IMPACT OF EMBEDDED GENERATION ON DISTRIBUTION LOSS MINIMIZATION

A dissertation submitted to the
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Abstract

Demand for Electricity has been increasing rapidly over the last decade and the cost of electricity generation too has been increasing due to the adverse impacts on hydro resources. Electricity loss reduction is a main concern to minimize the heavy cost on electricity generation. It has shown progress over the last five years by minimizing system losses by 5%.

Embedded generation has direct impact on the distribution loss level of the system due to the alteration in power flow. Absorption of the optimal output of the potentially available embedded generation is therefore important for the utility. It needs adequate facilitation for the developers and optimal allocation of these plants on the network.

Network analysis was carried out on a network in actual terms. Power flow study through Synergee software considering various arrangements of grid interconnection of embedded generators, was the approach. Key concerns on the simulation study was the reduction in distribution line losses, reduction in grid power demand where central generation replaced by embedded generation and the reduction in grid transformer losses due to altered current flows. The study consisted of analyzing the absorption of all potentially available capacity into the feeder. The optimal arrangement was compared with the conventional arrangement proposed by CEB thereby evaluating the profitability of the modified connection arrangement through NPV calculation.

Analysis revealed that connecting the embedded generators to the nearby load centers of the network has significant effect compared to connecting them to nearest branch of the distributor. It causes' a reduction in network losses and cost of generation due to the decrease in power demand by the transmission network. The effect is high when power from large capacity generators is directly transported to the load centers. A typical network would make an internal rate of return about 26% through the modification in the long run.

This could be employed in the planning process for preparation of the grid interconnection proposals for embedded generators.

DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated. It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

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Date : 01-02-2010

We endorse the declaration by the candidate.

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Thankfulness is extended to the management of the Ceylon Electricity Board especially to Eng. D.Withanage, Deputy General Manager (Uva Province) for the encouragement and support given to me for bringing this task to a success.

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R.M.S.M.B.Sumanasekara

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LIST OF ACRONYMS

ACSR - Aluminum Conductor Steel Reinforced

CEB - Ceylon Electricity Board

EG - Embedded Generation

GSS - Grid Substation

HFO - Heavy Fuel Oil

HV - High Voltage

IRR - Internal Rate of Return

LV - Low Voltage

MHP - Mini Hydro Plant

MV - Medium Voltage

NPV - Net Present Value

O&M - Operation and Maintenance

PCC - Point of Common Coupling

PU - Per Unit

RC - Reinforced Concrete

SPPA - Standardized Power Purchase Agreement

UG - Underground

Chapter 1

Introduction

1.1 Background Study

In Sri Lanka, demand for electricity has been rapidly increasing over recent years. Annual gross electricity generation in Sri Lanka has reached 10,000GWh margin while the maximum demand is over 1900 MW. Major electrification programmes implemented by the government owned utility Ceylon Electricity Board (CEB) has resulted in the proportion of grid connected household in the country increasing from 6% in 1976 to 83% in 2007. Over 4 million consumers are benefited by electricity in the country at present. With foreign aid, the government has initiated special projects such as Lighting Hambantota, Lighting Ratnapura, etc. to accelerate the rate of electrification in areas presently having comparably low level of electrification.

In the circumstances CEB as the utility has to make appropriate strategies to ensure sufficient reliability and the quality of the supply to its vast number of consumers in a background of an energy crisis and other financial go downs experienced currently.

Sri Lanka's Electricity generation is mainly sourced by hydroelectric power and thermal power. Over the recent years CEB has faced severe capacity shortages due to the drop in reservoir water levels. Power sector in Sri Lanka was in crisis due to inadequate new power generation capacity additions and sub optimal usage of fuel sources for power generation. The problems manifested in the form of chronic power shortages led to procurement of expensive emergency power generation capacity. This created a structural financial deficit in the power sector and unsustainable tariffs that weakened the competitiveness of local industries.

The government having initiated strong developments in many sectors including infrastructure development and production process, the adverse situation in the power sector could directly affect and decelerate the country's development processes. In the circumstances it is now seen that vital decisions are being taken and implemented to overcome this situation. Implementation of mass hydro power plants to the available potential and high capacity thermal plants including coal & HFO is fundamental in this regard. In addition, significant capacity of renewable power has been absorbed to the system. In general, renewable energy in Sri Lanka is low in cost.

In the transmission sector more Grid substations and transmission lines are being constructed to widen and strengthen the transmission network. Majority of the existing grid substations are being augmented and facilitated with modern GIS technology.

Another vital aspect in overcoming the crisis is the energy loss reduction. Special concern has been made on reducing the distribution losses in the network which exist at a high rate. This includes technical & non-technical loss reduction. With the special initiatives taken the distribution losses have been significantly reduced over the past few years and will be discussed in later chapters.

It is evident that these measures have positively contributed to make a significant impact to overcome the problems in power sector. However further attempts in this regard is yet required. Therefore is a vital requirement to come out with new strategies with more engineering considerations.

1.2 Motivation

Analysis on few salient items as described in the background study was selected as the matter of study under this research. A successful result will be useful for the utility to be adopted for its planning process. 'Inclusion of the Embedded Generation (EG) in the distribution network and the impact of these on distribution losses' was selected for the analysis.

Investment & development of embedded power plants connected to the national grid has been significantly increased over the past few years. Foreseeing probable crisis in the system due to capacity shortages, government encouraged private sector entrepreneurs for investment on EG. It is identified as a high-return investment for the investors due to the provision of an attractive tariff scheme for EG. More effectively it is an environment friendly, cheap and convenient source of electrical energy for the utility, when compared to other base plants of generating electricity.

As the System Planning Engineer attached to Uva province of CEB, design of grid interconnection for the absorption of embedded power plants (especially small hydro plants) to the national grid is one of requirements from myself. These interconnection proposals are outcome of stability, network capacity, geography and fault level studies carried out with respect to the proposed embedded power plant.

Contribution of EG to the national grid earlier was not considerable. However, due to the increased number of EG plants in the distribution network, a significant impact of these on the system operation has resulted. Special concern is on distribution losses.

Importance and timeliness of this subject matter and the possibility for the utility to optimally utilize EG for its operation, were the basic reasons motivated me for selection of the topic of this project.

1.3 Problem Statement

In Uva province of CEB the number of embedded generators (mainly small hydro plants) connected to its Medium Voltage distribution network is about 15 having total installed capacity of 34MW. The No. of embedded generating plants for which the Letters Of Intent have been issued is 14 for a capacity of 40MW.

Distribution development planning in the province is carried out once in every two years. Transformer loading, load distribution, voltage levels, line capacities and the reliability of the system are the main issues considered in planning. In distribution planning, EG is an excluded factor due to no commitment on its reliability and energy supply to the system throughout.

But the presence of embedded generation within the distribution network will introduce multidirectional power flows and will have to be considered in all aspects of planning.

Variation of distribution line losses and the transformer load losses in the grid substation transformers due to inclusion of EG will be studied. EG causes changes in the power demand by the transmission network and in some cases a net contribution of power to the transmission network. The cost of generation of a kWh unit using central generating plants and EG plant is different. Forecast on cost of generation in next few years can be figured out for embedded generation according to its firm tariff. But for a kWh unit generated using thermal or mass hydro plants, future cost cannot be forecasted unless analyzing past trends, available capacity and forecast on world fuel prices. Therefore comparative study of these two generating types and the impact on above factors was selected.

Selection of an existing network, gathering its actual historic data & features, study in detail regarding the variation of distribution losses of the same for several allocations of EG through power flow analysis thus making a final conclusion that how the EG has contributed for loss minimization and the methods it can be optimally utilized are the basic contents of this problem.

1.4 Scope of the Project

- To identify key factors considered in distribution development planning
- To study on the current & the anticipated contribution of embedded generation to the distribution system
- To study on the factors affecting the reliable operation of embedded power plants and its pattern of change.
- Analysis of past energy data of embedded power plants & distribution system.
- To run computer simulations in a planning software both including & excluding the embedded power plants
- By analyzing these, to reach a result that will represent the effect of the presence of embedded generators in distribution system for loss minimization.
- To conclude in a way that it can be used as a methodology in distribution development planning.

Chapter 2

Electricity Losses and Embedded Generation

2.1 Electricity Losses

Energy losses occur in every stage in a power system, electricity generation to supply point. This is common for power systems in anywhere in the world and the techniques they have imposed to minimize these energy losses decides on the financial saving that they can gain through loss minimization.

Electricity losses can occur in three main categories namely Generation losses, Transmission losses and Distribution losses. Distribution losses occur in a comparably large percentage due to the facts of operating voltage, large number of power devices such as transformers being associated and due to the distribution of the network in a large extent of area. Distribution line loss is the factor that contributes most to the system losses.

2.1.1 Distribution Line Loss

Distribution line loss is the result of electricity being converted to heat due to the resistance of the conductor of which the current flow through. Flow through the conductor results in a pressure drop which is in direct proportion to the flow. The energy lost is equal to the product of the pressure drop and the flow which gives rise to the energy lost being proportional to the square of the flow.

2.1.2 Electricity Losses in Sri Lanka

Electricity losses in the system especially in the distribution sector have prevailed at a high margin over the past decades and much concern has not been paid on same. Energy crisis which was faced by CEB over the last few years has led it to come across with new strategies to overcome the heavy energy losses in their system and to gain the ultimate financial saving. [1] As a result during the year 2008, CEB managed to reduce system energy losses to 14.99%. [2] This is nearly 1% reduction compared with the previous year. Effort of the distribution sector has contributed this improvement in a large proportion.

Variation of the overall electricity losses in Sri Lanka over the past years is shown in Figure 2.1.

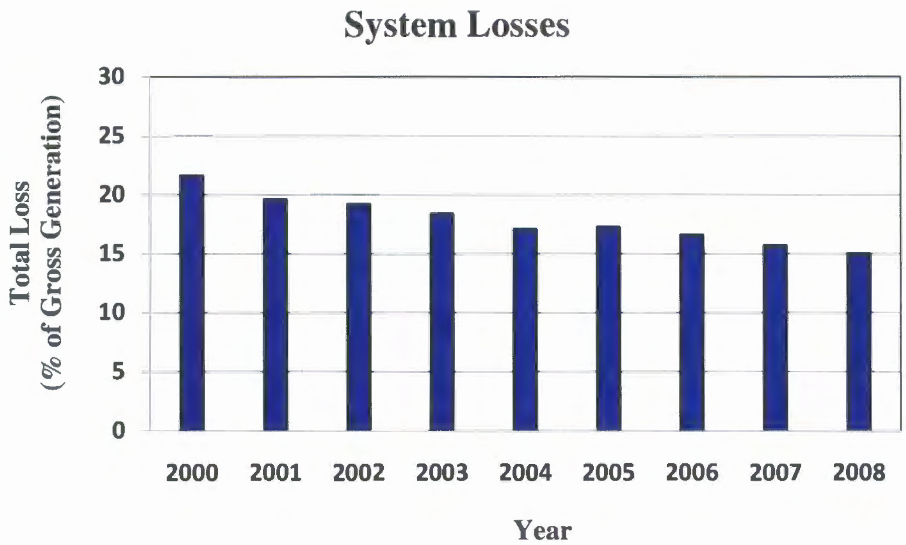

Figure 2.1 _ System Losses

Composition of overall losses for year 2008 is shown in Figure 2.2.

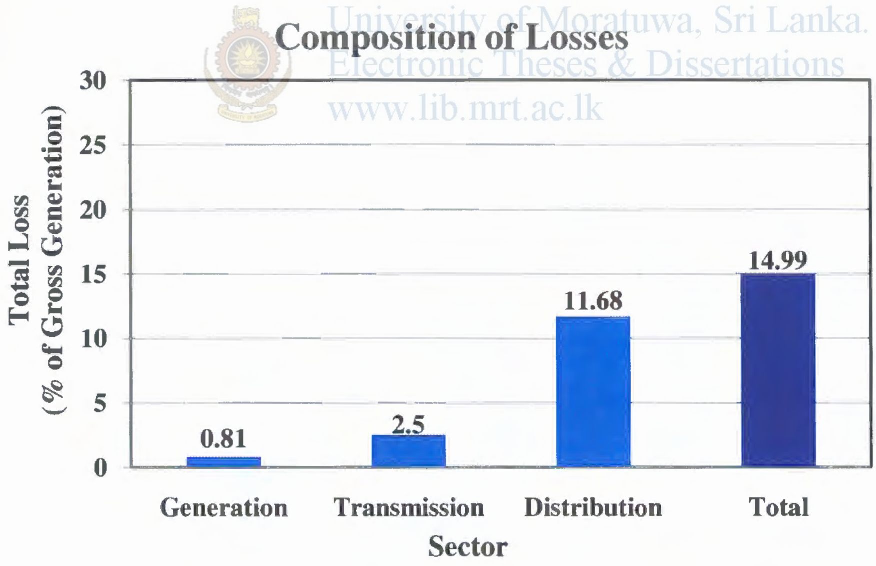

Figure 2.2 _ Composition of Losses in 2008

2.2 Embedded Generation

2.2.1 Modern Power Systems

Setup of modern electrical power systems having conventional arrangement consists of large central generating plants, a high voltage transmission network and a medium voltage distribution network.

Large central generators feed electrical power to high voltage transmission network through step-up transformers. Power is transported by the transmission network of which the transmission lines are extended over large distances to cover the locality of the power system concerned. Power is then extracted by the distribution network through step down transformers. Thereby it is distributed to low voltage network from the medium voltage network through distribution transformers. Delivery of power to ordinary consumers is at this low voltage level. Conversely, delivery could be directly at the distribution transformer or at MV level for bulk consumers.

Recently there has been a considerable revival in interest in connecting generation to the distribution network and it is known as Embedded or Dispersed Generation.

2.2.2 Definition of Embedded Generation

A generator or an electricity generation scheme which is electrically connected and intended to operate in a distribution network is classed as Embedded Generation (EG). Such schemes may also be referred to as 'Distributed Generators'. This mode of operation is sometimes described as "mains paralleling", since it involves operation of the generator in parallel with the mains electricity supply. [3]

2.2.3 Features of Embedded Generation

EG schemes remarkably differ from the central generating schemes by means of its size, connection, nature of operation etc. Several such features are,

- EG is not centrally planned by the utility. Implementation of an EG scheme is not a content of the scope of generation planning of the utility.
- EG schemes are not involved for the dispatch of power system. It can operate in the power system as long as the technical requirements for connection of the EG is fulfilled.
- Operation of the EG is affected by the reliability of the distribution network. Any supply outage of the upstream of the distribution network will restrict the

operation of the EG. In contrast islanded operation is possible (EG operate independently in a segment of the isolated distribution network) however due to the technical and safety constraints it is not usually employed in utilities.

- Maximum capacity of a single EG unit is to be lower than 10 MW (for Sri Lankan utility).
- Embedded Generators are scattered within the whole distribution system closer to the source of generation. i.e. hydro, wind, biomass etc.

2.2.4 Connection of Embedded Generators

Connection of an EG scheme to the distribution network requires fulfillment of various physical and contractual arrangements with the utility. Physical arrangements consist of construction of overhead lines, lay down of UG cables, installation of control, protection & metering equipment, switchgear & transformers etc.

The physical infrastructure which connects an embedded generator to a distribution network can be categorized into two sections as the infrastructure that owned by the developer, and that owned by the utility. Ownership boundary or the point of supply is the interface between these two parts.

The developer has sole responsibility for the design, installation and operation of the equipment on its own side of this interface, although the utility will want to assure itself that this equipment does not pose a hazard to their distribution network. [3]

Contractual arrangements are necessary between the developer & utility for power purchase.

Connection arrangement of an EG scheme to the distribution network could be either directly to the distributor or indirectly via a privately owned network (Figure2.3). In the first type energy is directly exported to the distribution network and in the other type, EG is used to offset some of the consumption associated with electricity demand of the same site. However this is facilitated to export excess energy for consumption to the distribution network.

First type is more widespread and commercially operated for electricity generation in Sri Lanka.

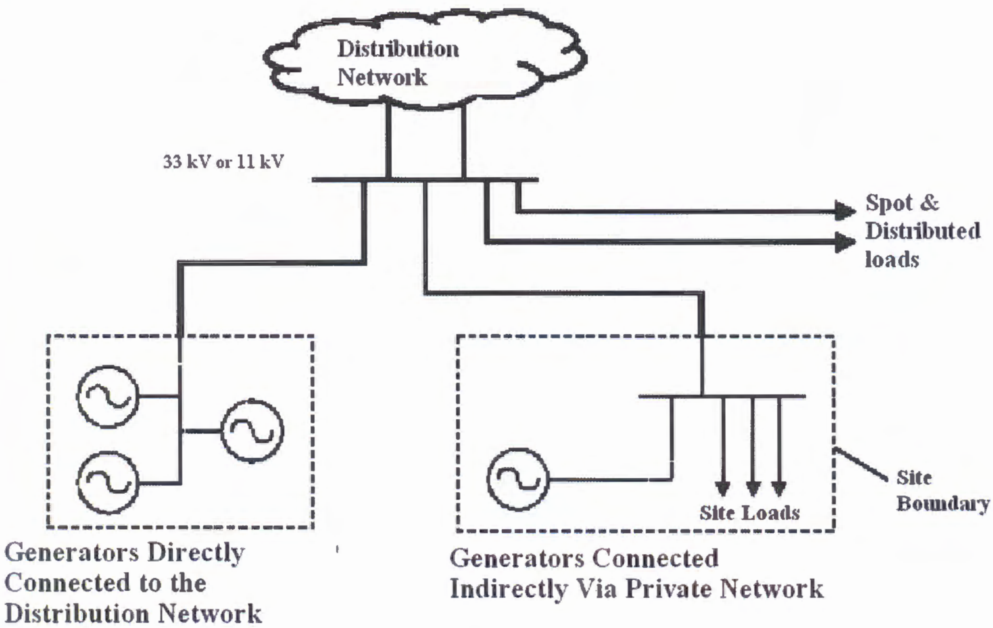

Figure 2.3_ Connection of EG plants to the Distribution Network

2.2.5 Comparison over Central Generation

Inclusion of EG in a distribution network could offer many advantages and several drawbacks to a conventionally arranged modern large power system. In a modern power system large generating units are available and those could be centrally operated with a relatively small number of people. The interconnected HV transmission network allows generator reserve requirements to be minimized and the most efficient generating plant to be dispatched at any time and bulk power can be transported large distances with limited electrical losses. The distribution networks can be designed for unidirectional power flows and sized to accommodate customer loads only.[4] With the inclusion of EG in the distribution network its impact has to be assessed and necessary alterations have to be made to suit the operation of EG scheme.

Presence of EG in a power system attribute for several advantages and those have become vital concerns and encouragements for development of EG.

- Higher proportion of the overall EG is by using renewable sources of energy. Run-off-river power plants and wind power plants are the most popular types of EG observed at present. As these power plants makes a considerable contribution to meet the electricity demand in a utility, it will replace certain proportion of thermal energy thus will result in reduction in greenhouse gaseous emissions.

- Deregulation and a competitive environment for electricity generation will result due to EG. It is helpful to meet the future power demand in a considerably, even if the major projects are delayed. Therefore it is a vital role for ensuring the availability of supply without causing major outages.
- Diversification of energy sources.
- Energy efficiency or rational use of energy.

2.2.6 Types of Embedded Generation Plants

The EG plants are in several types. Most popular types are,

- Hydro Energy (Small Hydro)
- Wind Energy
- Biomass (Dendro & Paddy husk) Energy
- Agricultural & Industrial Waste Energy
- Municipal Waste Energy
- Waste Heat Recovery Energy
- Wave Energy
- Solar Energy

Each type consists of technologies developed uniquely for the type, different features of operation and various degrees of reliability.

2.2.7 Impact of Embedded Generation on the Distribution system

Presence of EG in a distribution network has several technical impacts which have to be considered when connecting to the distribution network.

Power flow

Unidirectional power flow of a power system from transmission network to the end loads of the distribution network is altered due to the presence of EG. Reverse power flow from the distribution network to the transmission network could occur in case of considerable capacity of EG being available in lightly loaded condition of the distribution network.

