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EVOLVING COMPETITIVE ELECTRICITY MARKETS: RESEARCH PAPER ON OPERATIONS TECHNOLOGY AND MARKET MANAGEMENT SOLUTIONS - DEMAND FORECASTING

Jayaprakash Ponraj*
Research Scholar, VELS Institute of Science, Technology and Advanced Studies, Pallavaram, Chennai, India

Dr. A. Chandramohan
Registrar, Rajiv Gandhi National Institute of Youth Development, Sriperumpudur, Chennai, India

Dr. Sandeep Jain
Senior Managing Consultant, IBM GBS, Advance Analytics Center of Competence, India

ABSTRACT

Background / Objectives: *Worldwide governments, electricity regulatory bodies and utility organizations are converging on instituting new business models towards achievement of open access and thus autonomous electricity market objectives. Market operations and management solutions play an important in influencing the evolution of utilities transformation to autonomous state. The utilities are challenged to manage their power procurement decisions every day basis due to various uncertainties such as economic parameters, government policies on renewables, storage, energy efficiency, weather parameters, holidays and special events like rally, election etc., on a short, medium and long term basis. And this inefficiency is transferred to the consumers in to increasing tariffs. Availability of accurate forecasting & optimizations tools and algorithms interlaced with the utilities processes would significantly bring in synergy and hence reduce the inefficiencies in energy portfolio management. The optimization of revenue or procurement cost is associated with uncertainties in demand and supply. Accurate forecasting of demand and supply changes over intra-day, day ahead, weekly, monthly and a yearly is helps utility in buy and sell decisions of energy through energy exchanges, banking and bilateral contracts. Demand forecasting is dependent on various independent factors such as weather conditions, hour of a day, day of a week, holiday patterns, special events, etc.,*

Findings: *This paper elaborately discusses on an approach for accurate short (day ahead and intraday) and medium (biweekly, monthly) and long term (annual) demand forecasting to help to manage power procurement objectives through electricity exchanges, bilateral and banking contracts. This paper also discusses a methodology for long term forecasting considering various exogenous factors. This paper explains how these techniques can be applied to empower utility stakeholder with digital experience to ensure providing equal opportunity to perform their businesses in the world of uncertainties. This paper includes analysis results conducted over the survey on electricity consumers and suppliers which proves the significance of operation technology solution supports towards establishment of open access transformation.*

Applications / Improvements: *This paper does not include all other influences such as people, organization & social behaviors, traditional applications and solutions to help manage the business as usual. Hence it is proposed to continue the research work to cover other aspects and publish in the further proceedings.*

Keywords: electricity markets, advanced analytics, demand forecasting, **JEL Classification**: J11, C02, C15, C53, C55, C61, F17, F63, F64

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1. INTRODUCTION

Instituting and sustaining of autonomous state electricity markets is reliant on enactment of flexible and accurate electricity operations and market management solutions. The planning and operation department of electricity generation, distribution companies and retailers are key users of such solutions that help to manage their operational determinations viz., buy or sell or grid use. Accurate forecasting of electricity demand and supply changes over intra-day time blocks, day ahead, weekly, monthly and a yearly supports utility organizations in their day to day decisions including buy or sell through energy exchanges, banking and bilateral contracts, plan or invoke of demand response programs etc., The optimization of energy sales or procurement cost is linked with uncertainties in demand and supply. Demand of electricity follow various uncertainties such as economic parameters, government policies on renewables, storage, energy efficiency, weather parameters, holidays and special events like rally, election etc., on a short, medium and long term basis.

For simplicity and clarity the following expressions of time frames are used throughout this document. Intraday forecast describes 15 min (minute's granularity) time interval forecast for the same day or remaining day of operational decisions. Day ahead forecast means 15 min time interval forecast for the next day of operational decisions. Fortnightly forecast means 95 percentile 15 min time interval forecast for two fortnights in any month. The other forecast includes for medium term spanning from 1 to 12 months and for long term ranging from 1 to 10 years.

2. LITERATURE REVIEW

Competition, the process of challenge between organizations striving to gain sales and make profits, is the driving force behind markets. Former Undersecretary General of United Nations, Nitin Desai specifies (Pradeep S Mehta, 2007) that the competition is the one that promotes efficiency and accountability, ensures access for the citizen-consumer and widens his / her choices. Pradeep discussed elaborately about prospectus and challenges of electricity and telecommunication markets in India. He also focused mainly on existing state of infrastructure and provides a way forward in building the competitive electricity markets in India. He also stressed the need for detailed methodological study focusing on electricity competitive markets due to its inherent slow path of transformation. While comparing competitiveness and progress of telecommunication industry with electricity, the report termed the progress as failure and describes various aspects to focus on success path. This paper focuses on key subject area operation technology for market management. A market management solution consists of three key components viz., demand, supply and market price forecasting, energy and price optimization and data integration. This paper focuses on demand forecasting and its solution.

There are various research papers published for load forecasting. Friedrich and Afshari (Luiz Friedrich, 2015) use ARIMA (autoregressive integrated moving average) and ANN (artificial neural network) along with exogenous variables to forecast short term load. Taylor (Taylor, 2003) uses double seasonal Holt-Winters models to forecast next half-hour to day ahead. He also compares the performance of his Holt-Winters model with traditional ARIMA model. Mohamed and Naresh (MOHAMED A. ABU-EL-MAGD, 1982) present a review paper on load forecasting. They discuss about the various methods like multiple regression, spectral decomposition, exponential smoothing, time series, state space approach.

