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ORIGINAL CONTRIBUTION

Reducing Peak Demand by Time Zone Divisions

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Abstract For a large country like India, the electrical power demand is also large and the infrastructure cost for power is the largest among all the core sectors of economy. India has an emerging economy which requires high rate of growth of infrastructure in the power generation, transmission and distribution. The current peak demand in the country is approximately 1,50,000 MW which shall have a planned growth of at least 50 % over the next five years (Seventeenth Electric Power Survey of India, Central Electricity Authority, Government of India, March 2007). By implementing the time zone divisions each comprising of an integral number of contiguous states based on their total peak demand and geographical location, the total peak demand of the nation can be significantly cut down by spreading the peak demand of various states over time. The projected reduction in capital expenditure over a plan period of 5 years is substantial. Also, the estimated reduction in operations expenditure cannot be ignored.

Keywords Peak demand · Time zone divisions · Regional load dispatch centre (RLDC)

Introduction

In the east of the territory of India lies the state called Arunachal Pradesh and in the farthest corner in the west of India lies the state called Gujarat. The western corner has a longitude of 68°07′ and the eastern corner has a longitude of 97°25′. This covers a spread of more than 29° which is 1/12th of the earth's perimeter [2]. So, time difference between western and eastern corners of India is theoretically calculated as 1/12th of 24 h i.e. 2 h.

So, for practical reasons, the territory of India may be divided into different time zones where the farthest corners from east to west shall have a time difference of 2 h.

The current Indian Standard Time (IST) is based on a longitude of 82.5°(GMT + 5:30). The Planning Commission of India has consistently acknowledged in its Integrated Energy Policy documents the necessity of two time zones for energy savings [3, 4]. Several leading Institutes of India has carried out research in daylight savings time (DST) and multiple time zones. The National Institute of Advanced Studies (Indian Institute of Science Campus, Bangalore) has recommended the advancement of IST by half an hour (GMT + 6:00) and have estimated a benefit of Rs. 1,000 crore per annum. This is achieved by reducing the evening energy consumption with more daylight. This approach has the significant drawback that it does not reduce the peak demand. However, it clearly establishes that there will be lower electricity consumption due to lighting as there will be more daylight during the evenings [2]. But a major policy decision like advancing the clock calls for much higher benefits. Several other studies have been also carried out in India since 1990 by National Physical Laboratory (NPL) and The Energy and Resources Institute (TERI) to estimate the probable impact of various time-based measures for energy savings. Most significant are the detailed studies undertaken by TERI in 1988 [5] and 2011 [6]. The 1988 study by TERI was undertaken on behalf of the Government of India's Advisory Board on Energy and revealed only limited energy savings potential. The recommendations did not warrant a major policy decision. The study was unique in the sense that unlike the previous studies which only focused on DST, it also

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explored the reduction in peak load [5]. A further reinvestigation study was undertaken by TERI in 2011 where it went one step further by creating a third scenario to propose two time zones (GMT + 6:00 and GMT + 5:00) based on the load dispatch regions of India. The estimated results are surprising as it projected a net loss of energy. This study was carried out in great depth and established that the prospect of DST and advancement of clock has a very little potential compared to the risks [6]. It is also well established by several research work that the tropical countries near the Ecuador cannot expect significant benefits from DST or advancement of clock [1, 7].

In the present communication two observations have been made from the study made by TERI in 2011.

1. For proposing time zones, we may not limit ourselves to geography of Regional Load Dispatch Centres (RLDCs) but also explore the geography based on State Load Dispatch Centres (SLDCs), as each state is a governing Centre and may maintain its own timings.
2. The electricity demand of Eastern Region and North Eastern Region (time zone 1, GMT + 6:00 as proposed by TERI) is roughly about 10 % of the national demand and has different peak demand and off-peak demand timings from northern region, southern region and western region (time zone 2, GMT + 5:00 as proposed by TERI). This has resulted in negative energy savings in Scenario 3 proposed by TERI [6].

Due to administrative reasons, there are certain advantages of having a uniform time across the territory of India which may outweigh the practical difficulty of continued daylight during the late hours of a day or dark hours in the morning. In spite of these advantages, USA has four time zone divisions across its contiguous territory and makes considerable savings in energy by optimum use of the daylight across the different time zones. One of the problems of implementing such time zones across India is that the geographical landmass is not uniformly distributed from east to west like USA and the savings in energy in terms of daylight may not be significant.

Objective

Over the past ten years, the peak demand for electrical power in India has grown more than 100 % (from 60,000 MW in the year 2000 to 1,26,000 MW in 2010) [8–10]. There is a case for examination of the peak demand and the distribution of demand for electrical power of the various states in the territory of India to check if the peak demands across different time zones can be spread which will reduce the overall peak demand.

Data Collection

The demand for all the states and union territories have been shown separately except the following:

1. Sikkim
2. Andaman and Nicobar
3. Lakshadweep

The reason for excluding Andaman and Nicobar and Lakshadweep is that they are not connected to the National Grid. The Data for Sikkim is not separately shown and is clubbed with that of West Bengal. As Sikkim and West Bengal are in the same geographical region, it is appropriate to assume that they will fall in the same time zone.

As Damodar Valley Corporation (DVC) has separate, but overlapping jurisdiction with state of West Bengal and state of Jharkhand, there is a system constraint that DVC, West Bengal and Jharkhand should be in the same time zone division. As the data for state of Sikkim is not shown separately, it should also be in the same time zone as the State of West Bengal. There is no practical issue in having Sikkim, West Bengal, Jharkhand and DVC in the same time zone based on their geographical locations.

The peak demand for all states are available from the websites mentioned in [8, 11–16]. The minimum (off-peak) demand for all states and union territories are also available except those in western region. The hourly demand figures are not available from the websites but the following factual data are available:

- The monthly load duration curve for entire country is available in the monthly report from the website of the national load dispatch centre since April 2012 [16].
- The time and value for peak demand and the time and value for minimum (off-peak) demand for each region is available from the daily report of all RLDCs since July 2012 [11–15].
- The regional peak demand period is between 18:00 h and 20:00 h across all seasons. The occurrence time of peak demand varies across seasons for NRLDC, ERLDC and SRLDC. For NERLDC and WRLDC, it is same across all seasons.
- The regional off-peak demand occurs at 08:00 h for NERLDC, at 14:00 h for ERLDC and at 03:00 h for all other RLDCs across all seasons. This occurrence time for all RLDCs is same for all seasons.