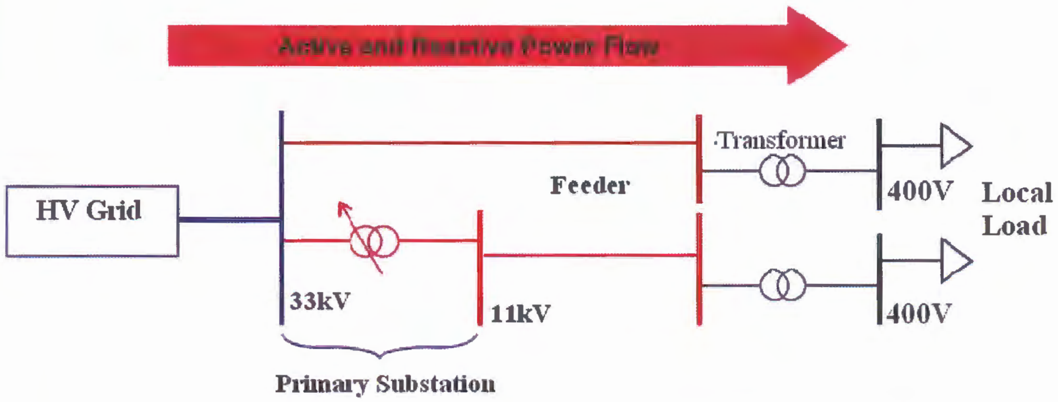

Figure 2.4_ Unidirectional Power flow without presence of EG

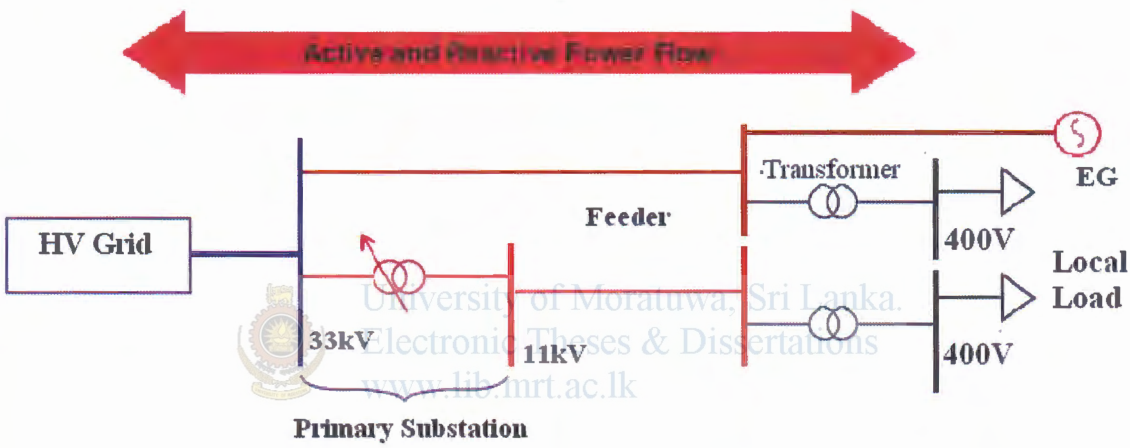

Figure 2.5_ Bidirectional Power flow due to presence of EG

When the embedded generators export more than enough power to supply all the loads on the system to which it is connected, the surplus power is transferred back through the power transformer, and is fed into a HV system. This is a concern where suitable bidirectional metering & protection devices should be made available in the system for reliable operation.

Fault Level

Most EG plants use rotating machines and these will contribute to the network fault levels. Both induction and synchronous generators will increase the fault level of the distribution system although their behavior under sustained fault conditions differs. [4]

Change in the fault level is a vital concern for the connection of an EG plant into the distribution network. In case it exceeds the available switchgear capacities, these have to be augmented in order to accommodate the EG plant. It is an expensive task which presently has to be borne by the developer of the EG plant. In contrast several other factors for limiting the fault level contribution of an EG plant to the network are available such as introduction of an impedance or transformer for the interconnection line. Due to the reasons of increased losses and voltage variations it is generally not employed.

According to the nature of the availability of resources for EG, the plants are generally located collectively in selected areas. Therefore connection of these plants to the utility will be at the same locality of the distribution network hence inadequacy of switchgear capacity in the substation concerned will occur.

Voltage Level

Load end voltage of radial distribution network has to be maintained within the nominal range such that the consumers will receive the supply at the required standard. Therefore the utility has an obligation to supply its consumers the voltage within its specified limits. Design and utilization of the network thus should be to have an optimal voltage profile throughout.

Presence of the EG plants are generally at the center or load ends of the distribution network hence causes a voltage boost at the load end. Accommodation of the EG plant in the system is subject to maintaining the system voltage profile within its specified limits. i.e. the voltage at any of the point in the network should not exceed the maximum allowable voltage in case of lightly loaded situations.

Variation of the voltage in the system with the presence of EG plant should be as shown in Figure 2.6 shown below.

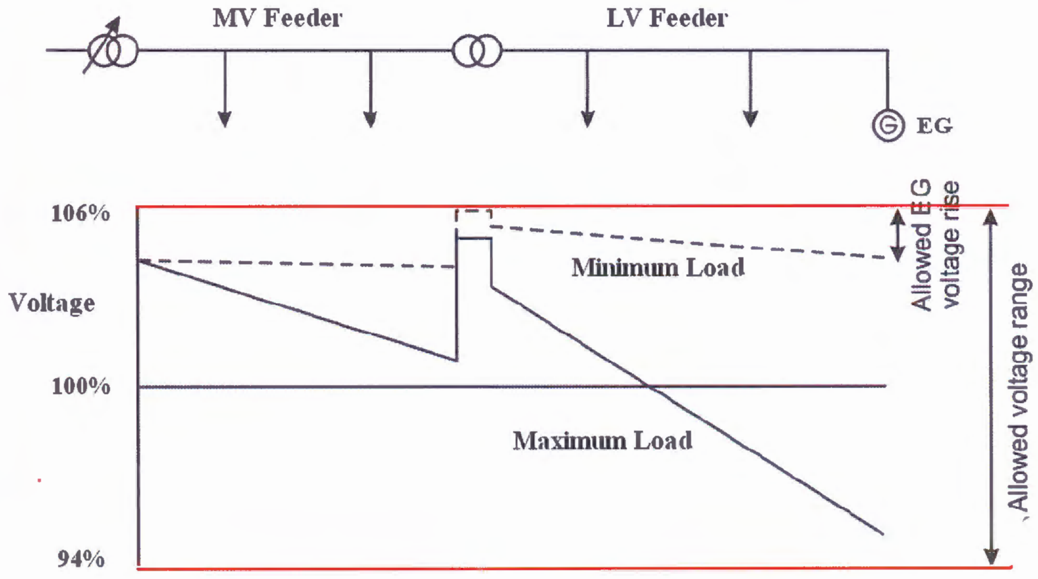

Figure 2.6_ Voltage Variation in Distribution Network due to EG

Protection

Connection of EG in to a distribution network can affect the existing network by providing flows of fault current which was not expected when the protection was originally designed. Therefore protection of the system and the EG plant is a vital consideration for EG connection. Impact of the EG for distribution system protection should be addressed from the aspects of [5]

- Protection of the generation equipment from internal faults.
- Protection of the faulted distribution network from fault currents supplied by the embedded generator.
- Loss of main protection to avoid islanded operation.

Power Quality

It is obvious that the EG causes improvement in end voltage of radial MV distribution networks. It is subjected to retention of the voltage within the specified limits at any instance. Therefore, in many situations embedded generation can improve network power quality as it can raise voltages at the remote ends of long feeders. Concerned on the fault level of the system, as the distribution fault level is raised due to EG, disturbances caused by customer loads, or even remote faults, will result in smaller voltage variation, improving power quality. More often above causes an improvement of power quality in the distribution network. However, embedded generation can also be detrimental to network power quality through: [6]

• Transient voltages
• Harmonic distortion
• Voltage Flicker
• Voltage Unbalance

Due to the connection and disconnection of EG plants there can be changes in the current in large amounts hence could cause transient voltage variations in the network. This is a vital concern with regard to the operation of the plants. Current transients can be limited by careful design of the generation plant. Earlier it was described that the voltage change is a key concern for the connection of an EG plant. But this transient voltage rise is a much more important concern over that steady state voltage rise especially when connecting into a weak system.

Transient voltage rise could be overcome by correct synchronization for synchronous generators and anti-parallel soft start units for induction generators. Also the disconnection of the plant from the system when operating at its full load, could cause a sudden voltage drop. [7]

Some forms of prime mover (eg. Fixed speed wind turbines) may cause cyclic variations in the generator output current which can lead to so-called 'flicker' nuisance if not adequately controlled.[8]

Harmonics is also another effect which may cause due to the incorrect design and specification of the EG plant having power electronic interfaces to the network. Network voltage distortion may result due to the injection of harmonic currents by these devices.

Voltage unbalance is also a similar effect caused by induction generators. Voltage of rural MV networks is frequently unbalanced due to the connection of single phase loads. An induction generator has a very low impedance to unbalanced voltage sand will tend to draw large unbalanced currents hence balance the network voltages at the expense of increased currents in the generator and consequent heating. [9].

Stability

Generator transient stability is not of great significance to the EG schemes. If a fault occurs in the distribution network and depress the network voltage the EG plant may trip and will lose short period of generation. As the power is restored in the network it will start automatically.

In contrast, if an embedded generator is viewed as providing support for the power system then its transient stability becomes of considerable importance. Both voltage and angle stability may be significant depending on the circumstances.

Network Losses

Distribution losses of the MV lines, transformers etc. tend to differ with the connection of EG plants into the distribution network. It could not be a general assessment of whether a reduction or increase in network losses. It is time variant and depends upon the conductor type, load level, allocation of the EG plants and the extent of availability and the reliability of operation of the EG plants. In general EGs are connected to the load ends of radial distribution network and as the load is increased the quantum of network loss reduction will improve. For the interconnection of an EG plant, the utility at present does not make much concern on this fact limiting to use of conductor types with comparably less dissipation of losses. [10]

All the EG plants are offered with similar basics for connection and tariff for the operation without taking into consideration its location. As far as the utility is concerned it gains a hidden effect on network losses by the allocation of EG plants.

This fact will be dealt in detail in further chapters which is the scope of research of this project.

Network Planning

Integration of embedded generation into existing power networks requires planning procedures that consider the impact of the new generation on the system. The aim of the planning process is to minimize or avoid adverse effects arising from the connection of a particular generator and to achieve this in the most cost effective method possible. This has been considered to be a reasonable approach as the existing asset base owned by the utility represents a major historic financial investment based on the equipment providing service that was expected to extend to between thirty and fifty years. [11]

Achievement of these planning goals is necessary to,

- Sufficient continuous supply of electrical energy to all the consumers over wide geographical area at lowest possible cost at specified voltage & frequency
- Highest possible security & reliability of supply
- Most economic generation, transmission & distribution
- Optimum use of energy resources [11]

Achieving above objectives with consideration on EG plants may become difficult due to,

- Decision regarding choice of equipment have long term effect and equipment may become obsolete in less time
- Sources of energy for generation of electricity are scattered away from load centers
- Economic analysis have uncertainties regarding cost of fuel, escalation in capital cost of future projects, interest rates etc
- Planning decisions are influenced by load management techniques

It is obvious that implementation of proper planning decisions in an appropriate time frame is essential for healthy operation of a distribution system. In practice it is difficult to achieve this due to above mentioned difficulties as well as the considerable delays which occur in decision making, procurement and construction process of the planning proposals. Connection of EG into the system would restrict the adverse effect of this situation up to certain extent which ultimately benefit the utility and its consumers.

2.3 Embedded Generation Plants in Sri Lanka

2.3.1 History

Absorption of small scale embedded power plants into the power system of Sri Lanka was initiated as a result of the government's policy decision to encourage hydro generation to obtain optimum capacity of those using the available resources. Hydro electricity generation is the cheapest source of electricity compared to other electricity sources in the country. Due to the scarcity of fossil fuel and non-availability of nuclear plants, forecasted demand growth of the electricity could be supplied at an economical rate only upon optimum utilization of hydro resources.

Therefore government directed the utility CEB to develop the hydro power generation potential of the country to its full potential as it is the major indigenous resource for power generation at present. Under this policy, all large-scale hydropower generation facilities were to remain under government control for the foreseeable future. Private sector financing was sought to be utilized for power generation from small hydro power plants.

Thus CEB promoted generation of electricity using Renewable Energy Resources since early nineties by giving the required assistance to the private sector, which included training & capacity building, pre feasibility studies and resource assessments. This was offered to all sources of embedded power plants of capacity less than 10 MW. [12]

2.3.2. Energy contribution to the system

Analysis of past energy data together with the gross energy generation figures out that the role of EG plants is vital quantitatively. Moreover hidden value is vital as most of the EG energy is generated by environmentally friendly renewable energy sources.

Growth of the EG energy contribution to CEB system in comparison to its gross energy generation for the past years are as in Table 2.1 below.

Year	Gross Generation of CEB (GWh)	EG Energy (GWh)	% Contribution of EG
2000	6686	43.3	0.6
2001	6520	64.8	1.0
2002	6954	103.5	1.5
2003	7612	120.3	1.6
2004	8043	206	2.6
2005	8769	280	3.2
2006	9389	346	3.7
2007	9814	344	3.5
2008	9901	433	4.4

Table 2.1_ Gross Energy Generation in Sri Lanka & Contribution by EG

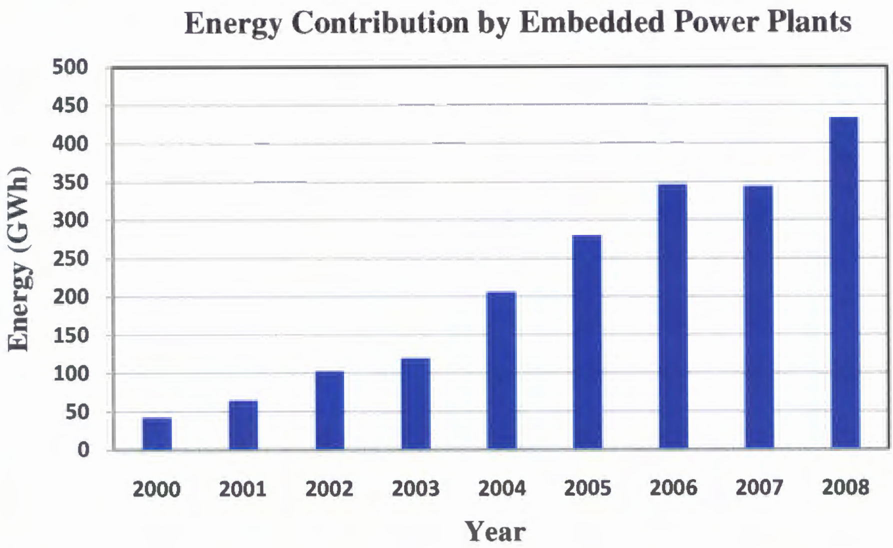

Figure 2.7_ Energy Contribution to the System by EG Plants

2.3.3 Applicable tariff

The procedure for electricity purchases from small power producers (MHPs) by the CEB was regularized from 1997 with the publication of a standardized power purchase agreement (SPPA) which included a scheme for calculating the purchase price based on the avoided cost principle.

Avoided Cost Tariff

Avoided cost is the incremental cost to the electric utility that the utility would either generate itself or purchase from thermal IPPs if it did not purchase from a renewable energy producer.[12] Whenever a renewable generating plant or any other EG plant is connected to the system total quantity of energy contributed by it to the system is equal to the saving of a mass generating plant which would have generated the same quantity of energy. Thus cost on fuel and other operations is saved. Avoided cost pricing has been composed on that basis and methodology is based on the principle of short run marginal cost pricing.

The avoided cost tariff which was offered by CEB since the inception of EG plants is mentioned in annexure I (1). In the pricing, dry season tariff is higher because the EG then replaces the thermal plants of higher generation cost instead of the mass hydro plants.

Three-tier Tariff

The government later identified the development of renewable energy projects, as a matter of policy to diversify the electricity sector from high cost thermal power generation. Therefore, required incentives and assistance was provided for the renewable energy resource development. Further, National Energy Policy 2006 has identified fuel diversification and energy security in electricity generation as a strategic objective and development of renewable energy projects was identified as a part of this strategy. In view of above, action has been taken to introduce a cost based, technology specific, three-tier tariff instead of avoided cost based tariff with effect from year 2007. [12]

This tariff is designed based on cost of an embedded power plant project. Through this tariff the developer of EG plant can decide and ensure that he receives the expected return on investment and covers the capital & operational cost of the power project. Moreover, the tariff estimation by this method solely depends on the cost and performance of the project

3-tier tariff which is applicable in the present context is mentioned in annexure I (2).

Flat Tariff

Flat Tariff is another optional tariff scheme which could be applied for EG Plants. The prices are non-escalable and no variable cost of O&M included. The EG project developers can use this tariff option as alternative to the 3-tier tariff scheme. The applicable rates are given in annexure I (3).

2.3.4 Available Plants & Future Additions

According to the current statistics 7% of the total installed capacity of the Sri Lanka's power system (including all IPPs) is from Embedded Power Projects. Majority of this quantum is granted by the small hydro power plants which are scattered mainly in the Sabaragamuwa, Uva & Central provinces. The plants which are located in the wet zone of the country accounts for continuous and considerable amount of energy contribution to the national grid. In these plants, plant factor is retained above 40%.

Several other types of EG plants including utility owned wind power projects are in operation.

Details of the number of commissioned private owned plants together with its capacity are mentioned in Table 2.2.

Type	No. of Plants	Total Installed Capacity (MW)
Mini Hydro Power	81	170.36
Biomass-Dendro Power	1	1.00
Biomass-Agri. & Ind. Waste Power	2	11.00
Waste Heat Recovery Power	1	0.10
Solar Power	1	0.02
Total	**86**	**182.48**

Table 2.2_Quantity of Commissioned EG plants in Sri Lanka

Potential of small hydro capacity of which the resources still have not been utilized is considerable. Through the new trends and the technological improvements, all this capacity would be absorbed into the system in future. Also, feasibility for many other sources of renewable energy available in the country has been studied. Another significant potential would be added from these as well. Future projects of EG addition to the system (for which permits have already been issued) are as in Table 2.3.[15]

Type	No. of Plants	Total Capacity (MW)
Mini Hydro Power	40	102.00
Wind	2	20.00
Biomass-Dendro	1	0.27
Total	**43**	**122.27**

Table 2.3_Quantity of Proposed EG plants in Sri Lanka

Therefore, it could be predicted that the total amount of EG capacity in the system would reach to around 10% of the total installed capacity in future.

Chapter 3

Network Analysis

3.1 Selection of a Network

EG has an impact on the power flow of the distribution system as briefed in chapter 2. Presence of EG causes an alteration in the conventional unidirectional power flow path. Accordingly presence of EG requires the protection & metering equipment, switchgear etc of the distribution system to be adjusted for the bidirectional power flow.

Connection of considerable quantity of EG capacity into the distribution network resulting variation in network losses is the basis for study. For the analysis of the network on the above mentioned aspect, it is necessary to select a distribution network which,

- Vitally shows sections for which network improvements are required to maintain supply standards.
- Distributed in a comparably large area so that the effect of distance & line length could be easily assessed.
- Comprises of sufficient amount of Embedded Generation potential in the area concerned.
- Having sufficient loads & load growth throughout.

A Feeder of Grid Substation Nuwara Eliya was selected in this regard which comprises most of the above features and study was based on it.

3.2 Estimation of Network Parameters

As an approach for the analysis, overall distribution losses of the feeders in the selected grid substation was determined. Based on the actual load data and the average load profile of year 2008, key parameters were determined which have a relationship with the feeder distribution losses. Peak & average demand (P_{av}, P_{max}) daily demand curves, Load factor *(e)*, Peak power loss (P_L). Utilization time of losses *(UTL)*, Annual energy loss (E_L) are the terms which were derived based on the average load profile of the feeders.

Average feeder demand of the feeders concerned on the data of all months in year 2008 are mentioned in annexure II and the Profile is as in Figure 3.1.

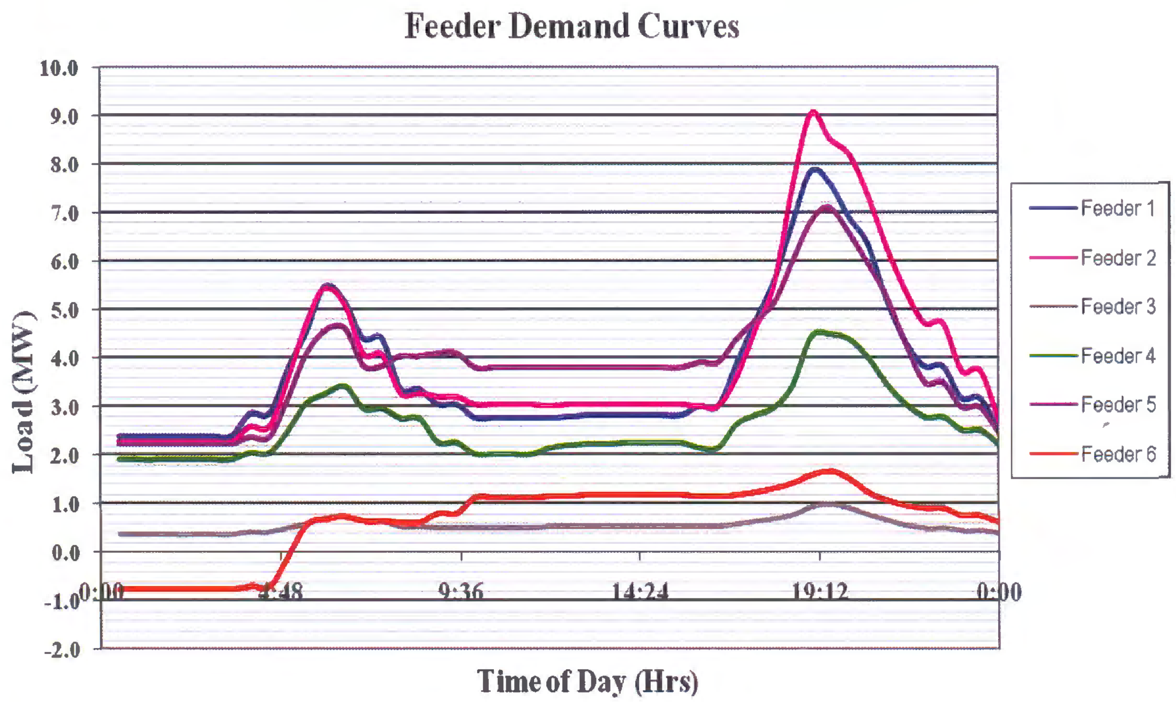

Figure 3.1_ Feeder Demand Curves of Nuwara Eliya GSS -2008

Following parameters were determined.

