- Total load shed
- Destination of trip signal (breaker number)
- Message indicating the current status

The display panel is shown in the next page.

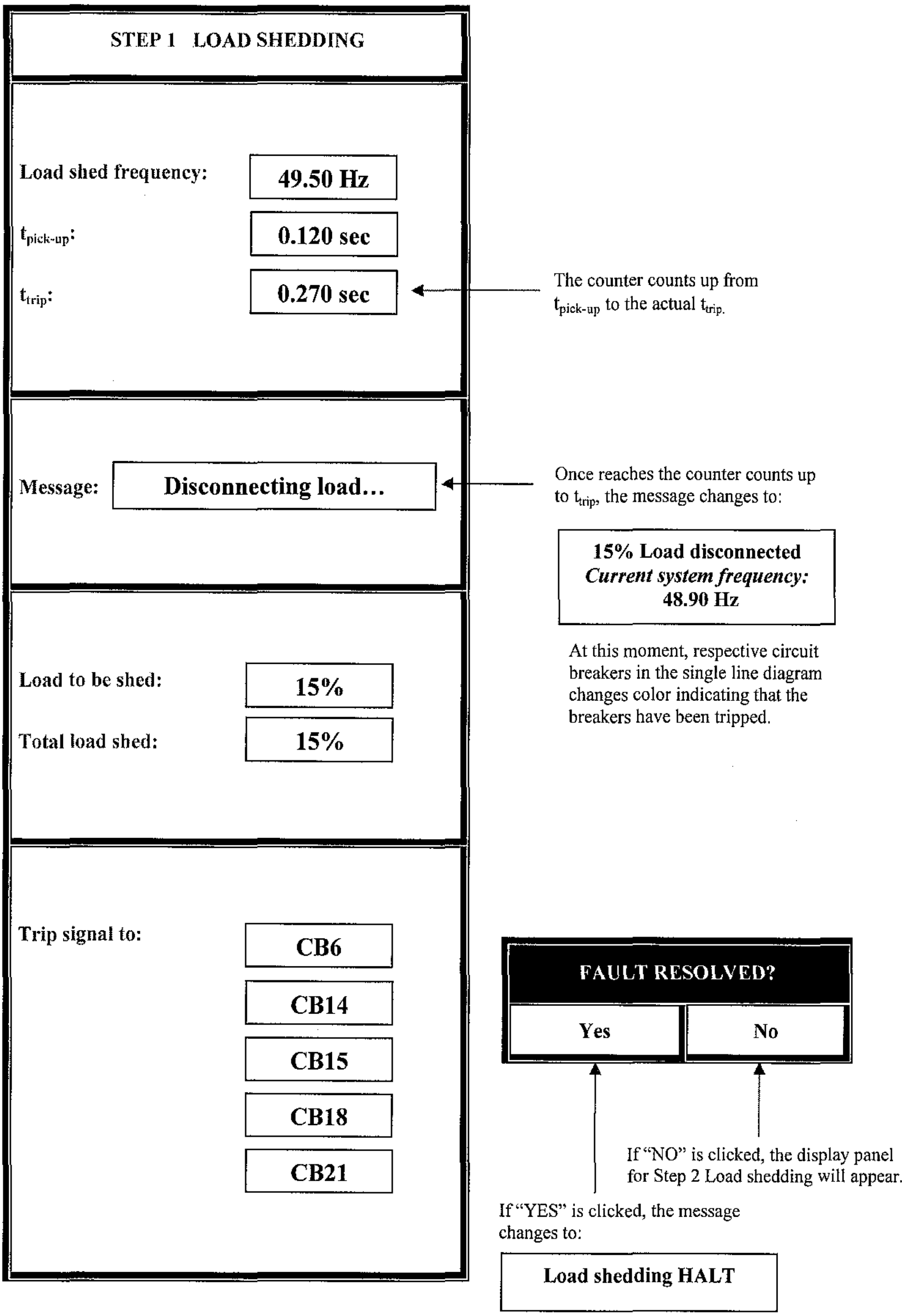


Figure 1: Display panel demonstrating the designed load shedding scheme

3.5 Tools

Software tool

ERACS Power Systems Analysis Software is utilized to design and simulate the Automatic Electric Load Shedding Scheme. ERACS allows users to simulate electrical power system networks and to undertake comprehensive power system analysis to investigate the steady-state and dynamic behavior of a network under user defined real life conditions and scenarios. The following modules are available:

- Graphical User Interface (GUI)
- Load Flow
- Fault
- IEC 909
- Harmonic Injection
- Harmonic Impedance
- Protection Coordination
- Transient Stability*
- Universal Dynamic Modeller (UDM)
- Wind/Wave Modelling

* **Transient Stability** module is used to execute simulation for the load shedding system designed.

Besides that, **Microsoft Visual Basic 6.0** and **Macromedia Flash 5** are used to illustrate the operation and expected results of the load shedding scheme designed. The purpose of having this interactive program is to en-easy the author, as well as reader to visualize the design and expected results better.

4. LOAD SHEDDING AND RESTORATION

4.1 Why underfrequency?

A brief description has been given about underfrequency and undervoltage load shedding systems in Chapter 2. Here, comparison of both schemes and justification as to why this project work is concentrated on underfrequency scheme are presented.

4.1.1 Limitations of undervoltage load shedding

During the occurrence of total or partial loss of generation, there will be a drop in system frequency and voltage.

Besides loss of generation, **voltage drop** may also occur as a result of system faults. Hence, voltage may not precisely indicate an overload or under-generation condition. Moreover, undervoltage load shedding can only be applied to slow-decaying voltage system with the under-voltage relay time delay settings typically between 3 to 10 seconds. It is inappropriate for **transient instability** because the relay time delay to trip is normally set long enough to avoid false tripping and, hence load tripping will not occur fast enough to mitigate a transient stability event.

4.1.2 Strengths of underfrequency load shedding

System frequency is directly associated with the speed of generator rotors. A loss of generation or an event of overload causes **frequency decline**. Since any upset in the balance of load and generation causes a frequency change, frequency is a reliable indication of generation and load mismatch.

Due to its efficiency and effectiveness, underfrequency load shedding is widely used in the world. Load shedding schemes throughout Malaysia are based on underfrequency principle.

This project will work towards developing an efficient underfrequency load shedding scheme and appending necessary enhancements to improve the existing schemes.

4.2 Underfrequency load shedding in depth

4.2.1 Frequency vs generation/load

When a power system is in stable operation at normal frequency:

Total mechanical power =
Total of all connected loads + Total power losses in the system

The huge rotating masses of turbine-generator rotors, act as repositories of kinetic energy.

When overload happens or there is loss in generation, there is insufficient mechanical power input to the system; the rotor slows down, supplying energy to the system. Conversely, when excess mechanical power input to the system, they speed up, absorbing energy. Any change in speed causes a proportional frequency variation.

Unit governors sense small changes in speed resulting from gradual load changes. These governors adjust the mechanical input power to the generating units in order to maintain normal frequency operation. Sudden and large changes in generation capacity through the loss of generation capacity through the loss of a generator or load imbalance, resulting in a rapid frequency decline. If the governor and boilers cannot respond quickly enough, the system may collapse. Rapid, selective, and temporary dropping of loads can make recovery possible, avoid prolonged system outage, and restore customer service with minimum delay.

4.2.2 Load shedding

For gradual increases in load, or sudden but mild overloads, unit governors will sense speed change and increase power input to the generator. Extra load is handled by using spinning reverse, the unused capacity of all generators operating and synchronized to the system. If all the generators are operating at maximum capacity, the spinning reverse is 0, and the governors may be powerless to relieve overloads.

In any case, the rapid frequency plunges that accompany severe overloads require impossibly fast governor and boiler response. To halt such a drop, it is necessary to intentionally and automatically disconnect a portion of the load equal to or greater than the overload. After the decline has been arrested and the frequency returns to normal, the load may be restored in small increments, allowing the spinning reserve to become active and any additional available generators to be brought on line.

Frequency is a reliable indicator of an overload condition. Frequency-sensitive relays can therefore be used to disconnect load automatically. Such an arrangement is referred to as an underfrequency load shedding scheme and is designed to reserve system integrity and minimize outstages. Although utilities generally avoid intentionally interrupting service, it is sometimes necessary to do so in offer to avert a major system collapse. In general, non-critical loads, usually residential, can be interrupted for short periods, minimizing the impact of the disturbance on service.

Automatic load shedding, based on underfrequency is necessary since sudden, moderate to severe overloads can plunge a system into hazardous state much faster than an operator can react. Underfrequency relays are usually installed at distributed substations, where selected loads can be disconnected.

The objective of load shedding is to balance load and generation. Since the amount of overload is not readily measured at the instant of a disturbance, the load is shed a block at a time, until the frequency stabilizes. This is accomplished by using several groups of frequency relay, each controlling its own block of load and each set to a successively lower frequency. The first line of frequency relays is normally set just below the normal operating frequency arrange. When the frequency drops below this level, these relays will drop a significant percentage of system loads. If this load drop is not sufficient, the frequency will stabilize or actually again, but at a slower rate. At this point, a second block of load is shed. This process will continue until the overload is relieved or all the frequency relays have operated. An alternative scheme is to set a number of relays at the same frequency or close frequencies and use different tripping time delays.

4.3 Design considerations

4.3.1 Definition of important parameters

Inertia constant, H

It is the ratio of moment of inertia of generator's rotating components to the unit capacity. It is the kinetic energy in these components at the rated speed.

A turbine-generator rated at 100MVA, with an inertia constant of 4, has kinetic energy of 400MW-sec, in its rotor when spinning at rated speed. If both output power and load are constant with declining frequency and speed, the generator could supply its full load (p=1) for 4 sec, with no power input to the turbine, before the rotor would come to a complete halt.[2]

The H for individual unit is available from the manufacturer or may be calculated from:

$$H = (0.231)(WR^2)(RPM^2)(10^{-6}) / kVA$$

The larger the H, the slower the frequency decline for a given overload.

Decelerating power in per-unit of connected kVA, ΔP

$$\Delta P = \frac{\text{(Total load to be shed in design} - \text{Load being removed)}}{\text{Remaining generation}}$$

When there are more overloads, ΔP increases, causing df/dt to increase too. When some loads are shed, there are fewer overloads, ΔP decreases, causing df/dt to decrease too.

[2] Protective Relaying Theory and Applications

Rate of frequency decline, df/dt

Before designing a relay scheme for system overload protection, it is necessary to estimate variations in frequency during disturbances. Let's assume that there are two interconnected generators, A and B. If there is more generation than load in A and more load than generation in B, the difference can be transferred by an intertie. If the total loads and losses are equal to the total mechanical power input, there will be no change in generator speed or frequency with time.

However, if the tie is suddenly loss as a result of a permanent fault, the kinetic energy in A generators must increase to absorb the excess power input; that is the generator must speed up. Conversely, B must slow down.

$$df / dt = -(\Delta P / 2H)$$

df/dt: per unit initial rate of change of frequency

H: Inertia constant

ΔP: Decelerating power in per-unit of connected kVA

4.3.2 Maximum anticipated overload

Underfrequency relay should be able to shed a load equal to the maximum anticipated overload. It is preferable to shed 100% of load, preserving interconnections and keeping generating units on line and synchronized, than to allow the system to collapse with customer still connected. The system should be studied with respect to the overload that would result from the unexpected loss of key generating units, transmission ties and busses.

