Security Constrained Economic Despatch – India: A Rolling Block Implementation Framework

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***Abstract*— Electric distribution utilities in India procure power through long term, medium term, as well as short term power purchase agreements (PPAs), most of which have been discovered through non-competitive route with regulatory approval. Optimisation of state/specific power procurement portfolio is undertaken by the Distribution Companies (DISCOMs) and utility implemented by the SLDCs on a day-ahead basis. Security Constrained Economic Despatch (SCED) is the major initiative taken by Power System Operation Corporation Limited (POSOCO) to ensure the minimum generation cost over the interstate power procurement portfolio across all states. This paper reviews development leading to introduction of SCED. Energy Analytics Lab (EAL) developed a SCED modelling framework and implemented the same and suggested SCED implementation on a rolling block basis spread over blocks. The results show the effectiveness in minimising the cost of generation by introducing multi-period, rolling time block algorithms. These algorithms have the efficacy to harness the cheaper generation resources at inter as well as intra-state level.**

Keywords — Electricity Market, Security Constrained Economic Despatch, Rolling Block, Power Procurement

I. INTRODUCTION

Cost of power procurement constitute about 70-75% of total cost of electricity supply to consumers. A reduction in the same can be ensured through competitive procurement of power and merit order scheduling of the power procurement portfolio [1]. While the power can be ensured by a reliable long-term demand forecast fostered by competitive procurement of power as per the desired procurement strategies, the latter needs to be implemented near to the time of consumption. Merit Order Despatch (MoD) is traditionally implemented by the respective state load despatch centre (SLDC) on a day-ahead basis. Even after effective implementation of the MoD within each state, there is room for further optimisation across the power procurement portfolio of states. This philosophy was implemented by POSOCO on a pilot basis since April 2019. It has resulted in cost savings through nationwide optimisation, after ISGS schedules have been frozen by respective states [2].

Current framework implemented by POSOCO applies block by block optimisation for ISGS schedules across states. Ramping constraints and technical minimum capacity of plants limit the optimisation space for single block SCED framework. We develop a multi-period SCED model and demonstrate higher savings by adoption of 4 to 7 blocks at a time. Based on least cost associated with an optimisation horizon of rolling blocks, followed by multi-period block and block by block, we suggest that the existing framework implemented by POSOCO can adopt multi-period SCED optimisation horizon by considering 5 blocks at a time.

The paper is organised as follows: Section I gives an insight into the reformation of Indian Power Sector from post-independence era to enactment of Electricity Act (EA) 2003. Section II presents brief overview of power procurement practices of distribution utilities, highlighting key statistics about few states. Recent developments in the Indian power market are discussed in Section III and Section IV and V present the proposed SCED implementation framework. Results and discussions are set out in section V. Section VI concludes the paper with key recommendations.

II. INDIAN POWER SECTOR: COMPETITIVE AND NEGOTIATED PROCUREMENTS

To meet the energy demand, vertically integrated State Electricity Boards (SEBs) made decisions for capacity addition or expansion of existing generating plants. Emergence of inter-state connections leading to development of regional grids, and setting up inter-state generating stations shifted part of the procurement from the publicly owned central sector entities. Investment decisions were purely focused on supply requirements. Post EA 2003, such investment and their tariff were either to be regulated (under section 62) or be determined on competitive basis (under section 63) [3]. EA 2003 also enabled development of short-term electricity market through trading and power exchanges [4]. Bilateral transactions between states continued as per prevailing operational practices under regulatory jurisprudence. However, long term power procurement continues to dominate overall portfolio of distribution utilities with 12% met through the short-term market.

A. Long-term Power Markets

Prior to Electricity Act 2003, the decisions for long-term power procurement rested with respective SEBs with due techno-economic clearances from Central Electricity

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Authority (CEA). After the implementation of the Act, the transmission and bulk supply companies were given the responsibility to procure power on behalf of the public distribution utilities. Currently, long-term market through PPA accounts for around 89% of the power market [1].

B. Short-term Power Markets

To meet short-term needs (less than a year), distribution utilities resort to procurement of electricity through the available regulated or competitive routes. Short term power market in India currently accounts for 12% of total generation (2019) up from 10% in 2017 [5].

Fig. 1, 2 and 3 shows the power procurement data for 9 different states for FY 2018-19.

