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Stochastic Modelling for Progress of Electricity Supply in India

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Abstract

This paper analyzes and determines the Stochastic Modelling for Progress of Electricity Supply in India during the years from 1981 to 2020. India is the third largest producer of electricity in the world. The national electric grid in India has an installed capacity of 403.759 GW as of 30 June 2022. Renewable power plants, which also include large hydroelectric plants, constitute 39.2% of total installed capacity. This study considers Autoregressive (AR), Moving Average (MA) and ARIMA processes to select the appropriate ARIMA model for Progress of Electricity Supply in India. ARIMA (p, d, q) and its components autocorrelation function (ACF), partial autocorrelation function (PACF), root mean square error (RMSE), mean absolute percentage error (MAPE), normalized BIC and ARIMA (1,2, 2). Based on the selected model, Progress of Electricity Supply in India is projected to increase from 471.97thousand MW in 2021 to 690.74thousand MW in 2030 in India.

I. INTRODUCTION

The power sector in India has grown significantly since independence, both in terms of installed power generation capacity and the transmission and distribution (T&D) system. Total power generation capacity (utilities and non-utilities) increased from 1362 MW in 1947 to 267 GW at the end of March 2015. Per capita power consumption increased from just 16.3 KWh in 1947 to 1010 KWh in 2010. -15. However, growth in power demand has outpaced power supply and despite the manifold growth over the years, our country faces power shortages during peak power demand. The Government of India lays special emphasis on reducing T&D losses and the need for side management for optimal utilization of limited resources. CEA has led and contributed immensely to the national initiative of the power sector in various specific areas such as introduction of new technologies, techno-economic clearance of projects, generation and transmission planning including Green Energy Corridor and operation and construction monitoring of projects. Design to engineering and dissemination of data and information. A current manual published by CEA is a regular feature containing important information such as maps, pie charts, graphs and tables. This information includes project-wise development patterns accomplished for various key indicators such as installed generating capacity, hydropower potential, state-wise forecast of the country's electricity demand, and electricity demand of megacities, power generation, transmission and distribution. Network, power distribution status, captive power plants, electricity consumption pattern of the country and per capita consumption. The manual also contains maps showing the state-wise installed power generation capacity, thus providing a broad view of our country.

Growing Demand

* With an installed power capacity of 401.01 GW as of April 2022, India is the third largest producer and consumer of electricity globally.
* Increasing population electrification and individual consumption will provide further impetus. Power consumption is estimated to reach 1,894.7 TWh in 2022.

Attractive Opportunities

* Under the Union Budget 2022-23, the government announced the issuance of sovereign green bonds, as well as granting infrastructure status to energy storage systems, including grid-scale battery systems.
* In the same budget Rs. 19,500 crore (US$ 2.57 billion) has been earmarked for the PLI scheme to increase production of high efficiency solar modules.

Policy Support

* Allowing 100% FDI in the power sector increased FDI inflows in the sector.

* Schemes like Deen Dayal Upadhyay Gram Jyoti Yojana (DDUGJY) and Integrated Power Development Scheme (IPDS) are expected to increase electrification across the country.

Higher Investments

* As per the National Infrastructure Pipeline 2019-25, the total expected capital expenditure is Rs. Energy sector projects accounted for the largest share (24%) in 2019-25. 111 lakh crore (US$ 1.4 trillion).

* Total FDI in the power sector between April 2000-March 2022 reached US$ 15.89 billion.