- Average Demand

$$P_{av} = \frac{1}{T}\int_{0}^{T} P(t)dt \qquad \text{(eqn.3.1)}$$

- Load Factor

$$e = \frac{P_{av}}{P_{\max}} = \frac{Sales}{P_{\max} * 8760} \qquad \text{(eqn.3.2)}$$

- Energy Delivered

$$E_{del} = P_{\max} * e * T \quad \text{kWh} \qquad \text{(eqn.3.3)}$$

- Utilization time of losses

$$UTL = \frac{e^2(2+e^2)*8760}{(1+2e)} \quad \text{hrs/year} \qquad \text{(eqn.3.4)}$$

- Energy Loss

$$EnergyLoss = P_L * UTL \quad \text{kWh/year [14]} \qquad \text{(eqn.3.5)}$$

Historic data of the feeder energy demand of year 2008 which was required for above calculation is mentioned in annexure III.

Result thus obtained using equations 3.1 – 3.5 for each of the 6 feeders separately are figured out in Table 3.1.

	Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5	Feeder 6
P_{av} (MW)	3.7	3.9	0.5	2.6	3.9	0.7
P_{max} (MW)	7.8	9.1	1.0	4.5	7.1	1.7
e (P_{av} / P_{max})	0.47	0.44	0.56	0.58	0.55	0.41
Annual Sales S (MWh)	31765	31490	4106	20106	32090	6649
e (S / P_{max} x 8760)	0.46	0.40	0.48	0.51	0.52	0.46
UTL (hrs./ Yr.)	2202.5	1800.8	2625.0	2848.7	2730.3	1931.9
P_L (MW)	0.207	0.452	0.002	0.051	0.222	0.004
Annual Energy Loss (MWh / Yr)	**455.9**	**814.0**	**5.2**	**145.3**	**606.1**	**7.7**
Total Annual En. Loss (MWh/Yr)	**2034**					

Table 3.1_ Results of Network Parameters

3.3 Radial Distribution Network

Radial distribution network consists of feeder sections which may be extending up to many kilometers. The loads connected to these branches may be either distributed or spot loads. When the distribution network covers a large geographical area, allocation of these loads may be at the far ends of the radial network, gathered within certain sections where the population and the availability of industrial loads are high. Therefore, distribution of the loads within the radial network is not uniform and a simplified network representing each section of the feeder by a branch including its loads was used. Each section was represented by the relevant available type of conductor and its length. Figure 3.2 shows simplified radial network of the feeder 1 of Nuwara Eliya GSS used for the analysis.

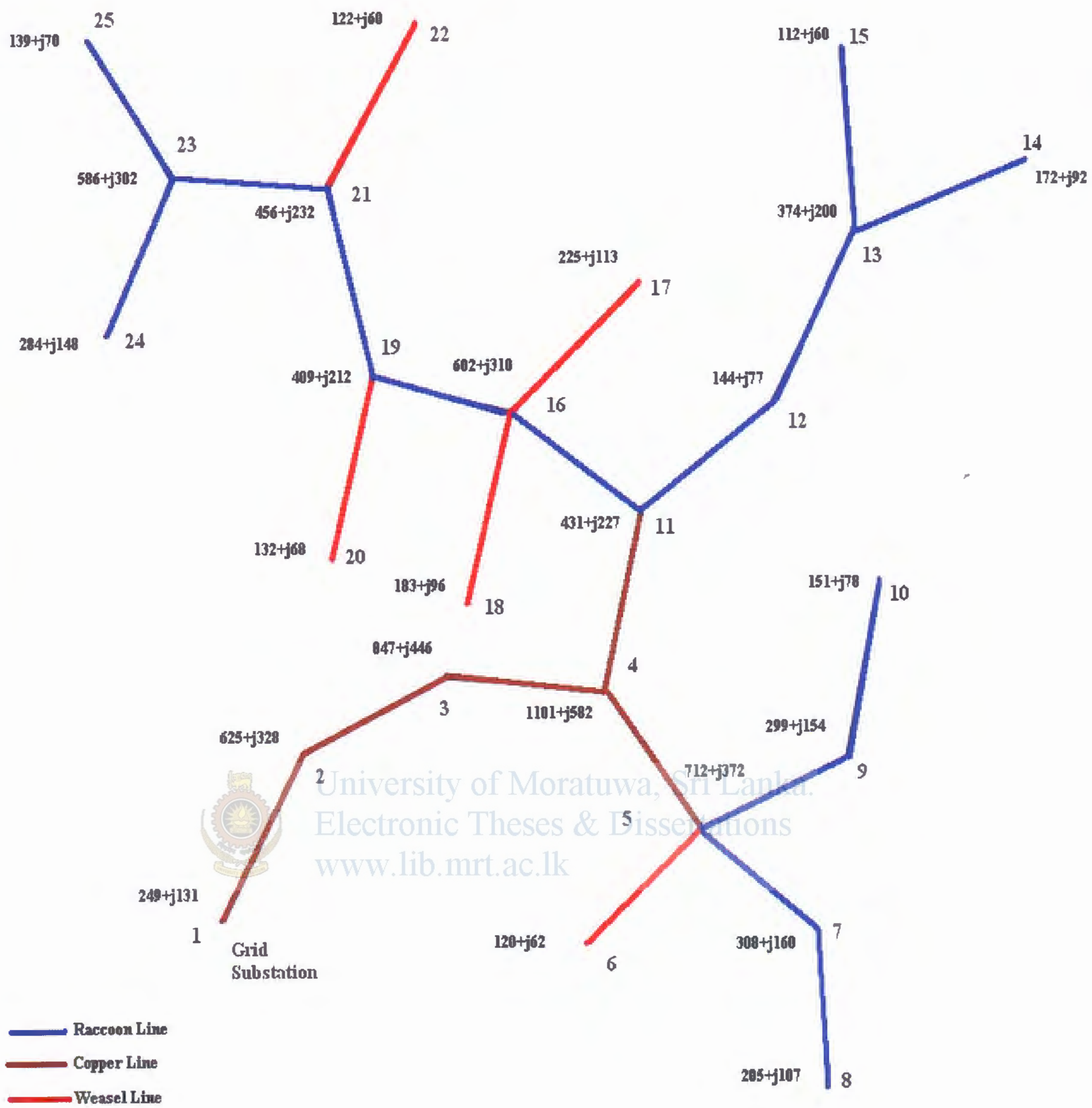

Figure 3.2_Radial network

For simplicity comparably shorter branches were considered to be of negligible length and the load connected to those were represented in the nearest connected branch. Feeding point of the feeder is the grid substation end. The voltage drop caused to the far end of the network is higher at this feeding point compared to the load center.

3.4 Load Center

Supply of load from load center of the network provides optimum voltage profile and minimum losses. Therefore, for any given radial network, load center is the optimal feeding point which results in minimum amount of distribution losses.

In the conventional feeding arrangements concern on this load center is generally not made. Cost considerations and addition of future loads being unpredictable, many practical difficulties are the major concerns for the deviation of feeding point from its load center in feeder design.

Impedance seen method was used in determination of load center of the feeder. Representation of each branch of the network with it's per unit impedance and all loads with its equivalent impedance was necessary. Branch impedance was calculated based on the type of conductor and approximate conductor length.

For the load impedance, load at each node was converted into its equivalent impedance assuming nominal voltage of 1 p.u. at each node, base capacity S_{base}=1000kVA and base Voltage V_{base} = 33 kV.

It was derived by,

$$S = VI^*$$

$$Z = V / I$$

$$S = P + jQ = \frac{V^2}{Z^*}$$

$$Z = \frac{V^2}{(P + jQ)^*}$$

$$\therefore z_p(i) = \frac{V^2}{[P(i) - jQ(i)]} \, p.u. \qquad \text{(eqn.3.6)}$$

where P(i) – Load Real Power at i^{th} node

Q(i) – Load Reactive Power at i^{th} node

V(i) – Voltage at i^{th} node

Z_P(i) – Load Impedance at i^{th} node

The simplified radial network consists of leaf nodes (branch end nodes). These leaf nodes were selected and its impedance was converted to its source node using following relationship. Node 1 was considered as the feeding point.

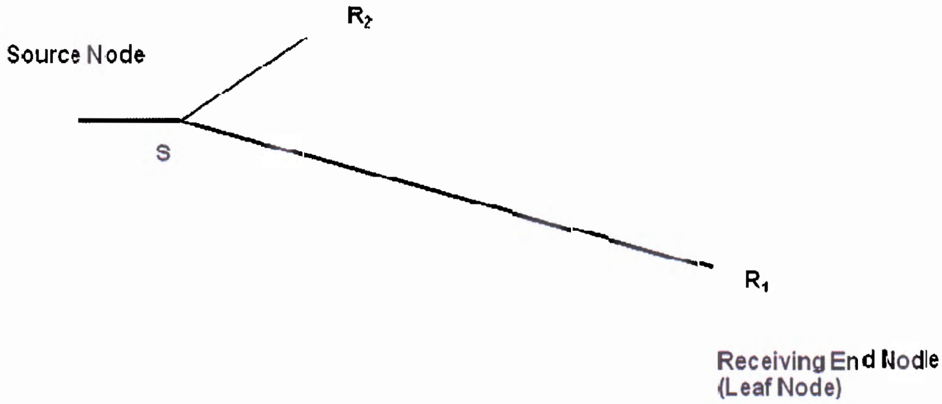

Figure 3.3_ Network Branch

$$Z_{PN}[S(j)] = \frac{Z_P[S(j)]\times\{Z(j)+Z_P[R(j)]\}}{\{Z_P[S(j)+Z(j)+Z_P[r(j)]\}} \qquad \text{(eqn.3.7)}$$

Where Z(j) – Branch p.u.impedance

$Z_p[S(j)]$ – Load p.u. Impedance at source node before updating

$Z_p[R(j)]$ – Load p.u. Impedance at end node

$Z_{PN}[S(j)]$ – Updated p.u. Impedance at source node

Upon completion of calculation for all the leaf nodes the network was simplified as in Figure 3.4 below.

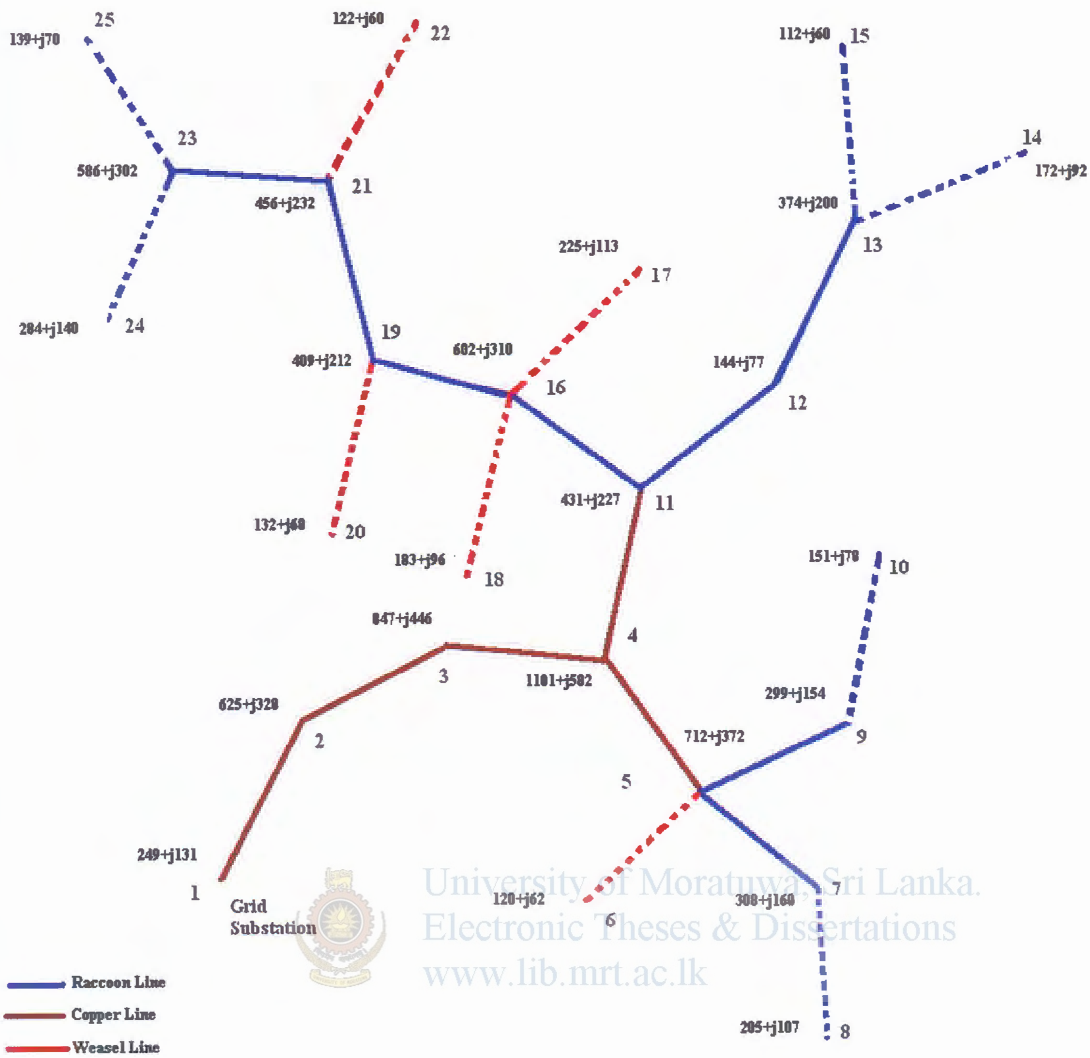

Figure 3.4 _Step 1 of simplified network

Nodes 7,9,13,23 have then become leaf nodes and the process was repeated to these and the calculation continued for the new leaf nodes in the simplified network. Finally the equivalent impedance as seen from node 1 was determined.

Similarly above process was repeated for all other nodes considering them as the feeding node at each step.

The node with least equivalent impedance is the load center.

Impedance (Ω)	Node Number
0.8 + j 0.41	4
1.0 + j 0.53	3
1.2 + j 0.63	5
1.4 + j 0.72	2
1.4 + j 0.74	16
1.5 + j 0.76	23
1.9 + j 0.97	21
2.0 + j 1.04	11
2.1 + j 1.09	19
2.3 + j 1.21	13
2.8 + j 1.45	7
2.9 + j 1.48	9
3.0 + j 1.57	24
3.4 + j 1.80	1
3.9 + j 1.94	17
4.2 + j 2.18	8
4.7 + j 2.45	18
4.9 + j 2.63	14
5.7 + j 2.94	10
5.9 + j 3.14	12
6.2 + j 3.15	25
6.5 + j 3.36	20
7.2 + j 3.53	22
7.2 + j 3.70	6
7.5 + j 4.04	15

Table 3.2 _ Impedances as Seen from Each Node of the Radial Network

Further studies and simulation will be based on above result which represent the main load center and the next 5 load centers. Main load center and the other load centers based on above result are shown in Figure 3.5.

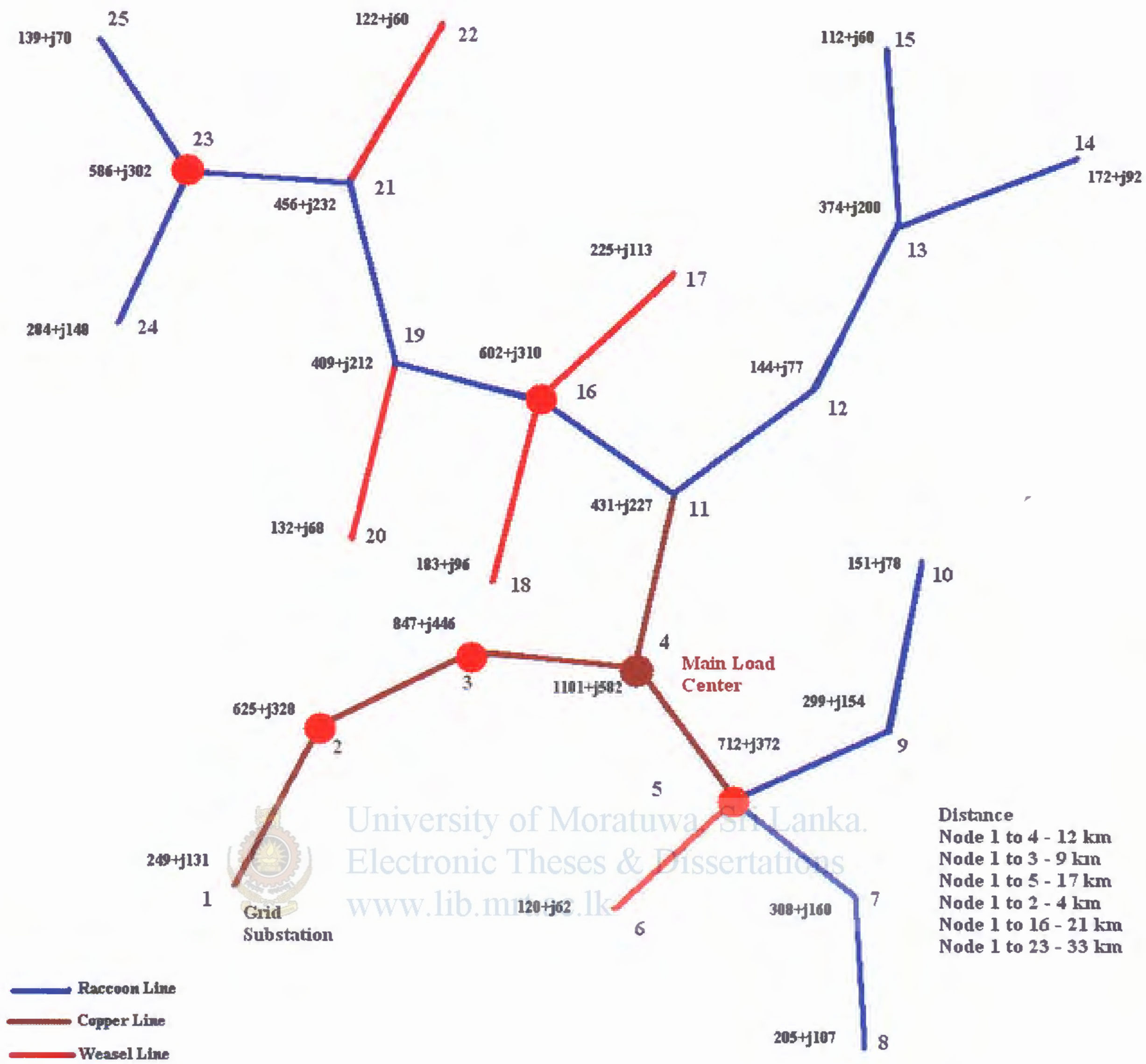

Figure 3.5 _Load Centers

It is expected to study the impact of EG on the system and the effectiveness of placement or making the common coupling of these plants to the main load center and other nodes.

Chapter 4

Power Flow Analysis

In order to study the effect of different placements of EG in the system, power flow studies were carried out. Objective is to identify the variation of the voltage profile and the line losses according to the Point of Common Coupling (PCC) of each of the EG plant. The nodes which are the main load centers of the radial network were already determined in chapter 3 and it will be utilized in the power flow analysis. Through the study on variation of losses with regard to placement of EG plants in the feeder, it is expected to quantitatively determine the saving of energy which could be utilized for planning of EG interconnections.

4.1 Case Study

It is mentioned that feeder1 of Nuwara Eliya GSS was selected for the analysis. Existing number of EG plants in the selected feeder is one and its capacity is 1.5 MW. It is observed that substantial potential of mini hydro power is available in the area of the feeder. It was identified that following mini hydro plants are proposed to be connected to feeder 1 at various locations.

