# Analysing the Electricity Demand Pattern


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*Abstract* — **The electricity demand of a nation speaks of its social standard, pace of economic growth, geographical variations and demography of the population at large. Understanding and forecasting of load characteristics have been complex due to its dependency on large number of factors which affects it i.e. weather condition, geographical diversity, sunrise/sunset times, seasonal diversity etc. The detailed study of the electricity consumption invokes a knowledge of its trend and seasonality which can be exploited to extrapolate the demand characteristics.**

**The authors have tried to analyze some of the quantifiable and predictable factors and their impact on a particular area on the nation as a whole. These factors have then been modeled as variables to develop linear regressions for modelling the expected demand.**



***Keywords – Supervisory Control and Data Acquisition (SCADA), National Load Despatch Center (NLDC), HVAC (Heating ventilation and Air Cooling load), Load Duration curve (LDC), Temperature Load Curve (TLC).***


## I. INTRODUCTION

Electricity perhaps, is the only commodity consumed the instant that it is produced. In an idealized case, when someone turns on lights or an air-conditioning equipment (holding all other loads constant), a power plant somewhere must ramp up its generation slightly to meet the increase in demand. Fortunately, India has sufficiently large number of electricity users; demarcated into five regions namely Northern, Eastern, Western, Southern and North-Eastern; that such small increase in loads in some places is well balanced by small decrease in loads or increase in generation elsewhere. But the aggregate all India demand still changes significantly all over the day and year. Due to these seemingly unpredictable changes, demand forecasting is a tedious job. Thus, for an accurate forecast we must first develop good analytical hindsight.

## II. LOAD CURVE

A plot showing the variation in demand met with respect to time is known as the load curve. If this curve is plotted over a period of time for 24 Hours it is known as daily load curve (**Figure 1**). If it is plotted for a week, month or a year it is named as weekly, monthly and yearly load curve respectively. The load curve reflects the activity of a population with respect to electrical power consumption over a given period of time. It gives an insight into the consumption pattern of an area. **Figure-2** shows the 3-dimensional annual variation of the All India demand met. The plot depicts comparatively higher demand in summers than in winters. Moreover, the daily variation in load and changing shape of the load curve through the year is quite evident from **Figure 2**.

