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Rapid Forecasting of Short-run Electric Power Demand Profiles of India Using the Statistical Method of Z Scores

Rupsha Bhattacharyya[1,*]

Abstract

Power demand profile prediction for a region or nation is a critical part of the energy system design and operational planning process. A simplified method based on non-dimensionalizing power demand data from previous years using Z scores calculated from the mean and standard deviation of the profiles is developed in this study to forecast monthly demand profiles at time resolution of 1 hour for future years. The Z score range is found to be limited to ± 2 for all the input data set and this is assumed to hold true for the profile to be forecasted. Monthly averaged data from India for years 2021-2023 are used to forecast the monthly profiles for every month of 2024. The maximum relative percentage error in the forecasted hourly demand value on comparison with actual demand data is seen to lie between +8.06% and -12.06% by the methodology proposed in this study. The mean absolute percentage error in forecasting is found to range between 0.97% to 10.25%, depending on the month under consideration. The method of this work may thus be described as providing reasonable accuracy with minimal data collection, processing, and modeling efforts compared to detailed methods available in literature. This may be expected to find application in the design and planning of operations of future energy systems, which must provide a supply profile in keeping with these forecasted demand profiles and the associated deviations estimated in this work. It may also be helpful in the management of power exchanges which facilitate energy trading and the development of electricity markets.

Keywords: Demand profile; electricity; forecasting; Z scores

INTRODUCTION

Energy use is intrinsically related to the development status of a nation. Energy use governs development indicators like national earnings, life expectancy, educational levels and so on. Therefore, energy planning is a critical activity for any nation, given its deep linkages with the country’s progress as a whole. There are two main aspects to it – prediction of future energy demand and planning of the energy mix that will cost effectively and reliably meet that demand without causing harmful environmental impacts and negative externalities. A nation consumes energy in various final forms such as electricity, heating fuels like coal and natural gas for domestic and industrial purposes, transportation fuels like liquid petroleum products for road, air and water-based transport as well as some non-commercial energy forms like biomass, waste and agricultural residues. The need for clean energy transition has established the need for extensive and direct electrification of many end-use sectors that today make use of fossil fuels. In addition, several sectors will achieve decarbonization through

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indirect electrification also, for example by the use of synthetic energy vectors like hydrogen, whose production depends on water electrolysis using clean electricity. Thus, projecting future electrical energy needs is a critical part of energy planning. For operational planning, the electrical energy demand projections must then be translated into hourly power demand figures. This is crucial because the various supply side options must then be examined that meets power demand at each instant of time to always ensure demand-supply matching, reliably and economically. The need for auxiliary services like energy storage and demand side management is also growing as the supply mix integrates greater share of variable and intermittent renewable generation sources.

LITERATURE REVIEW

Long term energy or electricity demand has been forecasted using methods that link energy use to various indicators of economic development, climatic factors, socio-political factors and so on. Econometric techniques such as regression analysis and time series projections have been used for this purpose, supported also by end use demand projections in different sectors. Power demand profiles on hourly or more granular basis have often been predicted using time series analysis techniques, which work reasonably well for short time frames. Detailed datasets and extensive computational work along with numerous assumptions about making these projections are characteristics of all these studies. For example, for India in 2026-27, peak power demand is expected to be about 277.2 GW and total electrical energy demand is likely to reach 1907.8 TWh, while in 2031-32, the figures have been projected to be 366.4 GW and 2473.8 TWh respectively **[1]**. In an older version of this study done in 2019, it was projected that India would need 1886.9, 2378.7 and 2976.3 TWh electricity in 2026-27, 2031-32 and 2036-37 respectively. The peak power demand was projected to be 256, 320 and 398 GW respectively **[2]**. In another study, it has been projected through a number of scenario-based assessments that aggregate grid electricity demand in India is expected to be between 2040-2857 TWh by 2030 **[3]**. Another study projects aggregate demand in India of 2060-2699 TWh by 2030, using both econometric and sectoral demand-based methods **[4]**.

Considering specifically the problem of forecasting of time series of power demand for India, Behera et al **[5]** forecast loads for one week at hourly resolution using a method of extrapolation and correlation, with errors ranging from 0.8% to 7.8%. Also, it is seen that currently artificial intelligence-based algorithms feature prominently in most such studies, given improved data availability and computing resources **[6]**. For example, Bareth et al **[7]** report the development of a Long Short-Term Memory (LSTM) based technique for load forecasting at 15-minute intervals in the Indian state of Odisha. It uses past power consumption data as well as meteorological data to predict the load profiles for the next week and next year, using one year of past load data, with mean absolute percent error (MAPE) of 0.2134%. A robust linear regression model has been reported for load forecasting of the state of Gujarat at 15-minute intervals, which is seen to forecast with MAPE of 0.176% **[8]**. Roy et al **[9]** have developed Artificial Neural Network and Vector Auto-regressive methods for demand profile forecasting for the state of Assam and they find that the MAPE ranges from 7.01% to 7.94% when forecasting the demand profile for 3 days ahead.

MOTIVATION FOR THE STUDY

A rapid and simple method using only the basic statistical features of the power demand data from previous years is proposed in this work for near term future demand curve forecasting for a country or region. This method is motivated by the possibility of being able to make forecasts using limited amounts of data and lower number of assumptions in the model, many of which only add to the uncertainty in the estimates obtained by the estimates described in the previous sections. Most studies reported in literature have looked at forecasts for a single state of India and not the country as a whole. Also, the use of Z-score as a feature of data for load forecasting and related predictive work is not found in current literature, so this is an important and significant element of novelty in this work. The proposed method is applied to the case of whole of India, a nation experiencing rapid electricity demand growth and which is one of the fastest growing economies of the world at present. The

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methodology and results from this study are expected to be useful for operational planning of the electricity system as a whole in a country in rapidly evolving circumstances, especially as the power exchanges and real time energy trading based on prices determined by demand-supply balancing become the norm for electricity transmission and distribution.