3. METHODOLOGY

This section covers approach and methodology into two parts; first part related to establishing importance of operation technology solution through consumer survey and second part related to detailed requirements of operation technology solution to support market management.

3.1 Survey Conducted on Electricity Consumers and Suppliers

A survey was conducted on electricity suppliers and consumers. Respondent profile of consumers was grouped as Consumer Categories viz., Residential, Commercial and Industrial. Similarly this was also grouped into various Organization Categories viz., Individuals, Private and Public. The following questions related to Infrastructure & Technology were raised.

Energy & Power System (EPS) Infrastructure

- Do you consider that the existing power system infrastructure is sufficient to support the requirements of open access?
- Do you consider that the infrastructure to manage distributed generation is sufficient to support the requirements of open access?
- Do you consider that the existing energy storage infrastructure is sufficient to support the requirements of open access?
- Do you consider that the existing demand response infrastructure is sufficient to support the requirements of open access?
- Do you consider that there is not much need for major investment to improve existing Energy & Power System Infrastructure to meet open access requirements?
- Do you consider that step by step investment in Energy & Power System Infrastructure could help meeting the open access targets?

Information Technology (IT)

- Do you consider that the existing Information Technology infrastructure and applications is sufficient to support the open access transformation?
- Do you consider that there is not much need for major investment to improve existing IT infrastructure and applications that enable open access requirements?
- Do you think that step by step investment in IT infrastructure and applications could help meeting the target transformation?

Operation Technology (OT)

- Do you consider that the existing Operation Technology infrastructure and applications is sufficient to support the pre-requisite of open access?
- Do you consider that there is not much need for major investment to improve existing Operation Technology infrastructure and applications to meet open access requirements?
- Do you think that that step by step investment in Operation Technology infrastructure and applications could help meeting the target transformation?

Market Systems (MS)

- Do you consider that existing Market operation and management systems is sufficient to support the pre-requisite of open access?
- Do you consider that there is not much need for major investment to improve existing Market Systems infrastructure and applications to meet open access requirements?
- Do you consider that step by step investment in Market and enterprise systems and applications could help meeting the targets?

Customer Systems (CS)

- Do you consider that electricity suppliers are doing well to manage customer acquisition and retention?
- Do you consider that there is not much need for major investment to improve existing Customer Systems and applications to meet open access requirements?
- Do you consider that step by step investment in Customer Systems and applications could help meeting the targets?

3.2. Operation Technology solution – Forecasting component

The details considered in this paper are an equivalent of a distribution organization based in India with an average demand of 1000 Mega Watts. In order to make this effort global and reusable, it is generalized that the company in deliberation distributes power to an area spread approximately 500 sq. km with an approximate customer base of 1.5 million spread in 10 districts. The Figure 1 represents the functional architecture of the solution. IBM SPSS modeler was used as advanced analytics tool to create statistical causal models. In order to analyze the data and build rules to identify, input the missing (blanks, Not Applicable), wrong (undefined, negative etc.) and outlier values (extreme high or low). One of the key activities is to convert actual load to unrestricted load by existing or proposed (N points moving average) method. Unrestricted load includes actual load data and undelivered energy. Assessment of undelivered energy is obtained by aggregation of energy undelivered due to planned outages and projected energy trend of the section or last mile after unplanned outages. Information related to unplanned outages are expected to be captured at SCADA/ADMS solution to get better accuracy.