Name of MHP	Capacity (MW)
Kurundugolla	5.0
Belihuloya	3.5
Ralatungoda Pallebowala	1.0
Manakola	2.5
Maliyadda	1.0
Karapalagama	2.5

Table 4.1_Proposed MHPs to Feeder 1

Locations of the above MHPs with regard to the simplified radial network of feeder 1 are as in the Figure 4.1 shown below.

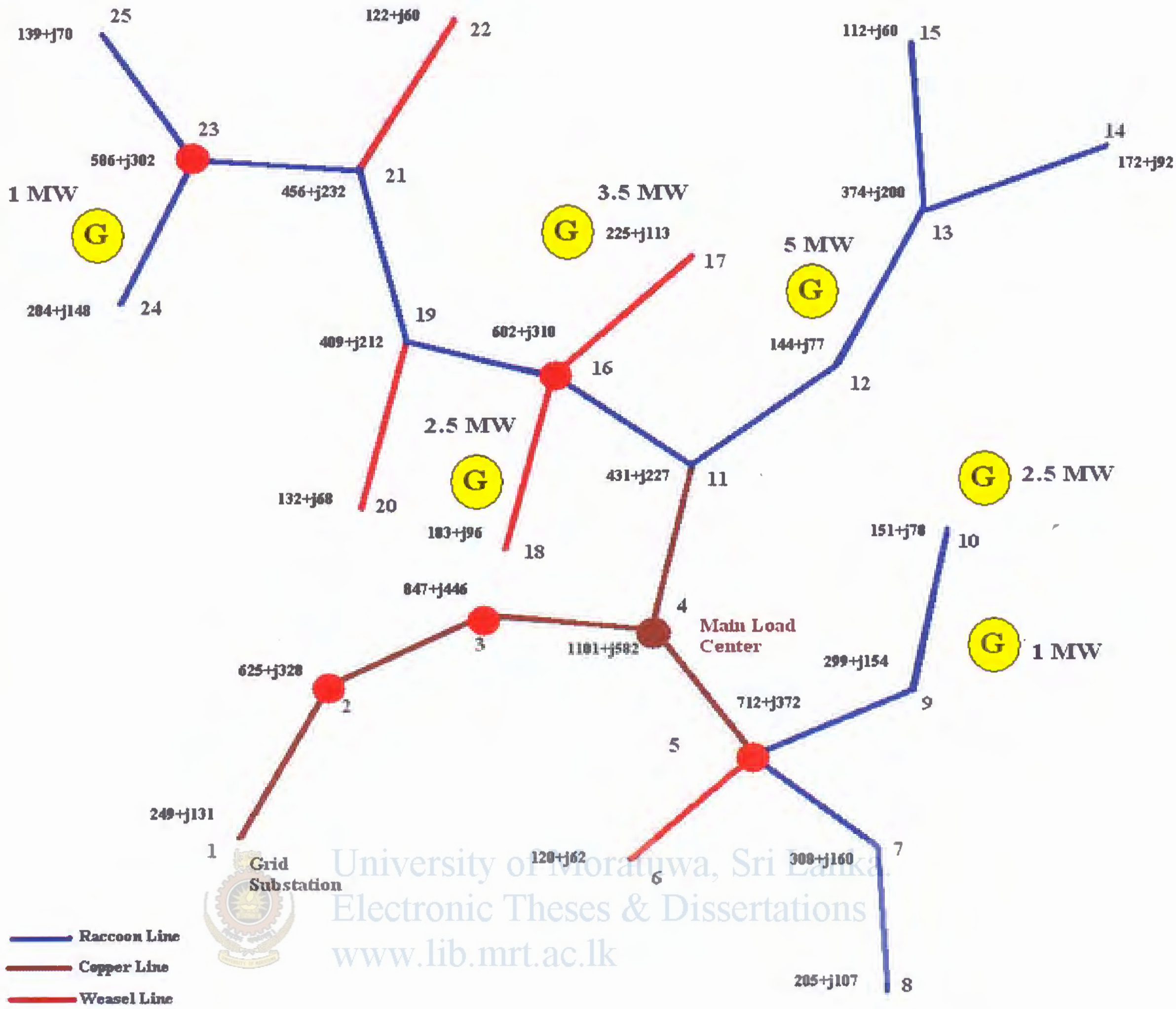

Fig 4.1_EG Potential in Feeder 1

Absorption of above capacity of EG into the system will make significant impact on the existing power flow patterns in the network. Therefore power flow analysis will be based on the presence of EG in the existing system. The analysis will be further extended to analyze the system for load growth and the future behavior of the network.

It is expected to extend this study on several possible connection arrangements for the load growth of a 20 year planning horizon. Variations of voltage and distribution losses are the main study areas.

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4.2 Planning Criteria

The planning criteria which is applicable to CEB for the network with overhead lines is as follows.

Conductor - ACSR (Raccoon, Lynx) on Tower, Lattice pole, Steel tubular, RC or Wooden poles

Voltage Regulation (%) - Within (+6%) or (-6%) of Nominal Voltage at the Point of Supply

Loading - Up to Max. 70% of thermal rating subject to voltage criteria

In each stage of the planning process with regard to the load growth, it was verified that the above parameters remain within the planning criteria.

4.3 Load Growth

In order to determine the variation of the system losses with regard to the load growth it was necessary to assess the growth rate of these loads. For this 'Time Trend Load Forecast Method' was used. In this method the pattern of historical load development is extended to predict the future load growth, [10]. Empirical relationship for this forecast is,

$$D = D_1(1+g)^{t-1} \qquad \text{(eqn. 4.1)}$$

Where D –Demand in t[th] year in GWh/year

t –Number of years

D_1 – Initial Demand in GWh/year

g – Growth rate

eqn. 4.1 gives,

$$\ln D = \ln(1+g)\times(t-1) + \ln D_1$$

This result in;

$$g = e^{m} - 1$$

Where m – Gradient of the linear curve of ln D Vs (t-1)

By analyzing historical demand data associated to the selected network, growth rate was obtained. Historical data for the selected feeder alone was not considered because changes in feeding arrangements from time to time would lead to misrepresentation of relevant historical demand data. Instead the whole network was considered assuming the fact that the feeder wise distribution of loads do not vary considerably. Analysis was carried out separately for industrial and other distribution loads.

4.3.1 Distributed Loads

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Demand (D_{Dis}) (GWh/Yr)	98.9	116.5	127	129.9	127	145.9	155.4	172.1	187.1	201.3

Table 4.2_ Historic demand Data of Distributed Loads

Historic data for 10 years since 1998 were considered thus year 1998 taken as t = 1. After calculating the relevant values graph shown in Figure 4.2 was resulted.

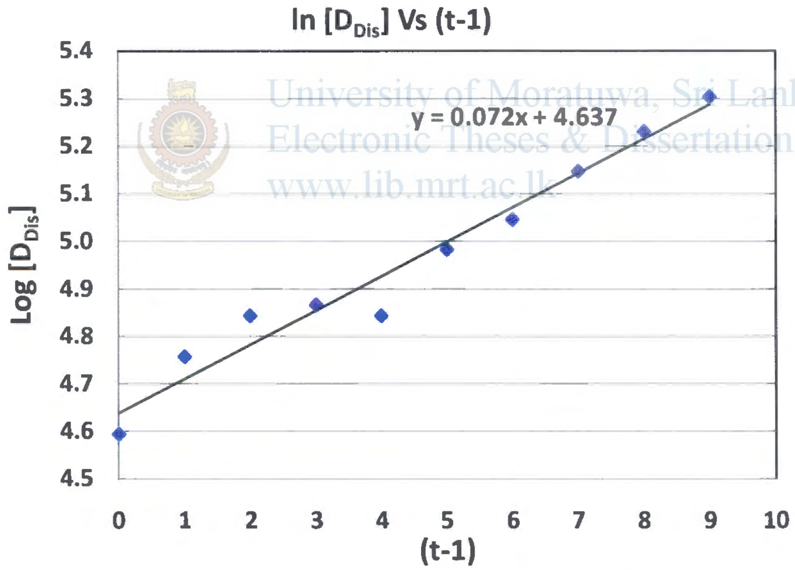


Figure 4.2_ ln [D_{Dis}] Vs (t-1) for distributed loads

Linear curve that best fits the data yields equation y = 0.072 x+4.637

Therefore,

Gradient m (Dis) = 0.072

Hence g (Dis) = $e^{.072}-1$

= 0.07466

Therefore, growth rate for distributed loads =7.5 %

Similarly the calculation was done for industrial loads too.

4.3.2 Industrial Loads

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Demand (D_{Ind}) (GWh/Yr)	82	82.3	82.5	86.1	85.4	88.9	88.1	93.4	92.8	91.2

Table 4.3_ Historic demand Data of Industrial Loads

For the above set of historic data graph shown in Figure 4.3 was resulted.

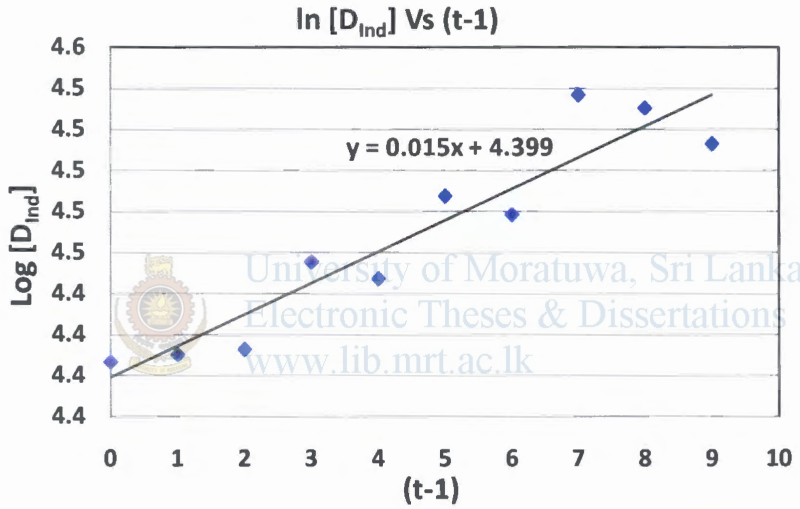


Figure 4.3_ ln [D_{Ind}] Vs (t-1) for industrial loads

Linear curve that best fits the data yields equation y = 0.015 x+4.399

Therefore,

Gradient m (Ind) = 0.015

Hence g (Ind) = $e^{.015}$-1

= 0.01511

Therefore, growth rate for industrial loads =1.5 % [14]

4.4 Use of Computer Software for Power Flow Analysis

Since the study is focused on analyzing the power flow and losses of existing distribution system for several cases, it is a requirement to use computer software for this purpose. According to the number of sections, loads etc involved in the network and due to existence of several cases for study, it could not be successfully completed through a simple load flow calculation technique. To avoid complications and perform the calculation in a quicker and accurate manner, suitable software was selected which is capable of successfully modeling and performing the activities of the power system in a user friendly manner.

4.4.1 About Syneree Software

SynerGEE Electric is a software package developed by Advantica Stoner, designed to aid in the simulation, analysis, and planning of power distribution feeders, networks, and substations. The package is a modular collection of tools built on a by-phase simulation engine. The simulation engine is based on an object-oriented design consisting of highly detailed models for power system devices such as lines, transformer banks, regulator banks, switched capacitors, active generators, and others. The models for these devices are built to reflect the actual construction of real power system equipment. Likewise, the usability and capability of SynerGEE demonstrate the level of commitment involved in producing quality analysis software.

SynerGEE allows quick construction of distribution system models.

These were the basic reasons to get this software for power flow simulation involved in the analysis.

A brief description on how the selected radial feeder is simulated in the program is given below.

4.4.2 Radial model loads

In a SynerGEE radial model, load models are placed in the center of the line portion of the section model. This is done for two reasons.

- Placing loads in the center of the section avoids ambiguity during switching. SynerGEE allows extensive switching actions. Since switches are placed at the ends of sections, load modeling at nodes would make it difficult to determine how loads would be fed during switching operations. The assignment of loads is clear with the loads in the center and the switches at the ends of sections.
- It can be shown that the modeling of a load in the center of the section more accurately simulates a distributed load with respect to voltage drop. Losses are also closely modeled in this manner. Studies and simulations show that the SynerGEE

approach to load placement and modeling is very well-suited for distribution system simulation.[13]

Each section may contain a by-phase spot and by-phase distributed load. Distributed load is generally calculated through load allocation analysis and does not necessarily represent the exact real-world load on each section. Spot loads, on the other hand, are considered to be known loads with metered demands. As such, they are not altered by SynerGEE load allocation. In the end, all distributed and spot loads combined should match the demands specified at the feeder or substation, a process handled by load allocation analysis.

Loads can only be entered into valid phases of a line section. It considers a line section containing conductors A, B, C and a neutral. Loads can be entered for phase A, B and phase C. If the load were connected line-line then only the 'phase AB' field could contain load. Both kW and kVAr values must be entered for loads. Entering only kW implies that the load has a power factor of 100%.

Only the load values for kW and kVAr are used during load-flow analysis. Values for kWh, kVA, and customers are not utilized during load-flow calculations. [9]

4.5 Simulation Study

Load, conductor and all other feeder data pertaining to feeder 1 of Nuwara Eliya GSS were gathered. These loads were then allocated to each branch in the radial distribution network. Feeder lengths and impedance values of the relevant conductors were also added. The program facilitates addition of generators with a user defined capacity and type.

In order to simulate the power flow pattern in the existing system it was required to determine the peak demand and the off peak demand of the feeder. Data pertaining to 2008 were gathered and the calculation of network parameters of average demand, peak demand, peak loss, load factor etc. were calculated in previous chapter. Using this calculation, peak and the average demand were determined. Off peak demand was found to be 44% of the peak demand of the feeder.

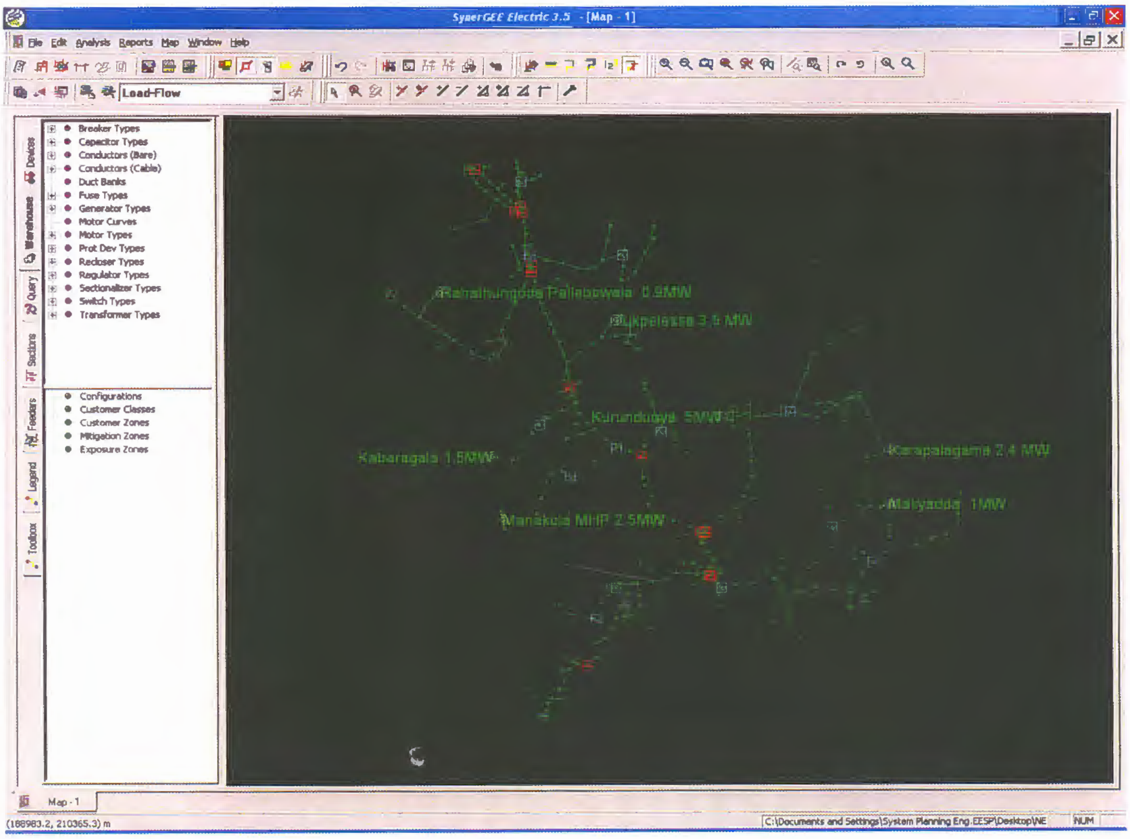


Figure 4.4_Synergee Model of analysis

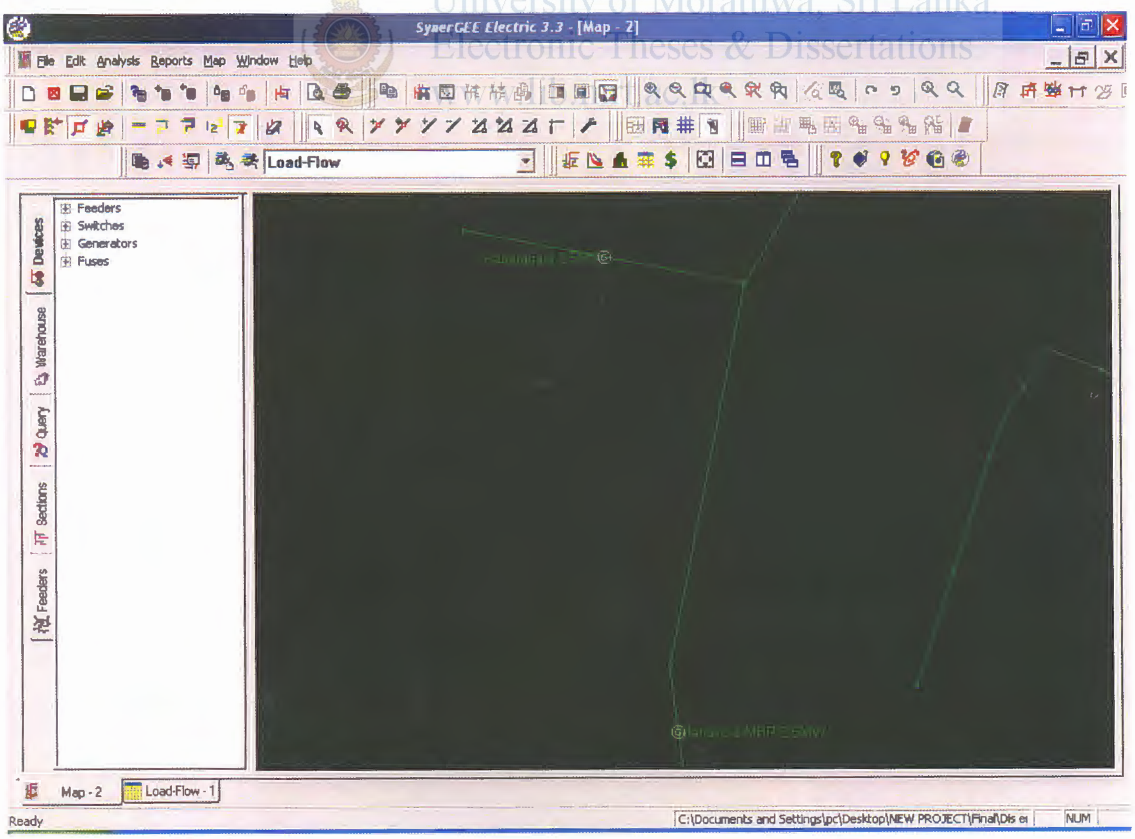


Figure 4.5_EGs included in the model

Also, it was necessary to determine the seasonal variation of the output of EG in that area. This variation is mainly caused by the changes in the rainfall patterns and it was assumed that the pattern is common for all the EG plants due to allocation in the same geographical area. In order to determine the variation of output patterns of EG, past data of 3 years were considered. (Annexure D). The % output pattern of the EG plants connected to Nuwara Eliya GSS (in all feeders) is shown in Figure 4.6.

