SIZING OF DISTRIBUTION TRANSFORMERS BASED ON "LIFE-CYCLE - COST"

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DECLARATION OF THE CANDIDATE & SUPERVISOR

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Prof. J.R. Lucas

DEDICATION

To my loving parents and husband

who always pick me up on time and encourage me to go on every adventure, especially this one

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ABSTRACT

Many energy audits in Sri Lanka have identified the installed presence of oversized transformers and excessive number of transformers. No proper study has been done on the effect of the no load losses added to the system due to oversized transformers. Thus, transformers have not always being properly sized at the design stage.

In this research, a sample of bulk consumers from the North Western Province was selected and their installed capacities were compared with the properly sized transformers. Analysis shows that the no load losses can be reduced, on the average by about 40% with the proper sizing. Having identified the importance of proper sizing of transformers, software has been developed to select the optimum transformer capacity comparing the total owning costs of the transformers. The effect of the load pattern, transformer life time, discounting factor and the tariff rate has been considered in the optimization. Also, the software permits the determination of the optimum transformer for a few different load curves as well. The software tool has been validated in comparison with manual calculations.

This software is a useful tool for the bulk consumer as well as electrical consultants to determine the optimum transformer capacity for a given load curve based on total owning cost. The consumer can select the optimum size at the initial stage of the project so that unnecessary future costs due to losses can be minimized. Moreover, this would not only be a blessing to the consumer, but would mean that the overall distribution loss in the total electrical network will be reduced.

Keywords:

Life Cycle Cost, Transformer, Optimization, Load Losses, No load losses, Total Owning Cost

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LIST OF ABBREVIATIONS

CEB	: Ceylon Electricity Board
IEC	: International Electrotechnical Commission
LKR	: Sri Lankan Rupees
TOC	: Total Owning Cost
DF	: Discounting Factor
Tf	: Transformer
Distn	: Distribution

1 INTRODUCTION

1.1 Background

Many energy audits [1-4] for Sri Lankan consumers have identified oversized transformers and the installation of excessive number of transformers as a serious deficiency leading to, not only the capital cost of excessive kVA capacity but also unnecessary no-load loss. It is recognized that the main reason for this is that transformers have not been properly sized at the design stage. The common method of selecting transformers is to first determine the anticipated total demand of the facility, then to add 10% - 20% as safety margin, further oversize for possible future expansion and finally to select nearest higher size transformer.

While it may not be feasible to replace oversize transformers already in use, where excessive number of transformers have been identified it is possible to keep some transformers un-energized to be used perhaps alternately. Further, consideration may be given to the fact that a certain amount of overloading beyond nameplate rating is possible for short periods of time.

1.1.1 Adverse impacts of oversized transformers

If the transformer is oversized, the initial cost will be much higher since transformer purchasing and the cost of other related components such as cables, circuit breakers are high. Moreover the no load losses increase with an oversized transformer.

When more oversized transformers are being installed in the national system it will increases the losses to the system. In the Sri Lankan tariff, the additional no load losses caused by unutilized transformer capacity are not considered when the customer is billed.

1.1.2 Sri Lankan Scenario

It has been noticed that the installed capacity of the consumer owned transformer is almost double their demand. In this study, a sample consumer base of bulk consumers in North Western Province with installed capacity of more than 160 kVA was considered. The total installed capacity of the consumer owned transformers more than 160kVA capacity is 218.8 MVA. However average total demand of all those consumers are only 107.4 MVA, which is even less than the 50% of the installed capacity.

1.2 Power System transformers

A transformer is an electrical device that transfers electrical energy between two networks through electromagnetic induction. In particular, transformers are used to increase or decrease the alternating voltages in electric power applications in all stages of the electrical system, such as in generation, transmission, distribution, and utilization of alternating current electrical energy. They are also used in metering and protection applications.

A wide range of transformers are used in electric power applications. Many types of transformers used in the power system are described to explain the significance of the distribution transformer, and why it has been selected for this study.

1. Generator transformer: A special purpose transformer connected to transform the voltage of the generated power to that of the grid.
2. Autotransformer: Transformer in which part of the winding is common to both primary and secondary circuits, leading to increased efficiency, smaller size, and a higher degree of voltage regulation. They are frequently used in power applications to interconnect systems operating at different voltage classes for transmission, such as 220kV to 132 kV.
3. Power transformer: These are high power transformers used to transfer electric energy between the high voltage transmission network and the medium voltage distribution networks. They transform the voltage from the transmission voltage of 220kV or 132kV to the medium voltage of 33kV or 11kV

4. Distribution transformer: These transformers are used to distribute energy from medium voltage distribution lines and networks to low voltage of 400V for local consumption.
5. Grounding transformer: Transformer used for grounding three-phase circuits to create a neutral in a three wire system, using a star-delta transformer, or more commonly, a zigzag grounding winding.
6. Instrument transformer: These transformers transform high currents and voltages to standardized low and easily measurable values that are isolated from the power system. They are used for metering and protection and provide voltage or current signals that are very accurate representations of the transmission line values in both magnitude and phase.
7. Capacitor voltage transformer: Used in power systems to step down extra high voltage and provide a low voltage signal for metering or protection. It consists of a capacitive divider and a wound transformer. The tuning of the divider to the line frequency makes the overall division ratio less sensitive to changes in the burden of the connected metering or protection devices.

Although each of the 7 transformers listed have the same basic function of stepping up or stepping down of the voltage, the constructional features and even the operational features are different.

While generator transformers on the one hand have large capacity and can have relatively high inherent impedance, the low voltage distribution transformers have relatively small capacity and must have low impedance to meet the consumer demand. While the generator transformers, power transformers and distribution transformers must have low designed power loss, an accurate voltage ratio corresponding to turns ratio is not very important. On the other hand, instrument transformers are designed to have very high accuracy and handle only very low power.

Of all the components in the Power System, the distribution transformers when taken collectively, contributes most to the power loss. Thus it is important to use them efficiently.

1.2.1 Distribution transformers

Distribution transformers are step down transformers used in low voltage electric power distribution. They are relatively small in size (generally from 50 kVA to 630 kVA and rarely exceeding 5 MVA). They are designed for low voltage regulation and would have leakage reactances of around 5% [5]. They are generally filled with insulating oil. The smaller size of modern distribution transformers are of sealed type so that no moisture can get in and hence the absence of a conservator. With the development of technology, dry type transformers are produced but at a higher cost, especially when used indoor, with the intention of minimizing environmental contamination, fire hazard and less maintenance.

1.2.2 Transformer losses

The "power loss" in machine transformer is the difference between its input power and its output power. Since the transformer is a static device, mechanical losses are not applicable and only electrical losses occur. These are the core loss and conductor loss.

1.2.2.1 Core Loss (Iron Loss)

Core Losses (also sometimes known as Iron Losses) are the losses that occur in the core, and which depend on the magnetic properties of the material used for the construction of core. Eddy current loss and hysteresis loss are the principle core losses in a transformer.

a) Hysteresis Loss

Hysteresis loss is due to reversal of magnetization in the transformer core. This loss depends upon the volume and grade of the iron, frequency of magnetic reversals and value of flux density.

It can be given by, Steinmetz formula:

Hysteresis Loss per unit volume $W_h = \eta B_{max}^{1.6} f$

where, η is the Steinmetz hysteresis constant

B_{max} is the peak value of the alternating flux density, and

f is the frequency

b) Eddy current loss in transformer:

In a transformer, the AC current is supplied to the primary winding which sets up an alternating magnetizing flux. When this flux links with secondary winding, it produces induced emf in it. But some part of this flux also gets linked with other conducting parts like steel core or iron body or the transformer, which will result in induced emf in those parts, causing small circulating current in them. This current is called as eddy current. Due to these eddy currents, some energy will be dissipated in the form of heat.

Eddy current loss per unit volume = $\frac{4}{3}\frac{B_m^2 f^2 t^2 k^2}{\rho}$

where B_m is the peak value of the alternating flux density

f is the frequency

t is the thickness

ρ is the resistivity

As the Eddy current losses depends on the square of the thickness of the material, by forming the core out of laminations the eddy current losses are controlled to acceptable values.

It is to be noted that both the hysteresis loss as well as the eddy current loss depends on the flux density and hence the voltage and not the current. Thus the core loss does not depend on the load and hence are known as no-load losses.

1.2.2.2 Conductor losses

Conductor loss (commonly known as Copper loss) is due to ohmic resistance of the transformer windings. They occur in both the primary winding and the secondary winding.

Conductor loss for the primary winding = $I_1^2R_1$

Conductor loss for the secondary winding = $I_2^2R_2$

where, I_1 and I_2 are current in primary and secondary winding respectively,

R_1 and R_2 are the resistances of primary and secondary winding respectively.

It is clear that conductor loss is proportional to square of the current, and current depends on the load. Hence conductor loss in transformer varies with the load and known as load losses.

1.3 Topic of Research

1.3.1 Research Motivation

When I was about to embark on my research for my Master's degree, I thought about my experiences in industry. This led me to the many energy audits for Sri Lankan consumers where I had seen that they have identified over-sized transformers and the installation of excessive number of transformers giving rise to unnecessary no-load losses. Preliminary investigations revealed to me that the main reason for this being that the size of the transformer has not been properly sized considering the life-time cost to the consumer. I felt that determining a method to help the consumer and the designer to find the most optimum transformer for a particular application would be most opportune.

1.3.2 Problem Statement

In Sri Lanka, most of the bulk consumers have installed oversized transformers or excessive number of transformers without properly analysing their requirement. This leads to high energy cost due to transformer losses and creates considerable amount of loss to total electrical network. A proper study has not been carried out to minimize the unnecessary no load losses caused by transformers and guide users to do so at the design stage of a project.

2 LITERATURE REVIEW

2.1 Background

Sri Lanka is now almost fully electrified [6] and the quest now is to be able to meet the growth in demand efficiently. Currently, system losses in the CEB Power System has been reduced to around 10.9% [6]. Out of this around 8.7 % [6] is in the distribution system. However, how the losses distribute within the distribution network has not been published for the Sri Lankan System.

Much research has been done on the transformer losses [5, 7-9] and methods to calculate life cycle cost [10-12]. Some significant research papers are discussed in the following sections to identify research already carried out and to identify any research gap.

2.2 Technical papers reviewed

A recent study [13] has shown that in a typical urban scenario the distribution transformer can account for about 55% of the total distribution losses (around 33% no-load losses and 22% load losses) and in a typical rural scenario about 34% of the distribution losses can be attributed to the low voltage distributions lines and a further 34% from the distribution transformer (around 23% no-load losses and 11% load losses). It is thus essential for the proper selection of energy efficient transformers in the distribution system.

While it is realised that energy efficient transformers have a higher purchase price, it does not mean that overall cost to the consumer is higher because a higher efficiency transformer has a lower operational cost. Thus the effective cost of purchase of the transformer must be based on the transformer Life-Cycle Cost. This has been effectively shown by Weyerhaeuser [14], who makes it very clear how much savings may be possible by the use of properly selected transformer.