Lemma 1 *The period of peak demand may be construed to occur between 17:30 h and 20:30 h which is for 3 h during the day of 24 h for all states in the RLDC where the peak demand occurrence is at 19:00 h. It may be proportionately adjusted for other RLDCs around the respective peak demand occurrence time.*

Proof This is available from daily reports [11–15] and monthly report [16].

Lemma 2 *The period of off-peak demand may be construed to occur between 06:30 h and 09:30 h for NERLDC, between 12:30 h and 15:30 h for ERLDC and between 01:30 h and 04:30 h for all other RLDCs.*

Proof This is available from daily reports [11–15] and monthly report [16].

Lemma 3 *During the period between off-peak demand to peak demand, the rate of rise in demand shall be uniform and between peak demand to off-peak demand, the rate of fall in demand shall be uniform. The specific variations in a State between peak and off-peak periods shall be ignored.*

Proof This is available from The National Load Duration Curve in Monthly Reports [16].

In absence of hourly demand figures during the day except during peak and off-peak hours, the hourly demand figures are constructed based on earlier Lemmas. Based on the construction methodology, the hourly values shall be in conformity with the national load duration curve.

A load duration data (Table 1) is prepared from the monthly load duration curves from April 2012 to October 2013 [16]. It is to be noted that the load duration curve for January 2013 is not available.

The rate of rise or fall of the load demand during peak period and off-peak period in the load duration curve is half of the actual rate of rise or fall of the load demand during peak period and off-peak period if there is only one peak and off-peak during the 24 h of a day. For all the infrastructural facilities in the world, it is seen in general that there are at least two peak demand periods and one off-peak demand period during a 24 h day. It is same for electricity demand. This can be verified from the load curves of the State of Punjab, Delhi and Eastern Region presented in Fig. 1. For the state of Punjab, there are three peaks. For Delhi, there are two peaks and for eastern region as a whole, there are two peaks. For two peaks, the rate of rise or fall of the load demand during peak period shall be four times the slope of the peak period in load duration curve, as the load will have to both rise and fall four times during these periods.

Lemma 4 *Hourly demand data for all states and union territories can be constructed based on the factual data of national load duration curve* (Fig. 2)*, the peak demand with its time and the off-peak demand with its time* [11–15].

Proof

Let the following points of GW demand in the monthly load duration curve be defined as

P_A = Peak load demand (0 % of time)

Table 1 Load duration data for percentage of time during a month it stays above a certain load in GW (Indian Power Grid)

Month	Peak demand period					Off-peak demand period				
	Peak demand	5 %	10 %	12.50 %	25 %	75 %	87.50 %	90 %	95 %	100 %
Apr-12	116.00	109	108	107.25	104	99	97.5	97	96	94.5
May-12	119	114	112.5	111.75	110	103	100.25	99.5	98	92
Jun-12	118	113.5	112.5	112	110.5	105.5	104.25	104	103	102
Jul-12	117.5	111	109	108.5	106.5	102	100.25	99.5	98	92
Aug-12	113	108.5	107	106	103	98	96.5	96	95.5	85
Sep-12	117	109	107	106.5	106	97	95.25	95	94	90
Oct-12	117	111	108	107.25	104.5	99.5	98	98	95.5	90
Nov-12	111	106	104	103.25	100.5	94.5	92.5	92	91	90
Dec-12	116	106.5	104.5	104	102	95.5	91.5	91	90	90
Jan-13	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Feb-13	116	110.5	109	108.5	106	98.5	96	95.5	94	92
Mar-13	121	115	113	112	109.5	103	100.5	100	98	92
Apr-13	122	117.5	115	114.25	110	104	102.5	102	101	99
May-13	124	121	119	118.5	117	110.5	108.5	108	107	92
Jun-13	118	116	114.5	113.75	111	105	102.25	101.5	99.5	95.5
Jul-13	120	117.5	115	114.25	111	105.5	103.75	103.5	102.5	92
Aug-13	125	117	114.5	113.75	111	103.5	100.25	99.5	97	92
Sep-13	128	121	119	118.25	116	108.5	106.5	106	104.5	102
Oct-13	123	116.5	113	112	108	101.5	98.25	97.5	95.5	92

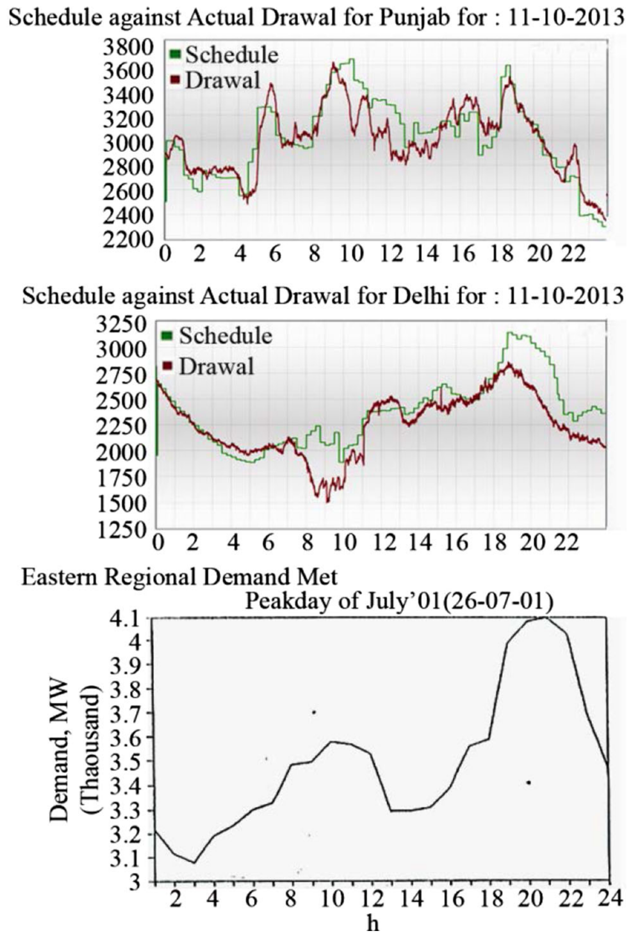

Fig. 1 Load curves of the state of Punjab, Delhi [14] and eastern region [18]