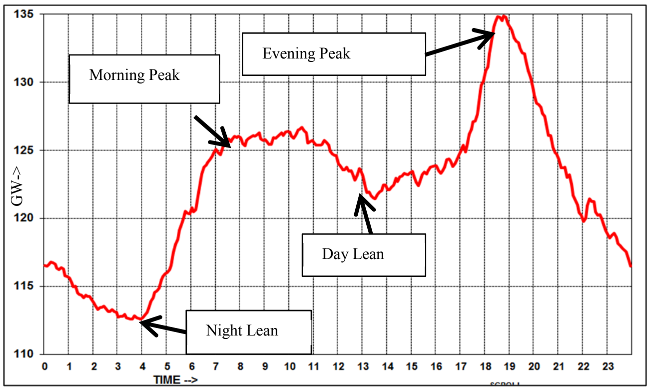


**Figure 1: A typical all India daily load curve.**

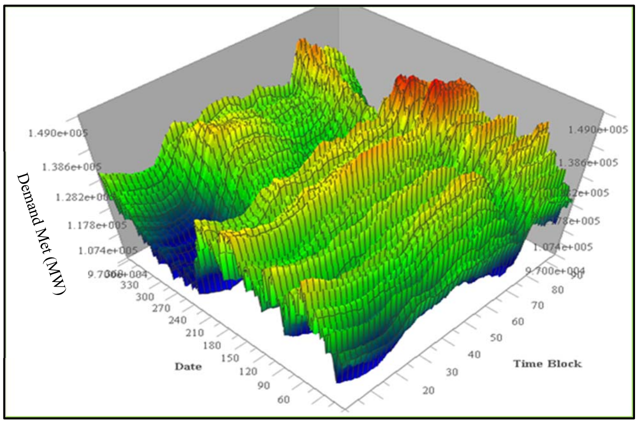


**Figure 2: 3-D plot of All India demand met (2015-16).**

## III. CHANGING SCENARIO OF ELECTRICITY CONSUMPTION PATTERNS IN INDIA

### A. Change in sector wise consumption:

The pattern of electricity consumption in India has gone tremendous change over the years. The industrial consumption has come down from 60% in 1970 to 44% during 2013-14. This decline in Industrial consumption can be accounted to increase in energy efficiency and conservation practices employed by various industries due to technological advancement. However, the agricultural sector witnessed an increase from 10% in 1970 to about 18% during 2013-14 showing shift towards modern farming techniques. The most phenomenal growth is witnessed in the domestic electricity consumption from 8.8% in 1970 to 22% in 2013-14 [6] owing to the rise in per capita income. The transition of electricity consumption of various sectors from 2000-01 to 2013-14 can be observed from **Figure 3**.

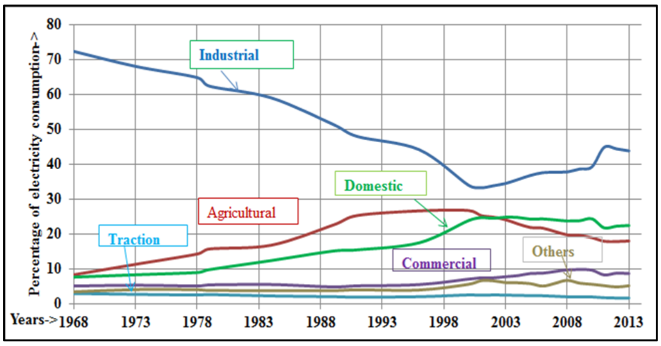


**Figure 3: Percentage of electricity consumption by various sectors [6].**

The increase in the share of the domestic sector in total electricity consumption, development in agricultural sector and technological advancement in the industrial sector have all together contributed in giving the all India load curve its present shape with large evening peaks; magnitude and duration of which varies according to the season showing a prominent impact of climate driven heating, ventilation and space cooling (HVAC) loads.

### B. Growth in energy consumption:

The All India average, maximum and minimum demands have increased over the years at a phenomenal rate (***Figure 4***). The installed generation capacity has similarly increased, now accounting for almost 4.8% of the global energy generation [7].

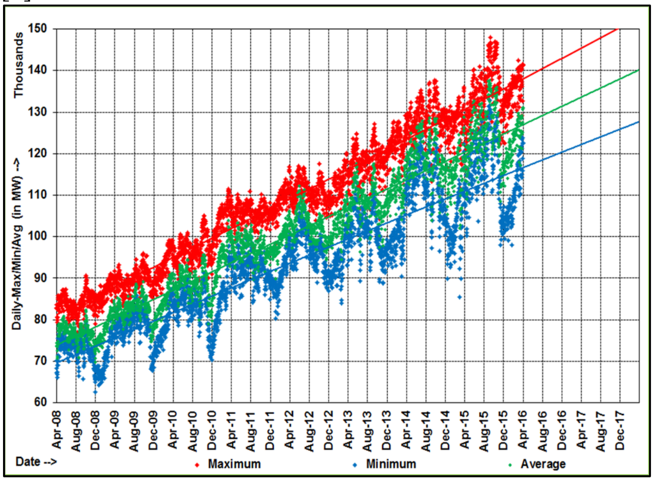


**Figure 4: Growth in all India maximum/minimum demand met from 2008-16.**

With such increase in the total daily energy consumption (***Figure 5***) it is now more crucial to forecast the future trends for adequate capacity planning. The major work behind extrapolating the demand curve for forecasting is to understand its important components: Trend, Seasonality and Cyclicity. The seasonal decomposition plot of All India energy consumption ***(Figure 6)*** helps to identify the seasonality and trend in this time series. The energy met data is decomposed into three parts by using third party software. The first part gives trend regarding the seasonal pattern of the data, which identifying the peak and lean seasons of a year. The second part shows the growth trend of All India energy consumption while the remaining part is the filtered out reminders and noise in data.