Table 2-1: Total Owning Cost Calculation Comparison

Option	Purchase Price	No-Load Loss (W)	Full-Load Loss (W)	15-Year Operating Cost	Total 15-Year Owning Cost
Low Efficiency	$1,336	375	2,829	$29,475	$30,811
High Efficiency	$3,214	190	993	$10,875	$14,084

Table 2-1 shows a result of the study where Olsun Electrics Corporation, provided a comparison of the cost of no-load and load losses of 75-kVA transformers. While the low-efficiency aluminium-wound transformer had an initial cost $1,336 the 15 year TOC was $30,811. The high-efficiency copper-wound unit cost $3,214 and had a 15 year TOC of $14,084. Both transformers have been evaluated on the assumption that they would operate continuously throughout the year.

J.P.R. Jayasinghe [5], in his Master of Science in Electrical Engineering dissertation in 2005 on "Segregation and Analysis of Distribution Losses and Mitigating Techniques" has discussed the fact that the distribution losses of the CEB are higher than that of developed countries, and that a detailed energy audit should be carried out to identify the areas where the loss level is high. He has gone on to describe the losses occurring in transformers and how the optimal capacity of the transformer can be selected based on the cost due to transformer losses, the load curve and estimate the Load Factor (LF) of the transformer. He has calculated the Load Loss Factor (LLF) and gone on to calculate the total annual losses of the transformer.

He has gone on to conclude that the major reasons for the high technical losses in the LV distribution system are the long length of low voltage lines and the over loading or over size transformers used.

He has related his findings to the distribution transformers and said that losses can be reduced by installing right capacity of transformers to the system

Kenneth Duane Harden [15] has optimized the Energy Efficiency Standards for Low Voltage Distribution Transformers. In his study, he investigates whether the current energy efficiency rulemaking in the US, that establishes transformer efficiency at only one point on the load curve, provides the level of energy savings expected by government rule makers, and evaluates alternate methods for specifying transformer efficiency. This study also attempts to characterize the operational load levels experienced by these transformers, including seasonal and daily load variations, and relates the operational load levels to the efficiency standard and alternate methods.

However, his study is limited to low voltage, dry type, distribution transformers and mainly focuses on reviewing the energy efficiency regulations that govern the measurement and specification of low voltage, dry type, and distribution transformers. Recommendations are presented for improving transformer rulemaking and for system considerations to realize higher energy savings in commercial and industrial facilities.

V. A. Kulkarni and P. K Katti[7] in their paper on Estimation of distribution transformer losses in feeder circuits have studied the significance of the loss due to distribution transformers is and its percentage contribution to the total input energy. He has found that in their system in the transformer losses for one month, while 100 kVA transformers contribute around 0.45%, 2000 kVA transformers contribute around 3.22% as seen in Table 2-3.

Table 2-2: Monthly Energy Loss of Total Transformer Circuit

SI No	Transformer size (kVA)	Qty	Energy Losses in Units (kWh)			Total Units (kWh)
			W_i	W_{wdg}	Other (Oil Joints, Life)	
1	100	15	3,240	4,410	810	8,460
2	200	10	3,384	4,752	1,230	9,220
3	315	07	3,108	4,656	1,020	7,864
4	500	15	9,720	13,799	2,340	25,839
5	1000	11	14,256	26,136	4,380	44,772
6	2000	10	21,600	31,680	7,110	60,390
Total Σ			**55,308**	**76,251**	**15,870**	**156,591**

Table 2-3: Rating Wise Transformer Losses for 1 Month

SI No	Transformer size (kVA)	Percentage (%) of Total input (import) Units (kWh)
1	100	0.45
2	200	0.50
3	315	0.63
4	500	1.38
5	1000	2.39
6	2000	3.22
Total Σ		**8.57**

Lloyd H. Dixon, Jr has discussed a research paper [8] on Eddy Current Losses in Transformer Windings and Circuit Wiring where he intended to explain why eddy current losses increase so dramatically with more winding layers, why paralleling thin strips doesn't work, how passive conductors (Faraday shields and current transformer windings) have high losses, and why increasing conductor surface area will actually worsen losses and parasitic inductance if the configuration is not correct.

Eleftherios I. et Al have discussed an Energy Efficient Transformer Selection Implementing Life Cycle Costs and Environmental Externalities [12]. The goal of their research has been to encourage electric utilities to install high-efficiency distribution transformers where they are cost-effective. This paper proposes a methodology that implements the complex economic analyses needed to accurately determine the emission reduction potential of high-efficiency distribution transformers.

The methodology properly introduces the environmental cost into the life cycle cost (total owning cost) calculations implemented by electric utilities, and its results are compared to the classical total owning cost (without environmental cost), indicating the importance of environmental aspects of transformer economy evaluation.

Moreover, a sensitivity analysis of the various factors involved in the transformer life cycle cost is implemented, factors such as the transformer loading profile, the specific characteristics of the network where the transformer is installed and the uncertainty of the environmental cost impact on the final energy cost.

K. B. M. I. Perera and J. R. Lucas have presented a paper [16] on the Software Guided Safe Loading of Transformers where the outcome of the research is a software package which has been developed based on IEC 60354: Loading guide for oil immersed power transformers. It identifies the risks involved and indicates how transformers may be loaded in excess of the nameplate rating (abnormal loading) without adverse effects for specific load curves.

The study shows that the results obtained for loss of life is more precise with the software package, than with the manual two step approximation. This will help to reduce unexpected future damage to the transformer. The practical results obtained for transformer voltage regulation shows that it has no significant effect on the distribution network at acceptable loading conditions above nameplate rating. Thus they recommend that maximum utilization of the transformer be made allowing loading beyond nameplate rating within specified limits.

K. B. M. I. Perera and J. R. Lucas have also published a paper [17] on the loading of transformers beyond nameplate rating. They have considered the consequences of loading a transformer beyond name-plate rating, namely the temperature increase of windings, insulation oil etc..., the increase in the leakage flux density outside the core giving rise to additional eddy current heating in metallic parts linked by the flux.

Consequently, the moisture and gas content in the insulation and in the oil increase with the temperature increase, and the bushings, tap-changers, cable-end connections and current transformers are exposed to higher stresses.

K. B. M. I. Perera and J. R. Lucas have also done research [16] on Estimation of Distribution Transformer Losses in Feeder Circuit, and have discussed in particular that the voltage drops caused by loading transformers above nameplate rating has no major effect on performance of induction motors other than for the reduction in the starting and maximum running torque, and that the maximum utilization of the transformer be made allowing loading beyond nameplate rating within specified limits.

W.D.A.S. Wijayapala, et Al has discussed Determination of Capitalization Values for No Load Loss and Load Loss in Distribution Transformers [11]. In this paper capitalization values for losses in distribution transformers used in Sri Lanka for rural, semi-urban and urban areas in Sri Lanka has calculated which can be used to calculate the total owning cost for a given area. By using the results of this, it is easy to compare two different transformers based on their designed no load losses and load losses

2.3 Research Gap

Having done a review of published literature on transformer cost and efficiency, and a gap in the literature in published research was identified.

Although several studies carried out for total owning cost, improving efficiency of transformers and the implication in loading of transformers beyond nameplate rating, most research has been done on improving the transformer design to reduce losses. The effect of installation of excessive number of transformers and a method to select optimum transformer for a given curve have not been discussed. Therefore it is important to determine the effect of oversized distribution transformers to the system.

The research has targeted to fill the above research gap and propose a method to evaluate the economic cost of a transformer in the Sri Lankan scenario. Further, industrial consumers have a problem of deciding the most cost effective transformer for their application. Hence the need of developing a computer programme to evaluate the cost of the transformer throughout its life time is important.

3 RESEARCH METHODOLOGY

3.1 Introduction

This research project systematically fills the research gap of optimizing distribution transformer selection by industrial users. This Chapter presents the methodology used in this project to fill the research gap.

The various stages of this methodology are detailed in the following sections.

3.2 Identification of Research Gap

Firstly a broad topic of research was identified, namely that of optimizing distribution transformer selection, based mainly on interest as I had worked overseas in an industrial concern, worked with a distribution transformer manufacturer and now in a commercial division with a supply authority.

A detailed literature review was carried out in order to identify a research gap and significant work has been given in the Literature Review chapter.

The effect of the no load losses to the system was examined from the literature survey carried out on various studies done on distribution systems. Further, the literature survey was concentrated on finding work done on two main areas. Firstly, determination of capitalization of no-load and load-losses in distribution transformers and secondly how transformers can be loaded beyond name plate rating without any adverse effects.

3.3 Theoretical Analysis

As the first step in the theoretical analysis, it was required to select a consumer base. Bulk consumers with installed capacity of more than or equal to 250kVA have been selected for the analysis. The second step was to determine whether to go for an approach that will discourage the use of oversize and excessive distribution transformers, or to develop a model to optimize the selection of the distribution transformers.

Having decided on the latter, sample data was collected from the bulk suppliers in North Western Province to analyse the effect of oversized transformers to the system. Then the average peak demand was taken for analysis of field data.

A survey was carried out to determine typical load curves of industrial consumers. Then at theoretical analysis was done for four different types of load curves to determine the effect of different factors to the total owning cost of the transformer.

3.4 Develop a Model to calculate the Total Owning Cost

Based on the theoretical calculations an algorithm was developed to calculate the total owning cost of a transformer for a given load curve. In this model the factors such as ability to load beyond nameplate rating, life time of the transformer and the time value of money have been considered. In addition to that as the transformer details depend on distribution voltage and since different tariffs are applicable to different types of industries, those details have been set as input variables in this software.

3.5 Validate the Model

Using the typical load curves, discounting factor, Life time of transformer and the tariff rates, the most economical transformer was determined from the designed software. For the same scenarios the most economical transformer was determined manually and compared to validate the model.

4 THEORETICAL ANALYSIS OF SIZING OF TRANSFORMERS

In a Power System, energy losses occur at each stage of the power system, starting from the generator transformers, to the high voltage transmission lines, power transformers, to the medium voltage distribution, to the distribution transformers and finally to the low voltage distribution lines. In Sri Lanka total system loss is 10.9% [6]. Out of that 8.7% [6] is in the distribution system which comes to 80% (8.7/10.9)of the total system loss.

4.1 Effect of the oversized transformers to the system

In this study, North Western Province has been taken as sample area to calculate the effect of the no load losses to the system. There were over 900 Bulk consumers registered in the province. Out of these bulk consumers, 330 consumers belong to the 90% of privately installed transformers, where the installed capacity is more than 250kVA. The actual installed transformer capacity of this group is 219MVA. However considering the highest demand during the recorded years 2013 and 2014, the required transformer capacity has been identified to be only 132MVA.