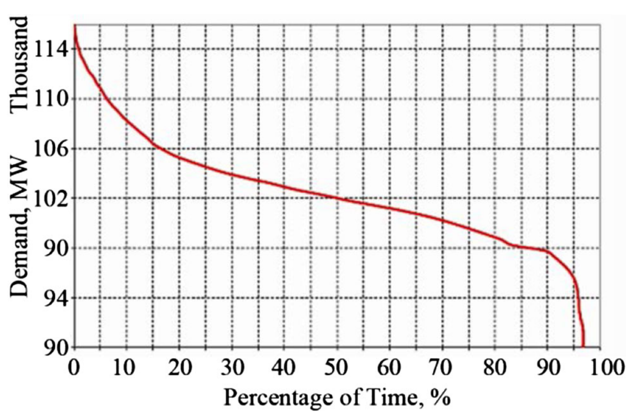

Fig. 2 National load duration curve for October 2013 (Indian Power Grid) [17]

P_B = Load demand for start of peak period (25 % of time), 6 h for 2 peaks

P_C = Load demand for start of off-peak period (87.5 % of time), 3 h

P_D = Off-peak load demand (100 % of time)

Hourly rate of rise or fall of the load demand in percentage during peak period $(u) = 4 \times (P_A - P_B) \times 100/(6 \times P_B)$

Hourly Rate of rise or fall of the load demand in percentage during off-peak period $(v) = 2 \times (P_C - P_D) \times 100/(3 \times P_D)$

Peak period value multiplier after an hour $= 1 + u/100$

Off-peak period value multiplier after an hour $= 1 + v/100$

Peak period value multiplier after 1.5 h $(x) = 1 + u \times 1.5/100$

Off-peak period value multiplier after 1.5 h $(y) = 1 + v \times 1.5/100$.

Based on these calculations from the load duration data table (Table 1) from April 2012 to October 2013, a rate of rise/fall of load demand during peak/off-peak/normal hours (Table 2) is prepared. However, the data for January 2013 is not available.

As it is desired to estimate the hourly peak values from the day's peak demand and off-peak demand for every state, the following terms are defined SP_A = Peak load demand of a state on a particular date, MW; SP_D = Off-peak load demand of a state on a particular date, MW; Hourly incremental load demand of the State in MW during the period from off-peak demand to peak demand is given by $(SP_A/x - SP_D \times y)$/(number of hours between end of off-peak period and start of peak period); Hourly incremental load demand of the state in MW during the period from peak demand to off-peak demand is expressed as $(SP_A/x - SP_D \times y)$/(number of hours between end of peak period and start of off-peak period).

The earlier construction methodology is applied for hourly peak and off-peak demand values of all states [11–16] for 11th October, 2013. The peak demand figures, the constructed hourly demands and the overall peak demand can be seen from Table 3. The overall peak demand is 1,25,228 MW on 11th October, 2013 which occurred at 20:00 h.

Analysis

With the assumption that the peak demand occurs at a particular time of day based on uniform official working hours, the official working hours will get shifted due to creation of separate time zone divisions and the peak demand of various states shall be spread over different times. As the geographical distance between the eastern and western corners of India limits the time difference to a maximum of 2 h, the maximum number of time zones is restricted to three. There are several options in grouping the states in different time zones. They are as follows: States may be grouped in three different time zones

Table 2 Rate of rise/fall of load demand during peak/off-peak/normal hours table (Indian Power Grid)

Month	Peak Period (6 h/25 % of time) in %	Off-Peak Period (3 h/12.5 % of time) in %	Peak to Off-Peak Ratio	Peak period value multiplier after an hour	Off-Peak period value multiplier after an hour	Peak period value multiplier after 1.5 h	Off-Peak period value multiplier after 1.5 h
Apr-12	11.22	1.75	1.22	1.1122	1.0175	1.1683	1.02625
May-12	8.79	5.98	1.29	1.0879	1.0598	1.13185	1.0897
Jun-12	7.24	1.47	1.16	1.0724	1.0147	1.1086	1.02205
Jul-12	8.14	5.98	1.25	1.0814	1.0598	1.1221	1.0897
Aug-12	7.77	1.77	1.19	1.0777	1.0177	1.11655	1.02655
Sep-12	13.21	3.89	1.30	1.1321	1.0389	1.19815	1.05835
Oct-12	12.44	5.93	1.30	1.1244	1.0593	1.1866	1.08895
Nov-12	10.28	1.85	1.23	1.1028	1.0185	1.1542	1.02775
Dec-12	15.69	1.11	1.29	1.1569	1.0111	1.23535	1.01665
Jan-13	NA	NA	NA				
Feb-13	6.92	2.90	1.24	1.0692	1.029	1.1038	1.0435
Mar-13	7.31	5.77	1.28	1.0731	1.0577	1.10965	1.08655
Apr-13	9.39	2.01	1.23	1.0939	1.0201	1.14085	1.03015
May-13	6.27	4.25	1.22	1.0627	1.0425	1.09405	1.06375
Jun-13	5.11	4.71	1.24	1.0511	1.0471	1.07665	1.07065
Jul-13	6.91	2.50	1.20	1.0691	1.025	1.10365	1.0375
Aug-13	13.51	5.59	1.35	1.1351	1.0559	1.20265	1.08385
Sep-13	11.21	2.94	1.25	1.1121	1.0294	1.16815	1.0441
Oct-13	13.58	4.14	1.33	1.1358	1.0414	1.2037	1.0621

1. Based on their distance from the farthest eastern corner of the territory of India;
2. According to load dispatch region;
3. With equitable distribution of aggregate peak demand across contiguous geography.