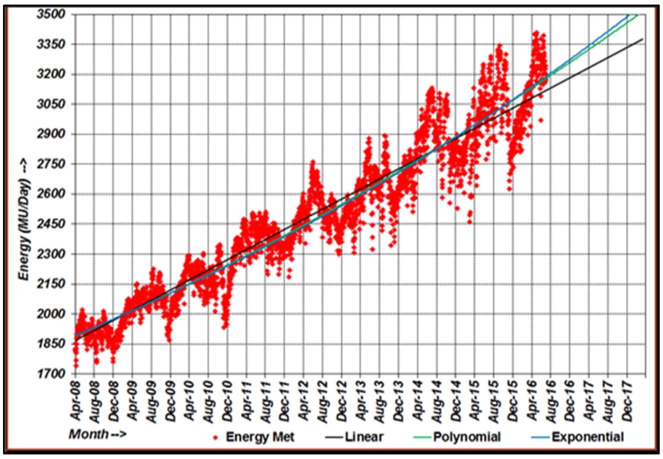


**Figure 5: Growth in All India energy consumption from 2008-16.**

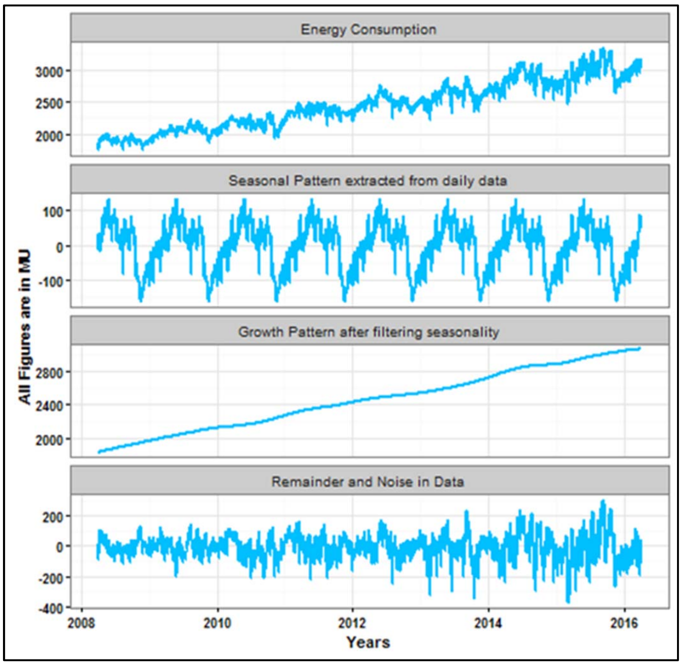


**Figure 6: Seasonal decomposition of All India energy consumption.**

## IV. Analyzing The Factors Affecting The All India Demand Curve

### A. Regional diversity in Demand

Each of the electrical regions has its unique characteristic. The type and nature of load, difference in climatic, geographical conditions and cultural practices have its due reflection in the demand curve of a region, making it very different from that of the other. This can be visualized for instance from **Figure-7** where the moving average demand met patterns of Northern and Western region (interval 10 days) are plotted throughout the year. When the average demand met of the Northern region is the maximum in a year (July to August) the demand met is the minimum in the Western region and vice-versa during October-November.