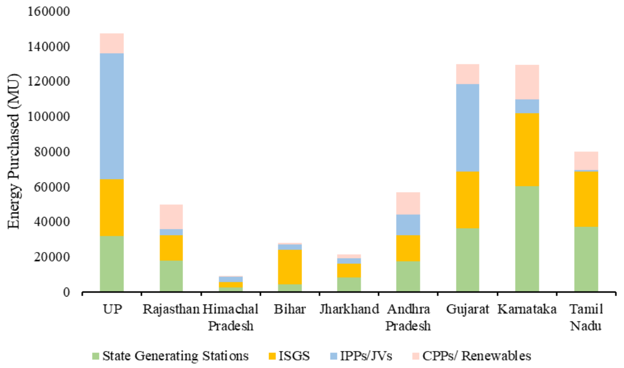

Fig. 1. Energy Purchased by different states for FY 2018-19

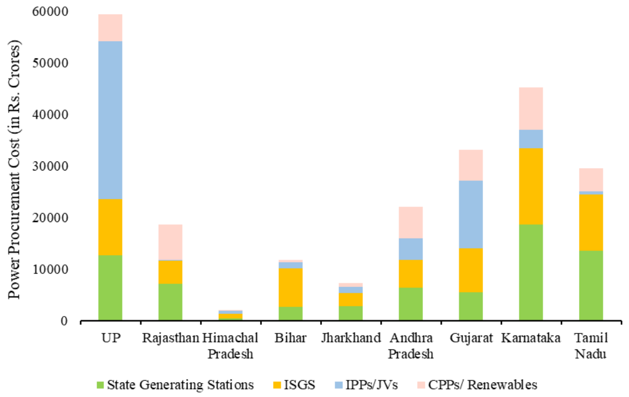

Fig. 2. Power Procurement Cost for different states for FY 2018-19

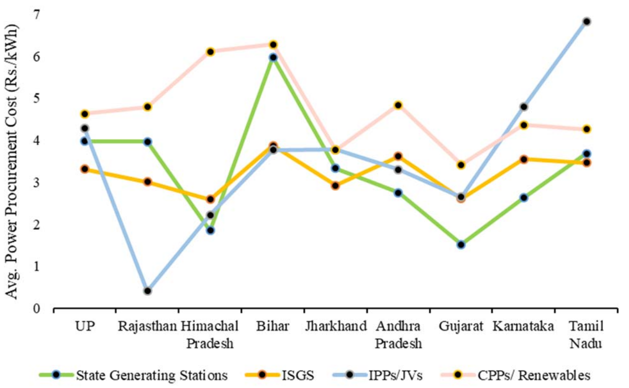

Fig. 3. Average Power Procurement Cost for different states for FY 2018-19

The total electricity generation in India was 108355.60 Million Units (MUs) excluding renewable and captive power plants. Of the total electricity generation, 14407.09 MUs (13.30%) was transacted through short-term, comprising of 7501.77 MUs (6.92%) through bilateral (through traders and term-ahead contracts on power exchanges and directly between distribution companies), followed by 4800.72 MUs (4.43%) through day ahead collective transactions on power exchanges and 2104.60 MUs (1.94%) through Deviation Settlement Mechanism (DSM) [5].

III. Recent Developments In Indian Power Market

Post Electricity Act 2003, Central Electricity Regulatory Commission (CERC) has been empowered to enable power market development. Consequently, CERC issued guidelines for setting up power exchanges, leading to setting up of Indian Power Exchange (IEX), the first power exchange. Later, another power exchange PXIL was set up on 2008. Day-ahead market remains the largest traded contract on the power exchange. Such collective transactions between prospective buyer and sellers are based on prices in a competitive manner. As mentioned earlier, this covers only 12% of the energy consumed in the sector, leaving most of the transaction out of the competitive framework. CERC has initiated discussions on bringing in greater competition and efficiency leading to a more competitive and cost-efficient market in future.

A. Redesigning of Real Time Market

On 25th July 2018, CERC released a discussion paper on "Redesigning the Real Time Electricity Market in India" expressing the need to change the framework of the real time market in India to reduce the energy and system imbalances [6]. Currently, the imbalances in power sector are handled through DSM and Ancillary Services Mechanism (ASM) and partly through rescheduling and intra-day market in the power exchanges. However, the stakeholders started depending on the DSM to meet their real time energy needs which became a challenge to the grid security.

To mitigate this issue, CERC proposed an hourly market based on Market Based Economic Despatch (MBED) with uniform clearing price which contrasts with the continuous trade in intra-day market segment. Another significant feature of this market is Gate Closure, required to bring the desired stability in schedule and market transactions in real time.

