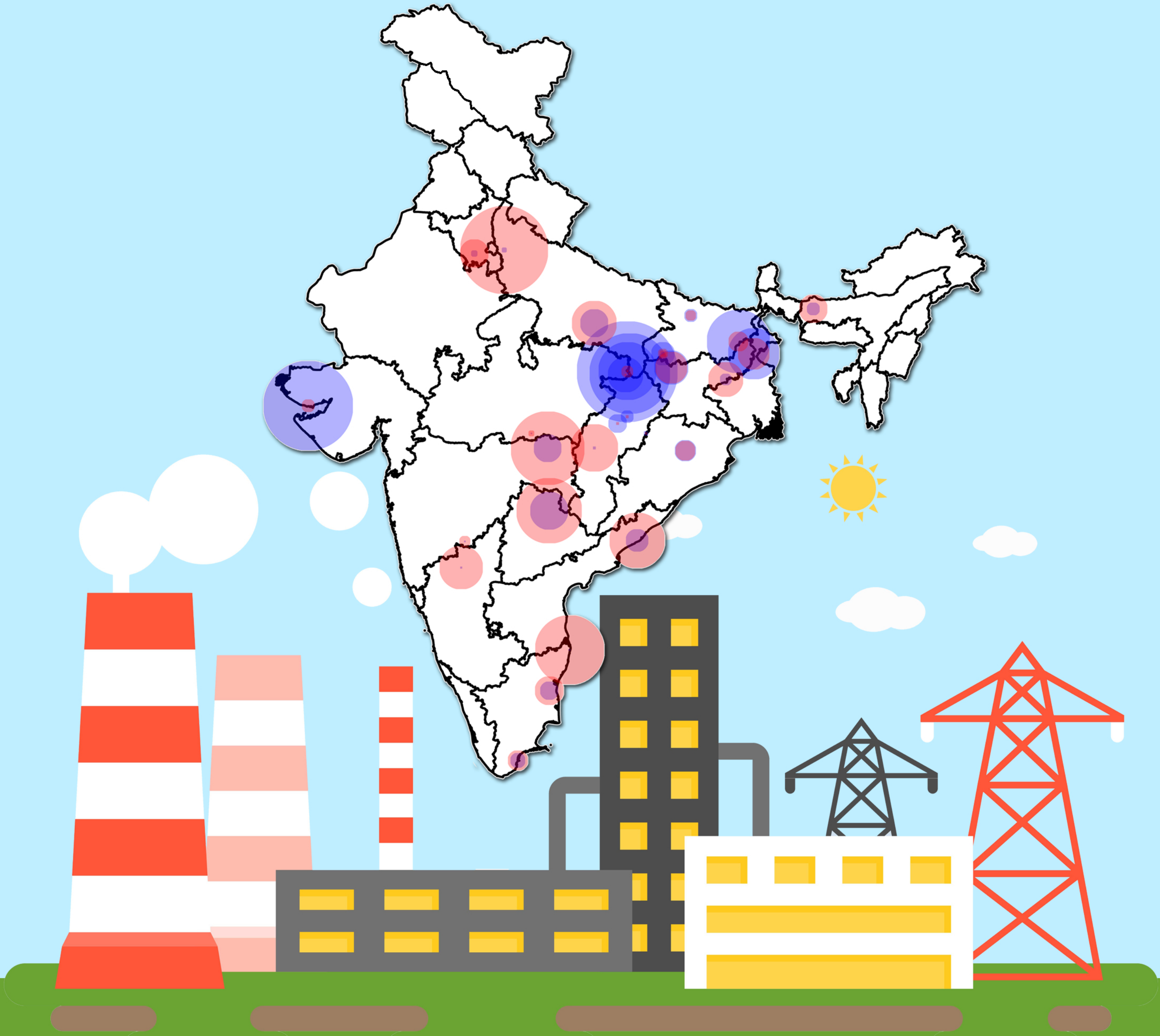
SECURITY CONSTRAINED ECONOMIC DESPATCH
of
Inter-state Generating Stations pan-India

Detailed Feedback Report on Pilot



January 2020

Power System Operation Corporation Limited

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ACRONYMS

ATC	Available Transmission Capability
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
DC	Declared Capability
GAMS	General Algebraic Modeling System
FTP	File Transfer Protocol
IEGC	Indian Electricity Grid Code
ISGS	Inter-State Generating Stations
MOP	Ministry of Power
NLDC	National Load Despatch Centre
RLDC	Regional Load Despatch Centre
SLDC	State Load Despatch Centre
RRAS	Reserve Regulation Ancillary Services
REA	Regional Energy Account
RPC	Regional Power Committees
SCED	Security Constrained Economic Despatch
SMP	System Marginal Price
URS	Un-Requisitioned Surplus
WAN	Wide Area Network
MCR	Maximum Continuous Rating
VSCED	Virtual Security Constrained Economic Despatch (Entity)
WBES	Web Based Energy Scheduling System

HIGHLIGHTS

S.No.	Title	Numbers#
1.	Number of Participating Generators	**52 Nos. (Coal & Lignite)**
2.	Number of Generating Units	**135 Nos.**
3.	Total Installed Capacity	**58,060 MW**
4.	All India System Marginal Price (Average)	**287 Paisa/kWh**
5.	Daily Average Perturbation	**1320 MW**
6.	Average Number of Plants perturbed	**Up (14 Nos.), Down (11 Nos.)** ***per time block***
7.	Number of Schedule Changes	**29 % Decrease post-SCED**
8.	Cumulative Quantum (MW) of Schedule Changes	**42 % Decrease post-SCED**
9.	Charges paid to SCED Generator *(April – December, 2019)*	**₹ 1715 Crore** ***(Avg. approx. ₹ 6.2 Crore/day)***
10.	Charges refunded by SCED Generator *(April – December, 2019)*	**₹ 2560 Crore** ***(Avg. approx. ₹ 9.3 Crore/day)***
11.	Reduction in Total Production Costs / Variable Charges	**₹ 845 Crore** ***(Avg. approx. ₹ 3.1 Cr./day)***
12.	Net Reduction in Average Variable Cost of Generation *(April – December, 2019)*	**3 paisa/ kWh** ***(206 to 203 paisa/ kWh)***
13.	Heat Rate Compensation payable *(as per latest available RPC Statements)*	**Approx. ₹ 134 Crore**

#1 Crore (Cr.) = 10 Million, 1 Lakh = 0.1 Million, ₹ 1 = 100 Paisa

EXECUTIVE SUMMARY

"SCED is merely a very complicated constrained optimization problem that involves a touch of art along with the science".[1]

The implementation of a Pilot on SCED in ISGS Pan India was directed by Hon'ble CERC w.e.f 1st April, 2019. The pilot has been implemented for all the thermal ISGS that are regional entities and whose tariff is determined or adopted by the Central Commission for their full capacity honouring the existing scheduling practices prescribed in the Grid Code. Further, the Central Commission directed the extension of the pilot upto 31st March, 2020.

The implementation of pilot on SCED gave rise to a paradigm shift in scheduling infrastructure terms of Information Technology, Hardware, Communication and Data Interfacing, which has been detailed in the report. A mix of technologies have been integrated and data exchange has been facilitated between different layers of applications at RLDCs and NLDC pan-India. The infrastructure was enhanced to comply with stringent timelines. The web-based energy scheduling software, hitherto, working on regional basis has been integrated at national level for implementation of pilot on SCED. The in-house development of SCED software application with self-healing / ride-through attributes was a major challenge as the software application had to be robust enough to run continuously in 24x7 real time environment within the given constraints and minimal manual intervention.

It has been observed that as the geographic and electrical ambit integrated under the SCED is expanded, there is a scope for additional reduction in production costs. During the course of the pilot on SCED, additional generation capacity of 3310 MW has been seamlessly integrated with the SCED software application in disruption-free manner. Further, in order to facilitate operational activities of the generators as well as regulatory compliances, suitable flexibility provisions were incorporated in the SCED software application. The integration process of the generators has been covered exhaustively in the report. Successful incorporation of the generators in a real-time manner has increased the confidence on the robustness of the SCED software application.

The mathematical formulation of the economic despatch model being used in the pilot on SCED and improvements made over the time have been detailed in the report. To prevent infeasibility of the mathematical model, artificial variables are being added to the equations and the objective function is penalized. Root causes reasons giving rise to infeasible conditions for the model have also been explored. The basic form of sensitivity analysis using dual values has been detailed in the report.

It has been observed that generally, the lower variable cost pit head generation is being increased in Western Region and Eastern Region whereas the higher variable cost generation is being decreased in Southern, Northern Region and Eastern Region. Further, the ramping

[1] Report on Security Constrained Economic Dispatch by the Joint Board for PJM/MISO Region https://www.ferc.gov/industries/electric/indus-act/joint-boards/pjm-rpt.pdf

from the higher variable cost generators is being done only when absolutely needed. Therefore, the pilot on SCED has led to optimization of the generation across India, thereby, lowering production costs.

In addition to optimizing the generation dispatch, the pilot on SCED has also helped address system reliability operation as a part of the 'security constrained' feature of SCED. SCED by design has control over the power imports of the regions, subject to the reserve availability in the importing region. In case of any sudden reduction in transfer capability due to line / equipment outage in the real time, thereby reducing the available transfer capability below the inter-regional schedule, SCED can quickly and automatically increase generation in the next time block in the importing region to relieve congestion, subject to reserve availability and ramp constraints.

