ELECTRICAL ENERGY FORECASTING - A PROBABILISTIC APPROACH

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ABSTRACT

Energy demand forecasting is essentially required for the optimal use of energy resources of a country. This paper presents a methodology to forecast the electrical energy demand of a power system. The methodology is based on the forecasting of hourly demand. A relationship is developed among the forecasted annual/seasonal average hourly load and the probabilistic laws of load ratios to forecast the hourly load. The proposed methodology is validated by applying it to a power system. The methodology is useful for long term hourly load forecasting and also for the forecast of electric energy requirement of a country.

Key Words - Electrical energy forecasting, Forecasted hourly load, Forecasted annual/seasonal average hourly load, Load ratios, Probability density functions of load ratios, Power system expansion planning.

1.0 INTRODUCTION

All human activities, industrial, commercial, social and individual, essentially require energy. Most of the commercial sources of energy, if not all, are depleted with their use. For the best use of natural resources long term optimal energy planning is a must. Optimal energy planning is based on the forecasting of energy demand. The effectiveness of energy planning depends on the closeness of the forecasted value to the actual one.

The forecasting of a variable for future period depends on the identification of the variation characteristics of the variable from its past history. Electrical demand is a random variable varies in the domain ranging from base to peak values. The demand of one hour is usually different from that of next or previous hour. Again the demand of any time of one year is different from that of the same time of some other years. A probabilistic law may be used, effective in many such cases, to model the monotonically varying such random variables.

The appropriateness of the projection of electric energy for a period depends mainly on the realistic forecasting of the electrical load of every moment of that period as the energy demand of a period is the sum of loads of every moment over that period. Forecasting the electrical load of every moment, especially for a long term of 20 to 25 years requires immense involvement. Instead, the load of small interval (an hour) may be considered.

The present practice of forecasting hourly load is almost confined to short term planning. The technique to forecast hourly load for future expansion plan is broadly developed in 1977. A recursive method for probabilistic forecasting of hourly load with lead-time of 1 to 168 hours (7 days x 24 hours) ahead is described by Keyhani [1]. Pansuka [2] presented a method for short-term hourly load forecast from a weather dependent load model. An algorithm using pattern recognition techniques and current weather parameters to forecast hourly electric load with a lead-time of 1 to 3 hours is proposed by S. Dehdashti et al. [3] in 1982. Srinivasan and Pronovost [4] developed a model for the hourly load forecast on the basis of linear estimation theory to obtain four different prediction models for the load at a particular hour corresponding to the four correlation periods, namely an hour, a day, a week and a year. The four predicted values are combined to obtain a composite forecast for an hour. Computer oriented probabilistic forecasting of hourly loads with lead-time of 1 to 24 hours using both historical data and weather forecasts are presented by Gupta and Yamada [5]. H. S Hippert et al. [6] presents a review of papers from 1991 to 1999, those reported the application of artificial neural network for short term load forecasting.

A significant development in the field of long term hourly load forecasting is the introduction of a new technique by Q. Ahsan and M.A Jalil [7, 8]. The methodology establishes a relation between the forecasted hourly and annual peak loads through some load ratios; hourly, daily, weekly and monthly. A load ratio is considered as a ratio between the peak loads of two different durations of that period. For example, the daily ratio is the ratio between the peak load of a day and the peak load of the week in which the day belongs. As such, the forecasted hourly load becomes a function of some single valued quantities; i.e. the peaks. Any sorts of load variations over a period cannot be characterized by the peak value of that period only. Moreover, the peak loads may not always represent the actual system demand, because during some peak hours the load may be shaded due to shortage of available generation. That is, the actual peak load would be the recorded load plus the shaded one.

This paper presents a methodology to forecast the electrical energy. It is based on the forecasting of hourly average loads of the energy-forecasting period. The probabilistic law in terms of probability density functions of each of the load ratios, hourly, daily and monthly, is developed from the historical load data. A load ratio is the ratio of average loads of two different durations. For example, the hourly load ratio is the ratio between average loads, instead of peak loads, of an hour and that of a day in which the hour belongs. Using a logical relationship the forecasted average hourly load is equated with the forecasted annual average hourly load through the probabilistic laws of these three load ratios. The essence of the methodology is that although the load at some time of some year may be widely different from the load at the same time of some other year, the load ratios of these two different times will lie within a narrow band. For example, the hourly loads of Bangladesh Power Development Board (BPDB) of 20:00 hours, February 1, of 1998 and 2002 were 1863 and 2895 MW, respectively and the daily average loads of that day of those two years are 1224.13 and 2044.88 MW, respectively. The corresponding hourly ratios are 1.5219 and 1.4157, respectively. That is, although the difference of hourly loads of those two years is 1032 MW, however, the difference of hourly ratios is only 0.1062.

