CHAPTER 2

LITERATURE REVIEW

2.1. ELECTRICITY PRICE MODELING AND FORECASTING

Electricity Price Modeling and Forecasting techniques/models in literature can be broadly classified under the following classes: (Weron 2006; Girish 2013)

1. Production-cost models: These models have the potential to simulate overall operation of electric power generating stations/units. The prime objective is to suffice demand of electricity at lowest cost. One of the major drawbacks of this approach is that strategic bidding practices adopted by other power market players is not considered.

2. Equilibrium models: These models are very much similar to Production-cost based models except the fact that strategic bidding practices adopted by other power market players is also considered. It has been observed that forecasting performance of Equilibrium models has not been satisfactory in deregulated markets. One of the drawbacks of this approach is that it becomes very difficult for drawing quantitative conclusions coupled with the fact that these approaches are computationally challenging.

3. Fundamental models: These models manifest electricity price dynamics by incorporating and modeling impact of all physical factors and economic factors. These models are believed to be better suited for medium-term electricity price forecasting compared to Short term electricity price modeling and forecasting.

4. Quantitative models: These models describe the statistical properties of electricity prices viz-a-viz time and have their practical application in valuation of derivatives and for risk-management motive and purpose.
5. Statistical/Technical analysis approach: These techniques are direct applications of methods inspired from electrical engineering/load forecasting or finance/time series econometric models. The effectiveness, efficiency and appropriate usefulness of adopting technical analysis approach is often questioned in financial/currency markets, however, the same techniques stand better chance in power markets irrespective of the time period considered. The main reason is the fact that electricity prices behave in the way we expect than randomly fluctuating financial asset prices aided mainly by the stylized facts\(^1\) of spot electricity markets and its prices namely Seasonality, Mean Reversion, Volatility and Jumps/Spikes. Spot electricity prices can be modeled with electric power load, price of fuel (fundamental factors) as exogenous variables for modeling and forecasting.

6. Artificial Intelligence techniques: In these techniques, spot electricity prices are modeled by adopting neural networks, expert systems, support vector machines, fuzzy logic etc which are non-parametric tools having the advantage of being flexible and capable of handling complexity and most importantly non-linearity. Being non-intuitive and often performing below par has been their biggest drawback.

Statistical models and artificial intelligence based approaches are useful for short-term electricity price forecasting purpose (Aggarwal, Mohan and Kumar, 2009; Girish, Vijayalakshmi, Panda and Rath, 2014; Weron, 2006).

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\(^1\) Electricity price series exhibits Stylized facts across different electricity markets i.e. Electricity prices exhibit Seasonality, Mean Reversion, Volatility and Jumps/Spikes (Cuaresma, Hlouskova, Kossmeier and Obersteiner, 2004; Conejo, Contreras, Espinola and Plazas, 2005; Weron, 2006; Aggarwal, Saini and Kumar, 2009; Bowden and Payne, 2008; Hickey, Loomis and Mohammadi, 2012; Girish, Vijayalakshmi, Panda and Rath, 2014; Girish and Vijayalakshmi, 2014)
Aggarwal et al. (2009) classify short term electricity price forecasting\(^2\) models into three categories namely: game theory models, simulation models and the time-series models (as seen in Table 8).

**Table 8: Classification of Forecasting Models**

<table>
<thead>
<tr>
<th>Category</th>
<th>Models</th>
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</thead>
<tbody>
<tr>
<td>Electricity Price Forecasting</td>
<td>Simulation Models, Time Series Models, Game Theory Models</td>
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<tr>
<td></td>
<td>Parsimonious Stochastic Models, Artificial Intelligence based Models</td>
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<tr>
<td></td>
<td>Regression or Causal Models, Data-mining Models</td>
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<td></td>
<td>Neural Network based Models</td>
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</table>

Source: Aggarwal et al. (2009), Girish and Vijayalakshmi (2013)

### 2.2. SHORT-TERM SPOT ELECTRICITY PRICE FORECASTING

Misiorek et al. (2006) have classified forecasting models for electricity prices based on the time-frame for which prediction of electricity price needs to be done as follows:

- **a)** Forecasting of electricity prices for long-term (more than 1 year): The prime objective is for analyzing and planning long term investment profitability particularly for deducing future sites/fuel sources of power plants.