DATA SET DESCRIPTION

The hourly electricity demand data of India for each month of 2021, 2022 and 2023 are first obtained from IEA real time electricity tracker tool. For each month, 3 time series profiles are obtained from this source – the hourly averaged power demand for weekdays, Saturdays, and Sundays of that month respectively. These are averaged to represent each month's load characteristics by a single profile, with the corresponding hourly power demand values being used for further analysis reported here. Thus, each month is represented by 24 values of average hourly power demand. In all, the data set has 24 X 12 X 3 = 864 data points, which is the raw data set used in this work for subsequent analysis. The data thus collected is shown in the form of heatmaps in Figs. 1a, 2a and 3a for 2021, 2022 and 2023 respectively.

PROPOSED METHODOLOGY OF POWER DEMAND CURVE FORECASTING

The proposed methodology is driven by statistical data analysis methods and has two main steps. The first step is the estimation of cumulative electrical energy needs for a given time frame in future, based on targeted development levels of the country, decarbonization targets and technologies chosen for it, nature of economy and evolution of the sectors in the economy, population growth and so on. An example of this kind of work has been shown in a previous work of the author **[10]**. This present study focuses on the second step – translating the annual electrical energy demand estimated in the first step into forecasts of hourly power demand profiles for the future time. The step-wise methodology adopted for this forecasting exercise for the specific case of India in 2024 are described in detail in the next paragraphs.

Description of Methodology

The data of power demand curves for each month of 2021, 2022, 2023 for India are used as the basic inputs. A single base year is not used in this study so as to capture any possible seasonal anomalies in demand and smoothen them over the time frame under consideration. The data are analyzed to get the mean, standard deviation, and coefficient of variation (i.e., standard deviation divided by mean, expressed as a percentage) for each month.

Integrating the power demand versus time data numerically gives the total electrical energy demand of that month. This is done for each month of the year and the percentage of total annual electricity consumption occurring in each individual month of the year is estimated. The year-on-year growth rate of total electricity demand is also estimated from the increase in annual electricity consumption figures in successive years.

The power demand versus time profile for each month is converted to an equivalent profile of Z scores **[11]** as per Eqn. 1, using that specific's month's mean and standard deviation as the normalizing factors. The Z score is a feature engineering method that allows the data set (i.e., the vector of power demand values at hourly resolution) to be expressed in non-dimensional terms, while also ensuring the values lie within the same range of maximum and minimum values. Thus, the hourly Z score profiles are obtained for each month of each of the three years, which represent the demand data in dimensionless, and normalized form.

$$Z(t) = \frac{(P(t) - \mu)}{\sigma} \quad (1)$$

The cumulative electricity demand for 2024 is projected from the average percentage demand growth observed in the years 2021-2023. The cumulative demand is then apportioned among the various months of 2024 based on the average fractions observed in the last three years. The mean monthly power demand is calculated by dividing energy demand by number of hours in that month. The variance for that month is calculated by using the average coefficient of variation observed in the last three years and the calculated mean monthly power demand.

Using the averaged Z scores calculated in Step (ii) and the forecasted mean and standard deviation of power demand for each month of 2024 estimated in Step (iii), Eqn. 1 is used again to obtain the hourly average power demand values, at hourly intervals. The averaged Z scores may thus be considered as the training data set for the calculation model proposed in this study.

Main Assumptions

The two principal assumptions made to implement this methodology are:

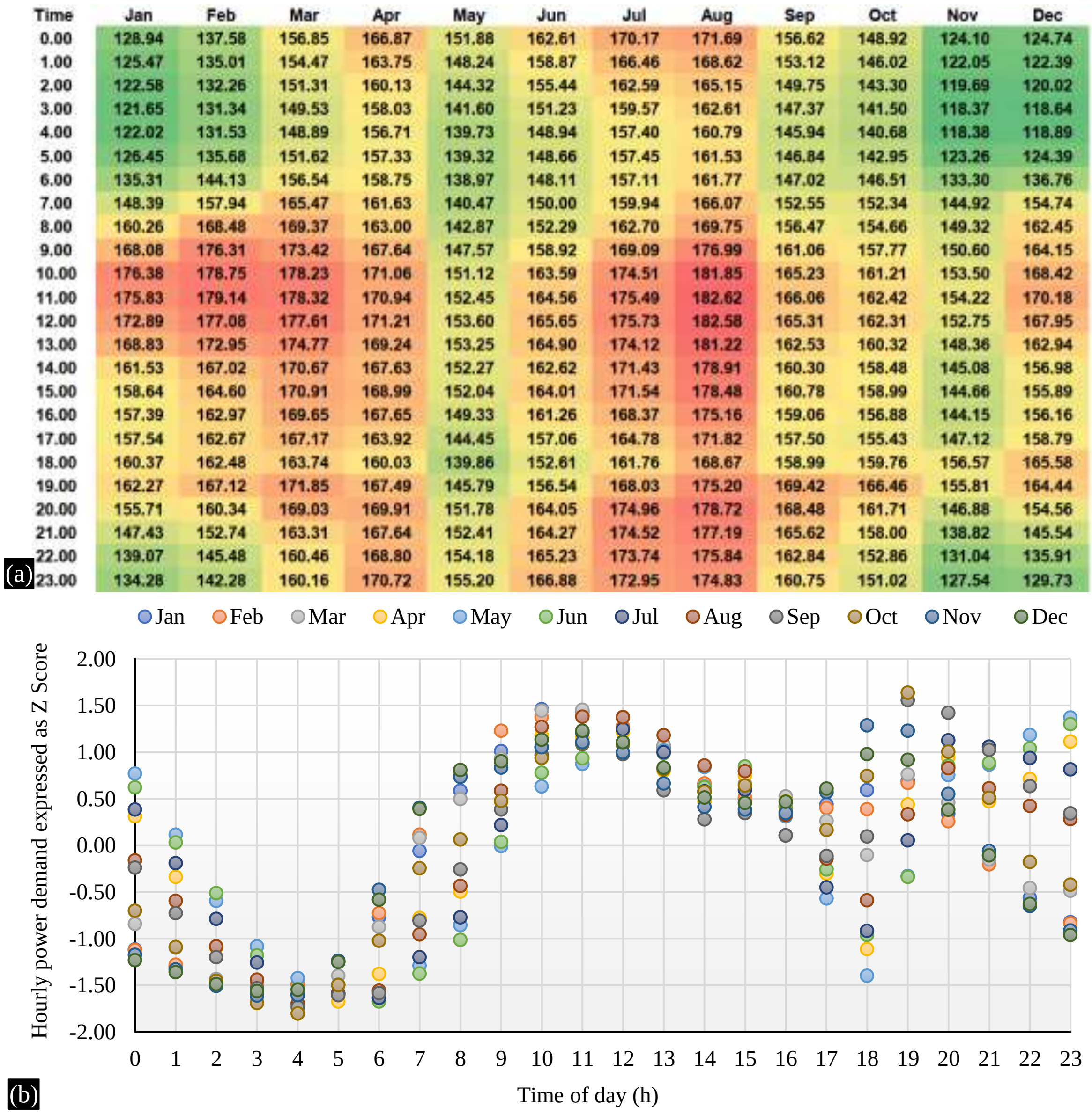
1. The Z score of future demand profile is well represented by the average of the Z scores of the previous years' demand profiles. These data are calculated as per Step iii above.
2. The coefficient of variation of the future demand profile is presented by the average of the coefficients of variation of the previous years' demand profiles. These data is calculated as per Step i above.