The proposed methodology is validated by applying it to the power system of BPDB. The validation shows an insignificant deviation of the forecasted energy from the actual one. The methodology is applicable for long-term hourly load forecasting, useful for expansion analysis of a power system. It is also useful for the assessment of the future electric energy requirement of a country.

2.0 METHODOLOGY

The forecasting of electrical energy is based on the forecasting of hourly load. An hourly load is the average load of an hour. The methodology establishes a relation between the forecasted hourly load and forecasted annual or seasonal average load through some load ratios. The basic steps of this methodology are (i) determination of load ratios, hourly, daily and monthly from the historical data; (ii) development of the probability density function (PDF) of each load ratio; (iii) evaluation of the expected value, mean, of each load ratio and (iv) forecasting of annual/seasonal average load.

2.1 Hourly Load Ratio

The hour1y load ratio of any i th hour, HR_i, is the ratio between the electrical average load of that hour and the average hourly load of that day in which i th hour belongs, that is:

$$HR_i = \frac{HL_i}{DAL_j} \;,\; i = 1,........,n_1 \;........(1)$$

Where HL_i is the hourly load of i th hour and n_1 is the number of operating, energy supply/consume, hours in the forecasted period. The maximum value of n_1 is the number of hours in a year, that is, 8760/8784, if the forecasted horizon covers the whole year. If the forecasted period is only a season, say winter, of some years, the value of n_1 is the operating hours of winter season only.

In equation (1), DAL_j is the daily average hourly load of j th day in which i th hour belongs. The daily average hourly load of a day is obtained by dividing the total energy supplied/consumed in a day by the total number of operating hours of that day. The daily average hourly load, DAL, may be expressed as:

$$DAL = \frac{1}{n_2}\sum_{i=1}^{n_2} HL_i \quad ....(2)$$

Where n_2 is the total number of operating hours in a day. The usual value of n_2 is 24.

The methodology requires the development of the PDF of each hourly load ratio. The PDF can be developed by sampling the corresponding load ratios, obtained from the historical load, at an appropriate interval of time, may be at an interval of a year or two, and considering an equal probability of occurrence of each sample or assigning a different weight to a different sample.

If $f_{HR_i}(hr_i)$ is the PDF of the random variable (RV) HR_i, representing hourly load ratio of ith hour, the expected value of HR_i, $m(HR_i)$, may be expressed as.

$$m(HR_i) = \int_{-\alpha}^{\alpha} HR_i \, f_{HR_i}(hr_i)\, dhr_i \text{ ....(3)}$$

Since the electrical demand cannot be negative and it is the case with HR_i, therefore, the lower limit of equation (3) will be zero. As the RV HR_i is discrete in nature, equation (3) may be written in the form:

$$m(HR_i) = \sum_j HR_{i,j} \, P_{HR_{i,j}} \text{ ....(4)}$$

Where $HR_{i,j}$ is the magnitude of jth sample of HR_i and $P_{HR_{i,j}}$ is the probability of its occurrence.

2.2 Daily Load Ratio

The daily load ratio of any ith day, DR_i, of jth month may be obtained by dividing the average hourly load of ith day by the average load of jth month, that is:

$$DR_i = \frac{DAL_i}{MAL_j} \text{ ....(5)}$$

Where DAL_i is the daily average hourly load of ith day and MAL_j is the monthly average hourly load of jth month in which ith day belongs.

The monthly average hourly load is obtained by dividing the total electrical energy consumed/supplied in a month by the total number of operating; energy supply/consume, hours in that month. The monthly average hourly load of any ith month, MAL_i, is:

$$MAL_i = \frac{1}{n_3} \sum_{i=1}^{n_3} HL_i \text{ ....(6)}$$

Where n_3 is the total number of energy supply/consume hours in a month. The usual value of n_3 is any one of 672, 696, 720 and 744 depending on the number of days in a month.

Next, in this process, the PDF of the daily load ratio of each day of a year/season is developed by sampling the corresponding load ratios, obtained from the historical data of previous years, at an appropriate interval of time and assigning equal or different probability to each sample. Note that the total number of daily load ratios will be 365/366 if forecasting horizon spreads over the whole year.