II. Material and Methods

As the aim of the study was to design and development of Stochastic Modelling for Progress of Electricity Supply in India, various forecasting techniques were considered for use. ARIMA model, introduced by Box and Jenkins (1976), was frequently applied for discovering the pattern and predicting the future values of the time series data. Box and Pierce (1970) measured the distribution of residual autocorrelations in ARIMA. Akaike (1970) found the stationary time series by an AR (p), where p is finite and bounded by the same integer. Moving Average (MA) models were applied by Slutzky (1973). Jai Sankar et al. (2010) applied ARIMA (1,1,0) model for cattle production and forecast the yearly production of cattle in the Tamil Nadu during the period of 1970 to 2010. Jai Sankar (2011) used a stochastic model approach to fit and forecast fish product export in Tamil Nadu during the period of 1969 to 2008. Jai Sankar et al (2011) selected ARIMA (1,1,0) model to for Bovine Production Forecasting in Tamil Nadu during the years from 1970 to 2008. Jai Sankar and Prabakaran (2012) applied ARIMA (1,1,0) model to forecast the milk production in Tamil Nadu during the period of 1978 to 2008. Jai Sankar (2014) considered ARIMA (0,1,1) model for designing of a Stochastic Model for Egg Production Forecasting in Tamil Nadu during the years from 1996 to 2008. Jai Sankar and Pushpa (2019) applied ARIMA (2,1,0) model for design and development of time series analysis for *Saccharum officinarum* Production in India during the years from 1950 to 2017. Lari Shanlang Tiewsoh et al. (2019) used Electricity Generation in India: Present State, Future Outlook and Policy Implications forecasted up to 2030.

The time series when differenced follows both AR and MA models and is known as ARIMA model. Hence, ARIMA model was used in this study, which required a sufficiently large data set and involved four steps: identification, estimation, diagnostic checking and forecasting. Model parameters were estimated to fit the ARIMA models.

Autoregressive process of order (p) is, $Y_t = \mu + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + ... + \phi_p Y_{t-p} + \varepsilon_t$;

Moving Average process of order (q) is, $Y_t = \mu - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - .... - \theta_q \varepsilon_{t-q} + \varepsilon_t$; and

The general form of ARIMA model of order (p,d,q) is

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + ... + \phi_p Y_{t-p} + \mu - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - .... - \theta_q \varepsilon_{t-q} + \varepsilon_t$$

Where Y_t is *Progress of Electricity Supply*, ε_t's are independently and normally distributed with zero mean and constant variance σ^2 for t = 1,2,..., n; d is the fraction differenced while interpreting AR and MA and ϕs and θs are coefficients to be estimated.

***Trend Fitting*:** The Box-Ljung Q statistics was used to transform the non-stationary data into Stationarity data and also to check the adequacy for the residuals. For evaluating the adequacy of AR, MA and ARIMA processes, various reliability statistics like R^2, Stationary R^2, RMSE, MAPE, and BIC as suggested by Gideon Schwartz (1978) were used computed as below:

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2 \right]^{1/2} \; ; \; MAPE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{(Y_i - \hat{Y}_i)}{Y_i} \right| and$$

BIC(p,q) = ln v*(p,q)+(p+q) [ln(n) / n]

where p and q are the order of AR and MA processes respectively and n is the number of observations in the time series and v* is the estimate of white noise variance σ^2.

III. Results and Discussion

In this study, data were collected from the Annual Report (2021 - 2022) of the Directorate of Economic Survey and Statistics (2021 - 2022) of the Ministry of Power, Government of India for the period 1981 to 2020 and applied to ARIMA. A model for predicting and forecasting future production of Electricity Supply.

Table 1: Actual Progress of Electricity Supply (Thousand MW) in India

Year	Electricity Supply	*Year*	Electricity Supply	*Year*	Electricity Supply
1981	33.4	*1995*	92.3	*2009*	175
1982	35.8	*1996*	95.1	*2010*	191
1983	39.4	*1997*	97.9	*2011*	208.1
1984	43.8	*1998*	102.3	*2012*	236.4
1985	47.7	*1999*	107.3	*2013*	264.1
1986	52.3	*2000*	112.6	*2014*	290.8
1987	54.9	*2001*	117.8	*2015*	319.7
1988	60.5	*2002*	122.2	*2016*	353.5
1989	66.5	*2003*	126.2	*2017*	378.4
1990	71.8	*2004*	131.4	*2018*	398.9
1991	74.7	*2005*	137.5	*2019*	431.3
1992	78.4	*2006*	145.6	*2020*	446.3
1993	82.5	*2007*	154.7		
1994	87.5	*2008*	168		