After receiving and considering comments on the proposed framework from 21 stakeholders, CERC released an explanatory memorandum on revising the market framework making it a half hourly market as opposed to the hourly market mentioned in the discussion paper. The right to revision is modified, changing it to seven/eight time blocks before the actual delivery of power. The revision made in odd time block to take effect from 7th block onwards, counting the revised block as 1 whereas the revision made in even time block would be effective from 8th block onwards, counting the revised block as 1. The proposed Real Time Market (RTM) framework has the objective of introducing DISCOMs to a multi-lateral platform for real time power procurement as well as allowing the Generation Companies (GENCOs) to schedule their un-requisitioned capacity.

B. *Market Based Economic Despatch (MBED): Redesigning of Day-Ahead Market (DAM) in India*

According to the current power sector regulations, a DISCOM in power purchase agreement with a Generator cannot procure power outside the agreement even though the power is available at a cheaper price than the contracted price. This can lead to sub-optimal utilisation of the generators available at a cheaper price.

To address this issue CERC proposed MBED framework in the discussion paper released on 31st December, 2018 under which all the contracted entities are to move to the day-ahead market for transaction of power. MBED is introduced with the objective to enhance the competition of all the generators as well to enable DISCOMs to procure power at a cheaper price [7]. In case, the DISCOMs procure power at a higher cost than the contracted price then the difference of price is to be paid to the DISCOM by the generator.

Although, the proposed framework leads to optimal utilisation of the generators but has certain limitations like there is no risk hedging for the generators and generators may quote higher fixed cost in case of lower variable cost getting scheduled in DAM.

Participation in MBED, when introduced, was proposed to be voluntary for all the entities for one month to get acquainted with the framework of MBED before being mandated to participate after completion of one month.

Hence, MBED does not provide for capacity payment. This may lead to investment inadequacy in future.

IV. Security Constrained Economic Despatch (SCED)

A. *Pilot on SCED by POSOCO*

Due to the variable nature of demand profile and supply portfolios across states, the current MOD implemented by individual state SLDCs optimises power procurement cost within the state on a day-ahead basis. The local level of optimisation is taking place at the state level and generation remains un-requisitioned in certain Inter-State Generating Station (ISGS). Some beneficiaries draw costlier power while the cheaper stations continue to have un requisitioned surplus (URS) [10]. Hence, there is a scope for further optimisation by despatching plants with low variable cost as shown in Fig. 4.

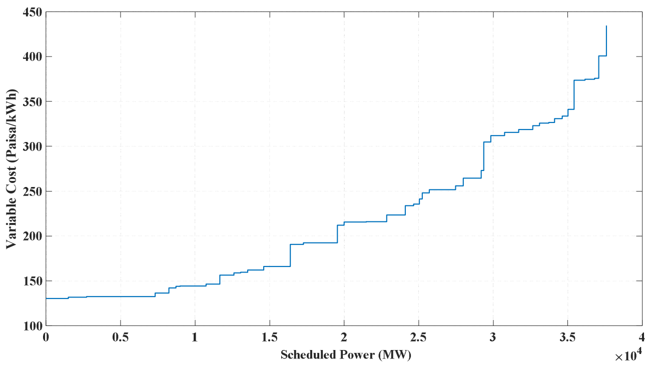

Fig. 4. Merit order of the SCED plants

To address this, POSOCO released a consultation paper on 27th September 2018 [8]. In this direction, CERC directed POSOCO to implement Security Constrained Economic Despatch (SCED) of Electricity for Inter-State Generating Stations (ISGS) on a pilot basis commencing from 1st April 2019.

The objective of SCED is to optimize the despatch of the generation resources at inter-state level which are participating in the SCED Pilot and reduce the overall variable charges for production of electricity. The implementation of SCED is a step towards introduction of optimization in the despatch processes at inter-state level in the Indian Power System.

B. *Experiences and Challenges so far*

The initial experience of the pilot on SCED has demonstrated savings in production cost and by increasing schedule of low variable cost generators and reducing that of high variable cost generators [9]. The reduction in variable cost primarily on account of fuel costs was around Rs. 389 Crores during the period of April – July 2019 and a reduction of 1.5% was observed in the generation cost. It led to a reduction of about 3.3 Paisa in the average variable cost of generation. During the stipulated period, POSOCO has observed an ease in operation of generators as there was a 43% reduction in number of schedule changes and 34% reduction in schedule MW changes. It led to increased Plant Load Factor (PLF) in cheaper power stations & vice versa. It was observed that the increased reduction in fuel cost on holidays and weekends due to irregular variations in demand profile is one of the major observations during pilot on SCED.