The load reduction factor, d should be considered, since it will reduce the overload once the frequency has dropped. However, its value is rarely known exactly and may vary with time. To design a conservative scheme, which will tend to shed enough load for system recovery to normal frequency, it is safest to assume that d equals zero.

4.3.3 Number of load shedding steps

A relatively simple scheme uses two groups of relays, one operating at a lower frequency than the other and each shedding half the predetermined load. The higher-set relays would trip first, halting the frequency decline as long as overload is half or less of the worst-case value. For more severe overloads, the frequency will continue to drop, although at a slower rate, until the second group of relays operated to shed the other half of the expandable load.

The number of load shedding steps can be increased virtually without limit with a great many steps, the system can shed load in small increments until the decline stops. Most utilities use between two and five load shedding steps, with three being the most common.

4.3.4 Size of the load shed at each step

The size of load shedding size should be related to expected overloads. When a study of the system configuration reveals that there is a relatively high probability of losing certain generating units or transmission lines, the load shedding blocks should be sized accordingly.

Each step sheds only enough loads to handle the next, more serious contingencies. Each step should be evenly spread over the system by dropping loads at diverse locations.

4.3.5 Frequency settings

The frequency at which a step will shed load depends on the system's normal operating frequency range, the operating speed and accuracy of the frequency relays and the number of load shedding steps.

The frequency of the first step should be just below the normal operating frequency band of the system, allowing the variation in tripping frequency of the relay. The remaining load shedding steps may be selected as follows:

1. Based on the best estimate of ΔP, calculate df/dt. Employing relay tripping curves, calculate the actual frequency at which load will be shed by the first step relays for the most severe expected overload.
2. Set the second step relays just below this frequency, allowing a margin that will tolerate any expected frequency drift for both sets of relays.
3. Calculate the actual frequency at which the second load shedding step will occur. The rate of frequency decline by the second step relays can be calculated as that resulting from the most severe expected overload minus the load shed in the first step.
4. Again, allowing a margin for relay drift, set the third step relays below the lowest second step shedding frequency.
5. Repeat the calculations until settings are obtained for all steps. Determine the system's lowest frequency value before the final load block is interrupted for the worst case overload. This value should not be below the systems low frequency operating limit.

[See sequence of underfrequency load shedding for Perak region in Appendix V]

4.4 Load recovery

4.4.1 Definition

Re-closing of feeders that have been tripped for load-shedding is called load recovery or restoration. Load restoration could be done manually or automatically. In either way, considerations when designing load restoration service are similar.

4.4.2 Important considerations

Frequency should be allowed to return to normal before any load is restored. Re-closing feeders when the frequency is still recovering may plunge the system back into crisis and will certainly prevent reunification of islands. Resetting of load shedding frequency relays cannot be used for supervision of restoration.

1. Once the frequency has returned to normal, all serviceable interconnections must be allowed to re-synchronized and reclose. Unifying an islanded system as much as possible generally facilitate service restoration.

2. Load should be restored in very small blocks, re-connecting an entire shedding step load at once, even at normal frequency, can cause an overload. Not only may its size exceed spinning reverse, but also high currents resulting from cold load pickup can temporarily cause a severe overload. Reconnecting small blocks of load will only cause some frequency dips, which can be handled by the governors.

3. More small blocks can be reconnected until most or all of spinning reverse is active. At this point, no further load should be added until additional generating capacity is available. Restoring excessive load may cause the frequency to settle below the normal system frequency, making further re-closing of interconnections impossible.

4. If a significant loss of generation occurs in a concentrated area of the system, transmission lines into that area may be heavily loaded just to supply essential loads. In this case, the imbalance should not be increases by restoring expendable loads.

5. If frequency relays are used for automatic restoration, as they sometimes are at unattended installations, they should have a frequency setting of the normal system frequency. The load **should be restored in blocks of 1% to 2 % of system load** and restoration should be sequenced by time delay.

6. After the initial system recovery to normal system frequency, there should be a delay of 30 seconds to several minutes, implemented automatically with a timer or manually via a timer or manually via supervisory control. This delay allows for re-synchronizing of islands, re-closing of interconnections, and starting of peaking g enerators when available. The first block of load may then be restored; the frequency will dip and return to the normal system frequency. The next block should also incorporate several seconds of delay to permit frequency stabilization.

7. **Each successive block should use a slightly longer time delay than the previous one.** Thus, the second block relays will time out before the third and recloses next. The frequency will re-establish at the normal system frequency, and the third block will time out and reclose. This process will continue until all blocks are restored or the spinning reverse is exhausted.

8. When restoring cold loads, it is necessary to temporarily disable the instantaneous over-current fault protection to prevent the initial current surge form re-tripping the feeder.

5. CASE STUDY ON PETRONAS PENAPISAN MELAKA

5.1 Introduction to Cogeneration Plant

Power generation

A cogeneration plant is designed to generate electricity and HP steam required by the refinery complex. It will utilize natural gas as fuel to drive a Gas Turbine / Heat Recovery Steam Generation Package (GT/HRSG).

The aim of the project is to provide better energy efficiency than the existing facilities, leading to both energy and cost savings.

Gas Turbine Generator + Heat Recovery Steam Generators

This is an open cycle gas turbine cogeneration. Two units of GTG/HRSG with supplementary firing capabilities, operating at 85% of designed load will be installed. TNB will continuously supply 21 MW non-firm stand-by. Additional high pressure steam requirement of 87 ton/hr will be generated via the two existing boilers.

Electricity generation specifications

Average normal load	= 75 MW
Peak load	= 90 MW
Total installed capacity	= 24 MW X 4 (GTG) + 24 MW X 1 (STG)
	= 120 MW
Top-up	= ZERO
Non-firm standby	= 21 MW

GTG - Gas Turbine Generator

STG – Steam Turbine Generator

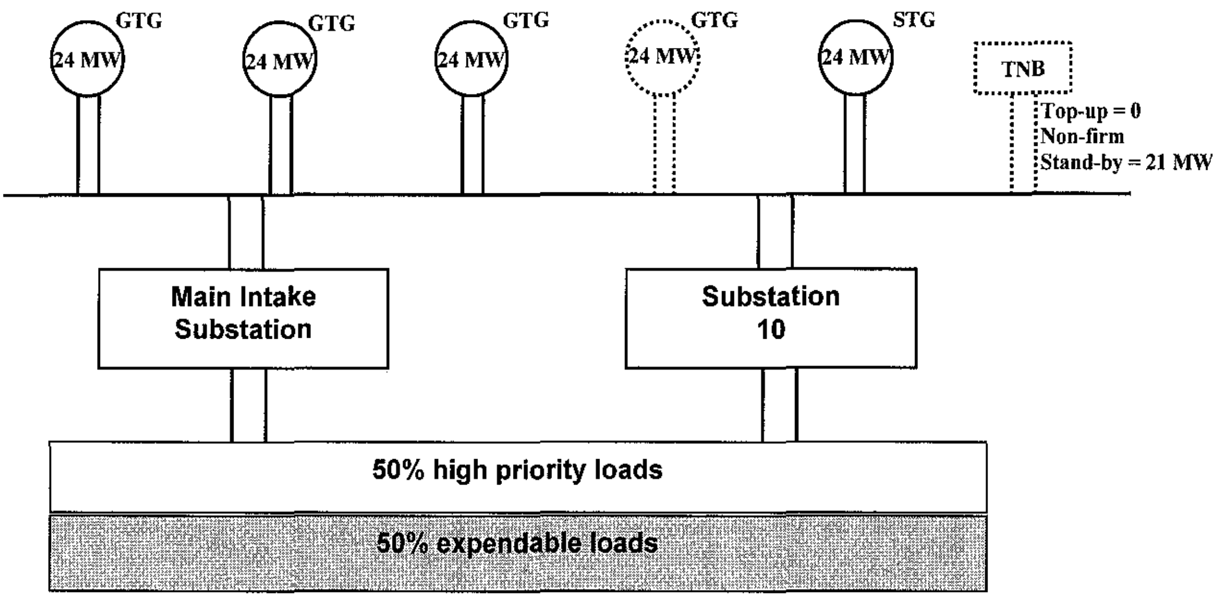


Figure 2: COGEN electrical distribution diagram

Normal operating condition

Under normal operating conditions, 3 X 24 MW (GTG) and 1 X 24 MW (STG) operate, supplying 96 MW. For transient operation below full load, typical gas turbine generators are able to operate down to a minimum limit of 93% of 50 Hz = 46.5 Hz. To ensure that the generators do not shut down before the load shedding system take effect, the maximum generation loss designed for by the scheme is 50% or 48 MW at system peak.

The spare 1 X 24 MW (GTG) and TNB non-firm stand-by (dotted lines) will be activated to ease overload and restore load after load shedding. Hence, they are not taken into account while designing the load shedding scheme.

5.2 Design strategy

Typically, underfrequency load shedding design begins with a classic or static model, where generally the number of steps, step frequencies and load shedding quantum is determined. The discrimination between load shedding stages and between last stage and machine tripping stage are checked in the static model. Then, load shedding feeders are assigned based on the required quantum and other criteria. Finally, dynamic simulations are performed to verify the dynamic performance of such design.

5.3 Design and calculations

Table 1: Anticipated generation loss

Event	Total % of generation loss
Losing 50% generation of 1st GTG	12.5%
Losing 100% generation of 1st GTG	25.0%
Losing 50% generation of 2nd GTG	37.5%
Losing 100% generation of 2nd GTG	50.0%

Table 2: Load Shedding Calculations and Result

Number of steps	4				
Initial Generation	50% (48 MW)				
Initial Demand	100% (96MW)				
System frequency	50 Hz				
System inertia	H = 5 MWs/MVA for GTG H = 7 MWs/MVA for STG				
Stage	**1**	**2**	**3**	**4**	
Generation at stage (%)	50	50	50	50	
System load at stage (%)	100	87.5	75	62.5	
Inertia constant (MWs/MVA)	5.5	5.67	5.67	6	
Frequency at stage (Hz)	49.5	48.77	48.22	47.86	
Overload at stage (%)	100	60	33.33	14.29	
df/dt at stage (Hz/sec)	-4.545	-3.307	-2.205	-1.042	
Time at stage (sec)	0.110	0.015	0.023	0.048	
Relay + CB opening time (sec)	0.150	0.150	0.150	0.150	
Load shed time (sec)	0.260	0.165	0.173	0.198	
Load shed frequency (Hz)	48.82	48.27	47.91	47.70	
Load shed amount (%)	12.5	12.5	12.5	12.5	
Cumulative load shed (%)	12.5	25	37.5	50	
Overload after load shed (%)	60	33.33	14.29	0	

[See detail load shedding calculations Appendix VI]

Table 3: **Final Load Shedding Scheme and relay settings**

Step	Load shed	Total load shed	Freq. relay seting (Hz)	df/dt (Hz/sec)	$t_{pick-up}$ (sec)	t_{trip} (sec)	Load shed freq. (Hz)
1	12.5%	12.5%	49.50	-4.545	0.110	0.260	48.82
2	Add. 12.5%	25.0%	48.77	-3.307	0.015	0.165	48.27
3	Add. 12.5%	37.5%	48.22	-2.205	0.023	0.173	47.91
4	Add. 12.5%	50%	47.86	-1.042	0.048	0.198	47.70

5.4 Design justification

1. To design a conservative scheme, which will tend to shed enough load for system recovery to normal frequency, load reduction factor, d is assumed to be zero.
2. The minimum acceptable frequency is **47.50 Hz**, as stipulated in the Malaysian Grid Code. When there is further frequency drop, the generators will trip out to protect the machines.
3. The last stage of the load shedding scheme is **47.86 Hz**. This allows some margin for the system to recover after the last stage of load shedding.
4. The following step relays are set ≥ 0.05 sec, just below the previous load shed frequency to allow a margin that will tolerate any expected frequency drift for both sets of relays.