The annual losses due to no load losses of this group is 2.7 GWh which could have been reduced to 1.65 GWh. Since the CEB practices high voltage metering for billing purposes, these losses would probably not have been included in the total system losses, but as part of the consumer load.

The total Energy sold for North Western Province is 1,094 GWh [18] and the above mentioned losses add up to 0.247% (2.7 GWh /1094 GWh) of the total loss, where it could have been reduced to 0.151% (1.65 GWh /1094 GWh). Moreover the annual distribution loss in Distribution Division 1 is 8.1% [6]. Therefore are around 3.05% (0.247%/8.1%) due to the no load losses where it could be reduced to 1.85% (0.151%/8.1%).

4.2 Factors for proper sizing of transformers (life cycle cost)

There are various types of factors that affect the sizing of a transformer. These factors can be broadly grouped into technical factors, financial factors and production/business related factors and should be considered when sizing the transformer at the design stage.

4.2.1 Technical factors

One of the main technical factors is the distribution voltage which together with the transformer rating determines the current. However, for a particular system this voltage is fixed (400V in the Sri Lankan low voltage system). Thus the most important technical factor becomes the transformer losses, both no-load losses as well as full-load loss.

The no-load losses do not depend on the load but on the voltage and the transformer capacity. As the distribution voltage is fixed within somewhat tight limits, the no-load losses are generally considered as fixed. However, as the no-load loss is a fixed percentage of the transformer rating, the use of oversize transformers would unnecessarily increase the total no-load loss.

The load losses depend on the load current and the transformer capacity. In practice, consumers do not require a fixed load throughout the day, but in a varying manner dependent on the load curve, which thus becomes a very important parameter in the evaluation of load losses. In particular, while a certain load and duration would give a particular amount of energy and energy losses, double the load for half the time while giving the same useful energy would actually double the energy consumed. Thus two other important parameters in the evaluation of load loss is the value of the peak load and its duration. The choice of a higher capacity transformer would give a lower inherent winding resistance and hence lower load losses for the same current.

It is seen that for a given load, a higher capacity transformer would increase the no-load losses while reducing the load losses. Thus for a given load curve, there would be an optimum size of transformer that should be used, while also considering any foreseen growth in demand.

While for the utility, the consumer load would be continually growing, for a specific consumer getting the supply at medium voltage the load growth would not be continuous, but is planned steps. Thus while a distribution transformer owned by the utility would have to perhaps rate the transformer based on the growth over a reasonable period of time, a medium voltage consumer does not have to oversize his distribution transformer, but could go for an optimum transformer. In fact standards actually allow for the operation of a transformer for short periods of time over its name plate rating provided overheating of the transformer does not occur. This fact can also be used in the proper sizing of the transformer.

4.2.2 Financial factors

Cost of the electricity of a county is one of the main financial factors that need to be taken into account. If the cost of electricity is very low consumers tend to add inefficient equipment to the system. In Sri Lankan context the commercial and industrial consumers pay somewhat high electricity tariff in the world. Therefore it is important for businesses to go for efficient equipment.

When going for efficient equipment it follows high capital investment. Therefore it is very important to consider the total owning cost of the transformer as it is one of the major capital investment attached to the electrical system. When calculating the total owning cost, discounting factor and the transformer life span should be considered.

4.2.3 Production/business related factors

The cost of the electricity depends on the type of the business. In Sri Lanka there are five main categories of tariffs out of which three are relevant to businesses. Those categories are General Purpose, Industrial and Hotel. Current tariff applicable for each categories are as given in Table 4-1.

Table 4-2: Tariff Rates

Tariff Category	Maximum Demand Charge per Month (LKR/kVA)	Fixed Charge (LKR/month)	Energy Charge (LKR/kWh)	Consumption per month (kWh)
Industrial-1	–	600	10.80	<301
			12.20	>300
Industrial-2	1,100	3,000	20.50	Peak (18.30-22.30)
			11.00	Day (5.30-18.30)
			6.85	Off-peak (22.30-05.30)
Industrial-3	1,000	3,000	23.50	Peak (18.30-22.30)
			10.25	Day (5.30-18.30)
			5.90	Off-peak (22.30-05.30)
General-1	–	240	18.30	<301
			22.85	>300
General-2	1,100	3,000	26.60	Peak (18.30-22.30)
			21.80	Day (5.30-18.30)
			15.40	Off-peak (22.30-05.30)
General-3	1,000	3,000	25.50	Peak (18.30-22.30)
			20.70	Day (5.30-18.30)
			14.35	Off-peak (22.30-05.30)
Hotel-1	–	600	21.50	
Hotel-2	1,100	3,000	23.50	Peak (18.30-22.30)
			14.65	Day (5.30-18.30)
			9.80	Off-peak (22.30-05.30)
Hotel-3	1,000	3,000	22.50	Peak (18.30-22.30)
			13.70	Day (5.30-18.30)
			8.80	Off-peak (22.30-05.30)
Distribution			15.5	Peak (18.30-22.30)
			9.5	Day (5.30-18.30)
			5.9	Off-peak (22.30-05.30)

Even the Operation pattern (daytime operation, shift operation, 24×7 etc…), and the growth of the business matters when selecting the economic analysis. In addition to that the interest in energy saving projects shall affect the load pattern and will reduce the consumption. Also if the management is interest in alternative electricity options such as solar, diesel generators etc. the energy cost shall be change accordingly.

4.3 Typical load patterns considered

In this study, only the technical and the financial factors along with the tariff are considered together with four typical load patterns, namely.

a) Type A: Distribution Load Curve
b) Type B: Industry with varying load during the day time
c) Type C: Industry with varying load during the day time and night time
d) Type D:Industry operate in shifts with varying load during the day time and night time

It is assumed that all four load curves have same peak load (700kVA) and. The load patterns are described in the following sections.

4.3.1 Type A Load Curve: Distribution Load Curve

The first load curve considered in the theoretical evaluation is the representation of a commercial type of load consuming a constant amount of power from 6am to 6pm as shown in Figure 4-1.

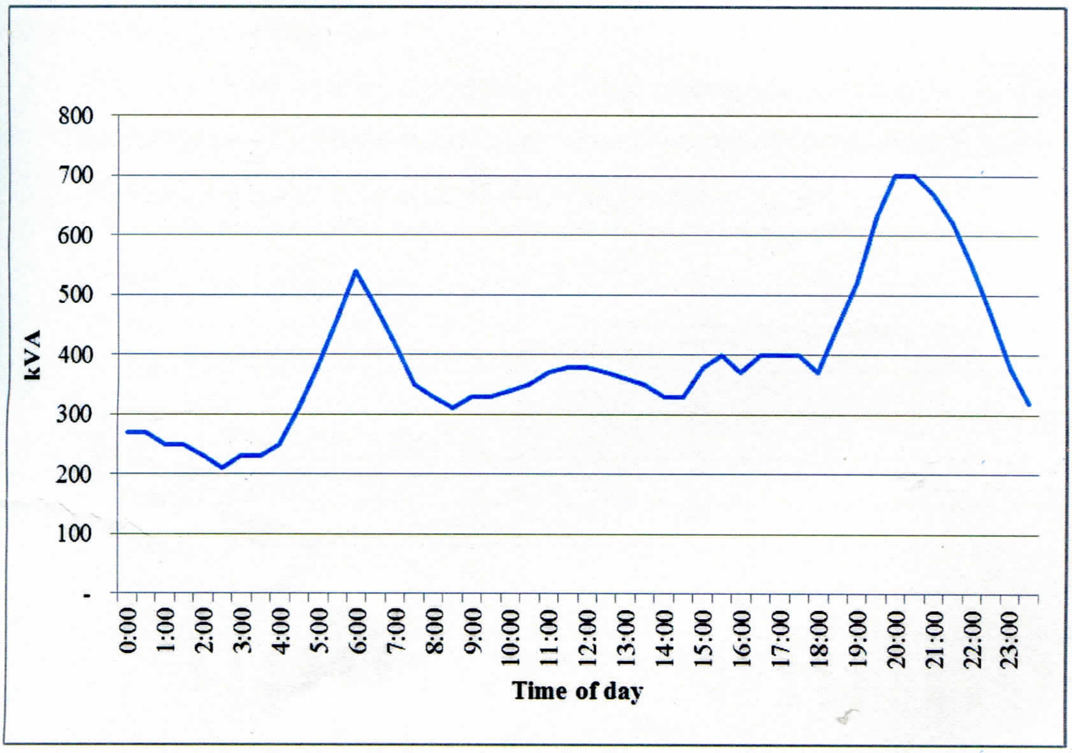

Figure 4-1: Type A load curve

4.3.2 Type B Load Curve:

The second load curve considered in the theoretical evaluation is the representation of a load consuming a varying amount of power during the daytime, typically factory as shown in Figure 4-2.

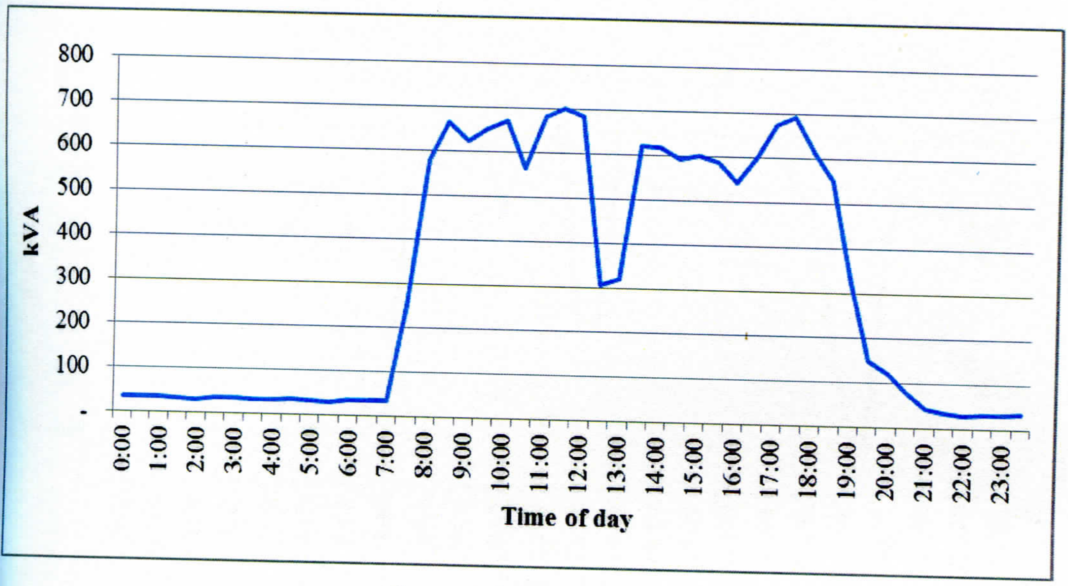

Figure 4-2: Type B load curve

4.3.3 Type C Load Curve:

The third load curve considered in the theoretical evaluation is the representation of a load consuming a varying amount of power during the day and night, Typically a Hotel as shown in Figure 4-3.