There has been 29 % decrease in the number of instructions (counting any change in the schedule of the generator by the RLDC as one instruction) in the injection schedules of participating generators and 42 % decrease in the cumulative MW schedule change. Therefore, pilot on SCED has facilitated the ease of generators' operations.

It was observed that during the holidays / weekends and extreme weather conditions, there is increased reduction in fuel costs as a result of variation in demand and therefore, diversity of the generation mix pan-India is harnessed.

The SCED accounts have been issued by respective RPCs till December, 2019. A total of ₹ 1715 Crore has been paid to SCED generators for incremental generation on account of SCED in the period from April – December, 2019. In the same period, a total of ₹ 2560 Crore has been paid by the SCED generators on account of decrement in generation on account of SCED. "National SCED Weekly Statement" is being uploaded to the NLDC-POSOCO website. In order to have smooth dispute free settlement, monthly reconciliation is carried out by NLDC with all SCED generators.

There has been around ₹ 845 Crore reduction in fuel cost for April – December, 2019 period which has been facilitated by pilot on SCED. Considering a base of approx. ₹ 54,000 Crore during April – December, 2019, around 1.5 % reduction in generation cost (without considering heat rate compensation) has been observed. There is reduction of about 3 paisa in the average variable cost of generation during the April – December'19 period.

As a result of optimization through SCED, the available spinning reserve is getting consolidated in the higher variable cost generators. The availability of reserve is constrained by the ramping capability of generation units carrying reserve. Therefore, a reduction in the cumulative reserve quantum constrained by ramp is being observed after the SCED optimization process. Typically, the 15-minute ramp constrained reserve is around 20 – 30 % of the total spinning reserve.

Presently, corridor wise path specific scheduling is carried out by the RLDCs. Inter-regional schedules are also being reconciled by the neighbouring regions. Deviations from schedules in the actual power flows are computed based on the energy meter readings and are accounted for in the regional energy accounts. The optimization in pilot on SCED is being done considering the net import capability constraints. Changing the scheduling methodology from corridor wise scheduling to net-injection/net-drawal for each region can be examined.

During the course of the SCED pilot, large volume of data was generated and recorded for each of the time blocks and for each of the generators (numbering 26400 time blocks during Apr- Dec 2019). Apart from the optimization model outputs, numerous other parameters were calculated and exported. There have been various learnings for future implementation, based on the analysis of data generated during the SCED pilot project.

One such learning is that to further reduce the production cost, minimum turn down levels could be brought down from the present 55%. The recent regulatory initiatives towards introduction of real-time market and gate closure would bring in more certainty of despatch especially in terms of reserves requirement & activation thereof.

It is recognized that expanding the ambit of SCED including implementation at intra-state level would lead to better scope for optimization & causing economy while at the same time consolidating the overall ramping capability available in the system. As and when the ambit of SCED is expanded to include more entities, the synchronization of entity schedules pan-India assumes significant importance. With the tight data exchange & processing timelines, the hardware, software, skilled manpower resources across all SLDCs/RLDCs/NLDC has to be enhanced in addition to addressing cyber security vulnerabilities.

There is a need for introduction of Security Constrained Unit Commitment (SCUC) to assure that the appropriate resources would be operational when they are needed for economic dispatch. The co-optimization of energy and ancillary services is being explored to bring more certainty and efficiency in the delivery of the demanded reserve by the system operator in a cost effective manner. It has been observed that the SCED directly impacts the emissions of the generating plants by systematically increasing the use of the most economic generation units leading to reduced costs and emissions. Need for efficiency data of generators is also felt for further improving the SCED process.

In near future, the aspects related to optimal scheduling and pricing across multiple market intervals for resources with intertemporal constraints, resource level constraints and system-wide constraints would assume significant importance. Therefore, initiatives have to be taken to evolve a multi-period SCED optimization model with a look-ahead time horizon in a dynamic environment.

"SCED has always been the necessary tool for ensuring reliable operations in modern systems"[2]

[2] Midcontinent Independent System Operator (MISO), USA submission to FERC, 2006

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1 INTRODUCTION

1.1 Preamble

This report of the pilot project on SCED presents the policy & regulatory framework, development process, coordination efforts, implementation aspects, optimization results, financial settlements, key learnings, challenges experienced, and lastly, way forward for economic despatch in the Indian power system. This report has been prepared in compliance to Central Electricity Regulatory Commission (CERC) order in Petition No. 02/SM/2019 (Suo-Motu) dtd. 31st January, 2019, for Pilot on Security Constrained Economic Despatch (SCED) of Inter-State Generating Stations (ISGS) Pan-India[3]. Further, CERC i.e. Central Commission vide order in Petition No. 08/SM/2019 (Suo-Motu) dated 11th September, 2019[4] in the matter of Extension of Pilot on SCED of ISGS Pan-India directed to apprise the Central Commission periodically regarding the experience gained in the form of a detailed feedback report covering all the aspects.

1.2 Present Scheduling and Despatch Framework

Electricity is part of the concurrent list of the Constitution of India, and both the central and state governments have jurisdiction over the subject. In practice, this has meant that the CERC/Central Transmission Utility (CTU)/National Load Despatch Centre (NLDC)/Regional Load Despatch Centres (RLDCs)/Regional Power Committees (RPCs) are responsible for all inter-state and international generation & transmission. The State Electricity Regulatory Commission (SERC)/State Transmission Utility (STU)/State Load Despatch Centres (SLDCs) are responsible for generation, transmission and distribution within a state. This arrangement has led to development of a decentralized, coordinated multilateral scheduling and despatch model in the

[3] Central Commission order in Petition No. 02/SM/2019 (Suo-Motu) dtd. 31st January, 2019, for Pilot on Security Constrained Economic Despatch (SCED) of Inter-State Generating Stations (ISGS) Pan India http://cercind.gov.in/2019/orders/02-SM-2019.pdf

[4] Central Commission order in Petition No. 08/SM/2019 (Suo-Motu) dated 11th September, 2019 in the matter of Extension of Pilot on SCED of ISGS Pan India http://cercind.gov.in/2019/orders/08-SM-2019.pdf

country. Electricity Act, 2003[5] mandates that the RLDCs/SLDCs would be responsible for optimum scheduling and despatch of electricity within the region/state, in accordance with the contracts entered into by the licensees or the generating companies operating in the region or the state, as the case may be.

In India, multiple beneficiaries have allocations or contracts (within and across regions) in the ISGS and each state schedules as per its own requirement. The allocations to different states/union territories as beneficiaries of around 150 ISGS has been depicted in Fig. 1. It has formed a block diagonal matrix due to multiple areas as explained in the classical paper on optimal power flow by H H Happ [1].

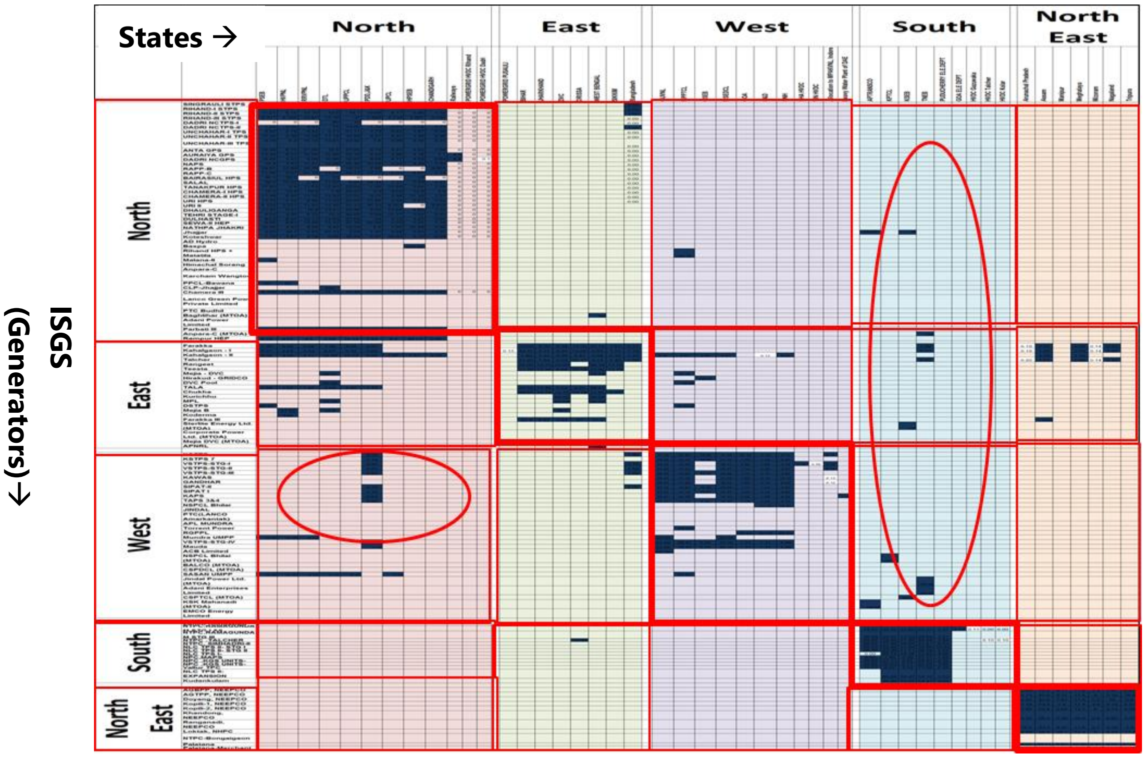

Figure 1: Allocation/Contract Matrix to Beneficiaries (Block Diagonal)

Thermal ISGS are spread pan-India at pit-head, coastal, load centre and other locations in various geographies. The geospatial distribution of variable cost of inter-state generators is depicted in Fig. 2. The state utilities schedule generation resources both from within the state and from inter-state generating stations (as per their entitlements) based on their forecasted demand. While scheduling and despatch, each

[5] Electricity Act, 2003 https://powermin.nic.in/en/content/electricity-act-2003

state is individually carrying out merit order despatch and thus, a local level of optimization is already taking place.