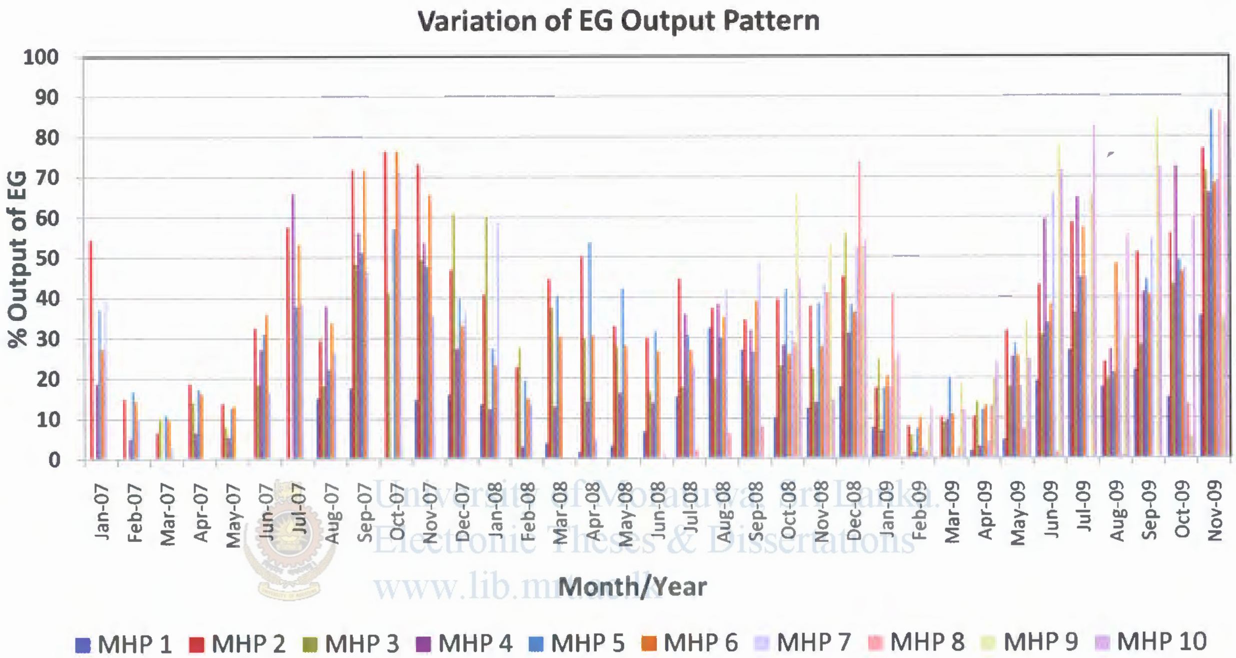


Fig. 4.6_Variation of EG plant output pattern

Using above, the variation of % output of proposed EG plants mentioned in above Table 4.1 was estimated and the result is as in Figure 4.7 given below.

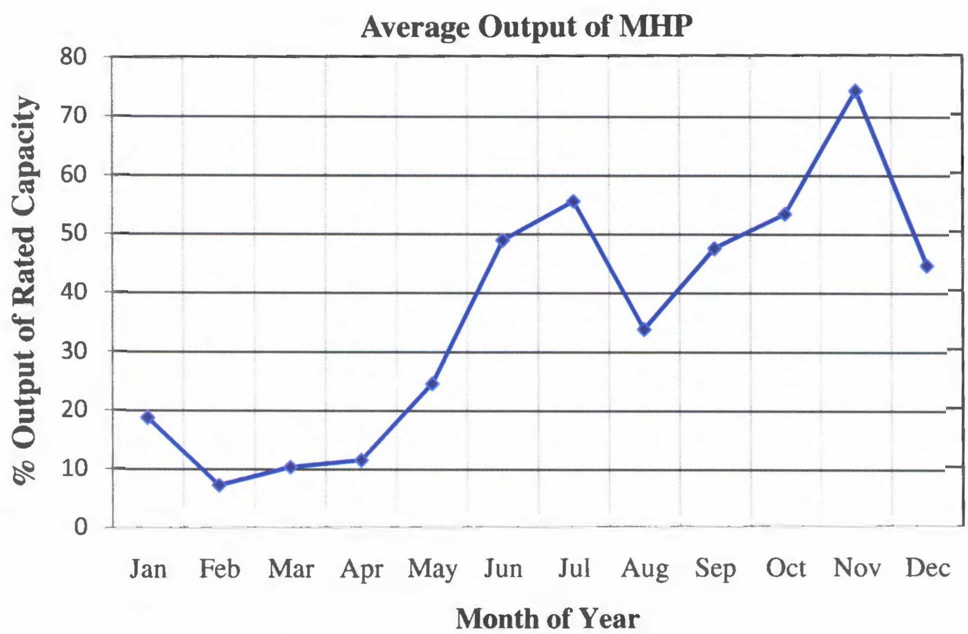
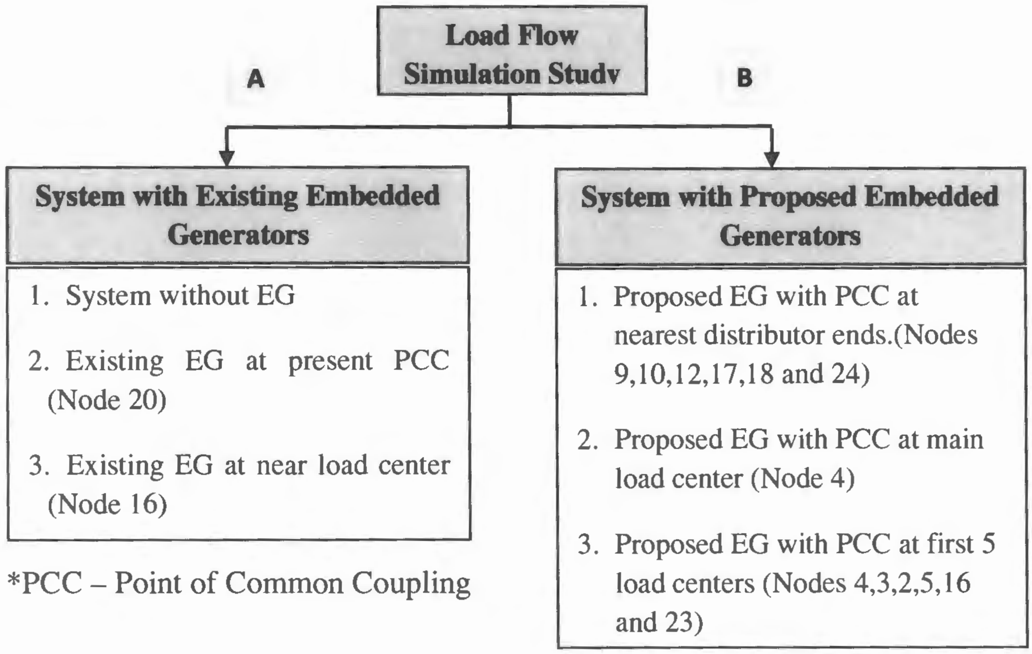


Fig. 4.7_Average output of MHP

Above values were considered in simulating the proposed system for further analysis. In the next stage simulation on load flow was performed to determine the feeder demand and the distribution loss for the system's operation during peak & off peak hours. Referred to the daily demand curve of feeder 1 (fig. 3.1) peak duration was assumed as 2 hours and off peak duration as 22 hours of the day. Objective of this analysis is to determine the variation of losses according to the addition & allocation of embedded generator. Hence load flow study was based on the following availabilities of EG on the system.



*PCC – Point of Common Coupling

Initially, the variation of voltage levels in the nodes of the radial network was studied for above states. By determining the voltage profiles this, it was studied that how the EG cause voltage improvement in the system to maintain it within standard range.

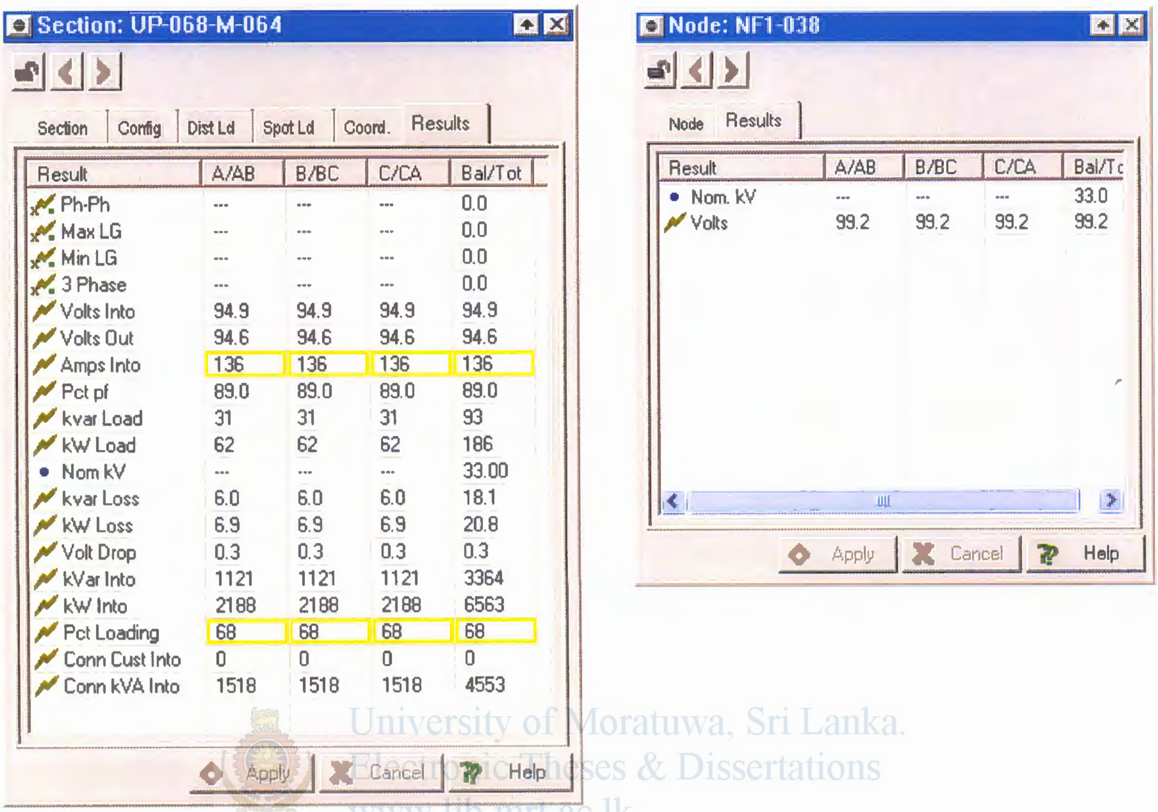


Figure 4.8_Two simulation outputs of voltage analysis

In load flow simulation, through the study on existing system on the above mentioned states in category A, it was expected to find out the impact of embedded generation on the existing conditions for minimization of system losses. Further, it was determined that to what extent CEB would have minimized its losses by making a simple change in the PCC.

With the findings of category A, simulation was carried out for category B. Through this it was expected to determine how the future addition of EG plants can be allocated in the system to optimize the loss reduction. By applying the load growth rate, the behavior of the power demand & losses was determined for the entire planning horizon of 10 years.

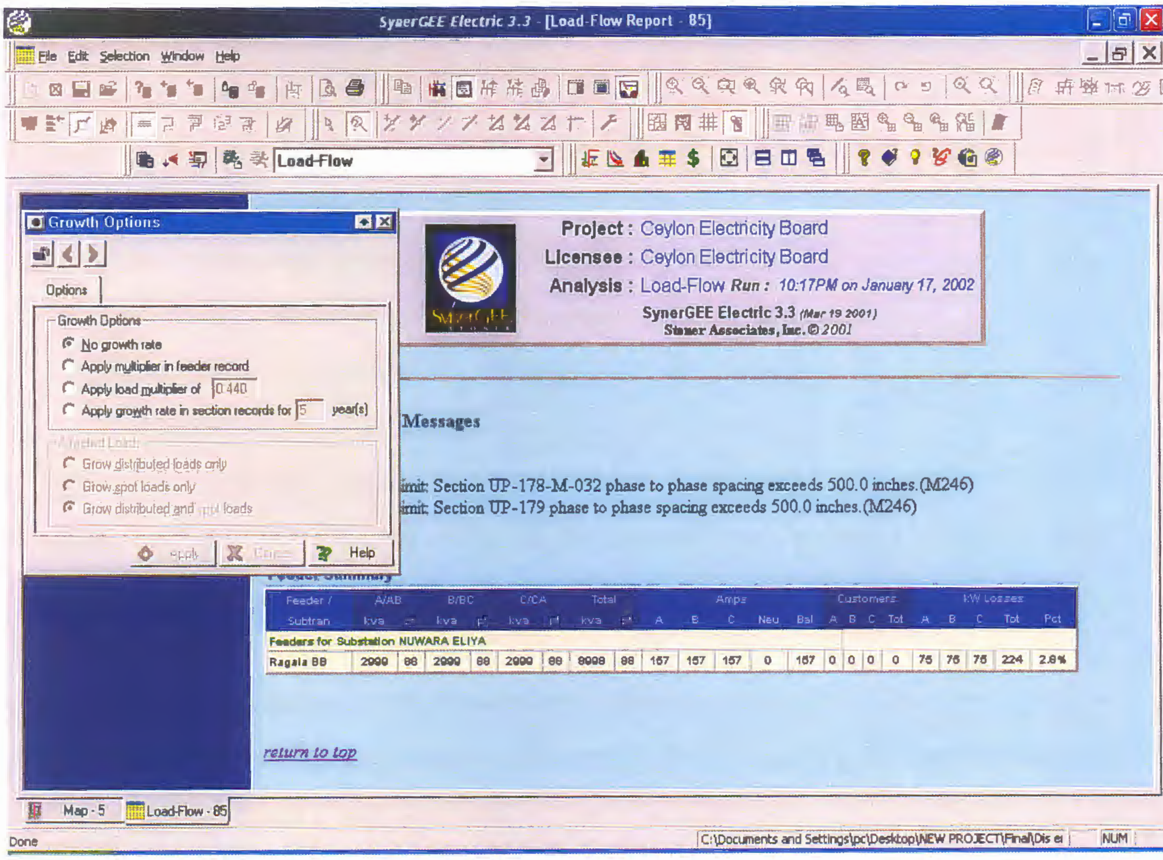


Figure 4.9_Simulation result for feeder power demand & losses

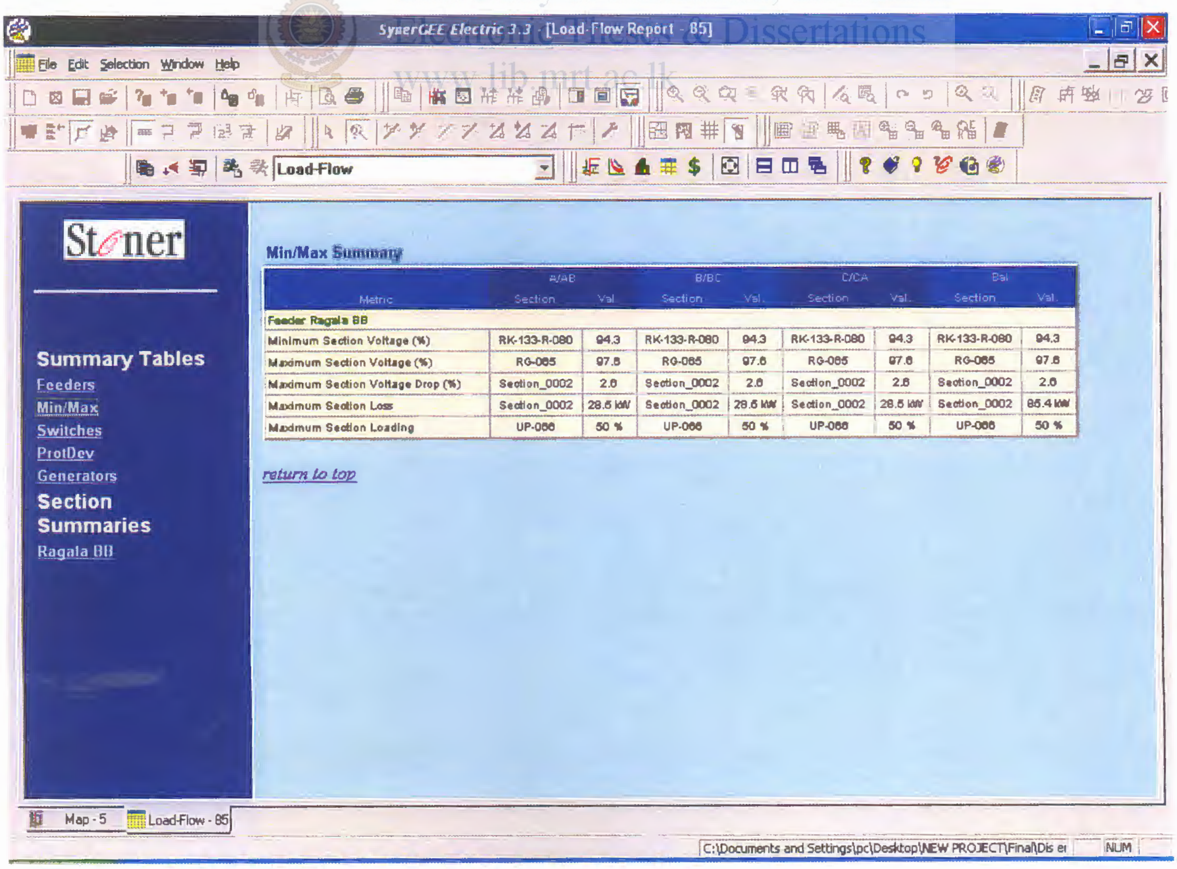


Figure 4.10_Simulation result for minimum & maximum values of the parameters

4.6 Calculations

4.6.1 Loss Reduction

This study was extended to calculate the losses at each state of above categories A & B and the reduction of losses. Simulation results were used for calculations.

Calculation of losses was considered for 3 factors.

1. Reduction in grid substation (transmission) energy demand
2. Reduction in distribution line losses
3. Reduction in grid transformer losses

Energy imported by the transmission network and the energy generated by the EG schemes have different 'values'. Cost of generation of a unit using central thermal generating plants is different from the cost of generation of an EG unit. Hence change in the transmission energy demand definitely has an impact on the cost of energy delivered to the consumers in the distribution network.

This energy difference was calculated considering the grid energy demand obtained in each case of simulation study.

Similarly distribution line loss reduction was obtained by the simulation results.

Transformer load losses are significantly affected by the current flow. The feeder current at grid substation changes according to the demand pattern. Since the EG causes changes in the grid substation demand the change in losses caused by same is calculated as follows.

Current through the transformer has a direct relationship to the load loss P by,

$$P \propto I^2$$

$$\therefore P = kI^2$$

Where k is a constant

Transformer which was subjected to the analysis has the specifications,

Power – 31.5 MVA

Voltage – 132/33 kV

load loss at rated current – 140 kW

$$S = \sqrt{3} V_L I_L$$

$$\therefore I_{rated} = \frac{31.5 \times 10^3}{\sqrt{3} \times 33}$$

$$I_{rated} = 551.1A$$

Applying this rated current in above equation,

$$P_{rated} = k \times I^2{}_{rated}$$

$$\therefore k = \frac{140 \times 10^3}{551.1^2}$$

$$k = 0.4609\Omega$$

Using this value the transformer loss in each case of simulation was determined.

4.6.2 Cost Analysis

According to the nature of the connection of EG plants it not only acts as another source of electricity but can potentially substitute for transmission facilities as well as probable reduction of losses in these networks. Therefore, apparently the units generated by an EG plant has a higher value than a unit generated at transmission level by central generating plant. [4]

In order to assess the cost benefit gained due to the EG schemes it is necessary to look into the existing & projected costs of generation of both above types.

The central generating system mainly consists of mass hydro power plants and thermal power plants. Larger proportion of the country's potential for mass hydro plants has already been absorbed in to the national grid. With regard to the increase in power demand high capacity thermal power plants which utilize HFO have been added to the system. These are mainly in the form of IPPs.

Total installed capacity of mass hydro power generation at present is 1345 MW while the same of thermal generation is 1285 MW. In a situation where the system maximum demand retains at a value of 1922 MW and the load factor at 58.6% and as the water levels of the reservoirs are not stable throughout, it is obvious that larger proportion of the demand is met by thermal generation. [2]

% Share of the total generation by source over the last few years is shown in Figure 4.11 below.

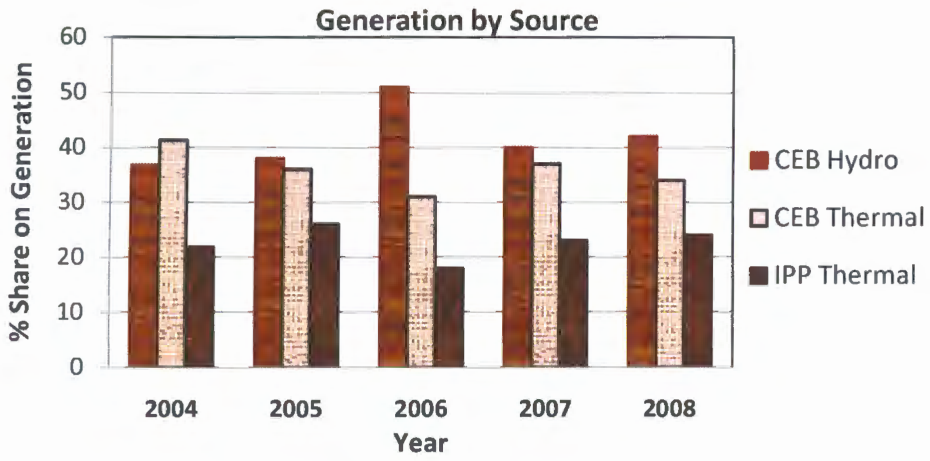
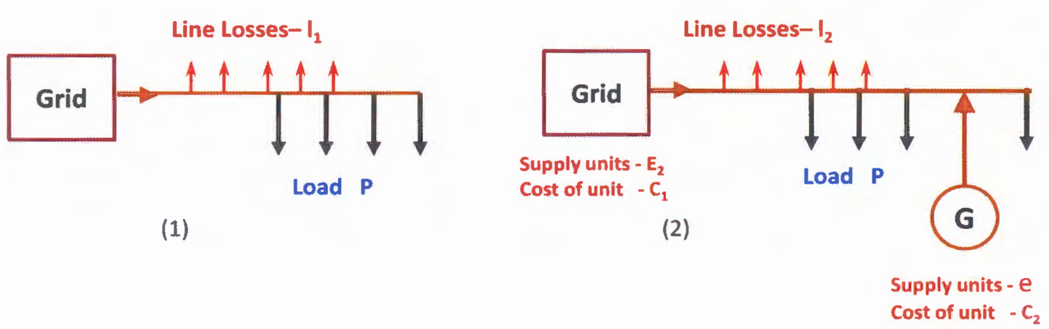


Figure 4.11_ Generation by Source

Estimation of the thermal unit cost for the planning horizon of next 10 years was done by regression analysis and the resulted values were used for calculation.