5. Underfrequency load shedding can be executed either based on frequency or rate of frequency decline. The "frequency" method is slower acting, but more reliable, easier to design and execute. The "rate of frequency decline" method or angle detection technique is fast acting. However, since $f = d\theta / dt$, when there is very rapid change in rotation angle, θ, there will be a step change in frequency. For a small system like the cogeneration plant, this type of load shedding scheme tends to be unstable and unreliable. Hence, the load shedding scheme designed is initiated using the frequency detection method.

6. For a system, a composite value of H is calculated a follows:

$$H_{system} = \frac{H_1 MVA_1 + H_2 MVA_2 + ... + H_n MVA_n}{MVA_1 + MVA_2 + MVA_3 + ... + MVA_n}$$

7. The cogeneration plant has three GTGs and one STG running under normal operation. The worst case expected for this load shedding design is failure of 2 GTG simultaneously. The design does not take into consideration the loss of the only STG, as the failure rate of STG relatively small and negligible as compared to GTG.

Table 4: Generator failure rate[3]

Equipment	Failure rate (failures per unit-year)
Steam Turbine Generator	0.032
Gas Turbine Generator	0.638

[3] IEEE Std 493-1980

8. With 50% generation loss initially and 50% load shed, the worst-case condition is handled with no frequency excursion below 47.70 Hz. Complete recovery occurs.

With any lower level of generation loss, recovery will occur with less frequency drop in each stage and fewer levels of underfrequency settings being reached. With inherent load shedding, the frequency decay is slower.

After the frequency decline has been arrested and the frequency returns to normal, the load may be restored in small increments, allowing the spare generator and TNB stand-by supply to be brought on line.

5.5 Load shedding priorities

Load shedding priorities are determined based on the criticality of the loads. The least important loads are shed in the first stage and the very important ones are shed in the last stage. Those units which are compulsory to ensure the safe operation of the plant are not included in the load shedding scheme. If there is really insufficient supply to these very vital units, the whole plant would have to be shut down.

In this load shedding design, five categories of load are defined, namely non-essential, essential, crucial, very crucial and mandatory. In determining the loads in each of these categories, safety is the main priority, followed by economy.

The **non-essential** loads are in the non-process area, including administration building, workshop and laboratory. The removal of these loads for short term does not have great impact on the refinery. As for **essential** loads, end product units, such as Distillate Hydrotreater Unit (DHT) and LPG Treating Unit (LTU) are in this category.

Following the process flow, the **crucial** category includes downstream units, such as Hydrocracker Unit (HCK), Delayed Coker Unit (DCU) and Sulphur Recovery Unit (SRU). This is trailed by the **very crucial** category, covering Catalyst Regeneration Unit (CCR) and Saturated Gas Plant (SGP).

Finally, the most critical units which could not be shut down in the load shedding system fall into the **mandatory** category. Upstream units, such as Crude Distillation Unit (CDU) and Vacuum Distillation Unit (VDU) are in this category. Besides that, the Main Control Building (MCB) and Utilities are also very critical and compulsory for the plant.

Table 5: Total load and priority of each substation

Priority	Substation	Total Load	Load shedding sequence
Mandatory	MISS	12209 kW	**Never**
49.05%	SS10	34 kW	**47085 kW**
	SS11	11976 kW	
	SS13	15109 kW	
	SS5	964 kW	
	SS21	4601 kW	
	SS1	2192 kW	
Very crucial	SS15	8518 kW	**Step 4**
50.95%	SS17	3228 kW	**11746 kW**
Crucial	SS 14	13164 kW	**Step 3**
38.72%			**13164 kW**
Essential	SS3	4155 kW	**Step 2**
25%	SS12	6628 kW	**11984 kW**
	SS16	531 kW	
	SS22	158 kW	
	SS23	234 kW	
	SS24	278 kW	
Non-essential	SS2	955 kW	**Step 1**
12.52%	SS4	750 kW	**12021 kW**
	SS6	1050 kW	
	SS7	1058 kW	
	SS8	2710 kW	
	SS20	897 kW	
	SS21	4601 kW	

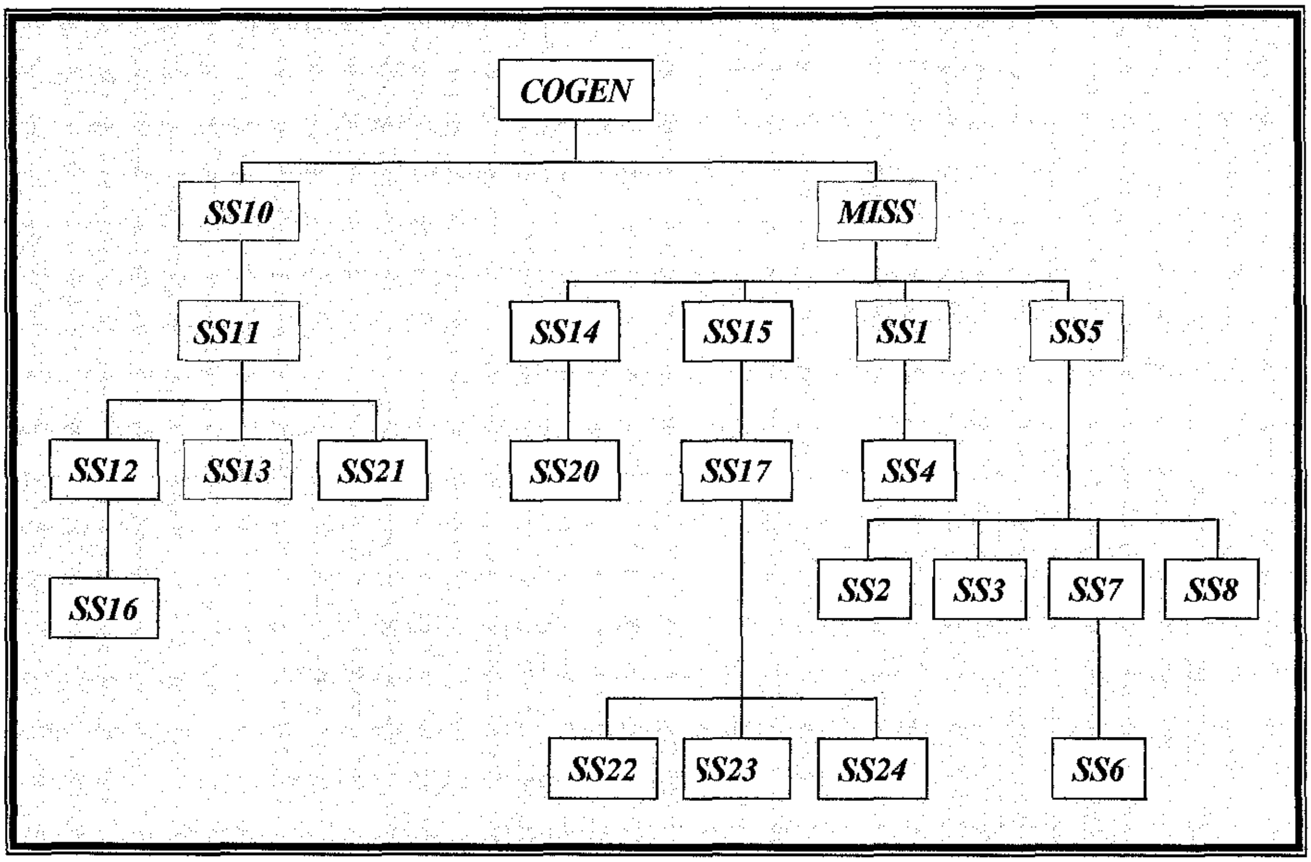


Figure 3: Illustration of load shedding priorities

Non-essential *Crucial* *Mandatory*

Essential *Very crucial*

[See PETRONAS Penapisan Melaka key line diagrams in Appendix VII]

5.6 Load restoration service

Table 6: Sequence of events for load restoration service (1st step)

Event	Frequency, Hz	Time, sec
Normal operation	50.00	0
Generation-load mismatch	50.00	1.00
1st step load shedding (Relay setting)	49.50	1.11
12.52% of load removed	48.82	1.26
Frequency rises above 50Hz due to excessive load shedding	50.05	1.88
Frequency back to normal	50.00	2.19
Delay for 45 sec for reclosing ties	50.00	47.19
Restore 1st block after 10 sec delay	50.00	57.19
Frequency dip	49.85	60.19
Frequency back to normal	50.00	63.19
Restore 2nd block after 12 sec delay	50.00	75.19
Frequency dip	49.85	78.19
Frequency back to normal	50.00	81.19
Restore 3rd block after 14 sec delay	50.00	95.19
Frequency dip	49.85	98.19
Frequency back to normal	50.00	101.19
Restore 4th block after 16 sec delay	50.00	117.19
Frequency dip	49.85	120.19
Frequency back to normal	50.00	123.19
Restore 5th block after 18 sec delay	50.00	141.19
Frequency dip	49.85	144.19
Frequency back to normal	50.00	147.19
System back to normal	50.00	> 147.19

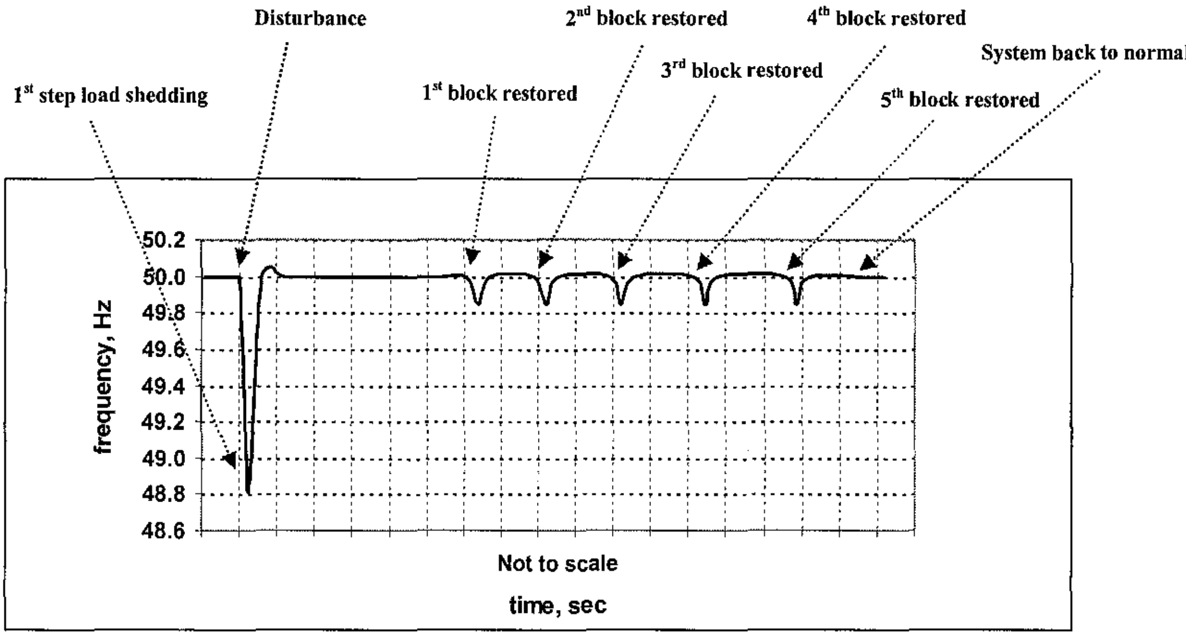


Figure 4: Frequency-time curve for load restoration service (1st step)

If the load shedding program has been successfully implemented, the system frequency stabilizes and then recovers to 50 Hz. Load restoration service is initiated **manually** after authorized personnel ensures that system frequency has completely recovered and sufficient generation reserve is confirmed to be available.