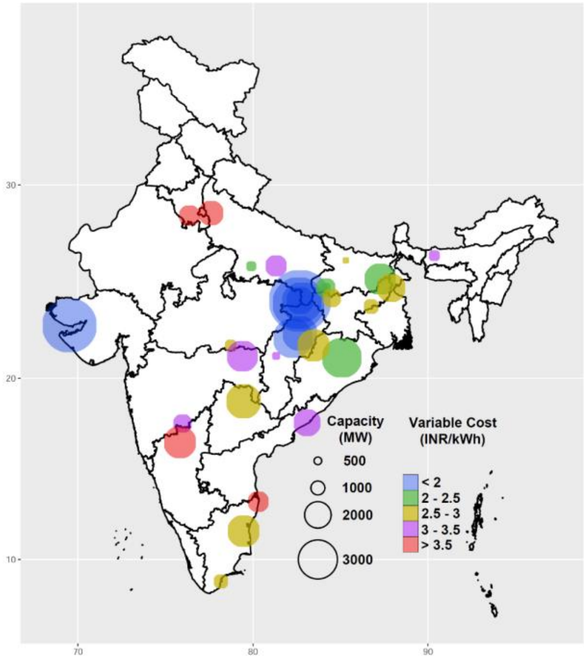

Figure 2: Spatial Distribution of Variable Cost of ISGS pan-India

Depending on the various factors local weather and other attributes, requirement of the states' varies and consequently, generation remains un-requisitioned in certain ISGS including lower variable cost generators. This leads to a situation where, some beneficiaries are drawing costlier power from ISGS even while some power in relatively lower variable cost stations may remain un-despatched. This is because the distribution utilities can requisition/schedule power only from the generating stations with which they have a contract. Several mechanisms are available to harness the most economical resources such as bilateral contracts between the states, scheduling the available un-requisitioned surplus (URS) power[6] and other orders by the Central Commission to allow generators to sell such URS power after getting a clearance from the beneficiary state. The requisitions by the states every day are typically based on the merit order of the variable cost of the power plants and the forecasted demand for that state. States can also revise the schedules of their

[6] Indian Electricity Grid Code http://cercind.gov.in/Regulations/Signed-IEGC.pdf

contracted generators, until half an hour before real time dispatch. Some states make bilateral contracts between each other for sale and purchase of surplus/deficit power to handle diversity, uncertainty and to facilitate unit commitment. States also have the option to buy/sell power in the electricity market. Several transmission links are available between lower variable cost pit head power plants to load centres.

Even though all these provisions are being harnessed, due to the information asymmetries and transaction costs involved (fixed costs, open access charges and losses etc.), some surpluses would invariably remain in lower variable cost power stations whereas relatively costlier stations are despatched on many days. Thus, there exists scope for optimization by despatching these fragmented lower variable cost generation in lieu of costlier variable cost generation on a pan India basis. This aspect has become all the more evident with the implementation of Reserve Regulation Ancillary Services (RRAS)[7] since 2016.

The seminal work of H. H. Happ in "Optimal power dispatch - A comprehensive survey," for IEEE Transactions on Power Apparatus and Systems, May 1977 [1] reviewed the evolution of Economic Dispatch in both classic single area as well as multi-area dispatch. Work by Felix Wu et al [2], focused on coordinated multilateral model trades. Classic economic dispatch of real power treats the network approximately and optimizes the generator power injections with the objective of minimization of production costs. It has been described that multi-area dispatch, similar to that of Indian power system, establishes the economic values of interchange between a number of separate utilities and thereby, economic dispatch is established in the entire system. It has been clarified that multi-area dispatch is used for the same purposes as single area dispatch namely for real time control in association with Automatic Generation Control (AGC), for Pool-to-Pool Interchange Evaluations and Cost Reconstruction, in Unit Commitment and for Billing within the Pool. Similar work carried out for pre-restructured Indian power system was reported in detail in a paper

[7] CERC (Ancillary Services Operations) Regulations, 2015
http://cercind.gov.in/2015/regulation/Noti13.pdf

in 1996 [3]. The classical economic dispatch as implemented at various places is surveyed by various literature [4],[5].

Given the federal structure with the coordinated multilateral scheduling model, a need has been felt for an overlay of centralization and optimization at the inter-state level duly factoring technical constraints such as technical minimum, maximum generation, ramping constraints, transmission constraints, etc. It is recognized that, in due course, expanding the ambit of generation resources under SCED optimization process would lead to possibility of greater reduction in the overall system operating costs. Hence, an algorithm-based dispatch software was needed to be developed, which can send incremental dispatch instructions close to real time (after all the states have tried to balance their demand-generation portfolio) and cause economy by increasing lower cost generator schedules and decreasing the costlier generation. A prototype software was prepared for this purpose and was run in open loop for more than 6 months to generate results for the purpose of the analysis; this trial exercise gave promising results and insights [8].

In line with the Ministry of Power, Govt. of India, scheme on Flexibility in Generation and Scheduling of Thermal Power Stations to reduce the cost of power, notified on 30th August, 2018, a consultation paper on "SCED of Inter-State Generating Stations pan India" was submitted to the CERC on 12th September, 2018. The paper explored the scope for an optimal solution to minimize the total production cost while honouring the technical constraints of the power plants and the grid. After consultation with all stakeholders, POSOCO in December 2018 requested the Central Commission for implementation of the SCED proposal on pilot basis for at least six months. CERC on 31st January, 2019, directed for pilot on SCED of central sector thermal generating stations pan India with effect from 1st April, 2019.

[8] P. Chilukuri, K. Gaur, S. K. Soonee, S. R. Narasimhan, N. Nallarasan and K. V. S. Baba, "Optimization Layer for Inter State Generation Schedules in India," 2018 20th National Power Systems Conference (NPSC), Tiruchirappalli, India, 2018, pp. 1-6.
https://ieeexplore.ieee.org/abstract/document/8771801

1.3 Objective of Pilot Project on SCED of ISGS Pan-India

The various objectives of the pilot project are detailed in the following figure (Fig. 3).

Optimization of Scheduling and Despatch

- To further optimize scheduling and despatch of thermal ISGS pan-India causing economy honouring the technical constraints of the power system

Retaining Freedom & Choice

- To maintain the freedom & choice of states to requisition power as per their demand requirements
- Keeping existing contracts and PPAs intact.

Honouring Constraints

- To improve the despatch process honouring the system wide operation related constraints and resource level constraints.

Testing Viability and Scalability

- To confirm viability, scalability and enable processes to be tested, implemented and changes thereon

Flexibility

- To facilitate flexibility of meeting the requirements of states starting from least cost generation resources while honouring technical constraints.

SWOT Analysis

- To identify the associated strengths, weaknesses, opportunities and threats of economic despatch through sensitivity analysis under various conditions before regulatory framework is put in place.

Capacity Building and Skill Development

- To foster a systematic and data driven process to strengthen human resources, learning and skills development in the country for development of economic despatch faculty.

Expanding the Ambit

- To determine specific actions and roadmap through lessons learnt to enhance the scope of optimization to regional entities at the inter-state level and also, at intra-state level.

Figure 3: Objectives of Pilot on SCED

1.4 Policy and Regulatory Approaches

1.4.1 Ministry of Power Scheme[9]

The objective of the Ministry of Power scheme on Flexibility in Generation and Scheduling of Thermal Power Stations to reduce the cost of power, notified on 30th August, 2018, is to reduce the overall cost of power in the country by utilizing any un-requisitioned surplus in existing lower cost generating stations by way of flexibility in scheduling of generation. As per the scheme, with generation company wise optimization, the lower cost generating stations could be dispatched up to its maximum capacity before scheduling the costlier stations till the power requisitioned by all the beneficiaries is met. The MOP scheme mentioned that the Appropriate Commission would initiate the regulatory changes to facilitate flexibility in scheduling.

1.4.2 Discussion Papers by the Central Commission

The staff of the Central Commission published discussion paper on "Market based Economic Dispatch of Electricity: Redesigning the Day-Ahead Market in India"[10], on 31st December, 2018, which provided for market-based optimization of the scheduled power on a day-ahead basis. It envisaged reduction of overall cost of power procurement at national level with better flexibility in the system. The discussion paper by the staff of the Commission on "Real Time Energy Market"[11] and "Re-designing Ancillary Services Mechanism in India"[12], in the long run, are expected to help the stakeholders manage their energy portfolio closer to Real Time.