Cost of an embedded generation unit was determined by the existing 3 –tier tariff and it was predicted for 10 years using escalation rate of 5%.

With these unit cost values, the saving of cost on kWh unit was determined as illustrated below.



Energy demand for (1),

$$E_1 = P + l_1$$
$$Cost = E_1 C_1$$

Energy demand for (2),

$$E_2 + e = P + l_2$$
$$Cost = E_2 C_1 + eC_2$$

Therefore, $Saving = E_1C_1 - (E_2C_1 + eC_2)$

$$= (E_1 - E_2)C_1 - (E_1 - E_2 + l_2 - l_1)C_2$$
$$= (E_1 - E_2)(C_1 - C_2) + (l_1 - l_2)C_2$$

Ultimately, the cost benefit the utility could gain within the planning horizon by optimal placement of EG plants in the network was determined. Basis for the NPV & IRR calculation was the two states of (1) and (3) in the proposed systems(category B). It was found that maximum loss reduction could be gained in case (3) in category B. i.e. Connecting the EG Plants to the nearest load center out of the 5 load centers obtained by the calculation.

The method which is currently used by CEB for interconnection of the proposed EG plants is the case (1) of category B. i.e. connecting them to the nearest end of the distributor.

Therefore the additional cost which has to be borne for new line construction to connect the EG plants to the load centers and the saving gained by reduction of grid demand & losses were subjected to find the profitability of implementing such scheme.

For the network modification to bring the connection of EG plants to the nearest load center, in this case study following work content is required and the relevant cost as per the existing actual rates is mentioned in Table 4.4 below.

Construction	Detail	Length (km)	Total Cost (million LKR)
Lynx conductor line	Kurunduoya 5MW to node 4	15	51
Lynx conductor line	Karapalagama 2.4 MW to Node 3	17	57.8
Lynx conductor line	Maliyadda 1MW to Node 5	8	27.2
Lynx conductor line	Manakola 2.5 MW to Node 16	10	34
Lynx conductor line	Kabaragala 1.5MW to Node 19	5	17
Lynx conductor line	Illukpelessa 3.5 MW to Node 23	10	34
Lynx conductor line	Rahatungoda 1 MW to Node 23	7	23.8
Total		**72**	**244.8**

Table 4.4_Required network modifications

These values were included as the project cost in NPV/ IRR calculation

Chapter 5

Results & Analysis

5.1 Voltage Profile

Result obtained for the variation of voltage profile in the radial distribution network is presented below. Voltage profile was analyzed for the existing network and for different cases of study mentioned earlier. Also, the study on voltage profile was extended to find out the variation in peak & off peak condition so that it could be revealed that whether the network voltage remains in the nominal range.

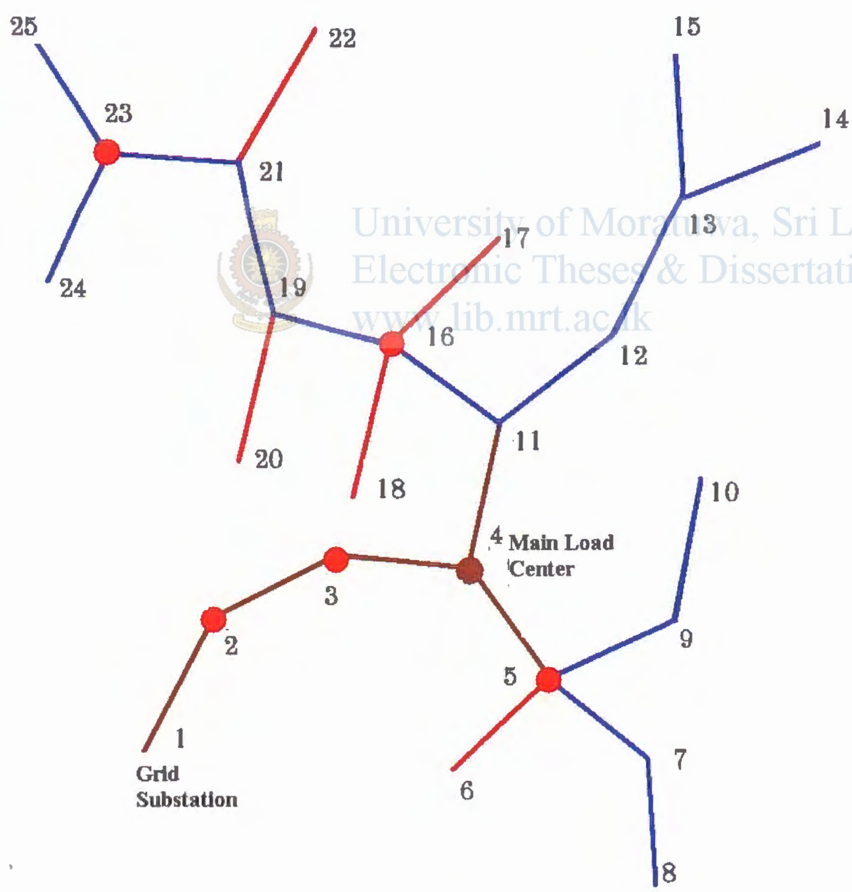


Fig 5.1_Radial distribution network of feeder 1

5.1.1 Variation of Network Voltage when EG is not present in the system

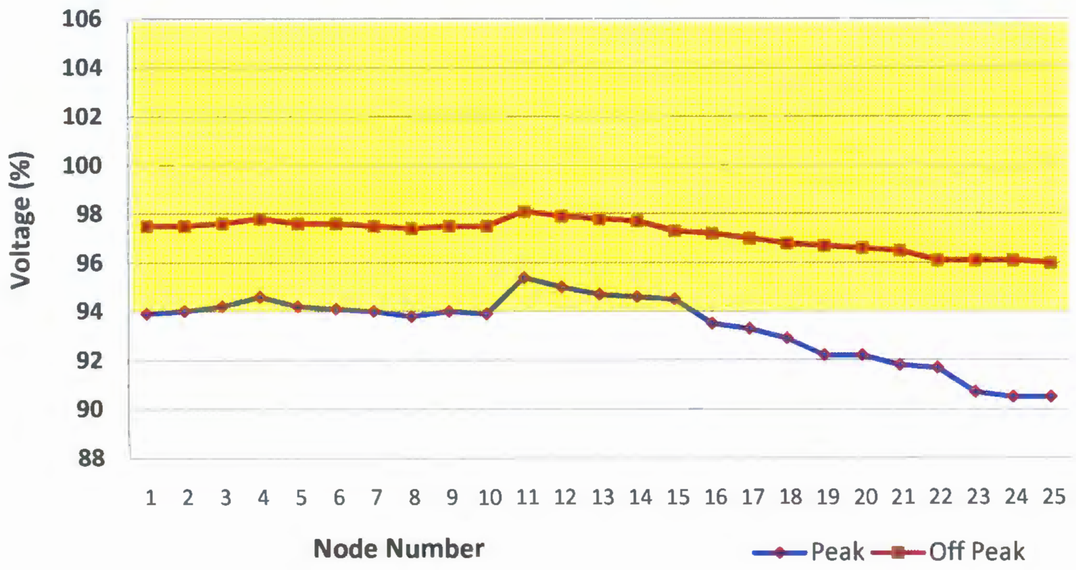


Fig. 5.2_ Variation of Network Voltage when EG is not present in the system

5.1.2 Variation of Network Voltage when each EG plant is connected at the distributor ends (Case 1 of category B-proposed system)

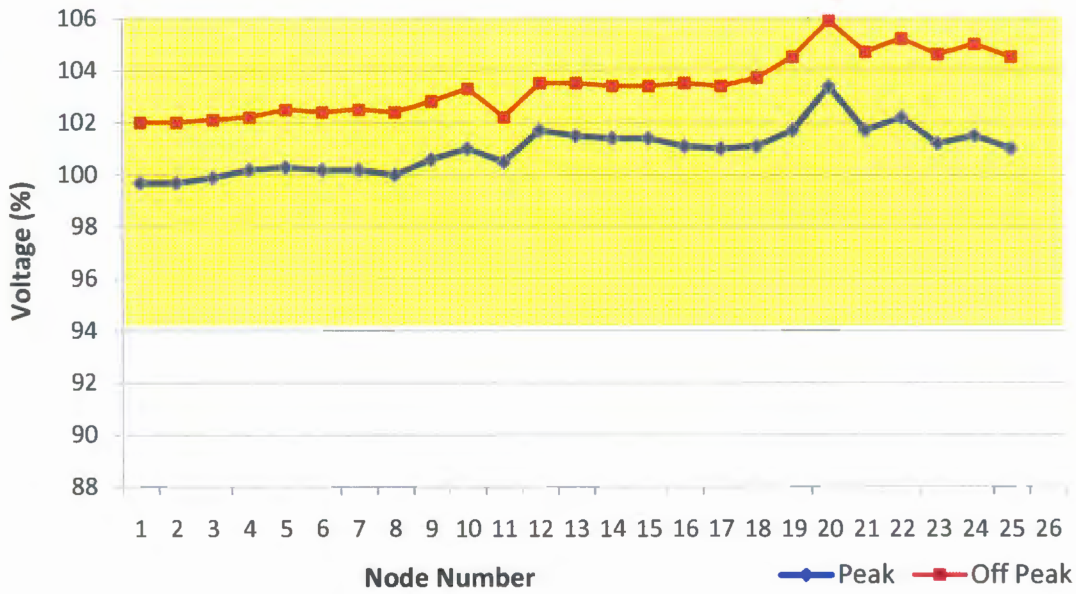


Fig. 5.3_ Variation of Network Voltage when each EG plant is connected at the distributor ends

5.1.3 Variation of Network Voltage when all EG plants are connected at the main load center (Case 2 of category B-proposed system)

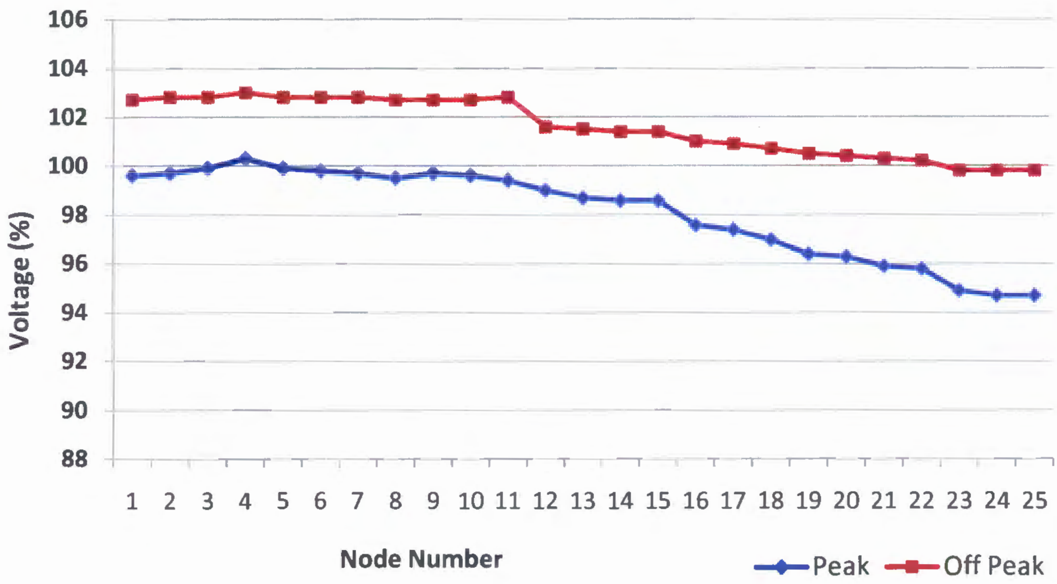


Fig. 5.4_ Variation of Network Voltage when all EG plants are connected at the main load center

5.1.4 Variation of Network Voltage when EG plants are connected at the nearest load center (Case 3 of category B-proposed system)

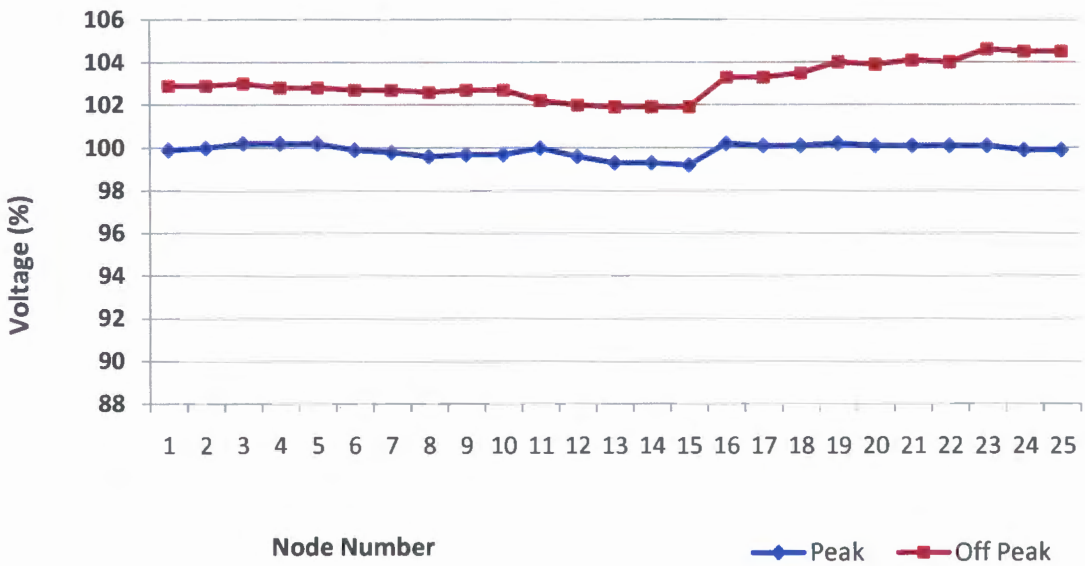


Fig. 5.5_ Variation of Network Voltage when EG plants are connected at the nearest load center

5.2 Network Losses

5.2.1 Results of the Analysis of System with Existing Embedded Generator

Following are the result obtained on further calculations of the simulation results. It shows how the existing EG on the feeder (1 No. of MHP – 1.5 MW) has caused for the variation of losses including distribution line & grid transformer. Result is given in the following tables which shows the overall losses for the three cases of,

1. System with no embedded generation all the time
2. System with existing EG at the present Point of Common Coupling(PCC) where the percentage output of EG in each of the month has been taken into consideration. There output percentages were obtained from historic data of that plant.
3. Simulation of a system if the existing generator had been connected to nearest load center via a separate line.

	Power Demand (kVA)		Power Loss (kW)		Annual GSS Energy Demand (MWh)	Annual Dist. Line Loss (MWh)	Annual GSS Transformer Energy Loss (MWh)
	Peak	Off Peak	Peak	Off Peak			
Period of 1 year	12141	5104	631	110	43866.3	1343.9	39.3
	Total				**43866.3**	**1343.9**	**39.3**

Table 5.1_ System with no embedded generation all the time

	EG Output of Rated Capacity (%)	Power Demand (kVA)		Power Loss (kW)		Monthly GSS Energy Demand (MWh)	Monthly Dist. Line Loss (MWh)	Monthly GSS Transformer Energy Loss (MWh)
		Peak	Off Peak	Peak	Off Peak			
Jan	25	11545	4577	557	85	3376.8	92.5	2.8
Feb	6	11963	4947	608	102	3271.2	96.9	2.9
Mar	9	11918	4908	603	100	3595.8	105.6	3.1
Apr	14	11808	4810	589	95	3417.1	98.0	2.9
May	18	11720	4732	578	91	3479.4	97.9	3.0
Jun	31	11415	4461	542	80	3193.7	85.3	2.6
Jul	36	11306	4365	530	77	3236.6	85.4	2.6
Aug	20	11676	4693	573	90	3453.6	96.9	2.9
Sep	28	11480	4519	550	82	3230.8	87.1	2.7
Oct	43	11134	4212	511	71	3135.3	80.1	2.5
Nov	71	10498	3646	448	58	2671.9	65.2	1.9
Dec	56	10835	3946	480	64	2959.4	73.4	2.2
	Total					**39021.6**	**1064.3**	**32.0**

Table 5.2_System with existing EG at the present PCC

	EG Output of Rated Capacity (%)	Power Demand (kVA)		Power Loss (kW)		Monthly GSS Energy Demand (MWh)	Monthly Dist. Line Loss (MWh)	Monthly GSS Transformer Energy Loss (MWh)
		Peak	Off Peak	Peak	Off Peak			
Jan	25	11545	4576	557	84	3376.2	91.8	2.8
Feb	6	11963	4947	608	102	3271.2	96.9	2.9
Mar	9	11918	4908	603	100	3595.8	105.6	3.1
Apr	14	11808	4810	589	95	3417.1	98.0	2.9
May	18	11720	4732	578	91	3479.4	97.9	3.0
Jun	31	11414	4460	541	79	3193.0	84.6	2.6
Jul	36	11305	4364	528	75	3235.9	83.9	2.6
Aug	20	11676	4693	573	89	3453.6	96.2	2.9
Sep	28	11479	4518	549	81	3230.1	86.4	2.7
Oct	43	11132	4210	509	69	3134.0	78.6	2.5
Nov	71	10490	3639	441	50	2667.4	59.5	1.9
Dec	56	10831	3942	476	58	2956.8	69.1	2.2
Total						**39010.6**	**1048.5**	**32.0**

Table 5.3_System if the existing generator had been connected to nearest load center

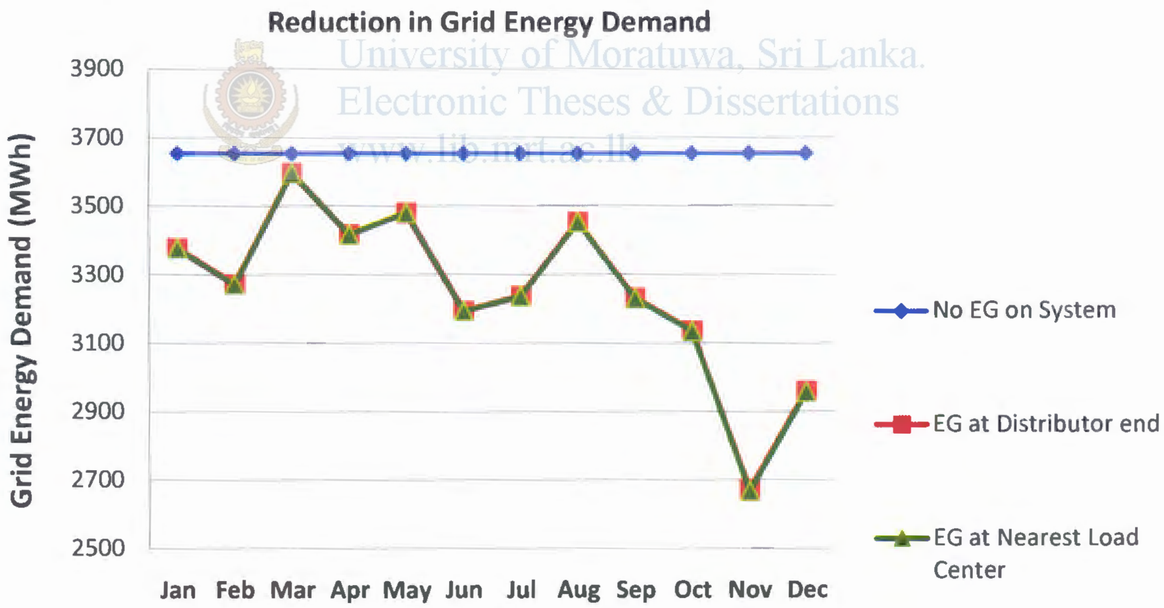


Fig. 5.6_Reduction in Grid energy demand due to EG (existing situation)

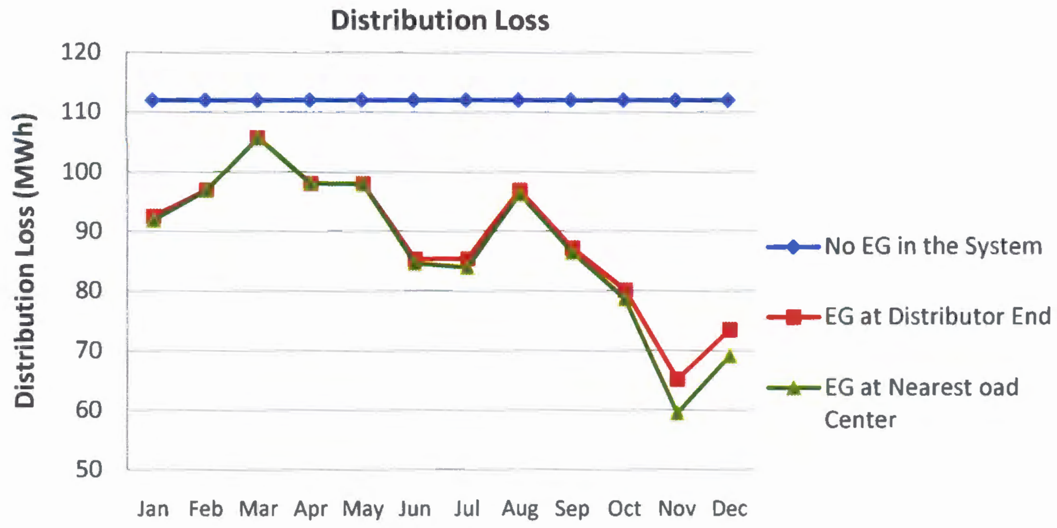


Fig. 5.7_Reduction in distribution losses due to EG (existing situation)

Above result revealed that the existing EG plant has caused reduction of the network losses from 1.3 GWh to 1 GWh per annum. Also it has caused reduction of nearly 15 GWh of transmission energy demand which has been met by EG. In turn it has resulted a reduction in the grid transformer losses by 7 MWh per annum and it is significant.

