DEVELOPING A MATHEMATICAL MODEL TO PREDICT THE DAILY DEMAND FOR ELECTRICITY, BASED ON WEATHER PARAMETERS

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Declaration

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Abstract

System Control Centre (SCC) of Ceylon Electricity Board (CEB) conducts short term (hour ahead, day ahead) and medium term (up to three years ahead) demand forecasting based on historic demand, seasonal patterns, time of day and regional sales forecast. However, there are no measures taken as yet to include the influence of weather conditions such as temperature, humidity, sky cover, wind speed, etc. in this forecasting exercise.

Ambient temperature and humidity has become dominant parameters for electricity demand with the introduction of space cooling methods in recent history. The study focuses not only the influence of temperature and humidity to electricity demand of Sri Lanka but also the influence of wind speed and wind direction.

Study focused to build up a linear model using hourly historical demand data and meteorological data of four consecutive years using IBM SPSS statistics V 21 software. Meteorological parameters were taken as the independent parameters and hourly demand data was taken as the dependent parameter. Correction factor was needed to include the effect of yearly demand growth, for a better correlation. Every demand data point was corrected based on the average demand growth (yearly) and time of day.

Weekdays were taken as one set and Saturday and Sunday were taken separately. Model consists of 72 independent equations (24 representing a weekday, 24 for Saturday and 24 for Sunday). Correction factors were calculated for calendar holidays which have major influence on electricity demand.

Model validation was done for historical weather data as well as forecasted weather data. Predicting average absolute error was under 9% decreasing more with the prediction date close to the real date. Model is recommended to be used for short term demand forecasting and power plant dispatching in Sri Lanka.
Key words: demand prediction, mathematical model, multiple-regression, daily demand

Dedication

I dedicate this thesis to my beloved parents, who have given me the world's biggest two gifts, LOVE and FREEDOM. And also to my little brother who has been the strength and joy for my whole life. And Gayathri, my loving wife who never lost faith in me even in very tense and difficult times and loved me unconditionally.

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I take this opportunity to extend my sincere thanks to all the officers of Department of Meteorology and engineers of System Control Centre of Ceylon Electricity Board who supported and facilitated with necessary data and information.

It is a great pleasure to remember all my lecturers of University of Moratuwa and all friends in the post graduate program, for backing me from beginning to end of this course.

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LIST OF ABBREVIATIONS

Abbreviation	Description
CEB	Ceylon Electricity Board
HVAC	Heating ventilation and air conditioning
IPP	Independent power producer
IBM	International Business Machines
LECO	Lanka Electricity Company
MATLAB	Matrix Laboratory
MS	Microsoft
PASW	Predictive analytic software
POP	Probability of precipitation
SPSS	Statistical Package for Social Sciences
SCC	System Control Centre

LIST OF ABBREVIATIONS

Abbreviation	Description
CEB	Ceylon Electricity Board
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Chapter 1

INTRODUCTION

1.1 Electricity Demand Forecasting

Electricity demand forecasting performs a vital role in power system planning. Long term forecasts are used for constructing of power plants, transmission and distribution lines, while short term demand forecasting strictly involve in economical dispatch of generators in the system. For economic dispatch the system control engineer should have known the future demand because committing a generator would take time. Any fuel stocks should be ready. Demand forecasts also used to determine the resource requirement of the national electrical system which influence the price of electricity in the country. Any deviation in the forecasts would cost huge amount of money and wastage of precious resources. Forecasts should be reliable and have a higher accuracy level to achieve quality power system planning.

1.2 Impact of Weather Conditions on Electricity Demand

When electricity was introduced for households and industries, initially there was no any powerful relationship between electricity demand and weather conditions. But this has changed rapidly with the introduction of electricity based heating ventilation and air conditioning (HVAC) systems since changing weather conditions has a clear impact on HVAC systems.

1.2.1 Relationship between electricity demand and weather conditions

Temperature and relative humidity are the two dominant parameters which affect cooling loads such as fans, refrigerators, AC systems etc. When the ambient temperature increases, cooling loads increase accordingly demanding more electrical power. Humidity level is related to electricity demand since air conditioning is done by removing heat and moisture from the air and when the vapor content of the air is high, air conditioners have to do more work to remove excess moisture (AC systems with humidity controllers). Humidity level and ambient temperature have a strong relationship with each other.

Rainfall and wind speed act as secondary parameters such that both affect humidity level of the surrounding. Rain would increase the humidity level while wind would decrease the humidity level of a particular place taking moisture away with the wind.
Sky cover or cloud cover affects the level of heat from radiation from the sun which again acts as a secondary related parameter to the demand since it would affect ambient temperature. When sky cover is high and thickness is more, natural flux level of the sun decreases, inversely increasing Lighting loads connected to the system at daytime.

Sea surface temperature and wind direction have a unique effect for seashore areas since when sea surface temperature get increased the moisture content would increase at sea surface air layer and if the wind direction is towards the land, those moisture would come to seashore areas increasing the level of relative humidity.

Lightning, heavy rain, storms cause distribution and transmission breakdowns resulting sudden variation of loads in the national electrical system. Apart from that thunder and lightning has an effect on the human behavior such that people disconnect household electric equipment from the supply for safety when they observe those conditions in weather.

1.2.2 Comparison of a wet day and a dry day

Analyzing the behavior of national daily electricity demand with weather conditions is very important in modelling a demand prediction model. Figure 1.1 presents daily demand of two days in year 2013, with almost same other conditions except the weather. 13th May 2013 is a rainy day having heavy rains throughout the country including Colombo area. 9th May 2013 is a dry day with almost zero rainfall. Comparatively day demand has decreased by around 400 MW from dry day to wet day and night peak has reduced by around 300 MW. But early morning demand shows no significant change.

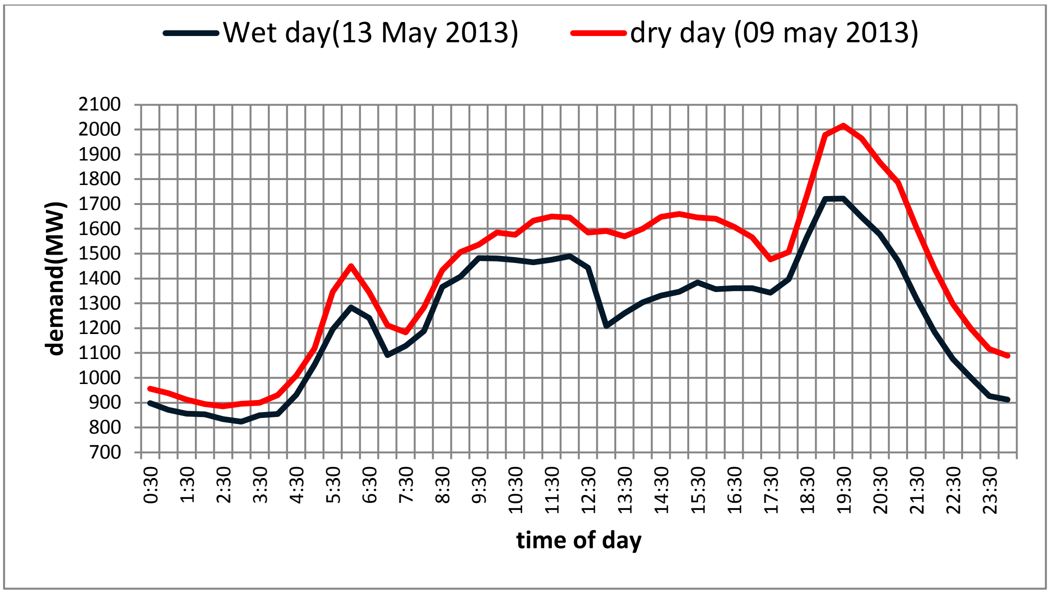

Figure 1.1: Comparison of a wet day and dry day

Source: Ceylon Electricity Board (CEB) historical demand data

1.2.3 Influence of ambient temperature on demand

Ambient temperature is one of the most influencing weather parameter to electricity demand. Figure 1.2 presents the variation of daily electricity load with ambient temperature.

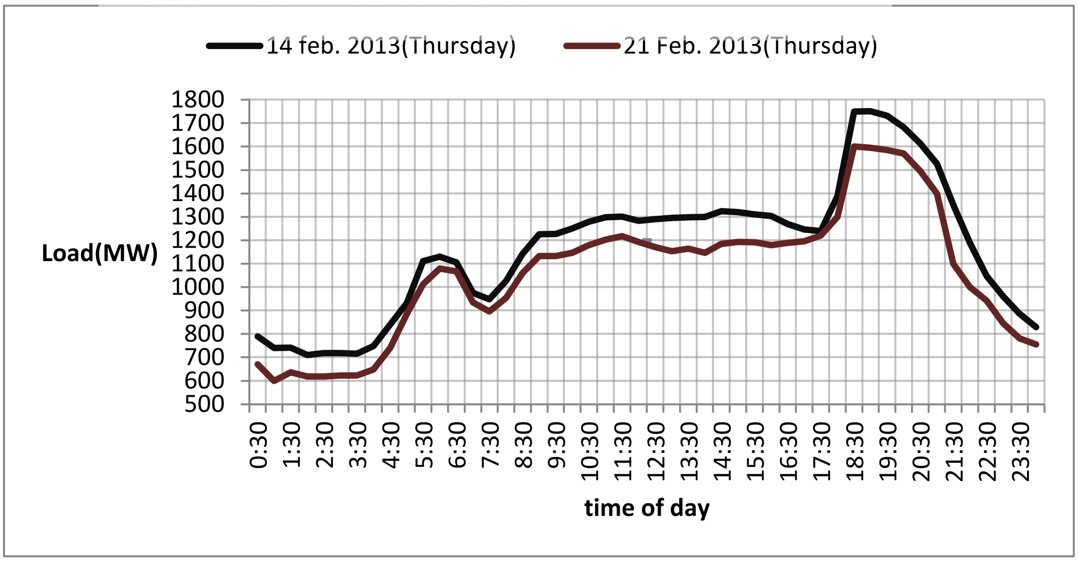

Figure 1.2: Influence of temperature on electricity demand

Source: CEB historical demand data

Table 1.1 : Temperature variation in Colombo in a wet day and a dry day [9]

	Colombo temp.(^{0}C)		
	Max.	Avg.	Min.
Thursday, February 14, 2013	30	27.5	25
Thursday, February 21, 2013	28	26	24

Source: Department of Meteorology, Colombo 07 historical weather data

Both days were identical in other factors except the ambient temperature. For 1.5 ^{0}C average temperature rise, more than 120 MW at day time and about 150 MW in the night peak have been increased. Reason for variation is increase of cooling loads such as air conditioning, fans, and refrigerators due to average ambient temperature rise.

1.3 Demand Prediction and Dispatch of Power Plants

System Control Centre (SCC) of CEB has the responsibility of merit order loading and economical dispatch of power plants. Dispatching of independent power producers (IPP) performs a vital role since the unit cost from an IPP is comparatively higher than CEB owned hydro plants or a coal power plant.

1.3.1 Dispatch during a dry day and wet day

Power plant economical dispatch varies according to the weather. For a dry day hydro reservoirs would be kept for night peak while more IPPs are dispatched during day time. Dispatch pattern of major power plants/complex for a dry day in year 2013 is shown in figure 1.3.

For a wet day, scenario gets reversed. If the hydro reservoirs get high inflow, usually hydro power plants would be dispatched more and IPPs would be kept to a minimum level. Dispatch pattern of major power plants/complex for a wet day in year 2013 is shown in figure 1.4.

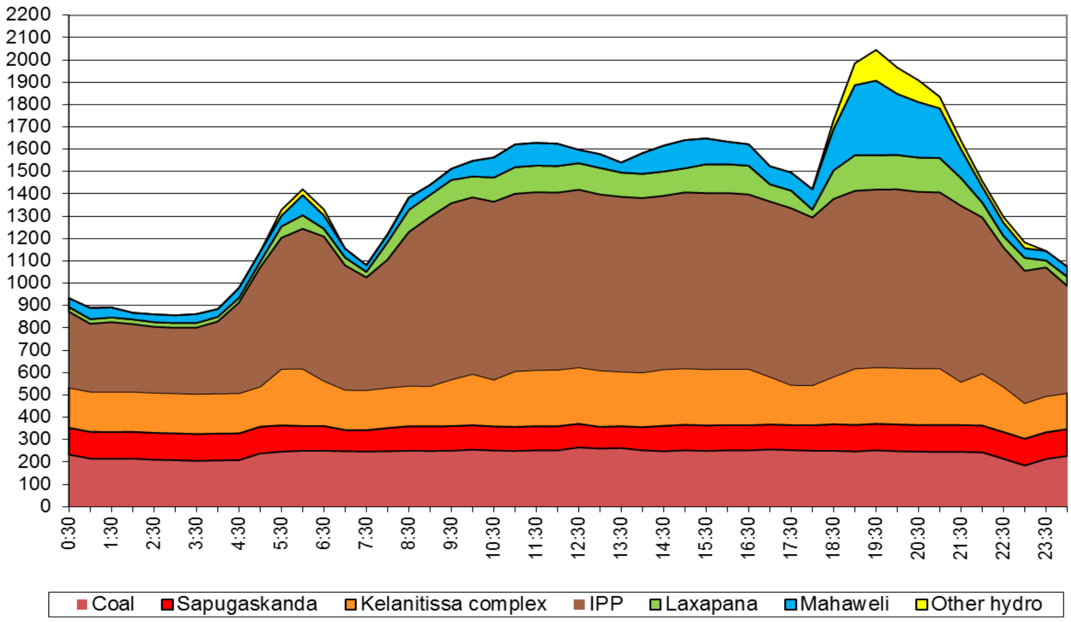

Figure 1.3: Dispatch during a dry day

Source: Energy dispatch forecasts from SCC of CEB

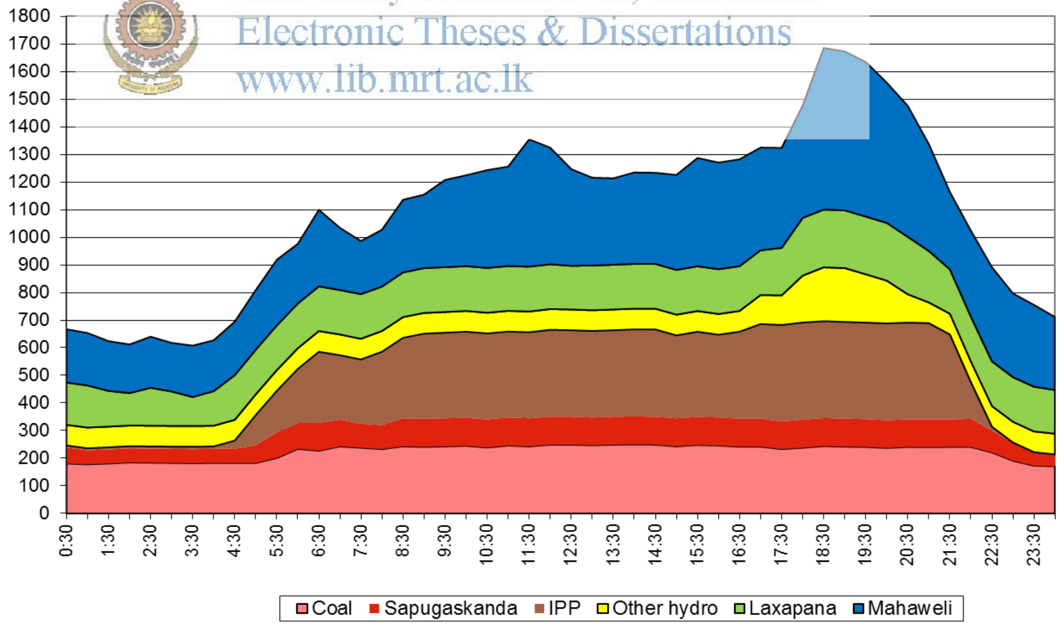

Figure 1.4: Dispatch during a wet day

Source: Energy dispatch forecasts from SCC of CEB

1.3.2 Demand prediction by SCC

SCC is responsible for yearly national electricity demand prediction and day to day power demand (daily load curve) prediction. Dispatch efficiency and effectiveness highly depend on the future demand prediction. SCC takes many factors for long term and short term demand prediction such as

- Historical data
- Speciality of the particular day
  - Weekday, weekend, public holiday, special function day etc.
- Seasonal patterns
  - New year vacation period, Christmas vacation period, monsoon period

At present SCC only consider whether the upcoming day is a rainy day or not for short term demand prediction. If it is a rainy day they include an offset for the predicted load curve. Proper method to use the meteorological parameter for the demand prediction has not been implemented yet. Dispatch decisions and responses to changes of weather entirely at the hands of the system engineer. The error of prediction can be easily observed by comparing predicted load curves with the relevant actual load curves, especially for weather changing days.

Figure 1.5 presents a comparison between actual and predicted load curves for a wet day.

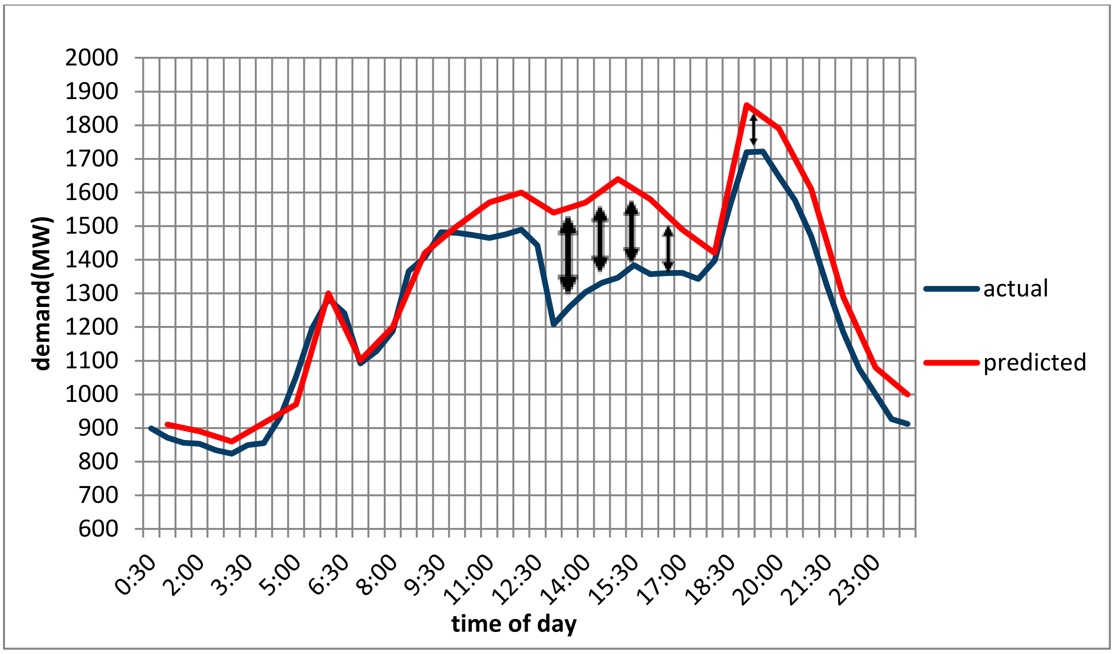

Figure 1.5: Comparison between actual and predicted load curves for a wet day

Source: Actual and predicted demand data for 13 May 2013, Monday from SCC

Figure 1.5 gives

- Max 25% MW error
- Overall energy error – below 10%

Actual demand deviation from the prediction started around 9.30 a.m. onwards and recorded a maximum 400 MW difference .Night peak also has shifted back and reduced from predicted to actual load curve. Heavy raining was recorded throughout the day for many areas of the country and relatively low ambient temperatures were recorded at night.

Towards last two decades electrically powered up HVAC systems have been developing in an accelerating rate in Sri Lanka stressing national power system and falsifying predictability of daily energy demand. CEB has to supply different daily load demands which results from various weather changes. This type of load variations could not be predicted by existing prediction method.

Example:

Assume a certain hydro power plant with the related reservoir filling up to the spilling level. According to the prediction SCC keep the plant for evening peak without utilizing it in full capacity at the day time. But the actual demand comes down suddenly in afternoon peak due to a weather change and power plant is not dispatched as planned. Reservoirs filled up and water spilled away wasting precious hydro potential. The loss of not taking the weather impact is hidden itself in the system, unfortunately without being recorded anywhere.

1.4 Expected Development

For most of the weather parameters there are reliable weather forecasts for days ahead (from global weather forecasting centres/from department of Meteorology in Sri Lanka).

Figure 1.6: Available weather forecasts

Source: www.accuweather.com

Developing a mathematical model to predict demand for electricity by utilizing these weather forecasts would be a good solution to correct the error between actual and predicted electricity demand predictions.

Reliable demand prediction could minimize the financial losses incurred in non-optimal unit commitment and load dispatch due to incorrect demand forecasting. Planning of purchasing /maintaining fuel stocks accurately for CEB owned thermal power plants and accurate management of water reservoirs would be easy with accurate demand predictions. Further, planning of scheduled maintenance of power plants can be done more efficiently.