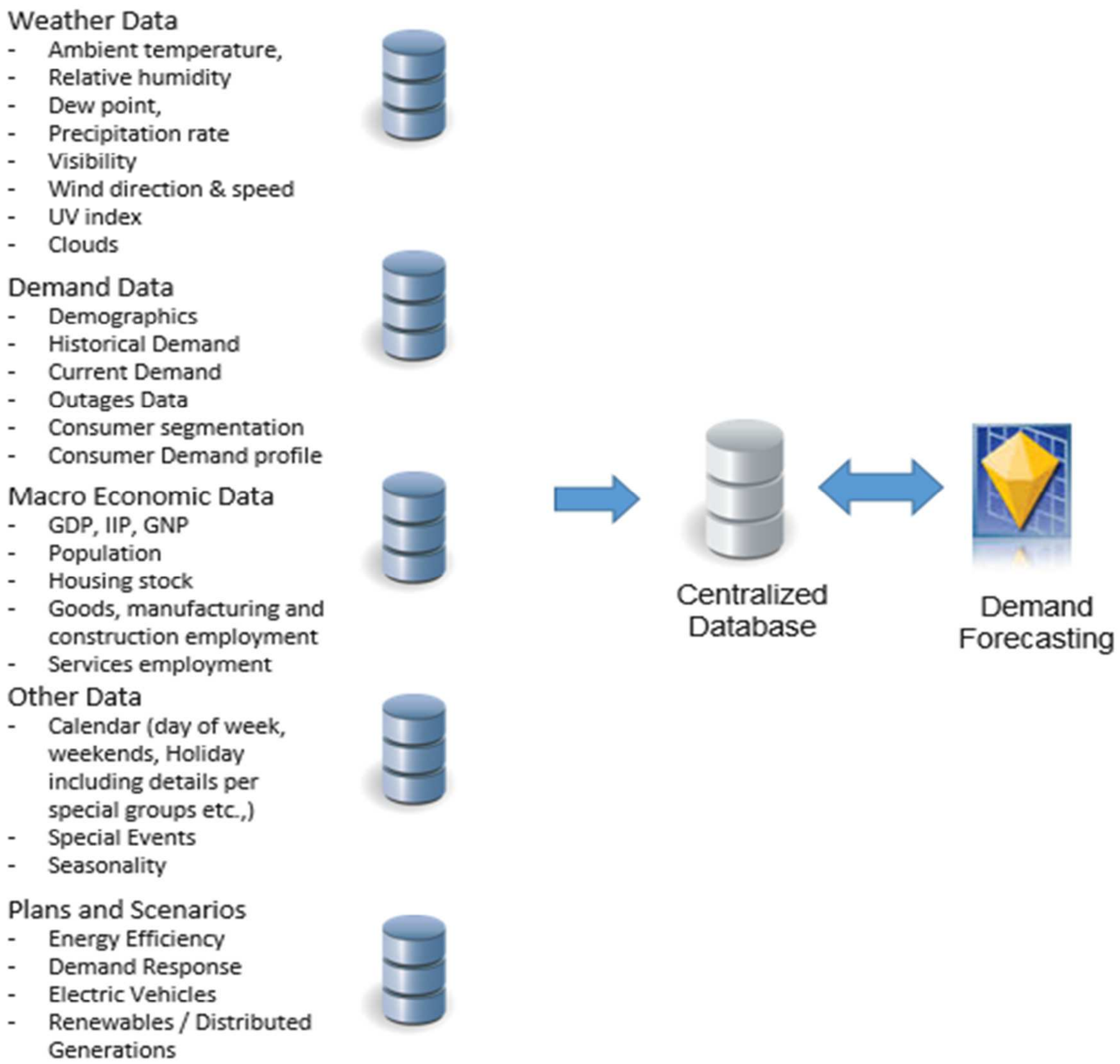

Figure 1 Functional architecture of demand or load forecasting solution

3.2.1. Short term load forecasts

The requirement of short term forecast with "kW" as unit at any instant which is a measure of one thousand watts of electrical power is to schedule the power requirements with its respective load dispatch centers who are responsible for maintaining reliability of the power system and to make buy or sell or allocate decision of energy such as use from existing bilateral contract or plan inter utility or banking transfers or buy or sell in day ahead and / or intra-day electricity exchanges.

3.2.2. Medium term demand forecasts

The requirement of medium term forecast is to estimate the peak power requirement in next one to six months based on historical trends, expected addition of new customers in various categories (residential, commercial, industrial etc.) and medium term weather forecast. Considering that it is challenge to get weather forecast for next 6 months especially building models based on historical trends of weather and scenarios to capture the impact of various parameters is anticipated.

3.2.3. Long term demand forecasts

The requirement of the long team forecast is to provide peak power requirement projects at yearly level (separate peaks for summer and winter). Macro-economic parameters such as Gross Domestic Product, Index of Industrial Production, Gross National Product, Population, Consumer segmented demand profile, House stack, Goods and manufacturing and construction equipment and services employment (Planning, 2012) helps achieving advanced accuracies of long term forecasting. In addition to this ability to manipulate various political, socio-economic plans and scenarios including energy efficiency programs and trends, demand response plans, electric vehicle and battery system targets and renewable energy trends and plans is expected to improve the reliability of the forecast model.

4. RESULTS AND DISCUSSION

This section covers results and discussion to two parts; first part related to establishing importance of operation technology solution through consumer survey and second part related to detailed requirements of operation technology solution to support market management.

4.1. Impact of infrastructure and Technology Factors on Open Access Electricity Market

Infrastructure and technology factors such as EPS Infrastructure, IT, OT, MS and CS are used as inputs in regression analysis to identify predictors of open access market. The method used to predict the open access market is Multiple Regression Analysis.

Hypothesis:

Ho: There is no significant impact of Infrastructure and Technology factors on open access market

H1: There is a significant impact of Infrastructure and Technology factors on open access market

Table 1 Multiple Regression Model for Open Access Market Based on Infrastructure and Technology factors

Independent variables	Unstandardized Coefficients		Standardized Coefficients			Statistical inference	
	B	Std. Error	Beta	T	Sig		F value
Constant	4.103	.454		9.042	.000	R = 0.330 R^2 = 0.109 Adjusted R^2 = 0.097	9.746***
X1	-.079	.015	-.331	-5.404	.000***		
X3	.029	.040	.057	.705	.481		
X4	.175	.039	.252	4.481	.000***		
X5	-.040	.057	-.053	-.691	.490		

***Significant at 1% level

In this study, open access market (Y) is dependent variable; EPS Infrastructure (X1), IT (X2), OT (X3), MS (X4) and CS (X5) are predictor variables. The **Table 1** Multiple Regression Model for Open Access Market Based on Infrastructure and Technology factors shows that the combination of four variables together contributed to 33% effect on open access market. The variable IT is excluded for the analysis because of co-linearity. The R2 for the overall study on the above four variables suggests that there is a less effect (10.9%) of these independent variables on open access market (dependent variable). However, based on the adjusted R square value of 0.097, the elements contribute 9% to dependent variable. The F value (9.746) is significant at 1% level which implies that the model is fit. From the table it is found that EPS Infrastructure and MS variables give significant impact to open access market. It is clear that independent variable with higher level of β has higher impact on dependent variable. In this study result reveal that the variable MS (β =0.252, p<0.01) is the most influential variable is exerted a statistically significant and positive influence on open access. EPS Infrastructure (β = - 0.331, p<0.01) is exerted a statistically significant and negative influence on open access market. The standardized coefficients Beta column, gives the coefficients of independent variables in the regression equation.