Looking the network size, the typical delay time for peaking of generator and reclosing tie-lines is 30 seconds to several minutes. In this design, 45 seconds is allocated for these purposes and the first block of load is restored after another 10 seconds. The system frequency will dip when additional load is connected and eventually return to normal frequency as the spinning reverse becomes active or the generator picks up the load. Each successive block of load is restored with additional 2 seconds time delay than the previous one to allow frequency stabilization as the system is burdened with more load.

Loads are connected on distributed basis to minimize power swing across the system. For the 1st stage of load shedding, loads are restored in 5 blocks sequentially.

5.7 Results of dynamic simulations

In verifying the load shedding scheme designed, first a stability study is conducted to see the decay of system frequency when generation is lost, without any load shedding. Using this frequency decrement curve, estimates are made for the amounts of load to be shed and the frequency and time delay settings for the underfrequency relays.

Then these data is used in the stability study program to calculate the system frequency versus time curve with the proposed load shedding. If sufficient load is shed fast enough to prevent system collapse, the validity of the proposed relay scheme and settings are confirmed. Usually several runs are made with different system conditions in each load shedding analysis.

In this section, dynamic simulation results of the first 2 steps of load shedding scheme designed is presented.

Please refer to *Table 3 in Page 30* for load shedding design and relay settings.

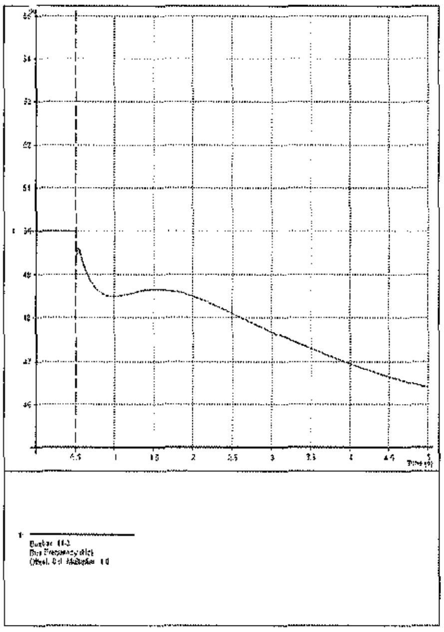


Figure 5:

Loss of 12.5% generation without load shedding

Event:

Lost of 12.5% of generation at 0.5sec.

Load Shedding:

NOT activated

Comment on graph:

System frequency collapses at the instance of generation loss. At about 1 sec, the system frequency stops decreasing as the spinning reserve of generators tries to relieve overloads. However, since the overload is much greater than spinning reserve, the system fails to recover and frequency continues dropping at a slower rate as time goes by due to load reduction factor.

Case 2

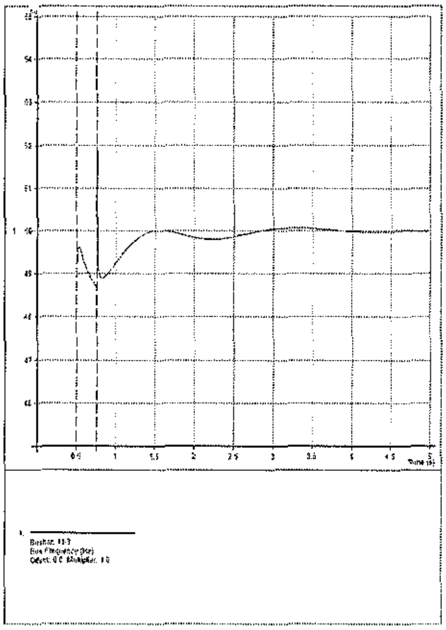


Figure 6:

Loss of 12.5% generation with load shedding

Event:

Lost of 12.5% of generation at 0.5sec.

Load Shedding:

Step 1 activated at 0.76 sec, shedding **12.52%** of load.

Comment on graph:

Initially, the system frequency drops rapidly. At trip time, when the predetermined loads are removed, the frequency rises rapidly due to sudden removal of excessive loads. The frequency drops again almost immediately and rises gradually. Since the amount of load shed is not less than overload, the system eventually stabilizes and normal frequency is restored.

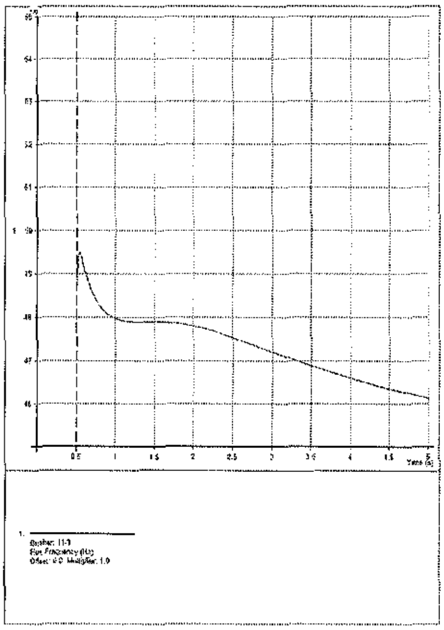


Figure 7:

Loss of 25% generation without load shedding

Event:

Lost of 25% of generation at 0.5sec.

Load Shedding:

NOT activated

Comment on graph:

This case is quite similar to case 1. System frequency collapses at the instance of generation loss. At about 1 sec, the system frequency stops decreasing as the spinning reserve of generators tries to relieve overloads. However, since the overload is much greater than spinning reserve, the system fails to recover and frequency continues dropping at a slower rate as time goes by due to load reduction factor.

If compared with case 1, the rate of frequency decay in case 3 is slightly higher due to higher generation loss and overload.

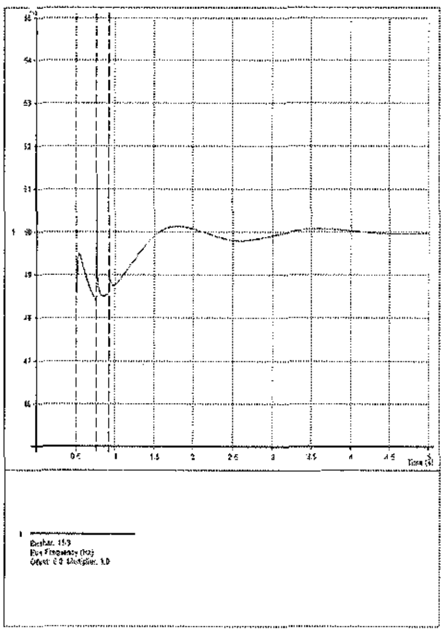


Figure 8:

Loss of 25% generation with load shedding

Event:

Lost of 25% of generation at 0.5sec.

Load Shedding:

Step 1 activated at 0.76 sec, shedding **12.52%** of load.

At 0.925 sec, **another 12.48%** of load is removed in step 2.

Comment on graph:

At the instance of generation loss, the system frequency drops rapidly until load is shed at 0.76 sec. The amount of load shed is equal to 50% of the lost generation. The frequency shoots up initially due to sudden removal of loads, but drops again since the amount of load shed is less than overload. The frequency continues to decay, but at a slower rate. This is insufficient to stop further decrease in frequency and restore frequency to normal.

At 0.925 sec, another 12.48% of load is dropped. The frequency stops dropping as the amount of load shed equals the overload.

Eventually, the system slowly stabilizes and

The dynamic simulation results have shown that the load shedding scheme designed is feasible, since it is able to prevent system collapse due to generation loss and normal frequency can be restored after load shedding.

6. CONCLUSION AND RECOMENDATIONS

6.1 Conclusion

This final year project spans over a duration of 2 semesters, which consists of approximately 38 weeks. The first semester, project work revolves around the project objective, which is aggressive and continuous research to acquire background knowledge about load shedding system. Through literature research, the definition, purpose, magnitude and sequence of load shedding are uncovered. Underfrequency load shedding is preferred over undervoltage as system frequency is directly associated with load and generation balance, while undervoltage may be also be caused by other faults. Before a load shedding program can be developed, several design considerations need to be addressed. It is necessary to determine the maximum overload level the program is to protect, the number of load shedding steps, the size of each step and the frequency level at which load shedding will be executed.

The second project objective is to design an automatic load shedding system. The creation of the simple load shedding scheme in the first semester is mainly a stepping stone towards the final design that was worked on in the second semester. The research work and design of a simple system have provided the author with the required groundwork in order to fully understand various aspects of the requirements for the project.

Project work in the second semester kicks off with case study on load shedding scheme for the upcoming cogeneration plant in PETRONAS Penapisan Melaka. The total installed capacity of the cogeneration plant is 120 MW. The peak load is 96 MW. The maximum generation loss designed for by the load shedding scheme is 50% or 48 MW at system peak. The scheme consists of 4 load shedding steps, removing 12.5% of load at each step. The frequency relay settings are 49.5, 48.77, 48.22 and 47.86 Hz. In the last step, the actual load shed frequency is 47.70 Hz. This is still higher than the minimum acceptable frequency of 47.50 Hz, as stipulated in the Malaysian Grid Code. When there is further frequency drop, the generators will trip out to protect the machines.

Project work is followed by the execution of dynamic simulations on the designed system using ERACS Power Analysis Software, fulfilling the third project objective, which is to verify load shedding design via dynamic simulations. The main purpose is to gauge the performance of the proposed scheme with due regard to power plant and network protections/controls and to system voltages. Transient stability studies are run and it is clear that system frequency decays when generation is lost, without any load shedding. Soon after load shedding is incorporated, system frequency stops decaying and normal frequency is restored. This result applies to four case studies, which are lost of 12.5% and 25% of generation with and without load shedding. The validity of the proposed relay scheme and settings are confirmed since sufficient load is shed fast enough to prevent system collapse during generation loss.