Chapter 2

PILOT STUDY – DEVELOPMENT OF AN ELECTRICITY DEMAND PREDICTION MODEL FOR WESTERN PROVINCE

2.1 Introduction

2.1.1 Purpose of pilot study

It is desirable to do a pilot study before going for the advanced complete modeling. It can be taken as a minor version of the project. From a pilot study, hypothesis and assumptions made can be effectively checked for their validities without consuming much time or resources. It may provide evidence and information to change the main framework of the project and the path to the final goal. It may lead to change the final goal too.

Pilot study for the project was focused on modeling an equation for western province to get evidence about the validity of the methods, assumptions and hypothesis used.

2.1.2 Method of data analysis and model development

It is clear that HVAC systems are the major weather dependent impact on the electricity demand. Ambient temperature is the most important factor to be considered [1] [5]. Relative humidity and other factors also affect the electric load of HVAC system. The relationship of each weather parameter to the electricity load needs to be determined. It can be linear, exponential, polynomial etc. There are several weather parameters which are interdependent, such as ambient temperature depends on rainfall and sky cover. These interdependencies need to be considered in developing the model.

There are plenty of researches done on load modeling based on weather parameters. Gustafson stated that "many factors affect the instantaneous demands of air conditioning. The ambient temperature is the most important factor to be considered. Relative humidity also affects the instantaneous demand. The cycling frequency is a more important factor. Factors such as temperature, humidity, the physical room dimensions, and hour of the day represent parameters that affect the air conditioner load demand "[1]. Lefebvre and Trancis, presented different value of a heating load characteristic for different ranges of temperature starting from 0 and up to -180^{0}C. The value of the load was found to increase smoothly with the temperature decrease [2]. Belhadj and Mansour studied the impact of the temperature and humidity variations on the air-conditioning load model characteristics based on several years of utility field measurements. The two dimensional and three dimensional analyses of the data have been conducted and mathematical relations have been extracted to represent the dependencies of the real power with both humidity and temperature for the two case studies [3].

Expected daily demand prediction model need to be developed to get future electricity demand as output (dependent variable) using weather parameters (independent variables) as inputs. Historic weather data and electricity demand data can be found from department of Meteorology and Ceylon Electricity Board. A relationship need to be determined between electricity demand and weather parameters using above mentioned historical records.

2.1.2.1 Forecasting vs prediction

Forecasting and prediction have been defined in various different ways. Forecasting can be defined as finding the number of possible future scenarios with their probability of occurrence while prediction more focuses on finding an estimate for a specific event in the future. [12]

In another definition forecasts are defined as a subset of predictions. Forecasts are about future. But if the parameters are given, prediction can be for past, present or future regardless of the time. Forecasts can be taken as a prediction but not vice versa. Forecasts are more useful in strategic decision making about what are the useful factors and what potential outcomes may exist while predictions are most often outcome focused. Because of that most projects are based on predictions. The user of the information wants an estimate of a specific future outcome at a specific time.

Objective of this project is to find a specific demand value when weather data are presented. It is clear that the project is based on prediction. Validity of the prediction may depend on the knowledge of the predictor of that specific field, method used and accuracy of data.

There are certain techniques that can be used for prediction such as Kalman filter, regression analysis, time series analysis etc. depending on the requirement. For a good formal prediction it is needed to make hypotheses first. Hypothesis is a kind of an explanation to a problem or a situation. Ideally formal hypotheses are constructed connecting systematic knowledge of an area which is often generated through a literature review. Once the hypotheses are made they can be tested using statistical techniques mentioned above [13].

A hypothesis was made based on literature review which is that the electricity demand depends functionally on weather parameters such that

$D = f(W_x)^n$

D - Electricity demand (dependent variable)

W_x - Weather parameters (independent variables)

n - Any rational number

Function (f) of the relationship is required to be determined through modelling. For such outcome, best prediction technique is regression analysis [4].

2.1.2.2 Regression analysis

In statistics, regression analysis is a process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables especially when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps to understand how the typical value of the dependent variable (criterion variable) is changed when anyone of the independent variables is varied, while the other independent variables are held fixed. Most commonly, regression analysis estimates the conditional expectation (it is the expected value of one variable given the value(s) of one or more other variables) of the dependent variable given the independent variables – that is, the average value of the dependent variable when the independent variables are fixed. In all cases, the estimated target is a function of the independent variables called the regression function. Regression analysis is widely used in both prediction and forecasting.

Regression analysis also can be used to understand among the independent variables which are related to the dependent variable, and to explore the forms of these relationships.

Many techniques for carrying out regression analysis have been developed. Familiar methods such as linear regression and ordinary least squares regression are parametric, in that the regression function is defined in terms of a finite number of unknown parameters that are estimated from the data. Nonparametric regression refers to techniques that allow the regression function to lie in a specified set of functions, which may be infinite-dimensional.

To use regression analysis for prediction, data should be collected on the variable that is to be predicted, called the dependent variable or response variable, and on one or more variables whose values are hypothesized to influence it, called independent variables or explanatory variables; in this case electricity demand was taken as dependent variable and the weather parameters were taken as independent variables.

A functional form, often linear, is hypothesized for the postulated causal relationship, and the parameters of the function are estimated from the data. In the estimation step, parameters are chosen so as to optimize the fit of the function, thus parameterized to the data. For the prediction step, explanatory variable values that are deemed relevant to future (or current but not yet observed) values of the dependent variable are input to the parameterized function to generate predictions for the dependent variable.

Lefebvre and Trancis, presented different value of a heating load characteristic for different ranges of temperature starting from 0 and up to -18^{0}C [2] which guides towards a hypothesis such that the weather parameters are linearly related to electricity demand. Multiple linear regression analysis was selected based on that hypothesis for the initial pilot study.

$D = \sum \{A_x (W_x)^n\}$ with n=1

D - Electricity demand (dependent variable)

W_x - Weather parameters (independent variables)

A_x - Coefficient (which should be found through modelling)

Other than Multiple linear regression analysis, logarithm (log) scale regression and natural logarithm (ln) scale regression were also tried.

Log scale regression - $\log D = \sum \{A_x \log (W_x)\}$

Ln scale regression - $\ln D = \sum \{A_x \ln (W_x)\}$

2.1.2.3 Multiple Linear regression analysis (step wise)

There are standard in build functions (which has tested for their reliability) in software solutions such as MS excel, Statistical Package for Social Sciences (SPSS), Matrix Laboratory (MATLAB) to perform multiple linear regression and estimate regression coefficients.

2.1.2.3.1 Theoretical equations of multiple linear regression analysis

Simple linear regression is used when there is only one independent parameter. Famous $y_i = mx_i + c$ linear equation can be taken as the basic where m and c need to be found. Here,

$$m = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2}$$

$$c = \bar{y} - m\bar{x}$$

When the number of independent variables is more than one, multiple regression analysis needs to be used. The multiple liner regression equation can be written as,

$y = X\beta + u$,

Where $y = (y_1 , . . . , y_n)$ is the data vector consisting of n observations on the response dependent variable, X is an $n \times (p +1)$ matrix of independent variables, the first of which is a column ones, $\beta = (\beta_0 , . . . , \beta_p)$ is a $(p +1)\times 1$ vector of regression parameters, assumed to be nonrandom and $u = (u_1 , . . . , u_n)$ is an $n\times 1$ vector of random errors. Indicating the columns of the X matrix by $x_0 , . . . , x_p$, each column x_j gives the n values of the j^{th} independent variable, corresponding to the n observations in y.

The coefficient β_j measures the change in the regression function,

$$E [y \mid X] = X \beta = \sum_{k=0}^{p} x_k \beta_k$$

Which corresponding to a unit change in the j^{th} independent variable, if the model is accurate, and all other independent variables are held constant.

To estimate regression coefficient (β) from the observed data (y), 'the least square estimator' can be used. The least square estimator is the value of β^* which minimizes the criterion function,

$(y - X \beta^*)'(y - X \beta^*)$ which has a solution given by $b = (X 'X)^{-1}X 'y$.

The j^{th} entry b_j is the coefficient of x_j in the fitted model,

$$\hat{y} = Xb = \sum_{k=0}^{p} x_k \beta_k \ .$$

Therefore bj can be taken as an estimate of the change in the expected value of the dependent variable y, corresponding to a unit change in the independent variable x_j, if all other independent variables are held fixed, assuming the model is correct [4].

2.1.2.3.2 Coefficient of correlation (R)

In a process of finding a relationship between one or more independent variables and a dependent variable, a special quantity is taken into consideration which is called as the coefficient of correlation denoted by R. The quantity R measures the strength and the direction of a linear relationship between two variables.

The mathematical formula for computing R for simple linear regression is called Pearson's formula.

$$R = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x^2)^2}\sqrt{n(\sum y^2) - (\sum y^2)^2}}$$

x – Data points of independent variable

y – Observation of the response of dependent variable

n – Number of pairs of data

The value of R is such that $-1 < R < +1$. The + and – signs are used for positive linear correlation and negative linear correlation, respectively.

Positive correlation: If x and y have a strong positive linear correlation, R is close to +1. R value of exactly +1 indicates a perfect positive fit. If R value is in between 0 and +1 it indicates a relationship between x and y variables such that as values for x increase, values for y also increase.

Negative correlation: If x and y have a strong negative linear correlation, R is close to -1. An R value of exactly -1 indicates a perfect negative fit. Negative values indicate a relationship between x and y such that as values for x increase, values for y decrease.

No correlation: If there is no linear correlation or a weak linear correlation, R is close to 0. A value near zero means that there is a random, nonlinear relationship between the two variables.

A perfect correlation of ± 1 occurs only when the data points all lie exactly on a straight line. If R = +1, the slope of this line is positive. If R = -1, the slope of this line is negative. R is a dimensionless quantity which means it does not depend on the units employed.

In multiple liner regression analysis R is used to address the correlation of a set of independent parameters to a dependent parameter. A correlation greater than 0.8 is generally described as strong, whereas a correlation less than 0.5 is generally described as weak. [13]

2.1.2.3.3 Difference between standard and stepwise analysis

In standard multiple regression, all independent (predictor) variables are entered into the regression equation at once. It gives a overall R value which presents the strength of the relationship of all independent parameters as a set to the dependent parameter.

Stepwise multiple regressions would focus on finding out what is the best combination of independent (predictor) variables would be to predict the dependent (predicted) variable. In a stepwise regression, independent variables are entered into the regression equation one at a time based upon statistical criteria. At each step in the analysis the independent variable that contributes the most to the prediction equation in terms of increasing the multiple correlation, R, is entered first. This process is continued only if additional variables add anything statistically meaningful to the regression equation. When no additional independent variables add anything statistically meaningful to the regression equation, the analysis stops. Thus, not all predictor variables may enter the equation in stepwise regression.

In analyzing the relationship of weather parameters to electricity demand there should be a way to estimates the influence of each weather parameter to electricity demand and relationship with each other. From a step wise analysis, individual influence of independent parameters can be analyzed.

2.1.2.4 Software selection

Regression analysis could be performed from MS excel, SPSS or from MATLAB. Rather than the traditional MS excel and MATLAB, SPSS is far more popular in modern day regression analysis.

SPSS is a software solution provided by International Business Machines (IBM) Corporation which initially called as Predictive Analytic Software (PASW). Since SPSS is specially build for statistical analysis it is highly user friendly than excel in regressions and higher number of tutorials are available and far more user friendly than MATLAB. To perform a regression analysis for large amount of data, excel would take relatively more time than SPSS. Further the number of built in functions are relatively high in SPSS resulting specific algorithm development is not required. Considering all advantages SPSS version 21 was chosen for the step wise multiple regression analysis.

Although SPSS is much more fast and easy in regression it is far more difficult in data rearranging and developing charts. Excel has more flexible functions in data handling. MS excel charts are more dynamic and can be embedded to power point presentation whenever needed. Considering above advantages MS excel was chosen to handle and rearrange weather and demand data.

2.2 Used Parameters and Data Availability

2.2.1 Weather parameters

Six weather parameters were chosen initially considering the influence of them to the electricity demand.

Table 2.1: Weather parameters used in the study [9]

Parameter	Measuring unit	Equipment	Hourly data was taken as
Temperature	Celsius degree(^{0}C)	PT 100	1 minute readings averaged hourly
Relative humidity	As a percentage (%)	Hygrometer	
Wind speed	Knot	Anemometer	
Wind direction	Degree (^{0})	Wind vane	
Rainfall	mm	Tipping bucket rain gauge	10 minute accumulated values added hourly
Solar radiation	MJ/m^2	Pyrometer	

For the project hourly weather data from 2009 to 2013 was used. Cloud cover measurement was needed but hourly historical data were unavailable. Instead solar radiation was used as a parameter to measure the effect of cloud cover to electricity demand.

2.2.2 Effect of time

Daily demand curve of Sri Lanka is a time dependent. It has an increase of demand in the morning (morning peak- indicate as region 1 in figure 2.1) when people wake up and starts household chores. Then country demand for electricity decreases when people travel to their work places (indicate as region 2 in figure 2.1). Day peak (indicate as region 3 in figure 2.1) occurs due to operation of heavy machineries at industries and lighting, air conditioning loads of work places. Then as in the morning there is a small decrease of demand when people travel back to their homes after finishing work (indicate as region 4 in figure 2.1). In the evening there is an unusual demand increase (night peak – indicate as region 5 in figure 2.1) due to household chores, lighting, television watching etc. which again drastically decays at the midnight and early morning (off peak – indicate as region 6 in figure 2.1). Insufficient supply for the night peak has been a crisis situation during past decades. High cost oil power plants have to be dispatched to supply power to the nation only for few hours per day.

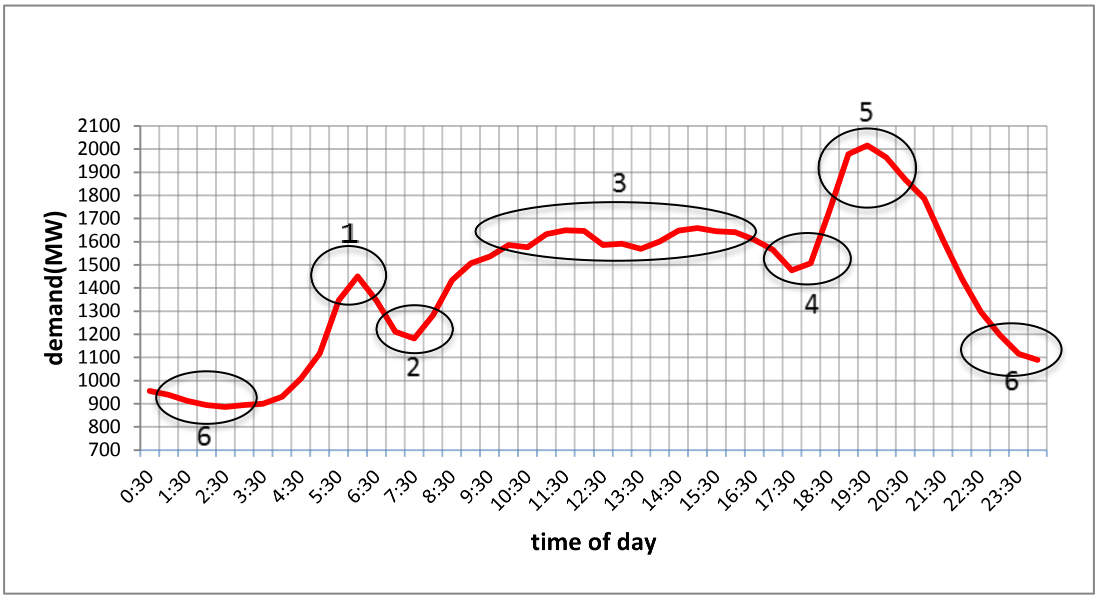

Figure 2.1: Daily demand curve, Sri Lanka (09th May 2013)

Source: Historical hourly demand data from SCC, CEB

It is clear that the daily electricity demand has a clear variation with the time of day. Seeking a relationship between weather parameters and electricity demand would not be accurate unless the effect of time is included. Because of that it was decided to include time of the day also as an independent parameter.

2.2.3 Demand data

CEB has the power transmission monopoly in Sri Lanka. Power generation was open up for IPPs in 1990s but the majority of power plants still owned by CEB. Power distribution is done by CEB and Lanka Electricity Company (LECO). SCC controls the national demand and supply balance. SCC has island wide demand data recorded and stored for every half an hour. From that hourly national electricity demand (MW) data from 2009 to 2013 (due to limitation of weather data) was taken for the analysis. Provincial wise or regional wise demand data would be much more useful for regression but were not available within SCC.

2.2.4 Expected model from pilot study

Independent parameters,

- Temperature - T
- Relative humidity - H
- Wind speed - W_{speed}
- Wind direction - $W_{direction}$
- Rainfall - R
- Solar radiation - S
- Time of day - T

Dependent parameter,

- Electricity demand - De

Expected multiple liner regression model,

$$De = A\,(T) + B\,(Te) + C\,(H) + D\,(W_{speed}) + E\,(W_{direction}) + F\,(R) + G\,(S) + \alpha$$

Expected logarithm (log) scale regression model

$$\text{Log}\,(De) = A \log(T) + B \log(Te) + C \log(H) + D \log(W_{speed}) + E \log(W_{direction}) + F \log(R) + G \log(S) + \alpha$$

Expected natural logarithm (ln) scale regression model

$$\text{Ln}\,(De) = A \ln(T) + B \ln(Te) + C \ln(H) + D \ln(W_{speed}) + E \ln(W_{direction}) + F \ln(R) + G \ln(S) + \alpha$$

2.3 Multiple Regression Analysis (Step Wise) – for Western Province

Western province has 55% of national energy sales in 2012 (Appendix A). It is clear that the national electricity demand is centralized in western province. Pre study was done for western province taking island wide electricity demand data. Provincial hourly demand data would be the best option but due to unavailability, island wide data had to be used. Island wide demand data was fractionized by 0.55 to reduce standard deviation of the data set. Weather data of Colombo was used for the pre study in western province [9].

Data rearranging was done as shown in table 2.2 from year 2009 to year 2013 and loaded to SPSS software. 55 % Demand (MW) was selected as the dependent parameter and combination of weather parameters and time of day was selected as independent parameters. Three major analyses were done with different combination of parameters and regression output analysis was done.

- Analysis 1: For all days of 2009 – 2013
- Analysis 2: For all days of 2009 – 2013(without solar radiation data set)
- Analysis 3: All days except weekends and public holidays of 2009 – 2013 (without solar radiation data set)

Table 2.2: Example data arrangement for pilot study for western province

Date	55% of Demand (MW)	Time of the day	Wind speed(knot)	Wind direction (^{0})	Rainfall (mm)	Air temp.(^{0}C)	Solar radiation (MJ/m ^{2})	Relative humidity (%)
23 April ,2011	489	04.59	0.9	155	3.0	25.0	0.07	91.1
	592	05.59	1.1	138	0.5	25.0	0.07	88.8
	574	06.59	1.0	92	1.0	24.4	0.08	89.9
	628	07.59	1.3	103	2.5	24.3	0.13	90.9
	654	08.59	1.2	102	3.5	24.5	0.25	91.0
	661	09.59	0.9	150	24.5	24.5	0.23	91.1
	683	10.59	0.9	91	10.5	24.5	0.36	91.4
	681	11.59	1.1	117	19.5	24.2	0.20	91.5
	636	12.59	1.1	107	5.0	24.1	0.28	91.5
	609	13.59	1.5	113	1.5	24.4	0.51	91.6
	…	…	…	…	…	…	…	…
	..	..	..	..	..	..	..	..
	.	.	.	.	.	.	.	.

2.3.1 Analysis 1: For all days of 2009 – 2013

For the first analysis, historical data for all days from 2009 – 2013 were loaded to SPSS and step wise multiple linear regression function was selected. Table 2.3 shows the descriptive statistics of dependent parameter and independent parameters and table 2.4 shows the output model summary of SPSS.

Table 2.3 : Descriptive statistics of analysis 1(all days of 2009 – 2013)

Descriptive Statistics

	Mean	Std. Deviation	N
55% of demand	679.153860	150.7584249	22031
time	12.262144	5.5985736	22031
Solar radiation(MJ/m2)	1.1051	1.10684	22031
Humidity(%)	73.1888	11.57277	22031
Air Temp.(0C)	28.2608	2.30978	22031
Rainfall(Section) (mm)	.2990	2.38679	22031
Wind speed(knot)	3.0826	1.53071	22031
Wind direction(°)	191.1091	85.68511	22031

Source: SPSS regression output of analysis 1

Table 2.4: Analysis 1 model summary (all days of 2009 – 2013)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.465[a]	.216	.216	133.5075
2	.528[b]	.279	.279	128.0317
3	.535[c]	.286	.286	127.3609
4	.545[d]	.297	.296	126.4501
5	.546[e]	.298	.298	126.3554
6	.546[f]	.298	.298	126.2870

a. Predictors: (Constant), time

b. Predictors: (Constant), time, Humidity(%)

c. Predictors: (Constant), time, Humidity(%), Wind speed(knot)

d. Predictors: (Constant), time, Humidity(%), Wind speed(knot), Air Temp.(0C)

e. Predictors: (Constant), time, Humidity(%), Wind speed(knot), Air Temp.(0C), Wind direction(°)

f. Predictors: (Constant), time, Humidity(%), Wind speed(knot), Air Temp.(0C), Wind direction(°), Rainfall(Section) (mm)

Source: SPSS regression output of analysis 1

Final step coefficient of correlation (R) is – 0.546

Solar radiation has been removed as a parameter from the model summary when reaching the final step R value.