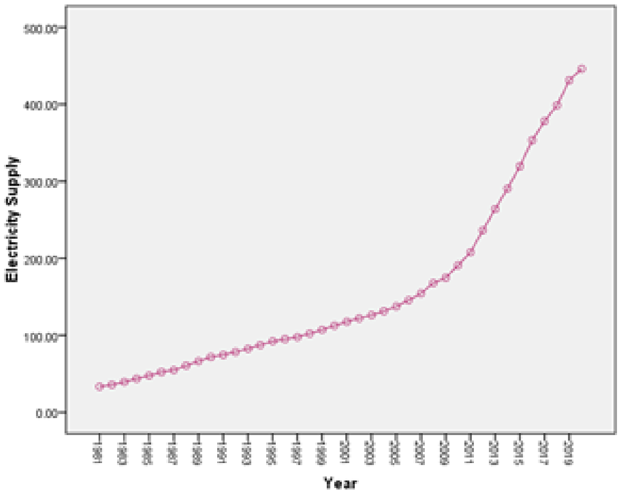


Figure 1. Time plot of Electricity Supply

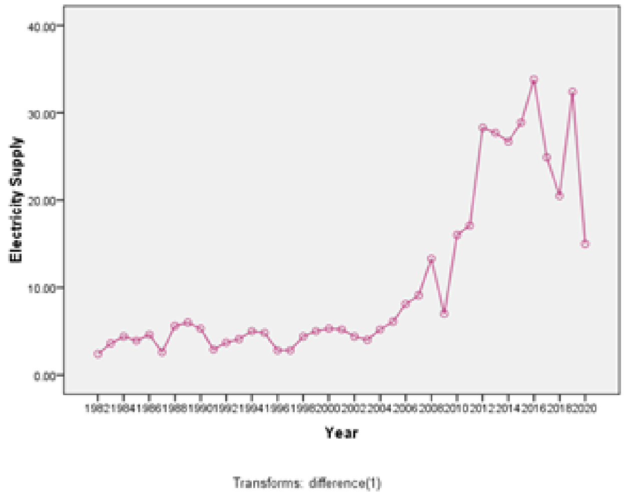


Figure 2. Time plot of Electricity Supply with d = 1

Figure 1 depicts that the data used were non-stationary. The time series plot of Electricity Supply from 1981to 2021 with d=1 was created as shown in Figure 2 and it is also non-stationary.

