Impact of Generation Constraints on Partial and Major Blackouts

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***Abstract*—The installed capacity gets reduced due to planned and forced outages. The capacity on bars is further reduced due to various generation constraints which include problems with plant auxiliaries, fuel shortages, bad quality of fuel etc. The generation constraints have an impact on the availability of generation and leads to severe power shortages especially in developing countries. By managing the generation constraints, the daily load shedding can be minimized to a great extent. The generation constraints have greater influence than major grid disturbances which occur once or twice in a year. The paper discusses in detail the extent of generation constraints in Western regional grid of India and suggests recommendations to overcome these. A case study of major grid disturbance that occurred on 30th July, 2002 is discussed in the paper which highlights the effect of generation constraints on the pre-fault conditions.**

***Index Terms*—Generation constraints, System blackout, Voltage collapse and Restoration.**

I. Introduction

A sizeable amount of generation is lost due to generation constraints. The generation constraints include problems with plant auxiliaries, fuel shortages, problems related to quality of fuel, high frequency, reduction of active power generation due to transmission line outages, generation reduction due to high frequency, minor and major grid disturbances etc. Due to planned outages, forced outages and generation constraints, about 70% of the installed capacity is only available to meet the loads thus leading to shortages and load shedding. Western region of India suffers from a deficit of 6000 MW and consumer load is shed in order to meet this large deficit. With an installed capacity of 31964 MW (as on 30th June, 2004) in Western region, the peak demand met is only of the order of 24000 MW whereas the demand of the region is of the order of 30000 MW.

The generation constraints have been examined for all the generating stations of Western region from three years data viz.,2000-01. 2001-02 and 2002-03. In 2001-02, grid disturbances accounted for hardly 213 Mus, out of 29225 Mus lost due to all the factors described above. Similarly, in 2002-03 (in five months from April 2002 to August 2002), 84 Mus accounted for grid disturbances out of total loss of generation of 11113 MUs on all the factors. The paper also discusses various other constraints faced by generating stations due to which the generation availability was seriously hampered.

A case study of generation constraints was also undertaken to examine the impact of generation constraints on the grid disturbance of 30th July, 2002. The generation constraints have been studied for each of the power stations. Out of effective total installed capacity of 31186 MW in Western region, 23454 MW capacity was on bars on 30.07.02 accounting for the planned and forced outages. However, the total generation available to meet consumer load was only 19578 MW. A staggering 4830 MW generation was lost due to various constraints including shortage of water in the reservoirs prevailing on the day. These constraints coupled with lack of hydro generation led to capacity shortage and low frequency prevailed around 48 Hz on that day. The entire Western regional grid collapsed due to onset of further loads during evening peak hours as frequency fell further to 47.5 Hz and the generating units tripped on under frequency protection. The loss of generation due to the grid disturbance on 30.7.02 was computed (the procedure explained in the paper) works out to 234 MUs. This is equivalent to loss of Rs.50 crores to the generating stations on account of non availability of generation and more than Rs.1000 crores to the Indian economy. These statistics on blackouts appear dramatic and significant due to sudden impact on normal life. But what is not adequately addressed is the generation constraints that cause reduced availability leading to load shedding and power cuts every day. In 2001-02, the generation lost due to constraints is staggering 3336 MW.

The paper describes a case study in which analysis in detail was carried out on generation constraints at various power stations and loss of generation due to the grid disturbance. The paper also discusses generation constraints related to various problems that are causing load shedding in the region on a daily basis. The paper also gives some recommendations for managing the constraints. If 10% more generation is made available by managing the constraints, additional 3000 MW consumer load can be met

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which can reduce the power deficit to a large extent. This would also save investment of more than Rs.12000 crores.

II. GENERATION CONSTRAINTS

Even though the installed capacity of Western region is 31964 MW, the peak demand met is of the order of 24000 MW only. Table-I gives details of installed capacity and peak demand met in Western region since 1991-92.