Lemma 5 *The maximum reduction in peak saving in distribution of a single peak to multiple peaks is obtained when the values of the multiple peaks are equal and numbers of peaks are more.*

Proof

Let the single peak value be P and the multiple peak values be P_X, P_Y, P_Z.
So, $P = P_X + P_Y + P_Z$, and $P_K = P_X = P_Y = P_Z = P/3$.
And the amount of peak saving shall be $= P - P_K$
If, P'_X, P'_Y, P'_Z are not equal and say, $P'_X > P'_Y$, P'_Z
So, $P'_X > P_K$ and the amount of peak saving shall be $= P - P'_X$

Hence $P - P'_X < P - P_K$ and the maximum peak savings will be $P - P_K$ and this occurs when the distributed multiple peak values are equal. If the distribution is among two peaks, $P'_K = P/2$. So, $P - P'_K < P - P_K$ and reduction in peak value is more if the number of peak values for distribution are more. As a consequence, from the earlier three groupings third option with three time zones for distribution of peak value will be the best to meet our objective.

Since our purpose is to spread the peak demand of the states to different hours of the day, the best strategy shall be to adopt option 3 from earlier. These groupings have been shown in Fig. 3 and Table 4. The groupings have been achieved by preparing a precedence table where each state will have one or more entries to specify its immediate adjacent state towards the west. The columns and rows of Table 4 have been prepared starting with 'Arunachal Pradesh' and precisely following the entries in the precedence table. This strategy has shuffled states across load dispatch regions but achieved equitable distribution of aggregate peak demand in the three time zones (Fig. 3). While grouping the states, the contiguity of the states in a time zone has been almost achieved by following the precedence table.

The hourly demand figures from Table 3 need to be recast with a view to the three time zones. Before this, the time zones need to be selected. The present IST is GMT + 5:30 h. This time standard may be considered for our central time zone (Time Zone 2) and the three time zones may be selected as follows:

Time Zone 1: GMT + 6:30 h
Time Zone 2: GMT + 5:30 h
Time Zone 3: GMT + 4:30 h

Table 3 Constructed hourly peak demand of states and union territories on 11th October, 2013

Hours of day	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
Eastern Region (peak: 1,900 h; off-peak: 1,400 h)												
Bihar	1,895	1,903	1,912	1,920	1,928	1,937	1,945	1,953	1,962	1,970	1,978	1,987
Damodar Valley	2,238	2,244	2,251	2,257	2,264	2,270	2,276	2,283	2,289	2,295	2,302	2,308
Jharkhand	871	882	893	903	914	925	936	947	957	968	979	990
Orissa	2,978	2,963	2,948	2,933	2,918	2,903	2,888	2,873	2,859	2,844	2,829	2,814
West Bengal	5,558	5,507	5,455	5,404	5,353	5,302	5,251	5,200	5,149	5,098	5,047	4,996
Sikkim	72	70	67	65	63	61	59	57	55	53	51	49
Northern Region (peak: 2,000 h; off-peak: 0,300 h)												
Chandigarh	168	158	150	144	150	154	157	160	163	166	169	172
Delhi	3,483	3,456	3,375	3,241	3,375	3,446	3,454	3,462	3,470	3,477	3,485	3,493
Haryana	5,145	5,129	5,021	4,821	5,021	5,123	5,128	5,133	5,137	5,142	5,147	5,151
Himachal Pradesh	943	912	879	844	879	901	910	918	927	936	945	954
Jammu & Kashmir	1,296	1,217	1,155	1,109	1,155	1,189	1,212	1,234	1,257	1,279	1,302	1,325
Punjab	5,741	5,833	5,764	5,535	5,764	5,866	5,840	5,814	5,787	5,761	5,735	5,708
Rajasthan	6,622	6,832	6,801	6,531	6,801	6,907	6,847	6,787	6,727	6,667	6,607	6,547
Uttar Pradesh	10,825	10,906	10,733	10,306	10,733	10,935	10,912	10,889	10,866	10,842	10,819	10,796
Uttarakhand	1,328	1,304	1,266	1,216	1,266	1,295	1,302	1,309	1,316	1,323	1,330	1,337
North Eastern Region (peak: 2,000 h; off-peak: 0,800 h)												
Arunachal Pradesh	86	86	85	85	84	84	83	81	78	81	83	84
Assam	1,016	996	977	957	938	918	899	872	837	872	899	918
Manipur	90	91	92	94	95	96	97	96	92	96	97	96
Meghalaya	228	227	225	224	223	222	220	216	207	216	220	222
Mizoram	52	53	53	53	53	54	54	53	51	53	54	54
Nagaland	78	76	75	73	71	69	68	66	63	66	68	69
Tripura	190	181	172	164	155	146	137	130	125	130	137	146
Western Region (peak: 2,000 h; off-peak: 0,300 h)												
Gujarat	8,062	7,982	7,786	7,477	7,786	7,953	7,976	7,999	8,022	8,044	8,067	8,090
Madhya Pradesh	5,044	4,994	4,872	4,678	4,872	4,976	4,991	5,005	5,019	5,033	5,048	5,062
Chhattisgarh	2,284	2,261	2,206	2,118	2,206	2,253	2,259	2,266	2,272	2,279	2,285	2,292
Maharashtra	12,622	12,497	12,191	11,706	12,191	12,452	12,488	12,523	12,559	12,595	12,631	12,666
Goa	313	310	302	290	302	309	310	310	311	312	313	314
Daman & Diu	216	214	208	200	208	213	213	214	215	215	216	216
Dadra & Nagar Haveli	517	512	500	480	500	510	512	513	515	516	518	519
Southern Region (peak: 1,900 h; off-peak: 0,300 h)												
Andhra Pradesh	9,296	9,434	9,316	8,946	9,316	9,476	9,423	9,370	9,317	9,265	9,212	9,159
Karnataka	5,019	4,503	4,161	3,996	4,161	4,344	4,542	4,741	4,939	5,138	5,337	5,535
Kerala	2,097	1,906	1,776	1,705	1,776	1,848	1,921	1,994	2,067	2,141	2,214	2,287
Tamilnadu	9,180	8,941	8,649	8,305	8,649	8,868	8,960	9,052	9,144	9,236	9,328	9,420
Puduchery	246	238	229	220	229	235	238	242	245	248	251	254
Total	105,799	104,817	102,545	99,000	102,400	104,242	104,509	104,762	104,999	105,357	105,701	106,029

