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Is Indian Spot Electricity Price Series Stationary?

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Abstract

Day-ahead spot electricity market of Indian energy exchange operates all 24 hours, 365 days a year. Many studies in literature have explored modeling spot electricity prices particularly in the context of NordPool, CalPx and PJM markets but very few studies in literature have explored modeling spot electricity prices in Indian context. Is Indian Spot Electricity Price Series Stationary? Answering this fundamental question paves way for application of techniques inspired from time series econometric modeling and forecasting literature which makes an inherent assumption that the underlying price-series is stationary. In this study we empirically investigate whether Spot Electricity Price Series is Stationary by using 17,520 hourly spot prices for each of the five regions of Indian electricity market and applying Augmented Dickey-Fuller Test, Phillips Peron Test, Kwiatkowski–Phillips–Schmidt–Shin Test and Narayan and Popp Test allowing for structural breaks. The results of the study will help power market participants understand the nitty-gritty's and nuances associated with Indian spot electricity prices for effective application of time series econometric models.

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Keywords: Spot electricity price; India; ADF; Unit root; Structural break; Narayan and Popp

1. Introduction

The Indian Electricity Act (IEA) 2003 has been influential in setting the 3rd largest electricity producer in the world [1] for strategic evolvement and improvement of electricity sector in India, streamlining of power tariffs in India, endorsing and executing policies ensuring in attaining energy efficiency together with being environmental friendly. However, India still faces a critical issue of energy shortfall. Post IEA 2003, power trading is a detached and distinctive

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activity. Day-ahead spot electricity market of Indian Energy Exchange (IEX) and Power Exchange India Ltd (PXIL) operates all 24 hours, 365 days a year [2].

Short-term electricity transactions in India having a time frame of less than a year have been growing consistently past few years. Figure 1 elucidates a growing trend in the amount of Short-term electricity transactions in MW over the last few years. Ever since IEX and PXIL became functional in 2008-09, average electricity price transacted through power exchanges has decreased considerably from almost Rs. 7.49 per KWh in 2008-09 to Rs. 2.72 per KWh in 2015-16 [3]. Figure 2 elucidates decreasing trend in average electricity price transacted through power exchanges.

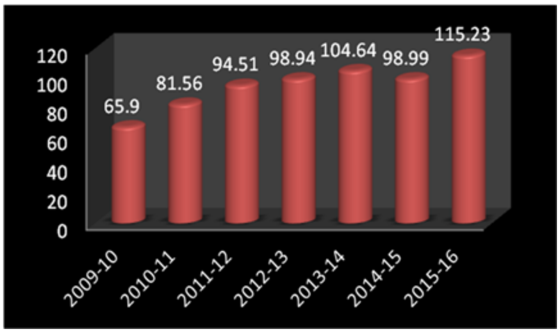

Fig 1. Short-term electricity transactions in India (less than 1 year)

Fig 2. Average electricity price transacted through IEX and PXIL

Today more than 3635+ Open Access participants/consumers actively trade in these exchanges. Figure 3 elucidates growing trend in the number of Open Access participants/consumers for 2015-16 in IEX [4]. The biggest issue encountered by market participants as well as regulator and system operator is that of congestion management. Table 1 elucidates details about total volume cleared after incorporating short-term transactions by both the exchanges IEX and PXIL. Congestion charges and its impact on earnings of IEX and PXIL is elucidated in Figure 4.