2.3.2 Interpretation of regression output – F statistic and t statistic

2.3.2.1 F statistic

In a regression analysis it is highly important to check the overall significance level of the model and the significance level of each independent parameter individually to the model. For this purpose "F statistic" and "t statistic" can be used.

The "F value" and "Prob(F)" are used to test the overall significance of the regression model. They used to decide whether the model as a whole has statistically significant predictive capability. They test the null hypothesis that all of the regression coefficients are equal to zero. This tests the full model against a model with no variables and with the estimate of the dependent variable being the mean of the values of the dependent variable. The F value is the ratio of the mean regression sum of squares divided by the mean error sum of squares. Its value will range from zero to an arbitrarily large number.

The value of Prob(F) is the significant level of F. It is the probability that the null hypothesis for the full model is true (i.e., that all of the regression coefficients are zero). For example, if Prob(F) has a value of 0.01 then there is 1 chance in 100 that all of the regression parameters are equal to zero. This low value would imply that at least some of the regression parameters are non-zero and that the regression equation does have some validity in fitting the data (i.e., the independent variables are not purely random with respect to the dependent variable). General rule used in regressions is that for a particular regression output if Prob(F) is less than 0.05 indicates that the null hypothesis can be rejected. The "F value" and "Prob(F)" of a particular regression is presented in the relevant "analysis of variance (ANOVA) table".

Table 2.5: ANOVA table of analysis 1(all days of 2009 – 2013)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	108049612.3	1	1.08E+08	6061.943	.000[b]
	Residual	392650490	22029	17824.25		
	Total	500700102.3	22030			
2	Regression	139614431.8	2	69807216	4258.583	.000[c]
	Residual	361085670.6	22028	16392.12		
	Total	500700102.3	22030			
3	Regression	143404087.2	3	47801362	2946.914	.000[d]
	Residual	357296015.1	22027	16220.82		
	Total	500700102.3	22030			
4	Regression	148512426.7	4	37128107	2322.011	.000[e]
	Residual	352187675.6	22026	15989.63		
	Total	500700102.3	22030			
5	Regression	149055722.3	5	29811144	1867.2	.000[f]
	Residual	351644380	22025	15965.69		
	Total	500700102.3	22030			
6	Regression	149452167.4	6	24908695	1561.829	.000[g]
	Residual	351247935	22024	15948.42		
	Total	500700102.3	22030			

a. Dependent Variable: @55ofdemand

b. Predictors: (Constant), time

c. Predictors: (Constant), time, Humidity

d. Predictors: (Constant), time, Humidity, Windspeedknot

e. Predictors: (Constant), time, Humidity, Windspeedknot, AirTemp0C

f. Predictors: (Constant), time, Humidity, Windspeedknot, AirTemp0C, Winddirection

g. Predictors: (Constant), time, Humidity, Windspeedknot, AirTemp0C, Winddirection, RainfallSectionmm

Source: SPSS regression output of analysis 1

According to the table 2.5 from first step to final step significant level is lower than the 3rd decimal point which indicates that the model has a significant prediction capability.

2.3.2.2 t statistic

The "t" statistic is computed by dividing the estimated value (coefficient) of the parameter by its standard error. This statistic is a measure of the likelihood that the actual value of the parameter is not zero. The larger the absolute value of t, the less likely that the actual value of the parameter could be zero. The "Prob(t)" value is the probability of obtaining the estimated value of the parameter if the actual parameter value is zero. The smaller the value of Prob(t), the more significant the parameter and the less likely that the actual parameter value is zero. For example, assume the estimated value of a parameter is 1.0 and it has a standard error of 0.7. Then the t value would be 1.43 (1.0/0.7). If the computed Prob(t) value is 0.05 then this indicates that there is only a 0.05 (5%) chance that the actual value of the parameter could be zero. As same as in Prob(F) , Prob(t) less than 0.05 indicates that the null hypothesis can be rejected.

In step-wise regression, predictor variables are entered into the regression equation one at a time, based upon statistical criteria. This process is continued only if additional variables add anything statistically to the regression equation. Thus, not all predictor variables may enter the equation in stepwise regression. To analyze the exclusion of solar radiation as a parameter from the SPSS output, "coefficients table" was taken in to consideration (shown in table 2.6) where it presents t-statistic and the Prob(t) (shown as “sig.” in coefficients table).

Table 2.6: Coefficients table of analysis 1(all days of 2009 – 2013)

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	525.765	2.166		242.767	0.000
	time	12.509	.161	.465	77.858	0.000
2	(Constant)	791.150	6.394		123.725	0.000
	time	10.921	.158	.406	68.999	0.000
	Humidity	-3.360	.077	-.258	-43.882	0.000
3	(Constant)	855.585	7.631		112.119	0.000
	time	11.201	.159	.416	70.665	0.000
	Humidity	-3.883	.084	-.298	-46.501	0.000
	Windspeedknot	-9.591	.627	-.097	-15.285	.000
4	(Constant)	447.356	24.063		18.591	.000
	time	10.844	.159	.403	68.359	0.000
	Humidity	-2.386	.118	-.183	-20.239	.000
	Windspeedknot	-12.777	.648	-.130	-19.718	.000
	AirTemp0C	11.069	.619	.170	17.874	.000
5	(Constant)	487.346	25.003		19.491	.000
	time	10.728	.160	.398	67.146	0.000
	Humidity	-2.504	.120	-.192	-20.951	.000
	Windspeedknot	-13.302	.654	-.135	-20.348	.000
	AirTemp0C	9.605	.668	.147	14.383	.000
	Winddirection	.069	.012	.039	5.833	.000
6	(Constant)	483.738	25.000		19.349	.000
	time	10.685	.160	.397	66.823	0.000
	Humidity	-2.556	.120	-.196	-21.317	.000
	Windspeedknot	-13.629	.657	-.138	-20.755	.000
	AirTemp0C	9.920	.670	.152	14.797	.000
	Winddirection	.066	.012	.037	5.599	.000
	RainfallSection mm	1.829	.367	.029	4.986	.000

a. Dependent Variable: @55ofdemand

Source: SPSS regression output of analysis 1

According to the figure 2.6, from 1st step to final step, t values of all six parameters and the constant are reasonable while having Probability of t (sig.) < 0.05, which implies that the null hypothesis can be rejected with confidence for all dependent parameters.

Although the significance of the model parameters was proven, reasons for exclusion of "solar radiation" yet to be determined. For that purpose and to reconfirm the findings of the stepwise multiple regression analysis, a "Standard multiple regression" was done for the same data set and coefficient table was taken. In analysis 1, "Step wise multiple regression" was used. Coefficients table of "Standard multiple regression" is shown in table 2.7.

Table 2.7: Coefficients table of Standard multiple regression analysis

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	481.877	25.081		19.213	0.000
time	10.64	0.167	0.395	63.675	0.000
Windspeedknot	-13.513	0.668	-0.137	-20.217	0.000
Winddirection	0.066	0.012	0.037	5.597	0.000
RainfallSectionmm	1.844	0.367	0.029	5.023	0.000
AirTemp0C	10.119	0.704	0.155	14.371	0.000
SolarradiationMJm2	-1.049	1.134	-0.008	-0.925	0.355
Humidity	-2.589	0.125	-0.199	-20.698	0.000

a. Dependent Variable: @55ofdemand

Source: SPSS output of "Standard multiple regression" (all days 2009-2013)

As shown in table 2.7 in standard multiple regression analysis all the parameters were taken into account. Prob(t) for solar radiation is more than 0.05 which implies that the null hypothesis couldn't be rejected. In step wise regression low significant level of the parameter to the model (high significant level of the null hypothesis) has been identified and the relevant parameter was excluded.

Although the t statistic has provided enough evidence about the exclusion of solar radiation further investigation were carried out to find practical explanations.

2.3.2.3 Collinearity

Predictors that are highly collinear to each other (linearly related) can cause problems in estimating the regression coefficients. Coefficients become unstable resulting reduction of coefficient of correlation. To analysis the collinearity “Pearson correlation” table was taken into consideration.

Table 2.8: Correlation table of analysis 1 (all days of 2009 – 2013)

Correlations

		@55ofdemand	time	Windspeedknot	Winddirection	RainfallSectionmm	AirTemp0C	SolarradiationMJm2	Humidity
Pearson Correlation	@55ofdemand	1.000	.465	.117	.218	-.030	.356	.169	-.351
	time	.465	1.000	.201	.241	.013	.272	-.003	-.229
	Windspeedknot	.117	.201	1.000	.346	.000	.503	.451	-.437
	Winddirection	.218	.241	.346	1.000	-.017	.492	.292	-.300
	RainfallSectionmm	-.030	.013	.000	-.017	1.000	-.176	-.102	.189
	AirTemp0C	.356	.272	.503	.492	-.176	1.000	.663	-.779
	SolarradiationMJm2	.169	-.003	.451	.292	-.102	.663	1.000	-.647
	Humidity	-.351	-.229	-.437	-.300	.189	-.779	-.647	1.000

Source: SPSS regression output of analysis 1

High correlation between temperature, humidity and solar radiation can be identified from table 2.8. When two parameters (temperature and humidity) are included to the equation other parameter becomes insignificant.

2.3.3 Analysis 2: For all days of 2009 – 2013 (without solar radiation)

Although the solar radiation was excluded as a parameter in the output model of step wise multiple regression analysis (2.3.1) Data set of the excluded variable solar radiation would decrease the strength of the overall relationship (reduce R). Next modelling was done after removing data set of solar radiation (removing solar radiation as an independent parameter). Improvement of R value from 0.546 to 0.598 could be observed by removing the data set from the regression.

Table 2.9: Analysis 2 descriptive statistics: For all days of 2009 -2013 (without solar radiation)

Descriptive Statistics

	Mean	Std. Deviation	N
55% of demand	651.527539	168.8315229	31735
time	12.100477	6.9291726	31735
Humidity(%)	75.4351	11.04174	31735
Air Temp.(0C)	27.6013	2.34452	31735
Rainfall(Section) (mm)	.2845	2.32998	31735
Wind speed(knot)	2.7339	1.51223	31735
Wind direction(°)	182.6322	85.10458	31735

Source: SPSS regression output of analysis 2

Table 2.10: Analysis 2 model summary: For all days of 2009 - 2013 (without solar radiation)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.501[a]	.251	.251	146.1565594
2	.585[b]	.342	.342	136.9920731
3	.590[c]	.348	.348	136.3256080
4	.596[d]	.355	.355	135.6291352
5	.597[e]	.356	.356	135.4576616
6	.598[f]	.357	.357	135.3908491

a. Predictors: (Constant), time

b. Predictors: (Constant), time, Air Temp.(0C)

c. Predictors: (Constant), time, Air Temp.(0C), Humidity(%)

d. Predictors: (Constant), time, Air Temp.(0C), Humidity(%), Wind speed(knot)

e. Predictors: (Constant), time, Air Temp.(0C), Humidity(%), Wind speed(knot), Rainfall(Section) (mm)

f. Predictors: (Constant), time, Air Temp.(0C), Humidity(%), Wind speed(knot), Rainfall(Section) (mm), Wind direction(°)

Source: SPSS regression output of analysis 2

Final step coefficient of correlation (R) is – 0.598

2.3.4 Analysis 3: Weekdays without public holidays of 2009 – 2013 (without solar radiation)

Daily electricity demand behavior has a dependency on the particular day which is taken into consideration. As an example Wesak poyaday night peak demand has been recorded as the maximum demand of the year for several times in near past. It is not because of any weather change but public use electricity for Wesak decorations and due to religious functions. Regression accuracy or the strength of the relationship (R value) should increase when the external effects such as described above are minimized.

To test the above hypothesis, weekend data and public holiday data were removed from the data set and remaining data was loaded (weekdays without public holidays) to SPSS and regression was performed. As done in analysis 2, solar radiation data was not included as an independent parameter.

Table 2.11: Analysis 3 descriptive statistics: for weekdays without public holidays of 2009 – 2013 (without solar radiation)

Descriptive Statistics

	Mean	Std. Deviation	N
55% of Demand MW	682.78	170.515	21100
time	12.113934	6.9309969	21100
Air Temp.(0C)	27.5997	2.33993	21100
Humidity(%)	75.4424	10.99021	21100
Wind speed(knot)	2.7292	1.49825	21100
Wind direction(°)	183.6494	84.35494	21100
Rainfall(Section) (mm)	.3065	2.53669	21100

Source: SPSS regression output of analysis 3

Table 2.12: Analysis 3 model summary: for weekdays without public holidays of 2009 – 2013 (without solar radiation)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.526[a]	.277	.277	144.992
2	.646[b]	.417	.417	130.234
3	.653[c]	.426	.426	129.189
4	.656[d]	.430	.430	128.723
5	.657[e]	.432	.432	128.513
6	.658[f]	.433	.432	128.469

a. Predictors: (Constant), time

b. Predictors: (Constant), time, Air Temp.(0C)

c. Predictors: (Constant), time, Air Temp.(0C), Humidity(%)

d. Predictors: (Constant), time, Air Temp.(0C), Humidity(%), Wind speed(knot)

e. Predictors: (Constant), time, Air Temp.(0C), Humidity(%), Wind speed(knot), Rainfall(Section) (mm)

f. Predictors: (Constant), time, Air Temp.(0C), Humidity(%), Wind speed(knot), Rainfall(Section) (mm), Wind direction(°)

Source: SPSS regression output of analysis 3

Final step R value has increased to 0.658

2.4 Evaluation of the Outcome

2.4.1 Summary of all analysis

Table 2.13: Summary of all analysis

Analysis	R value
1.For all days of 2009 -2013(with solar radiation)	0.546
2.For all days of 2009 -2013(without solar radiation)	0.598
3.Weekdays without public holidays of 2009 - 2013 (without solar radiation)	0.658

Results from the last analysis were taken for the model parameters of western province as it has the highest coefficient of correlation (R).

2.4.2 Linear Model for western province

Coefficients of the analysis 3 were taken as the Western Province pilot model parameters.

Table 2.14: Linear independent parameter coefficients of analysis 3

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations		
		B	Std. Error	Beta			Zero-order	Partial	Part
1	(Constant)	525.936	2.010		261.661	.000			
	time	12.948	.144	.526	89.903	.000	.526	.526	.526
2	(Constant)	-221.659	10.670		-20.774	.000			
	time	10.584	.134	.430	79.238	.000	.526	.479	.417
	Air Temp.(0C)	28.125	.396	.386	71.088	.000	.493	.440	.374
3	(Constant)	203.971	25.282		8.068	.000			
	time	10.518	.133	.428	79.356	.000	.526	.479	.414
	Air Temp.(0C)	19.319	.616	.265	31.353	.000	.493	.211	.164
	Humidity(%)	-2.410	.130	-.155	-18.539	.000	-.453	-.127	-.097
4	(Constant)	172.603	25.316		6.818	.000			
	time	10.566	.132	.429	79.975	.000	.526	.482	.416
	Air Temp.(0C)	21.760	.645	.299	33.756	.000	.493	.226	.175
	Humidity(%)	-2.576	.130	-.166	-19.783	.000	-.453	-.135	-.103
	Wind speed(knot)	-8.823	.710	-.078	-12.420	.000	.235	-.085	-.065
5	(Constant)	174.849	25.277		6.917	.000			
	time	10.522	.132	.428	79.701	.000	.526	.481	.414
	Air Temp.(0C)	22.064	.645	.303	34.228	.000	.493	.229	.178
	Humidity(%)	-2.696	.131	-.174	-20.614	.000	-.453	-.141	-.107
	Wind speed(knot)	-9.530	.714	-.084	-13.343	.000	.235	-.091	-.069
	Rainfall(Section) (mm)	2.985	.357	.044	8.364	.000	-.028	.057	.043
6	(Constant)	206.629	26.546		7.784	.000			
	time	10.482	.132	.426	79.197	.000	.526	.479	.411
	Air Temp.(0C)	20.886	.711	.287	29.356	.000	.493	.198	.152
	Humidity(%)	-2.790	.133	-.180	-20.987	.000	-.453	-.143	-.109
	Wind speed(knot)	-9.831	.718	-.086	-13.689	.000	.235	-.094	-.071
	Rainfall(Section) (mm)	2.918	.357	.043	8.169	.000	-.028	.056	.042
	Wind direction(°)	.050	.013	.025	3.906	.000	.288	.027	.020

a. Dependent Variable: 55% of Demand MW

Source: SPSS regression output of analysis 3

Model equation of Western Province pilot study is,

- $55\%D = 10.482\,T + 20.886\,Te - 2.790H - 9.831W(s) + 2.918R + 0.050W(d) + 206.629$

55%D : 55% Demand (MW)

T : Time (hh.mm)

Te : Air Temperature (^{0}C)

H : Relative Humidity (%)

$W(s)$: Wind speed (knot)

R : section Rainfall (mm)

$W(d)$: Wind direction (degrees)

- Coefficient of correlation (R) = 0.658.

Same procedure was carried out to obtain logarithm (log) scale regression model and natural logarithm (ln) scale regression model. Solar radiation was omitted in both models by the analysis itself.

Logarithm (log) scale regression model,

$$\text{Log (De)} = 0.091 \log (T) + 2.294 \log (Te) - 0.153 \log (H) - 0.121 \log (W_{speed}) + 0.003 \log (W_{direction}) + 0.001 \log (R) + 10.34$$

- Coefficient of correlation of 0.323

Natural logarithm (ln) scale regression model,

$$\text{Ln (De)} = 0.112 \ln (T) + 2.253 \ln (Te) + 0.215 \ln (H) + 0.093 \ln (W_{speed}) + 0.049 \ln (W_{direction}) + 0.025 \ln (R) + 13.21$$

- Coefficient of correlation of 0.219

Both logarithm (log) scale regression model and natural logarithm (ln) scale regression model showed a weak relationship between dependent parameter and independent parameters. Linear model can be taken as the best fitted model from tested 3 types of models.

2.4.3 Linear model validation

Actual hourly weather data for a particular day was put into the resulting equation according to the time and hourly electricity demand was predicted. Predicted demand valves were compared with the actual 55% of electricity demand values.