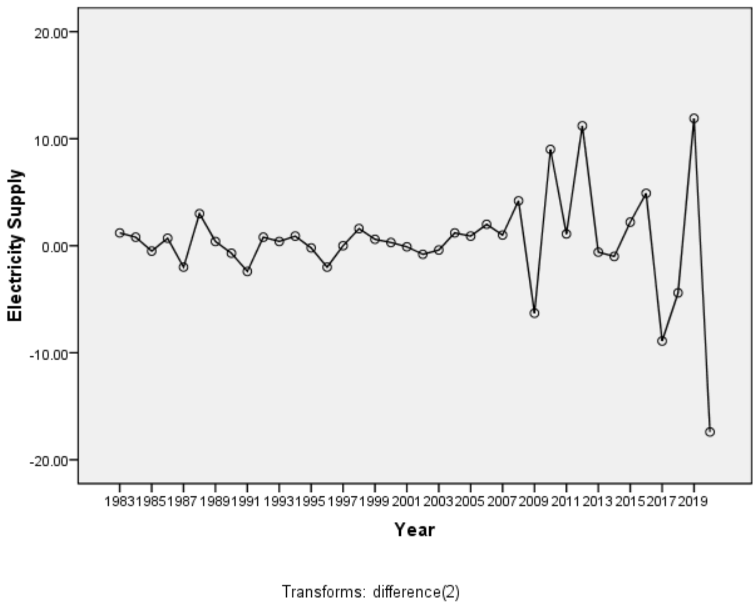


Figure 3. Time plot of Electricity Supply with d = 2

Figure 3 reveals that Second differencing of the data. The newly constructed variable Y_t could now be examined for Stationarity. Since, Y_t was stationary in mean, the next step was to identify the values of p and q. For this, the ACF and PACF of various orders of Y_t were computed and presented in Table 2 and Figure 4.

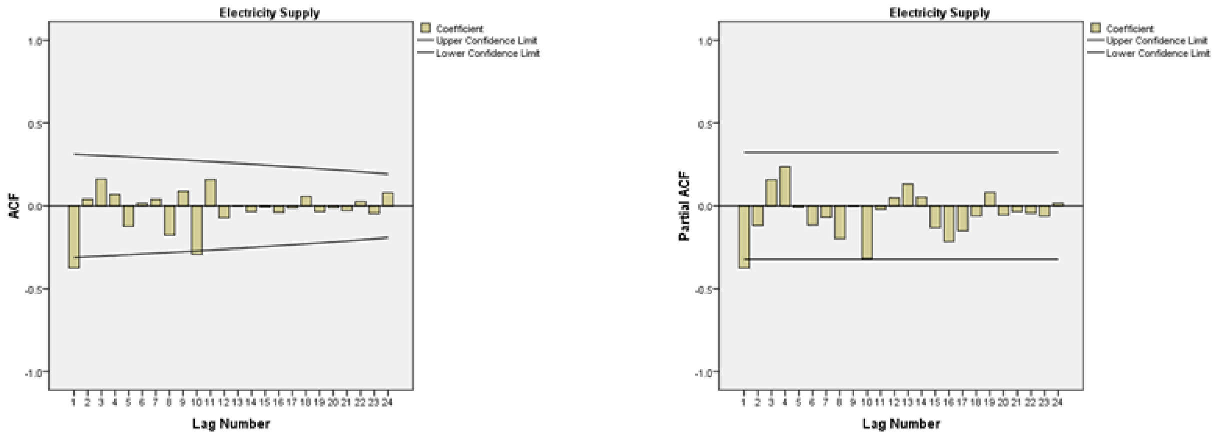


Figure 4. ACF and PACF of differenced data

Table 2: ACF and PACF of Electricity Supply

Lag	AC	Std. Error	Box-Ljung Statistic			PAC	Std. Error
			Value	df	Sig.		
1	-0.375	0.156	5.783	1	0.016	-0.375	0.162
2	0.040	0.154	5.852	2	0.054	-0.117	0.162
3	0.161	0.152	6.984	3	0.072	0.159	0.162
4	0.069	0.150	7.199	4	0.126	0.237	0.162
5	-0.123	0.147	7.892	5	0.162	-0.01	0.162
6	0.016	0.145	7.904	6	0.245	-0.114	0.162
7	0.039	0.143	7.978	7	0.335	-0.068	0.162
8	-0.177	0.140	9.573	8	0.296	-0.197	0.162
9	0.089	0.138	9.988	9	0.351	-0.003	0.162
10	-0.293	0.136	14.645	10	0.146	-0.317	0.162
11	0.159	0.133	16.070	11	0.139	-0.022	0.162
12	-0.072	0.131	16.373	12	0.175	0.047	0.162
13	0.001	0.128	16.373	13	0.230	0.131	0.162
14	-0.036	0.126	16.453	14	0.286	0.053	0.162
15	-0.007	0.123	16.457	15	0.352	-0.13	0.162
16	-0.039	0.120	16.564	16	0.414	-0.214	0.162
17	-0.012	0.118	16.574	17	0.484	-0.15	0.162
18	0.056	0.115	16.815	18	0.536	-0.06	0.162
19	-0.035	0.112	16.915	19	0.596	0.081	0.162
20	-0.011	0.109	16.925	20	0.658	-0.055	0.162
21	-0.029	0.106	17.002	21	0.711	-0.035	0.162
22	0.027	0.103	17.073	22	0.759	-0.044	0.162
23	-0.045	0.099	17.278	23	0.795	-0.06	0.162
24	0.079	0.096	17.948	24	0.806	0.016	0.162