Thus, a similarity of the geometrical and distributional characteristics of the demand profiles are assumed in making future projections based on past years' data. The monthly average power demand profiles for 2024 thus predicted by this methodology are then compared with the actual observed monthly average demand curves for 2024 to estimate the deviations and errors in prediction by the methodology proposed in this work.

RESULTS AND ANALYSIS

Key Results

The results derived from descriptive statistical analysis of power demand data of India in Figures. 1a, 2a and 3a respectively for the years 2021-2023 are shown in Table 1 and in Figures 1b, 2b and 3b respectively. It is seen that total annual electrical energy demand in India grew by 8.07% between 2021 and 2022 and by 7.51% between 2022 and 2024. Therefore, it was assumed that on average, the total demand for year 2024 would be approximately 7.79% (i.e., arithmetic mean of the last two growth rates) greater than the electricity demand in 2023. Thus, total annual electricity demand in 2024 is projected to be 1721 TWh(e). The Z scores lie between ±2 for all the months in each of the three years, and therefore, this trend is also assumed to continue for the year 2024 for the purpose of forecasting.



Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.00	128.94	137.58	156.85	166.87	151.88	162.61	170.17	171.69	156.62	148.92	124.10	124.74
1.00	125.47	135.01	154.47	163.75	148.24	158.87	166.46	168.62	153.12	146.02	122.05	122.39
2.00	122.58	132.26	151.31	160.13	144.32	155.44	162.59	165.15	149.75	143.30	119.69	120.02
3.00	121.65	131.34	149.53	158.03	141.60	151.23	159.57	162.61	147.37	141.50	118.37	118.64
4.00	122.02	131.53	148.89	156.71	139.73	148.94	157.40	160.79	145.94	140.68	118.38	118.89
5.00	126.45	135.68	151.62	157.33	139.32	148.66	157.45	161.53	146.84	142.95	123.26	124.39
6.00	135.31	144.13	156.54	158.75	138.97	148.11	157.11	161.77	147.02	146.51	133.30	136.76
7.00	148.39	157.94	165.47	161.63	140.47	150.00	159.94	166.07	152.55	152.34	144.92	154.74
8.00	160.26	168.48	169.37	163.00	142.87	152.29	162.70	169.75	156.47	154.66	149.32	162.45
9.00	168.08	176.31	173.42	167.64	147.57	158.92	169.09	176.99	161.06	157.77	150.60	164.15
10.00	176.38	178.75	178.23	171.06	151.12	163.59	174.51	181.85	165.23	161.21	153.50	168.42
11.00	175.83	179.14	178.32	170.94	152.45	164.56	175.49	182.62	166.06	162.42	154.22	170.18
12.00	172.89	177.08	177.61	171.21	153.60	165.65	175.73	182.58	165.31	162.31	152.75	167.95
13.00	168.83	172.95	174.77	169.24	153.25	164.90	174.12	181.22	162.53	160.32	148.36	162.94
14.00	161.53	167.02	170.67	167.63	152.27	162.62	171.43	178.91	160.30	158.48	145.08	156.98
15.00	158.64	164.60	170.91	168.99	152.04	164.01	171.54	178.48	160.78	158.99	144.66	155.89
16.00	157.39	162.97	169.65	167.65	149.33	161.26	168.37	175.16	159.06	156.88	144.15	156.16
17.00	157.54	162.67	167.17	163.92	144.45	157.06	164.78	171.82	157.50	155.43	147.12	158.79
18.00	160.37	162.48	163.74	160.03	139.86	152.61	161.76	168.67	158.99	159.76	156.57	165.58
19.00	162.27	167.12	171.85	167.49	145.79	156.54	168.03	175.20	169.42	166.46	155.81	164.44
20.00	155.71	160.34	169.03	169.91	151.78	164.05	174.96	178.72	168.48	161.71	146.88	154.56
21.00	147.43	152.74	163.31	167.64	152.41	164.27	174.52	177.19	165.62	158.00	138.82	145.54
22.00	139.07	145.48	160.46	168.80	154.18	165.23	173.74	175.84	162.84	152.86	131.04	135.91
23.00	134.28	142.28	160.16	170.72	155.20	166.88	172.95	174.83	160.75	151.02	127.54	129.73