Example calculation:

Table 2.15: Example calculation

Date	Time	Actual 55% MW	Predicted MW	Wind speed (knot)	Wind direction (°)	Rainfall (mm)	Air temp.(^{0}C)	Relative humidity (%)
06/03/2013	0.59	545	416	5.4	266	1.5	24.8	100

$$55\%De = 10.482\ T + 20.886\ Te - 2.790H \quad - 9.831W(speed) + 2.918R + 0.050W(direction) + 206.629$$

55%De = (10.482 × 0.59) + (20.886 × 24.8) - (2.79 × 100) - (9.831 × 5.4) + (2.981 × 1.5) + (0.050 × 266) + 206.629

55%De = 416.37MW

Table 2.16: Prediction for 3rd June 2013 with actual weather data

Date and time	Time	Actual 55% MW	Predicted MW	Wind speed (knot)	Wind direction (°)	Rainfall (mm)	Air Temp.(^{0}C)	Relative humidity (%)
6/3/2013	0.59	545	416	5.4	266	1.5	24.8	100
6/3/2013	1.59	535	441	2.9	297	1	24.3	100
6/3/2013	2.59	517	469	3.5	278	0	25.6	100
6/3/2013	3.59	525	531	4.3	277	0	26.8	87.8
6/3/2013	4.59	560	572	3.1	263	0	27.3	84.5
6/3/2013	5.59	600	593	2.9	271	0	27.5	83.2
6/3/2013	6.59	613	631	2.5	262	0	27.7	76
6/3/2013	7.59	576	684	3.5	267	0	28.8	65.6
6/3/2013	8.59	595	712	3.3	263	0	29.9	67.9
6/3/2013	9.59	618	724	4.1	252	0	30.6	69.9
6/3/2013	10.59	652	719	4.1	261	0	30.7	76.1
6/3/2013	11.59	650	720	3.3	271	0	30.5	81.5
6/3/2013	12.59	648	700	3.9	273	0.5	28.7	96.1
6/3/2013	13.59	625	691	5.1	296	0	29.6	86.2
6/3/2013	14.59	628	720	4.9	279	0	30	76.2
6/3/2013	15.59	633	730	3.7	252	0	29.8	70.8
6/3/2013	16.59	630	740	4.3	267	0	29.5	81.8
6/3/2013	17.59	664	737	4.1	274	0	29	83.5
6/3/2013	18.59	972	770	4.3	287	0	28.5	86.1
6/3/2013	19.59	982	830	4.1	273	0	28.2	94.3
6/3/2013	20.59	884	840	1.9	245	0	28	91.4
6/3/2013	21.59	767	757	2.7	246	0	28.1	89.1
6/3/2013	22.59	615	700	2.3	249	0	28.1	93.6
6/3/2013	23.59	558	650	3.3	242	0	28.2	98.8

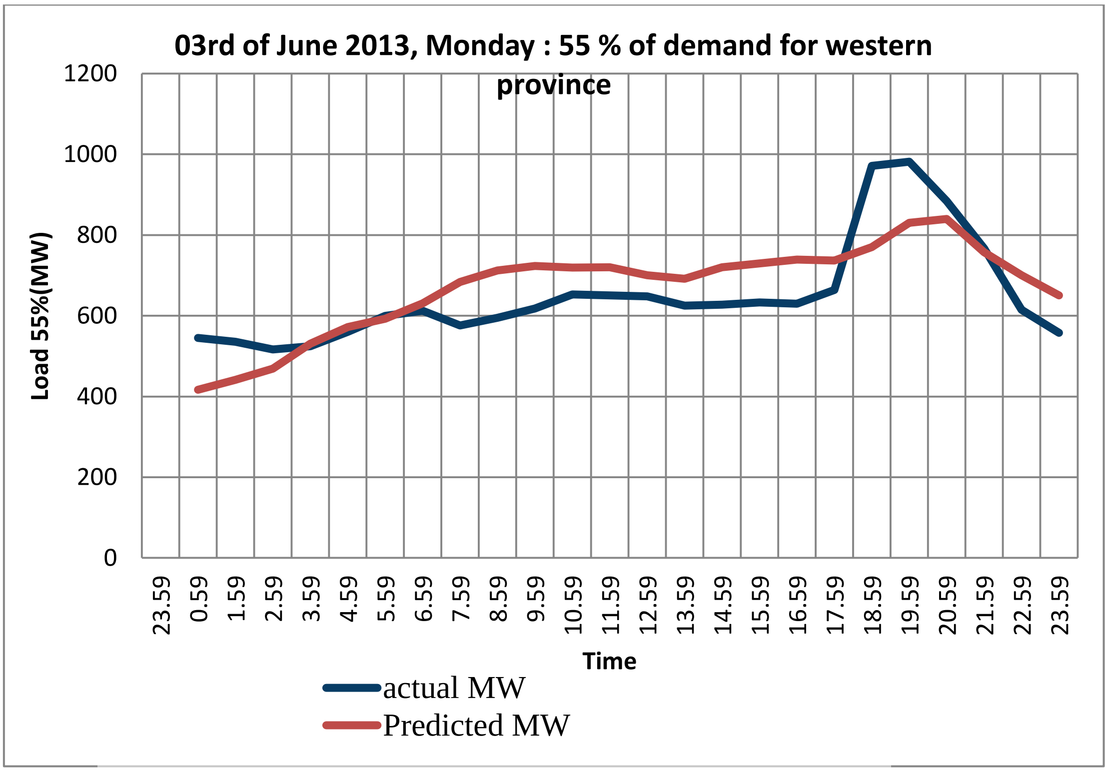

Figure 2.2: Comparison of actual 55% and predicted 55% demand (MW)

2.4.4 Evaluation of results

According to the figure 2.2 it is clear that the developed model is incapable of predicting electricity demand accurately. Especially model has failed in predicting daily peaks and off peaks.

Reasons for heavy variation:

- Western province actual demand data should have been the most promising data set. But due to unavailability, 55% of actual island wide demand (MW) data had to be used.
- The nature of the demand variation with time (peak demand at morning and evening) is not linear in Sri Lanka daily demand curve.
- Best coefficient of correlation (R) of 0.658 is not a strong correlation.

Lessons learnt for the full model:

- Time of the day should be removed as an independent parameter but need to take necessary measure to include the effect of the time.
- Electricity demand has been increased by a certain percentage per year. The effect of demand growth needs to be added to the regression. If it could be done R value may get increased.
- Although historical rainfall data exist, currently rainfall (mm) predictions are unavailable. Instead of rainfall all the prediction organizations give a parameter called probability of precipitation (POP). If the rainfall (mm) data are added to the demand prediction model it would be inaccurate in demand forecasting due to unavailability of forecasted rainfall data. But it is known that department of Meteorology of Sri Lanka is running load models in experimental basic to get rainfall predictions. Therefore those data can be used for rainfall predictions when it is available officially.
- Solar radiation data set should be removed in all future regressions since it has weakened the relationship between dependent parameter and independent parameters.

Chapter 3

DEVELOPING A MODEL TO PREDICT NATIONAL ELECTRICITY DEMAND OF SRI LANKA

With the results and guidelines had from the pilot study for Western Province it was decided to expand the study for whole country minimizing the adverse points identified from the pilot study.

3.1 Reduction of Independent Parameters

Six number of weather parameters were initially selected based on their influence level to the electricity demand.

- Temperature
- Relative humidity
- Wind speed
- Wind direction
- Rainfall
- Solar radiation

Solar radiation had been removed from the regression itself at the pilot study due to its overlapping with temperature and relative humidity. When step wise regression was done without including the data points for solar radiation, improvement of correlation (R value) was observed. Considering the adverse effect it was decided to remove solar radiation as an independent parameter.

Existing weather forecasts for Sri Lanka from department of Meteorology or from web based region wise hourly weather forecasts from http://www.weather.com/, http://www.accuweather.com/ do not have hourly rainfall forecast in millimeter. Instead of that web based forecasts includes probability of precipitation (POP) which is more focus on probability unlike other forecasted parameters such as temperature or wind.

$POP = C \times A$

C - The confidence that precipitation will occur somewhere in the forecast area.

A - The percentage of the area that will receive measurable precipitation, if it occurs at all.

For example, a forecaster might be 50% confident that under the current weather conditions precipitation will occur and it will happen over 80% of the area. This result in a POP of: (0.5×0.8) ×100= 40 %

Available historical data for rainfall was in millimeter while the existing forecasts are giving a rainfall probability which there is no such way to match each other. Rainfall in millimeter also had to remove as an independent parameter. Remaining four weather parameters were considered for the island wide model.

- Temperature
- Relative humidity
- Wind speed
- Wind direction

3.2 Minimize Drawbacks Identified in Pilot Study

Two major drawbacks been identified in pilot study which are,

- Time of day influence to the linear model
- Demand growth effect

3.2.1 Removing the time effect from the analysis

The nature of demand variation with time is far away from linearity. Figure 3.1 shows the incapability of predicting the morning and afternoon peak time demand from the pilot study model.

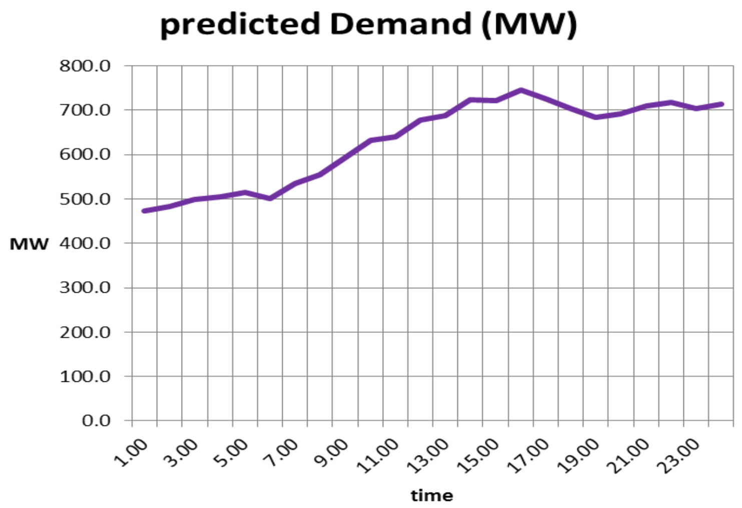

Figure 3.1: Predicted 55 % demand for 19th August 2013

Pre study equation:

$$55\%De = 10.482\,T + 20.886\,Te - 2.790H - 9.831W(speed) + 2.918R + 0.050W(direction) + 206.629$$

Instead of having time as an independent parameter it was decided to go for a more deep spot wise hourly analysis.

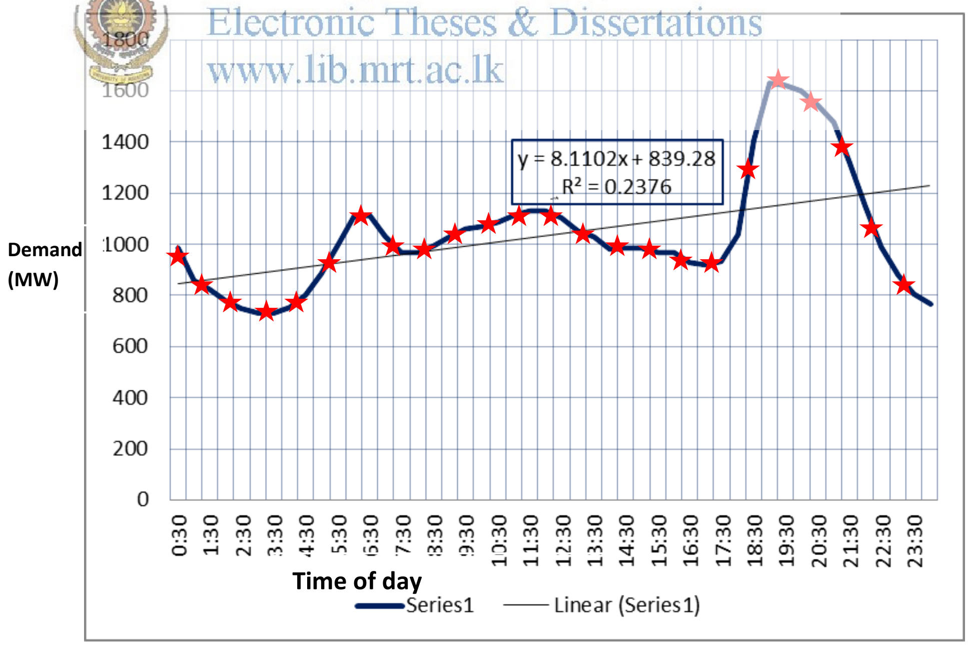

Figure 3.2: Spot wise prediction

It was decided to predict 24 spots for a particular day from 24 different model equations.

3.2.2 Coefficient of correlation – Demand growth effect

Yearly demand growth is an external factor which has no relationship with weather parameters. Demand growth effect should be included to the model as a correction factor otherwise it will give a wrong correlation.

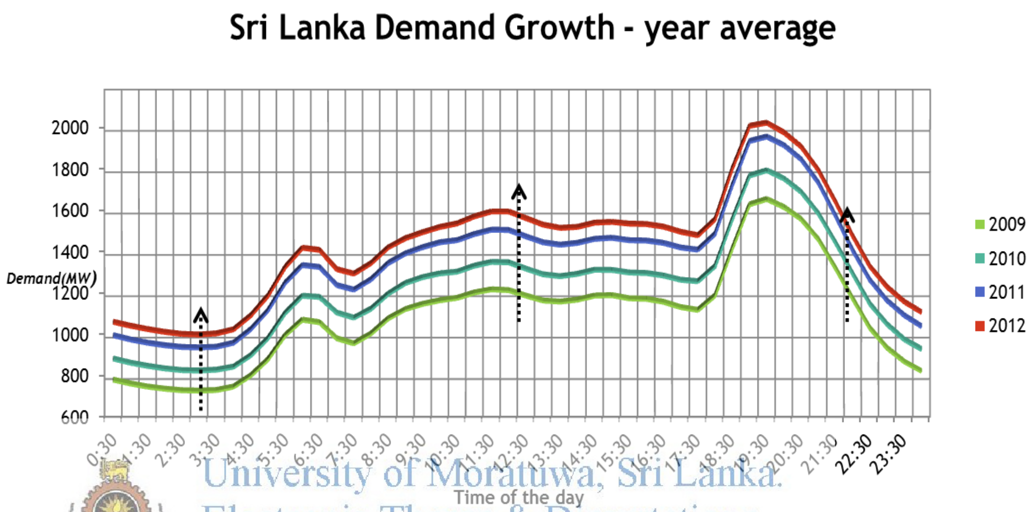

Figure 3.3: Yearly demand growth of Sri Lanka (from 2009 to 2012)

Source: CEB historical electricity demand data

The effect can be clearly seen by comparing daily electricity demand curves of different years with nearly same weather conditions with no other external effects.

Table 3.1: Effect of demand growth, example

Date	Demand (MW)	Wind speed(knot)	Wind direction (⁰)	Air Temp.(⁰C)	Humidity (%)
Monday 23 April 2010 ,1 a.m.	780	0.1	140	26	85.5
Monday 25 may 2011,1 a.m.	850	0.1	135	26	83.2
Monday 7 May 2012,1 a.m.	875	0.1	136	26	87

Source: Historical electricity demand data from CEB and historical weather data from department of Meteorology.

To calculate a correction factor, yearly average demand growth based method was used. Yearly average demand for each time slot was calculated for the existing data and percentage variation was calculated from relevant year to 2012 (Year 2012 was taken as the base year) (Appendix B).

As an example,

For 1.00 a.m. time slot 2009 yearly average demand was 738MW. For year 2012 it was 881MW. Percentage increase from year 2009 to 2012 is,

$$\frac{881-738}{738} \times 100 = 19\%$$

Table 3.2: Yearly average demand growth based on year 2012

Year	1:00 a. m.		2:00 a.m.		3:00 a.m.	
	% Variation to 2012	Average	% Variation to 2012	Average		
2007	12%	788	14%	749	…..	…..
2008	18%	745	18%	722	…..	…..
2009	19%	738	19%	713	…..	…..
2010	11%	793	11%	765	…..	…..
2011	2%	860	2%	832	…..	…..
2012	0%	881	0%	851	…..	…..
2013 Jan. - June	1%	892	1%	862	…..	…..

Source: Historical electricity demand data from CEB

Every demand data was multiplied by the calculated correction factor (yearly averaged demand growth percentage variation from the relevant year to year 2012). Correction factor varies with the year and the time slot which a particular demand data belongs to.

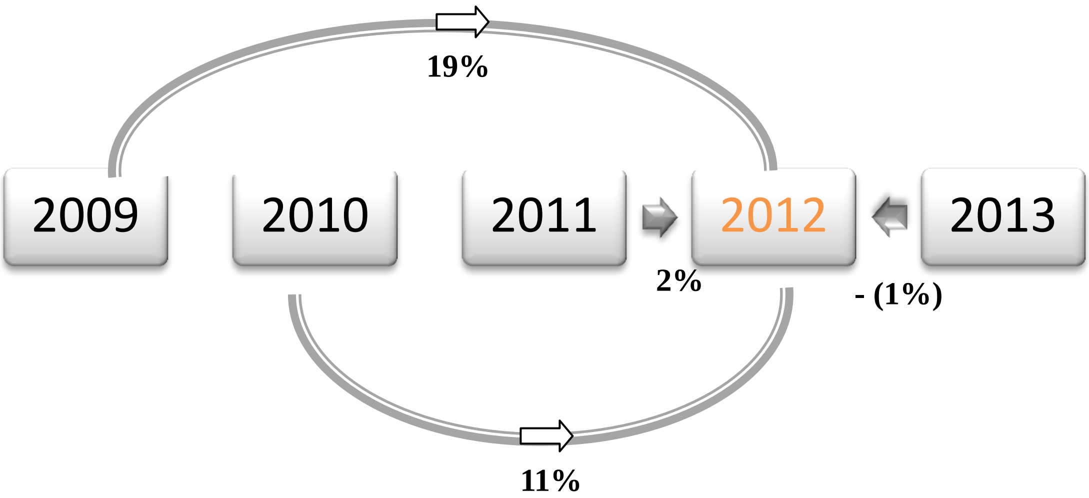

Figure 3.4: Demand growth correction example for 1.a.m. time slot

Source: Historical electricity demand data from CEB

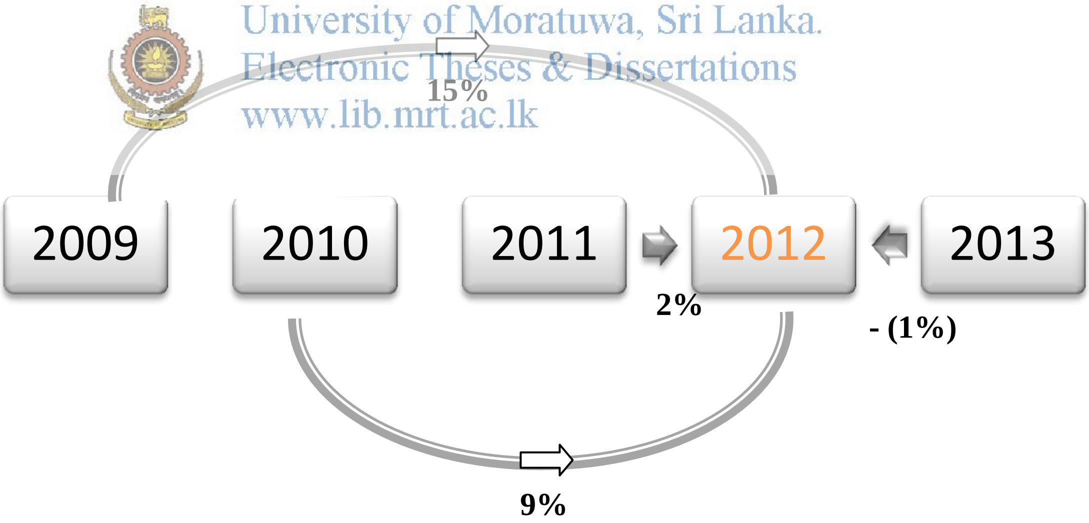

Figure 3.5: Demand growth correction example for 7.00 p.m. time slot

Source: Historical electricity demand data from CEB

time	2009	2010	2011	2012	2013 JAN - JUNE
1:00	19%	11%	2%	0%	1%
	738	793	860	881	892
2:00	19%	11%	2%	0%	1%
	713	765	832	851	862
3:00	19%	11%	2%	0%	1%
	703	755	822	838	847
4:00	19%	12%	2%	0%	1%
	723	774	844	863	875
5:00	20%	13%	3%	0%	2%
	855	912	1001	1026	1045
..	..	..	..	..	..
..	..	..	..	..	..
..	..	..	..	..	..
18:00	20%	11%	2%	0%	1%
	1164	1261	1371	1396	1409
19:00	15%	9%	2%	0%	1%
	1625	1698	1820	1848	1865
20:00	14%	8%	1%	0%	1%
	1592	1684	1800	1816	1836
..	..	..	..	..	..
..	..	..	..	..	..
23:00	17%	9%	2%	0%	1%
	911	979	1049	1069	1075
0:00	19%	10%	2%	0%	1%
	799	859	924	947	954

Figure 3.6: Demand growth correction for each time slot

Source: Historical electricity demand data from CEB

3.3 Final Data Arrangement

Table 3.3: Previous data arrangement

Date	Demand (MW)	Time of the day	Wind speed (knot)	Wind direction (^{0})	Rainfall (mm)	Air temp. (^{0}C)	Solar radiation (MJ/m^2)	Relative humidity (%)
23 April ,2011	890	4.59	0.9	155	3	25	0.07	91.1
	1077	5.59	1.1	138	0.5	25	0.07	88.8
	..	..	..	..	..	..	..	..
	.	.	.	.	.	.	.	.

Pre study was concentrated to develop a single model which could predict the daily demand curve. But with the additions and omissions project goal was revised to have 24 modelled equations to predict hourly daily demand. Full data set was separated to 24 subgroups according to the time of the day.

Ex: for Sunday 01.00 hours

Table 3.4: New data arrangement

Date	Corrected Demand (MW)	Wind speed(knot)	Wind direction (^{0})	Air temp.(^{0}C)	Relative humidity (%)
23 April ,2011	862	0.9	155	25	91.1
30 April ,2011	897.6	1.1	138	25	88.8
7 May ,2011	..	..	..	..	..
	.	.	.	.	.

3.4 Expanding the Analysis

3.4.1 Western province based national electricity demand prediction

The dominant region of Sri Lanka electricity demand is Western Province. Due to high population and industrialization Western Province has become the controlling center of electricity demand having 55% of total energy sales in 2012. Only North-Western Province apart from the Western Province has reached the 10% mark of total energy sales in 2012.