TABLE- I RATIO OF PEAK DEMAND MET TO EFFECTIVE CAPACITY

YEAR	EFFECTIVE INSTALLED CAPACITY (MW)	PEAK DEMAND MET(MW)	%
1991-92	20952	13585	64.84%
1992-93	22176	14663	66.12%
1993-94	22652	15553	68.66%
1994-95	24030	16760	69.75%
1995-96	24601	17644	71.72%
1996-97	24853	18417	74.10%
1997-98	26244	20402	77.74%
1998-99	26984	20926	77.55%
99-2000	30400	22373	73.60%
2000-01	31013	22334	72.01%
2001-02	31186	23574	75.59%
2002-03	31251	23907	76.50%

The peak demand met is about 76% of the installed capacity. The reduced availability of generation is due to planned outage of generating units for maintenance works(annual overhaul and capital overhaul), forced outage of generating units, partial outages (non availability of some auxiliaries) and generation constraints. Table-II list out the generation constraints and the loss of generation due to these constraints.

TABLE II GENERATION CONSTRAINTS

(ALL FIGURES IN MUS)

Problem	**2002-03**		**2001-02**		**2000-01**
	(WR)	**(C.S)**	**(WR)**	**(C.S)**	**(NTPC)**
Auxiliary problem	2220.671	1280.663	8651.257	5508.221	4904.687
Coal/Gas shortage	2517.422	762.362	4046.669	683.647	2950.476
Coal/Gas problem	453.51	0	2786.981	1484.887	623.57
High frequency	505.163	185.625	1916.922	986.387	50.738
Line outage	18.536	1.861	51.27	3.123	0
Line constraints	0	0	0	0	0
Grid disturbance	84.021	0	212.769	0	0
Other reasons	5313.686	0	11595.28	0	0
Total	11113.01	2230.511	29225.15	7679.88	8529.471

The data used for analysis[1] consists of all the generating plants in the region for the year 2001-02, and for five months (April '02-August '02) in the year 2002-03 and National Thermal Power Corporation (NTPC) plants only for the year 2000-01. In 2001-02, the loss of generation due to constraints is 29225 MUs which works out to 3336 MW at 100% load factor which is substantial. This is around 10.69% of the installed capacity in that year. Analysis of Table-II reveals:

1) In 2001-02, 29225. Mus of energy is lost (could not be generated) due to various constraints listed in Table-II. At 100% load factor, the energy lost is equivalent to 3336 MW (10.7% of installed capacity).
2) In 2002-03, 11113 Mus of energy is lost due to various constraints in five months (3672 Hrs) which is equivalent to 3026 MW (9.68% of installed capacity) at 100% load factor.
3) In 2000-01, 8529 Mus of energy is lost due to various constraints which is equivalent to 974 MW (17.2% of installed capacity of NTPC stations).
4) In general, about 10% of the capacity on bars is unavailable/unutilized due to the constraints listed in the table.
5) Generation capacity not available (backed down) due to the line outages is a minor factor.
6) Generation reduction due to high frequency conditions in the grid accounted for less than 1% of the capacity on bars and this problem has become insignificant after 01.07.2002 due to the introduction of ABT in Western region.
7) Fuel (coal/gas) related problems accounted for significant loss of generation with about 318 MW generation lost during 2001-02 and 123 MW during five months in 2002-03. The problem is more during the rainy season when problems such as conveyor belt problem, wet coal problem, coal mill problems, poor quality of coal are generally predominant.
8) The coal/gas shortages accounted for 22.6% of the generation lost in 2002-03 (685 MW); 13.8% in 2001-02 (462 MW). The gas based power stations of Uran, Kawas and Jhanor were affected due to non availability of gas.
9) The generation lost due to grid disturbances was also insignificant (less than 1%).
10) The most significant factor contributing to reduction of capacity on bars is due to problems with the auxiliaries – 29.5% in 2001-02 & 20% in 2002-03. The main problems encountered with auxiliaries include boiler feed pump problems, Induced draft (ID) fan problems, Electrostatic Precipitator (ESP) problem, Primary Air (PA) fan problem etc.

Other Constraints

1) The other problems reported to have been due to reduction of active power for generating reactive power (during Rabi season/agricultural season), raw water problem due to drying up of rivers, cooling tower problems, conveyor belt breakdowns etc.
2) The hydro generation constraints are predominantly due to less water in the reservoirs due to poor monsoon.
3) Commercial problems also account for bottling up of generation. Surplus generation available with some of

the licensees in Maharashtra could not be utilized. This problems are likely to be solved with the introduction of Intra-State Availability Based Tariff (ABT) in Maharashtra.

4) Generation at power stations operating on Naphtha are not dispatched due to high cost of fuel.