In a nutshell, all project objectives are achieved successfully. The design process of the load shedding scheme has not only taught the author the basics for the project development and enhancement, but has also imparted realization of the importance and significance of load shedding schemes in power systems.

6.2 Recommendations

Taking into consideration that the project duration is only about 38 weeks, there is certainly much room for improvement. Suggested future work for project expansion and continuation includes:

(i) Reduce assumptions made for elements in network diagram built for dynamic simulations, such as equipment ratings, element impedances etc. The more real data is obtained and plucked in, the more reliable the simulation results are.

(ii) Use software which can activate and execute load shedding scheme automatically. ERACS allows setting of network event at designated time. Simulations are done on time basis, instead of frequency. Software that is able to simulate load shedding based on frequency settings allows users to see the actual time a frequency level is reached and manipulate other settings accordingly to increase the effectiveness of load shedding scheme.

(iii)Develop the hardwired prototype of the project using microcontroller **PIC16F84**. The PIC chip will function as protective relay, where data is processed, decision is made and all inputs along with outputs are connected. DIP switches, LEDs, buzzer and LCD display are potential input and output components. These components will correspond to the circuit breakers, alarm and display panel in real application. This hardwired prototype can present the load shedding scheme more effectively and makes it more interesting and understandable.

(iv)Other recommendations include in-depth research on the slow coherency theory and enhancement of the adaptive feature, designing the restoration procedure to complete self- healing and application of the algorithm on a large system scale.

REFERENCES

[1] PETRONAS Technical Standard
PTS 33.64.10.10: "Electrical Engineering Guidelines"; Appendix 3

[2] Protective Relaying Theory and Applications
Walter A. Elmore; Marcel Dekker, Inc.; 1994; Page 345-355; TK2861.P764

[3] IEEE Std 493-1980

[4] Power System in Emergencies - From Contingency Planning to Crisis Management
U. G. Knight; John Wiley & Sons, LTD; 2001; Page 124-127, 130-133; TK 1010.K55

[5] Power System Dynamics - Stability and Control
K R Padiyar; John Wiley & Sons (Asia) Pte Ltd; Interline Publishing Pvt Ltd; 1996; Page 560-562; TK 1010.P33

[6] Independent Generation of Electric Power
David Stephen; Butterworth-Heinemann Ltd; 1994; Page 84-137; TK 1005.S6958

[7] Power System Dynamics and Stability
Jan Machowski, Janusz W. Bialek, James R. Bumby; John Wiley & Sons; 1997; Page 259-290; TK 1010.M33

[8] Power System Stability and Control
Prabha Kundur; Mc Graw Hill; 1993; Page 623, 1020, 1120-1121, 1164; TK 1005.K86

[9] New Straits Times; "No claim over blackout, says TNB"; 24/12/2003

[10] New Straits Times (HL); "Blackout Hits Five States"; 02/09/2003

[11] www.pm.geindustrial.com/FAQ/Documents/SFF/GET-6449.pdf

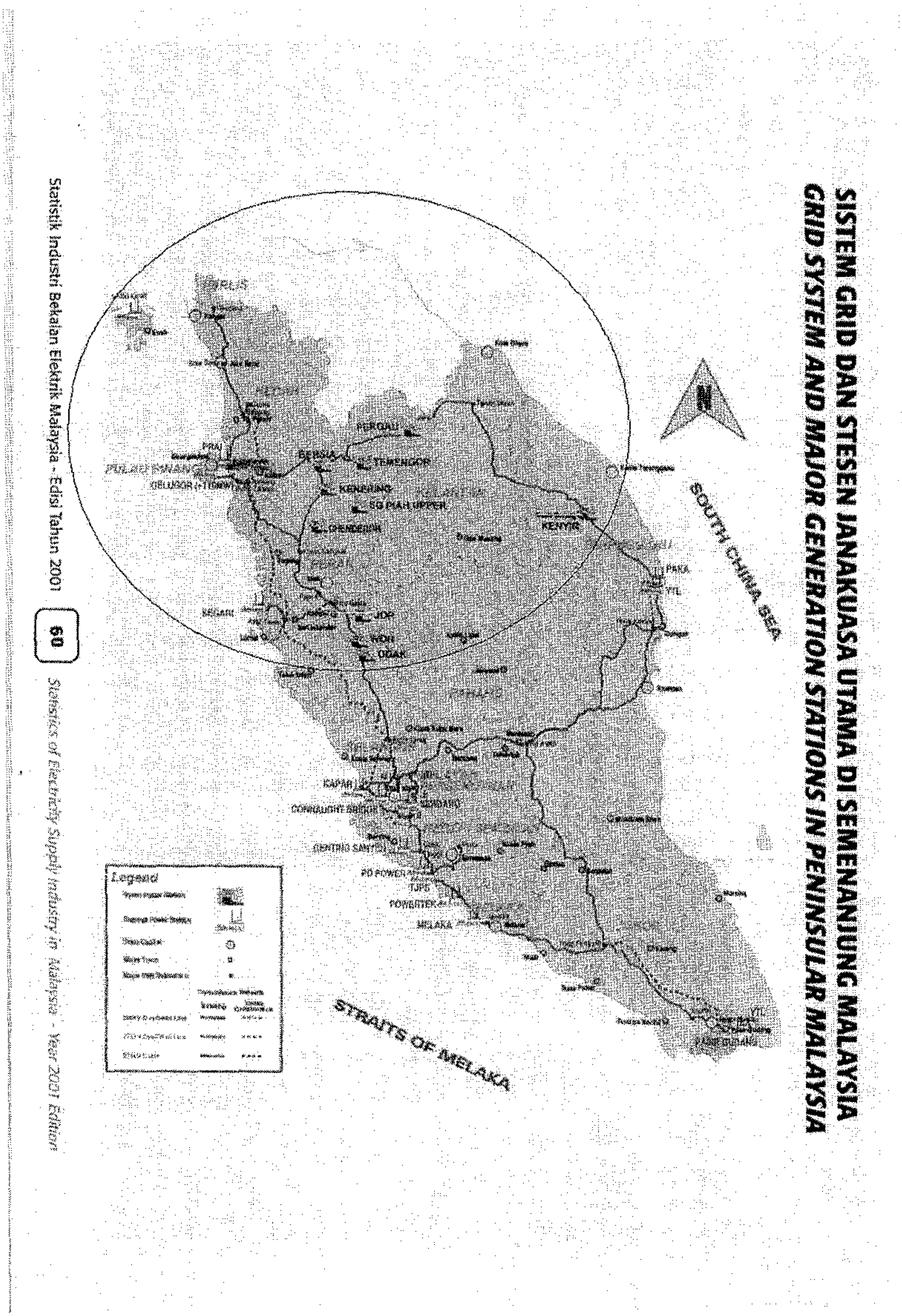
[12] Mr. Danial Md Noor, Operation & Production Planning (OPP), Tenaga National Berhad

[13] Dr. Morris Lockwood, Engineering Consultancy Services, Era Technology LTD

[14] Mr. Kevin Davey, Engineering Consultancy Services, Era Technology LTD

APPENDICES

Appendix I National Grid

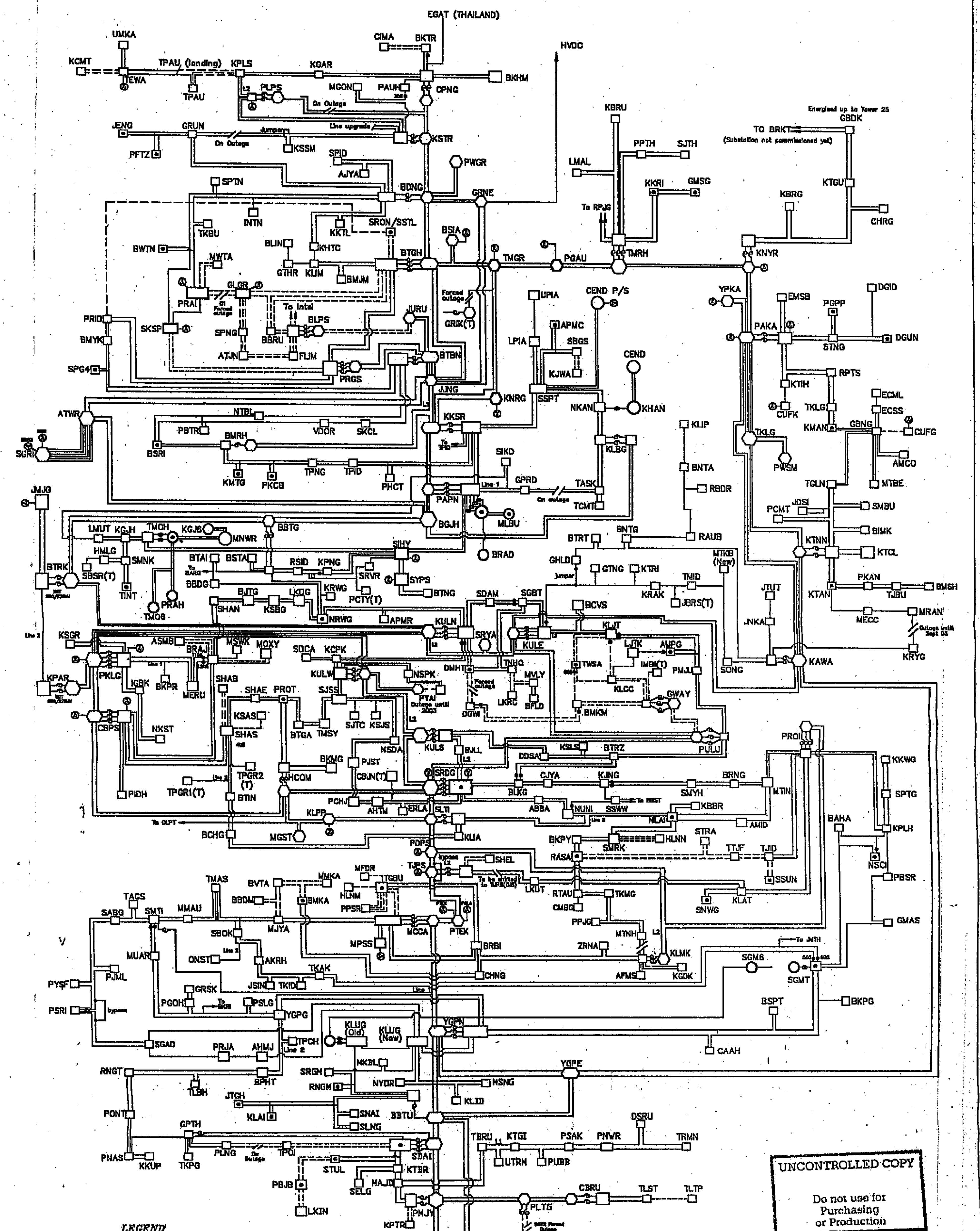


Appendix II

Grid system connectivity diagram of Peninsular Malaysia

TENAGA NASIONAL BERHAD

GRID SYSTEM CONNECTIVITY FOR FEBRUARY, 2003



LEGEND

- 500kV LINE
- 275kV LINE
- 275kV CABLE
- 230kV CABLE
- 132kV LINE
- 132kV CABLE
- 66kV LINE
- 500kV SUBSTATION
- POWER STATION OR 275kV SUBSTATION
- 132kV SUBSTATION
- 66kV SUBSTATION
- ● Off Point for 275 & 132kV