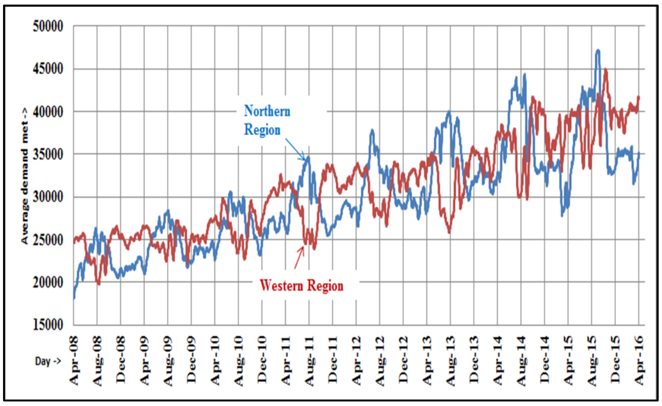


**Figure 7: Average demand met of Northern and Western region.**

The diversity of India in terms of demand met is further augmented by the term diversity factor which can be defined as the ratio of maximum load to the sum of the individual maximum loads. In this case maximum load is the daily maximum all India demand met while the individual loads are the daily maximum demand met by each state. Diversity factor is always greater than 1. Greater is the diversity factor, lesser is the cost of generation. It is an important indicator of variation of maximum load across different parts of the country. Interconnection of grid helps in harnessing this diversity and improving the load factor of the country. The diversity in All India demand met is shown in **Figure 8**.

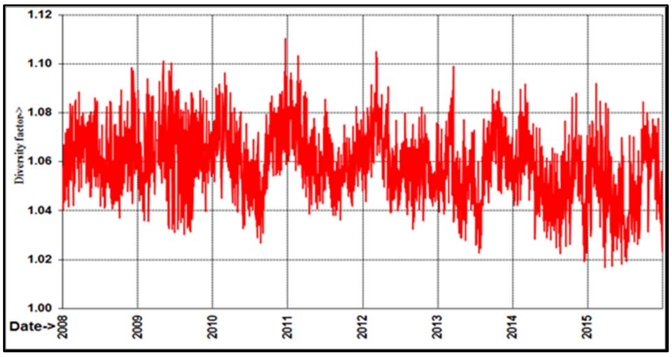


**Figure 8: Trend of All India Diversity factor.**

Observing this we can be fairly sure that any of the coefficients/variables we define/calculate in this paper for statistical modelling of demand are region specific and hence, unique for a particular region/state.

### B. Variation with the seasonal changes in the weather (Temperature Variable)

For the purpose of defining demand patterns, Indian climate can be broadly classified into two seasons:

***a) Summer Season***

In summers the demand starts to rise in the morning hours till noon, remaining more or less constant throughout the remaining day. It starts to decline in the early evening hours till 18 hours and then starts rising steeply, owing to the space cooling, till midnight attaining a maximum at 21-23 hours.

***b) Winter Season***

In stark contrast to a summer day, the electricity demand starts to rise in the early morning hours itself attaining a maximum between 9-10 hours and then falls till sunset. It then rises with the increase in lighting and heating loads till 1900-1930 hours afterwards it gradually falls to a minimum in the late night hours.

Also, the average, maximum and minimum demand met during the winter is lower than that of the summer respectively as in tropical to subtropical climates, like that of India, cooling loads dominate heating loads.

As the geographical area of India is quite large, the study of impact of load on the demand is quite difficult for the whole country.Thus, a small state or UT like Delhi is considered for analysis and modelling henceforth. Delhi has a tropical/subtropical climate typical of India. It has become increasingly urban, industrial and affluent. Majority of its demand is now determined by comfort loads and hence ideal for this analysis. A study published in "Global Trends in Urban Cooling and Heating" May 20, 2015 shows that more than 50% of the total annual electricity consumption of Delhi is temperature dependent (space cooling load) which is comparatively very large than the most affluent cities of the world including New York city, Tokyo, Los Angeles,Singapore etc. as shown in **Figure 9**.