The later two have not been included in the data given in Table-II.

III. CASE STUDY OF GRID DISTURBANCE ON 30.07.2002

Western Regional Grid demand had gone up from 13th of July, 2002 with stoppage of rains and regional requirement increased by more than 20% compared to that during the same period of previous year. Availability of power, on the other hand, had actually come down due to multiple thermal outages. Anticipating normal monsoon, number of thermal units were taken out for planned maintenance as per the annual overhaul plan. However, due to dry spell after first week of July, the demand shot up especially due to running of agriculture pump sets. Capacity under outage in the regional grid was in the range of 6000 to 6500 MW. On 30.7.02, the total capacity under planned and forced outage is as high as 6067 MW. This includes 1395 MW of bottled up power at Dabhol (740 MW) and units not scheduled at Gujarat Paguthan Energy Corporation (GPEC) (655 MW) under planned outage and 1675 MW under forced outage. Hydel availability had also reduced due to depleted reservoir levels. Hydro generation is less than half of the installed capacity even during peak hours. The hydro generation during peak hours is around 2280 MW whereas the installed hydro capacity is 4342 MW. About 2761 MW generation is not available due to partial outages/constraints at thermal and gas power plants out of the installed capacity of 26084 MW (10.6%). The availability works out to about 19578 MW against installed capacity of 31186 MW (excluding 589 MW wind power). All these factors had contributed to large gap between demand and availability (shortfall of about 5000 MW) leading to continuous low frequency operation from 13th July, 2002 as the load shedding done is of the order of only 4000 MW against the required quantum of 5000 MW. The generation constraints[2] and loss due to these constraints is detailed in Tables-III & IV.

TABLE –III SUMMARY OF LOSS OF GENERATION FOR 30.07.2002

Power Station / Unit	Derated Capacity (MW)	Capacity on bar (MW)	Generation on 30.7.02 (MW)	Gen.loss due to constraints (MW)
Gujarat				
Total (H)	547	150	150	397
Total (Thermal)	7088.1	4564	3980	584
Total (H+T)	7635.1	4714	4130	981
Madhya Pradesh				
Total (H)	801	184	184	617
Total (Thermal)	2147.5	1407.5	1191	216.5
Total (H+T)	2948.5	1591.5	1375	833.5
Chhattisgarh				
Total (H)	120	120	70	50
Total (Thermal)	1240	1040	969	71
Total (H+T)	1360	1160	1039	121
Maharashtra				
Total (H)	2891.38	2851.38	1773	1005.38
Total(Thermal)	9878	7527	6085	1451
Total (H+T)	12769.38	10378.38	7858	2456.38
Central Sector				
Total NPC	760.00	760.00	652.00	108.00
Total NTPC	5673.59	4810	4484	330
Western Region				
Hydro	4359.38	3305.38	2177	2069.38
Thermal	26066.99	19388.3	16749	2652.5
Nuclear	760.00	760.00	652.00	108.00
Grand Total	**31186.37**	**23453.68**	**19578**	**4829.88**

TABLE-IV LOSS OF GENERATION DUE TO CONSTRAINTS ON 30.7.02

(PLANT-WISE)

Power Station / Unit	Derated Cap. (MW)	Cap.on bar (MW)	Gen.on 30.7.02 (MW)	Gen.loss due to constraints (MW)	Remarks
Gujarat					
Hydro					
Ukai(H)	300.00	150.00	150.00	150.00	
Ukai LBCH	5.00	0.00	0.00	5.00	Low reservoir levels
Kadana	240.00	0.00	0.00	240.00	
Panam canal	2.00	0.00	0.00	2.00	
Total (H)	547.00	150.00	150.00	397.00	
Thermal					
AECO	490.00	457.50	418.00	39.50	-
Dhuvaran	561.00	230.50	65.00	165.50	Furnace oil shortage
Ukai(Th)	850.00	320.00	280.00	40.00	Ageing of units 1&2
Gandhi Nagar	870.00	750.00	678.00	72.00	Raw water problems & Coal problems
Wanakbori	1470.00	1470.00	1408.00	62.00	Coal related problems
Utran	174.00	174.00	85.00	89.00	
Sikka	240.00	120.00	120.00	0.00	
Kutch Lignite	215.00	0.00	0.00	0.00	
IPPs					
GIPCL	305.00	305.00	265.00	40.00	Gas shortage
Surat Lignite	250.00	125.00	124.00	1.00	-
Essar	515.00	515.00	440.00	75.00	Gas shortage
GPEC	655.00	0.00	0.00	0.00	Not scheduled due to high cost of Naphtha
Hazira GSEG	156.10	0.00	0.00	0.00	
RPL	240.00	0.00	0.00	0.00	
Import from GACL	97.00	97.00	97.00	0.00	
Total (Thermal)	7088.10	4564.00	3980.00	584.00	
Total(H + T)	7635.10	4714.00	4130.00	981.00	
Madhya Pradesh					
Hydro	801.00	184.00	184.00	617.00	Low reservoir levels