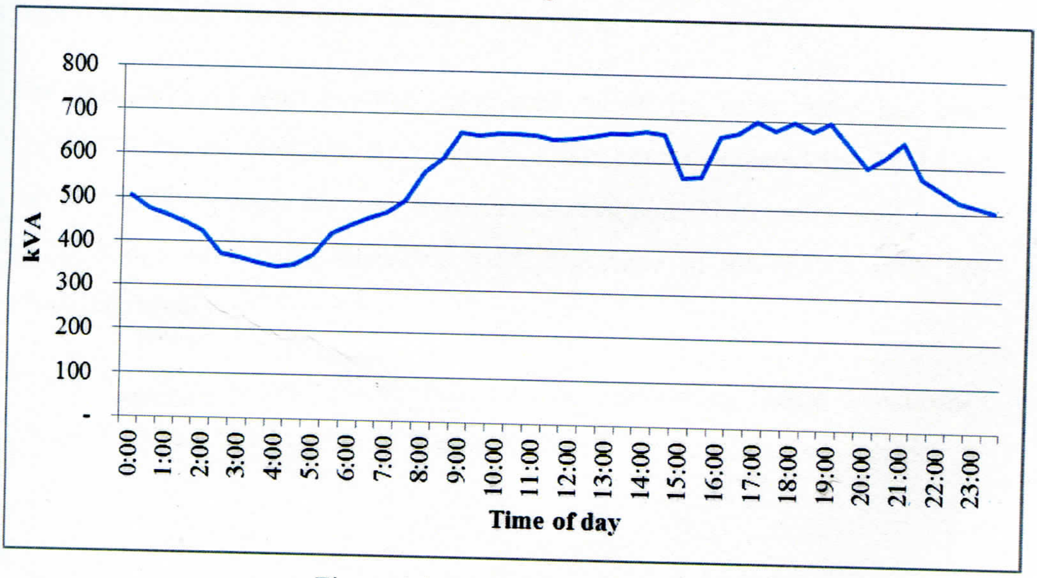

Figure 4-3: Type C load curve

4.3.4 Type D Load Curve:

The fourth load curve considered in the theoretical evaluation is the representation of a load consuming a varying amount of power during the day and night as shown in Figure 4-4.

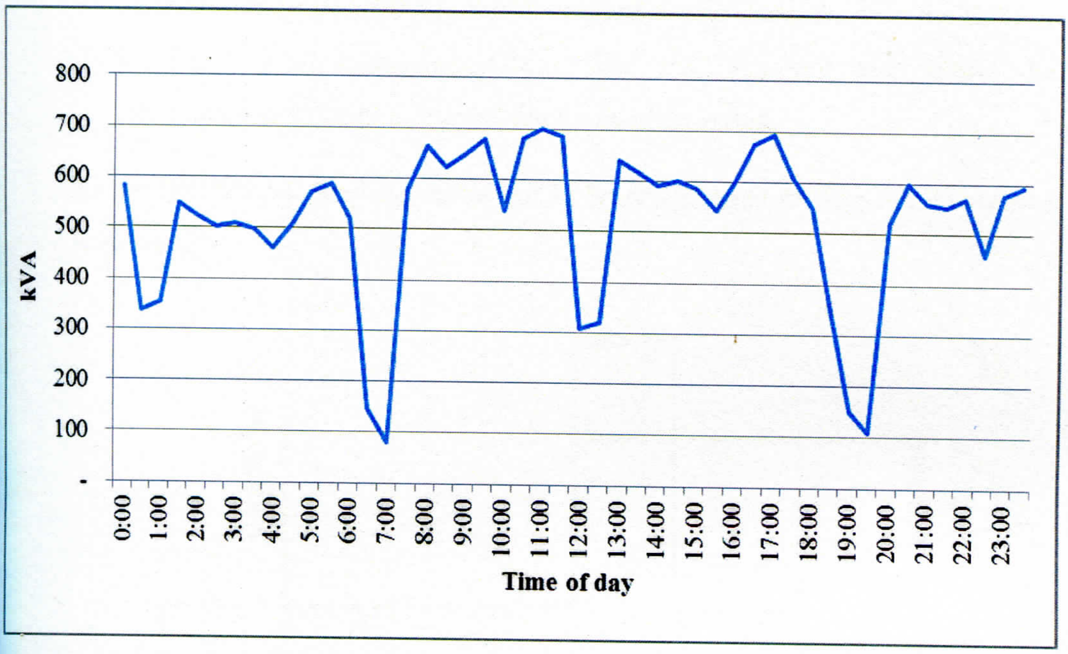

Figure 4-4: Type D load curve

Since the peak load is 700kVA the selected transformer combinations as 1×630 kVA, 1×800 kVA, 1×1000 kVA, 1×1250 kVA, 2×630 kVA, 2×400 kVA have been used, which can be used for each load curve.

The possibility to load beyond name pate raring for each curve has been considered for the analysis. Accordingly it has been calculated the total load losses & no load losses for each transformer selection. Then the present values of the losses have been calculated for the lifetime of the transformers and added the initial cost.

Finally the effect of each factor, load pattern, discounting factor, transformer life cycle and the tariff rate have been considered for the total owning cost.

4.4 Assumptions and Standards

a) All transformers have been assumed to be oil immersed and with cooling type ONAN.

b) IEC 60354Loading guide for oil-immersed power transformers permits transformers to be load beyond nameplate rating dependent on the time of loading beyond nameplate rating. The IEC standard also limits the continuous loading to 1.5 times the name plate rating.

As per IEC 60354, the load curve has to be represented in simplified two step load curve.

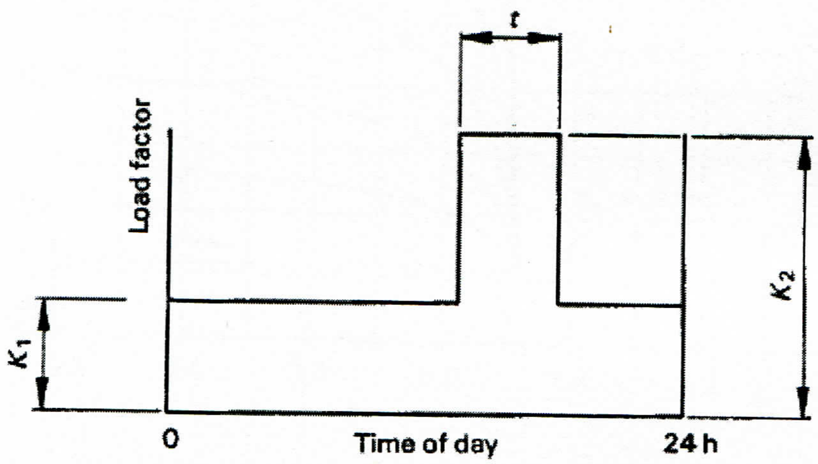

Figure 4-5: Equivalent two step load curve according to IEC 60354

Figure 4-6 describes how to check the possibility to load the transformer beyond nameplate rating after representing the load curve in two step load curve.

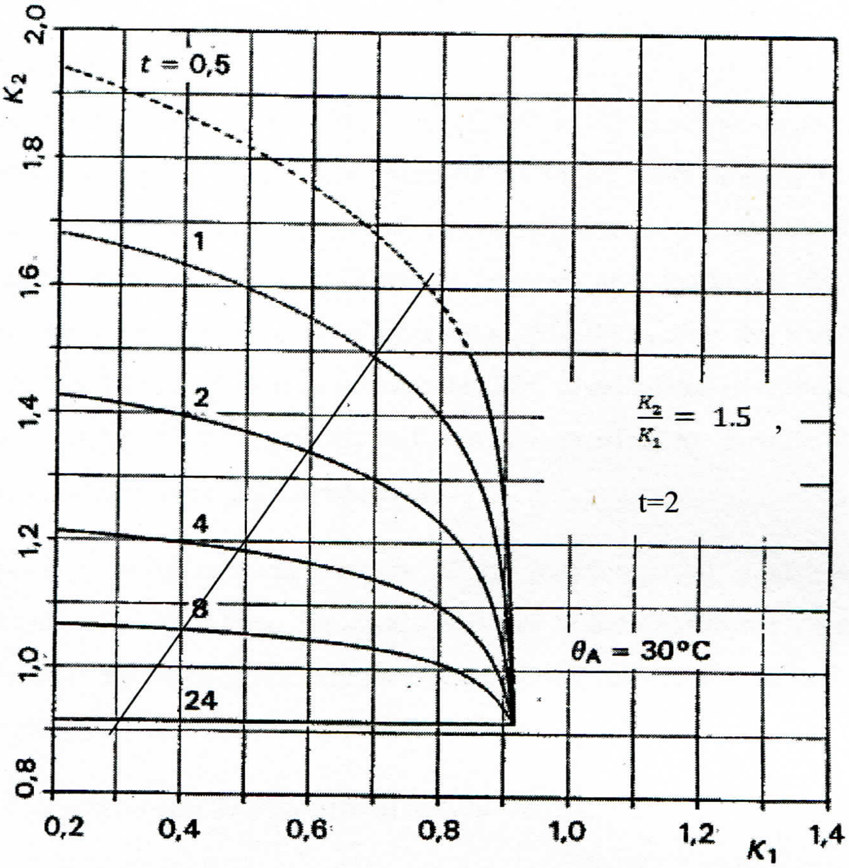

Figure 4-6 : Overload curve according to IEC 60354

As given in above example if the K2/K1 = 1.5 and t=2, it can be safely load for 1.325 times the nameplate rating value. If the transformer is 1000kVA for load pattern as explained above it can be safely loaded up to 1325kVA.

5 TOTAL OWNING COST OF TRANSFORMERS

5.1 Background

Transformers usually have a life time of around 30 years in operation and therefore to acquire a unit only based on its initial costs basis is not fully logical. The total owning cost (TOC) of a transformer is actually the lifetime cost of the transformer and takes into account not only the initial cost of the transformer, but also the cost of operating and maintaining the transformer over its full lifetime. This requires that the TOC is calculated over the lifetime of the transformer. With this method it is now possible to calculate the real economic choice for a given load pattern.

To perform an economical analysis of the transformer, it is necessary to calculate its life cycle cost. The capitalized cost of the transformer, comparing the costs of purchasing, operating and maintaining the transformer and taking into account the time value of money.

The TOC can be basically calculated as follows:

TOC = Initial Cost of Transformer + Cost of No-load Losses + Cost of Load Losses [14]

Table 5-1: Cost of no load and load losses of 75 kVA transformer

Total 15-Year Owning Cost	**15-Year Operating Cost**	**Full-Load Loss (W)**	**No-Load Loss (W)**	**Purchase Price**	**Option**
$30,811	$29,475	2,829	375	$1,336	Low Efficiency
$14,084	$10,875	993	190	$3,214	High Efficiency

Table 5-1 shows a result of a typical study where Olsun Electrics Corporation, provided a comparison of the cost of no-load and load losses of 75kVA transformers. While the low-efficiency aluminium-wound transformer had an initial cost $1,336 the 15 year TOC was $30,811. The high-efficiency copper-wound unit cost $3,214 and had a 15 year TOC of $14,084. Both transformers have been evaluated on the assumption that they would operate continuously throughout the year.