11/03/03

System Planning, Transmission Division

GRID SYSTEM – FEBRUARY, 2003

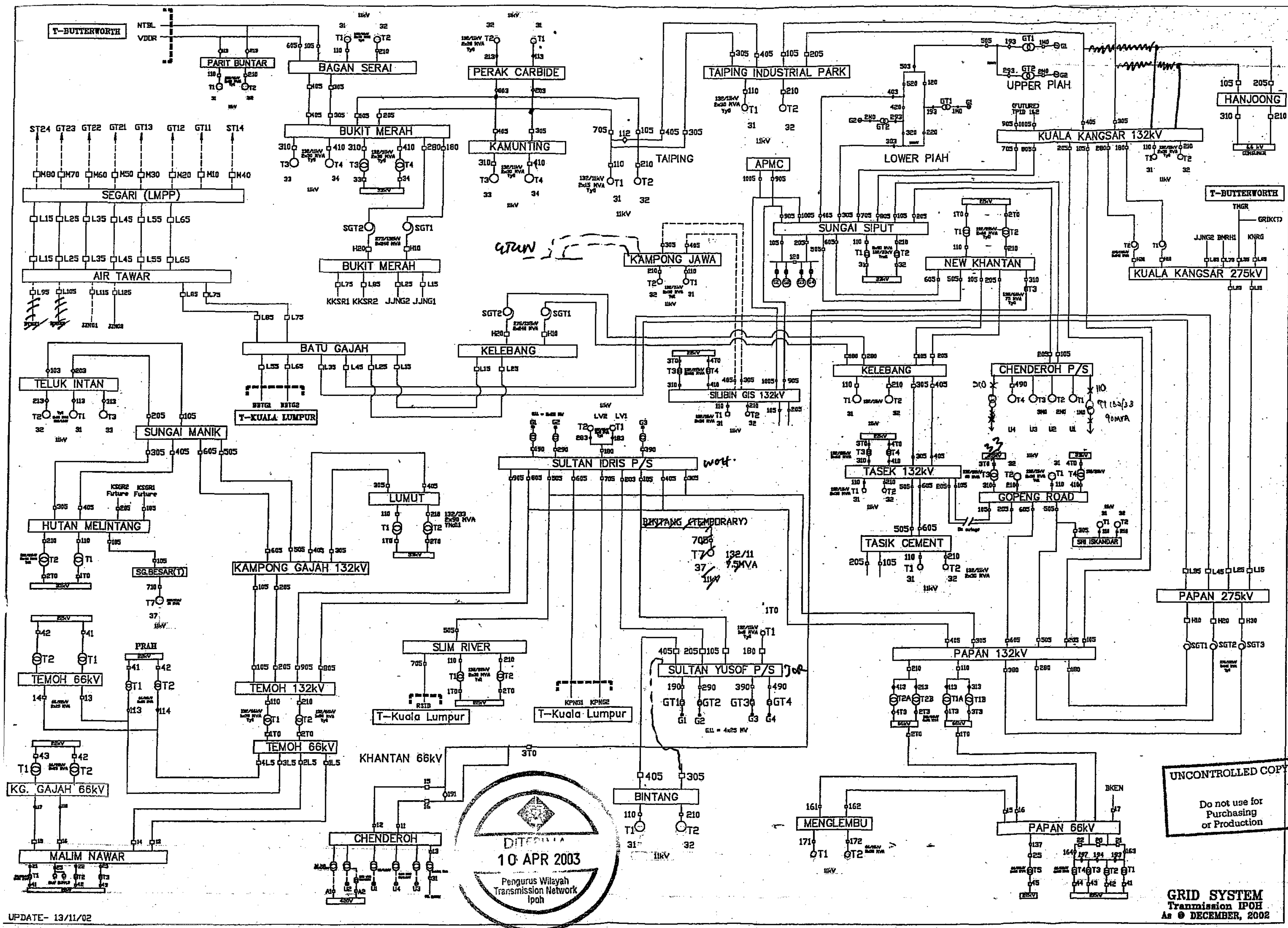
500/275/132/66kV SYSTEM CONNECTIVITY

Drawing No. 599-GS-002

Prepared by : Arjurin Bin Abd. Jalil

Appendix III

Transmission grid system diagram of Perak



T-BUTTERWORTH
PARIT BUNTAR
BAGAN SERAI
PERAK CARBIDE
TAIPING INDUSTRIAL PARK
UPPER PIAH
HANJOONG
LOWER PIAH
KUALA KANGSAR 132kV
SEGARI (LMPP)
BUKIT MERAH
KAMUNTING
TAIPING
APMC
AIR TAWAR
SUNGAI SIPUT
KAMPONG JAWA
NEW KHANTAN
KUALA KANGSAR 275kV
BATU GAJAH
KELEBANG
SILIBIN GIS 132kV
CHENDEROH P/S
TELUK INTAN
T-KUALA LUMPUR
SUNGAI MANIK
SULTAN IDRIS P/S
TASEK 132kV
LUMUT
GOPENG ROAD
HUTAN MELINTANG
BINTANG (TEMPORARY)
TASIK CEMENT
SG.BESAR(T)
KAMPONG GAJAH 132kV
PAPAN 275kV
SLIM RIVER
PAPAN 132kV
TEMOH 66kV
PRAH
TEMOH 132kV
SULTAN YUSOF P/S
T-Kuala Lumpur
T-Kuala Lumpur
KHANTAN 66kV
KG. GAJAH 66kV
BINTANG
MENGLEMBU
PAPAN 66kV
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GRID SYSTEM
Tranmission IPOH
As @ DECEMBER, 2002

Appendix IV Project Gantt Chart (1st semester)

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Selection of Project Topic																		
2	Submission and Conformation of Topic																		
3	Project planning																		
4	Preliminary Research Work																		
	- Definition and purpose of load shedding																		
	- Magnitude and sequence																		
5	Submission of Preliminary Report				●														
6	Research Work																		
	- Parameter for load shedding initialisation																		
	- Make comparison of different load shedding schemes																		
7	Research work																		
	- Typical design considerations of load shedding scheme																		
8	Submission of Progress Report								⊙										
9	Design of simple load shedding scheme																		
10	Preparation and compilation of interim report																		
11	Submission of Interim Report Final Draft															○			
12	Preparation for oral presentation																		
11	Submission of Interim Report																	◉	
12	Oral Presentation																		◎

● 15th August 2003 ◎ 05th November 2003 ○ TBA

⊙ 12th September 2003 ◉ 10th November 2003

Project Gantt Chart (2nd semester)

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Selection of data source/plant	■																			
2	Analysis of load behaviour and significance		■	■																	
3	Submission of Progress Report 1				●																
4	Design of underfrequency load shedding scheme on selected plant				■	■	■														
5	Execute dynamic simulations to justify design							■	■	■	■										
6	Submission of Progress Report 2								◉												
7	Preparation and compilation of Dissertation Final Draft										■	■									
8	Submission of Project Dissertation daft												◉								
9	Final amendments of project dissertation													■							
10	Preparation for oral presentation														■	■					
11	Submission of Project Dissertation (soft cover)														●						
12	Oral Presentation																●				
13	Preparation of extended abstracts																■	■			
14	Submission of extended abstracts																		○		
15	Submission of Project Dissertation (hard cover)																				◉

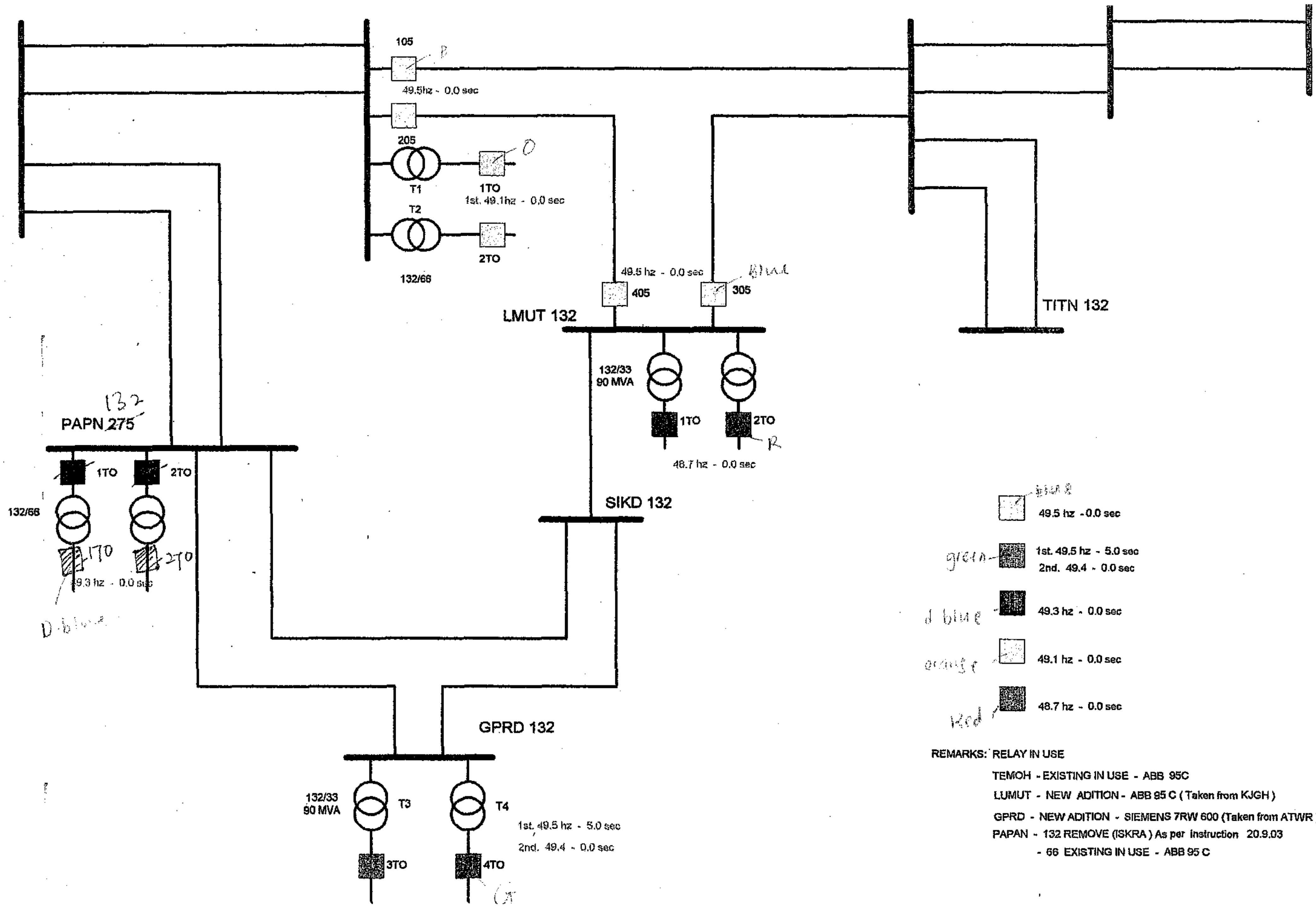
● 13th February 2004
◉ 05th April 2003
● 03rd - 05th May 2004
◉ 04th June 2004
◉ 19th March 2004
● 21st April 2004
○ 21st May 2004