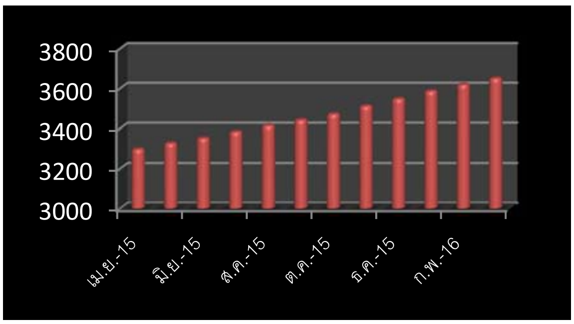

Fig 3. Number of Open Access Participants/Consumers for 2015-16 in IEX

Table 1. Volume of Short-Term Electricity transactions in the year 2015-16

Particulars	IEX	PXIL	Total
Unconstrained Cleared Volume (MU)	36210.32	149.54	36359.86
Actual Cleared Volume and hence scheduled (MU)	34063.32	136.84	34200.16
Volume of electricity that could not be cleared and hence not scheduled because of congestion	2147	12.7	2159.7

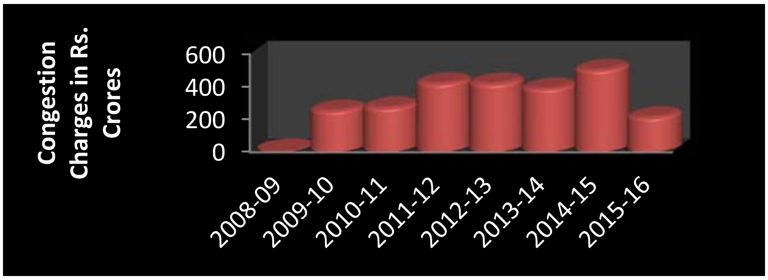

Fig 4. Congestion Charges in Rs. Crores (Revenue lost by IEX and PXIL)

Many studies in literature have explored modeling spot electricity prices particularly in the context of NordPool, CalPx and PJM markets but very few studies in literature have explored modeling spot electricity prices in Indian context [5-7]. Is Indian Spot Electricity Price Series Stationary? Answering this fundamental question paves way for application of techniques inspired from time series econometric modeling and forecasting literature which makes an inherent assumption that the underlying price-series is stationary. The rest of the paper is structured as follows: In section 2 we discuss the data and methodology used. In Section 3 we present our empirical findings and conclude our study in Section 4.

2. Data and Methodology

Spot electricity is defined as "intersection of total demand curve and the total supply curve, for a given particular hour, for each region of the electricity market" [5]. In this study we employ hourly spot electricity price data from January 1st 2014 to 31st December 2015 given by IEX accounting for 730 days and 17,520 hourly spot prices for all regions of Indian electricity market (publicly accessible). Following IEX's classification, we segregate the data in to peak (average of traded hourly price between 18-23 hours) and off-peak (average of traded hourly price between 1-17 and 24th hour) accounting for 730 observations. Table 2 presents' descriptive statistics for peak spot electricity prices and Table 3 elucidates descriptive statistics for off-peak spot electricity prices.

Table 2. Descriptive Statistics for Peak Spot Electricity Prices

	North East	East	North	South	West
Mean	3328.5825	3306.3864	3425.2281	6078.8584	3188.8438
Standard Deviation	1031.7425	1020.715	1002.0575	2146.7966	1024.8634
Kurtosis	6.8016923	7.3242727	7.0524095	1.6558563	8.1975433
Skewness	2.0280812	2.1051264	2.0095878	1.2005014	2.2415425
Minimum	1064.456	1064.456	1064.456	2321.228	903.762
Maximum	9599.428	9599.428	9599.428	15886.612	9599.428

Table 3. Descriptive Statistics for Off-Peak Spot Electricity Prices

	North East	East	North	South	West
Mean	2786.082	2779.506	2937.743	4737.51	2717.399
Standard Deviation	746.2376	749.4949	709.1284	1352.604	710.8916
Kurtosis	3.422121	3.526266	3.241412	0.989818	4.189171
Skewness	1.397317	1.344843	1.340797	0.632006	1.611426
Minimum	666.3405	293.8147	1077.603	1649.705	1077.603
Maximum	6300.499	6300.499	6300.499	11072.98	6300.499

The Augmented Dickey Fuller test (ADF) tests the null hypothesis that a time series y_t is integrated at order 1 i.e. I (1) against the alternative that it is I (0) assuming that data follows autoregressive moving average (ARMA process) structure. The ADF test is based on estimating the test regression [8]:

$$y_t = \beta' D_t + \phi y_{t-1} + \sum_{j=1}^{p} \psi_j \Delta y_{t-j} + \varepsilon_t$$

D_t is a vector of deterministic terms (constant, trend etc.), Δy_{t-j} with p lagged difference terms is used to estimate ARMA structure of errors. Value of p is set such that the error ε_t is serially uncorrelated and the error term is implicitly assumed to be homoskedastic.