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9 Ministry of Power Scheme on "Flexibility in Generation and Scheduling of Thermal Power Stations to reduce the cost of power"
https://powermin.nic.in/sites/default/files/webform/notices/Merit%20Order%20operation.pdf
10 CERC Staff Discussion Paper on "Market based Economic Dispatch of Electricity: Redesigning the Day-Ahead Market in India http://cercind.gov.in/2018/draft_reg/DP31.pdf
11 CERC Staff Discussion Paper on "Real Time Energy Market"
http://cercind.gov.in/2018/draft_reg/RTM.pdf
12 CERC Staff Discussion Paper on "Re-designing Ancillary Services Mechanism in India"
http://cercind.gov.in/2018/draft_reg/DP.pdf

1.4.3 Consultation Paper on SCED

Initially, a report on 'Security Constrained Economic Despatch pan India' was submitted by POSOCO to the Central Commission on 3rd August 2018 based on the analysis of the results from the prototype software. After discussions with the CERC staff and incorporating suggestions, POSOCO submitted a consultation paper on "Security Constrained Economic Dispatch (SCED) of Inter-State Generating Stations pan India"[13] to the Central Commission on 12th September, 2018. The Consultation paper sought to enhance the scope of optimization of ISGS schedules at pan India level leading to reduction in production cost. The paper explores the scope for an optimal solution to minimize the total production cost from all thermal ISGS whose tariff is determined or adopted by Central Commission while honouring the technical constraints of the power plants and the grid.

The scope of the consultation paper covered optimization after the unit commitment has taken place on a day-ahead timeframe. The SCED based optimization model advocated the introduction of Gate Closure to facilitate the proposed optimization process. Optimization would result in incremental/decremental changes in the existing schedules which would need to be settled. The variable charges declared by the generators for the purpose of ancillary services would be considered in the optimization process. It was suggested in the consultation paper that there is a need for implementation of the National SCED Pool to take care of changes in injection schedule for each generator due to optimization process on pan-India basis. There would be a need for pay-in/ pay- out from the National SCED Pool Account for incremental changes in schedules (Up/Down) on account of SCED.

The Central Commission, vide communication dated 27th September 2018, directed POSOCO to seek comments on the consultation paper from the stakeholders. Accordingly, the SCED consultation paper was put on NLDC/RLDCs website on 28th

[13] Consultation paper on "Security Constrained Economic Dispatch (SCED) of Inter-State Generating Stations pan India" https://posoco.in/download/consultation-paper-on-security-constrained-economic-dispatch-of-isgs-pan-india/?wpdmdl=19708

September 2018 seeking comments from the stakeholders till 28th October 2018 and subsequently extended the date to 20th November 2018 on request by some of the stakeholders. Ten (10) Nos. stakeholders submitted their comments on the consultation paper. POSOCO, vide its letter dated 28th December 2018, requested the Central Commission for implementation of the SCED proposal on pilot basis for at least six months.

1.4.4 Central Commission Order - Pilot on SCED of ISGS Pan India

The Central Commission, vide order in Petition No. 02/SM/2019 (Suo-Motu) dated 31st January, 2019, directed for Pilot on SCED of ISGS Pan India with effect from 1st April, 2019. It was observed that there is an overarching objective to optimize the scheduling and dispatch of the generation resources and reduce the overall cost of production of electricity without major structural changes in the existing system/framework in the pilot phase of SCED.

It was recognized that the implementation of SCED is a desired step in the Indian grid operation towards optimization methodologies. SCED implementation is an involved procedure requiring modifications in scheduling system, developing software, creating interfaces and establishing various protocols, information dissemination and streamlining settlement system. After rolling out the SCED mechanism on pilot basis, based on the stakeholder feedback, suitable regulatory framework can be evolved in due course.

1.4.5 Interim Report on Pilot on SCED

POSOCO submitted an interim feedback report to Central Commission on 19th August, 2019 highlighting benefits, and optimization results for the period between 1st April, 2019 - 28th July, 2019 on SCED Pilot. A robust, resilient, self-healing solution engine developed in-house runs every 15 minutes to determine the optimal schedule for each ISGS without any human intervention in the entire process, enabling significant reduction in the overall generation cost.

The various benefits accrued were explained in terms of optimization of generation based on merit order, reduction in fuel costs, ease of generators' operations, harnessing diversity, expanding the ambit and handling congestion. The challenges faced during the implementation were also highlighted such as information technology and data interfacing, communication and integration of regional scheduling software applications, self-healing / ride-through attributes, operational flexibility provisions in SCED, effect of SCED on ramping reserves, inter-regional scheduling and need for gate closure.

1.4.6 Central Commission Order – Extension of the Pilot

The Central Commission vide order in Petition No. 08/SM/2019 (Suo-Motu) dated 11th September, 2019 in the matter of Extension of Pilot on Security Constrained Economic Dispatch (SCED) of Inter-State Generating Stations (ISGS) Pan India directed to implement the SCED pilot for the thermal Inter State Generating Stations (ISGS) that are willing to participate in the SCED, for the period from 1st October, 2019 to 31st March, 2020. In the order, based on the feedback in the interim report, directions regrading sharing of benefits accrued from SCED were also given.

1.5 Meetings, Workshops and Stakeholder Consultations

1.5.1 High Level Reviews

High level reviews were conducted by the policy makers and regulators after the operationalization of the pilot. Secretary, Ministry of Power (Fig. 4) had taken a review of the pilot on SCED at NLDC on 15th May, 2019. Subsequently, on 03rd July, 2019, Chairperson and Members of the Central Commission along with the Staff had a detailed interaction at NLDC on implementation and insights from pilot on SCED.

Figure 4: High level Interactions - Pilot on SCED

1.5.2 Regional Power Committees (RPCs)

Subsequent to the Central Commission order for pilot on SCED in January, 2019, NLDC/RLDCs representatives had detailed interactions with all the stakeholders through respective RPCs. Interactions were held in NRPC (Delhi) on 12th February, 2019, WRPC (Mumbai) on 11th February, 2019, SRPC (Bengaluru) on 12th February, 2019, NERPC (Agartala) on 14th February, 2019 and ERPC (Mejia-DVC) on 21st February, 2019.

1.5.3 SCED Generators

There were detailed interactions with the generators participating in the pilot on SCED on 22nd & 25th March, 2019.

1.5.4 Interaction with Experts and Academia

There is continuous interaction on various operational and implementation aspects of pilot on SCED between POSOCO and International/National level academic experts such as Prof. Anjan Bose, Washington State University, USA, Prof. Abhijit Abhyankar, IIT-Delhi, Prof. Rohit Bhakar, MNIT, Jaipur, Prof. Saumen Majumdar, IIM-Tiruchirappalli and Dr. Debabrata Chattopadhyay from World Bank.

1.5.5 Forum of Load Despatchers (FOLD) Meeting

FOLD strives to achieve its vision through technical co-operation and knowledge sharing between inter-state and intra-state system operators through regular interactions. The implementation experience of pilot on SCED in ISGS was presented to all stakeholders in the 29th meeting of FOLD at Delhi on 14th May, 2019.

1.5.6 Workshops and Capacity Building

There were a series of workshops conducted for optimization through GAMS and hands-on training. A workshop was organized with Dr. Miklos Bankuti, World Bank (12th – 14th February, 2018). A training Program on "Implementation of Optimization Techniques for Indian Power System Operation" from 17th – 19th September, 2018 was also facilitated by a team of experts from MNIT, Jaipur, Dr. Kailash Sharma from Banasthali Vidyapeeth University and his team at NRLDC, Delhi.

1.6 Journey of SCED over the years

The journey of SCED over the years from foundation phase, transition phase to implementation phase has been detailed as follows:

Foundation Phase

CERC Roadmap on Reserves (2015)

Ancillary Services-RRAS (2016)

Generator wise Parameters Pmax, Pmin, Ramp Rates, Variable Charges etc.(2016)

Streamlining of Scheduling Process (2016)

Robust Accounting and Settlement (2016)

MS-Excel Version (2016)

Addition of Constraints (2017)

Extraction of SMP (2017)

Training in GAMS (2017)

Amendment of Grid Code by CERC for maximum scheduling limit, technical minimum (2017)

Transition Phase

Basic Model in GAMS (2018)

MOP Scheme (2018)

CERC Discussion Papers (2018)

Consultation Paper (2018)

Stakeholder Consultations (2018)

Capacity building (2017, 2018)

Implementation Phase

CERC Order (31 Jan, 2019)

Meeting with Generators and Stakeholders (22/25 Mar, 2019)

Hardware Augmentation, Software development and integration (Jan - Apr 2019)

Testing and quality assurance (Mar-May 2019)

Start of Pilot w.e.f 1 Apr, 2019

Extension of Pilot till 31 Mar, 2020

2 IMPLEMENTATION OF SCED

2.1 Modus Operandi of Pilot on SCED of ISGS Pan India

The Central Commission, vide order in Petition No. 02/SM/2019 (Suo-Motu) dtd. 31st January, 2019, directed for Pilot on SCED of ISGS Pan India with effect from 1st April, 2019. The implementation aspects of the CERC order for pilot on SCED are as follows:

2.1.1 Implementation

- The implementation of SCED optimization model would be for all the thermal ISGS that are regional entities and whose tariff is determined or adopted by the Commission for their full capacity without compromising the grid security on pilot basis for six months.
- The pilot for SCED would be implemented w.e.f. 1st April, 2019.