5.2 Total Owning Cost Calculation Software

The determination of the total ownership cost of a transformer could be somewhat tedious unless a software tool is developed for that purpose. The software has been developed in Microsoft Excel using Visual Basic for a user friendly graphical user interface.

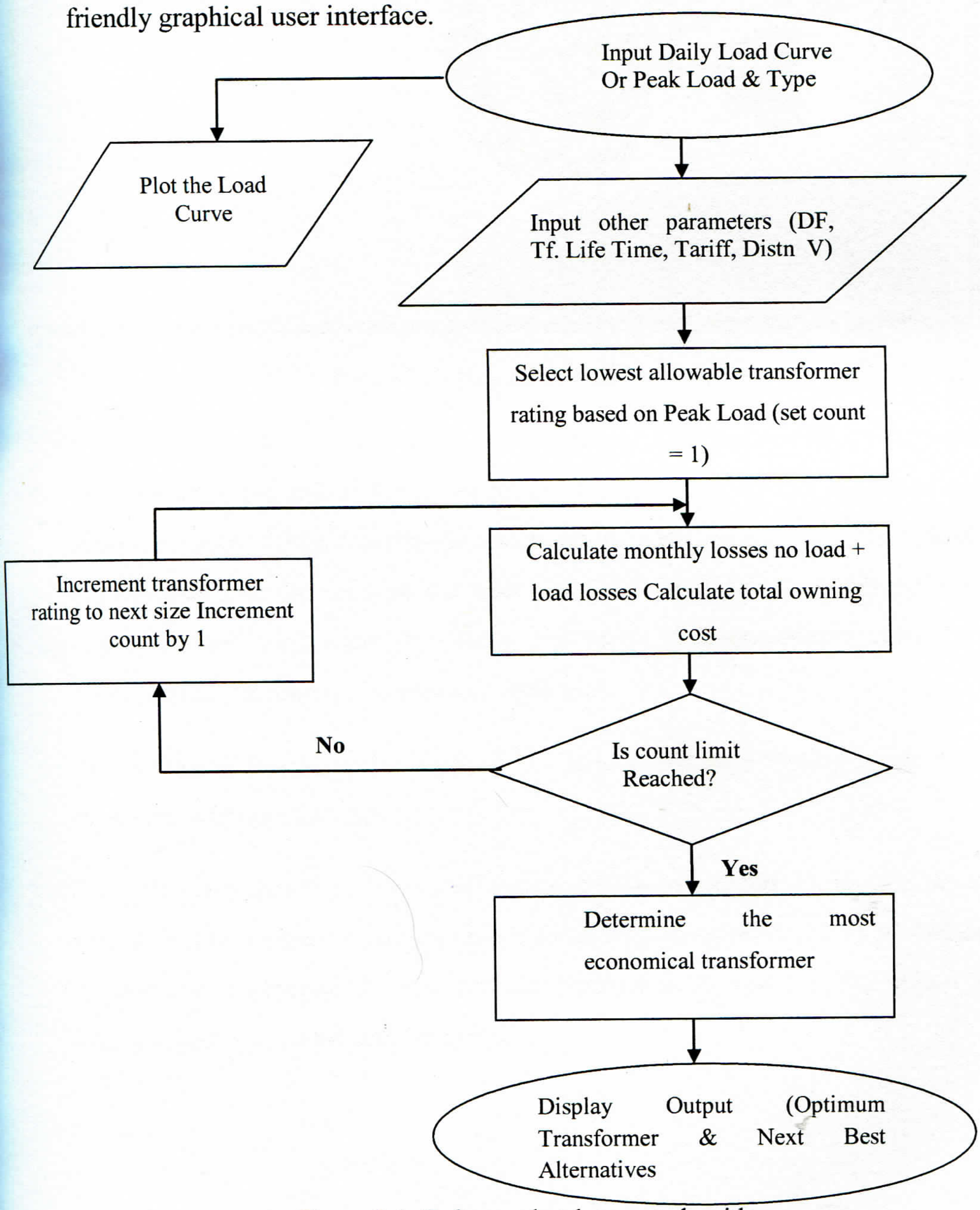

Figure 5-1: Software development algorithm

Figure 5-2 shows the main user-form from where the customer can start to enter his data.

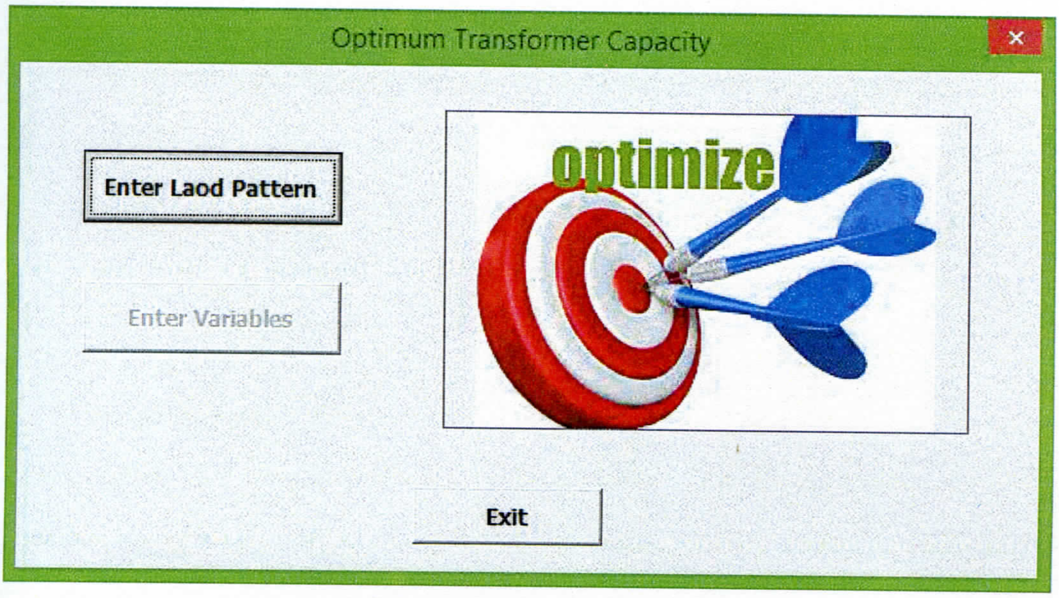

Figure 5-2: Interface of the software

The form requests the consumer to insert his load pattern in 15 minutes intervals or select one of the given load patterns and insert the minimum and maximum load. When entering the load pattern, provision is there for leaving out repeated data with at least the load changing points filled, so that software can create the load curve by filling the blank data considering that it is equivalent to the load in the previous time slot.

The consumer has to option to view the load paten as a plotted graph if he wants and confirm the data.

Then the program needs the system parameters to be entered. Figure 6.2 shows that at commencement all the fields are filled with the typical values so that the consumer can proceed if those are acceptable but he also has the option to change according to his requirements.

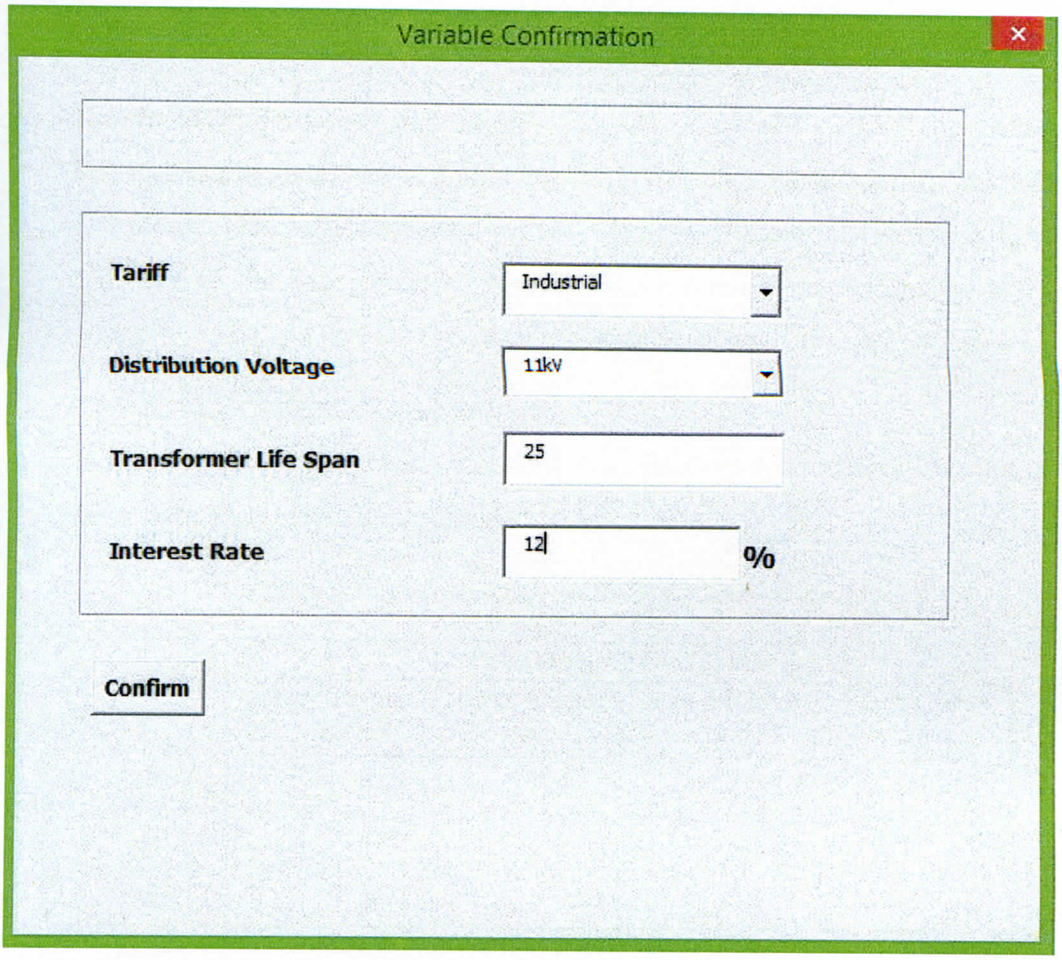

Figure 5-3: Variable inputs

Once the entered data is confirmed the program determines and displays the optimum transformer selection and two next best transformer selections as seen in Figure 5-4.