The first moment, expected value, of the daily load ratio of any ith day, $m(DR_i)$ may be expressed as:

$$m(DR_i) = \sum_j DR_{i,j} P_{DR_{i,j}} \text{ ....(7)}$$

Where $DR_{i,j}$ is the magnitude of jth sample of the daily load ratio of ith day and $P_{DR_{i,j}}$ is its probability of occurrence.

2.3 Monthly Load Ratio

The methodology also requires the evaluation of the first moment of monthly load ratios. The monthly load ratio is the ratio between the average hourly load of a month and that of a year in which that month belongs. The monthly load ratio of any ith month, MR_i, may be expressed as:

$$MR_i = \frac{MAL_i}{YAL_j} \text{ ....(8)}$$

Where MAL_i is the monthly average hourly load of ith month and YAL_j is the average annual/seasonal hourly load of jth year in which ith month belongs.

The annual average hourly load is obtained by dividing the total energy supplied/consumed in a year by the total number of energy supply/consume hours in that year. The annual average hourly load of any ith year, YAL_i, may be expressed as:

$$YAL_i = \frac{1}{n_4} \sum_{i=1}^{n_4} HL_i \text{ ....(9)}$$

Where n_4 is the total number of energy supply/consume hours in the year. The usual value of n_4 is 8760/8784. The mean value of the monthly ratio of ith month, $m(MR_i)$, may be given as:

$$m(MR_i) = \sum_j MR_{i,j} \, P_{MR_{i,j}} \text{ ....(10)}$$

Where $MR_{i,j}$ is the magnitude of jth sample of monthly ratio of ith month and $P_{MR_{i,j}}$ is its probability of occurrence.

2.4 Forecasted Hourly Load

The forecasted hourly load of any ith hour, FHL_i of jth day of kth month of lth year/season is the product of the expected values of respective hourly, daily and monthly ratios and the forecasted annual average hourly load of lth year/season, that is:

$$FHL_i = m(HR_i)m(DR_j)m(MR_k)FYA_l \quad \text{........ (11)}$$

Where, FYA_l is the forecasted annual/seasonal average hourly load of lth year/season. Methodologies are well established to forecast the future peak load. Using any standard peak load [9, 10] forecasting technique and the annual average hourly loads of the past, the same for the future may be forecasted. However, this paper uses the Least Square Method (LSM) to forecast the annual average hourly loads.

2.5 Forecasted Energy

Once the forecasted hourly load of each hour of the period, for which the energy forecast is required, is evaluated the forecasted energy of the period is simply the sum of all the forecasted hourly loads of that period. If n is the total number of hours of the forecasted horizon, period, the forecasted energy, FE, of that period may be expressed as:

$$FE = \sum_{i=1}^{n} FHL_i \quad \text{...........(12)}$$

Where FHL_i is the forecasted hourly load of ith hour.

3.0 NUMERICAL EVALUATION

The proposed methodology is applied to the system of BPDB, which was the only organization responsible for generation and transmission till the middle of last decade in Bangladesh. The past data of BPDB are used for validation.

3.1 Basic Data

BPDB records its system load in the log sheet. Since 2002, it started keeping the load data in the soft form as well. The hourly loads of BPDB are collected of five historical years, 1998 to 2002. The hourly data of randomly selected three months, April 1993, October 1995 and January 2003 are also collected. That is, a total of 46,032 hours of load data are copied [11] from the log sheet. The collection of data is restricted to only five years to avoid the problem of copying data. Annual peak loads of past few years and actual energies of 2003 and 2004 are also collected.

3.2 Development of Load Ratios and PDFs

The forecasting of energy requires first the determination of hourly ratio of each hour, daily ratio of each day and monthly ratio of each month of a year, if the forecasting period covers the whole year. The forecasting process requires, next, the development of the PDF of each load ratio. For example, it is necessary to develop the PDFs of hourly load ratio of 8760/8784 hours, that is, a PDF for each hour of a year. From the PDFs, the expected values are evaluated.

3.2.1 Hourly

The hourly load ratio of each hour of 1998-2002 are calculated by calculating, first, daily average hourly loads of each day of these five years and dividing each hourly load by the daily average hourly load of the day in which the hourly load belongs. Note that for each particular hour five hourly load ratios are obtained corresponding to five years. Using only these five data a PDF of hourly load ratio of a particular hour is developed. The expected value is, then, evaluated from the PDF. For an example, the hourly loads and corresponding daily average hourly loads and load ratios of hour 20:00 of 1st July of 1998-2002 are presented in Table 1. The PDF of hourly load ratio of this hour is depicted in Fig. 1. The figure shows that the probability of each impulse is same. Note that there are only five hourly load ratios of five years and the values are different. Sampling at an interval of a year five samples of five different values are obtained. The consideration of equal weight for each sample makes the probability of occurrence of each sample equal.