Table 3.5: Percentage energy sales by province

province	Percentage energy sales 2012
Western	55.4
North Western	10.04
Southern	9.02
Central	7.43
Sabaragamuwa	4.64
Eastern	4.52
Uva	3.65
North Central	3.62
Northern	2.04

Source: Historical electricity energy data from CEB

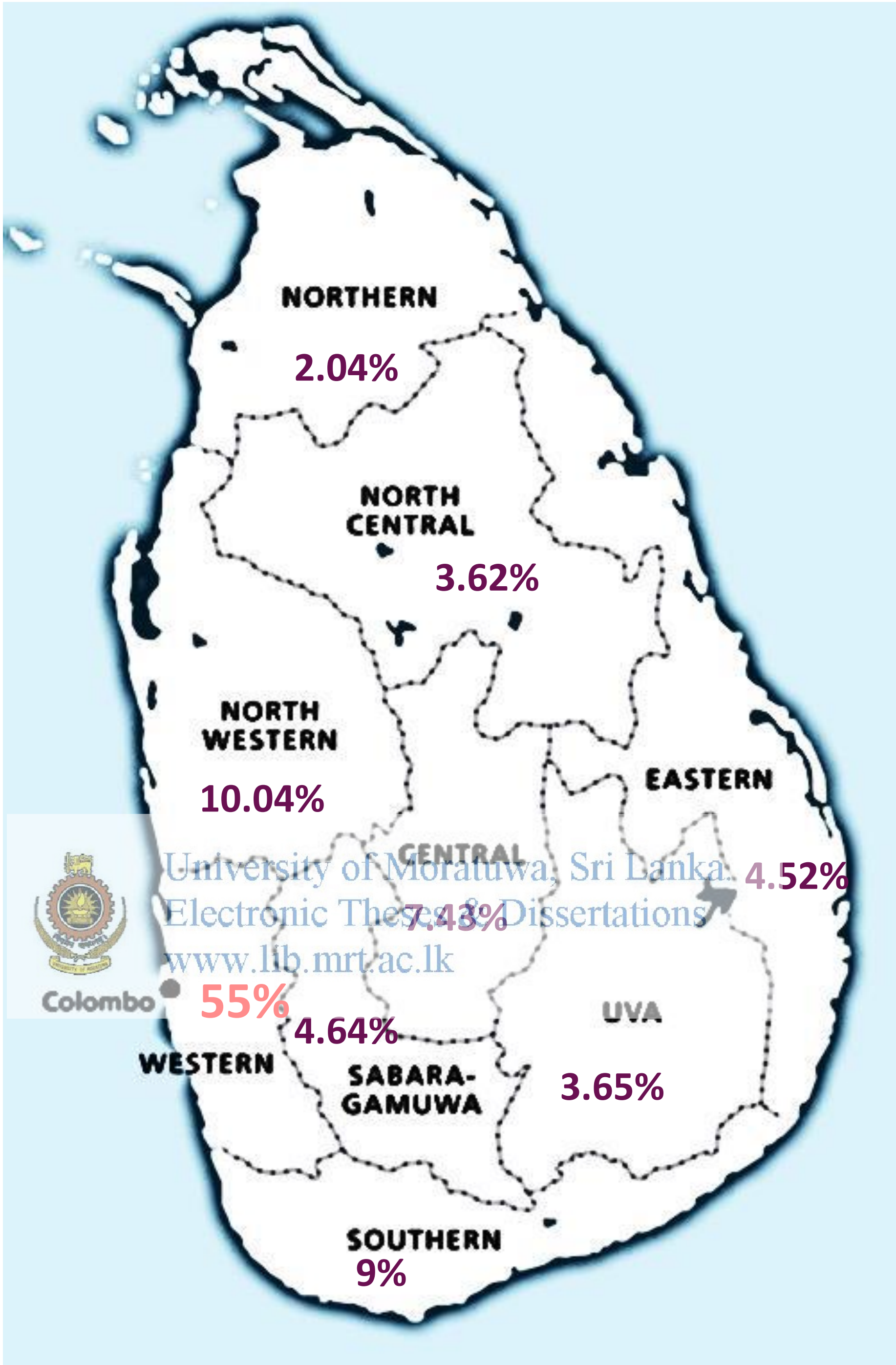

Figure 3.7: Percentage electrical energy sales by province – 2012

Source: Historical electricity energy data from CEB

Pilot study was based on weather data of Colombo area. Considering the dominance of western province it was decided to take the whole country as a one region which depends on the Colombo weather data. Region wise or provincial wise analysis would have given more accurate prediction capability. But though weather data are available for every district of the country (sometimes several measuring stations for a district), demand data are available only national wise. There were no records of hourly regional or provincial demand data.

3.4.2 Separate analysis for weekends and weekdays

After removing the time effect to the analysis, problem raised whether all the 7 days of the week behaves as the same or not. When comparing demand curves for the seven days of the week it was realized that demand curves for weekdays are roughly equal to each other (if only there is not any special external factor and the weather is same) but Saturday and Sunday behaved different way. Demand curves of Saturdays and Sundays were lower than the weekdays and Sunday curves are the lowest. This is expected as in weekends most of the factories and workshops are closed.

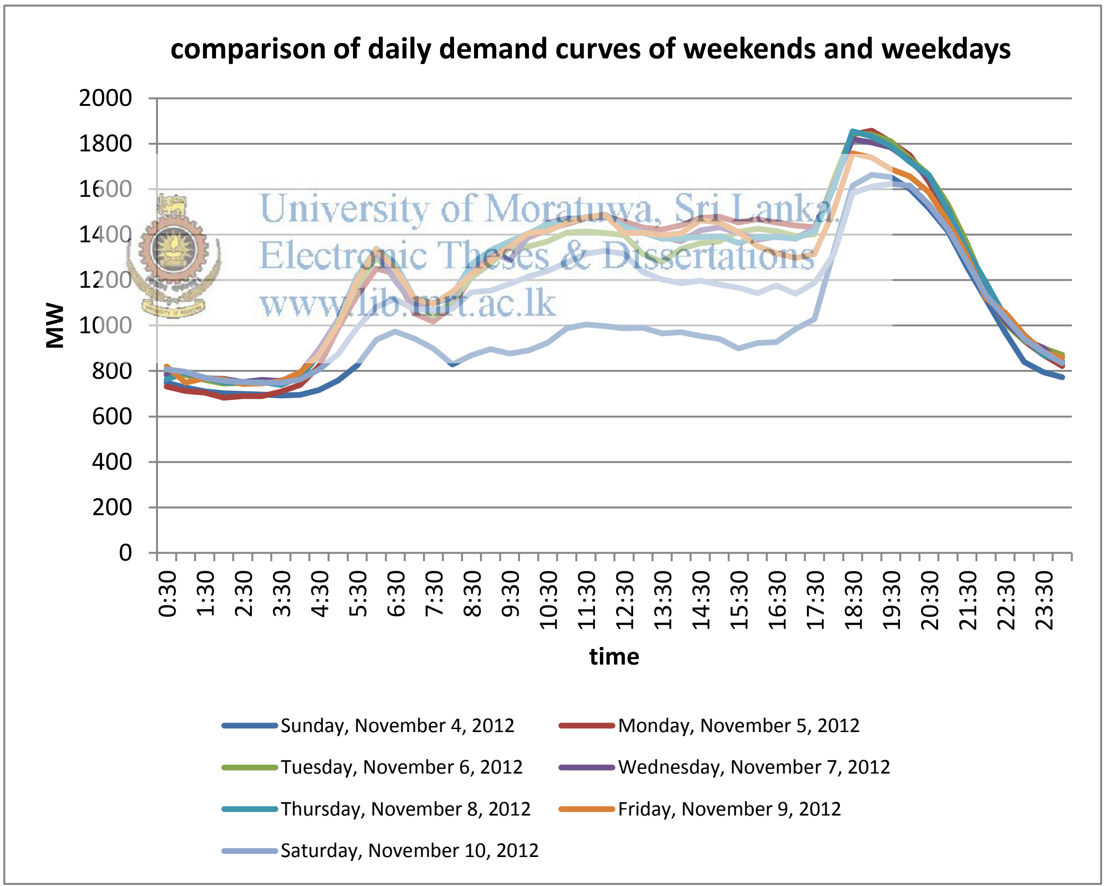

Figure 3.8: Comparison of daily demand curves of weekend and weekdays

Source: Historical electricity energy data from CEB

Considering the variation, it was decided to expand the analysis by separating it into 3 sections as weekdays, Saturday and Sunday.

3.4.3 Final outcome

Demand prediction model would consist of three sections (weekday, Saturday, Sunday) each having 24 equations representing the hourly demand. Full model would consist of 72 equations developed from separate 72 analyses.

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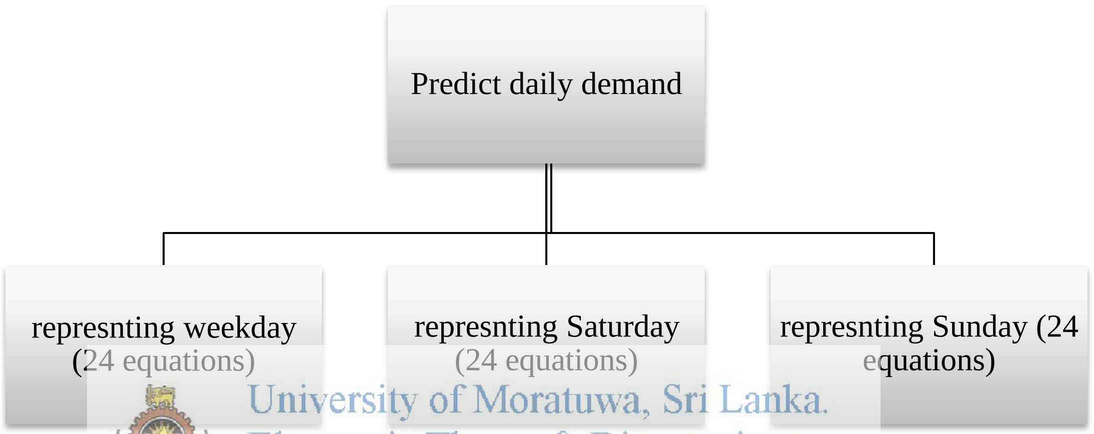

Figure 3.9: Final model

3.4.3.1 Data rearrangement

All the demand data and weather data were regrouped according to the time of day (24 sets) and whether a particular day is a weekday or Saturday or a Sunday (24*3).

Table 3.6 Example data arrangement for weekday 1.00 a.m. analysis

date		time	actual MW	Corrected MW	Corrected 55% MW	Wind speed (knot)	Wind direction (°)	Air Temp. (^{0}C)	Humidity (%)
4-May-09	Monday	0.59	735	875	481	1.3	30	25.6	85.8
5-May-09	Tuesday	0.59	784	933	513	2.2	50	25.6	85.6
6-May-09	Wednesday	0.59	687	818	450	2.3	45	24.3	87.1
7-May-09	Thursday	0.59	651	775	426	1.4	70	23.6	85.1
8-May-09	Friday	0.59	756	900	495	1.6	106	24.8	80.5
11-May-09	Monday	0.59	751	894	492	1.4	112	27	78.8
....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....
..	..	..	..	..	..	..	..	..	..

Source: Historical electricity demand data from CEB and historical weather data from department of Meteorology.

Table 3.7 Example data arrangement for Saturday 1.00 a.m. analysis

date		time	actual MW	Corrected MW	Corrected 55% MW	Wind speed (knot)	Wind direction (°)	Air Temp. (^{0}C)	Humidity (%)
25-Apr-09	Saturday	0.59	832	990	545	0.6	134	27	83.2
2-May-09	Saturday	0.59	710	845	465	0.8	57	24.2	92.7
9-May-09	Saturday	0.59	779	927	510	1	112	23.5	88.2
16-May-09	Saturday	0.59	754	897	493	1.7	96	24.7	81.3
23-May-09	Saturday	0.59	755	898	494	1.2	69	23.9	92.7
30-May-09	Saturday	0.59	590	702	386	0.6	116	24	95.3
....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....
..	..	..	..	..	..	..	..	..	..

Source: Historical electricity demand data from CEB and historical weather data from department of Meteorology.

Table 3.8 Example data arrangement for Sunday 1.00 a.m. analysis

date		time	actual MW	Corrected MW	Corrected 55% MW	Wind speed (knot)	Wind direction(°)	Air Temp. (^{0}C)	Humidity(%)
26-Apr-09	Sunday	0.59	794	945	520			26.3	83.4
3-May-09	Sunday	0.59	808	962	529	1	111	26.8	79.9
10-May-09	Sunday	0.59	678	807	444	1.7	70	22.8	93
17-May-09	Sunday	0.59	784	933	513	1	118	25.9	76.4
24-May-09	Sunday	0.59	731	870	478	2.9	54	25.2	80
31-May-09	Sunday	0.59	731	870	478	0.8	99	24.9	91.5
....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....
..	..	..	..	..	..	..	..	..	..

Source: Historical electricity demand data from CEB and historical weather data from department of Meteorology.

72 data sets were separately fed to the SPSS software and linear multiple regression analyses (step wise) was processed.

Independent parameters

- Temperature
- Relative humidity
- Wind speed
- Wind direction

Dependent parameter

- 55% of corrected electricity demand

72 sets of weather parameter coefficients were resulted with the related R values to predict 55% of daily energy demand which can by multiplied by (1/0.55) to get the national predicted electricity demand.

3.4.3.2 Final model coefficients

Table 3.9: Resultant coefficient to represent a weekday

	coefficient					
analysis	Air temp.	humidity	wind speed	wind direction	constant	R
1:00:00 AM	14.228	-1.115	-8.377	0.000	217.144	0.893
2:00:00 AM	13.325	-1.099	-9.575	0.000	230.217	0.851
3:00:00 AM	13.781	-1.100	-9.353	-0.054	223.505	0.837
4:00:00 AM	13.460	-1.075	-9.757	-0.056	249.895	0.812
5:00:00 AM	12.594	-0.961	-12.817	-0.061	380.717	0.810
6:00:00 AM	11.028	-1.098	-14.897	-0.143	592.663	0.800
7:00:00 AM	0.902	-1.126	0.000	-0.141	761.220	0.760
8:00:00 AM	4.370	-0.599	-3.504	0.000	614.922	0.739
9:00:00 AM	11.001	0.000	0.000	0.000	460.512	0.854
10:00:00 AM	12.818	0.000	0.000	0.074	419.576	0.882
11:00:00 AM	13.370	0.000	0.000	0.092	418.484	0.785
12:00:00 PM	13.316	0.000	0.000	0.114	417.579	0.797
1:00:00 PM	14.193	0.000	0.000	0.109	353.208	0.834
2:00:00 PM	15.039	0.000	0.000	0.135	322.948	0.845
3:00:00 PM	16.245	0.000	0.000	0.131	311.736	0.838
4:00:00 PM	15.727	0.000	-2.906	0.112	345.947	0.883
5:00:00 PM	7.991	0.000	0.000	0.062	549.668	0.758
6:00:00 PM	-3.169	0.000	-12.384	0.000	943.367	0.766
7:00:00 PM	6.048	-1.945	-5.716	0.097	1019.377	0.861
8:00:00 PM	10.831	-1.877	-4.310	0.121	857.069	0.891
9:00:00 PM	14.884	-1.899	-4.586	0.115	654.828	0.902
10:00:00 PM	17.730	-1.375	-7.331	0.101	368.362	0.905
11:00:00 PM	15.518	-1.251	-7.227	0.056	290.714	0.910
12:00:00 AM	15.421	-1.038	-6.885	0.000	221.618	0.900

Source: SPSS regression output for each time slot representing weekday

Table 3.10: Resultant coefficient to represent a Saturday

	coefficient					
analysis	Air temp.	humidity	wind speed	wind direction	constant	R
1:00:00 AM	15.793	-1.013	-10.208	0.000	184.474	0.849
2:00:00 AM	15.837	-1.203	-11.820	0.000	187.952	0.862
3:00:00 AM	14.595	-1.029	-11.533	0.000	200.042	0.833
4:00:00 AM	13.064	-1.014	-10.295	0.000	247.840	0.828
5:00:00 AM	10.119	-1.474	-14.584	0.000	430.926	0.810
6:00:00 AM	7.255	-1.391	-14.415	0.000	593.615	0.790
7:00:00 AM	1.040	-1.580	0.000	-0.105	782.495	0.720
8:00:00 AM	4.431	-0.989	-5.802	0.000	626.148	0.759
9:00:00 AM	9.973	0.000	0.000	0.000	417.638	0.783
10:00:00 AM	10.611	0.000	0.000	0.000	407.187	0.753
11:00:00 AM	9.223	0.000	0.000	0.111	451.970	0.742
12:00:00 PM	11.123	0.000	0.000	0.109	405.462	0.797
1:00:00 PM	11.746	0.000	0.000	0.113	339.896	0.813
2:00:00 PM	11.165	0.000	0.000	0.117	330.963	0.770
3:00:00 PM	10.509	0.000	0.000	0.000	375.778	0.729
4:00:00 PM	10.099	0.000	0.000	0.000	386.211	0.722
5:00:00 PM	5.479	0.000	0.000	0.000	510.693	0.712
6:00:00 PM	-1.014	0.000	-12.009	0.139	733.693	0.705
7:00:00 PM	14.264	-1.557	-6.185	0.000	724.634	0.850
8:00:00 PM	12.394	-1.436	0.000	0.154	716.074	0.866
9:00:00 PM	18.171	-1.428	-8.679	0.142	484.177	0.910
10:00:00 PM	18.651	-1.567	-9.301	0.120	336.353	0.920
11:00:00 PM	19.240	-0.980	-7.726	0.000	177.697	0.887
12:00:00 AM	16.883	0.000	0.000	0.000	81.138	0.826

Source: SPSS regression output for each time slot representing Saturday

Table 3.11: Resultant coefficient to represent a Sunday

	coefficient					
analysis	Air temp.	humidity	wind speed	wind direction	constant	R
1:00:00 AM	4.987	-1.629	-8.399	0.164	476.347	0.863
2:00:00 AM	5.411	-1.613	-10.763	0.124	457.201	0.841
3:00:00 AM	5.389	-1.589	-8.888	0.091	450.058	0.812
4:00:00 AM	4.709	-1.414	-6.878	0.092	456.196	0.784
5:00:00 AM	4.843	-1.325	-12.335	0.099	498.372	0.782
6:00:00 AM	15.863	-1.128	-12.833	-0.233	336.204	0.855
7:00:00 AM	4.871	-1.202	0.000	-0.184	591.539	0.720
8:00:00 AM	0.954	-1.032	0.000	0.000	634.102	0.702
9:00:00 AM	5.578	-0.824	0.000	0.000	457.526	0.783
10:00:00 AM	10.479	0.000	-3.897	0.000	275.783	0.800
11:00:00 AM	10.711	0.000	-4.562	0.000	296.696	0.790
12:00:00 PM	12.407	0.000	-4.209	0.000	262.819	0.802
1:00:00 PM	11.116	0.000	-7.304	0.000	292.876	0.804
2:00:00 PM	13.118	0.000	-5.786	0.000	203.103	0.866
3:00:00 PM	16.540	0.000	-5.967	0.000	96.861	0.851
4:00:00 PM	14.382	0.000	0.000	0.000	139.957	0.790
5:00:00 PM	7.261	0.000	0.000	0.000	358.262	0.747
6:00:00 PM	-5.372	0.000	-9.622	0.000	837.445	0.703
7:00:00 PM	10.975	-1.329	0.000	0.000	735.914	0.861
8:00:00 PM	21.074	0.000	-4.682	0.100	348.577	0.928
9:00:00 PM	19.626	-1.186	0.000	0.105	379.437	0.939
10:00:00 PM	24.577	0.000	0.000	0.000	10.436	0.912
11:00:00 PM	19.813	-0.821	-9.060	0.000	100.370	0.921
12:00:00 AM	18.640	-0.640	-7.573	0.000	53.059	0.928

Source: SPSS regression output for each time slot representing Sunday

For most of the time slots as pilot study predicted full model analysis also shows a positive linear relationship between demand and temperature, negative linear relationship between demand and relative humidity, negative relationship between demand and wind speed and a positive constant. In pilot study relationship between wind direction and demand is positive with a very small coefficient but in full model analysis it shows both positive and negative relationship with respect to the time slot with a very low coefficient.

3.4.3.3 Model behavior analysis

Some deviations from the expected could be found out in time slots shown in table 3.12 with some relatively low R values and high constants. Deviations are concentrated at the time period in the morning and in the evening which can be interpreted as the errors due to transition period, from night to day and day to night. HVAC system loads and lighting loads would be less and roughly constant in the transition period causing relatively weak relationship between whether and electricity demand.

Normally environmental temperature of human comfortability range is 25^{0}C – 27^{0}C . Automatic air conditioning system set points are normally kept in above range. Once the human interference is less in the morning and evening (travelling time) there is a high probability of AC systems are being operated in constant loads despite of small weather variations. But this would differ when people occupy air conditioned spaces.