Y = -0.331X1 + 0.057X3 + 0.252 X4 – 0.053X5

This would suggest that EPS Infrastructure and MS play a significant role on open access market.

4.2. Requirements for load forecasting component for a distribution company based in India

Using IBM SPSS models were built covering all those identified variables and Regression causal models were created and trained. As the data utilized for modeling involves every 15min interval data and hence it is intended to show only graphs not the data tables in this publication. The following are typical characteristics of model and tool features. It was proposed that selected models were tested and results are summarized. Based on the review of results the selected best model can be released for further production or go live.

- Time series: Decomposition, Holt & Winter's Model (additive, multiplicative), ARIMA, ARIMAX etc.
- Machine learning: Neural Network, Random Forest, CART

4.2.1 Short term load forecasting models

Short term forecast especially day ahead and intraday models were built considering inputs such as current and historical demand data sourced from either SCADA or AMI or tariff metering systems sampled every 15 minutes. Historical weather conditions sampled at 1 hour duration, whereas current and forecast weather parameters were sampled at 15 minutes time block. Wherever there was a requirement for weather conditions with 15 minutes interval, 1 hour sampling was further interpolated. Also manual updates on demand data were carried out to estimate unrestricted demand data considering SCADA measurement error, planned and unplanned outages. The model dynamics were enriched with an ability to bring in user or stakeholder insights in to the model for capturing various uncertainties such as special events, holidays, weekends, feel like, etc. Data sets ranging from January 2010 to March 2017 were used.

The simplified forecast representation in an additive model is:

$Pf(t) = A*(t) = Pw(t) + B*Purl(t) + C*Ps(t) + D$, whereas Pf (t) is Power forecast at any instant, Pw (t) is trend component correlating with varying due to weather, Ps (t) is simulated Power trend with special events, consumer segmentation and its demand components derived through user insights / perception and Purl (t) can be represented as:

$Purl(t) = X*Pfs(t)$+Y, whereas Pfs (t) is Simulated Power forecast based on inputs on undelivered energy calculations from planned and unplanned outages forecasted through user insights or perception and inputs / capabilities of advanced distribution automation solutions.

In regression model, we use both recent load and weather parameters.

$$Load(t) = \beta 0 + \beta 1*Load(t-1) + \beta 2*Load(t-2) + \beta 3*ST(t) + \beta 4*RH(t) + \beta 5*cc(t) + \beta 6*ppt(t)$$

Where Load(t) is forecasted load, Load(t-1) is previous period actual load, ST(t) is forecasted surface temperature, RH(t) is Relative humidity, cc(t) is cloud coverage, ppt(t) is precipitation andβ are intercept and coefficients. We have considered linear and non-liner variants of temperature in the model.

4.2.2. Historical Weather

The Figure 2 represents multiple year correlation of historical seasonal conditions which includes patterns of surface temperature, Relative Humidity, Surface Dew point temperature, Cloud coverage, Apparent Temperature, Wind Chill Temperature, Wind Chill Index, Heat Index, Temperature Humidity Index, Temperature Wind Chill Index, Wind Speed, and Modified Precipitation where all Temperature readings are represented in Celsius. This gives an overview of seasonal variations and further guides towards inference of appropriate correlating variable with demand patterns. Figure 3 represents correlation of actual weather with instantaneous power.