TABLE I. Highlights of Pilot on SCED (1st April 2019 to 28th July 2019)

Title	Remarks
Number of Participant Generators	49 (Coal and Lignite based)
Number of Generating units	132
Total Installed Capacity	55940 MW
Average System Marginal Price	298.27 Paisa/unit
Decrease in number of revisions	- 43 %
Percentage decrease in quantum (MW) of revisions	- 34%
Daily average perturbation	1276 MW
Charges to be paid to SCED Generator	759 Crores (Approx. Rs. 6.3 Crores/day)
Charges refunded by SCED Generator	1149 (Approx. Rs. 9.6 Crores/day)
Net variable charges payable (+) / Receivable (-)	(-) 389 Crores (Approx. Rs. 3.3 Crores/day)

So: POSOCO (Interim report on 'Pilot on SCED', August 2019)

POSOCO's report on "Pilot on Security Constrained Economic Despatch" has identified major challenges during implementation of Pilot on SCED [9] as follows: The data interfacing is a major challenge across the RLDCS to exchange the data, regional exports and imports will affect the optimisation further leading to infeasible solutions. During certain contingencies on the power system, certain operational requirements, regulatory compliances and operational flexibility provisions should be merged in the SCED. Some of the instances like on 2nd May 2019 (23:00 hrs) to 3rd May 2019 (19:30 hrs) due to cyclone 'FANI' forced outages of the major links in East-South region corridors leading to exclusion of all the south region generators from SCED. After the SCED optimisation process, a reduction in cumulative reserve quantum was observed due to ramp constraints [9]. The optimization of energy and reserve leads to an impact on inter regional corridor schedules which can affect the methodology for corridor-wise scheduling. The current SCED framework is allowing the market participants to revise generation as per the 'Scheduling and Despatch Code' under the Indian Electricity Grid Code (IEGC). This has been flagged as a problem in arriving at a real time estimate of the availability of reserves in the system. By implementing 'gate-closure' mechanism, more certainty of despatch can be assured.

A single block model based SCED framework can be further enhanced by adopting a rolling block based optimisation as discussed in the following section.

V. SCED: A ROLLING WINDOW BASED OPTIMISATION

Optimisation of a constrained system can be implemented if the applicable constraints can be relaxed to provide a larger optimisation space. The mathematical modelling of the SCED is as follows. The objective of the model is to minimise the total variable cost of ISGS plants as given in (1) subjected to the power balance, ramp and generation constraints as given from (2) to (5). The technical minimum is assumed to be 55% of the declared capacity. Ramp rates and Variable Cost of ISGS plants are taken from Reserves Regulation Ancillary Services (RRAS) reports issued by POSOCO.

$$C = Min \sum_{t=1}^{T} \sum_{k=1}^{n} (VC_k \times G_k) + (LS_k \times PN) \tag{1}$$

Subjected to the constraints given by

$$\sum_{k=1}^{n} G_k = L - \sum_{k=1}^{n} LS_K \tag{2}$$

$$G_{k,min} \leq G_k \leq G_{k,max} \tag{3}$$

$$G_{k,t} - G_{k,t-1} \leq RU_k \tag{4}$$

$$G_{k,t} - G_{k,t-1} \leq RD_k \tag{5}$$

where,

C	=	total variable cost of generation
n	=	number of plants participating in SCED
t	=	time blocks from 1 to T (15 minutes each)
T	=	Number of blocks considered for multi-period optimisation
VC_k	=	variable cost of k[th] plant in paisa/kWh
G_k	=	power generated by k[th] plant in MW
LS_k	=	Load shed in MW
PN	=	Penalty due load shedding
L	=	Load
$G_{k,min}$	=	Min. power generation limit of k[th] plant
$G_{k,max}$	=	Max. power generation limit of k[th] plant
RU_k	=	Ramp up limit of k[th] plant
RD_k	=	Ramp down limit of k[th] plant

We do not explicitly consider transmission constraints. In case of transmission adequacy which doesn't result in congestion, the results of this model would be same as that with transmission constraints. Given that there were very few instances of congestion witnessed during the period of analysis, the results of the model can be considered as reliable and dependable.