Appendix V

Sequence of underfrequency load shedding for Perak region

.K TRANSMISSION - SEQUENCE OF LOAD SHEDDING DUE TO U/FREQUENCY OPERATION

U/ FREQUENCY SETTING		STATION	FEEDER	CB NO.	REMARK
STAGE	TIME				
49.5 hz	0.0	LUMUT	SMNK	305	
49.5 hz	0.0		TMOH	405	
49.5 hz	0.0	TEMOH	SMNK	105	
49.5 hz	0.0		LMUT	205	
49.5 hz	5.0	GPRD	132/33 T3	3TO	
49.5 hz	5.0		132/33 T4	4TO	
49.5 hz	5.0	KHANTHAN 132	132/22 T1	1TO	
49.5 hz	5.0		132/22 T2	2TO	
49.5 hz	5.0	TASEK 132	132/22 T1	1TO	
49.5 hz	5.0		132/22 T2	2TO	
49.5 hz	5.0	SILIBIN GIS	132/11 T1	31	
49.5 hz	5.0		132/11 T2	32	
49.4	0.0	TEMOH	SMNK	105	1st. Stage 49.5hz - 0.0 Secs
49.4	0.0		LMUT	205	1st. Stage 49.5hz - 0.0 Secs
49.4	0.0	GPRD	132/33 T3	3TO	
49.4	0.0		132/33 T4	4TO	
49.4	0.0	KHANTHAN 132	132/22 T1	1TO	
49.4	0.0		132/22 T2	2TO	
49.4	0.0	TASEK 132	132/22 T1	1TO	
49.4	0.0		132/22 T2	2TO	
49.4	0.0	SILIBIN GIS	132/11 T1	1TO	
49.4	0.0		132/11 T2	2TO	
49.3	0.0	PAPAN	132/66	1TO	
49.3	0.0		132/66	2TO	
49.2	0.0	KJWA	132/11 T1	31	
49.2	0.0		132/11 T2	32	
49.1	0.0	KKSR	TPID 1	305	
49.1	0.0		TPID 2	405	
49.1	0.0	BMRH	TPNG 1	105	
49.1	0.0		TPNG 2	205	
49.1	0.0	TEMOH	132/66	1TO	
49.1	0.0		132/66	2TO	
48.7	0.0	LUMUT	132/33	1TO	
48.7	0.0		132/33	2TO	



REMARKS: RELAY IN USE

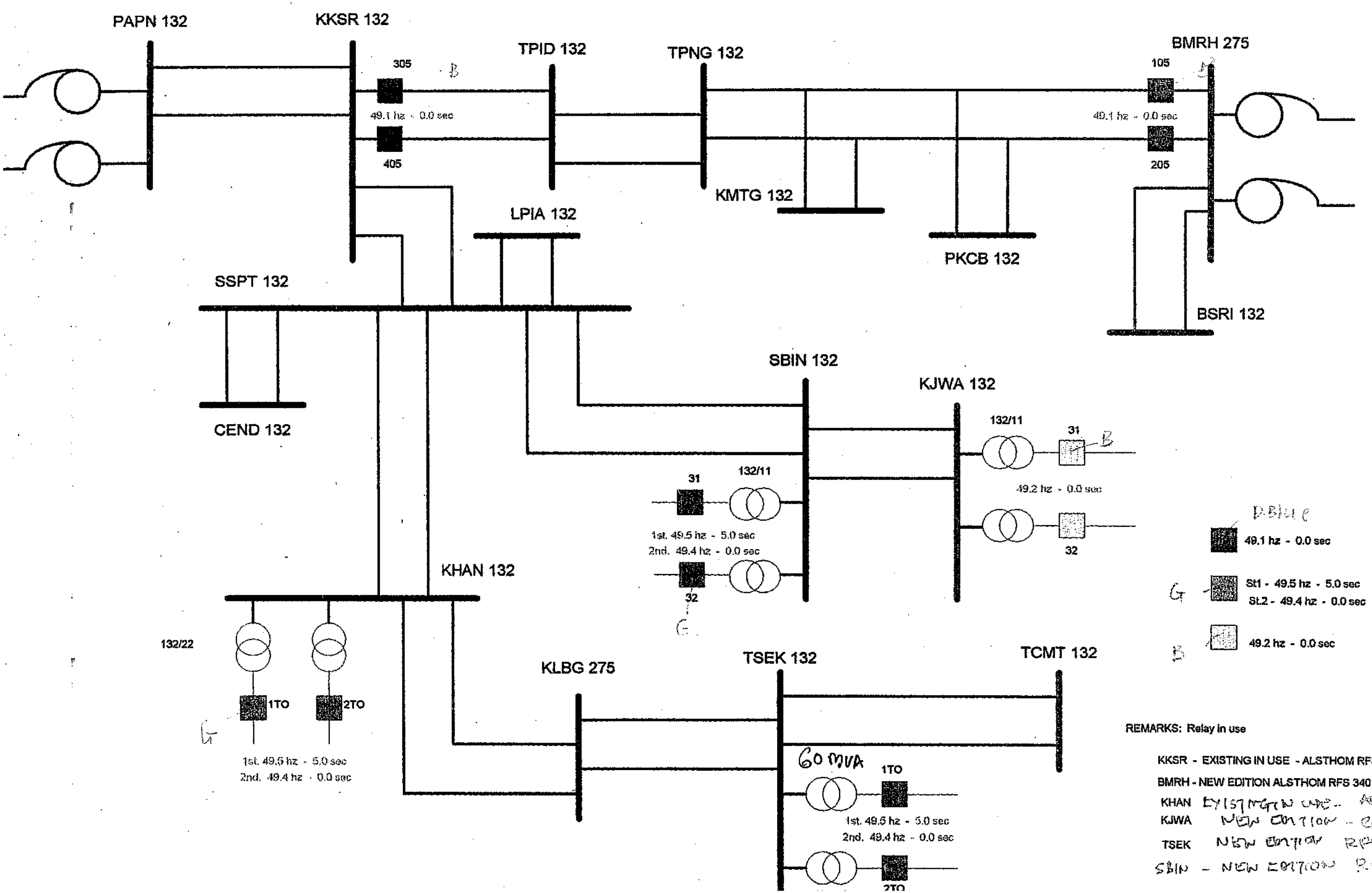
TEMOH - EXISTING IN USE - ABB 95C

LUMUT - NEW ADITION - ABB 95 C (Taken from KJGH)

GPRD - NEW ADITION - SIEMENS 7RW 600 (Taken from ATWR)

PAPAN - 132 REMOVE (ISKRA) As per instruction 20.9.03

- 66 EXISTING IN USE - ABB 95 C



REMARKS: Relay in use

KKSR - EXISTING IN USE - ALSTHOM RFS 3401
BMRH - NEW EDITION ALSTHOM RFS 3401
KHAN EXISTING IN USE
KJWA NEW EDITION
TSEK NEW EDITION
SBIN - NEW EDITION

Appendix VI Detail load shedding calculations

Formula:

% overload = [(Total load – remaining generation) / remaining generation] X 100%

Table A1: Percentage of overload due to generation loss

Event	% of generation lost	% overload
Loss of 1 incoming line	12.5%	14.29%
Loss of 2 incoming lines	25.0%	33.33%
Loss of 3 incoming lines	37.5%	60.00%
Loss of 4 incoming lines	50.0%	100.00%

Table A2: Predetermined load shedding steps

Load shedding stepsStep	Load shed	Total load shed
1	12.5%	12.5%
2	Additional 12.5%	25.0%
3	Additional 12.5%	37.5%
4	Additional 12.5%	50%

Frequency relay settings

Formula:

Rate of frequency change, df/dt = - (ΔP/2H)

H: Inertia constant (H = 5)

ΔP: Decelerating power in per-unit of connected kVA

$\mathbf{t_{trip} = t_{pick\text{-}up} + t_{breaker} + t_{relay}}$

$t_{breaker}$: Breaker opening time

($t_{breaker}$ = 100ms for Merin Gerin Fluarc FG 2 circuit breaker)

t_{relay} : Relay internal pick-up time

(t_{relay} = 50ms for Alstom RFS 3000 frequency relay)

$t_{pick\text{-}up}$ = (original frequency – frequency relay set point) / rate of frequency change

Calculations

Step 1

Total maximum load that could be shed = 50%

Remaining generation = 50%

ΔP = 1.000 (worst expected overload from Table 1)

H = 5.5

df/dt = - 1.000 / (2X5.5) = -0.091 per unit X 50 = **- 4.545 Hz/sec**

Original frequency = 50 Hz

Frequency relay set point = 49.50 Hz

$t_{pick\text{-}up}$ = (50 – 49.50) / 4.545 = 0.110 sec

t_{trip} = 0.110 + 0.1 + 0.05 = **0.260 sec**

Frequency at t_{trip} = 50 – [(4.545) (0.260)] = **48.82 Hz**

Hence, at 0.260 sec after fault is detected, 12.5% of load is disconnected from the system and the system frequency at that instance is 48.82 Hz.

Step 2

Total maximum load that could be shed = 50%

Remaining generation = 50%

Load removed in Step 1 = 12.5%

$\Delta P = (50-12.5) / 50 = 0.750$

$H = 5.67$

df/dt = - 0.750 / (2X5.67) = -0.066 per unit X 50 = **- 3.307 Hz/sec**

Original frequency = 48.82 Hz

Frequency relay set point = 48.77 Hz

$t_{pick\text{-}up} = (48.82 - 48.77) / 3.307 = 0.015$ sec

$t_{trip} = 0.015 + 0.1 + 0.05 =$ **0.165 sec**

Frequency at t_{trip} = 48.82 – [(3.307) (0.165)] = **48.27 Hz**

Hence, at 0.165 sec after removing 12.5% of load in Step 1, additional 12.5% of load is disconnected from the system, making the total load removed equals 25%. The system frequency at that instance is 48.27 Hz.

Step 3

Total maximum load that could be shed = 50%

Remaining generation = 50%

Total load removed in Step 1 and 2 = 25%

$\Delta P = (50-25) / 50 = 0.500$

$H = 5.67$

df/dt = - 0.500/ (2X5.67) = -0.044 per unit X 50 = **- 2.205 Hz/sec**

Original frequency = 48.27 Hz

Frequency relay set point = 48.22 Hz

$t_{pick\text{-}up} = (48.27 - 48.22) / 2.205 = 0.023$ sec

$t_{trip} = 0.023 + 0.1 + 0.05 =$ **0.173 sec**

Frequency at t_{trip} = 48.27 – [(2.500) (0.173)] = **47.91 Hz**

Hence, at 0.173 sec after removing 25% of total load, <u>additional 12.5%</u> of load is disconnected from the system, making the total load removed equals 37.5%. The system frequency at that instance is 47.91 Hz.