If the existing network had been modified to connect the EG common coupling point to the nearest coupling point it shows a slight improvement in the loss reduction. This gives an indication that the operation of an EG plant in the distribution network has a positive impact on network loss reduction. However analysis has to be extended to see this behavior with regard to future addition of whole potential of MHP and for the load growth for the entire planning horizon. Results of this analysis are furnished in the following.

5.2.2 Results of the Analysis of System with Proposed Embedded Generators

Results given following is the outcome of the power flow analysis carried out with regard to all proposed EG plants in the feeder. Analysis was done for three different cases of,

1. Proposed EG plants connected to its nearest distributor ends (method generally proposed by CEB)
2. Proposed EG plants all connected to the main load center of the feeder
3. Proposed EG plants connected separately to the closest load centers

Month	EG Output of Rated Capacity (%)	Power Demand (kVA)		Power Loss (kW)		Monthly GSS Energy Demand (MWh)	Monthly Dist. Line Loss (MWh)	Monthly GSS Transformer Energy Loss (MWh)
		Peak	Off Peak	Peak	Off Peak			
Jan	20	9506	1448	297	31	1342.9	38.3	0.9
Feb	20	9506	1448	297	31	1342.9	38.3	0.8
Mar	20	9506	1448	297	31	1342.9	38.3	0.9
Apr	20	9506	1448	297	31	1342.9	38.3	0.8
May	20	9506	1448	297	31	1342.9	38.3	0.9
Jun	31	8100	249	219	36	572.3	36.9	0.5
Jul	36	7120	-106	207	46	314.4	42.8	0.4
Aug	20	9506	1448	297	31	1342.9	38.3	0.9
Sep	28	8694	795	237	32	920.8	35.3	0.6
Oct	43	5767	-1925	169	70	-813.5	56.3	0.6
Nov	71	569	-6788	184	256	-3912.4	180.0	3.8
Dec	56	677	-4212	155	139	-2410.6	101.0	1.5
Total for Annum						**2728.4**	**682.1**	**12.5**

Table 5.4_ Proposed EG plants connected to its nearest distributor ends

Month	EG Output of Rated Capacity (%)	Power Demand (kVA)		Power Loss (kW)		Monthly GSS Energy Demand (MWh)	Monthly Dist. Line Loss (MWh)	Monthly GSS Transformer Energy Loss (MWh)
		Peak	Off Peak	Peak	Off Peak			
Jan	20	9756	1749	376	47	1530.9	53.6	1.0
Feb	20	9756	1749	376	47	1530.9	53.6	1.0
Mar	20	9756	1749	376	47	1530.9	53.6	1.0
Apr	20	9756	1749	376	47	1530.9	53.6	1.0
May	20	9756	1749	376	47	1530.9	53.6	1.0
Jun	31	8298	365	337	67	650.1	64.4	0.5
Jul	36	7344	-534	325	79	77.6	71.6	0.4
Aug	20	9756	1749	376	47	1530.9	53.6	1.0
Sep	31	8298	365	337	67	650.1	64.4	0.5
Oct	45	5653	-2128	313	109	-937.5	90.7	0.6
Nov	70	1121	-6426	354	255	-3673.0	189.5	3.4
Dec	55	3812	-3870	317	157	-2046.4	122.6	1.3
Total for Annum						**3906.6**	**924.9**	**12.6**

Table 5.5_ Proposed EG plants all connected to main load center

Month	EG Output of Rated Capacity (%)	Power Demand (kVA)		Power Loss (kW)		Monthly GSS Energy Demand (MWh)	Monthly Dist. Line Loss (MWh)	Monthly GSS Transformer Energy Loss (MWh)
		Peak	Off Peak	Peak	Off Peak			
Jan	20	8787	1191	246	17	1194.2	26.8	0.7
Feb	20	8787	1191	246	17	1078.6	24.2	0.6
Mar	20	8787	1191	246	17	1194.2	26.8	0.7
Apr	20	8787	1191	246	17	1155.7	26.0	0.7
May	20	8787	1191	246	17	1194.2	26.8	0.7
Jun	31	7545	-270	173	11	241.6	17.6	0.4
Jul	36	6478	-1314	139	15	-435.2	18.8	0.5
Aug	20	8787	1191	246	17	1194.2	26.8	0.7
Sep	31	7545	-270	173	11	241.6	17.6	0.4
Oct	45	4587	-3070	92	36	-1592.2	30.3	1.0
Nov	70	-580	-7993	55	172	-4673.0	116.8	5.2
Dec	55	2326	-5179	60	80	-2981.3	58.3	2.3
Total for the Annum						**-2187.4**	**417.1**	**14.0**

Table 5.6_ Proposed EG plants separately connected to nearest load center

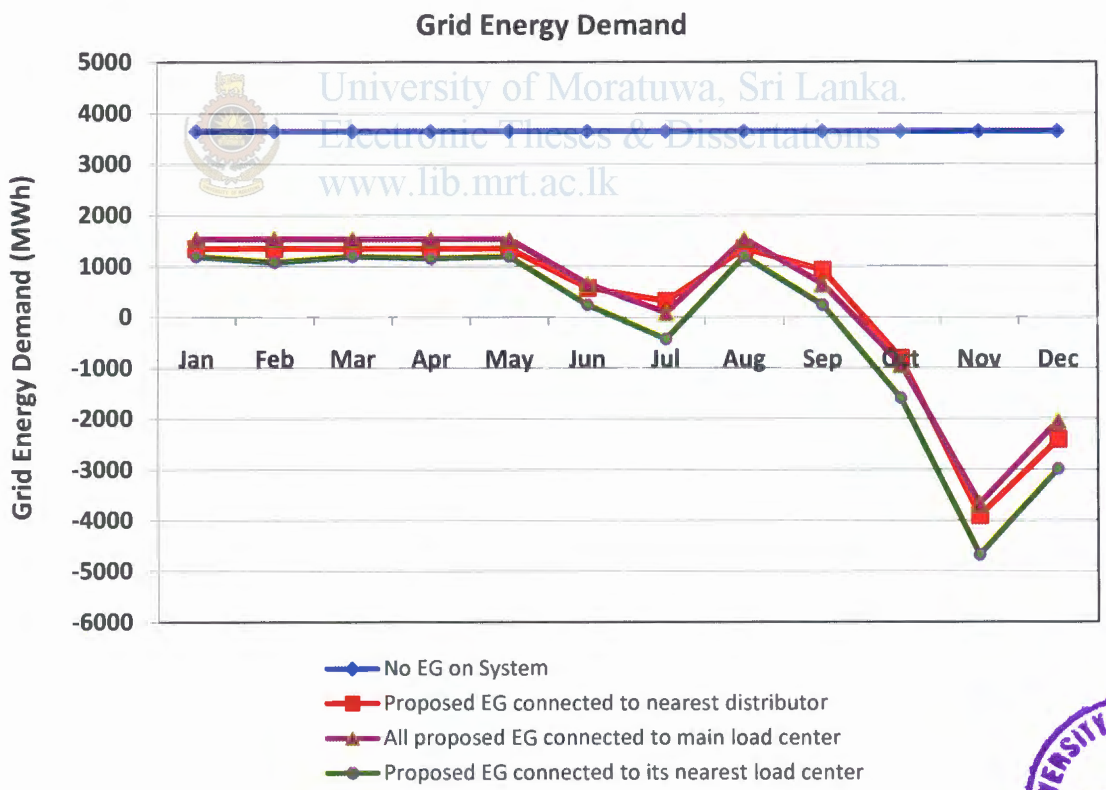


Fig. 5.8_Reduction in Grid energy demand due to EG (proposed situation)

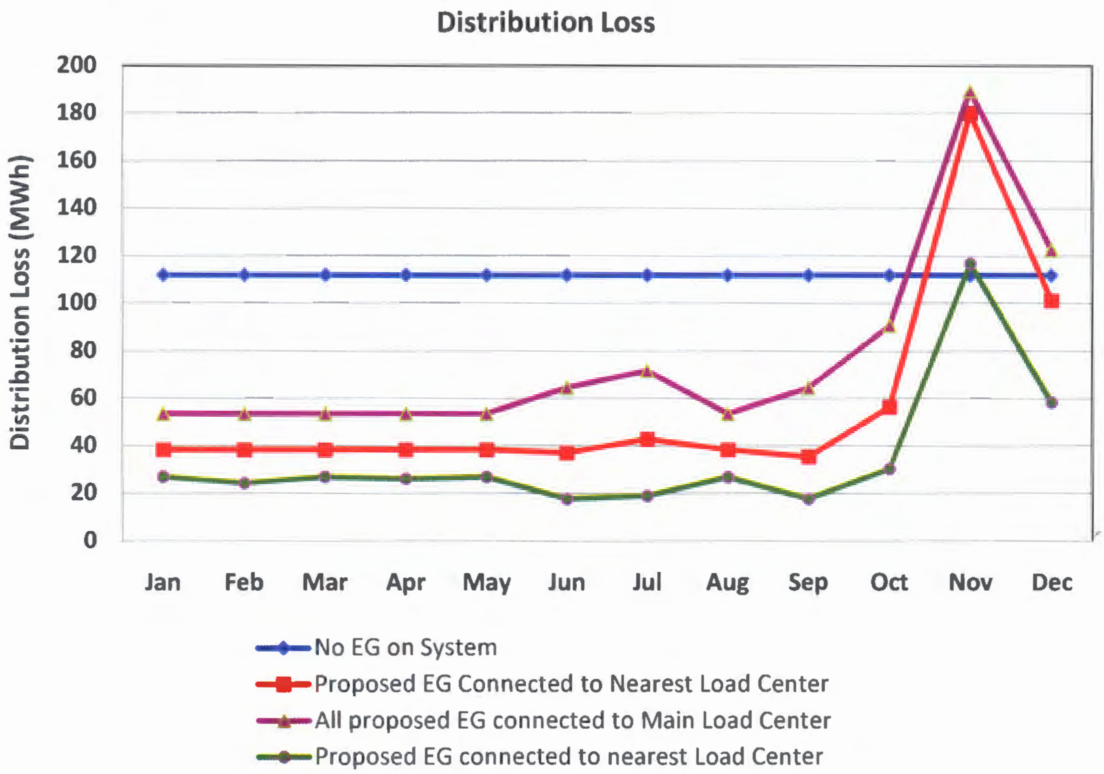


Fig. 5.9_Reduction in distribution losses due to EG (proposed situation)

Above result revealed that connection of all potentially available mini hydro capacity into the distribution network causes reduction in grid energy demand, line losses and grid transformer losses significantly. Out of the above three possibilities of connection it is seen that the optimal connection to reduce losses & generation costs operation wise, is the 3rd state in which the EG plants are connected with separate lines to the nearest load centers.

Generally, procedure is to connect the EG plant to the nearest distributor subject to other conditions such as voltage, fault level, protection etc. are satisfied. Hence further analysis was done to make a comparison of the reduction in network losses & generation costs for the connection arrangements 1st vs. 3rd . For the calculated rate, the load growth of the system was studied for a period of 10 years. Energy demand and the losses were determined for two states (wet season & dry season) in each year based on the average plant factors. Demand & Loss pattern for these two cases are as in Table 5.7 and Table 5.8.

5.2.3 Forecast on 10 year period

Year	PF 30% Dry Season				PF 65% Wet Season				GSS Energy Demand (MWh)	Dist. Line Loss (MWh)	GSS Tr. Energy Loss (MWh)
	Power Demand (kVA)		Power Loss (kW)		Power Demand (kVA)		Power Loss (kW)				
	Peak	Off Peak	Peak	Off Peak	Peak	Off Peak	Peak	Off Peak			
1	8998	730	224	34	2353	-5466	166	204	**2381.6**	**672.1**	**11.9**
2	10044	1151	272	36	3331	-5065	181	195	**5995.5**	**703.2**	**13.3**
3	11184	1608	331	39	4395	-4633	203	186	**9917.0**	**748.4**	**15.6**
4	12428	2101	402	44	5553	-4166	232	177	**14157.4**	**814.9**	**18.7**
5	13787	2636	489	50	6817	-3660	272	168	**18763.5**	**899.0**	**23.0**
6	15275	3215	595	59	8197	-3114	325	161	**23757.0**	**1018.9**	**28.7**
7	16909	3842	724	70	9706	-2523	394	154	**29177.7**	**1167.8**	**36.0**
8	18707	4522	883	84	11361	-1884	483	149	**35069.9**	**1360.1**	**45.5**
9	20693	5260	1078	102	13180	-1194	597	145	**41481.2**	**1605.0**	**57.6**
10	22893	6062	1319	124	15184	-463	743	144	**48450.0**	**1912.3**	**72.9**

Table 5.7_Load growth for EG Connection at distributor ends of the feeder

Year	PF 30% Dry Season				PF 65% Wet Season				GSS Energy Demand (MWh)	Dist. Line Loss (MWh)	GSS Tr. Energy Loss (MWh)
	Power Demand (kVA)		Power Loss (kW)		Power Demand (kVA)		Power Loss (kW)				
	Peak	Off Peak	Peak	Off Peak	Peak	Off Peak	Peak	Off Peak			
1	8460	239	180	10	1216	-6526	51	130	**-2218.2**	**366.5**	**13.0**
2	9502	654	226	11	2184	-6128	61	120	**1353.9**	**387.7**	**13.8**
3	10636	1107	282	14	3237	-5699	77	109	**5244.0**	**427.5**	**15.4**
4	11873	1599	350	17	4385	-5235	101	98	**9469.9**	**475.5**	**17.8**
5	13225	2131	434	23	5635	-4734	135	89	**14047.0**	**557.0**	**21.2**
6	14174	2502	497	27	6511	-4385	162	81	**17242.3**	**613.3**	**24.2**
7	15368	2964	584	34	7611	-3950	203	73	**21229.2**	**705.6**	**28.5**
8	16649	3455	681	42	8787	-3489	253	66	**25472.0**	**813.1**	**33.8**
9	17947	3946	799	51	9975	-3028	312	61	**29725.1**	**943.8**	**40.0**
10	19665	4588	961	66	11540	-2426	399	55	**35297.5**	**1142.7**	**49.2**

Table 5.8_Load growth for EG Connection to nearest load centers

Variation and the extent of reduction in the grid energy demand caused due to the above two connection arrangements is given in the following Figure 5.10 for the first year, for load growth in fifth year and the tenth year of the project period.

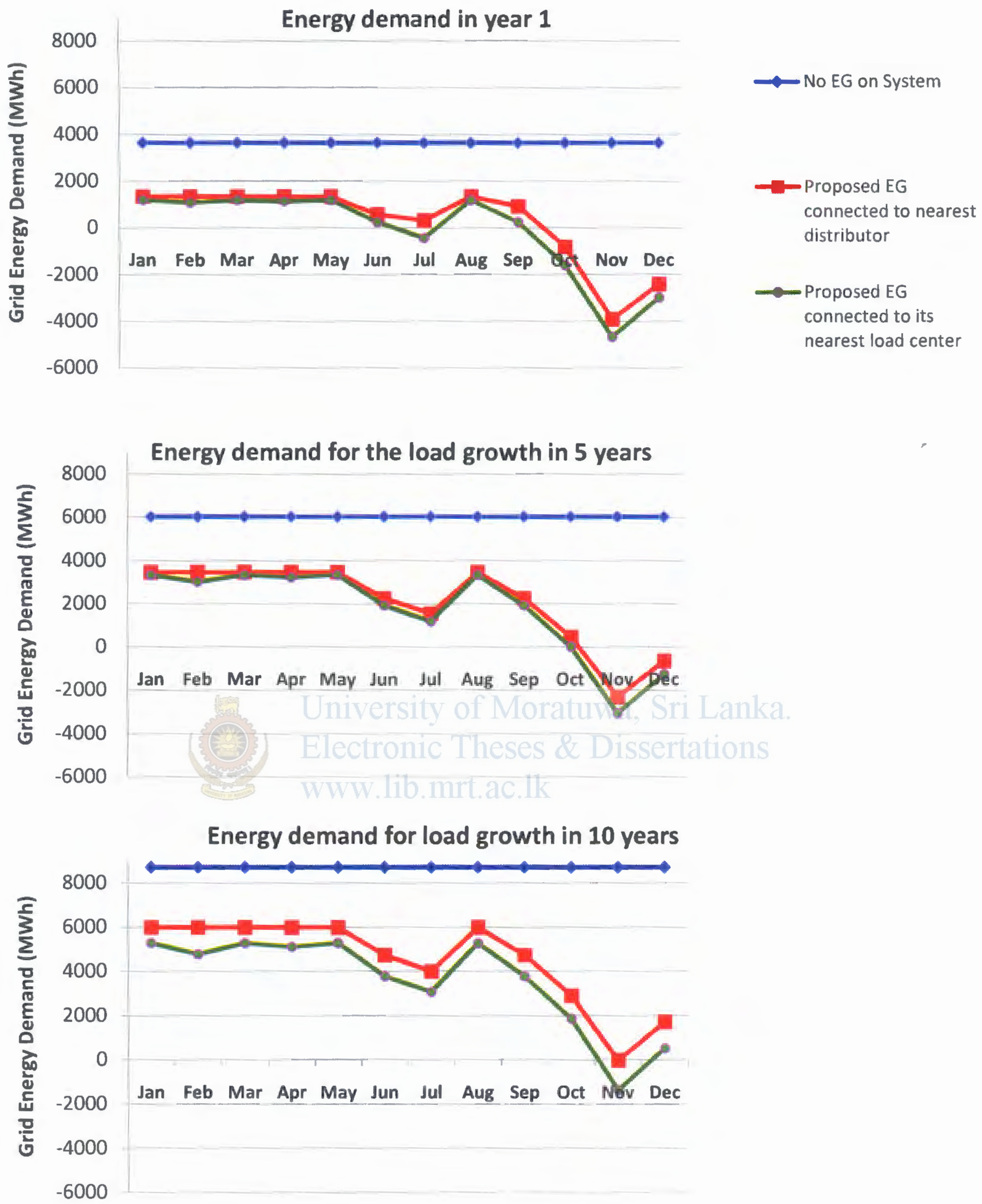


Fig. 5.10_Variation of grid energy demand for load growth

Also significant variation was observed in the distribution losses. In the first year, when the percentage output remains at a higher value around 70% it is seen that it has caused to increase the distribution losses than the existing system. This is particularly when the generation is high while the loads are less causing reverse power flow to the transmission network. With the load growth, it is seen that these losses have been reduced. The simulation included total potential of EG capacity hence the total analysis for 10 years will yield a result indicating the overall variation of losses as indicated in the Figure 5.11.