Hours of day	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Eastern Region (peak: 1,900 h; off-peak: 1,400 h)												
Bihar	1,995	1,960	1,882	1,960	1,966	1,899	1,977	2,246	1,977	1,870	1,878	1,887
Damodar Valley	2,315	2,272	2,182	2,272	2,292	2,241	2,348	2,667	2,348	2,219	2,225	2,232
Jharkhand	1,001	986	947	986	963	876	883	1,003	883	839	849	860
Orissa	2,799	2,737	2,628	2,737	2,851	2,970	3,211	3,647	3,211	3,022	3,007	2,993
West Bengal	4,945	4,823	4,631	4,823	5,123	5,532	6,079	6,905	6,079	5,711	5,660	5,609
Sikkim	47	45	43	45	54	71	84	95	84	78	76	74
Northern Region (peak: 2,000 h; off-peak: 0,300 h)												
Chandigarh	175	178	181	183	186	189	192	205	233	205	188	178
Delhi	3,501	3,508	3,516	3,524	3,531	3,539	3,547	3,763	4,274	3,763	3,537	3,510
Haryana	5,156	5,161	5,165	5,170	5,175	5,179	5,184	5,497	6,243	5,497	5,178	5,162

Table 3 continued

Hours of day	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Himachal Pradesh	962	971	980	989	997	1,006	1,015	1,080	1,227	1,080	1,004	973
Jammu & Kashmir	1,347	1,370	1,392	1,415	1,437	1,460	1,482	1,583	1,798	1,583	1,454	1,375
Punjab	5,682	5,656	5,630	5,603	5,577	5,551	5,524	5,841	6,634	5,841	5,557	5,649
Rajasthan	6,487	6,427	6,367	6,307	6,247	6,187	6,127	6,462	7,339	6,462	6,202	6,412
Uttar Pradesh	10,773	10,749	10,726	10,703	10,680	10,656	10,633	11,256	12,785	11,256	10,662	10,744
Uttarakhand	1,344	1,351	1,358	1,365	1,372	1,379	1,386	1,473	1,673	1,473	1,378	1,353
North Eastern Region (peak: 2,000 h; off-peak: 0,800 h)												
Arunachal Pradesh	84	85	85	86	86	87	87	92	105	92	87	87
Assam	938	957	977	996	1,016	1,035	1,054	1,128	1,281	1,128	1,054	1,035
Manipur	95	94	92	91	90	89	88	92	105	92	88	89
Meghalaya	223	224	225	227	228	229	230	245	278	245	230	229
Mizoram	53	53	53	53	52	52	52	55	62	55	52	52
Nagaland	71	73	75	76	78	80	81	87	99	87	81	80
Tripura	155	164	172	181	190	199	207	225	255	225	207	199
Western Region (peak: 2,000 h; off-peak: 0,300 h)												
Gujarat	8,113	8,136	8,159	8,181	8,204	8,227	8,250	8,755	9,944	8,755	8,221	8,141
Madhya Pradesh	5,076	5,091	5,105	5,119	5,133	5,148	5,162	5,478	6,222	5,478	5,144	5,094
Chhattisgarh	2,298	2,305	2,311	2,318	2,324	2,331	2,337	2,480	2,817	2,480	2,329	2,306
Maharashtra	12,702	12,738	12,774	12,809	12,845	12,881	12,916	13,708	15,569	13,708	12,872	12,747
Goa	315	316	317	318	318	319	320	340	386	340	319	316
Daman & Diu	217	218	218	219	219	220	221	234	266	234	220	218
Dadra & Nagar Haveli	521	522	523	525	526	528	529	562	638	562	527	522
Southern Region (peak: 1,900 h; off-peak: 0,300 h)												
Andhra Pradesh	9,106	9,053	9,000	8,947	8,895	8,868	9,342	10,611	9,342	8,884	9,021	9,159
Karnataka	5,734	5,932	6,131	6,329	6,528	6,627	7,234	8,216	7,234	6,568	6,051	5,535
Kerala	2,360	2,434	2,507	2,580	2,653	2,690	2,928	3,326	2,928	2,668	2,478	2,287
Tamilnadu	9,511	9,603	9,695	9,787	9,879	9,925	10,616	12,058	10,616	9,898	9,659	9,420
Puduchery	258	261	264	267	270	272	291	331	291	271	263	254
Total	106,357	106,450	106,311	107,191	107,988	108,543	111,622	121,745	125,228	112,667	107,762	106,780

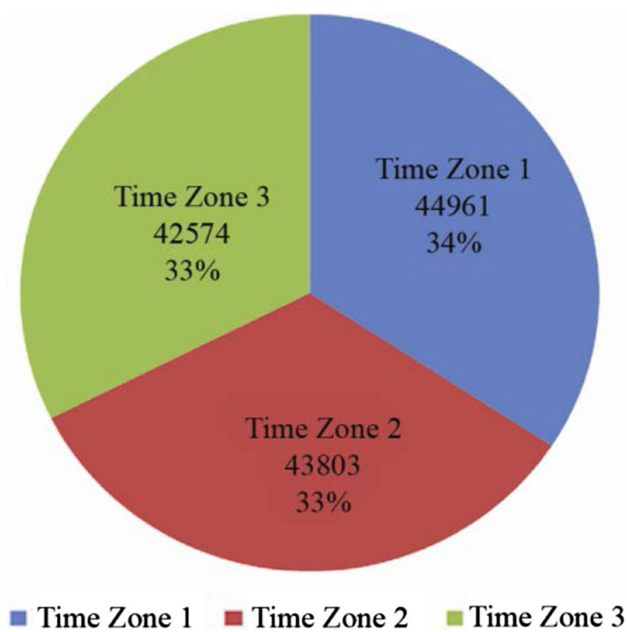

Fig. 3 Equitable distribution of aggregate peak demand in the three time zones

The earlier time zone divisions maintain a difference of 2 h only which is in line with the distance covered by the territory of India from east to west with respect to the perimeter distance of the earth surface. The earlier is expected to result in energy savings in time zone 1 due to additional daylight hours in the evenings. It is also expected to result in energy loss in time zone 3 due to reduced daylight hours in the evenings. As the aggregate peak demand in these time zones are nearly equal, the overall daylight savings effect shall be near zero.