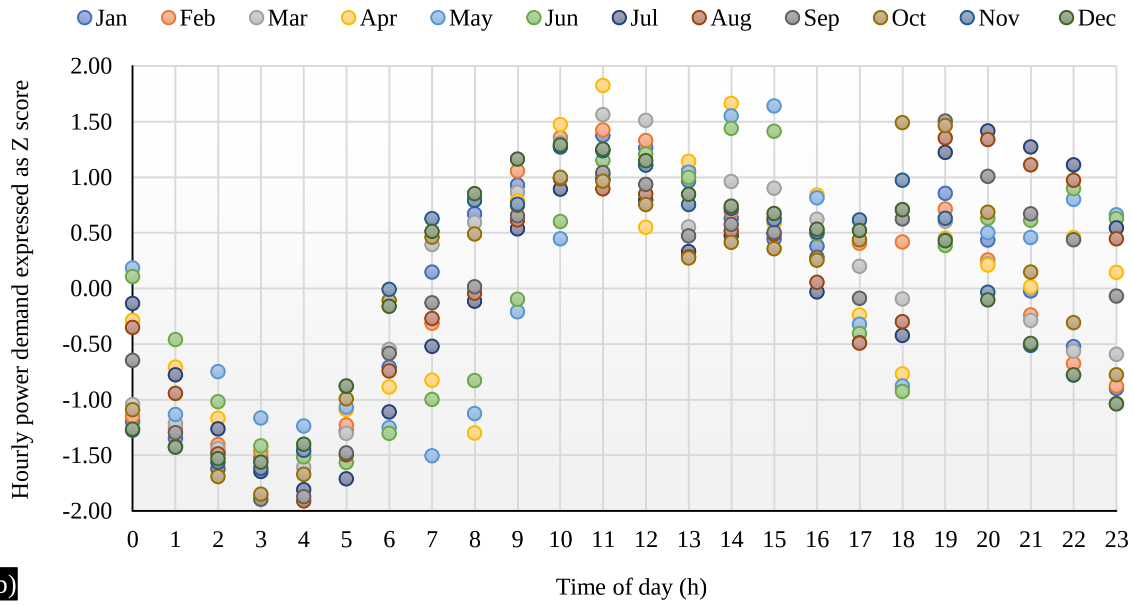
Figure 1. (a) Heatmap of hourly average power demand in India for 2021. (b) Z scores of hourly power demand in India for 2021.

Table 1. Mean (μ) and standard deviation (σ) of monthly power demand profiles of India in years 2021-2023.

Year 2021	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
μ (GW(e))	149.47	156.08	164.72	165.38	147.61	158.68	167.68	172.84	158.32	154.19	139.60	147.51
σ (GW(e))	18.42	16.48	9.36	4.81	5.54	6.31	6.46	7.09	7.14	7.50	13.20	18.47
Year 2022	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
μ (GW(e))	150.79	161.76	174.39	183.07	181.68	185.38	171.78	174.50	176.36	154.05	157.25	163.29
σ (GW(e))	20.05	18.69	10.70	6.42	6.78	6.70	6.39	6.12	7.00	9.56	15.59	21.21
Year 2023	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
μ (GW(e))	164.11	176.35	173.15	183.25	184.38	194.72	187.70	205.14	196.37	188.10	167.57	166.02
σ (GW(e))	20.51	17.35	11.62	6.67	8.50	8.30	7.61	9.51	8.18	12.04	16.21	20.78

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.00	126.77	140.20	163.21	181.20	182.92	186.09	170.92	172.34	171.82	143.60	137.37	136.40
1.00	123.77	138.14	161.38	178.51	173.98	182.28	166.81	168.73	167.27	140.43	134.96	132.98
2.00	121.25	135.50	158.96	175.55	176.61	178.55	163.70	165.39	164.99	137.85	132.84	130.79
3.00	120.14	134.32	157.69	173.94	173.77	175.89	161.25	163.12	163.07	136.35	132.01	130.14
4.00	120.42	134.23	157.18	173.95	173.28	175.24	160.21	162.80	163.24	138.06	134.51	133.54
5.00	125.05	138.75	160.41	176.06	174.43	174.88	160.83	165.34	165.99	144.55	143.52	144.64
6.00	136.55	151.47	168.48	177.37	173.19	176.63	164.68	169.96	172.27	152.99	157.11	159.83
7.00	153.70	155.88	178.60	177.76	171.46	178.68	168.45	172.83	175.45	158.45	167.02	174.12
8.00	164.20	176.71	180.72	174.72	174.04	179.83	171.04	174.23	176.46	158.71	169.58	181.34
9.00	169.44	181.50	183.61	188.10	180.24	184.72	175.20	178.26	180.93	161.18	169.04	187.95
10.00	176.30	187.06	188.37	192.51	184.71	189.40	177.48	180.54	183.33	163.59	177.10	190.62
11.00	178.33	188.37	191.11	194.77	188.61	193.08	178.05	179.98	183.64	163.25	176.56	189.82
12.00	176.12	186.58	190.53	186.58	189.22	193.47	176.86	179.68	182.90	161.26	174.51	187.66
13.00	170.17	181.54	180.29	190.39	188.76	192.06	173.89	176.23	179.66	156.65	168.99	181.22
14.00	163.40	174.63	184.65	193.73	192.20	195.02	174.80	177.66	180.39	158.00	168.45	178.97
15.00	159.68	173.64	184.02	186.83	192.81	194.85	174.90	177.50	179.88	157.44	166.91	177.57
16.00	158.39	171.48	181.02	188.45	187.20	188.65	171.58	174.83	178.32	156.46	165.15	174.56
17.00	159.50	169.30	176.49	181.53	179.48	182.66	168.65	171.48	175.73	158.23	166.86	174.34
18.00	164.96	169.54	173.36	178.13	175.72	179.17	169.07	172.66	180.73	168.29	172.42	178.28
19.00	167.94	175.09	180.85	185.97	184.62	187.96	179.60	182.77	186.90	168.04	167.06	172.39
20.00	159.50	166.55	176.74	184.40	185.07	189.59	180.82	182.69	183.40	160.60	156.69	161.07
21.00	150.33	157.28	171.30	183.16	184.77	189.49	179.91	181.30	181.06	155.44	149.25	152.76
22.00	140.27	149.07	168.33	186.00	187.10	191.40	178.88	180.45	179.43	151.09	145.08	146.76
23.00	132.71	145.32	168.03	183.98	186.16	189.57	175.26	177.23	175.87	146.60	141.07	141.21

(a)



(b)

Figure 2. (a) Heatmap of hourly average power demand in India for 2022. (b) Z scores of hourly power demand in India for 2022.

Figure 4 shows how the energy consumption is apportioned among the different months for each of the years 2021-2023. Figure 5 shows how ratio of mean to standard deviation of power demand (i.e., the coefficient of variation) varies through the months of the year.