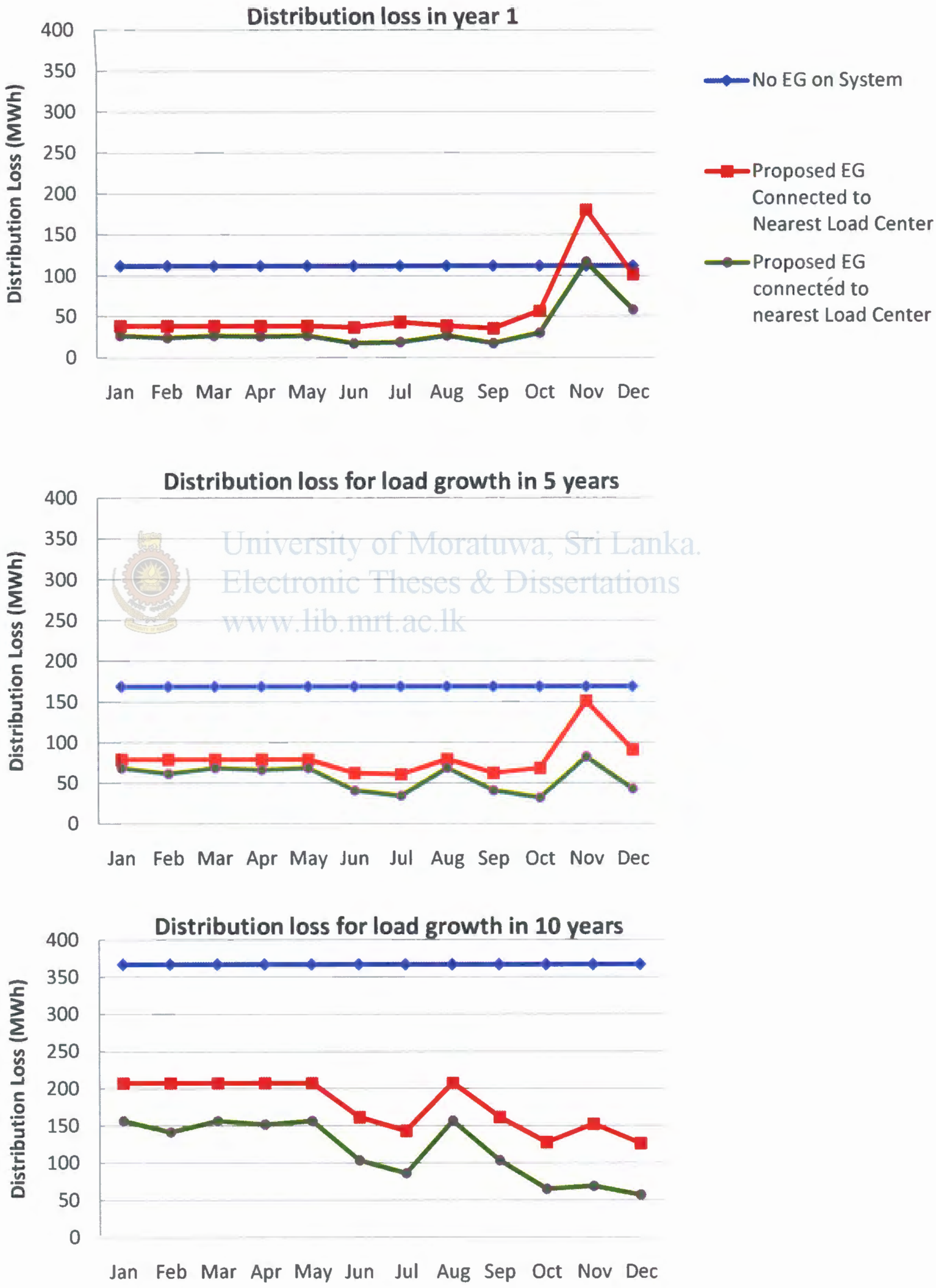


Fig.5.11_Variation of grid energy demand for load growth

Based on the above result, further calculation was done to evaluate whether modification of the distribution network to above 3rd connection arrangements would be worth for the utility. For the network modification, project cost mentioned in table 4.4 will be incurred and the relevant saving achieved due to same is obtained using data on tables 5.7 & 5.8. Costing of thermal unit and EG unit for the 10 year period is according to the discussion in chapter 4.

Accordingly, the Net Present Value (NPV) of the project which includes the financial return through network modification was calculated. Interest rate of 15% was assumed.

Result in Table 5.9 below figures out the NPV of the project for the planned period of 10 years and the achievable rate of return for the utility through the project.

Year	Project Cost	Saving by Reduction in GSS Energy Demand	Saving by Reduction in Distribution Line Losses	Saving by Reduction in GSS Transformer Losses	Net Cash Flow	Discount Factor (15%)	Present value	Net Present value	IRR
	(million LKR)	(million LKR)	(million LKR)	(million LKR)	(million LKR)		(million LKR)	(million LKR)	
0	-244.8				-244.8	1.0	-244.8		26%
1		1.6	4.8	-0.018	6.4	0.9	5.5	217.7	
2		14.4	5.0	-0.009	19.3	0.8	14.6		
3		26.5	5.1	0.004	31.6	0.7	20.8		
4		39.8	5.4	0.023	45.2	0.6	25.8		
5		52.0	5.5	0.047	57.6	0.5	28.6		
6		88.4	6.6	0.133	95.1	0.4	41.1		
7		129.2	7.5	0.245	136.9	0.4	51.5		
8		180.1	8.9	0.411	189.4	0.3	61.9		
9		357.8	4.9	0.668	363.4	0.3	103.3		
10		435.1	5.8	0.962	441.8	0.2	109.2		

Table 5.9_NPV & IRR

Chapter 6

Conclusion

This project is based on a study which was focused on the distribution losses, operation of embedded generators on the distribution network and its impact on minimization of network losses & generation costs by means of optimal allocation of embedded generators. Through the study it was possible to come out with several important findings which will benefit the utility in achieving above mentioned goals.

Presence of the embedded generation on a distribution network causes an improved voltage profile compared to a system with no embedded generators. In the distribution planning process this is a positive feature yet constrained by the reliability of embedded generation. It was seen that inclusion of more embedded generators in the system causes a better voltage profile.

Embedded generators do make significant contribution for distribution loss minimization and saving of generation cost. It takes place by means of reduction in distribution line & grid transformer losses and replacing the thermal generation by embedded generation of which the generation cost is comparably less. It is found that the distribution system in the existing situation has line losses of about 1 GWh per year and it could have been around 1.4 GWh per year if the embedded generation were not present in the distribution system. Therefore in the present scenario, contribution of the embedded generator for loss minimization is 23%. In addition the embedded generator has caused reduction of nearly 25% of transmission energy demand. Thus the utility has been benefited by it due to the EG energy being lower in cost than a thermal unit. Therefore it is concluded that operation of embedded generator of capacity 1.5 MW in feeder 1 of Nuwara Eliya grid substation has caused overall reduction in network losses and generation costs.

The study was then extended to evaluate on the network performance when significant capacity of additional embedded generation is connected to the network. All proposed mini hydro plants in feeder 1 of Nuwara Eliya GSS were selected as the case study and simulation was carried out in actual terms. It revealed that when significant capacity of embedded generators (16 MW) is connected to the distribution system it changes the power losses, and decrease the grid substation energy demand. Power losses may increase in case of reverse power flow to the transmission network. Power flow study revealed that the proposed embedded generation scheme when connected in the common method (i.e. to the distributor ends) causes an overall network loss reduction of 40% for annum. In further studies it revealed that if the network was modified to connect the embedded generators to the nearest load center with a separate interconnection line, further improvement is possible to raise the figure up to 60%. Distribution line losses reduce significantly while the grid transformer losses also reduce in a smaller proportion of about 10% of line losses. Analyzing the results it is also concluded that the EG scheme if operated reliably, will cause significant reduction of transmission energy demand by about 80% in the best scenario and it could be further improved through the modification of the network interconnection of the EG plants.

Finally it was studied whether a project for modification of the interconnection arrangement of the embedded generators as above, would be profitable for the utility by means of saving by loss reduction and generation costs. The growth of the system was studied with respect to the two connection arrangements for a period of 10 years. It revealed that it yields a satisfactory NPV and an acceptable Internal Rate of Return of 26%.

Therefore it is concluded that the concept of interconnecting the embedded generators specifically to the main load centers of the network is profitable to the utility.

The length of lines, availability of EG sources, spreading of loads etc. have been moderate for the feeder concerned for study. Significant deviation of any of these factors in a network could make deviations in the final result as well. Hence this concept may be applied to the network by studying its features separately.

Main constraint on implementation of above is the reliability of EG plants. There is no commitment on the reliability of these EG plants hence its energy contribution for the system may not reach the expected values.

Finally, how this concept could be included in our utility is briefed as follows.

In present practice of CEB when planning grid interconnection proposals for embedded generators, network losses are not taken as a major consideration. Connection arrangement is planned through studies on network voltage levels, fault levels, geographical constraints and protection issues. If the planning process is extended to concern the network losses too, it would be profitable for the organization in long term. Optimal allocation of the embedded generators could be planned using above concept. In highly loaded lengthy feeders within urban areas, the loss levels could be significantly minimized by optimal allocation of embedded generators.

It could be further suggested that either the utility itself could carry out the required network modifications at its cost and gain the full return of it. Else the modification could be imposed on the plant developer for implementation and allowance of certain return to the developer through a formal tariff incentive or through distribution loss adjustment factor. The latter type is already practiced in certain developed countries by its distribution network operators. For this, calculation of site specific & connection loss adjustment factors using a standard methodology is required.

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Appendix A

1. Avoided Cost Based Tariff

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Dry Season (LKR/kWh)	2.90	3.38	3.51	3.22	3.11	4.20	5.13	6.06	5.70	6.05	6.73	7.64	9.65	11.17
Wet Season (LKR/kWh)	2.90	2.89	3.14	2.74	2.76	4.00	4.91	5.85	4.95	5.30	5.82	6.94	8.94	10.59

Dry Season: February, March & April
Wet Season: Other Months

2. Three-tier Tariff

Type of Plant	Escalable	Escalable	Non-escalable		Escalable Year 16+	
	Base O&M	**Base Fuel**	**Tier 1**	**Tier 2**	**Tier 3**	**Royalty Payment**
	LKR/kWh	**LKR/kWh**	**Year 1 - 14 LKR/kWh**	**Year 9- 15 LKR/kWh**	**Year 16 - 20 LKR/kWh**	
Mini-hydro	1.55	None	14.18	5.16	1.62	10% of total tariff
Wind	2.46	None	22.53	8.19	1.62	10% of total tariff
Biomass (Dendro)	1.24	7.14	8.5	3.09	1.62	No royalty
Agri. & Industrial Waste	1.24	3.56	8.5	3.09	1.62	No royalty
Municipal Waste	3.13	None	12.26	4.46	1.62	No royalty
Waste Heat Recovery	0.49	None	10.15	3.69	1.62	No royalty
Escalation rate for 2009	0.08	0.05	-	-	0.054	

3. Flat Tariff Option

Type of Plant	All Inclusive Rate (LKR/kWh) for years 1-21
Mini-hydro	14.58
Wind	23.07
Biomass (Dendro)	18.56
Agricultural & Industrial Waste	13.88
Municipal Waste	15.31
Waste Heat Recovery	9.55

Appendix B

Average Power Demand of the Feeders in Nuwara Eliya GSS for year 2008

Time of Day	Feeder Demand (MW)					
	Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5	Feeder 6
0:30	2.4	2.3	0.4	1.9	2.2	-0.8
1:00	2.4	2.3	0.4	1.9	2.2	-0.8
1:30	2.4	2.3	0.4	1.9	2.2	-0.8
2:00	2.4	2.3	0.4	1.9	2.2	-0.8
2:30	2.4	2.3	0.4	1.9	2.2	-0.8
3:00	2.4	2.3	0.4	1.9	2.2	-0.8
3:30	2.4	2.3	0.4	1.9	2.2	-0.8
4:00	2.9	2.6	0.4	2.0	2.4	-0.7
4:30	2.9	2.6	0.4	2.0	2.4	-0.7
5:00	3.8	3.6	0.5	2.5	3.2	-0.1
5:30	4.5	4.7	0.6	3.1	4.1	0.6
6:00	5.5	5.4	0.7	3.3	4.6	0.7
6:30	5.2	5.1	0.7	3.4	4.6	0.7
7:00	4.4	4.1	0.6	3.0	3.8	0.6
7:30	4.4	4.1	0.6	3.0	3.8	0.6
8:00	3.4	3.3	0.5	2.8	4.0	0.6
8:30	3.4	3.3	0.5	2.8	4.0	0.6
9:00	3.1	3.2	0.5	2.3	4.1	0.8
9:30	3.1	3.2	0.5	2.3	4.1	0.8
10:00	2.8	3.0	0.5	2.0	3.8	1.1
10:30	2.8	3.0	0.5	2.0	3.8	1.1
11:00	2.8	3.0	0.5	2.0	3.8	1.1
11:30	2.8	3.0	0.5	2.0	3.8	1.1
12:00	2.8	3.0	0.5	2.2	3.8	1.2
12:30	2.8	3.0	0.5	2.2	3.8	1.2
13:00	2.8	3.0	0.5	2.2	3.8	1.2
13:30	2.8	3.0	0.5	2.2	3.8	1.2
14:00	2.8	3.0	0.5	2.3	3.8	1.2
14:30	2.8	3.0	0.5	2.3	3.8	1.2
15:00	2.8	3.0	0.5	2.3	3.8	1.2
15:30	2.8	3.0	0.5	2.3	3.8	1.2
16:00	3.0	3.0	0.5	2.2	3.9	1.2
16:30	3.0	3.0	0.5	2.2	3.9	1.2
17:00	3.9	3.6	0.6	2.6	4.4	1.2
17:30	4.7	4.6	0.6	2.8	4.8	1.2
18:00	5.6	5.5	0.7	3.0	5.1	1.3
18:30	6.8	7.6	0.8	3.5	6.0	1.4
19:00	7.8	9.1	0.9	4.4	6.8	1.6
19:30	7.6	8.5	1.0	4.5	7.1	1.7
20:00	6.9	8.2	0.9	4.4	6.6	1.5
20:30	6.4	7.4	0.8	4.0	6.0	1.2
21:00	5.2	6.3	0.7	3.5	5.3	1.1
21:30	4.4	5.4	0.6	3.1	4.3	1.0
22:00	3.8	4.7	0.5	2.8	3.5	0.9
22:30	3.8	4.7	0.5	2.8	3.5	0.9
23:00	3.2	3.7	0.4	2.5	3.0	0.8
23:30	3.2	3.7	0.4	2.5	3.0	0.8
0:00	2.5	2.7	0.4	2.2	2.5	0.6
Average Demand (MW)	**3.7**	**3.9**	**0.5**	**2.6**	**3.9**	**0.7**

Appendix C

Energy Demand of the feeders of Nuwara Eliya GSS in year 2008

	Feeder 1 (MWh)	Feeder 2 (MWh)	Feeder 3 (MWh)	Feeder 4 (MWh)	Feeder 5 (MWh)	Feeder 6 (MWh)
January	3000	2700	200	1800	3000	500
February	3010	2662	203	1951	3137	558
March	3169	2955	189	1340	3326	532
April	2635	2710	189	884	3068	743
May	2970	2703	310	1651	3314	819
June	2600	2600	350	1650	3000	650
July	2000	2243	431	1672	2562	527
August	2032	2670	504	1707	2420	590
September	2500	2670	420	1750	2300	450
October	2944	2681	381	1860	2088	366
November	2620	2430	458	2423	2121	364
December	2286	2466	470	1416	1754	551
Total Annual Demand (MWh)	**31765**	**31490**	**4106**	**20106**	**32090**	**6649**

Past Energy Export Data of MHPs - Nuwara Eliya Grid Substation

	MHP 1		MHP 2		MHP 3		MHP 4		MHP 5		MHP 6		MHP 7		MHP 8		MHP 9		MHP 10	
	Export Energy (kW)	Monthly Output (% of Rated Capacity)	Export Energy (kW)	Monthly Output (% of Rated Capacity)	Export Energy (kW)	Monthly Output (% of Rated Capacity)	Export Energy (kW)	Monthly Output (% of Rated Capacity)	Export Energy (kW)	Monthly Output (% of Rated Capacity)	Export Energy (kW)	Monthly Output (% of Rated Capacity)	Export Energy (kW)	Monthly Output (% of Rated Capacity)	Export Energy (kW)	Monthly Output (% of Rated Capacity)	Export Energy (kW)	Monthly Output (% of Rated Capacity)	Export Energy (kW)	Monthly Output (% of Rated Capacity)
Jan-07			1021000	55	0	0	27214	19	698513	37	531349	27	368264	39						
Feb-07			279000	15	0	0	7248	5	316396	17	281203	14	94560	10						
Mar-07			122494	7	109275	10	11	0	206239	11	190644	10	27593	3						
Apr-07			351746	19	153643	14	9476	7	328418	18	315412	16	0	0						
May-07			259549	14	86788	8	7834	5	235075	13	256751	13	0	0						
Jun-07			607756	32	200300	19	39207	27	585620	31	698794	36	156129	17						
Jul-07			1079609	58	0	0	94813	66	712810	38	1036210	53	359922	38						
Aug-07	21823	15	551468	29	197290	18	54720	38	418666	22	658520	34	248469	27						
Sep-07	25376	18	1344682	72	521100	48	80877	56	961020	51	1395414	72	436260	47						
Oct-07	175	0	1433000	77	444568	41	61355		1073430	57	1486416	76	666487	71						
Nov-07	21349	15	1371190	73	534132	49	77390	54	895840	48	1274460	66	332890	36						
Dec-07	23206	16	877400	47	656550	61	39396	27	748320	40	642630	33	342630	37						
Jan-08	19657	14	762673	41	651050	60	17688	12	515738	28	452223	23	548260	59						
Feb-08	0	0	426203	23	299562	28	4326	3	363935	19	288028	15	130627	14						
Mar-08	5876	4	833304	45	406346	38	18909	13	760381	41	591615	30	0	0						
Apr-08	2577	2	939202	50	324283	30	20305	14	1006236	54	597839	31	46624	5						
May-08	4747	3	616533	33	301061	28	23579	16	792630	42	545889	28	0	0	Commissioning					
Jun-08	9913	7	559670	30	181582	17	20040	14	594100	32	518600	27	0	0	21617	1				
Jul-08	22504	16	833266	45	192256	18	51778	36	578801	31	522528	27	218832	23	40496	2				
Aug-08	46966	33	699905	37	214320	20	55302	38	564027	30	683223	35	395911	42	113927	6				
Sep-08	38931	27	645235	34	210541	19	45960	32	497680	27	759954	39	456619	49	143549	8	Commissioning		Commissioning	
Oct-08	14898	10	739372	39	249908	23	40669	28	790956	42	503096	26	299103	32	520544	29	380472	66	180945	45
Nov-08	18287	13	708678	38	241954	22	20095	14	722192	39	541155	28	405944	43	739567	41	305030	53	58692	15
Dec-08	25643	18	844866	45	603360	56	44961	31	718858	38	707120	36	491103	52	1329224	74	303589	53	219534	54
Jan-09	11353	8	327418	17	269145	25	10127	7	330562	18	397791	20	165702	18	738681	41	140555	24	106667	26
Feb-09	0	0	149842	8	63308	6	1944	1	142377	8	198301	10	23281	2	30119	2	47254	8	52609	13
Mar-09	38	0	192095	10	98568	9	13879	10	378525	20	212791	11	6089	1	46813	3	109429	19	48853	12
Apr-09	2741	2	194822	10	152359	14	4344	3	227228	12	258278	13	40072	4	235178	13	117123	20	97869	24
May-09	6942	5	595363	32	193503	18	36587	25	540462	29	496862	26	170841	18	131447	7	198817	35	100741	25
Jun-09	27944	19	808422	43	333471	31	85635	59	633421	34	742826	38	617094	66	23129	1	449402	78	289003	72
Jul-09	38933	27	1098220	59	392409	36	93390	65	843481	45	1116679	57	423002	45	2621	0	375966	65	332667	83
Aug-09	25823	18	448973	24	213203	20	39368	27	402411	21	939554	48	383977	41	14551	1	174607	30	224425	56
Sep-09	31811	22	959521	51	306024	28	59494	41	834196	45	787491	41	516256	55	3447	0	486373	84	292832	73
Oct-09	22099	15	1046422	56	466396	43	104463	73	923735	49	900023	46	444293	47	242226	13	30495	5	242200	60
Nov-09	51119	35	1440487	77	770159	71	95017	66	1618766	86	1330625	68	648979	69	1551304	86	200284	35	336200	83

	Name of MHP	Rated Capacity (MW)
MHP 1	Wedamulla	0.2
MHP 2	Glassaugh	2.6
MHP 3	Kabaragala	1.5
MHP 4	Radella	0.2
MHP 5	Agra Oya	2.6
MHP 6	Dunsinane	2.7
MHP 7	Delta	1.3
MHP 8	Manelwala	2.5
MHP 9	Somerset	0.8
MHP 10	Sheen	0.6