Power Station / Unit	Derated Cap. (MW)	Cap.on bar (MW)	Gen.on 30.7.02 (MW)	Gen.loss due to constraints (MW)	Remarks
Thermal					
Amarkantak	290.00	170.00	130.00	40.00	
Satpura	1017.50	397.50	371.00	26.50	Coal mill problems
S.Gandhi TPS	840.00	840.00	690.00	150.00	Coal mill problems& Silica content high
Total Thermal	2147.50	1407.50	1191.00	216.50	
Total (H + T)	2948.50	1591.50	1375.00	833.50	
CHHATISGARH					
Hydro					
Hasdeo Bango	120.00	120.00	70.00	50.00	Low reservoir levels
Thermal					
Korba (E)	400.00	200.00	174.00	26.00	Coal related problems
Korba(W)	840.00	840.00	795.00	45.00	Coal related problems
Total Thermal	1240.00	1040.00	969.00	71.00	
Total(H+T)	1360.00	1160.00	1039.00	121.00	
MAHARASHTRA					
Koyna	1960.00	1920.00	1339.00	581.00	Low reservoir levels
Tata Hydro	447.00	447.00	374.00	-	
Small Hydro	484.38	484.38	60.00	424.38	Low reservoir levels
Total(H):	2891.38	2851.38	1773.00	1005.38	
Thermal					
Nasik	910.00	700.00	575.00	125.00	Coal related problems
Trombay	1330.00	1330.00	1307.00	23.00	-
Koradi 1-4	1080.00	755.00	626.00	129.00	Coal related problems
Bhusawal	478.00	420.00	342.00	78.00	Coal related problems
Parli	690.00	690.00	388.00	302.00	Coal problems & active energy back down to generate reactive energy
Paras	58.00	0.00	0.00	0.00	Non-availability of gas
Uran	912.00	912.00	417.00	495.00	
Chandrapur	2340.00	1630.00	1409.00	221.00	Coal problems & Pollution control norms & ESP problems
Kaperkheda	840.00	840.00	762.00	78.00	Coal related problems
Dahanu-1&2	500.00	250.00	259.00	-	
IPP					
Dabhol PH - I	740.00	0.00	0.00	0.00	Not scheduled
Total Thermal	9878.00	7527.00	6085.00	1451.00	
Total(H+T)	12769.38	10378.38	7858.00	2456.38	
Goa, Reliance power, Salgoancar	39.80	39.80	40.00	0.00	
Central Sector					
N P C					
Tarapur	320.00	320.00	300.00	20.00	
Kakrapar	440.00	440.00	352.00	88.00	Cooling water problem
Total NPC	760.00	760.00	652.00	108.00	
N T P C					
Korba S T P S	2100.00	1920.00	1870.00	50.00	Poor quality of coal
Vindhyachal STPS	2260.00	1850.00	1812.00	50.00	Poor quality of coal
Kawas	656.20	540.00	432.00	100.00	Gas shortage
Gandhar	657.39	500.00	370.00	130.00	Gas shortage
Total NTPC	5673.59	4810.00	4484.00	330.00	
Western Region					
Hydro	4359.38	3305.38	2177.00	2069.38	
Thermal	26066.99	19388.30	16749.00	2652.50	
Nuclear	760.00	760.00	652.00	108.00	
Grand Total	31186.37	23453.68	19578.00	4829.88	

The hydro generation constraints mainly comprise low reservoir level (2069 MW). In respect of thermal and gas based power stations, the following constraints have been reported:

- Shortage of gas (840 MW at GIPCL, Essar, Kawas, Jhanor, Uran)
- Coal related problems (843 MW at Korba, Vindhyachal, Wanakbori, Korba East, Korba West, Nasik, Koradi, Bhusawal, Khaperkheda & Parli).
- Coal mill problems and high silica content in coal (177 MW at Satpura and Birsinghpur)
- Furnace oil shortage (166 MW at Dhuvaran)
- Raw water shortage (72 MW at Gandhinagar)
- Pollution control norms and ESP problem (221 MW at Chandrapur)
- Cooling water problem (83 MW at Kakrapar)
- Active power backed down for reactive power generation (102 MW at Parli)
- Not scheduled due to high cost of Naphtha(655 MW at GPEC)
- Others (257 MW)

Under continuous low frequency conditions, the States in the region have been overdrawing at low frequency and consequently reduced the security levels. The States in the region were unable to carry out scheduled load shedding as per the scheme worked out by Western Regional Load Despatch Centre (WRLDC). System frequency touched 48 Hz more than 50 times each day from 28th July onwards. On 30.7.02, system frequency touched 48 Hz on 74 occasions. The continued low frequency operation around 48 Hz led to bypassing of the under frequency relays by the constituents in view of repeated under frequency (UF) relay operations and consumer protests.

On 30.07.2002, during evening peak hours, Western region was catering to a demand of around 19900 MW with a load shedding of 3900 MW with frequency hovering around 48 Hz[3]. Table-V shows the details of utility-wise catered demand and load shedding in the region during evening peak hours. A comparison of utility-wise load shedding and generation constraints indicates the impact of generation constraints on load shedding.

TABLE-V PRE-FAULT CONDITIONS

S. No	Constituent	Catered Demand (MW)	Load Shedding (MW)	Gen. constraints (MW)
1.	CSEB	1100	100	121
2.	GEB	6000	1000	981
3.	MPSEB	3150	1000	834
4.	MSEB	9550	1800	2456
5.	GOA	100	NIL	NIL
	TOTAL	19900	3900	4392*

*Additional constraints at Central Sector stations amount to 438 MW.

At 1930 hrs, system frequency was 48.2 Hz and the frequency decayed to 47.60 Hz by 1932 hrs. Madhya Pradesh State Electricity Board(MPSEB) was overdrawing by 470 MW and Maharashtra by 90 MW. Gujarat carried out distress load shedding of 150 MW immediately and frequency improved to 48.60 Hz. However, MPSEB's overdrawal continued and increased upto 700 MW. At 2007 hrs, system frequency was 48.30 Hz and system frequency decayed steadily to 47.59 Hz in about 4 minutes. At this

time, the onset of peak load in Gujarat started. Some of the hydro stations in Maharashtra and M.P also withdrew units at this time due to reduction of demand in these States. The U.F relays (discrete) at 48.2 Hz and 47.9 Hz did not operate apparently as the relays are bypassed or the feeders with UF relays were tripped for manual load shedding. The constituents also could not react to falling frequency by carrying out distress load shedding. Distress load shedding or U/F load shedding of even 150 MW could have saved the system.

At 201126 hrs. Western Regional Grid frequency dipped to 47.59 Hz due to overdrawal of MPSEB by 500 MW (Schedule 1246 MW, Drawal 1750 MW). As frequency touched 47.6 Hz, the islanding schemes of Tata Power Company (TPC) /Reliance Energy Ltd (REL), Kakrapar, Ahmedabad Electric Co.(Gas) and Gujarat Industrial Power Corporation Ltd (GIPCL) Stage-I operated. Utran units and Jhanor units went on house load and survived.

With all the four islanding schemes operated, the rest of the grid lost about 180 MW. At 2011 hrs. the system stiffness of WR grid is around 650 MW per Hz. The loss of 180 MW resulted in frequency going below 47.5 Hz and a number of gas, thermal and nuclear generating units at Tarapur Atomic Power Station (TAPS) tripped in cascade due to operation of generator under frequency protection (set at 47.5 Hz).