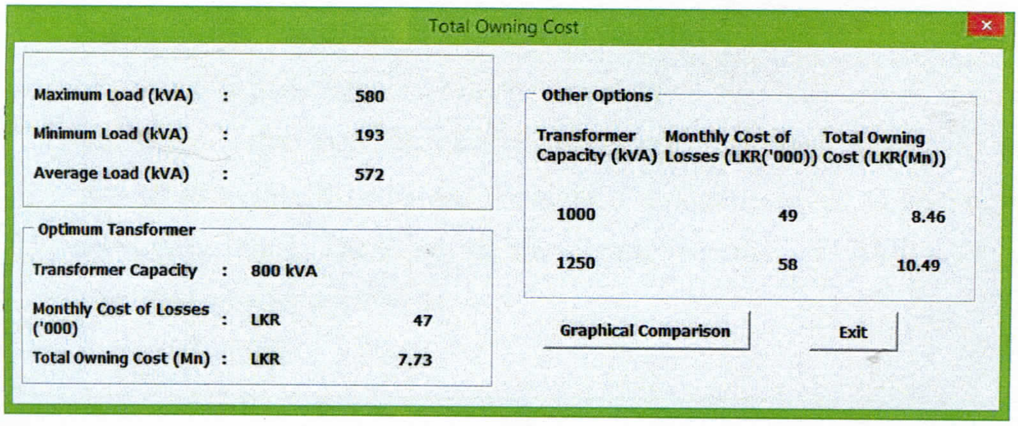

Figure 5-4: Results–Evaluated best transformers

6 RESULTS

6.1 Results of the Theoretical Analysis

For the results given below following factors considered as normal scenario. The normal load pattern selected is Load curve C, Discounting Factor as 12%. Life time of the transformer as 30 years and the tariff rate applicable is H3. However it is noted that the results of the theoretical analysis were as follows.

6.1.1 Scenario 1 - Effect of Load Pattern

In this scenario it has been compared four different load curves keeping all other three factors remain unchanged.

Table 6-1: Total owning cost for different load curves

Transformer combination	Total Owning Cost (LKR (Mn))			
	Load Curve A	Load Curve B	Load Curve C	Load Curve D
630 × 1	4.31	4.17	5.15	4.78
800 × 1	4.68	4.56	5.33	5.04
1000 × 1	5.02	4.93	5.55	5.32
1250 × 1	6.09	6.02	6.46	6.30
630 × 2	6.95	6.88	7.37	7.19
400 × 2	5.57	5.44	6.31	5.99

If the load patterns is with a considerable peak load compared to average load it is economical to select a transformer with a nameplate rating of lower value than to the peak load. However it need to be check the possibility of loading beyond name plate rating, when creating the two step load curves to sample load curves other than Distribution load pattern all other curves had peak demand more than 8 hours and therefore it was not possible to load beyond name plate rating. Therefore the transformer selection of 1x630 kVA was applicable only for the load curve A.

6.1.2 Scenario 2– Effect of discounting factor

Three different discounting factors considered for this analysis. Two different discounting factors considered for the evaluation in addition to 12%

Table 6-2: Total owning cost for different discounting factors

Transformer combination	Total Owning Cost (LKR (Mn))		
	15%	12%	5%
800 × 1	4.83	5.33	7.79
1000 × 1	4.99	5.46	7.76
1250 × 1	6.00	6.46	8.72
630 × 2	6.83	7.37	10.02
400 × 2	5.73	6.31	9.16

When the Discounting Factor is low the operating cost is much considerable for the Total Owning Cost. As per the above results, if the discounting factor is 5% the 1000kVA Transformer has become the optimum transformer. The IRR value for the given scenario is 5.73%, where it is the discounting rate which changes the optimum solution 800kVA transformer to 100kVA transformer

6.1.3 Scenario 3 : Effect of Transformer Life time

Three different life times considered for this analysis, which are 35, 30 and 25.

Table 6-3: Total owning cost for different transformer life times

Transformer combination	Total Owning Cost (LKR (Mn))		
	25Yrs	30Yrs	35Yrs
800 × 1	5.27	5.33	5.36
1000 × 1	5.40	5.46	5.49
1250 × 1	6.41	6.46	6.50
630 × 2	7.30	7.37	7.41
400 × 2	6.24	6.31	6.35

The optimum transformer selection is not varying with the change of the transformer life time. However the total owning cost changes with the transformer life time in an exponential pattern.

6.1.4 Scenario 4: Effect of Tariff

The third tariff range of all four types of tariffs applied for the selected Load Curve.

Table 6-4: Total owning cost for different tariffs

Transformer combination	Total Owning Cost (LKR (Mn))			
	Industrial 3	Hotel 3	General Purpose 3	Distribution
800 × 1	4.86	5.33	6.48	4.53
1000 × 1	5.11	5.46	6.63	4.80
1250 × 1	6.03	6.46	7.53	5.73
630 × 2	6.86	7.37	8.62	6.51
400 × 2	5.77	6.31	7.64	5.38

The optimum transformer selection is 800kVA transformer for each category.

6.2 Results of the software analysis

Same scenarios analysed in Section 6.1 has been module in the software and it gives the results same as the theoretical values calculated manually.

6.2.1 Scenario 1 - Effect of Load Pattern

The results are same as the theoretical analysis as represent in the Table 6-5.

Table 6-5: Total owning cost from Software for different discounting factors

Transformer combination	Total Owning Cost (LKR (Mn))			
	Load Curve A	Load Curve B	Load Curve C	Load Curve D
630 × 1	4.31	Not Calculated	Not Calculated	Not Calculated
800 × 1	4.68	4.56	5.33	5.04
1000 × 1	5.02	4.93	5.55	5.32
1250 × 1	Not Calculated	6.02	6.46	6.30

As per the results obtained using the software shows that gives the same results as the manual calculation and even more the software has checked the possibility of loading beyond nameplate rating and eliminated the calculations for such transformer capacities.

6.2.2 Scenario 2– Effect of discounting factor

Same results have been obtained validating the model.

Table 6-6: Total owning cost from software for different discounting factors

Transformer combination	Total Owning Cost (LKR (Mn))		
	15%	12%	5%
800 × 1	4.83	5.33	7.79
1000 × 1	4.99	5.46	7.76
1250 × 1	6.00	6.46	8.72

6.2.3 Scenario 3: Effect of Transformer Life time

Same results have been obtained validating the model.

Table 6-7: Total owning cost for different transformer life times

Transformer combination	Total Owning Cost (LKR (Mn))		
	25Yrs	30Yrs	35Yrs
800 × 1	5.27	5.33	5.36
1000 × 1	5.40	5.46	5.49
1250 × 1	6.41	6.46	6.50

6.2.4 Scenario 4: Effect of Tariff

Same results have been obtained validating the model.

Table 6-8: Total owning cost for different tariffs

Transformer combination	Total Owning Cost (LKR (Mn))			
	Industrial 3	Hotel 3	General Purpose 3	Distribution
800 × 1	4.86	5.33	6.48	4.53
1000 × 1	5.11	5.46	6.63	4.80
1250 × 1	6.03	6.46	7.53	5.73

7 CONCLUSIONS AND RECOMMENDATIONS

The study has been identified that there is a considerable effect of unnecessary no-load losses to the system. North Western Province has been considered as the sample area for the research, and it has been found that the installed transformer capacity is more than double the minimum required transformer capacity. Due to this excessive transformer capacity, an additional 1GWh is lost to the electricity network as unnecessary losses. It counts to 0.1% of the total energy sales and 1.15% of the distribution losses.

Having identified that there is a considerable effect of unnecessary no load losses to the system, a software has been developed to do the proper sizing of transformers for a given load pattern considering total owning cost. This software has been validated by comparing the total owning costs of the optimum solution and the next best alternative with manual calculated results for four typical load curves representing distribution, single shift factory, hotel and two shift factory. Results show that impact of discounting factor and the tariff category have a major impact on the optimum transformer selection, whereas the total life time of the transformer, while affecting the total owning cost does not seem to affect the optimum transformer selection. In addition to the above factors, the ability to load beyond nameplate rating of transformer has been considered for the optimum transformer selection, which depends on the load curve.

The developed software has the ability to select the distribution voltage of the area, and either enter a load curve manually or select one of three typical load patterns (these can be increased without much difficulty in the future), select a tariff category, specify a discounting factor and specify the transformer lifetime. The software then determines the most optimum and the second best alternative comparing the total owning cost. The software can be used by industrial consumers and consultants to identify the optimal transformer capacity required for a particular application.

7.1 Limitations

This software is basically developed by considering the losses of the transformers of "LTL Transformers (Pvt) Ltd. as it is the main transformer supplier to the Sri Lankan market. In addition, the current tariff scheme has been used together with the 2016 prices of transformers for the comparison, in the software.

The drawback of this process is the difficulty in predicting the future load profile and electricity costs and tariffs with confidence and the change of initial costs, which needs to be updated at least once a year. In addition this software has not considered the material prices, particularly the cost of conductor which varies with the location of the installation of the transformer.

7.2 Recommendations and Further Work

Further the analysis of the effect of load losses and the no load losses of distribution transformers to the system can be carried out for the total electricity network to get the actual statistics, which can be used to educate people during energy audits.

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ANNEXURE

Software Code

Main User Form

//Display User Form 'Load Curve Method' to select the method to enter the load curve//

```
Private Sub CommandButton1_Click()
    frmLoadCurveMethod.Show
End Sub
```

//Display User Form 'Variable Confirmation' to enter the variable data required for calculation//

```
Private Sub CommandButton2_Click()
    frmVariableConfirmation.Show
End Sub
```

//Exit form the Main User Form//

```
Private Sub CommandButton3_Click()
    Unload Me
    Application.DisplayAlerts = True
End Sub
```

//Load the image inthe Main User Form & Disaable the Variable Confiamation Button at the Initial Stage//

```
Private Sub UserForm_Initialize()
    Image1.Picture = LoadPicture("C:\Users\HP\Pictures\HP Wall.jpg")
    CommandButton2.Enabled = False
End Sub
```

Load Curve Method User Form

```
Private Sub CommandButton2_Click()
//Display User Form frmLoadPattern to enter the load values//
    formLoadPattern.Show
```

//Set the method as'Nil' to Export Direct data entered in the User Form 'Load Pattern'//

```
    Dim wb As Workbook
    Dim ws As Worksheet

    Set wb = ActiveWorkbook
    Set ws = Sheets("Variable Confirmation")
    ws.Cells(5, 10).Value = "Nil"
//Exit from User Form LoadPattern//
    Unload Me
```

```
End Sub

//Display User Form 'Load Pattern' to enter the load values//
   Private Sub CommandButton3_Click()
      frmTypicalLoadCurves.Show
      Unload Me
   End Sub
```