Year	Hourly Load of Hour 20:00 (MW)	Daily Average Hourly Load of 1st July (MW)	Hourly Ratio
1998	1946	1750.08	1.11
1999	1974	1677.38	1.18
2000	2636	2072.79	1.27
2001	2851	2166.55	1.32
2002	3046	2292.10	1.33

Table 1: Hourly Ratios of Hour 20:00 of July 01

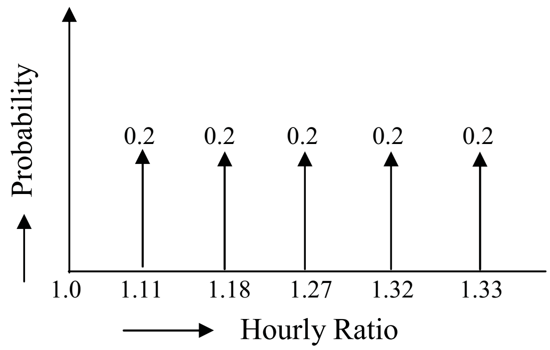

Fig. 1: PDF of Hourly Ratio of Hour 20:00 of July 01

3.2.2 Daily

The daily load ratio of each day of five years, 1998-2002, the only period of collected data, are calculated by dividing the daily average hourly load of a day by the monthly average hourly load of the corresponding month in which the day belongs. From these calculated daily load ratios, the PDF of daily ratio corresponding to each day is developed. That is, a total 365/366 PDFs are developed. Each PDF is developed sampling only five data corresponding to five years. The mean value of each daily load ratio is evaluated from the corresponding PDF. The daily load ratios of a day, for an example 31 December, of 1998-2002 are shown in Table 2. The table also shows corresponding daily and monthly average hourly loads and the mean ratio.

Year	Daily Average Hourly Load of 31 December	Monthly Average Hourly Load of December	Daily Ratio	Mean Daily Ratio
1998	1599.25	1537.59	1.04	0.996
1999	1658.54	1694.29	0.98	
2000	1519.38	1746.26	0.87	
2001	1885.33	1815.69	1.04	
2002	1938.33	1843.86	1.05	

Table 2: Daily Ratios of 31 December

3.2.3 Monthly

Monthly ratios (MR) for five years, 1998-2002, are calculated by dividing the monthly average hourly load by the corresponding annual average hourly load. The monthly ratios of twelve months for five different years along with the mean values are presented in Table 3.

Year/ Months	Monthly Ratio (MR)					Mean MR
	1998	1999	2000	2001	2002	
January	0.918	0.914	0.860	0.920	0.885	0.899
February	0.937	1.005	0.947	0.955	0.942	0.957
March	0.959	1.021	0.981	0.986	1.016	0.993
April	0.953	1.034	1.019	1.078	1.021	1.021
May	0.969	0.977	0.998	0.986	0.985	0.983
June	1.030	1.024	1.049	1.023	1.069	1.039
July	1.069	0.999	1.079	1.056	1.066	1.054
August	1.062	1.044	1.078	1.069	1.069	1.065
September	1.041	1.048	1.049	1.067	1.084	1.058
October	1.097	1.026	1.051	1.020	1.044	1.047
November	0.997	0.959	0.966	0.968	0.963	0.970
December	0.969	0.951	0.922	0.872	0.852	0.913

Table 3: Monthly Ratios and Corresponding Mean

3.3 Forecasted Annual/Seasonal Average Hourly Loads

The forecasted annual/seasonal average hourly load is another requirement of forecasting hourly load and in turn energy.

3.3.1 Forecast with Inadequate Past Data

From the collected five years (1998-2002) hourly loads the annual average hourly load of each year is calculated. Using these annual average hourly loads at first, it is endeavoured to forecast the annual average hourly loads of the future. The Least Square Method (LSM) [11] is applied to forecast the annual average hourly loads from year 1998 to 2028. Annual average hourly loads of 1998-2004 are validated in Table 4 with the actual ones. The maximum deviation is 3.152%. The positive and negative values indicate over and under forecasting respectively. The forecasted annual average hourly loads of the remaining years, 2005 to 2028, are presented in Table 5. Although Table 4 shows a reasonable deviation of the forecasted values, a negative average load appears in Table 5. Moreover, the forecasted value starts to decrease from the year 2008. This trend does not match with that of the average loads of the past. It is considered that inadequate data may be the reason of this type of abnormal result. This problem of inadequate historical data is overcome through a technique, presented in next section.