TABLE VI LOSS OF GENERATION DUE TO GRID DISTURBANCE ON 30.07.2002

(All figures in MUs)

State/ system	Gen. on 27.7.02	Gen. on 28.7.02	Gen. on 29.7.02	Total gen. of 3 days	Gen. on 30.7.02	Gen on 31.7.02	Gen on 1.8.02	Total gen of 3 days	Gen lost due to grid dist.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(4)-(8)
GEB	80.84	79.74	84.85	245.42	74.80	56.49	78.19	209.48	35.94
MPSEB	34.13	40.40	32.81	107.34	28.22	16.46	31.71	76.39	30.96
CSEB	27.54	26.08	23.28	76.90	20.14	20.05	26.10	66.29	10.61
MSEB	164.21	156.74	163.18	484.13	139.48	96.25	154.45	390.19	93.94
Goa	0.78	0.78	0.73	2.29	0.00	0.74	0.79	1.53	0.76
NTPC	117.75	113.58	114.33	345.66	98.13	85.80	117.00	300.93	44.73
NPC	18.09	17.69	16.80	52.58	13.65	9.45	12.79	35.89	16.68
Western Region	**443.33**	**435.01**	**435.98**	**1314.32**	**374.43**	**285.23**	**421.04**	**1080.70**	**233.63**

The loss of generation due to this major grid disturbance has been computed by comparing the generation available (from the units on bar on the day of the occurrence) three days prior to the occurrence and three days from the day of the occurrence (including the day of occurrence) as total normalization took around three days[2]. The detailed calculation is shown in Table-VI. the loss of generation is around 233.63 MUs which is equivalent to 9735 MW.

IV. CONCLUSIONS ON IMPACT OF GENERATION CONSTRAINTS

The impact of generation constraints is equivalent to inability to meet more than 3000 MW load on each day. The load shedding (partial blackouts) can be drastically reduced if the generation constraints are minimized. The partial blackouts that are experienced everyday can be contained.

The major grid disturbances are also preceded by severe generation constraints as seen from the case study of 30.07.2002 major occurrence. Better pre-fault conditions would reduce the extent and duration of the blackout.

More attention should be given to managing the generation constraints and this thrust should be equivalent to that given for defense plans against major collapses. A major disturbance once in a while could be less painful than a partial blackout each day.

The financial loss in one year (2001-02) due to the generation constraints is of the order of Rs.6000 crores in one year whereas the financial loss due to a major grid disturbance is around Rs.50 crores to the generators and utilities.

The availability of the generators and their P.L.F increase significantly if the generation constraints are properly addressed.

V. RECOMMENDATIONS

Many of the problems faced by the thermal generating units is due to coal related problems. At present, the auxiliary consumption from all thermal stations in the region is around 2000 MW. It is possible to reduce auxiliary consumption by at least by 2% which would enable wheeling of additional 400 MW demand. Bad quality of coal even leads to more forced outages and increased anciliary consumption. Blending of Indian coal with imported coal would improve the availability & P.L.F of thermal units to a great extent.

Introduction of ABT at the inter-regional level helped in merit order operation and total elimination of high frequency. Due to lack of similar mechanism at the intra-state level, utilization of surplus power with licensees, Independent Power Producers (IPPs) and Captive Power Plants (CPPs) could not be done. Intra-state ABT would release all bottled up generation and ensure merit order.

Restructuring and reforms should be speeded up so that separate generating companies (GENCO) would give more focus to generation constraints. Application of ABT norms in the intra-state level (as at the inter-state level) would ensure high availability.

Shortage of gas supplies has been adversely affecting the power sector. In Western region, the gas based power plants at Kawas & Jhanor were seriously affected due to shortage of gas. Out of the 1310 MW capacity, about 500 MW generation from these plants could not be used. In case of Uran power station of Maharashtra, shortage of gas led to generation of around 450 MW even though the installed capacity of the station is 912 MW. Back to back contracts with the gas suppliers would compensate the generators and allow them to arrange for alternative supplies.

Hydro power projects should be conceived with pumped storage schemes so that water can be reused and conserved. Pumped storage schemes also make the demand profile flatter and help in effective frequency control. Some of the pumped storage schemes in the region (150 MW pumped storage scheme at Bhira, 240 MW plant at Kadana) could not be made operational due to non-availability of cheap off-peak power. With the introduction of ABT at the intra-state level, even the plants of private licensees can draw cheap off-peak power for pumping at the unscheduled interchange (UI) rates applicable under ABT.

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VII. REFERENCES

[1] Minutes of the Operating Committee Meetings of Western region.
[2] Data collected from the power utilities in Western Region constituents.
[3] Report of “Grid disturbance on 30.07.2002” prepared by WRLDC, POWERGRID.

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