The Phillips-Perron (PP) unit root test differs from the Augmented Dickey Fuller (ADF) test chiefly in how serial correlation is dealt with along with heteroskedasticity of error terms. The test regression for the PP test is given by [9]:

$$\Delta y_t = \beta' D_t + \pi y_{t-1} + \mu_t$$

Where μ_t is I (0) and might also be heteroskedastic in nature. The advantage of using PP test over ADF test is that PP test is more robust to general forms of heteroskedasticity of the error term μ_t and also that the researcher need not specify a lag length for the test regression.

Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests for the null hypothesis that y_t is integrated at order 0 i.e. I (0). They derive their test with the model [6]:

$$y_t = \beta' D_t + \mu_t + u_t$$
$$\mu_t = \mu_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim WN(0, \sigma_\varepsilon^2)$$

D_t is a vector of deterministic terms (constant or constant plus time trend), u_t is I (0) and may be heteroskedastic. μ_t is a pure random walk with variance of innovation being σ_ε^2. The null hypothesis that y_t is I (0) is formulated as $H_0 \colon \sigma_\varepsilon^2$ implying that μ_t is a constant.

Narayan and Popp's [10] unit root is based on the following steps of data greeting process.

$$Y_t = d_t + u_t$$
$$u_t = \rho_{t-1} + \varepsilon_t$$
$$\varepsilon_t = \psi^*(L)\epsilon_t = A^*(L)B(L)^{-1}e_t$$

Y_t is the electricity price with two components a deterministic component, d_t and a stochastic component, u_t, with $e_t \sim iid\ (0,\ \sigma^2)$. The test also assumes roots of the lag polynomials, *A* (L)* and *B (L),* which are of order *p* and *q* lie exterior to unit circle. In our study we considered two different models with first model allowing two structural breaks (level) and second model allowing two structural breaks (level and trend)

3. Empirical Findings

A time-series with mean, variance and covariance becoming time-invariant is said to be covariance/weakly stationary. A non-stationary process is referred to as unit root process. Econometric models using non-stationary data have high probability of infringing advantageous statistical properties of the estimators resulting in disingenuous inferences. Hence it is imperative to test whether data is stationary prior to attempting any econometric implementation of modeling/estimation/forecasting.

We have presented the results for Stationarity for Peak and Off-Peak Spot Electricity Prices using ADF, PP and KPSS tests in Table 4 and Table 5 respectively. The results leads us to believe that Indian spot electricity prices – both peak and off-peak are stationary according to ADF and PP test however contrasting results is obtained as per KPSS test indicating that Indian spot electricity peak and off-peak prices are not stationary (except the case of Southern region for off-peak prices).

Table 4. Stationarity Test Results for Peak Spot Electricity Prices

	East	North	North-East	South	West
Augmented Dickey Fuller Test (ADF) Statistic	-4.198*	-4.161*	-4.733*	-7.057*	-3.776**
Phillips Perron (PP) Test Statistic	-8.185*	-7.167*	-7.882*	-11.064*	-7.718*
Kwiatkowski–Phillips–Schmidt–Shin (KPSS) LM Test Statistic	0.24*	0.21**	0.24*	0.23*	0.22*

Note: Null Hypothesis for ADF and PP: Series has unit root
Null Hypothesis for KPSS: Series is Stationary