Year	Forecasted Annual Average Hourly Load (MW)	Actual Annual Average Hourly Load (MW)	Deviation of Forecasted Value from Actual (%)
1998	1590.54	1588.28	+ 0.20
1999	1767.24	1781.29	- 0.80
2000	1922.92	1894.37	+ 1.53
2001	2057.58	2081.59	- 1.15
2002	2171.22	2163.97	+0.32
2003	2263.84	2285.97	-0.97
2004	2335.44	2411.45	-3.152

Table 4: Comparison of Forecasted Annual Average Hourly Loads with the Actual Ones

Year	Forecasted Annual Average Hourly Load (MW)	Year	Forecasted Annual Average Hourly Load (MW)
2005	2386.02	2017	1353.42
2006	2415.58	2018	1130.74
2007	2424.12	2019	887.04
2008	2411.64	2020	622.32
2009	2378.14	2021	336.58
2010	2323.62	2022	29.82
2011	2248.08	2023	-297.96
2012	2151.52	2024	-646.76
2013	2033.94	2025	-1016.58
2014	1895.34	2026	-1407.42
2015	1735.72	2027	-1819.28
2016	1555.08	2028	-2252.16

Table 5: Forecasted Annual Average Hourly Load

3.3.2 Forecast with Estimated Past Data

From annual average hourly loads, YAL, and peaks, YPL, annual load factors (LF) of 1998-2002 are computed. These are presented in Table 6 along with the mean value. It is observed that all the LFs lie very close to the mean value.

Year	YAL (MW)	YPL (MW)	LF	Mean of LF
1998	1588.28	2331	0.681	0.676
1999	1781.29	2634	0.676	
2000	1894.37	2858	0.668	
2001	2081.59	3084	0.675	
2002	2163.97	3208	0.675	

Table 6: Load Factors (Annual)

Using the mean LF of 0.676 and peak loads of the past, the annual average loads from 1995 to 1997 are estimated. Applying these estimated annual average hourly loads and actual annual average hourly loads of 1998-2002; the annual average hourly loads of 1998-2028 are forecasted using LSM. The forecasted results along with the actual ones of 1998- 2004 are presented in Table 7. The comparison of forecasted annual average hourly loads of 1998- 2004 with the actual ones shows reasonable deviation and unlike Table 5, there is no abnormality in the forecasted values of other years. Therefore, these forecasted annual average loads are used in forecasting hourly average loads of 2005-2028.

Year	Annual Average Load (MW)		Year	Annual Average Load (MW)	
	Actual	Forecasted		Actual	Forecasted
1998	1588.28	1568.33	2014	-	4785.75
1999	1781.29	1783.05	2015	-	5073.29
2000	1894.37	1906.79	2016	-	5371.75
2001	2081.59	2041.45	2017	-	5681.13
2002	2163.97	2187.03	2018	-	6001.43
2003	2285.97	2340.54	2019	-	6332.65
2004	2411.45	2510.95	2020	-	6674.79
2005	-	2689.29	2021	-	7027.85
2006	-	2878.55	2022	-	7391.83
2007	-	3078.73	2023	-	7766.73
2008	-	3289.83	2024	-	8152.55
2009	-	3511.85	2025	-	8549.29
2010	-	3744.79	2026	-	8956.95
2011	-	3988.65	2027	-	9375.53
2012	-	4243.43	2028	-	9805.03
2013	-	4509.13			

Table 7: Forecasted Annual Average Hourly Loads Using Known and Estimated Data of the Past

3.4 Validation

The proposed methodology is applied to forecast the hourly load in turn energy. This section presents the validation of hourly load, monthly and annual energy comparing with the known historical data of BPDB.

3.4.1 Validation of Hourly Load

The hourly loads of two randomly selected months, April 1993 and October 1995 are forecasted using equation (11). These forecasted results are compared with the hourly loads collected from BPDB. To avoid occupying large space randomly selected one hour forecasted loads of fifteen/sixteen days of each months, 10:00 hour load of April 1993 and 22:00 hour load of October 1995 are compared with the actual ones in Table 8. The table also presents the percentage error of forecasted values. It shows that the maximum and minimum errors are 13.234 % and 0.0597% respectively and most of the errors are less than 10%.