The proposed mathematical model for SCED is implemented on commercially available software General Algebraic Modelling System (GAMS). The Linear Programming (LP) is used to optimize the objective function (1) using the CPLEX solver using ISGS schedules data from 01[st] April 2019 to 11[th] August 2019 [10], we estimated cost savings under different modelling simulations.

The SCED model employed by POSOCO carried out for economic despatch independently for one time block at a time by considering the inter-regional transmission constraints. The block-level optimisation reduces the room for optimisation. The proposed EAL's SCED model optimises the generation by considering multiple time blocks at a time. This multi-period optimisation increases the room for optimisation and should decrease the generation cost as compared to the block-level optimisation. Fig. 5 shows the mechanism of multi-period optimisation. The optimal scheduled generation results of the last time block act as an input to the next optimisation window.

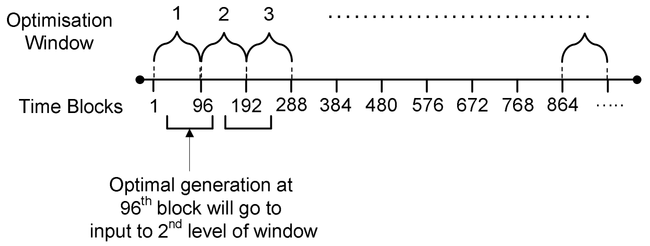

Fig. 5. Multi-period optimization of SCED

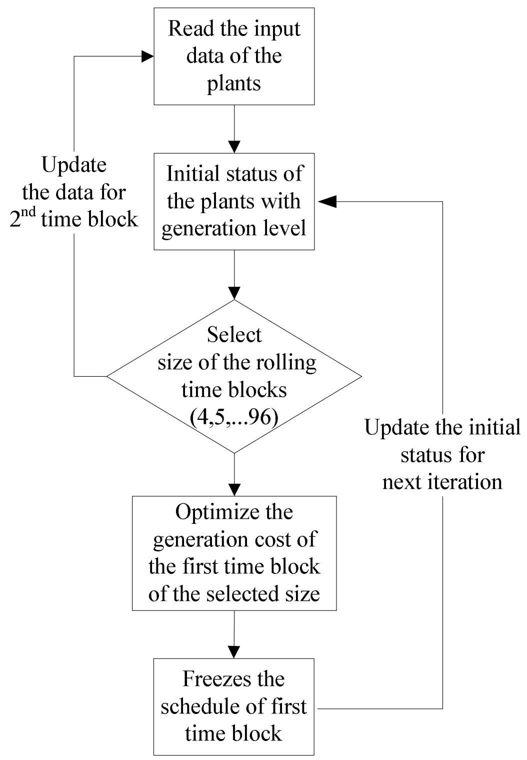

Fig. 6. Flow chart: Rolling block-wise optimisation of SCED

According to the results shown in Fig. 7, multi-period SCED model indicates lower generation cost which highlights the need for adopting multi-period optimisation. Further, the rolling window was selected for 4, 5, 6, 7 and 96 time blocks and observed further reduction in total cost as compared to the single block model. Fig. 6 demonstrates the operational procedure for multi-period optimisation. The proposed rolling window takes into account a group of time blocks (say, 4 time blocks at a time) and optimises the generation for 1st time block in the first optimisation cycle. The selection of the rolling window size depends on the gate closure conditions.

TABLE II. NET SAVINGS BY VARIOUS SCED MODELS (01ST APRIL 2019 TO 11TH AUGUST 2019)

Method	Symbol	Savings (in Rs. Crores)
POSOCO SCED (Single Block)	PSCED	289.54
EAL SCED (Single Block)	Block wise	370.30
Rolling Block (4 time blocks)	RB4	375.19
Rolling Block (5 time blocks)	RB5	375.60
Rolling Block (6 time blocks)	RB6	375.78
Rolling Block (7 time blocks)	RB7	375.87
Rolling Block (96 time blocks)	RB96	376.21

Note: As compared to cost of pre-SCED schedule of ISGS (WSCED)

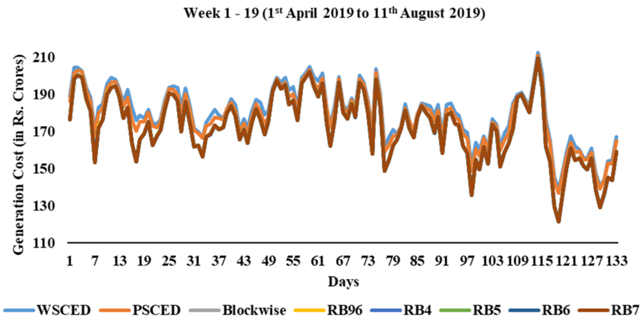

Fig. 7. Generation Cost Comparison of SCED Models

EAL's SCED model demonstrates higher savings in cost of ISGS schedule (Table II). Further, based on the simulation carried out for different length of rolling block windows, we find that rolling block windows can yield higher cost savings.