Load Pattern User Form

```
Sub Activate_Workbook()
  //Activate Workbook//
      Workbooks("Final Working.xlsm").Activate

 //Activate Worksheet//
      Workbooks("Final Working.xlsm").Sheets("Variable
Confirmation").Activate
End Sub

//Display Load Pattern Entered//
   Private Sub cmd_Load_Load_Pattern_Click()
      frmLoadPatternGraph.CommandButton1.Value = True
      frmLoadPatternGraph.Show
   End Sub

Private Sub cmdBack_Click()
   End
End Sub

//Activate Command to Confirm the Load Pattern Entered//
Private Sub cmdConfirm_Click()
   CmdConfirmLoadPattern.Value = True

//clear data once Confirm the data//
   L0000.Text = ""
   MainUserForm.CommandButton2.Enabled = True
 End Sub

//Load the Entered Pattern to Excel Sheet//
Public Sub CmdConfirmLoadPattern_Click()
  Dim wb As Workbook
  Dim ws As Worksheet
  Set ws = Sheets("Variable Confirmation")

//validate first three controls have been entered//
   If Me.L0000.Text = Empty Then 'h0000
```

```
        MsgBox "Please enter Load at 0000h.", vbExclamation
        Me.L0000.SetFocus 'position cursor to try again
        Exit Sub 'terminate here - why continue?
    End If

//If a field kept unfilled fill that with the value of the previous field//
    If Me.L0015.Text = Empty Then 'h0015
        Me.L0015.Text = Me.L0000.Text
    End If
    If Me.L0030.Text = Empty Then 'h0030
        Me.L0030.Text = Me.L0015.Text
    End If
    If Me.L0045.Text = Empty Then 'h0045
        Me.L0045.Text = Me.L0030.Text
    End If
    If Me.L0100.Text = Empty Then 'h0100
        Me.L0100.Text = Me.L0045.Text
    End If
     If Me.L0115.Text = Empty Then 'h0115
        Me.L0115.Text = Me.L0100.Text
    End If
    If Me.L0130.Text = Empty Then 'h0130
        Me.L0130.Text = Me.L0115.Text
    End If
    If Me.L0145.Text = Empty Then 'h0145
        Me.L0145.Text = Me.L0130.Text
    End If
    If Me.L0200.Text = Empty Then 'h0200
        Me.L0200.Text = Me.L0145.Text
    End If
    If Me.L0215.Text = Empty Then 'h0215
        Me.L0215.Text = Me.L0200.Text
    End If
    If Me.L0230.Text = Empty Then 'h0230
        Me.L0230.Text = Me.L0215.Text
    End If
    If Me.L0245.Text = Empty Then 'h0245
        Me.L0245.Text = Me.L0230.Text
    End If
    If Me.L0300.Text = Empty Then 'h0300
        Me.L0300.Text = Me.L0245.Text
    End If
     If Me.L0315.Text = Empty Then 'h0315
        Me.L0315.Text = Me.L0300.Text
    End If
    If Me.L0330.Text = Empty Then 'h0330
        Me.L0330.Text = Me.L0315.Text
```

```
End If
If Me.L0345.Text = Empty Then 'h0345
    Me.L0345.Text = Me.L0330.Text
End If
If Me.L0400.Text = Empty Then 'h0400
    Me.L0400.Text = Me.L0345.Text
End If
If Me.L0415.Text = Empty Then 'h0415
    Me.L0415.Text = Me.L0400.Text
End If
If Me.L0430.Text = Empty Then 'h0430
    Me.L0430.Text = Me.L0415.Text
End If
If Me.L0445.Text = Empty Then 'h0445
    Me.L0445.Text = Me.L0430.Text
End If
If Me.L0500.Text = Empty Then 'h0500
    Me.L0500.Text = Me.L0445.Text
End If
If Me.L0515.Text = Empty Then 'h0515
    Me.L0515.Text = Me.L0500.Text
End If
If Me.L0530.Text = Empty Then 'h0530
    Me.L0530.Text = Me.L0515.Text
End If
If Me.L0545.Text = Empty Then 'h0545
    Me.L0545.Text = Me.L0530.Text
End If
If Me.L0600.Text = Empty Then 'h0600
    Me.L0600.Text = Me.L0545.Text
End If
If Me.L0615.Text = Empty Then 'h0615
    Me.L0615.Text = Me.L0600.Text
End If
If Me.L0630.Text = Empty Then 'h0630
    Me.L0630.Text = Me.L0615.Text
End If
If Me.L0645.Text = Empty Then 'h0645
    Me.L0645.Text = Me.L0630.Text
End If
If Me.L0700.Text = Empty Then 'h0700
    Me.L0700.Text = Me.L0645.Text
End If
If Me.L0715.Text = Empty Then 'h0715
    Me.L0715.Text = Me.L0700.Text
End If
If Me.L0730.Text = Empty Then 'h0730
```

```
    Me.L0730.Text = Me.L0715.Text
End If
If Me.L0745.Text = Empty Then 'h0745
    Me.L0745.Text = Me.L0730.Text
End If
If Me.L0800.Text = Empty Then 'h0800
    Me.L0800.Text = Me.L0745.Text
End If
If Me.L0815.Text = Empty Then 'h0815
    Me.L0815.Text = Me.L0800.Text
End If
If Me.L0830.Text = Empty Then 'h0830
    Me.L0830.Text = Me.L0815.Text
End If
If Me.L0845.Text = Empty Then 'h0845
    Me.L0845.Text = Me.L0830.Text
End If
If Me.L0900.Text = Empty Then 'h0900
    Me.L0900.Text = Me.L0845.Text
End If
 If Me.L0915.Text = Empty Then 'h0915
    Me.L0915.Text = Me.L0900.Text
End If
If Me.L0930.Text = Empty Then 'h0930
    Me.L0930.Text = Me.L0915.Text
End If
If Me.L0945.Text = Empty Then 'h0945
    Me.L0945.Text = Me.L0930.Text
End If
If Me.L1000.Text = Empty Then 'h1000
    Me.L1000.Text = Me.L0945.Text
End If
If Me.L1015.Text = Empty Then 'h1015
    Me.L1015.Text = Me.L1000.Text
End If
If Me.L1030.Text = Empty Then 'h1030
    Me.L1030.Text = Me.L1015.Text
End If
If Me.L1045.Text = Empty Then 'h1045
    Me.L1045.Text = Me.L1030.Text
End If
If Me.L1100.Text = Empty Then 'h1100
    Me.L1100.Text = Me.L1045.Text
End If
 If Me.L1115.Text = Empty Then 'h1115
    Me.L1115.Text = Me.L1100.Text
End If
```

```
If Me.L1130.Text = Empty Then 'h1130
   Me.L1130.Text = Me.L1115.Text
End If
If Me.L1145.Text = Empty Then 'h1145
   Me.L1145.Text = Me.L1130.Text
End If
If Me.L1200.Text = Empty Then 'h1200
   Me.L1200.Text = Me.L1145.Text
End If
If Me.L1215.Text = Empty Then 'h1215
   Me.L1215.Text = Me.L1200.Text
End If
If Me.L1230.Text = Empty Then 'h1230
   Me.L1230.Text = Me.L1215.Text
End If
If Me.L1245.Text = Empty Then 'h1245
   Me.L1245.Text = Me.L1230.Text
End If
If Me.L1300.Text = Empty Then 'h1300
   Me.L1300.Text = Me.L1245.Text
End If
 If Me.L1315.Text = Empty Then 'h1315
   Me.L1315.Text = Me.L1300.Text
End If
If Me.L1330.Text = Empty Then 'h1330
   Me.L1330.Text = Me.L1315.Text
End If
If Me.L1345.Text = Empty Then 'h1345
   Me.L1345.Text = Me.L1330.Text
End If
If Me.L1400.Text = Empty Then 'h1400
   Me.L1400.Text = Me.L1345.Text
End If
If Me.L1415.Text = Empty Then 'h1415
   Me.L1415.Text = Me.L1400.Text
End If
If Me.L1430.Text = Empty Then 'h1430
   Me.L1430.Text = Me.L1415.Text
End If
If Me.L1445.Text = Empty Then 'h1445
   Me.L1445.Text = Me.L1430.Text
End If
If Me.L1500.Text = Empty Then 'h1500
   Me.L1500.Text = Me.L1445.Text
End If
 If Me.L1515.Text = Empty Then 'h1515
   Me.L1515.Text = Me.L1500.Text
```

```
End If
If Me.L1530.Text = Empty Then 'h1530
   Me.L1530.Text = Me.L1515.Text
End If
If Me.L1545.Text = Empty Then 'h1545
   Me.L1545.Text = Me.L1530.Text
End If
If Me.L1600.Text = Empty Then 'h1600
   Me.L1600.Text = Me.L1545.Text
End If
If Me.L1615.Text = Empty Then 'h1615
   Me.L1615.Text = Me.L1600.Text
End If
If Me.L1630.Text = Empty Then 'h1630
   Me.L1630.Text = Me.L1615.Text
End If
If Me.L1645.Text = Empty Then 'h1645
   Me.L1645.Text = Me.L1630.Text
End If
If Me.L1700.Text = Empty Then 'h1700
   Me.L1700.Text = Me.L1645.Text
End If
 If Me.L1715.Text = Empty Then 'h1715
   Me.L1715.Text = Me.L1700.Text
End If
If Me.L1730.Text = Empty Then 'h1730
   Me.L1730.Text = Me.L1715.Text
End If
If Me.L1745.Text = Empty Then 'h1745
   Me.L1745.Text = Me.L1730.Text
End If
If Me.L1800.Text = Empty Then 'h1800
   Me.L1800.Text = Me.L1745.Text
End If
If Me.L1815.Text = Empty Then 'h1815
   Me.L1815.Text = Me.L1800.Text
End If
If Me.L1830.Text = Empty Then '10830
   Me.L1830.Text = Me.L1815.Text
End If
If Me.L1845.Text = Empty Then 'h1845
   Me.L1845.Text = Me.L1830.Text
End If
If Me.L1900.Text = Empty Then 'h1900
   Me.L1900.Text = Me.L1845.Text
End If
 If Me.L1915.Text = Empty Then 'h1915
```

```
    Me.L1915.Text = Me.L1900.Text
End If
If Me.L1930.Text = Empty Then 'h1930
    Me.L1930.Text = Me.L1915.Text
End If
If Me.L1945.Text = Empty Then 'h1945
    Me.L1945.Text = Me.L1930.Text
End If
If Me.L2000.Text = Empty Then 'h2000
    Me.L2000.Text = Me.L1945.Text
End If
If Me.L2015.Text = Empty Then 'h2015
    Me.L2015.Text = Me.L2000.Text
End If
If Me.L2030.Text = Empty Then 'h2030
    Me.L2030.Text = Me.L2015.Text
End If
If Me.L2045.Text = Empty Then 'h2045
    Me.L2045.Text = Me.L2030.Text
End If
If Me.L2100.Text = Empty Then 'h2100
    Me.L2100.Text = Me.L2045.Text
End If
 If Me.L2115.Text = Empty Then 'h2115
    Me.L2115.Text = Me.L2100.Text
End If
If Me.L2130.Text = Empty Then 'h2130
    Me.L2130.Text = Me.L2115.Text
End If
If Me.L2145.Text = Empty Then 'h2145
    Me.L2145.Text = Me.L2130.Text
End If
If Me.L2200.Text = Empty Then 'h2200
    Me.L2200.Text = Me.L2145.Text
End If
If Me.L2215.Text = Empty Then 'h2215
    Me.L2215.Text = Me.L2200.Text
End If
If Me.L2230.Text = Empty Then 'h2230
    Me.L2230.Text = Me.L2215.Text
End If
If Me.L2245.Text = Empty Then 'h2245
    Me.L2245.Text = Me.L2230.Text
End If
If Me.L2300.Text = Empty Then 'h2300
    Me.L2300.Text = Me.L2245.Text
End If
```

```
If Me.L2315.Text = Empty Then 'h2315
   Me.L2315.Text = Me.L2300.Text
End If
If Me.L2330.Text = Empty Then 'h2330
   Me.L2330.Text = Me.L2315.Text
End If
If Me.L2345.Text = Empty Then 'h2345
   Me.L2345.Text = Me.L2330.Text
End If

//Copy the load details to the calculation sheet//
   ws.Cells(2, 6).Value = Me.L0000.Value
   ws.Cells(3, 6).Value = Me.L0015.Value
   ws.Cells(4, 6).Value = Me.L0030.Value
   ws.Cells(5, 6).Value = Me.L0045.Value
   ws.Cells(6, 6).Value = Me.L0100.Value
   ws.Cells(7, 6).Value = Me.L0115.Value
   ws.Cells(8, 6).Value = Me.L0130.Value
   ws.Cells(9, 6).Value = Me.L0145.Value
   ws.Cells(10, 6).Value = Me.L0200.Value
   ws.Cells(11, 6).Value = Me.L0215.Value
   ws.Cells(12, 6).Value = Me.L0230.Value
   ws.Cells(13, 6).Value = Me.L0245.Value
   ws.Cells(14, 6).Value = Me.L0300.Value
   ws.Cells(15, 6).Value = Me.L0315.Value
   ws.Cells(16, 6).Value = Me.L0330.Value
   ws.Cells(17, 6).Value = Me.L0345.Value
   ws.Cells(18, 6).Value = Me.L0400.Value
   ws.Cells(19, 6).Value = Me.L0415.Value
   ws.Cells(20, 6).Value = Me.L0430.Value
   ws.Cells(21, 6).Value = Me.L0445.Value
   ws.Cells(22, 6).Value = Me.L0500.Value
   ws.Cells(23, 6).Value = Me.L0515.Value
   ws.Cells(24, 6).Value = Me.L0530.Value
   ws.Cells(25, 6).Value = Me.L0545.Value
ws.Cells(26, 6).Value = Me.L0600.Value
ws.Cells(27, 6).Value = Me.L0615.Value
ws.Cells(28, 6).Value = Me.L0630.Value
ws.Cells(29, 6).Value = Me.L0645.Value
ws.Cells(30, 6).Value = Me.L0700.Value
ws.Cells(31, 6).Value = Me.L0715.Value
ws.Cells(32, 6).Value = Me.L0730.Value
ws.Cells(33, 6).Value = Me.L0745.Value
ws.Cells(34, 6).Value = Me.L0800.Value
ws.Cells(35, 6).Value = Me.L0815.Value
ws.Cells(36, 6).Value = Me.L0830.Value
ws.Cells(37, 6).Value = Me.L0845.Value
```

```
ws.Cells(38, 6).Value = Me.L0900.Value
ws.Cells(39, 6).Value = Me.L0915.Value
ws.Cells(40, 6).Value = Me.L0930.Value
ws.Cells(41, 6).Value = Me.L0945.Value
ws.Cells(42, 6).Value = Me.L1000.Value
ws.Cells(43, 6).Value = Me.L1015.Value
ws.Cells(44, 6).Value = Me.L1030.Value
ws.Cells(45, 6).Value = Me.L1045.Value
ws.Cells(46, 6).Value = Me.L1100.Value
ws.Cells(47, 6).Value = Me.L1115.Value
ws.Cells(48, 6).Value = Me.L1130.Value
ws.Cells(49, 6).Value = Me.L1145.Value
ws.Cells(50, 6).Value = Me.L1200.Value
ws.Cells(51, 6).Value = Me.L1215.Value
ws.Cells(52, 6).Value = Me.L1230.Value
ws.Cells(53, 6).Value = Me.L1245.Value
ws.Cells(54, 6).Value = Me.L1300.Value
ws.Cells(55, 6).Value = Me.L1315.Value
ws.Cells(56, 6).Value = Me.L1330.Value
ws.Cells(57, 6).Value = Me.L1345.Value
ws.Cells(58, 6).Value = Me.L1400.Value
ws.Cells(59, 6).Value = Me.L1415.Value
ws.Cells(60, 6).Value = Me.L1430.Value
ws.Cells(61, 6).Value = Me.L1445.Value
ws.Cells(62, 6).Value = Me.L1500.Value
ws.Cells(63, 6).Value = Me.L1515.Value
ws.Cells(64, 6).Value = Me.L1530.Value
ws.Cells(65, 6).Value = Me.L1545.Value
ws.Cells(66, 6).Value = Me.L1600.Value
ws.Cells(67, 6).Value = Me.L1615.Value
ws.Cells(68, 6).Value = Me.L1630.Value
ws.Cells(69, 6).Value = Me.L1645.Value
ws.Cells(70, 6).Value = Me.L1700.Value
ws.Cells(71, 6).Value = Me.L1715.Value
ws.Cells(72, 6).Value = Me.L1730.Value
ws.Cells(73, 6).Value = Me.L1745.Value
ws.Cells(74, 6).Value = Me.L1800.Value
ws.Cells(75, 6).Value = Me.L1815.Value
ws.Cells(76, 6).Value = Me.L1830.Value
ws.Cells(77, 6).Value = Me.L1845.Value
ws.Cells(78, 6).Value = Me.L1900.Value
ws.Cells(79, 6).Value = Me.L1915.Value
ws.Cells(80, 6).Value = Me.L1930.Value
ws.Cells(81, 6).Value = Me.L1945.Value
ws.Cells(82, 6).Value = Me.L2000.Value
ws.Cells(83, 6).Value = Me.L2015.Value
ws.Cells(84, 6).Value = Me.L2030.Value
```

```
        ws.Cells(85, 6).Value = Me.L2045.Value
        ws.Cells(86, 6).Value = Me.L2100.Value
        ws.Cells(87, 6).Value = Me.L2115.Value
        ws.Cells(88, 6).Value = Me.L2130.Value
        ws.Cells(89, 6).Value = Me.L2145.Value
        ws.Cells(90, 6).Value = Me.L2200.Value
        ws.Cells(91, 6).Value = Me.L2215.Value
        ws.Cells(92, 6).Value = Me.L2230.Value
        ws.Cells(93, 6).Value = Me.L2245.Value
        ws.Cells(94, 6).Value = Me.L2300.Value
        ws.Cells(95, 6).Value = Me.L2315.Value
        ws.Cells(96, 6).Value = Me.L2330.Value
        ws.Cells(97, 6).Value = Me.L2345.Value
        ws.Cells(98, 6).Value = Me.L0015.Value

//Exit form the Load Pattern Form//
    Unload Me
End Sub

Private Sub frmLoadPatternGraph_Initialize()
   Dim Fname As String

//Display the Load Pattern relevant to the entered Data//
   Call SaveChart
   Fname = ThisWorkbook.Path & "\temp1.gif"
   Me.Image1.Picture = LoadPicture(Fname)
End Sub
```