2.1.2 Scheduling and Despatch

- The existing scheduling practices prescribed in the Indian Electricity Grid Code would be honoured.
- The variable charges declared by the generators for the purpose of Reserve Regulation Ancillary Services (RRAS) would be considered in optimization process.
- Schedules of the states/beneficiaries would not be disturbed due to SCED and the beneficiaries would continue to pay the charges for the scheduled energy directly to the generator as per the extant practices based on their requisition and schedule.
- For any increment in the injection schedule of a generator due to optimization, the generator would be paid from the National Pool Account (SCED) for the incremental generation at the rate of its variable charge.
- For any decrement in the schedule of a generator due to optimization, the generator would pay to the aforesaid National Pool Account (SCED) for the decremental generation at the rate of its variable charge after factoring compensation due to part load operation as certified by RPC as per IEGC.

- The incremental changes in schedules of SCED generator on account of optimization would not be considered for incentive computation.
- The deviation in respect of such generators would be settled with reference to their revised schedule after factoring SCED changes.
- The increment/decrement of generation under SCED would not form part of RRAS.

2.1.3 Accounting and Settlement

- The RPCs would issue weekly SCED accounts along with the DSM, RRAS, FRAS and AGC accounts based on the data provided to them by RLDCs.
- NLDC would indicate a consolidated all India statement, week wise and month-wise indicating the schedules on account of SCED.
- RPCs would issue the regional accounts including the SCED schedules.
- NLDC would issue a consolidated "National SCED Settlement Statement" comprising payment and receipts to/from all generators participating in the SCED.

2.1.4 Sharing of Benefits

- The Central Commission vide order in Petition No. 08/SM/2019 (Suo-Motu) dated 11th September, 2019 in the matter of Extension of Pilot on SCED of ISGS Pan India gave directions regrading sharing of benefits accrued from SCED as follows:
    - The net benefits accrued in the pool after adjusting compensation for part load operation of the generators would be shared in the ratio of 50:50 between the generators participating in SCED and the concerned beneficiaries / discoms, on a monthly basis.
    - The benefits (50% of the net benefit accrued in the pool) corresponding to the beneficiaries/ discoms would be shared in proportion to their final schedule from the generating stations covered under SCED pilot on a monthly basis as per the Regional Energy Account (REA).
    - The generators benefit (i.e. 50% of the net savings / benefit accrued in the pool) would be shared between SCED UP and SCED DOWN generators in the ratio of 60:40 respectively for each time block.

- Further, share for each generator would be calculated in proportion to their SCED schedule for the corresponding time block to take into account their contribution in benefits during SCED pilot.
- Benefits received by the SCED generators would then be summed every month to estimate the cumulative benefit for each generator in a month. RPCs while preparing REA shall provide and settle monthly benefit for each generator participating in SCED pilot.

2.1.5 Miscellaneous

- POSOCO would procure the required hardware and develop/procure the necessary software along with optimization tools for the implementation of SCED framework.
- CTU would ensure reliable communication between the respective generating stations and Load Despatch Centres.

2.2 Roles and Responsibilities

The roles and responsibilities of different stakeholders such as NLDC, RLDCs, RPCs and Beneficiaries/SLDCs have been outlined in the Procedure for Pilot on Security Constrained Economic Despatch for Inter- State Generating Stations pan India[14] as follows:

[14] Procedure for Pilot on Security Constrained Economic Despatch for Inter- State Generating Stations pan India https://posoco.in/download/revised-detailed-procedure-w-e-f-01-10-2019/?wpdmdl=25183

NLDC

- To frame the detailed procedure containing the guidelines regarding operational aspects of SCED
- To develop, procure and implement requisite software applications for the SCED Pilot and update it from time to time for all the SCED Generators honouring the existing scheduling practices prescribed in the Indian Electricity Grid Code (IEGC).
- To run the SCED software application to generate the SCED schedules (up/down) for the SCED Generators and communicate the same to the RLDCs for incorporation in the schedules.
- To maintain and operate a separate bank account in the name of "National Pool Account (SCED)" for settlement of payments to/from the SCED Generators.
- To prepare a consolidated all India monthly statement indicating the schedules on account of SCED.
- To issue a consolidated "National SCED Weekly Statement" indicating the payment and receipts to/from all SCED generators which would be made available to the stakeholders through the NLDC website.
- To issue a Monthly statement "National net SCED Benefits Distribution statement" detailing disbursal for different utilities in the net accrued amount due to reduction in total variable charge through SCED mechanism in "National Pool Account SCED".
- To conduct stakeholder awareness programs for smooth implementation of SCED

RLDCs

- To incorporate the SCED schedules as received from NLDC and maintain the relevant scheduling data during the operation of the SCED pilot (including but not limited to generating station-wise installed capacity, declared capacity, schedule, Un-Requisitioned Surplus (URS), generator wise Variable cost, RRAS, SCED schedules for up/down and requisitions from the generating stations).
- To reconcile schedules on account of SCED with the data provided by NLDC before forwarding to RPCs.

RPCs

- To issue weekly SCED accounts along with the DSM, RRAS, FRAS and AGC accounts based on the data provided to them by the RLDCs.
- To issue monthly "Statement of Compensation due to Part Load Operation on Account of SCED" separately in its accounts for all SCED generators.

Beneficiary(ies) of SCED Generators

- To provide the Bank account details to NLDC to facilitate payments to/from the beneficiary of SCED generator due to net benefits accrued in National Pool Account (SCED).
- To reconcile the amount received due to benefits accrued in National Pool Account (SCED) with NLDC on monthly basis based on the RPCs statement.
- To reconcile the SCED payment details with NLDC within 15 days of receipt of reconciliation statement; else it shall be treated as deemed reconciled.

Figure 5: Roles and Responsibilities of Various Stakeholders

2.3 Pre-implementation Challenges

The major issues faced during implementation of pilot on SCED were in terms of:

2.3.1 Information Technology, Hardware and Data Interfacing

A mix of applications had to be integrated and data exchange was to take place between different layers of technologies at RLDCs and NLDC. The data exchange requirements have to comply with stringent timelines. The WBES application of respective RLDCs is accessed through public internet by different regional entities in respective regions and hence, ensuring cyber security and data integrity is important.

2.3.2 Integration of Scheduling Software Applications pan-India

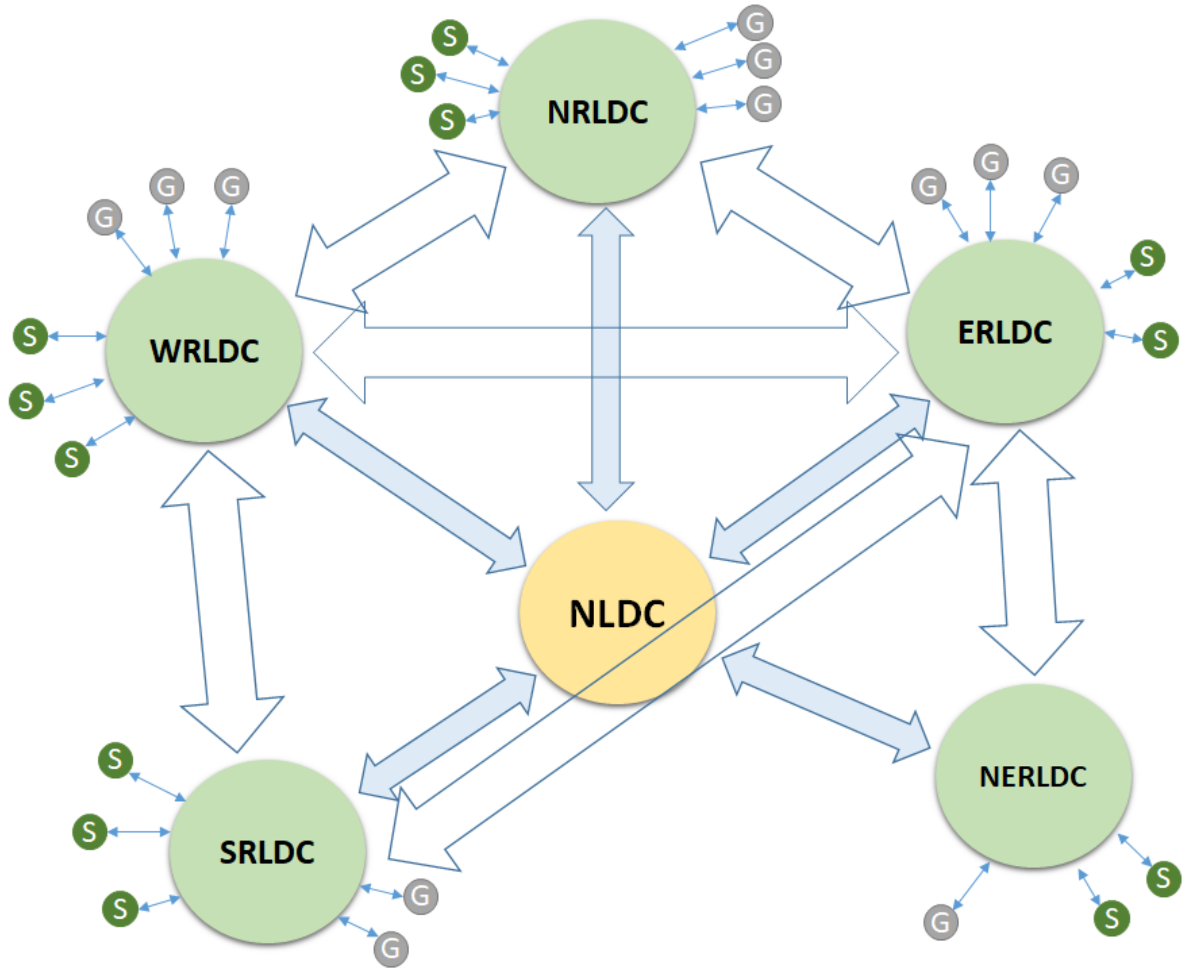

Figure 6: Integration of Scheduling Applications pan-India

The web-based energy scheduling software, hitherto, working on regional basis was integrated at national level for implementation of SCED. During the implementation phase, WBES test bench was setup at each RLDC with a copy of the latest data on the test server. Similarly, test bench of WBES and SCED was setup at NLDC. The auto service of scheduling was set up with the task to fetch schedule data ate pre-designated times. Some challenges were encountered initially such as issues on test bench, server instance of WBES was hanging at times at some RLDCs, need for upgradation in hardware for speedy processing and auto-schedule execution.