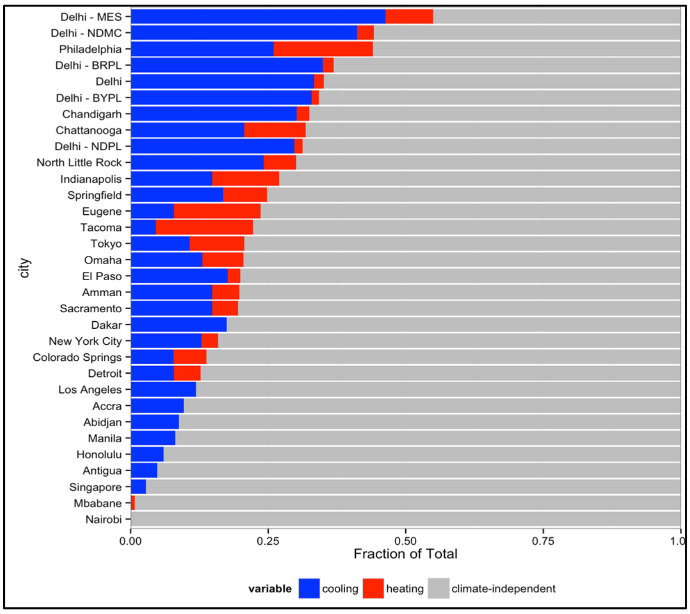


**Figure 9: Fraction of total electricity consumption for comfort. (*Source: global trends in Urban heating and cooling, May 20, 2015*)**

The plot of demand met against temperature is called Temperature load curve (TLC). The demand met is a U-shaped function with respect to temperature which can be separated to obtain different summer and winter responses giving rise to a change point regression. By definition, change-point regression allows complex dynamics to be reduced to a multiple parameter model that can be evaluated using minor adjustments to traditional single-variable linear regression analysis when the system being evaluated responds to a variable in two or more regimes. In its most basic form, this is used when the influence of a single variable on some response depends on whether it is less than or greater than some "change-point" value. For example, in this case at low ambient air temperatures, energy demand decreases as temperature increases because heating demands are reduced; however, at higher ambient air temperatures, energy demand increases [8] (**Figure 10**).

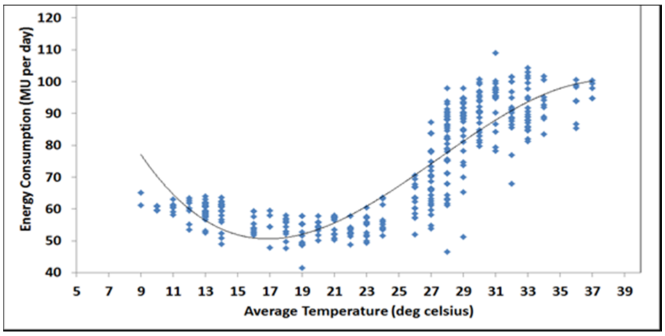


**Figure 10: Temperature elasticity curve for electricity demand met of Delhi.**

For analysis the peak demand met of Delhi during the summer season (April- June) of the last two years (2014-2015) is plotted against the maximum temperature for each day. From the slope of the best fit linear regression for summers it is found that with rise in 1 degree Celsius of temperature the demand of Delhi increases by approximately 120 MW owing to the increase in domestic and commercial air conditioning load with rising temperature (**Figure 11**).

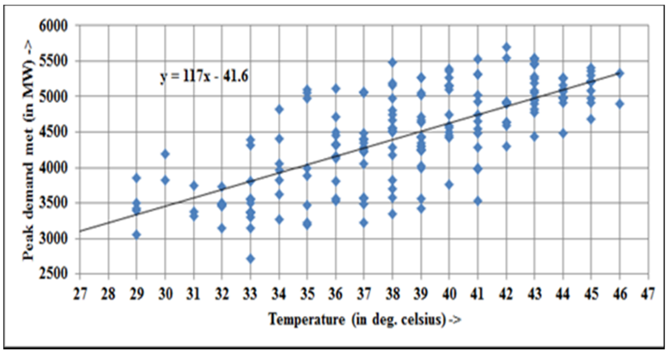


**Figure 11: Change in peak demand met of Delhi with maximum temperature in summer season (April-June).**

While when the same analysis was done for winters (December-February) for the last two years (2014-16) it is found that with rise in 1 degree Celsius of temperature the demand met of Delhi falls approximately by **50 MW** due to decrease in the heating load. Using this temperature coefficient can be defined to take into account the demand variation due to increase and decrease in temperature in summer and winter season respectively (**Figure 12**).