Table 3.12: Deviations from the expected behavior

analysis		coefficient				constant	R
		Air temp.	humidity	wind speed	wind direction		
weekdays	7:00:00 AM	0.902	-1.126	0.000	-0.141	761.220	0.760
	6:00:00 PM	-3.169	0.000	-12.384	0.000	943.367	0.766
Saturday	7:00:00 AM	1.040	-1.580	0.000	-0.105	782.495	0.720
	6:00:00 PM	-1.014	0.000	-12.009	0.139	733.693	0.705
Sunday	8:00:00 AM	0.954	-1.032	0.000	0.000	634.102	0.702
	6:00:00 PM	-5.372	0.000	-9.622	0.000	837.445	0.703

Source: Extracted from SPSS regression output for each time slot

Chapter 4

MODEL VALIDATION

Model validation is possibly the most important step in the model building sequence. Validation can be described as the process of determining the degree to which a simulation model and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model. Numerical methods or graphical methods or both can be used for model validation. For this model percentage error calculation with variance and standard deviation was used.

The variance and the standard deviation are both measures of the spread of the distribution about the mean. The variance is the nicer of the two measures of spread from a mathematical point of view, but due to the algebraic formula the physical unit of the variance is the square of the physical unit of the data.

$$\text{Absolute error \%} = \frac{(|\text{Real power} - \text{Predicted power}|) * 100}{\text{Real power}}$$

$$\text{Average |error\%|} = \frac{\sum \text{Absolute error\%}}{\text{Time period}}$$

Standard deviation (for a population) $\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (x_i - \mu)^2}$

- Where N = number of population data
- $\mu = \frac{\sum_{j=1}^{n} x_j}{N}$

Variance (for a population) $\sigma^2 = \frac{1}{N}\sum_{i=1}^{N} (x_i - \mu)^2$

Model validation was preceded for two sets of weather data,

- Historical weather data
- Forecasted weather data

4.1 Model Validation for Historical Weather Data

Historical weather parameters from 01st July 2013 to 10th November 2013 were put into the model and daily demand (55%) for the above period was predicted. Predicted 55% demand was converted to 100% electricity demand and the values were compared with the actual demand values taken from SCC, CEB.

Table 4.1: Example prediction for 7th July 2013 with historical weather data

Analysis		Coefficient: Air temp.	Coefficient: Relative humidity	Coefficient: Wind speed	Coefficient: Wind direction	Coefficient: Constant	R	R^2	Air temp.(^{0}C)	Relative humidity (%)	Wind speed (knots)	Wind direction (degrees from north)	Predicted MW 55%	Predicted MW
Sunday	1:00:00 AM	4.987	-1.629	-8.399	0.164	476.347	0.863	0.745	29.3	93.8	3.7	226	475.70	864.90
	2:00:00 AM	5.411	-1.613	-10.763	0.124	457.201	0.841	0.707	29.1	97.5	3.7	229	445.88	810.69
	3:00:00 AM	5.389	-1.589	-8.888	0.091	450.058	0.812	0.659	29	97.3	3.5	236	442.19	803.98
	4:00:00 AM	4.709	-1.414	-6.878	0.092	456.196	0.784	0.615	28.6	99.5	3.1	245	451.31	820.56
	5:00:00 AM	4.843	-1.325	-12.335	0.099	498.372	0.782	0.612	26.1	100	3.1	247	478.58	870.15
	6:00:00 AM	15.863	-1.128	-12.833	-0.233	336.204	0.855	0.731	25.9	100	3.7	245	529.73	963.14
	7:00:00 AM	4.871	-1.202	0.000	-0.184	591.539	0.720	0.518	27.6	100	3.7	244	560.86	1019.74
	8:00:00 AM	0.954	-1.032	0.000	0.000	634.102	0.702	0.493	28.7	99.2	3.9	250	559.06	1016.49
	9:00:00 AM	5.578	-0.824	0.000	0.000	457.526	0.783	0.613	29.5	93.3	5.1	259	545.15	991.18
	10:00:00 AM	10.479	0.000	-3.897	0.000	275.783	0.800	0.640	30	91.5	4.3	254	573.39	1042.52
	11:00:00 AM	10.711	0.000	-4.562	0.000	296.696	0.790	0.624	30	94.3	4.1	252	599.32	1089.67
	12:00:00 PM	12.407	0.000	-4.209	0.000	262.819	0.802	0.643	30.1	93.5	3.9	249	619.85	1126.99
	1:00:00 PM	11.116	0.000	-7.304	0.000	292.876	0.804	0.646	30.2	94.6	4.1	248	598.63	1088.42
	2:00:00 PM	13.118	0.000	-5.786	0.000	203.103	0.866	0.750	30.7	88.7	4.3	251	580.94	1056.25
	3:00:00 PM	16.540	0.000	-5.967	0.000	96.861	0.851	0.724	30.7	84.9	4.7	261	576.59	1048.35
	4:00:00 PM	14.382	0.000	0.000	0.000	139.957	0.790	0.624	30.5	88.1	4.1	256	578.61	1052.03
	5:00:00 PM	7.261	0.000	0.000	0.000	358.262	0.747	0.558	30.2	92.5	3.9	247	577.54	1050.07
	6:00:00 PM	-5.372	0.000	-9.622	0.000	837.445	0.703	0.494	29.7	96.7	3.1	240	648.07	1178.31
	7:00:00 PM	10.975	-1.329	0.000	0.000	735.914	0.861	0.741	29.4	99.5	2.5	245	926.38	1684.33
	8:00:00 PM	21.074	0.000	-4.682	0.100	348.577	0.928	0.861	29.3	100	3.1	233	974.92	1772.57
	9:00:00 PM	19.626	-1.186	0.000	0.105	379.437	0.939	0.882	29.2	100	3.7	229	857.88	1559.78
	10:00:00 PM	24.577	0.000	0.000	0.000	10.436	0.912	0.832	29.1	100	3.5	230	725.62	1319.31
	11:00:00 PM	19.813	-0.821	-9.060	0.000	100.370	0.921	0.848	29.1	100	3.1	228	566.78	1030.51
	12:00:00 AM	18.640	-0.640	-7.573	0.000	53.059	0.928	0.861	29	99.9	3.3	241	504.69	917.62

Table 4.2: Example error calculation for 03rd July 2013, Wednesday

Time	Air Temp. (^{0}C)	Humidity (%)	Wind speed (knot)	Wind direction (°)	**predicted 55%**	predicted 100%	real MW	error %
1:00:00 AM	28.2	100	3.5	220	**477.6**	868.29	821.3	-6%
2:00:00 AM	26.8	100	3.1	232	**447.8**	814.14	793.2	-3%
3:00:00 AM	27.4	100	2.9	221	**452.1**	822.06	782.8	-5%
4:00:00 AM	28.3	100	3.7	231	**474.3**	862.43	839.8	-3%
5:00:00 AM	28.4	100	3.9	227	**578.5**	1051.75	1019.8	-3%
6:00:00 AM	28.4	100	4.1	226	**702.6**	1277.48	1319.4	3%
7:00:00 AM	28.3	100	3.9	226	**616.8**	1121.48	1123.2	0%
8:00:00 AM	29.1	100	3.7	226	**669.3**	1216.82	1245.5	2%
9:00:00 AM	30	96.1	4.9	224	**790.5**	1437.34	1378.1	-4%
10:00:00 AM	30.6	91.8	5.6	219	**827.9**	1505.29	1472.4	-2%
11:00:00 AM	31	87.9	5.6	223	**853.4**	1551.58	1472	-5%
12:00:00 PM	31.2	82.9	6.6	222	**858.4**	1560.70	1507.8	-4%
1:00:00 PM	31.6	81.9	6.2	215	**825.1**	1500.16	1448.2	-4%
2:00:00 PM	31.1	84.4	6.2	224	**820.8**	1492.42	1461	-2%
3:00:00 PM	30.6	86.5	5.8	218	**837.3**	1522.44	1493	-2%
4:00:00 PM	31.3	81.8	6.6	221	**843.7**	1534.08	1497	-2%
5:00:00 PM	30.9	83.9	6.6	220	**810.2**	1473.15	1413.5	-4%
6:00:00 PM	30.3	90	5.1	225	**784.2**	1425.80	1351.9	-5%
7:00:00 PM	29.3	98.3	4.1	224	**1003.7**	1824.84	1745	-5%
8:00:00 PM	29.2	100	4.1	217	**994.3**	1807.83	1762.6	-3%
9:00:00 PM	29.2	100	5.2	214	**900.3**	1636.91	1576.4	-4%
10:00:00 PM	29.1	100	4.7	214	**733.9**	1334.29	1259.6	-6%
11:00:00 PM	29	100	3.9	217	**599.6**	1090.19	1033.9	-5%
12:00:00 AM	28.8	100	3.9	207	**535.1**	972.91	905.6	-7%

$$\text{Error \%} = \frac{(\text{Real power} - \text{Predicted power}) * 100}{\text{Real power}}$$

For more than 10% plus or minus error points, reasoning was done collaborating with SCC of CEB. If there is an emergency external factor such as distribution feeder tripping, transmission line tripping or a power plant emergency outage those points were removed and average error and variance calculation was done for each time slot (24 separated sets)

Table 4.3: Example average absolute error and variation calculation for 5.00 a.m. time slot

date	Time	error %	Absolute error
Monday, July 1, 2013	5:00:00 AM	-4.54%	0.045
Tuesday, July 2, 2013	5:00:00 AM	-5.95%	0.059
Wednesday, July 3, 2013	5:00:00 AM	-3.13%	0.031
Thursday, July 4, 2013	5:00:00 AM	-3.96%	0.039
Friday, July 5, 2013	5:00:00 AM	-1.98%	0.019
Saturday, July 6, 2013	5:00:00 AM	4.63%	0.046
Sunday, July 7, 2013	5:00:00 AM	-10.45%	0.104
Monday, July 8, 2013	5:00:00 AM	-12.56%	0.125
Tuesday, July 9, 2013	5:00:00 AM	-0.18%	0.001
Wednesday, July 10, 2013	5:00:00 AM	0.00%	0.000
Thursday, July 11, 2013	5:00:00 AM	-0.23%	0.002
Friday, July 12, 2013	5:00:00 AM	1.74%	0.017
Saturday, July 13, 2013	5:00:00 AM	-3.12%	0.031
Sunday, July 14, 2013	5:00:00 AM	-2.38%	0.023
Monday, July 15, 2013	5:00:00 AM	-1.34%	0.013
Tuesday, July 16, 2013	5:00:00 AM	1.70%	0.017
Wednesday, July 17, 2013	5:00:00 AM	0.98%	0.009
….	….	….	….
….	….	….	….
Sunday, November 10, 2013	5:00:00 AM	0.65%	0.006

Average |error|	0.06104	6.1%
St. Deviation	0.045251	4.5%
Variance	0.002048	0.2%%

$$\text{Average }|\text{error}\%| = \frac{\sum \text{Absolute error}\%}{\text{Time period}}$$

Table 4.4: Average absolute error, standard deviation and variance for all time slots

Time of day	Average absolute Error (%)	St. deviation (%)	Variance (%%)
1:00:00 AM	8.1	5.8	0.34
2:00:00 AM	8.4	5.7	0.32
3:00:00 AM	8.2	5.8	0.34
4:00:00 AM	7.7	5.5	0.30
5:00:00 AM	6.1	4.5	0.20
6:00:00 AM	5.4	3.8	0.15
7:00:00 AM	4.2	3.3	0.11
8:00:00 AM	4.9	3.5	0.12
9:00:00 AM	5.3	3.5	0.13
10:00:00 AM	5.7	3.8	0.14
11:00:00 AM	5.4	3.4	0.12
12:00:00 PM	5.4	3.5	0.12
1:00:00 PM	5.6	3.7	0.14
2:00:00 PM	6.0	3.6	0.13
3:00:00 PM	6.3	3.5	0.12
4:00:00 PM	5.4	3.3	0.11
5:00:00 PM	4.6	2.8	0.08
6:00:00 PM	7.2	4.3	0.19
7:00:00 PM	3.9	2.7	0.08
8:00:00 PM	4.1	2.8	0.08
9:00:00 PM	5.0	3.7	0.13
10:00:00 PM	5.8	3.9	0.16
11:00:00 PM	6.6	4.7	0.22
12:00:00 AM	6.9	5.1	0.26

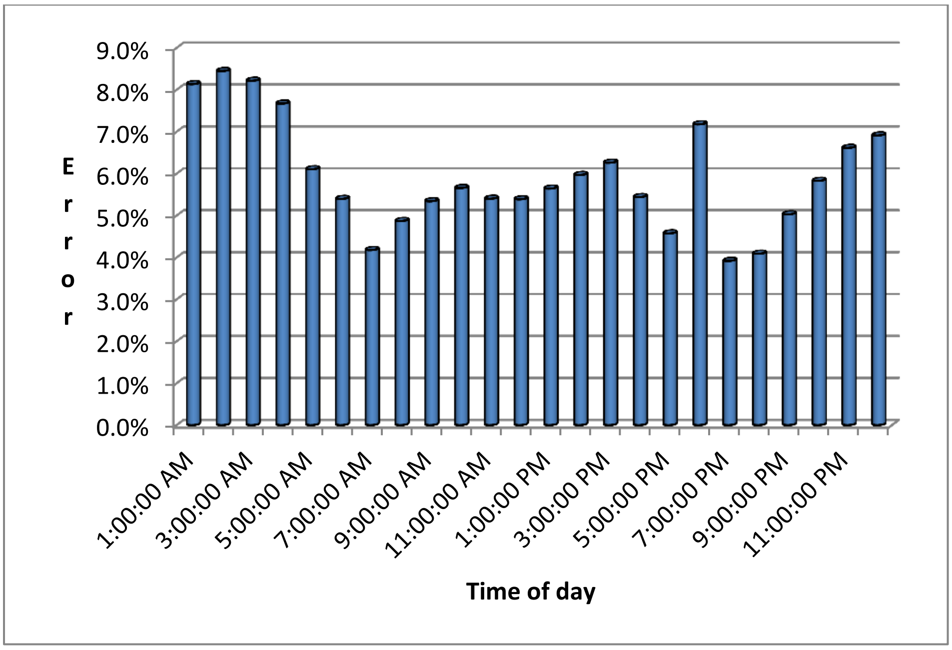

Figure 4.1: Percentage average absolute error of time slots.

Relatively high error margin could be seen at the early morning hours form 1.00 a.m. to 5.00 a.m. 6.00 p.m. slot also shows relatively high error margin. All average absolute error margins are below 10%.

4.2 Model Validation for Forecasted Weather Data

Purpose of the developed model is to predict future demand curve based on forecasted weather data. For Model validation forecasted hourly weather data for Colombo from website http://www.accuweather.com was used. Website gives hourly weather forecast for upcoming four days free of charge. Weather forecast from Department of Meteorology Sri Lanka would be the best option. But due to unavailability of detail hourly forecast at the time when validation was carried out, web based option was used. However currently department of Meteorology also running forecasting models in research basis and in near future much more accurate hourly weather forecasts would be available for local areas from department of Meteorology.

Figure 4.2: Example hourly weather predictions for Colombo

Source: www.accweather.com

Temperature and humidity forecasts were straight forward but wind speed and wind direction measuring units were different from the model and needed to convert in to "knots" from km/h and "degrees from north" from the given direction.

Factor 0.539957 was used to multiply wind speed data to convert into knots. (1km/h = 0.539957 knots). For wind direction conversion following table was used.

Table 4.5: Cardinal direction to degrees conversion

1	North	N	0°
2	North by east	NbE	11.25°
3	North-northeast	NNE	22.50°
4	Northeast by north	NEbN	33.75°
5	Northeast	NE	45.00°
6	Northeast by east	NEbE	56.25°
7	East-northeast	ENE	67.50°
8	East by north	EbN	78.75°
9	East	E	90.00°
10	East by south	EbS	101.25°
11	East-southeast	ESE	112.50°
12	Southeast by east	SEbE	123.75°
13	Southeast	SE	135.00°
14	Southeast by south	SEbS	146.25°
15	South-southeast	SSE	157.50°
16	South by east	SbE	168.75°
17	South	S	180.00°
18	South by west	SbW	191.25°
19	South-southwest	SSW	202.50°
20	Southwest by south	SWbS	213.75°
21	Southwest	SW	225.00°
22	Southwest by west	SWbW	236.25°
23	West-southwest	WSW	247.50°
24	West by south	WbS	258.75°
25	West	W	270.00°
26	West by north	WbN	281.25°
27	West-northwest	WNW	292.50°
28	Northwest by west	NWbW	303.75°
29	Northwest	NW	315.00°
30	Northwest by north	NWbN	326.25°
31	North-northwest	NNW	337.50°
32	North by west	NbW	348.75°

Source: https://en.wikipedia.org/wiki/Cardinal_direction

Colombo weather forecasts were taken four days ahead (as permissible by the web) and logged from January 2014 to March 2014. For a particular day four weather forecast were taken as 4 days before, 3 days before, 2 days before and a day before. For each and every forecast power demand was predicted from the model (for a single day, four demand (MW) predictions).

Actual hourly electricity demand were taken from SCC and compared with the predicted electricity demand.

Table 4.6: Example no 1, detail model validation for maximum four days a head weather forecasts, 29th January 2014

			forcasted 4 Days before						forcasted 3 Days before						forcasted 2 Days before						forcasted 1 Day before					
date	Time	real MW	Air Temp. (°C)	Humi dity (%)	Wind speed(knot)	Wind directio n (°)	predicted 100%	error %	Air Temp.(° C)	Humi dity (%)	Wind speed(knot)	Wind directio n(°)	predicted 100%	error %	Air Temp.(° C)	Humi dity(%)	Wind speed(knot)	Wind directio n(°)	predicted 100%	error %	Air Temp.(° C)	Humid ity(%)	Wind speed(knot)	Wind directi on(°)	predicted 100%	error %
1/29/2014	1:00:00 AM	920.0	25.0	80	7.8	22.5	760.2	17%	25.0	80	7.8	22.5	760.2	17%	25.6	81	6.1	45.0	799.1	13%	25.6	86	1.7	0.0	855.1	7%
	2:00:00 AM	897.4	25.0	83	7.8	22.5	722.3	20%	25.0	83	7.8	22.5	722.3	20%	25.0	82	6.1	22.5	754.6	16%	25.0	86	2.6	0.0	807.1	10%
	3:00:00 AM	891.3	24.4	84	7.8	22.5	715.7	20%	24.4	84	7.8	22.5	715.7	20%	25.0	83	6.1	22.5	761.2	15%	25.0	86	3.5	0.0	801.7	10%
	4:00:00 AM	903.5	23.3	86	7.8	22.5	716.3	21%	23.3	86	7.8	22.5	716.3	21%	24.4	83	7.0	22.5	764.7	15%	24.4	86	4.3	0.0	807.4	11%
	5:00:00 AM	1127.8	23.9	85	7.8	22.5	906.0	20%	23.9	85	7.8	22.5	906.0	20%	24.4	84	7.0	22.5	940.7	17%	24.4	86	5.2	0.0	980.2	13%
	6:00:00 AM	1436.3	24.4	84	8.7	22.5	1158.8	19%	24.4	84	8.7	22.5	1158.8	19%	23.9	85	7.0	22.5	1192.7	17%	23.9	86	2.6	0.0	1314.3	8%
	7:00:00 AM	1323.1	25.0	83	8.7	22.5	1208.3	9%	25.0	83	8.7	22.5	1208.3	9%	24.4	84	7.8	22.5	1206.3	9%	24.4	85	4.3	0.0	1210.0	9%
	8:00:00 AM	1303.7	25.0	82	8.7	22.5	1172.1	10%	25.0	82	8.7	22.5	1172.1	10%	25.0	82	8.7	22.5	1172.1	10%	25.0	82	6.1	0.0	1188.7	9%
	9:00:00 AM	1501.9	26.1	76	9.6	22.5	1359.6	9%	26.1	76	9.6	22.5	1359.6	9%	26.1	75	9.6	22.5	1359.6	9%	26.1	76	7.0	0.0	1359.6	9%
	10:00:00 AM	1519.4	27.8	71	8.7	22.5	1413.2	7%	27.8	71	8.7	22.5	1413.2	7%	27.2	70	8.7	22.5	1400.3	8%	27.2	70	7.8	0.0	1397.3	8%
	11:00:00 AM	1576.0	28.9	65	7.8	22.5	1466.9	7%	28.9	65	7.8	22.5	1466.9	7%	28.3	64	8.7	22.5	1453.4	8%	28.3	64	7.8	0.0	1449.6	8%
	12:00:00 PM	1604.5	29.4	60	7.8	22.5	1476.8	8%	29.4	60	7.8	22.5	1476.8	8%	30.0	59	8.7	0.0	1485.6	7%	30.0	61	5.2	22.5	1490.2	7%
	1:00:00 PM	1557.1	30.6	57	7.0	22.5	1435.2	8%	30.6	57	7.0	22.5	1435.2	8%	31.1	54	9.6	0.0	1445.1	7%	31.1	56	7.0	22.5	1449.5	7%
	2:00:00 PM	1552.4	31.1	54	7.0	0.0	1437.9	7%	31.1	54	7.0	0.0	1437.9	7%	28.9	68	9.6	0.0	1377.1	11%	28.9	70	7.8	22.5	1382.6	11%
	3:00:00 PM	1616.5	31.1	53	7.0	0.0	1485.7	8%	31.1	53	7.0	0.0	1485.7	8%	28.3	75	10.4	337.5	1483.9	8%	28.3	77	8.7	22.5	1409.0	13%
	4:00:00 PM	1601.4	30.6	55	7.0	0.0	1466.0	8%	30.6	55	7.0	0.0	1466.0	8%	28.9	70	10.4	0.0	1399.9	13%	28.9	71	8.7	22.5	1413.7	12%
	5:00:00 PM	1556.8	29.4	60	7.0	0.0	1427.2	8%	29.4	60	7.0	0.0	1427.2	8%	28.9	70	9.6	0.0	1419.1	9%	28.9	70	8.7	22.5	1421.7	9%
	6:00:00 PM	1562.1	28.3	67	7.0	0.0	1395.4	11%	28.3	67	7.0	0.0	1395.4	11%	28.3	71	9.6	0.0	1336.7	14%	29.4	61	7.0	0.0	1389.0	11%
	7:00:00 PM	1981.2	27.2	71	7.0	22.5	1833.4	7%	27.2	71	7.0	22.5	1833.4	7%	27.8	74	8.7	0.0	1806.9	9%	28.9	66	7.0	0.0	1865.4	6%
	8:00:00 PM	1873.7	26.7	74	7.0	22.5	1781.4	5%	26.7	74	7.0	22.5	1781.4	5%	26.7	79	7.8	22.5	1757.5	6%	27.8	70	6.1	0.0	1818.7	3%
	9:00:00 PM	1666.0	26.1	76	7.0	45.0	1586.3	5%	26.1	76	7.0	45.0	1586.3	5%	26.1	81	7.0	22.5	1564.3	6%	27.2	73	6.1	0.0	1624.6	2%
	10:00:00 PM	1346.9	26.1	78	6.1	45.0	1243.6	8%	26.1	78	6.1	45.0	1243.6	8%	26.1	81	7.0	22.5	1220.4	9%	26.7	76	5.2	0.0	1269.9	6%
	11:00:00 PM	1082.2	25.6	80	6.1	45.0	992.2	8%	25.6	80	6.1	45.0	992.2	8%	25.6	82	6.1	22.5	985.4	9%	25.6	81	5.2	0.0	996.8	8%
	12:00:00 AM	949.5	25.6	80	6.1	45.0	892.4	6%	25.0	81	5.2	45.0	885.8	7%	25.6	81	6.1	45.0	890.5	6%	25.0	82	5.2	22.5	883.9	7%