Date	10:00 Hour Loads of April 1993 (MW)			22:00 Hour Loads of October 1995 (MW)		
	Forecasted	Actual	% Error	Forecasted	Actual	% Error
1	1241	1239	0.16	1643	1735	-5.6
3	1167	1237	-6	1687	1745	-3.44
5	1218	1173	3.69	1721	1706	0.87
7	1182	1243	-5.2	1723	1668	3.19
9	1081	1265	-17	1732	1726	0.35
11	1214	1194	1.65	1723	1706	0.99
13	1239	1199	3.23	1741	1624	6.72
15	1246	1143	8.27	1690	1682	0.47
17	1242	1200	3.38	1673	1680	-0.42
19	1239	1232	0.56	1685	1462	13.2
21	1155	1282	-11	1661	1565	5.78
23	1155	1229	-6.4	1673	1738	-3.89
25	1182	1212	-2.5	1675	1674	0.06
27	1114	1190	-6.8	1660	1592	4.1
29	1186	1163	1.94	1611	1675	-3.97
31				1598	1605	-0.44

Table 8: Comparison of the Forecasted Hourly Loads with the Actual Ones

The hourly loads of five years 1998-2002 are also forecasted. The same are compared with the collected data. The overall deviation of the forecasted results from the actual ones is depicted in Fig. 2. It is clearly observed from the figure that only in 20% cases the errors are more that 10%.

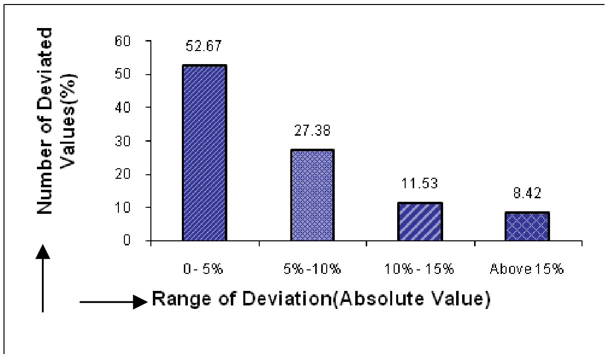

Fig. 2: Deviation of Forecasted Hourly Loads of 1998 to 2002

3.4.2 Monthly Energy

The forecasted monthly energy of some randomly selected months, April 1993, October 1995, March 1998, July 2000, November 2002 and January 2003 as obtained using equation (12) are compared with the actual values in Table 9. The table also presents the percentage deviation from the actual values. It is observed that the maximum and minimum deviations (absolute values) are 4.83% and 1.80% respectively.

Month & Year	Forecasted Energy (GWh)	Actual Energy (GWh)	% Deviation (Absolute Value)	Mean of % Deviation
April 1993	898.56	857.14	4.83	2.78
October 1995	1034.81	1012.50	2.20	
March 1998	1158.51	1133.49	2.21	
July 2000	1489.97	1520.97	2.04	
November'02	1527.85	1500.77	1.80	
January 2003	1567.97	1513.89	3.57	

Table 9: Validation of Monthly Energy

3.4.3 Annual Energy

Forecasted annual energies are compared with the known values of seven years, 1998-2004, in Table 10. The fourth column of this table presents the percentage deviation of the forecasted energy from the actual ones. In this case, the maximum deviation is 3.907% and the mean deviation is 1.594%.

Year	Forecasted Energy (GWh)	Actual Energy (GWh)	% Deviation (Absolute Value)	Mean % Deviation
1998	13724.50	13918.76	1.396	1.594
1999	15603.52	15601.27	0.014	
2000	16722.81	16640.25	0.279	
2001	17864.78	18234.84	2.029	
2002	19138.76	18956.53	0.962	
2003	20540.32	20025.11	2.573	
2004	22009.83	21182.19	3.907	

Table 10: Validity Check of Annual Energy

4.0 CONCLUSIONS

A methodology is proposed to forecast electrical energy, essentially required for energy planning or long-term expansion planning of a power system. The methodology is based on the forecasted values of hourly load of the forecasting period and a straight-forward revealing relationship among the forecasted annual/seasonal average hourly load and expected values of different load ratios is developed to forecast the hourly load. The paper also presents a technique to forecast the long- term hourly load with an inadequate historical data.

The proposed methodology is applied to the power system of BPDB. Although the probability laws of load ratios are developed from a short historical data, the validation of the forecasted results shows an insignificant deviation from the actual values.

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