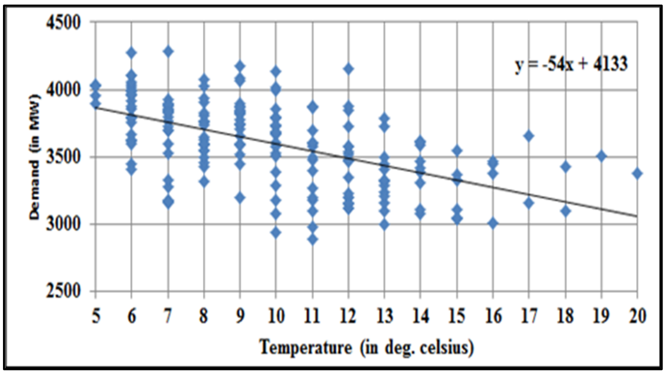


**Figure 12: Change in peak demand met of Delhi with average temperature in winter season (November-March).**

Similarly, the demand varies with humidity. This can be modelled in an equation as:

**Demand (t, h) = Temperature coeff. (t) X temperature + humidity coeff. (h) X humidity + constant.**

### C. Effect of sunset time (The sunset variable)

#### *a) Variation in peak load occurrence time:*

Although the effect of temperature on daily load demand curve is quite major, other physical factors cannot be ignored in its wake. The load curve is determined by the daily life cycle of population which is predominantly diurnal. Hence the key to understand its pattern is to analyze its correlation with the sunset time which affects energy consumed in illumination, consumption pattern etc. As mentioned above, the demand met increases during evening hours as offices are closed and people return to their homes and switch on various lighting, heating or air conditioning loads depending upon the weather. Hence, to understand this the time at which maximum all India demand occurs is plotted for each day since 2008 (**Figure 13**)

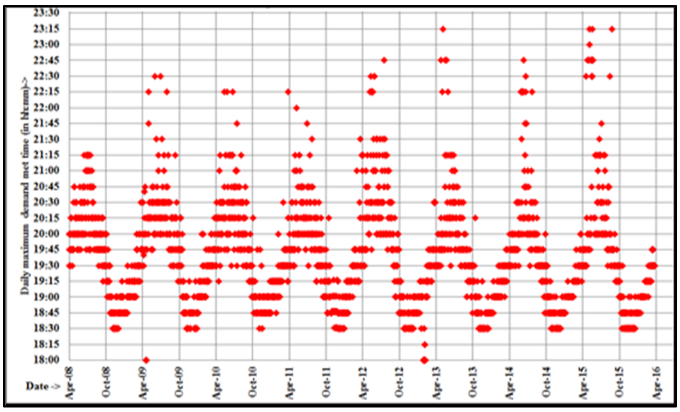


**Figure 13: Maximum demand occurrences of the all India over the years since 2008.**

As we observe the maximum demand time occurrence has a tendency to shift from evening to night hours as we move from winter to summer season through a year. To observe its relation with the sunset time, the same plot of northern region is plotted with the average sunset time (Delhi) (**Figure 14**)

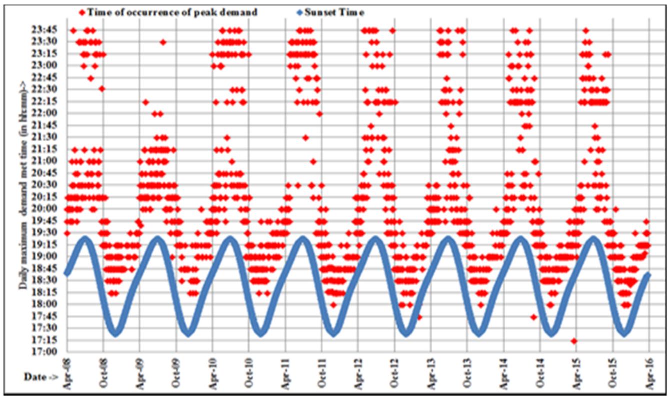


**Figure 14: Maximum demand and sunset occurrence time for North India.**

This plot shows that the maximum demand met time and sunset time both varies quite similarly through the year.