The recast hourly demand figures for the states and union territories with groupings under the three time zones are given in Table 4. This has changed the overall peak demand to 1,18,426 MW. This gives a reduction of peak demand of 6,802 MW. The representation of the time zones in the map of India is presented in Fig. 4.

The 24 h load curves for October 11, 2013 with and without time zones is presented in Fig. 5. The Load Curves clearly establish that there is a curve flattening effect due to the introduction of three time zones. Apart from peak

Table 4 Grouping of states with equitable distribution of aggregate peak demand in the three time zones

Hours of day	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00
Time zone-1 GMT + 6:30												
Arunachal Pradesh	86	85	85	84	84	83	81	78	81	83	84	84
Nagaland	76	75	73	71	69	68	66	63	66	68	69	71
Manipur	91	92	94	95	96	97	96	92	96	97	96	95
Mizoram	53	53	53	53	54	54	53	51	53	54	54	53
Assam	996	977	957	938	918	899	872	837	872	899	918	938
Tripura	181	172	164	155	146	137	130	125	130	137	146	155
Meghalaya	227	225	224	223	222	220	216	207	216	220	222	223
West Bengal	5,507	5,455	5,404	5,353	5,302	5,251	5,200	5,149	5,098	5,047	4,996	4,945
Bihar	1,903	1,912	1,920	1,928	1,937	1,945	1,953	1,962	1,970	1,978	1,987	1,995
Damodar Valley	2,244	2,251	2,257	2,264	2,270	2,276	2,283	2,289	2,295	2,302	2,308	2,315
Jharkhand	882	893	903	914	925	936	947	957	968	979	990	1,001
Orissa	2,963	2,948	2,933	2,918	2,903	2,888	2,873	2,859	2,844	2,829	2,814	2,799
Chhattisgarh	2,261	2,206	2,118	2,206	2,253	2,259	2,266	2,272	2,279	2,285	2,292	2,298
Andhra Pradesh	9,434	9,316	8,946	9,316	9,476	9,423	9,370	9,317	9,265	9,212	9,159	9,106
Uttar Pradesh	10,906	10,733	10,306	10,733	10,935	10,912	10,889	10,866	10,842	10,819	10,796	10,773
	37,810	37,393	36,437	37,251	37,590	37,448	37,295	37,124	37,075	37,009	36,931	36,851
Hours of day	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	0:00
Time zone-1 GMT + 6:30												
Arunachal Pradesh	85	85	86	86	87	87	92	105	92	87	87	86
Nagaland	73	75	76	78	80	81	87	99	87	81	80	78
Manipur	94	92	91	90	89	88	92	105	92	88	89	90
Mizoram	53	53	53	52	52	52	55	62	55	52	52	52
Assam	957	977	996	1,016	1,035	1,054	1,128	1,281	1,128	1,054	1,035	1,016
Tripura	164	172	181	190	199	207	225	255	225	207	199	190
Meghalaya	224	225	227	228	229	230	245	278	245	230	229	228
West Bengal	4,823	4,631	4,823	5,123	5,532	6,079	6,905	6,079	5,711	5,660	5,609	5,558
Bihar	1,960	1,882	1,960	1,966	1,899	1,977	2,246	1,977	1,870	1,878	1,887	1,895
Damodar Valley	2,272	2,182	2,272	2,292	2,241	2,348	2,667	2,348	2,219	2,225	2,232	2,238
Jharkhand	986	947	986	963	876	883	1,003	883	839	849	860	871
Orissa	2,737	2,628	2,737	2,851	2,970	3,211	3,647	3,211	3,022	3,007	2,993	2,978
Chhattisgarh	2,305	2,311	2,318	2,324	2,331	2,337	2,480	2,817	2,480	2,329	2,306	2,284
Andhra Pradesh	9,053	9,000	8,947	8,895	8,868	9,342	10,611	9,342	8,884	9,021	9,159	9,296
Uttar Pradesh	10,749	10,726	10,703	10,680	10,656	10,633	11,256	12,785	11,256	10,662	10,744	10,825
	36,535	35,986	36,456	36,834	37,144	38,609	42,739	41,627	38,205	37,430	37,561	37,685
Hours of day	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
Time zone-2 GMT + 5:30												
Madhya Pradesh	5,044	4,994	4,872	4,678	4,872	4,976	4,991	5,005	5,019	5,033	5,048	5,062
Puduchery	246	238	229	220	229	235	238	242	245	248	251	254
Tamilnadu	9,180	8,941	8,649	8,305	8,649	8,868	8,960	9,052	9,144	9,236	9,328	9,420
Uttarakhand	1,328	1,304	1,266	1,216	1,266	1,295	1,302	1,309	1,316	1,323	1,330	1,337
Himachal Pradesh	943	912	879	844	879	901	910	918	927	936	945	954
Delhi	3,483	3,456	3,375	3,241	3,375	3,446	3,454	3,462	3,470	3,477	3,485	3,493
Haryana	5,145	5,129	5,021	4,821	5,021	5,123	5,128	5,133	5,137	5,142	5,147	5,151
Chandigarh	168	158	150	144	150	154	157	160	163	166	169	172
Karnataka	5,019	4,503	4,161	3,996	4,161	4,344	4,542	4,741	4,939	5,138	5,337	5,535