Table 3: Estimated ARIMA Model Fit Statistics

Fit Statistic	(0,2,0)	(0,2,1)	**(1,2,0)**	(1,2,1)
Stationary R-squared	2.11E-16	0.173	.223	-1.331E-16
R-squared	0.998	0.999	.999	-1.331E-16
RMSE	4.857	4.477	4.341	116.930
MAPE	1.549	1.575	1.682	90.877
MaxAPE	4.597	5.101	4.786	366.587
MAE	2.791	2.77	2.877	91.779
MaxAE	17.732	14.52	11.414	290.460
Normalized BIC	3.257	3.189	**3.128**	9.615

The ARIMA models are discussed with values differenced twice (d=2) and the model which had the minimum normalized BIC was chosen. The various ARIMA models and the corresponding normalized BIC values are given in Table 3. The value of normalized BIC of the chosen ARIMA was 3.189.

Table 4: Estimated ARIMA Model of Electricity Supply

		Estimate	SE	t	Sig.
Constant		0.496	0.445	1.090	0.283
AR	Lag 1	-0.568	0.185	-3.071	0.004
Difference		2			

The ACF and PACF of the residuals are given in Figure 5, which also indicated the 'good fit' of the model. Hence, the fitted ARIMA model for the Progress of Electricity Supply data was

$$Y_t = \mu - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - .... - \theta_q \varepsilon_{t-q} + \varepsilon_t$$

$$\mathbf{Y_t = 0.481 - 0.410\varepsilon_{t-1} + \varepsilon_t}$$

Table 5: Residual of ACF and PACF of Electricity Supply

Lag	ACF	Std. Error	PACF	Std. Error	*Lag*	ACF	Std. Error	PACF	Std. Error
1	-0.052	0.162	-0.052	0.162	13	-0.015	0.184	0.041	0.162
2	0.04	0.163	0.037	0.162	14	-0.043	0.184	-0.087	0.162
3	0.198	0.163	0.203	0.162	15	-0.039	0.185	-0.105	0.162
4	0.036	0.169	0.059	0.162	16	-0.066	0.185	-0.121	0.162
5	-0.073	0.169	-0.089	0.162	17	-0.002	0.186	-0.041	0.162
6	-0.027	0.17	-0.088	0.162	18	0.039	0.186	0.031	0.162
7	-0.09	0.17	-0.114	0.162	19	-0.049	0.186	-0.004	0.162
8	-0.139	0.172	-0.125	0.162	20	-0.075	0.186	-0.156	0.162
9	-0.03	0.174	-0.009	0.162	21	-0.039	0.187	-0.072	0.162
10	-0.236	0.175	-0.2	0.162	22	0.004	0.187	-0.084	0.162
11	0.076	0.183	0.112	0.162	23	0.015	0.187	0.045	0.162
12	-0.074	0.184	-0.039	0.162	24	0.043	0.187	0.013	0.162

Model parameters were estimated and reported in Table 3 and Table 4. The model verification is concerned with checking the residuals of the model to improve on the chosen ARIMA (p,d,q). This is done through examining the autocorrelations and partial autocorrelations of the residuals of various orders, up to 24 lags were computed and the same along with their significance which is tested by Box-Ljung test are provided in Table 5. This proves that the selected ARIMA model is an appropriate model.