Table 4.7: Example no 2, model validation for 3rd Feb. 2014

date	time	actual	4 day before		3 day before		2 day before		1 day before	
Monday, February 3, 2014	1:00:00 AM	848.9	780.6	8%	771.5	5%	810.3	9%	899.1	-6%
	2:00:00 AM	829.6	750.6	10%	739.4	7%	767.7	11%	849.1	-2%
	3:00:00 AM	808.0	739.1	9%	728.3	6%	757.8	10%	812.1	-1%
	4:00:00 AM	849.5	725.3	15%	744.9	9%	773.8	12%	816.3	4%
	5:00:00 AM	1116.2	926.1	17%	942.3	12%	980.6	16%	990.9	11%
	6:00:00 AM	1357.4	1197.3	12%	1195.3	10%	1216.8	12%	1303.3	4%
	7:00:00 AM	1177.0	1200.5	-2%	1198.5	-2%	1196.4	-2%	1210.4	-3%
	8:00:00 AM	1185.6	1191.9	-1%	1185.3	0%	1190.9	0%	1199.7	-1%
	9:00:00 AM	1408.1	1359.6	3%	1359.6	3%	1359.6	3%	1359.6	3%
	10:00:00 AM	1490.6	1413.2	5%	1400.3	5%	1413.2	6%	1400.3	6%
	11:00:00 AM	1527.3	1463.1	4%	1463.1	4%	1463.1	4%	1466.9	4%
	12:00:00 PM	1568.7	1555.6	1%	1485.6	5%	1485.6	5%	1548.7	1%
	1:00:00 PM	1515.2	1507.3	1%	1445.1	0%	1511.7	5%	1508.4	0%
	2:00:00 PM	1523.7	1530.2	0%	1453.1	-1%	1535.7	5%	1509.7	1%
	3:00:00 PM	1543.5	1635.3	-6%	1615.2	-4%	1609.8	-5%	1578.5	-2%
	4:00:00 PM	1536.5	1580.3	-3%	1582.3	-3%	1582.3	-3%	1527.4	1%
	5:00:00 PM	1485.4	1486.9	0%	1489.5	0%	1486.9	0%	1453.9	2%
	6:00:00 PM	1418.7	1405.4	1%	1405.4	1%	1405.4	1%	1431.4	-1%
	7:00:00 PM	1887.1	1950.0	-3%	1946.5	-2%	1930.4	-3%	1909.5	-1%
	8:00:00 PM	1886.6	1811.2	4%	1839.9	3%	1833.1	2%	1880.7	0%
	9:00:00 PM	1635.1	1560.4	5%	1648.4	0%	1633.0	-1%	1692.4	-4%
	10:00:00 PM	1368.8	1252.1	9%	1289.7	7%	1278.1	6%	1319.4	4%
	11:00:00 PM	1142.2	1010.6	12%	1035.3	11%	1021.6	9%	1042.5	9%
	12:00:00 AM	995.2	880.0	12%	912.2	10%	899.5	8%	891.5	10%

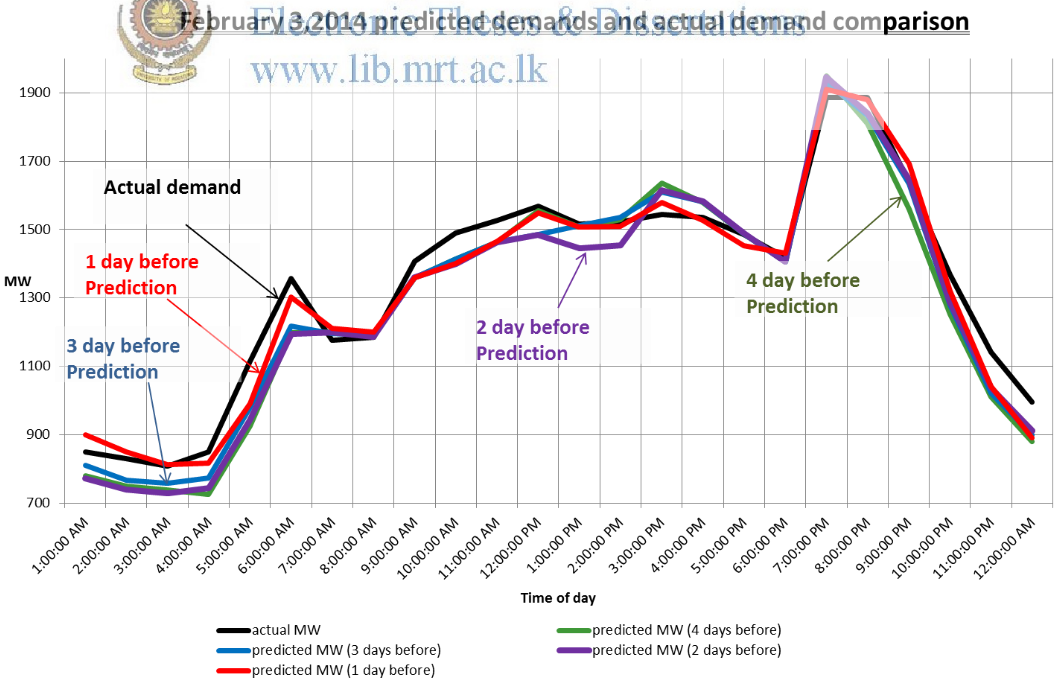

Figure 4.3: Comparison of predicted demand and actual demand 3rd February 2014

4.2.1 Error evaluation

For time period from Jan 2014 to March 2014, obtained predictions and error values were grouped according to the time of day. (24 groups representing 24 hours of the day). Error values were summarized and analyzed. Error values related to public holidays were removed since the nature of the holiday (as an example in Wesak poyaday night time demand increase abnormally) would affect the demand prediction. Also errors due to failures of the national power system (transmission line tripping, load shedding etc.) were removed since those are external factors for the prediction.

Table 4.8: Example error evaluation for 1.00 a.m. time slot

Date	Time	Actual demand (MW)	4 days before			3 days before			2 days before			1 day before		
			predicted demand (MW)	Error%	Absolute error %	Predicted demand (MW)	Error%	Absolute error %	Predicted demand (MW)	Error %	Absolute error %	Predicted demand (MW)	Error%	Absolute error %
....	1.00 a.m.	...	..	..	..	..	..	..	..	..	..	..	..	..
....	1.00 a.m.	...	..	..	..	..	..	..	..	..	..	..	..	..
Saturday, January 25, 2014	1.00 a.m.	954.5	794.74	17%	17%	798.60	16%	16%	796.76	17%	17%	882.75	8%	8%
Sunday, January 26, 2014	1.00 a.m.	930.8	774.95	17%	17%	752.89	19%	19%	778.80	16%	16%	800.17	14%	14%
Monday, January 27, 2014	1.00 a.m.	837.9	778.49	7%	7%	778.49	7%	7%	756.01	10%	10%	823.38	2%	2%
Tuesday, January 28, 2014	1.00 a.m.	914.6	766.32	16%	16%	768.35	16%	16%	768.35	16%	16%	827.37	10%	10%
Wednesday, January 29, 2014	1.00 a.m.	908.8	760.24	16%	16%	760.24	16%	16%	799.06	12%	12%	855.10	6%	6%
....	1.00 a.m.	...	..	..	..	..	..	..	..	..	..	..	..	..
....	1.00 a.m.	...	..	..	..	..	..	..	..	..	..	..	..	..
Monday, February 3, 2014	1.00 a.m.	848.9	780.63	8%	8%	810.26	5%	5%	771.45	9%	9%	899.10	-6%	6%
Tuesday, February 4, 2014	1.00 a.m.	808.4	817.17	-1%	1%	826.42	-2%	2%	814.07	13%	13%	853.96	9%	9%
....	1.00 a.m.	...	..	..	..	..	..	..	..	..	..	..	..	..
....	1.00 a.m.	...	..	..	..	..	..	..	..	..	..	..	..	..
Average |error|					**12.10%**			**11.74%**			**11.01%**			**8.24%**
Standard deviation				**8.28%**			**7.05%**			**8.36%**			**7.05%**	
Variation				**0.69% %**			**0.50% %**			**0.70% %**			**0.50% %**	

Table 4.9: Hourly average absolute error and overall average absolute error calculation

Time	Average |error%|				Standard deviation (error %)				Variation (error %%)			
	4 days before	**3 days before**	**2 days before**	**1 day before**	4 days before	3 days before	2 day before	1 days before	4 days before	3 days before	2 days before	1day before
1:00:00 AM	**12.10%**	**11.74%**	**11.01%**	**8.24%**	8.28%	7.05%	8.36%	7.05%	0.69%%	0.50%%	0.70%%	0.50%%
2:00:00 AM	**13.56%**	**13.37%**	**13.20%**	**9.22%**	8.61%	7.69%	7.82%	7.21%	0.74%%	0.59%%	0.61%%	0.52%%
3:00:00 AM	**13.73%**	**12.81%**	**12.63%**	**9.01%**	8.46%	7.44%	8.37%	6.41%	0.72%%	0.55%%	0.70%%	0.41%%
4:00:00 AM	**13.73%**	**13.59%**	**13.33%**	**10.76%**	7.91%	7.93%	7.35%	6.76%	0.62%%	0.63%%	0.54%%	0.46%%
5:00:00 AM	**15.10%**	**15.07%**	**14.61%**	**13.24%**	6.41%	6.75%	5.51%	5.21%	0.41%%	0.46%%	0.30%%	0.27%%
6:00:00 AM	**13.53%**	**13.42%**	**13.23%**	**7.51%**	5.20%	6.73%	4.54%	6.92%	0.27%%	0.45%%	0.21%%	0.48%%
7:00:00 AM	**6.46%**	**6.35%**	**5.80%**	**5.24%**	3.82%	4.25%	3.81%	4.16%	0.15%%	0.18%%	0.14%%	0.17%%
8:00:00 AM	**6.76%**	**6.61%**	**6.56%**	**6.19%**	4.71%	4.58%	3.86%	4.51%	0.22%%	0.21%%	0.15%%	0.20%%
9:00:00 AM	**6.65%**	**6.47%**	**6.29%**	**6.27%**	3.32%	3.38%	3.78%	2.72%	0.11%%	0.11%%	0.14%%	0.07%%
10:00:00 AM	**7.45%**	7.37%	7.16%	6.97%	2.81%	3.20%	3.86%	3.16%	0.08%%	0.10%%	0.15%%	0.10%%
11:00:00 AM	**7.55%**	7.10%	7.08%	6.65%	4.21%	3.15%	4.35%	2.72%	0.18%%	0.10%%	0.19%%	0.07%%
12:00:00 PM	**7.67%**	6.82%	6.41%	6.39%	4.21%	3.15%	4.35%	2.72%	0.18%%	0.10%%	0.19%%	0.07%%
1:00:00 PM	**7.15%**	6.31%	6.17%	5.59%	3.51%	3.83%	4.88%	3.73%	0.12%%	0.15%%	0.24%%	0.14%%
2:00:00 PM	**6.23%**	6.12%	4.58%	4.56%	4.88%	3.72%	6.84%	5.20%	0.24%%	0.14%%	0.47%%	0.27%%
3:00:00 PM	**6.16%**	5.47%	4.77%	4.38%	6.24%	4.90%	8.42%	5.83%	0.39%%	0.24%%	0.71%%	0.34%%
4:00:00 PM	**5.78%**	5.02%	4.96%	4.83%	5.91%	5.00%	7.22%	4.95%	0.35%%	0.25%%	0.52%%	0.24%%
5:00:00 PM	**5.85%**	5.09%	4.77%	4.64%	4.35%	4.23%	7.36%	2.80%	0.19%%	0.18%%	0.54%%	0.08%%
6:00:00 PM	**8.75%**	7.73%	7.15%	6.99%	5.65%	5.95%	6.81%	5.60%	0.32%%	0.35%%	0.46%%	0.31%%
7:00:00 PM	**5.37%**	**3.94%**	**3.37%**	**2.86%**	2.72%	2.98%	4.10%	10.33%	0.07%%	0.09%%	0.17%%	1.07%%
8:00:00 PM	**4.47%**	**3.86%**	**3.50%**	**3.41%**	2.82%	2.19%	3.48%	5.43%	0.08%%	0.05%%	0.12%%	0.29%%
9:00:00 PM	**4.46%**	**4.44%**	**4.31%**	**3.62%**	3.41%	2.79%	3.48%	4.06%	0.12%%	0.08%%	0.12%%	0.17%%
10:00:00 PM	**7.91%**	**7.91%**	**7.66%**	**7.31%**	4.59%	3.95%	4.59%	4.50%	0.21%%	0.16%%	0.21%%	0.20%%
11:00:00 PM	**11.17%**	**10.68%**	**9.88%**	**9.80%**	5.05%	3.16%	4.08%	4.13%	0.26%%	0.10%%	0.17%%	0.17%%
12:00:00 AM	**10.50%**	**9.69%**	**9.26%**	**8.13%**	4.87%	4.12%	4.93%	4.79%	0.24%%	0.17%%	0.24%%	0.23%%
Overall average absolute error calculated for 3 months period												
For full dataset	**8.67%**	**8.21%**	**7.82%**	**6.74%**	6.48%	6.25%	6.80%	5.97%	0.42%%	0.39%%	0.46%%	0.36%%

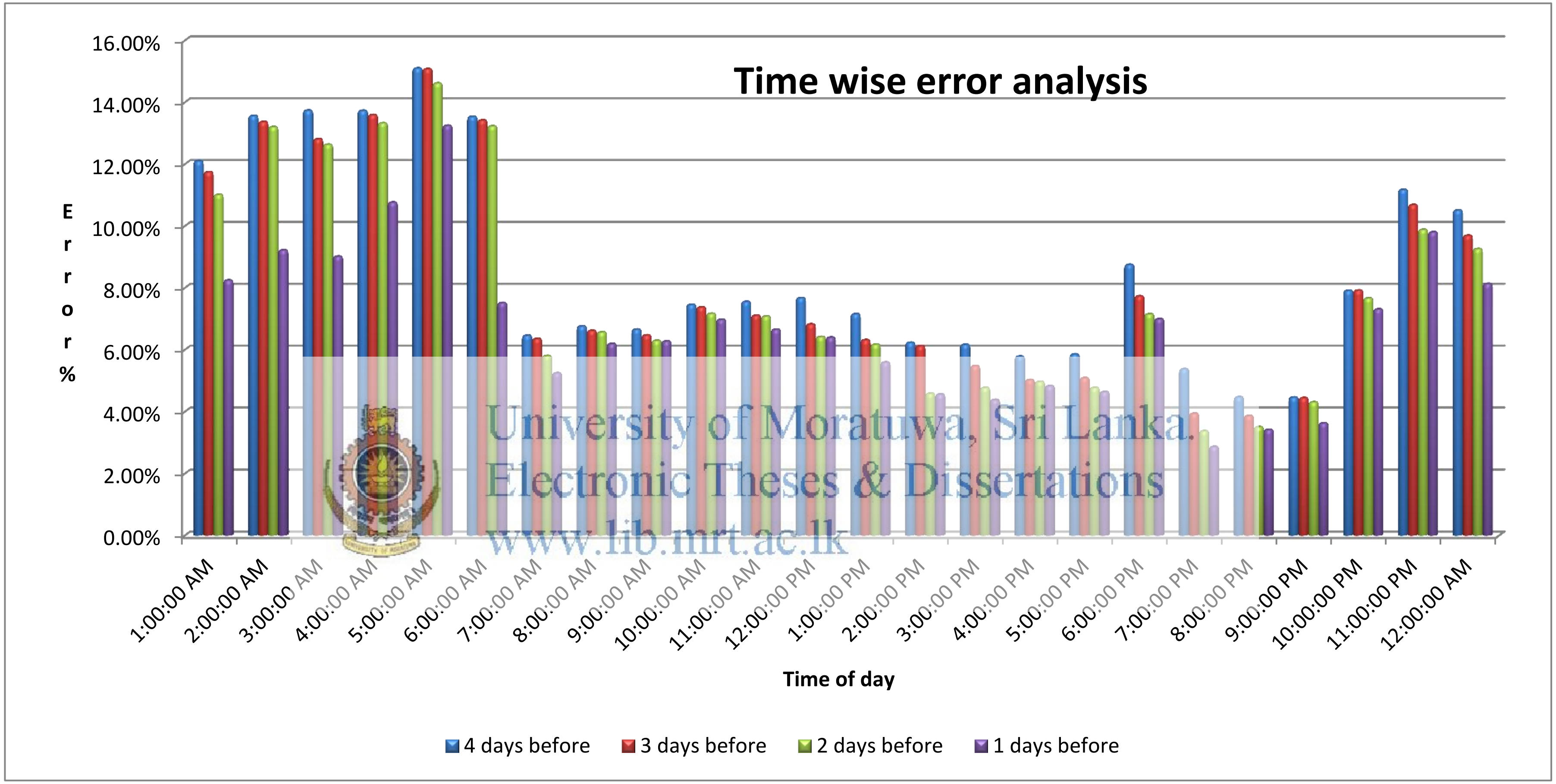

Figure 4.4: Time wise error analysis

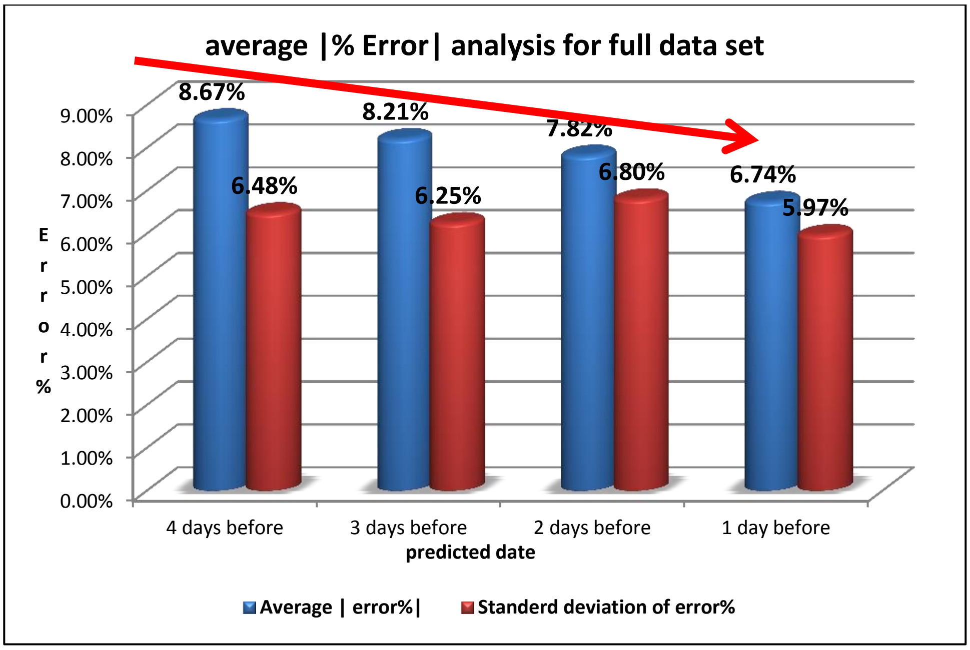

Figure 4.5: Average absolute percentage error for full data set

4.3 Most Relevant Parameter

Identifying the relevance level of used four weather parameters to the model is important for analytical purpose.