Table 4 continued

Hours of day	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
Kerala	2,097	1,906	1,776	1,705	1,776	1,848	1,921	1,994	2,067	2,141	2,214	2,287
	32,653	31,541	30,378	29,170	30,378	31,190	31,603	32,016	32,427	32,840	33,254	33,665
Hours of day	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Time zone-2 GMT + 5:30												
Madhya Pradesh	5,076	5,091	5,105	5,119	5,133	5,148	5,162	5,478	6,222	5,478	5,144	5,094
Puduchery	258	261	264	267	270	272	291	331	291	271	263	254
Tamilnadu	9,511	9,603	9,695	9,787	9,879	9,925	10,616	12,058	10,616	9,898	9,659	9,420
Uttarakhand	1,344	1,351	1,358	1,365	1,372	1,379	1,386	1,473	1,673	1,473	1,378	1,353
Himachal Pradesh	962	971	980	989	997	1,006	1,015	1,080	1,227	1,080	1,004	973
Delhi	3,501	3,508	3,516	3,524	3,531	3,539	3,547	3,763	4,274	3,763	3,537	3,510
Haryana	5,156	5,161	5,165	5,170	5,175	5,179	5,184	5,497	6,243	5,497	5,178	5,162
Chandigarh	175	178	181	183	186	189	192	205	233	205	188	178
Karnataka	5,734	5,932	6,131	6,329	6,528	6,627	7,234	8,216	7,234	6,568	6,051	5,535
Kerala	2,360	2,434	2,507	2,580	2,653	2,690	2,928	3,326	2,928	2,668	2,478	2,287
	34,077	34,490	34,902	35,313	35,724	35,954	37,555	41,427	40,941	36,901	34,880	33,766
Hours of day	23:00	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
Time zone-3 GMT + 4:30												
Jammu & Kashmir	1,375	1,296	1,217	1,155	1,109	1,155	1,189	1,212	1,234	1,257	1,279	1,302
Punjab	5,649	5,741	5,833	5,764	5,535	5,764	5,866	5,840	5,814	5,787	5,761	5,735
Maharashtra	12,747	12,622	12,497	12,191	11,706	12,191	12,452	12,488	12,523	12,559	12,595	12,631
Rajasthan	6,412	6,622	6,832	6,801	6,531	6,801	6,907	6,847	6,787	6,727	6,667	6,607
Goa	316	313	310	302	290	302	309	310	310	311	312	313
Dadra & Nagar Haveli	522	517	512	500	480	500	510	512	513	515	516	518
Daman & Diu	218	216	214	208	200	208	213	213	214	215	215	216
Gujarat	8,141	8,062	7,982	7,786	7,477	7,786	7,953	7,976	7,999	8,022	8,044	8,067
	35,380	35,389	35,397	34,707	33,328	34,707	35,399	35,398	35,394	35,393	35,389	35,389
National hourly demand	105,843	104,323	102,212	101,128	101,296	103,345	104,297	104,538	104,896	105,242	105,574	105,905
Hours of day	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00
Time zone-3 GMT + 4:30												
Jammu & Kashmir	1,325	1,347	1,370	1,392	1,415	1,437	1,460	1,482	1,583	1,798	1,583	1,454
Punjab	5,708	5,682	5,656	5,630	5,603	5,577	5,551	5,524	5,841	6,634	5,841	5,557
Maharashtra	12,666	12,702	12,738	12,774	12,809	12,845	12,881	12,916	13,708	15,569	13,708	12,872
Rajasthan	6,547	6,487	6,427	6,367	6,307	6,247	6,995	6,127	6,462	7,339	6,462	6,202
Goa	314	315	316	317	318	318	319	320	340	386	340	319
Dadra & Nagar Haveli	519	521	522	523	525	526	528	529	562	638	562	527
Daman & Diu	216	217	218	218	219	219	220	221	234	266	234	220
Gujarat	8,090	8,113	8,136	8,159	8,181	8,204	8,227	8,250	8,755	9,944	8,755	8,221
	35,385	35,384	35,383	35,380	35,377	35,373	36,181	35,369	37,485	42,574	37,485	35,372
National hourly demand	105,997	105,860	106,741	107,527	108,245	109,936	116,475	**118,423**	116,631	116,905	109,926	106,823

demand savings, this has also the effect of raising the demand during the off-peak demand period. This is expected to eliminate the problem of high frequency and high voltage during off-peak hours and improve System Stability [18, 19].

The results for the entire available dataset (July 2012–October 2013) [8, 11–16] is presented in Table 5. The Peak Demand savings ranges from 3,034 to 6,865 MW across all seasons. The average peak demand savings is 5,094 MW across all seasons.

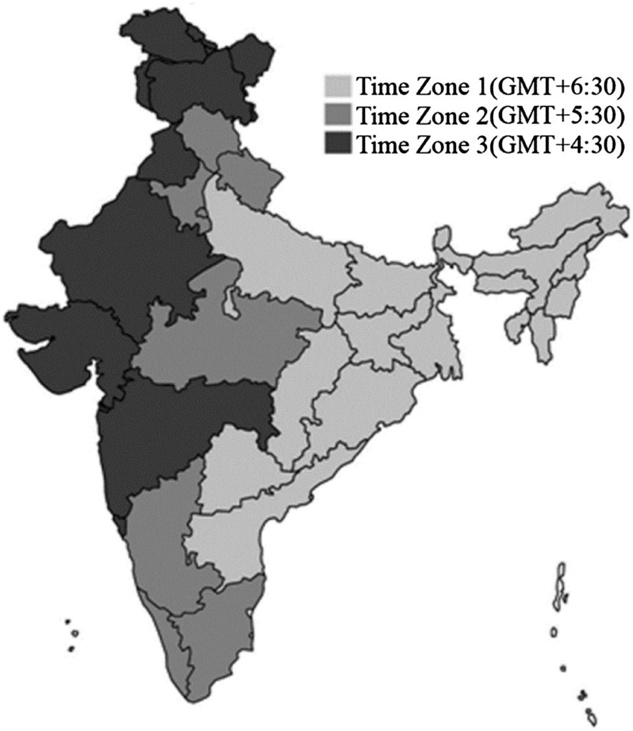

Fig. 4 Proposed time zones for reducing peak demand in Indian Power Grid

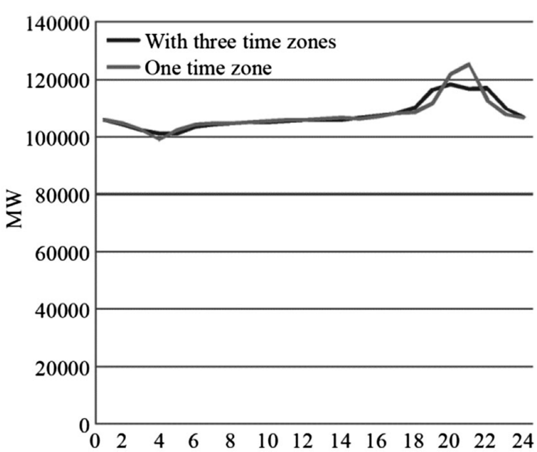

Fig. 5 Load curve for Indian Power Grid on October 11, 2013

The peak demand savings are relatively low in summer months due to air-conditioners and electric fan loads which does not vary with time. Day light savings also reduces the lighting load in evening hours. From the sector-wise power consumption pattern presented in Table 6, it is seen that the share of domestic consumption is going up [20, 21].