Table 5. Stationarity Test Results for Off-Peak Spot Electricity Prices

	East	North	North-East	South	West
Augmented Dickey Fuller Test (ADF) Statistic	-7.077*	-7.395*	-7.199*	-6.356*	-6.716*
Phillips Perron (PP) Test Statistic	-7.101*	-7.354*	-7.233*	-7.732*	-6.632*
Kwiatkowski–Phillips–Schmidt–Shin (KPSS) LM Test Statistic	0.25*	0.15**	0.25*	0.06	0.23*

Note: Null Hypothesis for ADF and PP: Series has unit root
Null Hypothesis for KPSS: Series is Stationary

Results of Narayan and Popp [10] unit root test for peak and off- peak prices is presented in Table 6 and Table 7 respectively. The results from the table suggest that Indian spot electricity for both peak and off-peak hours prices are stationary. There is no unit root.

Table 6. Results of Narayan and Popp (2010) unit root test for off- peak prices

Region	M1				M2			
North East	-6.4†	5/3/2014	16/5/2014	5	-6.3†	5/3/2014	16/5/2014	5
East	-6.6†	5/3/2014	16/5/2014	5	-6.5†	5/3/2014	16/5/2014	5
North	-6.2†	5/3/2014	14/8/2014	4	-6.3†	5/3/2014	14/8/2014	4
South	-6.3†	31/3/2014	15/4/2014	1	-6.3†	31/3/2014	15/4/2014	1
West	-5.2†	5/3/2014	14/8/2014	5	-5.6†	5/3/2014	14/8/2014	5

Note. Critical values for Model 1 with 50,000 replications with two breaks test at 1%, 5% and 10% level of significance are −4.672, −4.081, and −3.772, respectively.
Critical values for Model 2 at 1%, 5%, and 10% are −5.287, −4.692, and −4.396, respectively.
† denotes that all the coefficients of t-statistic are significant at 1% level

Table 7. Results of Narayan and Popp (2010) unit root test for peak prices

Region	M1				M2			
North East	-5.18†	5/3/2014	4/7/2014	5	-5.38†	5/3/2014	4/7/2014	5
East	-5.30†	5/3/2014	4/7/2014	5	-5.44†	5/3/2014	4/7/2014	5
North	-4.69†	5/3/2014	11/7/2014	5	-6.31†	5/3/2014	11/7/2014	5
South	-7.14†	31/3/2014	27/5/2014	1	-7.13†	31/3/2014	27/5/2014	1
West	-4.79†	21/2/2014	4/7/2014	5	-4.86**	21/2/2014	4/7/2014	5

Note. Critical values for Model 1 with 50,000 replications with two breaks test at 1%, 5% and 10% level of significance are −4.672, −4.081, and −3.772, respectively.
Critical values for Model 2 at 1%, 5%, and 10% are −5.287, −4.692, and −4.396, respectively.
† denotes that all the coefficients of t-statistic are significant at 1% level except western region in Model 2 where coefficient is significant at 5% (**)

4. Conclusion

Spot electricity market operates all 24 hours, 365 days a year in IEX and PXIL. In this study we tried to answer the fundamental question whether Indian Spot Electricity Prices are Stationary? Answering this fundamental question paves way for application of techniques inspired from time series econometric modeling and forecasting literature which makes an inherent assumption that the underlying price-series is stationary. We used data from January 1st 2014 to 31st December 2015 given by IEX accounting for 730 days and 17,520 hourly spot prices for all regions and segregated the data in to peak (average of traded hourly price between 18-23 hours) and off-peak (average of traded hourly price between 1-17 and 24th hour) accounting for 730 observations. We empirically investigated whether Peak and Off-Peak spot electricity prices of Indian electricity market is stationary by employing ADF, PP, KPSS and Narayan and Popp test allowing for structural breaks. The results of the study suggest that both Peak and Off-Peak prices are stationary as per ADF, PP and Narayan Popp test. These results will help power market participants in India understand the nitty-gritty's and nuances associated with Indian spot electricity prices for effective application of time series econometric models.

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