The projected apportionment of electrical energy consumption per month for year 2024 as well as the averaged coefficients of variation are shown in Table 2, as averaged figures for each month from the data in Figures 4 and 5 respectively. Table 3 shows the estimated total energy demand per month in 2024, based on the apportionment, along with the mean load (based on dividing total demand by total number of hours in the month) and standard deviation of load for 2024 (using the average coefficient of variation for each month from last 3 years' data and the calculated mean demand).

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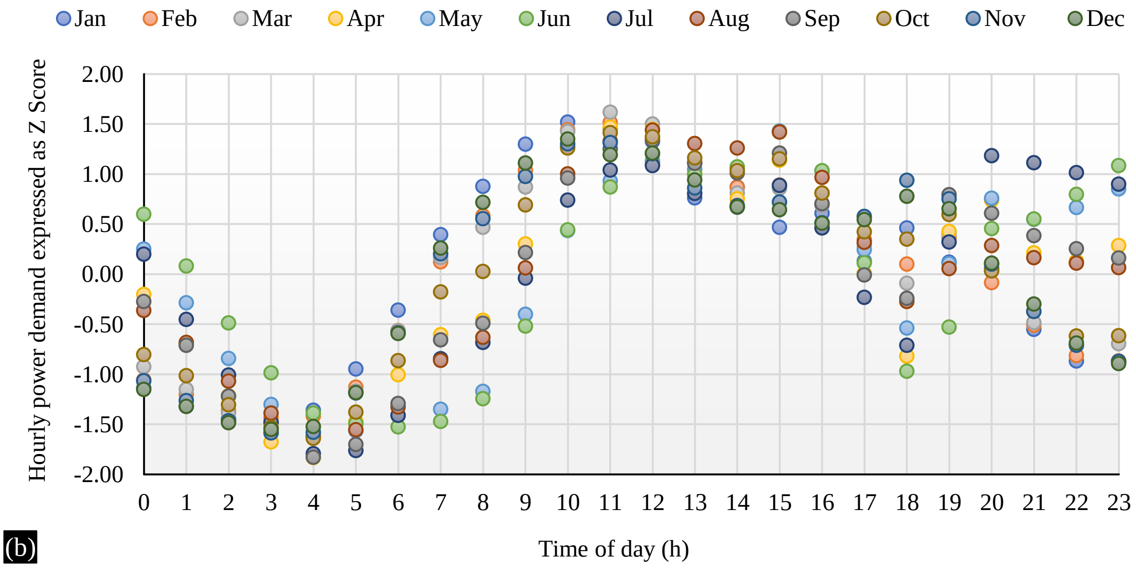
0.00	140.73	158.04	162.39	181.90	186.52	199.68	189.21	201.69	194.15	178.41	150.30	142.08
1.00	137.00	155.45	159.76	178.58	181.94	195.39	184.26	198.66	190.55	175.89	147.10	138.54
2.00	134.42	152.69	157.06	175.14	177.23	190.68	180.02	194.96	186.41	172.38	143.82	135.18
3.00	133.74	151.43	155.25	172.07	173.31	186.55	176.44	191.93	183.43	169.67	141.83	133.75
4.00	136.21	151.74	155.37	171.02	170.71	183.21	174.03	189.69	181.40	168.35	141.92	134.35
5.00	144.69	156.74	159.55	173.41	171.08	182.33	174.29	190.36	182.45	171.49	148.30	141.44
6.00	156.74	166.56	166.56	176.54	172.38	182.05	176.96	192.53	185.79	177.71	158.05	153.68
7.00	172.21	178.46	175.10	179.21	172.91	182.51	181.28	196.96	191.00	185.97	170.87	171.44
8.00	182.10	186.44	178.58	180.18	174.43	184.39	182.52	199.14	192.35	188.41	176.55	180.96
9.00	190.74	194.33	183.28	185.27	180.97	190.41	187.39	205.72	198.13	196.40	183.39	189.08
10.00	195.23	201.36	189.74	191.75	188.09	198.40	193.32	214.65	204.24	203.26	188.65	194.05
11.00	193.87	202.63	191.94	193.05	192.29	201.94	195.62	217.75	206.60	205.12	188.88	190.79
12.00	191.35	200.12	190.58	192.90	193.99	203.85	195.97	218.81	207.33	204.60	187.04	191.15
13.00	179.76	195.70	186.15	189.96	193.26	202.99	193.84	217.54	205.44	202.09	181.50	185.57
14.00	181.95	191.37	182.54	188.27	193.39	203.62	192.80	217.11	204.66	200.55	178.65	180.00
15.00	173.71	191.81	183.11	190.84	196.54	206.51	194.45	218.64	206.28	201.94	179.22	179.38
16.00	176.62	188.49	181.14	188.64	193.13	203.29	191.22	214.33	202.14	197.83	175.89	176.60
17.00	166.78	182.35	176.48	183.31	186.46	195.66	185.93	208.17	196.30	193.18	176.90	177.35
18.00	173.54	178.10	172.10	177.78	179.80	186.66	182.30	202.55	194.40	192.32	182.78	182.19
19.00	166.58	182.72	177.85	186.10	185.30	190.34	190.15	205.68	202.88	195.28	179.76	179.62
20.00	165.29	174.86	173.48	188.19	190.82	198.50	196.70	207.86	201.36	188.51	169.18	168.33
21.00	152.83	167.50	167.50	184.66	189.03	199.30	196.18	206.70	199.53	183.60	161.53	159.83
22.00	146.31	162.25	164.94	184.12	190.04	201.33	195.42	206.20	198.46	180.64	156.04	151.73
23.00	146.17	161.29	165.08	185.16	191.62	203.73	194.55	205.76	197.70	180.70	153.46	147.44

(a)



(b)

Figure 3. (a) Heatmap of hourly average power demand in India for 2023. (b) Z scores of hourly power demand in India for 2023.

Table 2. Averaged monthly shares of electricity consumption and coefficient of variance of India using data from 2021-2023.