There is scope for further investigation into the pattern of sector-wise hourly consumption for possible measures in peak savings in specific sectors. An attempt was made in this regard by different authors [17, 22]. This problem is complex in nature and may be explored with emerging

Table 5 Peak demand savings in available dataset July 2012 to October 2013

Date	10/7/2012	10/8/2012	11/9/2012	11/10/2012	12/11/2012	11/12/2012	11/2/2013	11/3/2013	11/4/2013	10/5/2013	11/6/2013	11/7/2013	12/8/2013	11/9/2013	11/10/2013
Peak demand in Indian power grid with one time zone	120,538	117,016	117,120	124,724	118,678	119,444	117,733	120,797	130,139	135,640	127,839	126,449	117,687	128,889	125,228
Projected peak demand in Indian power grid with three time zones	116,416	112,937	110,809	117,877	113,322	112,848	114,393	116,790	125,117	131,785	124,805	122,603	111,455	122,024	118,423
Peak saving	4,122	4,079	6,311	6,847	5,356	6,696	3,340	4,007	5,022	3,855	3,034	3,846	6,232	6,865	6,805

Table 6 Sector-wise % power consumption in past 20 years

Year	Domestic	Others	Industry	Agriculture
1989–90	13	19.3	41.8	25.9
2001–02	21.3	20.5	29.3	28.9
2007–08	22.2	18.5	35.9	23.4
2008–09	22.8	18.9	35.1	23.2
2009–10	23.8	17.6	34.7	23.9
2010–11	24	18.4	35	22.6
2011–12	24.3	18.3	35.3	22.1

smart grid tools and techniques. The present paper leaves such investigation outside its scope.

Conclusion

It is seen that with figures of savings in peak demand, the maximum demand across all seasons using a single time zone is 135,640 MW and the maximum demand across all seasons using three time zones is 131,785 MW. The overall National Peak Demand can be reduced at least by 3,855 MW. It may be seen with a view that the domestic demand is not time dependent and it may not shift with shift of time zone. As domestic demand is approximately 25 % of overall demand, the reduction in overall National Peak Demand is cut down to 2,891 MW. As the Peak Demand is estimated to grow by 50 % during the twelfth 5 years plan, the peak savings is expected to increase by 50 % to 4,337 MW at the end of twelfth plan period, i.e. in the year 2017 [20, 25]. The requirement of generation capacity for a load demand of 4,337 MW is 50 % more i.e. 6,505 MW [20, 21]. So, the savings in Peak Demand will result in reduction of additional generation capacity by 6,505 MW. Based on the latest estimates by US Energy Information Administration (April 2013) [23, 24]. Capital Expenditure for creation of every 1 MW in coal-fired generation capacity (excluding transmission) is US$3.5 million i.e. approximately Rs. 20 Crore/MW. Therefore, reduction in additional generation capacity by creation of time zones is 6,505 MW and expected savings in capital expenditure in the next 5-year plan period is Rs. 1,30,100 Crore.

In addition to savings in capital expenditure, this strategy will improve the utilization of the existing generating stations and increase their plant load factor. There is also savings in fixed operation and maintenance cost which would be required for the additional generation capacity.

Substantial savings are also expected in operation cost. The average peak demand savings may be cut down by 25 % to consider the domestic demand factor and a peak demand savings of 3,820 MW on an average across all seasons is arrived. It may be fairly estimated that on a daily basis, 4,000 MW unit capacity will not be required to be fired. Based on the latest estimates by US Energy Information Administration (April 2013) [23, 24], the operating cost for generating 1 MWh is estimated to be US$50/MWh i.e. Rs. 3,000/MWh. For 1 h of additional peak load of 4,000 MW, the additional coal-fired units will have to operate for at least 4 h. Whereas the peak demand is flattened and energy consumption is met by spinning units, the additional units will consume fuel for additional 3 h every day.

So, daily savings in operation cost due to reduction of peak generation by 4,000 MW is Rs. 3.6 Crore

In a year, the estimated savings in operating costs is Rs. 365 × 3.6 Crore = Rs. 1,314 Crore.

To conclude, a comparative assessment of the various suggested schemes is made and presented in Table 7.

The costs associated with implementation of the earlier time zones must not be neglected. There will be both one-time and recurring expenses for publicity, advertisements, time tables, mandatory hoardings in the State borders where time zone changeover occurs. This is estimated to be within a total of Rs. 100 crore for the next 5 years.

The major expenses for time zone divisions shall be for the equipment of NPL for the standard time and frequency systems. The changes required in the transmitter-end equipment may be incorporated with little time and cost but the receiver-end equipment are widely spread across India and are almost countless. The time and cost required for the changes in the receiver-end equipment can be estimated only by the concerned authorities. However, this

Table 7 Comparative assessment of suggested schemes

	Net saving in energy, million kWh/year	Net savings in per year, Rs. crores	Net reduction in installed capacity, MW	Net savings in capital cost in a 5 years plan, Rs. crores
Adavaning IST by ½ h (NIAS)	1,825	547.5	Nil	Nil
Two Time Zones—GMT + 6 and GMT + 5 (TERI)	−540	−162	Nil	Nil
Three Time Zones—GMT + 6:30, GMT + 5:30 and GMT + 4:30 (present paper)	4,380	1,314	6,505	1,30,100

is only a one-time expenditure and will not be repeated in the future 5-year plan periods. This one-time expenditure may be fairly estimated to be within Rs. 100 crore.

The earlier estimation shows that against the savings in capital expenditure of Rs. 1,30,100 crore, the expenses shall be limited to Rs. 200 crore over a 5 years time period. Whereas the expenditure is one-time only, the national savings and benefits will be perpetual. In addition, it has also been explained that there will be daily savings of Rs. 3.6 crore in recurring expenditure of operation and maintenance necessary for operating additional Power Generation of 4,000 MW on an average. In the premises, it is expected that the implementation of time zone division shall result in substantial savings in both capital and recurring expenditure. The benefits of the proposed scheme shall be best availed in the integrated national power grid operation proposed in 2014.

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