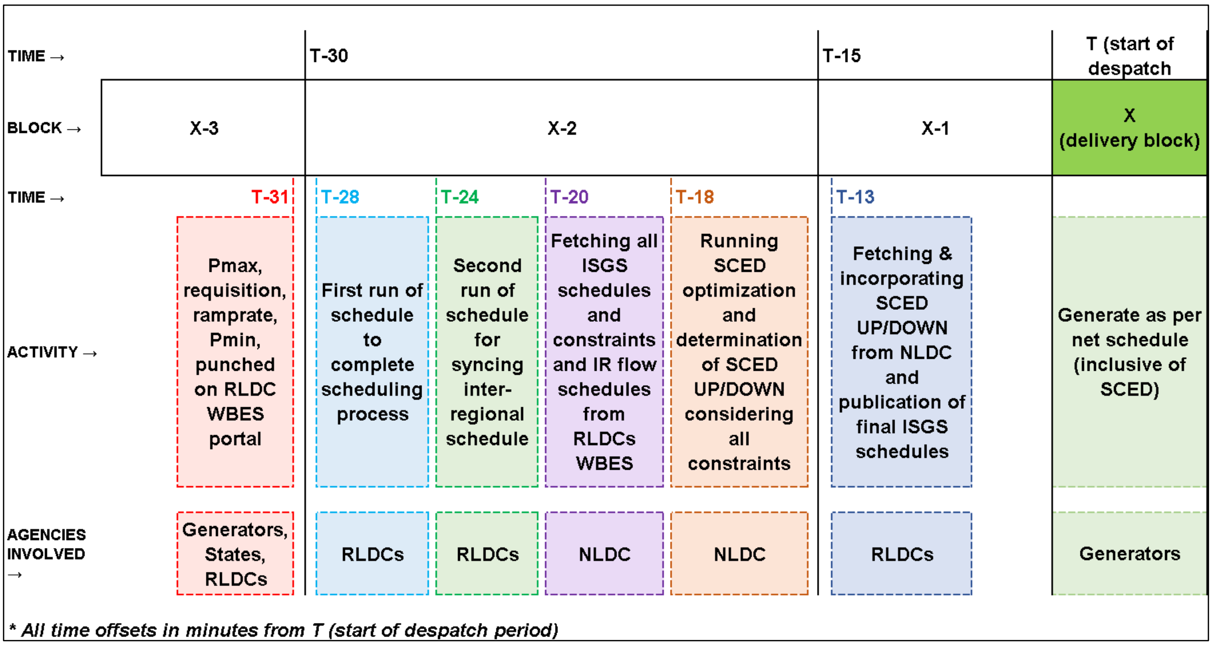

Figure 7: Data Exchange Timelines

These challenges were overcome with suitable measures in terms of patches in software applications, augmentation & strengthening of communication and hardware infrastructure along with capacity building and awareness programs for system operators. The schedule revisions which were triggered manually & on-demand earlier have been reconfigured to run automatically at pre-defined times. With tight data exchange & processing timelines, there is time bound execution at every step with less than 3 minutes available at NLDC. The complete process has to repeated every time block with around ~1,80,000 parameters handled by SCED on a daily basis.

2.3.3 Self-healing / Ride-through Attributes

The SCED software application had to be robust enough to run continuously in real time environment with self-healing / ride-through attributes within the given constraints in case of infeasibility. It was envisaged that there would be no manual user intervention. It was recognized that, as the scheduling is a real-time 24x7 critical application, the triggering in of the SCED optimization (smooth take-off) and reverting to normal schedules (smooth landing) in case of any interruption of SCED algorithm due to any reason are issues that need to be taken care of.

In the case of an interruption, safe landing and secure grid operation has to be ensured such that the impact would be minimized with the generators reverting gradually to the RLDC schedules as per the ramp rates. In case of failure or interruption of the SCED software program or a communication failure for any reason, the schedules without SCED have to become applicable. After resolving the issues leading to interruption, SCED optimization algorithm would have to be triggered in again.

2.3.4 Operational Flexibility Provisions in SCED

Normally, ATC would be fetched by the SCED software application directly from the WBES of respective RLDC. However, during severe exigencies/major congestion issues, a need was felt to have provision for the control room system operators to intervene and enter ATC from NLDC directly to maintain some margin for secure grid operation. Sometimes, in case of local transmission constraints/generation related issues/regulatory compliance testing, it was recognized that a need might arise to exclude one or more generators from SCED.

Therefore, real time system operators have been given control to include/exclude the generator(s) in the event of contingencies. Further, in case of extreme exigencies, start/stop SCED feature has been provided in the SCED software application to the authorized personnel so as to ensure normalcy in the scheduling operations. Some case studies are presented in the subsequent sections.

2.3.5 Concept of Gate Closure

In the present framework, revision of schedules by the market participants is permitted and as per the 'Scheduling and Despatch Code' under the Indian Electricity Grid Code (IEGC), the schedules can be revised by giving a notice of four (4) time blocks (each of 15-minutes). Given the large number of participants, there are requests for revisions in schedule on an almost continuous basis. This also poses problems in real time assessment of the available 'hot' and 'cold' reserves available in the system for despatch under ancillary services. For the SCED implemented at present, gate closure for constituents was kept unchanged. But, after operating SCED since 1st April, it was felt that continuous revisions until dispatch period, combined with any communication delays can cause deviation of generators from the economic schedule, in turn increasing the production cost.

This aspect has also been highlighted in the recent publication on gate closure[15] by NREL and POSOCO. It has been recognized that in a large grid like India, there are multiple regional-level control areas for the purpose of scheduling and energy accounting. Therefore, the introduction of gate closure would support in having more certainty of despatch, especially in terms of reserves requirement & activation, thereby, achieving greater efficiency and optimization in Indian electricity market.

2.3.6 Short timeframe for Implementation

The Central Commission gave the directions for implementation of pilot on SCED on 31st January, 2019 w.e.f 1st April, 2019. This led to a short timeframe of less than two months to implement pilot on SCED on ISGS pan-India. The issues at various levels ranging from in house development of software suites, hardware, communication, interfacing, data exchange, skilled manpower covering power system optimization, accounting and financial aspects, regulatory compliance, information technology,

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[15] National Renewable Energy Laboratory (NREL), USA and POSOCO Publication on Opening Markets, Designing Windows, and Closing Gates: India's Power System Transition - Insights on Gate Closure https://www.nrel.gov/docs/fy19osti/72665.pdf

information dissemination and quality assurance had to be resolved and streamlined for smooth implementation of pilot on SCED w.e.f 1st April, 2019.

2.4 Information Flow of SCED Software Application

The SCED software application at NLDC has been designed through different stages such as fetching input data from the respective regional scheduling software applications, pre-processing data for the validation checks, running the core optimization engine of linear programming using GAMS, post processing the optimized output data, data warehousing in a database and relaying back the optimized output data to respective RLDC WBES. These stages are run in a batch mode based on a trigger every 15 minutes, along with revision mapper, fetching data from RLDC WBES into the NLDC SCED software application database. The information flow between SCED ISGS generators, States, RLDCs and NLDC for the SCED process is depicted below (Fig. 8):