***a) Variation in the magnitude of peak load:***

As the sunset time varies much throughout the year, for the ease of visualization, computing and analysis of variation of peak demand with the time of sunset we define a sunset time variable. It is expressed as the sunset time in minutes before or after 18:30 hours (a reference). **Figure 15** depicts distribution of sunset time variable throughout a year (April- March).

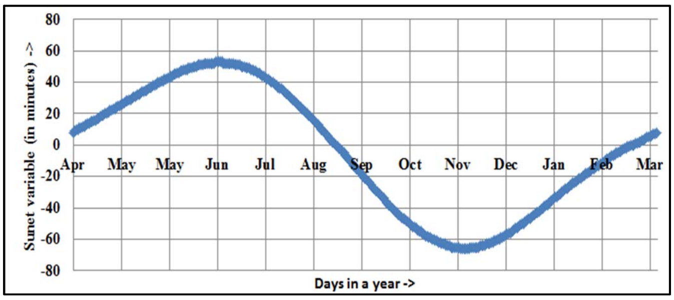


**Figure 15: Values of sunset variable over a year (April-March).**

Now to ascertain the demand vs. sunset variable characteristics the demand of a small state/UT (where the average sunset time does not vary much throughout the state/UT) say Delhi and its variation with respect to the average sunset time is considered **Figure 16**.

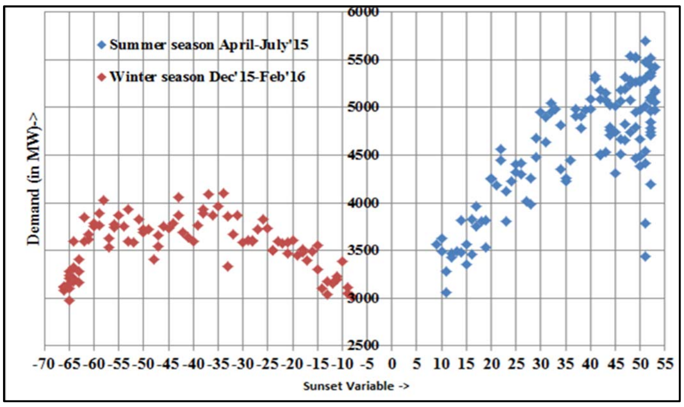


**Figure 16: Plot between Demand of Delhi and its sunset variable.**

During summer, the demand met increases with the increase in sunset variable i.e. as the day gets longer, the demand (for cooling loads) increases, while during winters as the day gets shorter the demand (for illumination etc.) increases. Thus, change in demand met with respect to the sunset variable can be modeled in equation form as:

**Demand(s) = sunset coeff.(s) x sunset variable +constant**

### D. Variations due to particular day of the week

Demand of a region is a reflection of the lifestyle of the population of that region. During weekends when most of the offices are closed the demand is lower as compared to the working weekdays. In general it has been found that maximum demand met occurs on Thursday/Friday which can be seen from **Figure-17**.

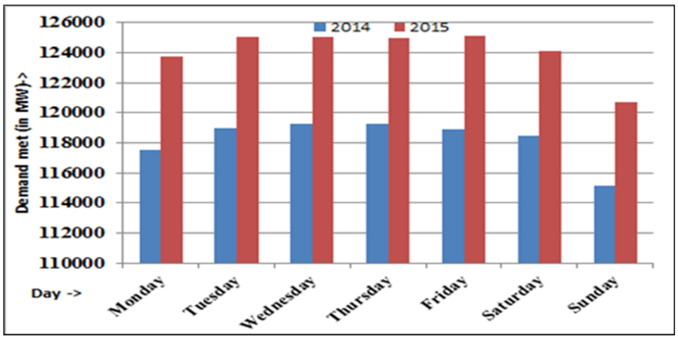


**Figure 17: All India average maximum demand met during a week.**

This gives us an approximately fair idea that the behavior of demand on each weekday is same when compared to that of the weekend which is quite low. Thus for analyzing demand variation throughout a week we divide a week into two parts: weekdays and weekends and provide them a dummy variable 1 and 0 respectively.