- **b)** Forecasting of electricity prices for medium-term (3 months to 1 year): These classes of models are normally favored for balance-sheet calculations, derivatives pricing and also

\(^2\) Weron (2006), Aggarwal et al. (2009) and Girish et al. (2014) have reviewed techniques inspired from energy economics literature and electrical engineering/load forecasting literature for spot electricity price forecasting for different electricity markets. Most and Keles (2010) have reviewed stochastic modeling of electricity prices having traits and inspired from operation research literature.
risk management. The focus is on distributions of future electricity prices for medium term rather than exact point forecasts.

c) Forecasting of electricity prices for Short-term price (up to 3 months): Power market participants belonging to auction-type spot markets\(^3\) are particularly interested with forecasting of electricity prices for Short-term where they should participants communicate their bids quoting the price for buying/selling along with quantities.

2.3. UNIVARIATE TIME SERIES MODELS

Cuaresma, Hlouskova, Kossmeier and Obersteiner (2004) in their study forecasted day-ahead hourly spot electricity prices of Leipzig Power Exchange (LPX) Germany using linear univariate time-series models and compared their forecasting performances. The authors used data from 16\(^{th}\) June 2000 to 15\(^{th}\) October 2001 i.e. 11,688 hourly spot electricity price observations (in Euro/MWh) out of which 10,607 observations was considered as in-sample and 1080 observations was considered as out-of-sample. The authors calibrated a battery of univariate time series models including AR(1), AR(1) process having time varying intercept, ARMA process having time varying intercept, Crossed ARMA process having time varying intercept, ARMA processes having jumps and Unobserved components models. After calibration, estimating and forecasting spot electricity prices, the authors employed Diebold–Mariano\(^4\) (DM) predictive accuracy test in order to ascertain model having best forecasting power within each class. The authors found that the crossed ARMA model having time varying intercept with jumps was the

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\(^3\) In spot electricity markets (buy/sell) (bid/ask) orders are accepted in order of (increasing/decreasing) prices till (total demand/total supply) has been met.

\(^4\) Diebold–Mariano (1995) predictive accuracy test is a statistical test which is used to assess whether the differences observed in forecasting performance across different models is statistically significant or not.
best model for forecasting spot electricity price of Leipzig Power Exchange (LPX) Germany. The results also empirically provided evidence that strategy of modeling hour-by-hour i.e. by using Disaggregated models was better compared to forecasting using Global models i.e. by considering all 24 hours of a day as a single time-series. The results of this study has motivated us to investigate forecasting performance of linear univariate time series models on Indian spot electricity price series which has never been done before.

Contreras, Espinola, Nogales and Conejo (2003) in their study predicted the next-day spot electricity prices of Spain and Californian electricity markets using ARIMA model. Market clearing spot prices of day-ahead pool of Spain and California which were publicly available was used for the study. The authors in general found inherent differences between the two markets spot price series: (a) the authors observed that the Spanish market showed more volatility. The ARIMA model for Spanish market needed data from previous five hours and did not need any differentiation for attaining stable mean; (b) Price predictions for Californian electricity market were found better before its collapse. The Californian market showed relatively less volatility for the period considered. The ARIMA model for California required data from previous two hours and required three differentiations.

Conejo, Contreras, Espinola and Plazas (2005) in their study compared the forecasting performance of ARIMA model, dynamic regression model and transfer function model by forecasting 24 hour day ahead market-clearing prices of PJM interconnection spot electric energy market. The authors employed time series analysis, artificial neural networks and wavelets in their study. The authors suggest that for PJM interconnection data, time series models were found to be more efficacious than wavelet-transform model or artificial neural network model. The results of the studies by Cuaresma et al., 2004; Conejo et al., 2005 has further
motivated us to investigate forecasting performance of time series models on Indian spot electricity price series which has never been done before empirically.