Month of the year	Average share of annual electric energy demand experienced in the month (%)	Average coefficient of variation of power demand profile in the month (%)
January	7.77	12.50
February	7.46	10.28
March	8.57	5.84
April	8.60	3.29
May	8.56	4.09
June	8.69	4.00
July	8.81	3.94
August	9.22	3.93

September	8.57	4.01
October	8.28	5.54
November	7.50	9.42
December	7.97	12.38

Using averaged Z scores from Figures 1, 2 and 3 and values from Table 3, the forecasted hourly power demand values for 2024 are shown in Figure 6a, while the corresponding actual power demand data are shown in Figure 6b for each month. The forecasted peak demand is seen to be 223.5 GW in June as against the observed peak of 228.5 GW in August.

Error Analysis

The percent relative error (calculated from Eqn. 2) between each hourly projection from 2024 and actual observed figure from 2024 (i.e., difference calculated from Figures 6a and 6b) is used as the metric to gauge the effectiveness of the proposed forecasting methodology and the calculated results are shown in Figure 7.

$$\%\, relative\ error(t) = \frac{100\times(P_{actual}(t) - P_{forecast}(t))}{P_{actual}(t)} \quad (2)$$

It is seen that the maximum relative error in the forecasted hourly demand value lies between +8.06% and -12.06% by this method, occurring in the months of May and August respectively. Excluding these months, the maximum average error is seen to be +4.65% and -8.79%. These upper and lower bounds on the forecast errors may be considered acceptable for the purpose of energy system design and operational planning. The error is seen to be entirely positive at all points for months like May and June, which indicates underprediction by the methodology of this study, whereas for months like August, September, November and December, the errors are seen to be negative at all times, thereby hinting at overprediction of the hourly demand.

The mean absolute percentage error for each month is also evaluated for the actual and forecasted profiles of that month, using Eqn. 3 and the results are shown in Figure 8.

$$Mean\ absolute\ \%\ error\ (MAPE) = \frac{1}{24}\left(\sum_{t=0}^{t=23} \frac{100\times\left|\left(P_{actual}(t) - P_{forecast}(t)\right)\right|}{P_{actual}(t)}\right) \quad (3)$$

The value of MAPE is seen to lie between 0.97% for May 2024 and 10.25% for August 2024, with the annual average being 3.77%. Thus, the simplified forecasting method presented in this work can be considered a reasonably accurate way of rapidly predicting future demand profiles based on statistical characteristics of past demand profiles.

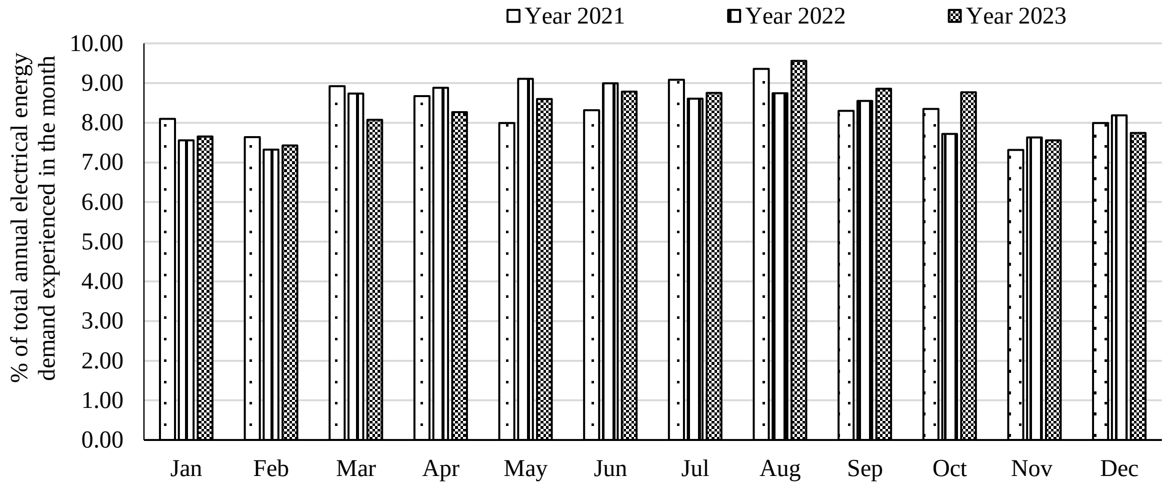


Figure 4. Share of total annual electric energy consumed per month in India in years 2021, 2022 and 2023.

Table 3. Forecasted data for demand curves of India in 2024 using data from 2021-2023.

Month of the year	Forecasted total electricity consumption in the month (TWh(e))	Forecasted mean power demand in the month (GW(e))	Forecasted standard deviation of power demand in the month (GW(e))
January	133.63	179.61	22.45
February	128.35	184.42	18.95
March	147.56	198.34	11.58
April	148.03	205.60	6.76
May	147.35	198.05	8.09
June	149.63	207.82	8.31
July	151.63	203.80	8.02
August	158.67	213.27	8.37
September	147.44	204.77	8.20
October	142.44	191.46	10.61
November	129.04	179.23	16.88
December	137.12	184.31	22.81