Variable Confirmation User Form

```
Private Sub cmdVariableConfirmtion_Click()
   Dim wb As Workbook
   Dim ws As Worksheet

   Set wb = ActiveWorkbook
   Set ws = Sheets("Variable Confirmation")


   If Me.ComboBox1.ListIndex = -1 Then 'h0000
     MsgBox "Please Select a Tariff Category.", vbExclamation
     Me.ComboBox1.SetFocus 'position cursor to try again
     Exit Sub 'terminate here - why continue?
   End If
   If Me.ComboBox2.ListIndex = -1 Then 'h0000
     MsgBox "Please Select the Distribution Voltage at your area.", 
vbExclamation
     Me.ComboBox2.SetFocus 'position cursor to try again
     Exit Sub 'terminate here - why continue?
```

```
  End If
  If Me.txtTransformerLife.Text = Empty Then 'h0000
    MsgBox "Please enter Expected Lifespan of the Transformer.", vbExclamation
    Me.txtTransformerLife.SetFocus 'position cursor to try again
    Exit Sub 'terminate here - why continue?
  End If
   If Me.txtInterestRate.Text = Empty Then 'h0000
    MsgBox "Please enter Discounting Rate.", vbExclamation
    Me.txtInterestRate.SetFocus 'position cursor to try again
    Exit Sub 'terminate here - why continue?
  End If

  ws.Cells(1, 10).Value = Me.ComboBox1.Value
  ws.Cells(2, 10).Value = Me.txtInterestRate.Value
  ws.Cells(3, 10).Value = Me.txtTransformerLife.Value
  ws.Cells(4, 10).Value = Me.ComboBox2.Value

Unload Me
frmOutPutDisplay.Show

End Sub


Private Sub ComboBox1_Change()

End Sub

Private Sub UserForm_Initialize()
  ComboBox1.List = Array("Industrial", "Domestic", "Hotel", "General Purpose")
  Me.ComboBox1.Text = Me.ComboBox1.List(0)
  ComboBox2.List = Array("11kV", "33kV")
  Me.ComboBox2.Text = Me.ComboBox2.List(0)
  txtTransformerLife.Value = "25"
  txtTransformerLife.SetFocus
  txtInterestRate.Value = "12"
  txtInterestRate.SetFocus

End Sub
```

Output Display Form

```
Public Sub UserForm_Initialize()
```

```
 Dim wb As Workbook
  Dim ws As Worksheet

  Set wb = ActiveWorkbook

//Display the relevant results from the calculation Sheet//
  Set ws = Sheets("Display")
  lMonthlyCostOfLosses.Caption = ws.Range("C10").Text
  lDisplayTOC.Caption = ws.Range("C9").Text
  lDisplayTansformerCapacity.Caption = ws.Range("C8").Text
  lMaxLoad.Caption = ws.Range("C2").Text
  lMinLoad.Caption = ws.Range("C3").Text
  lAvgLoad.Caption = ws.Range("C1").Text
  Label50.Caption = ws.Range("C13").Text
  Label51.Caption = ws.Range("C14").Text
  Label55.Caption = ws.Range("D13").Text
  Label53.Caption = ws.Range("D14").Text
  Label58.Caption = ws.Range("E13").Text
  Label56.Caption = ws.Range("E14").Text


End Sub
```