Nogales, Contreras, Conejo and Espinola (2002) in their study provided two precise and capable price forecasting models based on dynamic regression model, time series analysis and transfer function models. The authors empirically tested the calibrated models on real world data from the electricity markets of mainland Spain and California. The Average forecast errors for Spanish electricity market was around 5% and the average forecast errors was around 3% for Californian market for the considered time period of study. The authors conclude that price predictions obtained were precise enough to be used by power producers and power consumers for preparing their bidding strategies in competitive power markets of Spain and California. It would be interesting to investigate forecasting performance of time-series models in Indian spot electricity market’s context.

Weron and Misiorek (2008) in their study forecasted day-ahead short-term spot electricity prices of Californian and Nord Pool markets using time series models with an objective of comparing the forecasting accuracy of the calibrated models. For Californian market, 1999-2000 data was considered and for Nord Pool market data of 1998-1999 and 2003-2004 was considered for complete evaluation of models under different scenarios. The results of the study showed that models having system load as exogenous variable in most of the cases out-performed pure price models particularly for California power market. The results in addition suggest that air-temperature is not a statistically significant driver of spot electricity prices compared to electricity load for Nord pool market. Findings of the study also suggest that semi-parametric models lead to better point forecasting results than models having Gaussian assumption of
innovations. Furthermore these models seemed to have potential for performing well in spite of different market conditions.

Taylor, Menezes and McSharry (2006) in their study empirically compared the forecasting performance accuracy of six univariate time-series models on short-term electricity demand (load) data having lead time of up to one day ahead. Hourly demand data of Rio de Janeiro and half-hourly electricity demand data of England and Wales market was used to assess forecasting performance. The study suggested that the overall best forecasting performance results were obtained with the exponential smoothing technique which is relatively very simple compared to other complex models considered for their study. The study motivates us to start our forecasting performance comparison exercise by considering relatively simpler models and then extend to other complex models while forecasting Indian spot electricity prices.

Kriechbaumer, Angus, Parsons and Casado (2014) in their study assessed the usefulness of wavelet-ARIMA approach compared to normal ARIMA model fitting for forecasting monthly prices of lead, aluminum, copper and zinc. The rationale behind using wavelet analysis was to capture cyclicality by decomposing the time series into frequency and time domains. The results of the study suggest that taking into account of cyclicality when forecasting metal prices substantially increases forecasting performance of classic ARIMA models. The result of this study motivates us to pre-process spot electricity price data of Indian electricity market before fitting ARIMA models.

Kristiansen (2012) in his study forecasted the day-ahead hourly electricity price of Nord Pool by using hourly spot electricity price data from January 1st 2007 to May 31st 2011 which accounted for 1612 days and 38688 observations in Euro per megawatt (Euro/MWh). The author applied
natural logarithmic transformation to spot price, electricity load and data on wind for attaining a stable variance. Combination of Auto-regressive structure with exogenous variables i.e. daily dummy variables helped in capturing weekly seasonality. The author was successful in developing a simple, user-friendly, regression model considering Danish wind power and Nordic data on demand as exogenous factors for forecasting hourly electricity prices of Nord Pool with slight modification of Weron and Misiorek’s (2008)’s model and also for forecasting electricity price. The author concluded that incorporating minimum price and maximum price in the regression models yielded better results with MAPE of 5% compared to simple Auto-regressive models with exogenous variables. Further Kristiansen (2014) was successful in using past spot prices, futures prices, and the data for inflow with reservoir levels for forecasting electricity prices for Nord Pool market. The results of the study suggest that relatively accurate price forecasts were achieved for weekly spot prices with MAPE of approximately 7.5%. Results of Kristiansen (2012, 2014) studies have motivated us to investigate forecasting performance of AutoRegressive models for hourly spot electricity price data in Indian context and empirically investigate the forecasting performance.