<u>Step 4</u>

Total maximum load that could be shed = 50%

Remaining generation = 50%

Total load removed in Step 1, 2 and 3 = 37.5%

$\Delta P = (50-37.5) / 50 = 0.250$

$H = 6$

df/dt = - 0.250/ (2X6) = -0.028 per unit X 50 = **- 1.042 Hz/sec**

Original frequency = 47.91Hz

Frequency relay set point = 47.86 Hz

$t_{pick\text{-}up} = (47.91 - 47.86) / 1.042 = 0.048$ sec

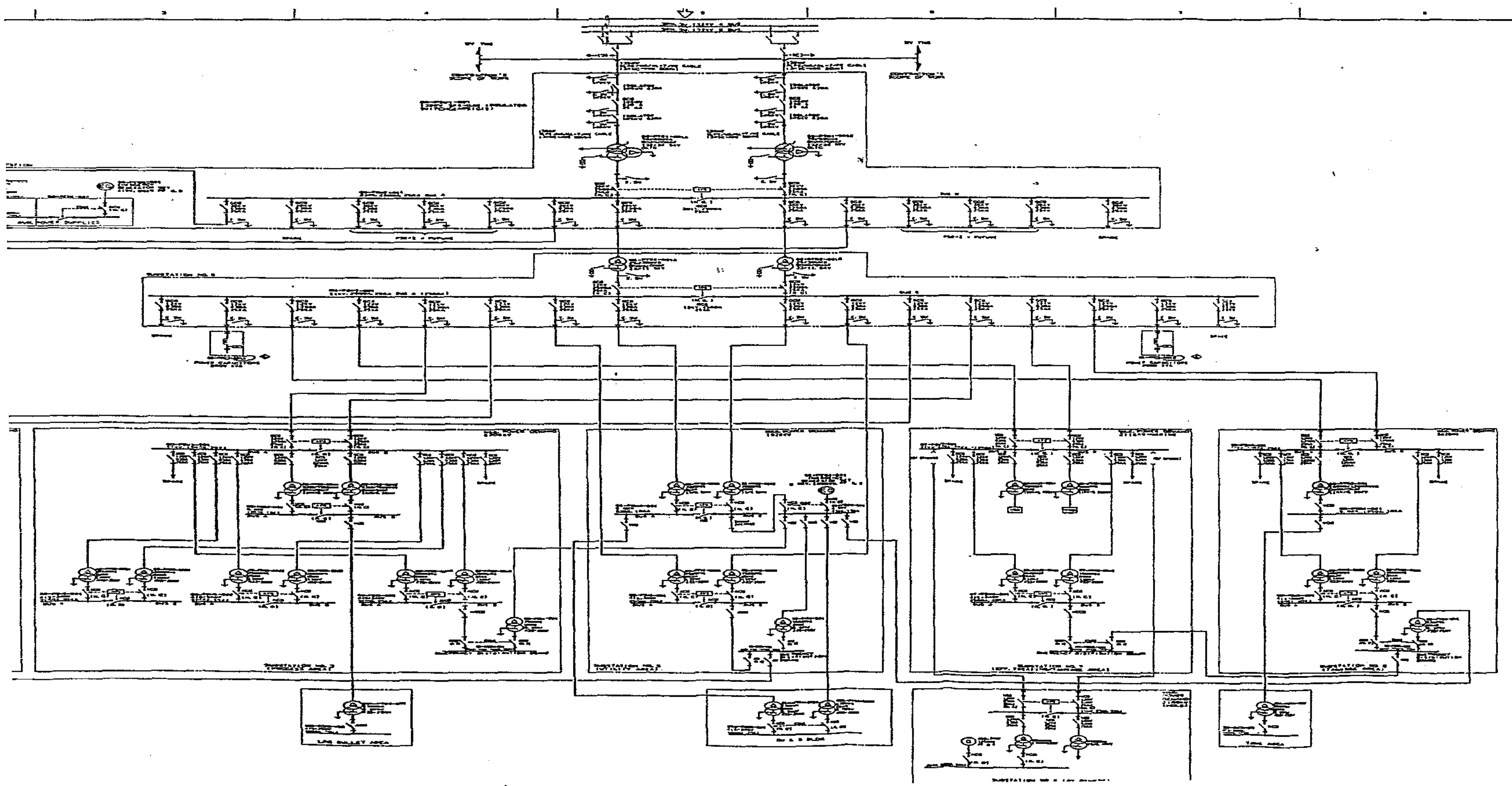
$t_{trip} = 0.048 + 0.1 + 0.05 =$ **0.198 sec**

Frequency at $t_{trip} = 47.91 - [(2.500) (0.198)] =$ **<u>47.70 Hz</u>**

Hence, at 0.198 sec after removing 37.5% of total load, <u>additional 12.5%</u> of load is disconnected from the system, making the total load removed equals 50%. The system frequency at that instance is 47.70 Hz.

Appendix VII

PETRONAS Penapisan Melaka electrical key line diagrams



AS-BUILT

PENAPISAN MELAKA

PETRONAS PENAPISAN (MELAKA) SDN BHD

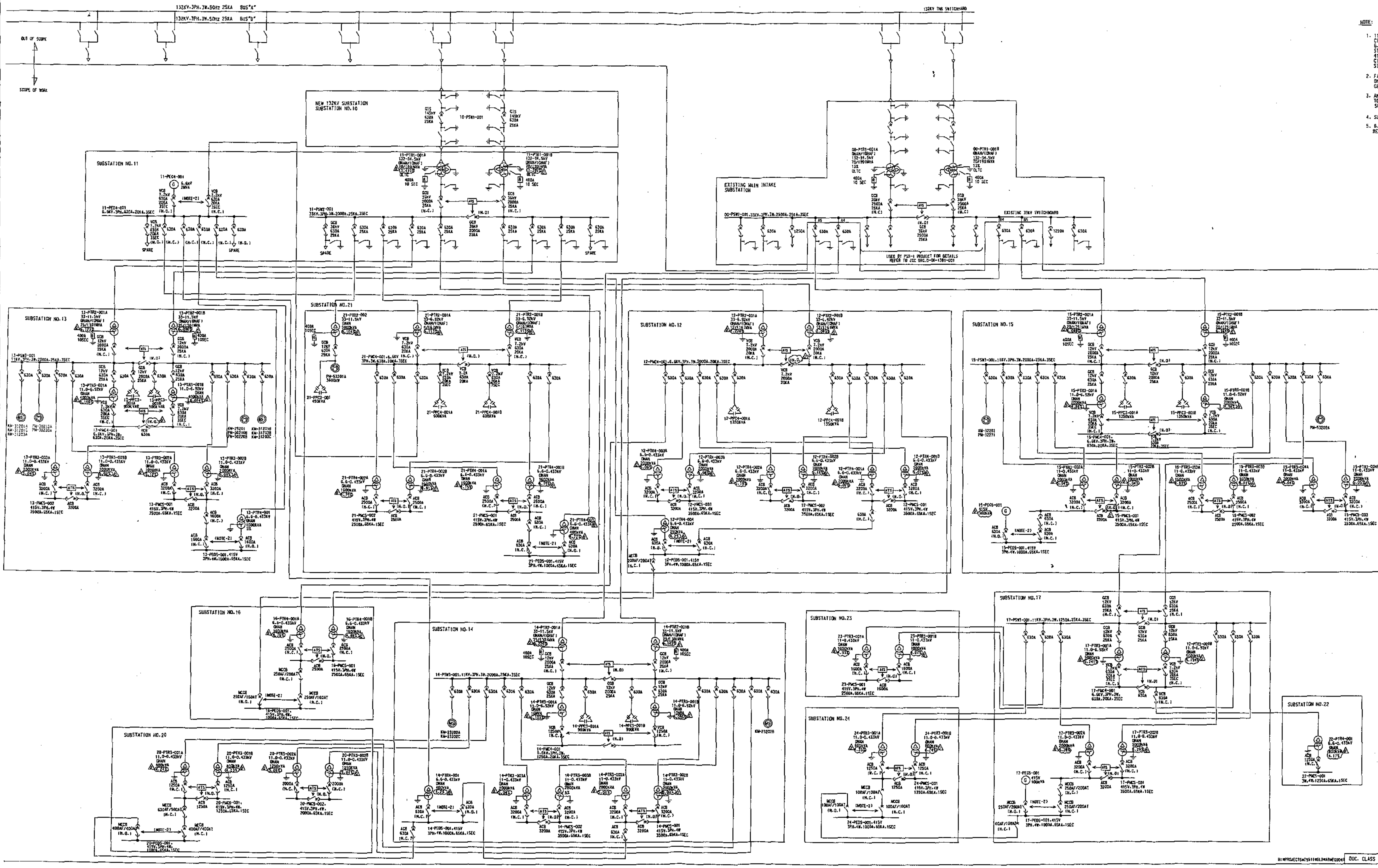
MELAKA REFINERY

JGC CORPORATION

C.ITOH & CO., LTD.

OVERALL KEY SINGLE LINE DIAGRAM
FOR
ELECTRICAL DISTRIBUTION SYSTEM

c:\DATAWRKS\TEMP\45617\041D0001.dgn



NOTE:

1. 11KV SWITCHBOARDS SHALL HAVE 1 SPARE OUTGOING CIRCUIT BREAKER PANEL ON EACH BUS.
   6.6KV SWITCHBOARDS SHALL HAVE 1 SPARE MOTOR STARTER PANEL ON EACH BUS.
   415V MCC'S SHALL HAVE APPROXIMATELY 10% SPARE CIRCUITS WITH A MINIMUM OF 1 CIRCUIT OF EACH SIZE.
2. FAILURE OF NORMAL SUPPLY OPENS N.C. CIRCUIT BREAK ON EACH SWITCHBOARD. STARTS THE ASSOCIATED E.M. GENERATOR AND CLOSES THE N.O. CIRCUIT BREAKERS.
3. AN AUTOMATIC TRANSFER SYSTEM (A.T.S.) SHALL BE AP TO ALL SWITCHBOARDS CONTAINING ONE OR MORE BUS SE SWITCHES.
4. SUBSTATION NO.18,19 IS DELETED AND NUMBER NOT USE
5. 6.6KV MOTORS ARE NOT SHOWN. REFER TO THE 6.6KV SINGLE LINE DIAGRAM.

REV	A	DATE	11 NOV '95	APPROVED
ISSUED FOR CONSTRUCTION				
DATE	24.MAY.'95	24.MAY.'95	25.MAY.'95	25.MAY.'9
BY	Y.S	A.S	Y.S	T.S
	DRAWN	CHECKED	CHKD	APVD

MALAYSIAN REFINING COMPANY SDN.

PSR-2 MELAKA REFINERY PROJECT S
Melaka - Malaysia

CHIYODA CORPORATION — MMC Engineer — CHIYODA MALAYSIA SDN. BHD. — MITSUI &

TITLE
KEY SINGLE LINE DIAG

SCALE NONE — JOB NO. 3107

PROJECT PSR2 — DRAWING NO. D-400-00-73-0041

DWG SIZE A0

DOC. CLASS : 2