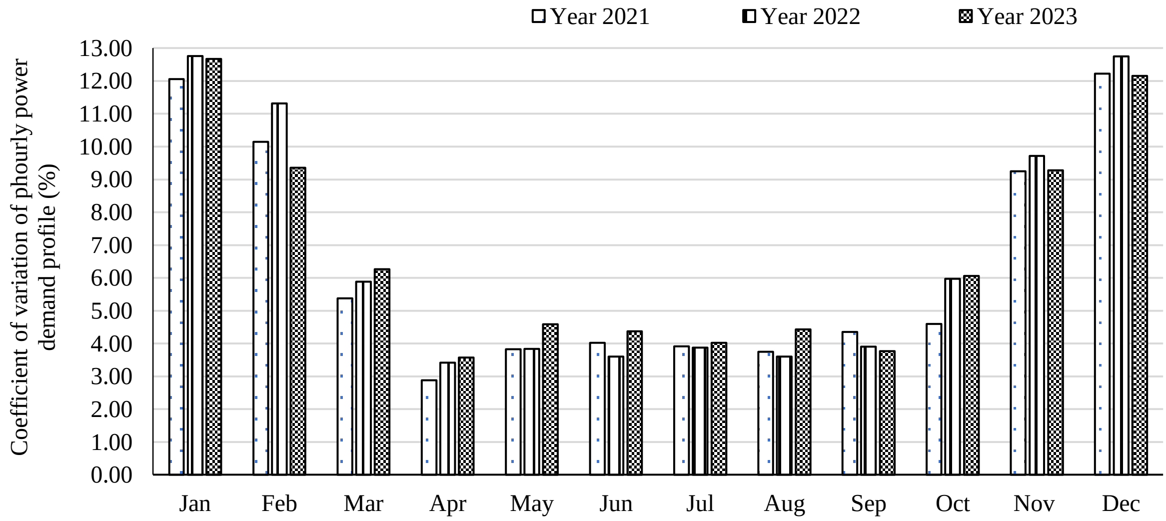


Figure 5. Coefficient of variation of power demand profiles of each month in India in years 2021, 2022 and 2023.

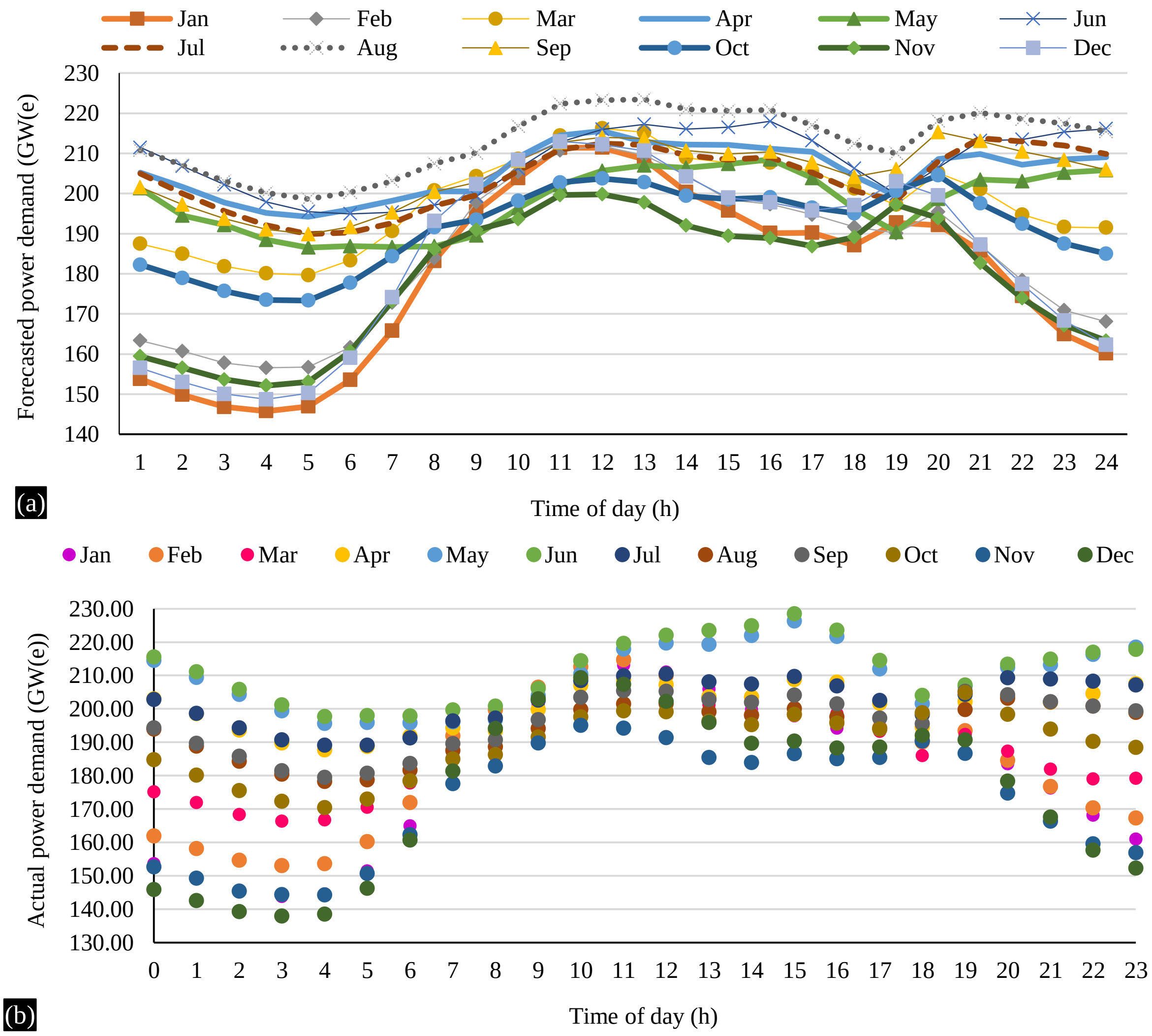


Figure 6. (a) Forecasted hourly electric power demand profiles of India in 2024 using the method of Z scores. (b) Actual observed hourly electric power demand profiles of India in 2024.