Misiorek, Trueck and Weron (2006) evaluated the short-term forecasting performance of time-series models for Californian electricity market by using hourly spot prices data of California Power Exchange (CalPX). The authors considered data from July 5th 1999 to April 2nd 2000 i.e. 272 days and 6528 observations for calibrating time series models and considered time period from April 3rd 2000 to December 3rd 2000 for out-of-sample investigation of the calibrated models. The authors deseasonalized the data using hybrid method involving both sinusoidal and

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5 Weron and Misiorek (2008) in their study forecasted day-ahead spot electricity prices of Californian and Nord Pool markets using time series models with an objective of comparing the forecasting accuracy of the calibrated models.
a constant piece-wise function. The results support adequacy of time series models from point forecasting of spot electricity prices perspective. The best forecasting accurateness was secured using non-linear TARX model and by simple Autoregressive model which used load as exogenous variable in both cases. The results of the study also showed that forecasting performance achieved from regime switching models was below par compared to simple linear approach. The results of this study have helped us streamline our evaluation of forecasting performance of time-series models starting with simple linear univariate time series models.

2.4. VOLATILITY MODELS

Hickey, Loomis and Mohammadi (2012) in their study investigated the short-term forecasting performances of four classes of ARMAX–GARCH volatility models namely the APARCH model, GARCH model, CGARCH model and EGARCH model and evaluated their out-of-sample forecasting performance for the 5 hubs of Midwest Independent Transmission System Operator (MISO) namely Illinois, Cinergy, Michigan, First Energy and Minnesota by using hourly day-ahead spot electricity price data from June 1st 2006 to September 29th 2007 i.e. 11664 observations accounting for 486 days for each of the five hubs of MISO which was collected from MISO website and MISO's Look Ahead Report. The authors used data from September 30th 2007 to October 6th 2007 for out-of-sample forecasting. Spot electricity price data was empirically put to test for existence of unit root using Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test, the Augmented Dickey Fuller (ADF) test, Phillips Peron (PP) test, Ng-Perron test, ERS-Po test and Dickey Fuller GLS test. For all 5 hubs and tests, null hypothesis of unit root being there was strongly rejected at 1% significance level. Seasonality was captured using
monthly, hourly and daily dummy variables. EGARCH (1,1), GARCH (1,1), APARCH (1,1), and CGARCH (1,1) were calibrated using the deseasonalized data. Authors employed Mean Squared Error (MSE) and Mean Absolute Error (MAE) for measuring forecasting accuracy and performance of the calibrated models. Diebold and Mariano test (DM test) was used to judge whether divergence in forecasting accurateness of any 2 models was statistically significant or not. For shorter forecasting time-frame, all 4 volatility models displayed equivalent forecasting capabilities i.e. irrespective of the hub which was considered. APARCH model’s performance was best in case of hubs of deregulated states. Volatility dynamics were better captured by simple GARCH model in regulated states (in general) compared to other considered complex models. The results suggest that electricity price volatility is area-specific in nature and the best possible volatility model to be calibrated depended on certain key factors such as location of the hub, time horizon considered for forecasting and the regulatory status of the market (regulated or unregulated). This study is one of the biggest driving forces for our research and it would be interesting to evaluate the forecasting performance of time-series models in Indian spot electricity market’s context using volatility models and the results obtained by Hickey et al. (2012).