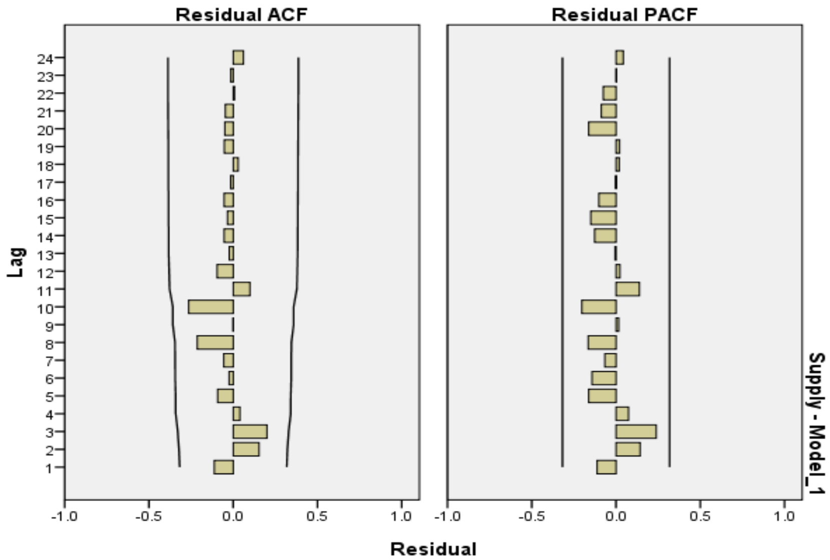


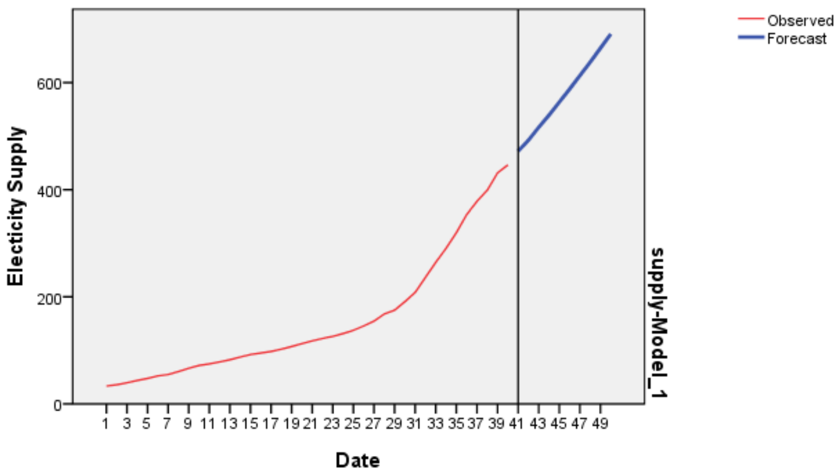
Figure 5. Residuals of ACF and PACF

Forecasting value of Electricity Supply from the year 2021 to 2030 given in Table 6. To assess the forecasting ability of the fitted ARIMA (1,2,0) model, important measures of the sample period forecasts' accuracy were computed. Figure 6 shows that the actual and forecasted value of Electricity Supply data with 95% confidence limits.

Table 6: Forecast of Electricity Supply

Year	Forecast	UCL	LCL
2021	471.97	480.77	463.16
2022	492.35	507.72	476.97
2023	516.51	541.14	491.87
2024	539.3	573.88	504.71
2025	563.65	609.57	517.72
2026	587.89	646.02	529.75
2027	612.96	684.32	541.61
2028	638.34	723.74	552.94
2029	664.33	764.61	564.05
2030	690.74	806.67	574.82

Figure 6. Actual and Estimate of Electricity Supply



IV. Conclusion

The results showed that the Electricity Supply would not remain stable throughout the year. The most appropriate ARIMA model for Progress of Electricity Supply forecasting of data was found to be ARIMA (1,2,0). From the temporal data, it can be found that forecasted Electricity Supply would increase from 471.97thousand MW in 2021 to 690.74thousand MW in 2030 in India.

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