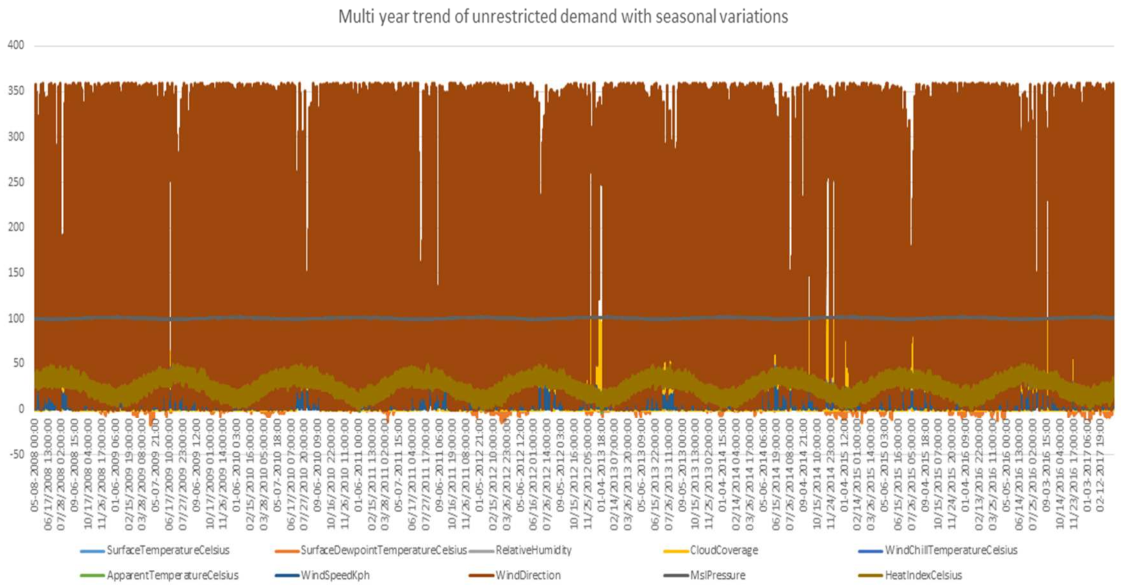

Figure 2 Multiple year annual correlation of historical seasonal conditions

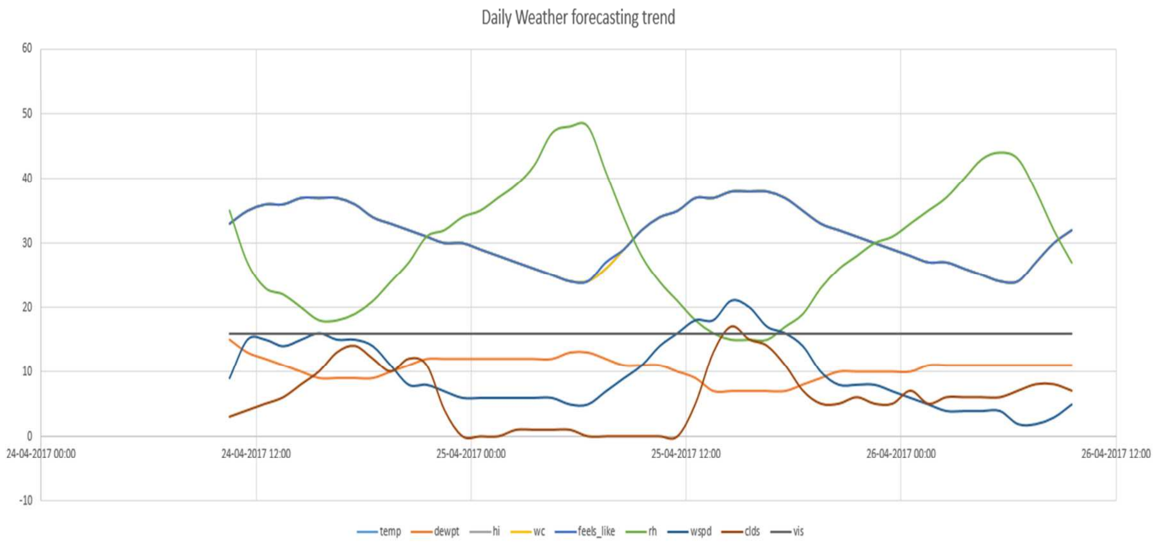

Figure 4 Daily weather forecast

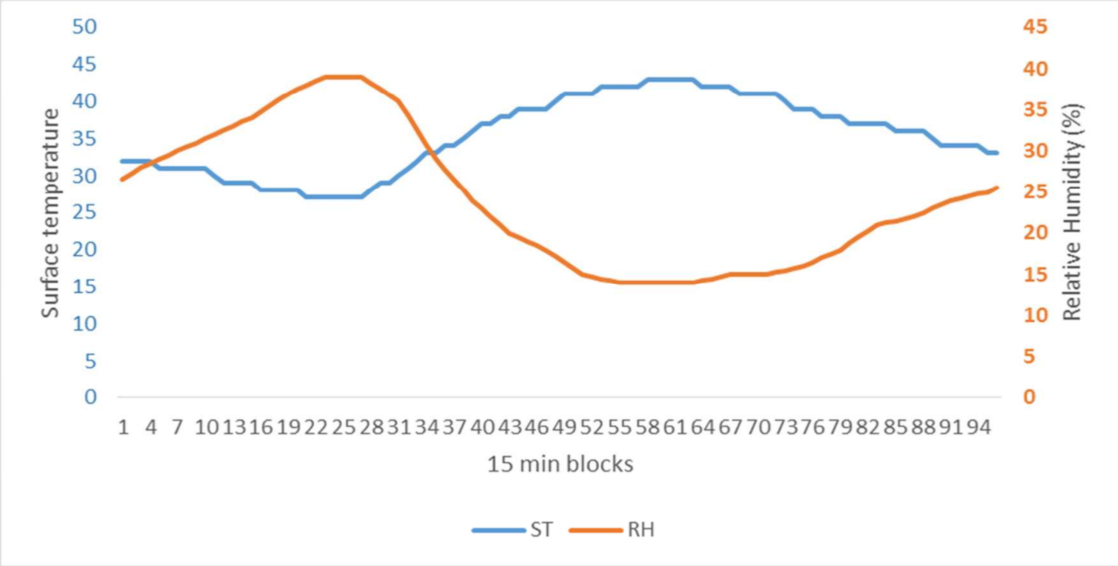

Figure 5 Weather change in a day

The represents summary definition of weather parameters (measured) and Table 3 Definition of Derived weather Variables summarizes definition of derived weather parameters used by forecasting model.