Cifter (2013) in his study forecasted Nordic power market’s electricity price volatility using GJR model, MS-GARCH model and GARCH model. The authors estimated the volatility models by means of Gaussian distribution, Student-t distribution and skewed Student-t distribution with an objective of finding the effect of the selection of distributions on the forecasting accurateness of the models. The study found that electricity price volatility in Nordic power market was strongly regime-dependent and also highly volatile. The empirical results of this study found that MS-GARCH model enabled more precise forecasting compared to ordinary GARCH models. It was
also found that using Skewed Student t distribution increased the forecasting performance of all the considered GARCH models. The results of the study provide evidence that using MS-GARCH model for forecasting electricity prices would be beneficial for power market participants of Nordic power market. **It would be interesting to investigate forecasting performance of volatility models in Indian spot electricity market’s context which has never been done before.**

Zhang and Tan (2013) proposed a new hybrid forecasting method by using Wavelet Transform (WT), Exponential Generalized Autoregressive Conditional Heteroskedastic (EGARCH) model and Chaotic Least Squares Support Vector Machine (CLSSVM) for short term day-ahead spot electricity price forecasting. The authors considered the Locational marginal price (LMP) of the PJM electricity market and also considered the market clearing price (MCP) of Spanish electricity market. For selected weeks and days (which need justification), the authors found the weekly and daily MAPE values obtained from proposed model to be lesser than that obtained by using other techniques. The benefit of the proposed hybrid model is the fact that it can incarcerate multifaceted dynamic behavior of electricity price series well. This has been possible due to Chaotic Least Squares Support Vector Machine (CLSSVM) combined with Wavelet Transform (WT) which has the ability to incarcerate the chaotic behavior without annihilating the important dynamics and performance of the spot price series. This has been ably complemented by EGARCH model which captures characteristics of high volatility effectively. **The results of this study motivate us to examine forecasting performance of volatility models in Indian spot electricity market’s context which has never been done before.**

Tan, Zhang, Wang and Xu (2010) in their study propose a novel short-term price prediction model based on Wavelet Transform (WT) combined with ARIMA model and GARCH model.
The authors used wavelet transform to fragment and recreate historical spot electricity price series into rough estimated series and detail series. Then each of the sub-series was independently forecasted using a suitable time-series model and the ending forecast was obtained by putting together forecasted results of each of the sub-series. The authors empirically examined the calibrated models on Spanish and PJM electricity markets and compared the results with other predicting methods. **The results of this study lay importance to spot electricity price pre-processing which is crucial.**

Bowden and Payne (2008) in their study assessed the day-ahead spot electricity price predicting performance of ARIMA-EGARCH model, ARIMA model and the ARIMA-EGARCH-M model by considering hourly spot electricity price data from Midwest Independent System Operator (MISO) for all the five hubs given by MISO and the Locational Marginal Prices (which is nothing but the expenditure of supplying next increase of electricity to a particular precise grid at a particular specified pricing node. Spot electricity prices from July 9th 2007 to August 6th 2007 accounting for 29 days i.e. 696 observations for each of the five hubs were considered for calibrating the models and assessing forecasting accuracy. Descriptive statistics showed that spot electricity prices across all the regions were found to be positively skewed, leptokurtic and non-normally distributed. Initial investigation of price series indicated presence of seasonality. To overcome this non-seasonal as well as seasonal differencing was rendered. The results of the study suggested that all five hubs of MISO exhibited seasonality and time varying unpredictability (due to non-storable nature of electricity, market power exerted by generators, unyielding demand and supply and convex marginal expenditure. Presence of Autoregressive conditional heteroskedasticity (ARCH) was revealed by ARIMA models. For each of the hub, inverse leverage effect in electricity prices was observed under EGARCH specification for the
variance equation. The authors concluded that no particular single class of volatility model clearly out-performed other models based on in-sample forecasting performance. The authors also found that ARIMA-EGARCH-M model outperformed all other models calibrated in terms of out-of-sample prediction accurateness (except for Michigan hub). **This study motivates our research and inspires us to evaluate the forecasting accurateness of time-series volatility models in Indian spot electricity market’s context which has never been done before.**

Diongue, Guegan and Vignal (2009) in their study investigated the conditional-mean and conditional-variance short-term forecasts using dynamic model following k-factor GI-GARCH process for German electricity market. The authors successfully provided the analytical expression for conditional variance of prediction error. The authors compared the prediction accurateness of the calibrated model with SARIMA–GARCH yardstick model. The results of the study suggest that k-factor GI-GARCH process could indeed be an appropriate model to predict spot electricity prices under RMSE criteria.