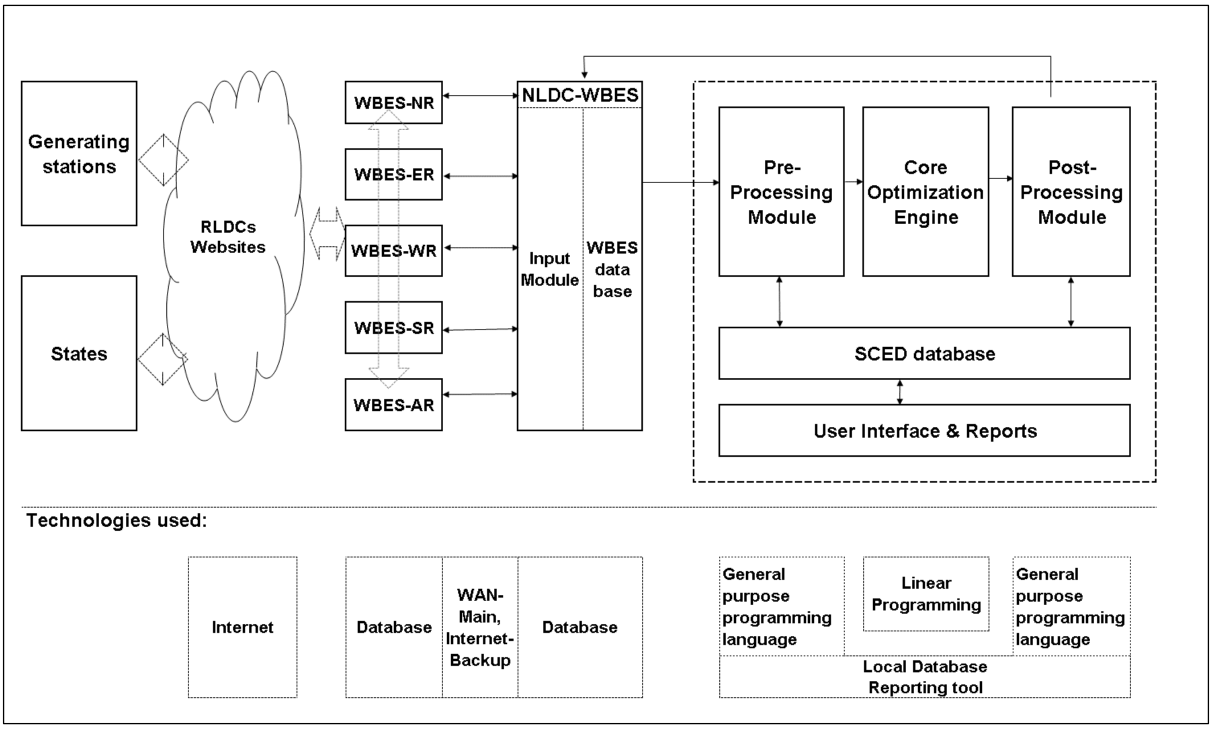

Figure 8: Architecture of Information Flow in SCED

- **Input Module and Pre-Processing Module**

Various data viz., gen max limit, turn down level, schedule, ramp rates, revision number, available transfer capability (ATC) values, transmission tie line schedules etc. are fetched from the respective WBES of RLDCs to NLDC SCED software application database using secure application programming interface. The pre-processing module looks at the data to filter out non-plausible data and replace them with old/plausible data before passing on to the core engine.

- **Core Optimization Engine**

The core optimization engine using CPLEX solver through GAMS based software program fetches the data from SCED software database. The objective function is minimization of the variable cost. The sum of the generator optimal schedules should be equal to the total schedules issued by RLDCs before SCED optimization process. The impact on the inter-regional flows as a result of variation in generation in the regions should not exceed the ATC. The maximum each plant can be scheduled is Pmax which is the DC reduced by normative auxiliary consumption. The minimum optimal schedule of each plant can be upto Pmin. The optimal generator schedule should always honour the up and down ramp rate limits of each plant. In addition to optimal schedules, one of the other outputs is the System Marginal Price (SMP).

The core optimization engine using linear programming-based software fetches the data from SCED software database. The objective function and constraints are defined in the core engine. The output is relayed to the post processing module.

- **Post Processing Module**

Post-processing module checks the output data for limit violations and receives flags from all the modules regarding the health of the solution. In case of violations under infeasible conditions, the output data is clamped to the limits and corresponding flags are passed on to the user interface.

- **SCED Database, Visualization and Reporting**

The final data is placed in the SCED application database and RLDCs WBES database. The final data is read from the application database for creating the operator dashboard for visualization and populating the information in the user interface.

- **Hardware**

The requisite computing resources at different RLDCs were strengthened and augmented and additional & redundant communication links were established for robust and seamless communication.

2.5 Overview of SCED Platform

A secure POSOCO Wide Area Network (WAN) has been setup for data exchange between databases (e.g. Oracle DB, .NET) of the WBES in different RLDCs and SCED application database in NLDC. For the core optimization engine, GAMS software was procured for the pilot project. Other technologies such as PHP, JavaScript, node.js, Python were used for user interface and reports.

Various software development efforts have been made at NLDC and RLDCs for seamless data flow for implementation of pilot on SCED. The databases used in the application development store the data for the user interface interaction and graph rendering. The backup database is also used to keep a replica of data for faster access. This also helps in the keeping application database responsive as the number of data requests from main application database is reduced. The user interface and data analysis web application use Node.js and Python software tools. Node.js has been used for web application backend development. Python has been used for development of Core-Engine and scripts for fetching data at regular intervals.

The SCED software application dashboard for 24x7 operations has been depicted in Figure 9 below.

Figure 9: SCED Dashboard – 24x7 Monitoring

The visualization dashboard for the real time control room system operators has been evolved as per the need. The various diagnostic tools for monitoring, debugging and auditing the various intermediate steps have also been evolved. As part of the development process, around 12 different sections involving more than 25 options has been evolved so far, for display of region-wise, station-wise fundamental variables and derived parameters. A learning centre link has also been created where the relevant publications extracted out of the continuous literature survey are being collated for ready reference.

3 CORE OPTIMIZATION ENGINE

3.1 Introduction

The software options available for solving linear programming formulations were explored since 2016. Internationally also, it was observed that there are system operators[16] who use Linear Programming formulations for performing SCED. The utility of *General Algebraic Modeling System (GAMS[17])* language for solving the linear programming formulation was, generally, found to be stable, with improvisations made over a period of time, and resource faculty for capacity building were available.

The core algorithm of SCED is built using in-house efforts over a period of time, evolving from an experimental setup to a real-time application. Experimental setup, as explained in the earlier sections, was aimed at demonstrating the potential benefits that can arrive out of the optimization and it lacked special features to run robustly in real time. Hence, the core algorithm of SCED was improved with the guiding principles of –

A. To be robust enough to run continuously in real time within seconds

B. To ride-through during potential infeasibility conditions

C. To avoid any manual user intervention

The objective function and constraints considered for the SCED optimization problem are given below.

3.2 Objective Function

Out of the various broad objectives discussed in Section 1, minimization of total variable cost was chosen as the main objective for SCED optimization. The standard centralized unit commitment techniques or the 'entire output through a spot market'

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[16] In the practical use of Linear Programming in power sector, Singapore Electricity Market Rules have the market clearing formulation based on LP. https://www.emcsg.com/marketrules

[17] The demo version of GAMS is available at https://www.gams.com/download/. It includes all features and solvers, but the size of the models that can be solved with the demo version is limited (for LPs: 300 constraints, 300 variables, 2000 non-zeros). GAMS example for converting mathematical model to GAMS language is available at https://www.gams.com/products/simple-example/

are incongruent with the coordinated multilateral scheduling model in vogue in India. A mechanism of compensation for heat rate degradation, increased auxiliary and secondary fuel oil consumption due to part load operation and multiple start-stop of units is also in place. There is a regulatory roadmap to maintain a spinning reserve corresponding to the largest unit outage in each region.

The scope of this exercise, to start with, is limited to the optimization part after the unit commitment has taken place at a day ahead level viz. minimization of only the total variable cost on a pan-India basis for an identified set of participating generators. The present problem, hence, assumes participating generating plants are already despatched and a base case schedule of these plants exists for the day of operation.

The objective function of SCED is to minimize the total variable cost of generation. It may be noted that the regulated power plants in India have a multi part tariff. The two parts of multi-part tariff are fixed cost and variable cost, with units in ₹/kWh (Rupees per kWh). Equation 1 provides the mathematical formulation for the objective function. Violation Penalties are added to the objective function to handle probable infeasibility conditions mathematically by adding an artificial variable and penalizing the objective function using a 'Big-M' penalty described in classical optimization techniques [5]. Big-M penalty is chosen greater than variable cost of all the plants.

$$\text{Minimise } \sum_{i=1}^{k} C_i P_i + \sum(Violation\ Penalties) \quad \text{.........................(1)}$$

- k = *total number of Plants*
- *Where* C_i *is the variable per unit cost of the* i^{th} *Plant*
- P_i *is the optimised scheduled power of the* i^{th} *Plant*

3.3 Constraints

Different technical constraints have been identified which have to be honoured (or can cause technical problems if breached) at the power plant or at the power system level in the pursuit of achieving the objective function of total variable cost minimization. They are listed down under:

3.3.1 Meeting Total Requisition by States from Generators

In practice, the schedule of each plant is discretized across 96 time blocks of 15 minutes each, for the day of operation. The sum of schedules of generators of all regions is the combined generation requisition by all the states to meet a part of the demand through their entitlement portfolio from central sector plants. This quantity serves as a proxy for the total system demand for the purpose of optimization.

Hence, the sum of optimal schedules of all generators for the time block under consideration should be equal to the sum of schedules given by the states/beneficiaries, as an equality constraint. Put differently, the model adheres to the commitment and the total schedule of the generator already in place while optimizing the despatch process.

Schedule violation in equation 2 is an artificial variable inserted to avoid infeasibility in case there is a shortfall of available generation.

$$\sum_{i=1}^{k} P_i = \sum_{i=1}^{k} S_i - Schedule\ violation \qquad \text{.......................... (2)}$$

- Where *S* is the *scheduled power* before optimization

3.3.2 Available Transfer Capability (ATC)

Available Transfer Capability (ATC) derived considering the network security constraints is the hard limit for the flow of power between the regions. Base case schedule of generation for each region is prepared such that the resulting scheduled inter regional flows do not exceed the ATC limit. This has to be honored in the case of preparation of optimal schedule also.