Table 2 Definition of measured weather variables

#	Field	Symbol	Unit	Definition
1	Surface Temperature	Temp	Celsius	Surface air (dry bulb) temperature at 2 meters
2	Surface Dew Point Temperature	Dewpt	Celsius	Atmospheric humidity metric (temperature at which dew will form)
3	Surface Wet Bulb Temperature	Tb	Celsius	Atmospheric humidity metric (evaporative cooling potential of moist surface)
4	Relative Humidity	Rh		Percent of water vapor in the air relative to its saturation point
5	Surface Air Pressure		Kilopascals	Atmospheric pressure
6	Cloud Coverage	Clds		Percentage of the sky covered by clouds
7	Wind Chill Temperature	Wc	Celsius	Air temperature that includes impact of wind
8	Apparent Temperature	feels_like	Celsius	Air temperature that includes impact of wind and humidity
9	Wind Speed	Wspd	Kph	Unobstructed wind speed at 10 meters
10	Wind Direction	Wdir		Upwind direction (e.g., wind from east = 270, from south = 180, etc.) at 10 meters
11	Precipitation Previous Hour	Qpf	Centimeters	Liquid equivalent for types: warm rain, freezing rain, sleet, snow

Table 3 Definition of Derived weather Variables

#	Field	Symbol	Unit	Description
1	Temperature Humidity Index	THI	Degree Fahrenheit	THI is a measure of the degree of discomfort experienced by an individual in warm weather; it was originally called the discomfort index. The index is essentially an effective temperature based on air temperature and humidity and cloud cover
2	Wind Chill Index	WCI	Degree Celsius	Wind chill factor is the felt air temperature on exposed skin due to wind. Wind chill temperature is always less than the air temperature and is undefined at temperature above 10˚C
3	Temperature Wind Chill Index	TWCI	Degree Celsius	New formula which gives greater accuracy than WCI which incudes temperature in Celsius

4.2.3. Historical Unrestricted Load

The Figure 6 represents multiple year correlation of historical unrestricted load which includes various special patterns of weekdays, weekends, holidays, special events etc., Figure 6also covers annual load or demand variations. Model performance such as accuracy and reliability depends on the ability of the solution to collect or estimate unrestricted load which is power demand by all categories of consumers at any point of time assuming there were no undelivered energy to end consumers.

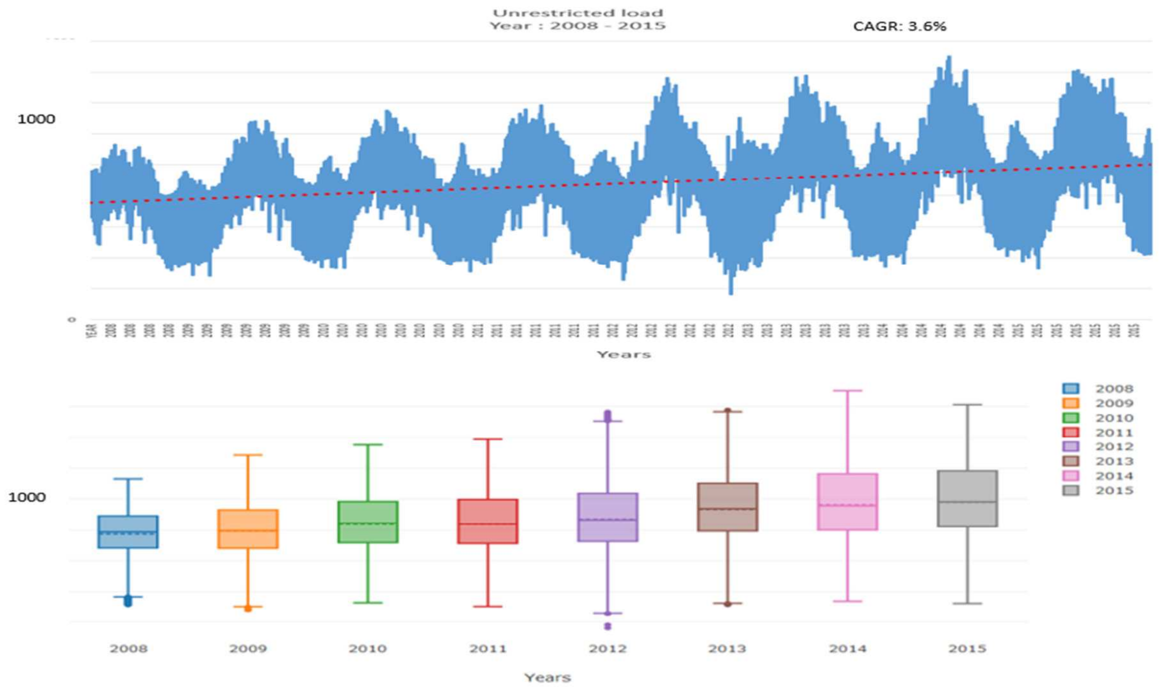

Figure 6 Multiple year annual trend of historical unrestricted load conditions

4.2.4. Capture of forecast Scenario

It is important for an operator to adapt forecast with the inputs such as type of the day e.g., identify similar holidays in the past and associate them with other inputs such as behavior of demand while it falls on weekends or on weekdays plus apply weather scenarios. And some of the patterns such as elections, rallies, cricket matches etc. helps to increase overall accuracy results and % inbounds. Figure 7 and Figure 8 summarizes correlation of unrestricted load pattern trends with the day type that includes weekday, holiday, weekends, day of the week, as well as special events.