Accordingly, demand can be modelled with respect to each day of the week in the form:

**Demand (w) = weekday coeff.(w) x weekday variable + constant**.

### E. Special day exceptions

The linear regressions developed above can be used to forecast demand for each hour of the day, however, there are some days such as festivals like Diwali, Holi or Govt. holidays like the Independence and Republic day when the demand curve shows abrupt fall due to office and school holidays. In order to create coefficients for these days, the weekend coefficients can be copied for them which will give an approximately accurate prediction. One more exception is the sudden load loss due to bad weather. Unfortunately, such unpredictable occurrences of nature cannot be taken into account in this linear regression.

## V. Modelling The Demand Equation

This paper aims to develop demand equation as a multiple linear regression with variables as temperature, humidity, sunset variable. The coefficients pertaining to these variables can be easily computed by running ordinary least square method on any of the software available in the market. In this case GRETL software is chosen because of the ease of availability and usage. For a more accurate model it is necessary to divide the year into small intervals wherein the weather conditions are nearly constant throughout. Hence, the multiple linear regressions are modelled for three months (April – June) by using data of peak demand met of Delhi from SCADA (2014 and 2015) and weather data from the internet.

The result obtained from the software in equation form is:

**Demand (t, h, s, w) = 387.5 + 69.5 (Temperature) + 4.32 (Humidity) + 31.44 (Sunset variable) + 192.12 (Weekday variable)**

The validity of the method can be judged by comparing the actual model with the fitted model (model obtained by fitting the variables in the equation). **Figure 18** is the actual result of the software exported in pdf format depicting actual and fitted demand model on y-axis against 182 observations on x-axis (April- June' 14 and 15).

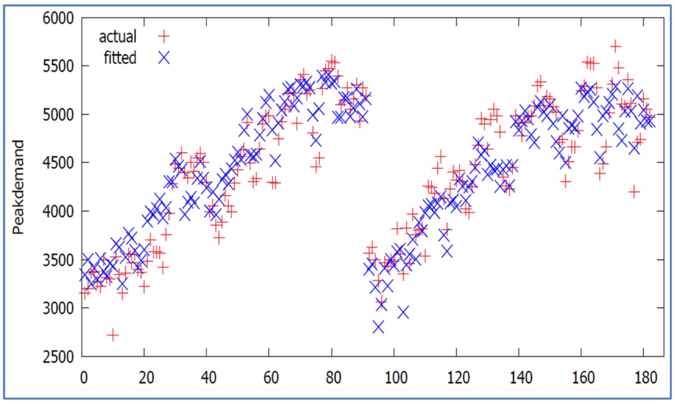


**Figure 18: Comparison between the actual and fitted model for calculating peak demand met of Delhi from April- June (2014 -15). Source: GRETL**

Hence, by visualization the model appears to be fairly accurate. By inspection the computed model is 92% able to justify the variations in peak demand met with respect to temperature, humidity, and sunset variable.

## VI. CONCLUSION

Population and economic size drive base load electricity demand at annual to decadal timescales; climate drives seasonal variability; and human physiology and meteorology drive diurnal patterns. This paper makes an effort to analyze and evaluate climatic and other diurnal factors to gauge its impact on the consumption pattern of the population at large. As shown all the factors considered are very well able to explain the variations in the demand met pattern which hitherto appeared to be random or unpredictable. Although, many of the factors are localized but since it is an integrated grid hence affects the overall demand patterns and that needs to be addressed properly while doing forecasting. Forecasting of demand control area wise is must in a current complex power system and would also help the operators to manage it in secure manner by taking necessary action in advance.

## ACKNOWLEDGMENT

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