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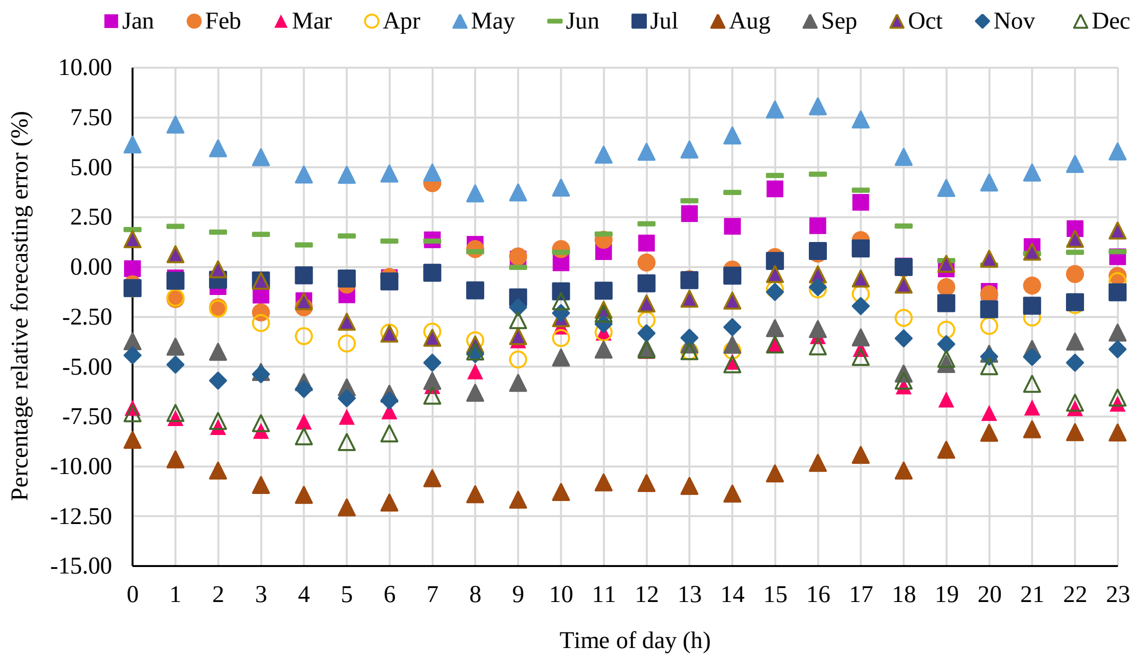

Figure 7. Calculated relative errors in forecasting instantaneous values of hourly demand profiles of India in 2024 using Z scores.

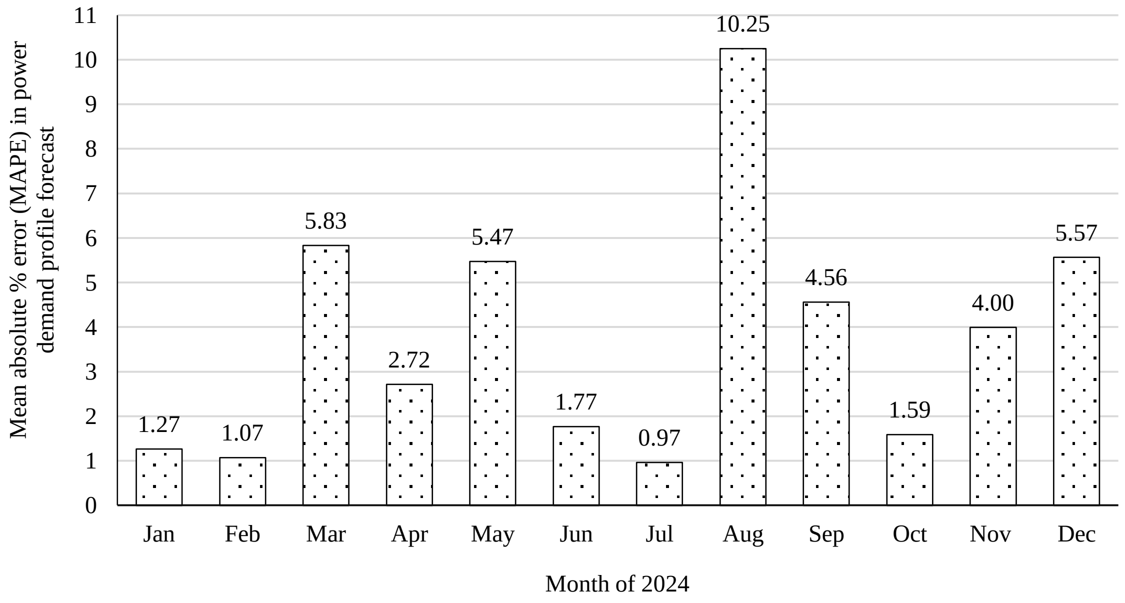

Figure 8. Calculated mean absolute percentage errors in forecasting hourly demand profiles of India in 2024 using Z scores.

SUMMARY AND CONCLUSIONS

The work presents the development of a novel methodology for forecasting the hourly power demand of an entire country, based only on the elementary statistical characteristics of the power demand profiles observed at similar intervals for that country in previous years. The method in this work is simple and based on a form of pattern matching using the basic statistical features of the previous data sets, such as the mean, standard deviation and non-dimensional Z scores of the hourly data in a given profile. It is easily deployable in a spreadsheet-based calculation system. No special coding environment is needed and it does not require detailed evaluation of the characteristics of the time series data (e.g., whether it is an autoregressive process or a moving average one based on nature of autocorrelation functions, use of lagged variables and differenced series, etc.) or time series regression methodologies. Neither does it need to capture individual features of the demand curves like drift, seasonality and cyclic behaviour.

The methodology is applied to India for forecasting the demand data for 2024 using data from 2021-2023. On comparison with actual data from 2024, the method is seen to perform the forecasting with reasonable accuracy, showing maximum forecasting error levels of -8% and +12% at specific hours of the day. All other values lie within this range. It may thus be concluded by stating that the method proposed in this work is useful for rapid assessment of demand profiles over the short-term using demand data from a few previous years, with an acceptable accuracy. As part of the way forward for this study, the method reported may be utilized to analyze demand curves from other nations, make projections for them over the short run and compare the accuracy obtained with them as well.

In discussing the limitations of the method, it may be said that the longer-range projections using near term data may have greater uncertainty due to various factors affecting long term energy demand and power consumption profiles (e.g., changing nature of economy, energy use technological changes like efficiency improvement and increasing electrification and decarbonization of various end use sectors which today make use of fossil fuels, climatic factors, especially temperature which create string seasonal and diurnal impacts on energy consumption and power demand) and this may lead to higher deviations between the actual and predicted values. Also, over the shorter term as well, the method will be unable to project any anomalously high or low power demand projection, since it assumes that the range of past Z scores of the power demand themselves will be experienced or replicated in future demand curves. These anomalies can arise due to rapid evolution of abnormal weather conditions, major economic shocks (e.g., like the disruptions due to COVID 19 pandemic) and geopolitical events of widespread significance, none of which can be foreseen by energy planners.

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