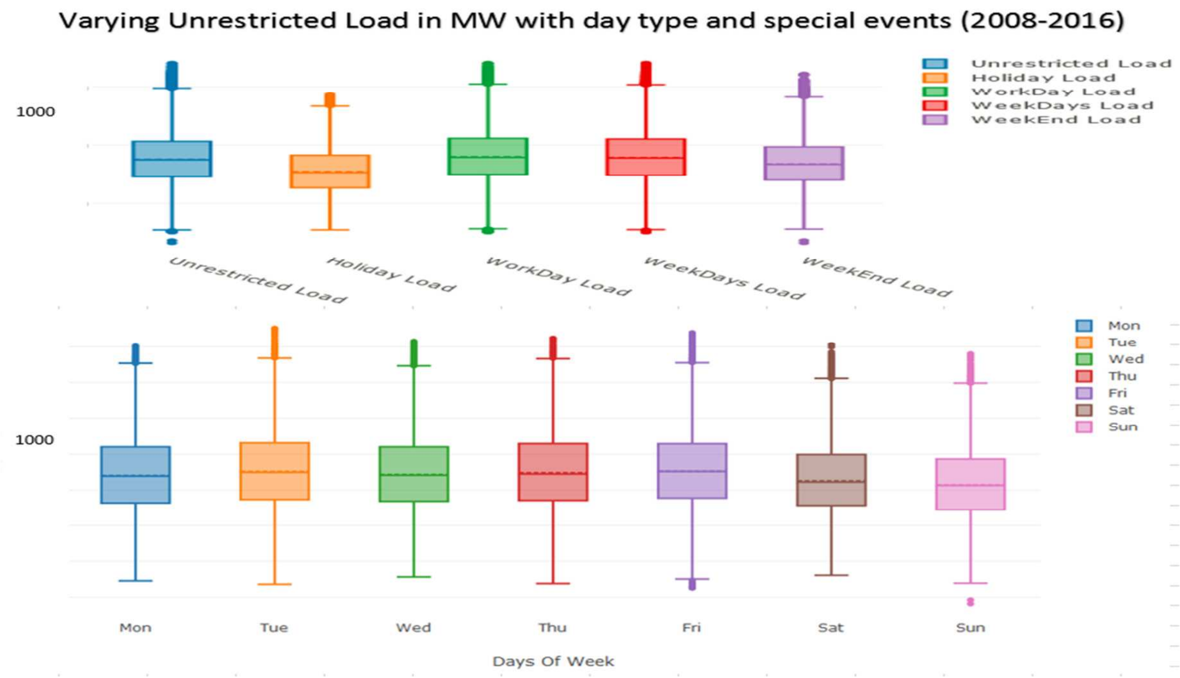

Figure 7 Patterns during Weekends and Weekdays

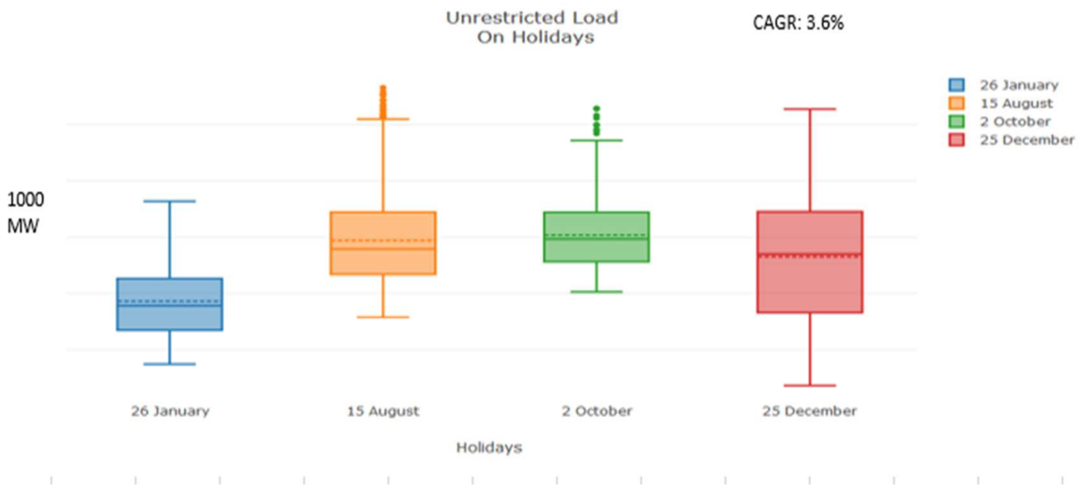

Figure 8 Patterns during Holidays

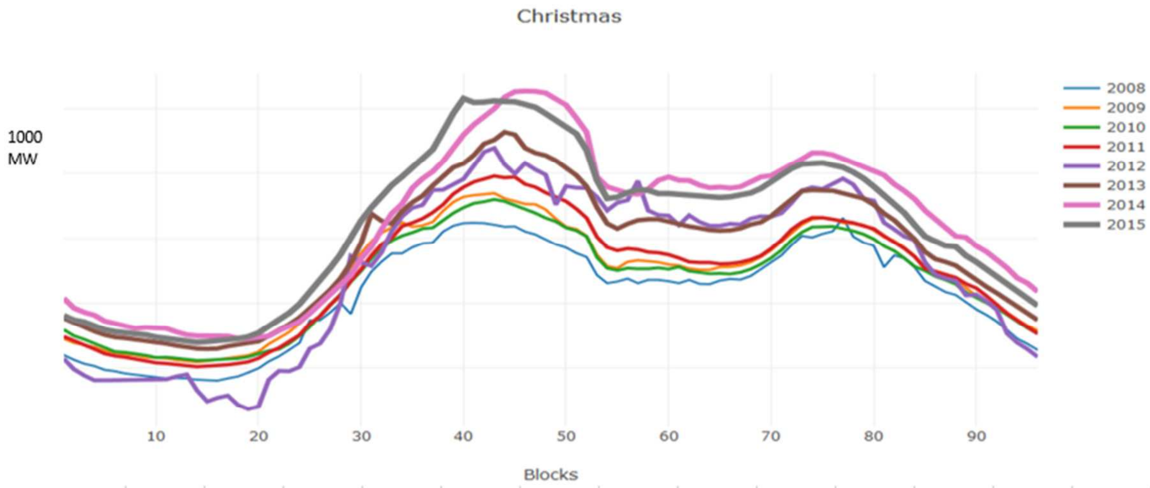

Figure 9 Trend plotted for Specific Holiday

4.2.5. Capture of forecast results

Figure 9 represents Sample of day ahead forecast against actual unrestricted load measured and published at the next of actual scenario day.