VI. CONCLUSION

After running the GAMS model for different time frames for 19 weeks starting from 1st April 2019 till 11th August 2019, it was found that EAL's SCED model is able to bring in greater savings for single block model itself. The savings are further enhanced using multi-period optimisation framework. The choice of the length of rolling block would be guided by two key aspects – gate closure and advance visibility of system parameters and confidence associated with the same. A gate closure of four-to-six blocks ahead basis would require that multi-period SCED model shouldn't have an optimisation window lower than that. Further, going far away into the future may increase uncertainty associated with the Declared Capacity of plants, the expected load to be served, net of RE generation. We recommend a rolling block window of 4 - 6 time blocks that should be linked to the gate closure conditions.

Given the savings in cost demonstrated through the SCED framework, we recommend that a similar framework be implemented for intra-state schedules, especially where different distribution entities optimise their individual portfolios, and thus leave room for further optimisation. Expansion of the eligibility of generators under SCED framework would also enhance cost savings.

The SCED framework has not yet specified the mechanism for sharing the savings obtained from its implementation. It is important to ensure that the resultant savings are redistributed based on a criteria in consultation with all stakeholders.

The SCED framework is a near term option for enhancing economic efficiency of the electricity market. However, it doesn't address capacity charges that continue to be paid by the respective beneficiaries. A nationwide market framework, while giving due attention to capacity market, should be long-term objective for the regulators and the policy makers.

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APPENDIX

LIST OF ISGS PLANTS PARTICIPATING IN SCED

S. No.	Name of the Plant	Installed Capacity (MW)	Region
1	BARH TPS	1320	ER
2	BRBCL	1000	ER
3	FSTPP – I & II	500	ER
4	FSTPP – III	1600	ER
5	KHSTPP – I	840	ER

S. No.	Name of the Plant	Installed Capacity (MW)	Region
6	KHSTPP – II	1500	ER
7	MTPS – II	210	ER
8	TSTPS – I	1000	ER
9	Maithon Power Limited	1050	ER
10	Ramagundam Super Thermal Power Station (Units 1-6)	2100	SR
11	Ramagundam Super Thermal Power Station (Unit 7)	500	SR
12	Simhadri Super Thermal Power Station - II	1000	SR
13	Talcher Super Thermal Power Station – Stage II	460	SR
14	Vallur Thermal Power Station	1500	SR
15	NLCTPS – I	630	SR
16	NLCTPS – II	840	SR
17	NLCTPS – I Expansion	420	SR
18	NLCTPS – II Expansion	500	SR
19	NTPL Thermal Power Plant	1000	SR
20	Simhadri Super Thermal Power Station - I	1000	SR
21	KUDGI – I	2400	SR
22	CGPL	4000	WR
23	KSTPS – I & II	2100	WR
24	KSTPS – VII	500	WR
25	MOUDA	1000	WR
26	MOUDA – II	1320	WR
27	NSPCL	500	WR
28	SASAN	3960	WR
29	SIPAT – I	1980	WR
30	SIPAT – II	1000	WR
31	Solapur	1320	WR
32	VSTPS – I	1260	WR
33	VSTPS – II	1000	WR
34	VSTPS – III	1000	WR
35	VSTPS – IV	1000	WR
36	VSTPS – V	500	WR
37	GADARWARA – I	800	WR
38	DADRI TPS	840	NR
39	DADRI – II TPS	980	NR
40	IGSTPS – JHAJJAR	1500	NR
41	RIHAND STPS	1000	NR
42	RIHAND – II STPS	1000	NR
43	RIHAND – III STPS	1000	NR
44	SINGRAULI	2000	NR
45	UNCHAHAR – I TPS	420	NR
46	UNCHAHAR – II TPS	420	NR
47	UNCHAHAR – III TPS	210	NR
48	UNCHAHAR – IV TPS	500	NR
49	BONGAIGAON	750	NER