Time	Equation
01 00	$D = 14.228T - 1.1150H - 8.377W_{(speed)} + 0.000W_{(direction)} + 217.144$
02 00	$D = 13.325T - 1.099H - 9.575W_{(speed)} + 0.000W_{(direction)} + 230.217$

Highest coefficient

Figure 4.6: dominant coefficient

In a quick view first impression would be that the highest coefficient parameter would be the most relevant one for a particular equation of the model. But the dominant parameter depends on not only the coefficient but also the real time value.

Ex: - for 2 .00 a.m. equation,

Assuming for a particular day forecasted temperature and wind speed are 20^{0}C and 28 knots at 2.00 a.m.

Demand share from temperature => 13.325 × 20 = 266.5 MW

Demand share from wind speed => 9.575 × 28 = 268.1 MW

Wind speed has given more share of the demand.

As shown in the example calculation not only the strength of coefficient but consideration of parameter range is also necessary in finding most relevant parameter.

It is quite clear that the temperature influencing considerably to electricity demand due to high usage of HVAC system. Based on the assumption that the temperature is the most relevant parameter in any circumstance, simple algorithm was developed to check the validity of the assumption.

[(temperature coefficient × minimum limit of temperature range) > (humidity coefficient × maximum limit of humidity range)] AND [(temp. coefficient × minimum limit of temperature range) > (wind speed coefficient × maximum limit of wind speed range)] AND [(temp. coefficient × minimum limit of temperature range) > (wind direction coefficient × maximum limit of wind direction range)]

If the assumption is true the statement should become true.

To check the statement it is need to identify maximum and minimum limits of the parameters.

Table 4.10: Recorded minimum and maximum limits of the data used

Limits	Wind speed(knots)	Wind direction(°)	Temp.(°C)	Relative humidity (%)
Recorded min.	0.1	1	18.4	31.8
Recorded max.	9.7	360	36	100

Recorded limits were adjusted considering practical situation and possibilities.

A storm is defined as a wind speed of 48 knots or higher (89 km/h). Since storm condition is highly unlikely in predicting electricity demand "Squall" situation was considered to adjust the wind speed high limit. Squall is defined as sudden onset of wind increase of at least 16 knots (30 km/h) or greater sustained for at least one minute.

Temperature limits and humidity limits were adjusted considering worse condition in Sri Lanka introducing up and down bias values.

Table 4.11: Adjusted minimum and maximum limits

Limits	Wind speed(knots)	Wind direction(°)	Temp.(°C)	Relative humidity (%)
Adjusted minimum	0	1	15	20
Adjusted maximum	16	360	40	100

Validity checking statement of temperature as the most relevant parameter can be rewritten as,

- [(temp. coefficient × 15) > (humidity coefficient × 100)] AND [(temp. coefficient × 15) > (wind speed coefficient × 16)] AND [(temp. coefficient × 15) > (wind direction coefficient × 360)]

Statement was checked for true or false in excel for every time slot of 3 analyses (weekday, Saturday, Sunday).

Table 4.12: Temperature as the most relevant parameter (statement checking for weekday analysis)

Analysis for weekday	Coefficient					Temperature most dominant parameter
	Air temp.	Relative humidity	Wind speed	Wind direction	Constant	
1:00:00 AM	14.228	-1.115	-8.377	0.000	217.144	TRUE
2:00:00 AM	13.325	-1.099	-9.575	0.000	230.217	TRUE
3:00:00 AM	13.781	-1.100	-9.353	-0.054	223.505	TRUE
4:00:00 AM	13.460	-1.075	-9.757	-0.056	249.895	TRUE
5:00:00 AM	12.594	-0.961	-12.817	-0.061	380.717	FALSE
6:00:00 AM	11.028	-1.098	-14.897	-0.143	592.663	FALSE
7:00:00 AM	0.902	-1.126	0.000	-0.141	761.220	FALSE
8:00:00 AM	4.370	-0.599	-3.504	0.000	614.922	TRUE
9:00:00 AM	11.001	0.000	0.000	0.000	460.512	TRUE
10:00:00 AM	12.818	0.000	0.000	0.074	419.576	TRUE
11:00:00 AM	13.370	0.000	0.000	0.092	418.484	TRUE
12:00:00 PM	13.316	0.000	0.000	0.114	417.579	TRUE
1:00:00 PM	14.193	0.000	0.000	0.109	353.208	TRUE
2:00:00 PM	15.039	0.000	0.000	0.135	322.948	TRUE
3:00:00 PM	16.245	0.000	0.000	0.131	311.736	TRUE
4:00:00 PM	15.727	0.000	-2.906	0.112	345.947	TRUE
5:00:00 PM	7.991	0.000	0.000	0.062	549.668	TRUE
6:00:00 PM	-3.169	0.000	-12.384	0.000	943.367	FALSE
7:00:00 PM	6.048	-1.945	-5.716	0.097	1019.377	FALSE
8:00:00 PM	10.831	-1.877	-4.310	0.121	857.069	FALSE
9:00:00 PM	14.884	-1.899	-4.586	0.115	654.828	TRUE
10:00:00 PM	17.730	-1.375	-7.331	0.101	368.362	TRUE
11:00:00 PM	15.518	-1.251	-7.227	0.056	290.714	TRUE
12:00:00 AM	15.421	-1.038	-6.885	0.000	221.618	TRUE

Table 4.13: Temperature as the most relevant parameter (statement checking for Saturday analysis)

Analysis for Saturday	Coefficient					Temperature most dominant parameter
	Air temp.	Relative humidity	Wind speed	Wind direction	Constant	
1:00:00 AM	15.793	-1.013	-10.208	0.000	184.474	TRUE
2:00:00 AM	15.837	-1.203	-11.820	0.000	187.952	TRUE
3:00:00 AM	14.595	-1.029	-11.533	0.000	200.042	TRUE
4:00:00 AM	13.064	-1.014	-10.295	0.000	247.840	TRUE
5:00:00 AM	10.119	-1.474	-14.584	0.000	430.926	FALSE
6:00:00 AM	7.255	-1.391	-14.415	0.000	593.615	FALSE
7:00:00 AM	1.040	-1.580	0.000	-0.105	782.495	FALSE
8:00:00 AM	4.431	-0.989	-5.802	0.000	626.148	FALSE
9:00:00 AM	9.973	0.000	0.000	0.000	417.638	TRUE
10:00:00 AM	10.611	0.000	0.000	0.000	407.187	TRUE
11:00:00 AM	9.223	0.000	0.000	0.111	451.970	TRUE
12:00:00 PM	11.123	0.000	0.000	0.109	405.462	TRUE
1:00:00 PM	11.746	0.000	0.000	0.113	339.896	TRUE
2:00:00 PM	11.165	0.000	0.000	0.117	330.963	TRUE
3:00:00 PM	10.509	0.000	0.000	0.000	375.778	TRUE
4:00:00 PM	10.099	0.000	0.000	0.000	386.211	TRUE
5:00:00 PM	5.479	0.000	0.000	0.000	510.693	TRUE
6:00:00 PM	-1.014	0.000	-12.009	0.139	733.693	FALSE
7:00:00 PM	14.264	-1.557	-6.185	0.000	724.634	TRUE
8:00:00 PM	12.394	-1.436	0.000	0.154	716.074	TRUE
9:00:00 PM	18.171	-1.428	-8.679	0.142	484.177	TRUE
10:00:00 PM	18.651	-1.567	-9.301	0.120	336.353	TRUE
11:00:00 PM	19.240	-0.980	-7.726	0.000	177.697	TRUE
12:00:00 AM	16.883	0.000	0.000	0.000	81.138	TRUE

Table 4.14: Temperature as the most relevant parameter (statement checking for Sunday analysis)

Analysis for Saturday	Coefficient					Temperature most dominant parameter
	Air temp.	Relative humidity	Wind speed	Wind direction	Constant	
1:00:00 AM	4.987	-1.629	-8.399	0.164	476.347	FALSE
2:00:00 AM	5.411	-1.613	-10.763	0.124	457.201	FALSE
3:00:00 AM	5.389	-1.589	-8.888	0.091	450.058	FALSE
4:00:00 AM	4.709	-1.414	-6.878	0.092	456.196	FALSE
5:00:00 AM	4.843	-1.325	-12.335	0.099	498.372	FALSE
6:00:00 AM	15.863	-1.128	-12.833	-0.233	336.204	TRUE
7:00:00 AM	4.871	-1.202	0.000	-0.184	591.539	FALSE
8:00:00 AM	0.954	-1.032	0.000	0.000	634.102	FALSE
9:00:00 AM	5.578	-0.824	0.000	0.000	457.526	TRUE
10:00:00 AM	10.479	0.000	-3.897	0.000	275.783	TRUE
11:00:00 AM	10.711	0.000	-4.562	0.000	296.696	TRUE
12:00:00 PM	12.407	0.000	-4.209	0.000	262.819	TRUE
1:00:00 PM	11.116	0.000	-7.304	0.000	292.876	TRUE
2:00:00 PM	13.118	0.000	-5.786	0.000	203.103	TRUE
3:00:00 PM	16.540	0.000	-5.967	0.000	96.861	TRUE
4:00:00 PM	14.382	0.000	0.000	0.000	139.957	TRUE
5:00:00 PM	7.261	0.000	0.000	0.000	358.262	TRUE
6:00:00 PM	-5.372	0.000	-9.622	0.000	837.445	FALSE
7:00:00 PM	10.975	-1.329	0.000	0.000	735.914	TRUE
8:00:00 PM	21.074	0.000	-4.682	0.100	348.577	TRUE
9:00:00 PM	19.626	-1.186	0.000	0.105	379.437	TRUE
10:00:00 PM	24.577	0.000	0.000	0.000	10.436	TRUE
11:00:00 PM	19.813	-0.821	-9.060	0.000	100.370	TRUE
12:00:00 AM	18.640	-0.640	-7.573	0.000	53.059	TRUE

GRAPHICAL USER INTERFACE

5.1 Graphical User Interface Development

Graphical user interface was developed for easy handling of the model. Hourly weather parameters need to input to the model by the operator. Modelled equations are attached using excel functions such that the given weather parameters are multiplied by the modelled equation coefficients and multiply the predicted 55% by (1/0.55) to get the national predicted electricity demand.

Two drop down lists were developed for the model. Data selection drop down list gives three options to the operator to categorize the day as weekday or Saturday or Sunday. When the selection has been done algorithm would change the multiplication coefficients according to the selection. Holiday bias gives the operator to select pre-recorded special days such as Wesak poyaday, New Year, Christmas and any other poyaday etc. Once the selection has been done predicted demand would be multiplied by a predetermined bias value. This option could be improved or developed as necessary. Apart from predetermined bias values which apply for the whole predicted demand spots, individual bias option has given so the operator could add a certain bias value to a single predicted demand spot if needed.

Once the demand values are predicted demand curve would be drawn automatically with predicted 24 spots.

From the island wide model, daily electricity demand curve can be predicted for any day as long as the hourly weather parameters are available, which assists SCC engineers to plan their power plants dispatch schedules.

Weekday
Saturday
Sunday

Daily Demand prediction based on weather parameters

Date selection	=	Sunday
(pick from drop down list)		
holiday bias	=	newyear
(pick from drop down list)		

Wesak
Poyaday
New Year
Christmas

Provision for manual bias based on operator experience or special occasion

Time	air temp.(^{0}C)	humidity (%)	wind speed(knots)	wind direction (degrees from north)	Individual bias	PREDICTED DEMAND(MW)
1:00:00 AM	22.60	100	1.4	72		852.4
2:00:00 AM	22.60	100	1.4	77		825.2
3:00:00 AM	22.40	100	1.4	113		819.5
4:00:00 AM	22.20	100	1.2	90		838.7
5:00:00 AM	22.00	100	1.4	69		924.0
6:00:00 AM	22.00	100	1	92		1,076.2
7:00:00 AM	22.30	100	1.4	80		1,130.5
8:00:00 AM	24.00	94.6	2.5	47		1,118.7
9:00:00 AM	26.50	79.9	2.5	61		1,078.9
10:00:00 AM	28.20	65.4	2.7	57		1,121.5
11:00:00 AM	28.70	59.3	3.5	342		1,176.3
12:00:00 PM	29.10	59.3	3.9	331		1,214.9
1:00:00 PM	29.50	61.7	4.1	288		1,181.7
2:00:00 PM	29.80	64.1	4.9	297		1,131.3
3:00:00 PM	29.40	65.9	6	327		1,094.7
4:00:00 PM	29.10	66.8	7.4	315		1,117.0
5:00:00 PM	28.40	77.8	6.4	328		1,128.9
6:00:00 PM	28.10	79.5	5.4	327		1,269.1
7:00:00 PM	27.90	74.8	4.3	347		1,885.5
8:00:00 PM	27.10	73.4	4.3	4		1,799.9
9:00:00 PM	26.80	77	3.7	10		1,630.3
10:00:00 PM	26.20	82.5	2.9	50		1,308.7
11:00:00 PM	25.40	88.9	3.1	62		1,005.2
12:00:00 AM	25.20	93.1	1.7	68		900.7

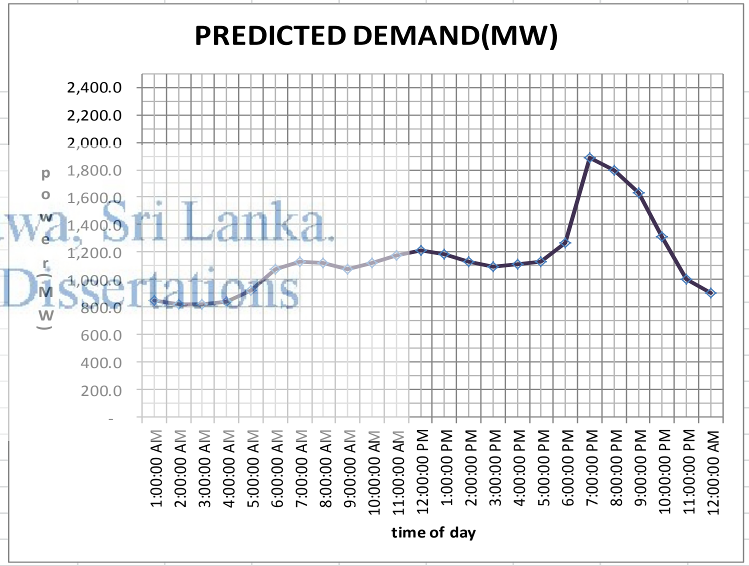

Figure 5.1: Graphical user interface developed using MS excel

Chapter 6

CONCLUSION AND RECOMMENDATIONS

Developed model can be used for the prediction of daily load curve in Sri Lanka based on the weather parameters limited to accuracy level mentioned in table 6.1.

Table 6.1: Summarized predicting accuracy level of the model

Average |error%|			
4 days before	3 days before	2 days before	day before
8.67%	8.21%	7.82%	6.74%

Model can be recommended for System Control Centre of Ceylon Electricity Board, to use for short term demand forecasting and power plant dispatching.

National level demand database (auto updating with province wise/region wise demand data) is essential for accurate power system planning .At present SCC takes grid substation load readings at 3 hour interval. Only the total demand value been logged in every half an hour. There is no any computerized region wise data base which should have been highly useful in improving accuracy of the developed model. The portion of embedded generation has not being corrected by SCC, for the used demand data from 2009 - 2013. Therefore the model predicts the national demand without the embedded generation such as mini hydro power plants etc.

Developed model should be revised timely to include the demand growth and should improve the correlation by adding more and more historical data. An auto updating system would be ideal which automatically include weather data and demand data and do the regression daily/weekly to update the modelled equations. It is essential to have a collaborative working relationship between CEB and department of Meteorology to enhance the accuracy of the model.

This model will be the small but first step of a national auto updating electricity demand prediction system. Recommend for further work/follow-up research.

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National energy sales 2012

CEB supply 2012	GWh	Percentage 2012
Colombo City	1247	11.94%
North Western	1049	10.04%
North Central	384	3.68%
Northern	213	2.04%
Region - 1 Total	**2893**	**27.69%**
Western-North	1755	16.80%
Central	776	7.43%
Eastern	472	4.52%
Region - 2 Total	**3003**	**28.74%**
Western- South II	1072	10.26%
Uva	381	3.65%
Sabaragamuwa	485	4.64%
Region - 3 Total	**1938**	**18.55%**
Western-South I	537	5.14%
Southern	801	7.67%
Region - 4 Total	1338	12.81%
Bulk Sup. to LECO	1276	12.21%
TOTAL	10448	100.00%

Western Province 2012	GWh	Percentage
CEB		
Colombo City	1247	12%
Western-North	1755	17%
Western- South II	1072	10%
Western-South I	537	5%
LECO		
WPN	434	4%
WPS I	405	4%
WPS II	316	3%
Total	**5766.46**	**55%**

LECO supply 2012	GWh	Percentage 2012
WPN	434	4.16%
SP	121	1.16%
WPS I	405	3.88%
WPS II	316	3.03%
Total	**1276**	**12.21%**

[Appendix – B: Yearly average demand growth and percentage variation to year 2012]

YEARLY AVERAGE DEMAND GROWTH AND PERCENTAGE VARIATION TO YEAR 2012

year	1:00		2:00		3:00		4:00		5:00		6:00		7:00		8:00		9:00		10:00		11:00		12:00	
	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand
2007	12%	788	14%	749	15%	730	19%	728	30%	788	28%	981	11%	1037	27%	932	23%	1057	22%	1116	23%	1147	21%	1187
2008	18%	745	18%	722	18%	711	18%	732	19%	861	19%	1058	20%	962	20%	987	18%	1103	19%	1143	19%	1183	20%	1194
2009	19%	738	19%	713	19%	703	19%	723	20%	855	20%	1047	21%	957	21%	981	19%	1098	19%	1141	20%	1178	20%	1190
2010	11%	793	11%	765	11%	755	12%	774	13%	912	13%	1117	11%	1036	12%	1054	11%	1179	11%	1225	12%	1262	12%	1279
2011	2%	860	2%	832	2%	822	2%	844	3%	1001	3%	1220	3%	1123	3%	1151	2%	1276	2%	1330	3%	1370	3%	1390
2012	0%	881	0%	851	0%	838	0%	863	0%	1026	0%	1258	0%	1155	0%	1184	0%	1304	0%	1359	0%	1410	0%	1433
2013 jan. - june	1%	892	1%	862	1%	847	1%	875	2%	1045	2%	1282	2%	1181	2%	1209	1%	1323	1%	1378	2%	1434	2%	1456

year	13:00		14:00		15:00		16:00		17:00		18:00		19:00		20:00		21:00		22:00		23:00		0:00	
	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand	%variation to 2012	average demand
2007	19%	1151	21%	1123	21%	1145	21%	1133	19%	1123	27%	1103	29%	1433	7%	1692	2%	1596	-4%	1364	1%	1056	8%	878
2008	20%	1141	19%	1141	19%	1160	20%	1148	20%	1112	19%	1176	13%	1630	12%	1618	12%	1465	13%	1162	17%	917	18%	804
2009	20%	1139	19%	1144	19%	1165	20%	1147	21%	1107	20%	1164	15%	1605	14%	1592	14%	1436	14%	1149	17%	911	19%	799
2010	12%	1221	11%	1223	11%	1242	12%	1227	12%	1194	11%	1261	9%	1698	8%	1684	8%	1515	7%	1224	9%	979	10%	859
2011	3%	1330	2%	1327	2%	1352	3%	1338	2%	1305	2%	1371	2%	1820	1%	1800	1%	1619	2%	1291	2%	1049	2%	924
2012	0%	1370	0%	1359	0%	1383	0%	1373	0%	1335	0%	1396	0%	1848	0%	1816	0%	1634	0%	1316	0%	1069	0%	947
2013 jan. - june	1%	1390	1%	1376	2%	1410	2%	1404	1%	1347	1%	1409	1%	1865	1%	1836	1%	1644	1%	1323	1%	1075	1%	954