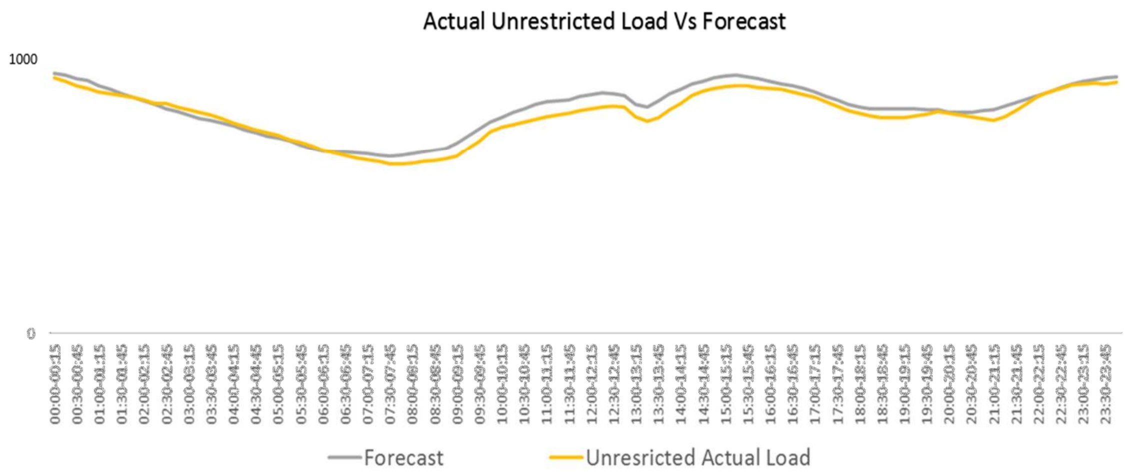

Figure 10 Daily Forecasts vs actual during a week day

Although the functional architecture shown in Figure 1 represents entire demand and load forecasting solution details of performing medium and long term forecast are planned to be shared in subsequent publications. The activities performed to improve capabilities to capture various data sources and provide insights to stakeholder of forecasting solution to utilize the data appropriately to build robust and reliable forecast model is planned to be explained in subsequent publications.

5. CONCLUSION

Continuous regulation forecast model with the facility for what-if analysis was developed for the short term (day ahead and intraday) forecast for a utility scale with track of 15 minutes electricity consumption. Accurate data inputs such as a) current and historical unrestricted demand, b) historical, current and forecast weather data including parameters such as ambient temperature, specific humidity, feel like, etc., and c) historical trend of consumer load / demand profile is critical to get better accuracy forecasting. More accurate results could be achieved by the usage of zone wise load distribution inputs along with consumer segmented load profile data. The influence of zone based multi-location weather variables including ambient temperature, specific humidity, and wind speed adjusted to localized feel like trends improves the accuracy of forecasting. Tuning of forecast results based on requirements of accuracy measurements such as MAPE, MAE, %In-bounds is also an important decision while tuning the forecast models. OLS regression model was found to be more appropriate model and yielded results of MAPE <2.5%, MAE <20.43 and Least % In-bounds within +/- 2% for consecutive two weeks is more than 65%.

Market operations and management solutions play an important role in shaping the electricity market and thus help large scale implementation of the wholesale and retail electricity markets. As the number of market participants grow especially with the number of prosumers and consumers moving towards buying and selling electricity through the energy exchange, accuracy of forecasting becomes highly significant. This means availability of cost effective advanced analytics solutions and its ease of practice by every market participants to make them digitally enabled will impact the end establishment and performance of the competitive electricity markets.

5.1. Research Implications and Policy Implications

This Study combined with review of global utility stakeholders' approaches suggests that for realization of autonomous market maturity requires coherence of appropriate strategy & roadmap followed by step by step implementation of various solutions which includes not just technology applications but also various initiatives to align their people, legal & regulatory framework, social & organizational behavior. This paper focused on study of detailed requirements of forecasting component in operation technology solution to support market management emphasizing on key facets of this technology and presented some of use cases. Analysis and interpretation clearly highlights detailed list of the Infrastructure & Technology subject areas.

5.2. Limitations of the Study and Scope for Further Research

This paper did not discuss impact of people, other technologies and organization environment and behavior framework. And also there are other enabling technologies such as internet of things (IOT), cloud, social and mobile to support enabling utility organization to perform better towards competitive autonomous journey were not discussed. The point of view to empower every stakeholder with digital experience has not been covered in this publication. It is important to highlight that focus on extracting maximum benefits from any targeted technology investments includes advanced analytics, cognitive solutions powered by cloud, IOT and mobile capabilities will bring success in the journey of autonomous transformation. It is proposed to discuss every challenges and do deep dive into design of utility system architecture and also to provide insight on data governance and management methods which would play vital role in shaping the utilities analytics and cognitive journey in future.

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