Koopman, Ooms and Carnero (2007) analyzed every day electricity spot prices by new periodic protractions of dynamic long-memory regression models with ARCH errors for four European power markets namely: Nord Pool power exchange (Norway), Powernext (France), EEX (Germany) and APX (Netherlands). The parameters of the models were estimated using maximum likelihood. The study found that mode of power generation in each of these power markets i.e. hydro powers, thermal power using fossil fuels or nuclear power played an important role in dynamic behavior of electricity prices. The results of the study add significantly to the existing models especially in terms of capturing memory uniqueness which are critical while pricing derivative and real options investigation.
Garcia, Contreras, Akkeren and Garcia (2005) in their study forecasted next-day hourly spot electricity prices of mainland Spain and Californian markets using GARCH model. The authors found that the calibrated GARCH model outperformed ordinary time-series ARIMA model especially when the volatility and price spikes are present. The authors also found that including demand as an exogenous variable to the GARCH model further improves the forecasting performance of the model.

Bosco, Parisio and Pelagatti (2007) in their study modeled high degree of autocorrelation and multiple seasonalities existent in spot electricity prices of daily average prices of Italian electricity market using periodic time-series models having GARCH disturbances as well as leptokurtic distributions and are compared with the forecasting performance with ARMA-GARCH model. The outcome of the study advocates that variability in price series was explained by interactions between deterministic-multiple seasonalities. The results also show that Periodic AR-GARCH models perform fairly well mimicking the features of stochastic part of spot electricity price process. The results of Diongue et al., (2009); Koopman et al., (2007); Garcia et al., (2005); Bosco et al., (2007) further motivates us to investigate forecasting accurateness of time-series volatility models in Indian spot electricity market’s context which has never been done before.

Liu and Shi (2013) in their study model and predict day ahead hourly spot electricity prices of ISO New England market using autoregressive moving average (ARMA) models, models with generalized autoregressive conditional heteroskedasticity (GARCH) processes i.e. ARMA–GARCH models and their modified forms like ARMA–GARCH-in-mean (ARMA–GARCH-M). Data from January 1st 2008 to February 28th 2010 accounting for 18,960 observations has been used for the study with the initial two years of data i.e. 17,544 observations have been used to
calibrate different ARMA–GARCH (-M) models. The Remaining 1416 observations have been used for out-of-sample forecasting to ascertain the forecasting accuracy of the calibrated and fitted models. The results of the study suggest that ARMA–SGARCH-M models which are simple are equally robust and the ARMA–GJRGARCH-M model is competitive. The authors observed that the hourly electricity prices exhibited daily seasonality, weekly seasonality and monthly seasonality and also exhibited non-linear, asymmetric, time-varying volatility coupled with inverse leverage effect. The study drives us into investigating the forecasting accurateness of time series models in Indian spot electricity market’s context using ARMA-GARCH models.

2.5. GAPS IN LITERATURE

After extensive review of the literature, we observed the following gaps in the literature:

1) There is a need to study the emergence of competitive wholesale deregulated spot electricity market in India.

2) There is a need to study the dynamics, behavior of Indian spot prices and empirically investigate the stylized facts of electricity markets for Indian electricity market.

3) There is a need to study the seasonality exhibited by Indian spot electricity prices.

4) There is a need to empirically model and forecast Indian Spot Electricity prices, which, to the best of our knowledge, has never been done before (especially for a market where demand outstrips supply).
5) There is a need to empirically investigate whether deseasonalizing spot electricity prices yield better forecasts compared to modeling spot electricity prices directly.

6) There is a need to empirically investigate the performance of Volatility models for forecasting spot electricity prices as there is no consensus regarding the forecasting performance of these models.