SCED tries to utilize the margin available on transmission lines for any extra power flow from the low variable cost power plants to the load centres for bringing economy. Available transfer capability (ATC) on the tie lines between the regions is calculated by

NLDC, factoring N-1 criteria[18]. Pre-SCED generator schedules are prepared by RLDCs in such a way that the inter-regional tie line flows are n-1 compliant and their net sum is below the available transfer capability. So, a constraint is added in SCED so that the post-SCED generator injections result in inter-regional schedule below ATC and N-1 criteria is adhered to. ATC violation in equation 3 is an artificial variable inserted to sail through conditions of infeasibility which can be caused, if there are no surplus power reserves in the importing region and the tie lines are overloaded.

$$\forall\, r \in R,\ \ \sum_r \left(P_{i,r} - S_{i,r}\right) \geq \ (SCHIR_r - ATC_r) - ATC\ violation \text{ .....(3)}$$

- *R* -represents each of the regions viz., North, East, West, South and North East
- *ATC* -is the Available Transmission Capability of each region *R*
- *SCHIR* -is the Scheduled Net Interchange of the region *R*

3.3.3 Maximum Generation

The maximum each thermal generating plant can be scheduled is the Declared Capability on bar (DC on bar) of each plant. As mentioned in sections 1 and 2, this information is communicated by the power plants to RLDCs frequently with every schedule revision based on operating conditions linked mainly with plant conditions, fuel etc.

$$P_i \leq (DC\ on\ bar) \quad \text{............................(4)}$$

3.3.4 Technical Minimum

The technical minimum (turn down level) for operation of thermal ISGS units as decided by CERC is 55% of Maximum Continuous Rating (MCR) loading. The maximum each thermal generating plant can be scheduled is the Declared Capability on bar (DC on bar) of each plant.

$$P_i \geq P_{i,min} \text{ ....(5)}$$

[18] S. R. Narasimhan et al., "Challenges in assessment of transfer capability under a high growth high uncertainty restructured scenario in India", CIGRE Proceedings, 2014, Paper C2-108_2014

3.3.5 Ramp Up and Ramp Down Rate

Every thermal plant has its own ramp up or ramp down limits. This ramping data in units of MW per 15 minutes is also collected as per declaration by the generator under RRAS. The optimal generator schedule would always honour the up and down ramp rate limits of each plant with respect to its previous schedule.

SCED output schedule should always honour the up and down ramp rate limits of each plant with respect to its previous schedule. Modeling ramp rate limit constraints need consideration of time as shown in equation 6 and 7.

$$P_{i,t} \leq P_{i,t-1} + \ Ramp\ up\ rate + Ramp\ up\ violation \ \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$P_{i,t} \geq P_{i,t-1} \ - \ Ramp\ down\ rate - Ramp\ down\ violation \ \ldots\ldots\ldots(7)$$

- t -represents current time of execution

The above equations 1 to 7 are modeled in a linear programming software, as the objective function and the constraints are linear. These equations are solved for the optimized MW schedule of each power plant and duals of the binding constraints.

4 ANALYSIS & INFERENCES

A large volume of data was generated during the progress of the SCED pilot. Many analytical exercises were carried out over this data set to derive patterns and inferences. Duals of the binding constraints are also gathered. The main motives for data analysis were threefold:

a. To ascertain whether SCED pilot results are as generally expected, to ensure macro level correctness.
b. To provide indirect signals for technological interventions in generation and transmission expansion, for enhancing reliability and economy.
c. To gather insights for future outlook in terms of further work etc.

4.1 Generation

It can be observed from Fig. 10 below that generation in the southern region (SR) and northern region (NR) of the Indian grid has generally been decreased by SCED during the period Apr-Dec 2019 causing NR and SR to import more energy from the rest of the grid. This is considering that, in general, relatively lower cost pit head plants are located in eastern region (ER) and western region (WR) of India and variable cost of thermal generation in SR is on the higher side.

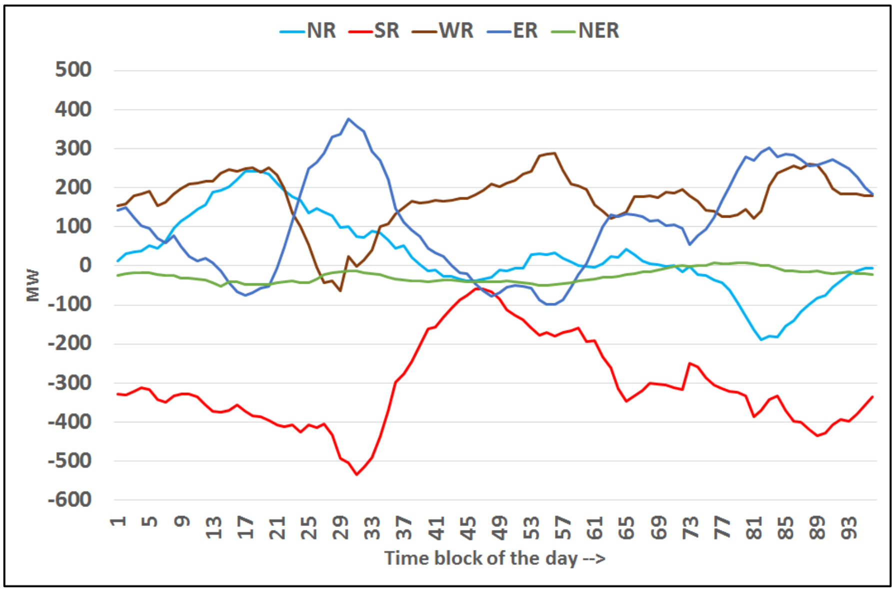


Figure 10: Diurnal Pattern of Region-wise Increase/Decrease in Generation

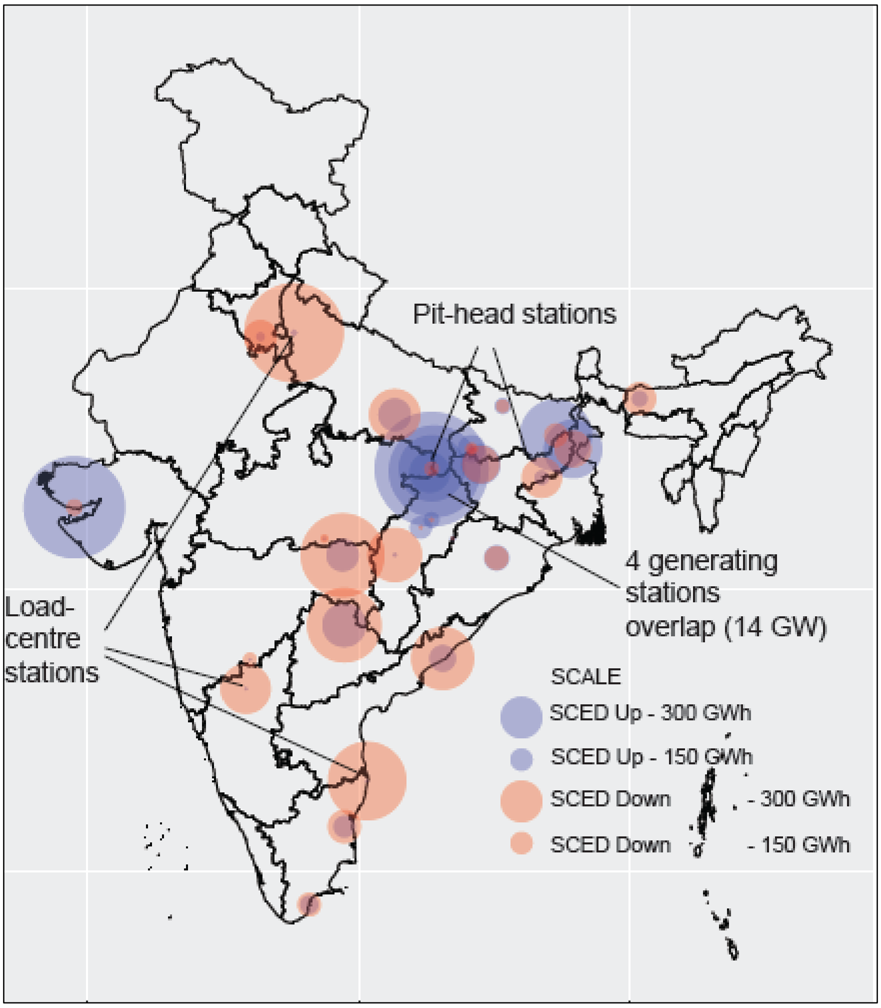


Figure 11: Geospatial distribution of SCED up and down energy (Apr – Dec’19)

Figure 11 shows the geospatial distribution SCED up and down quantum given to generators pan-India. Large SCED up quantum in pit-head stations and similar large SCED down in load-centre stations can clearly be seen. Mid-merit plants pan-India get both SCED up and down, depending on the demand conditions prevailing at the time.

4.1.1 Schedule and Optimal Schedule of Generators

The schedule (without SCED) and optimal schedule (with SCED) of all participating generators for Apr’19- Dec’19 period are depicted in supplementary volume of the report. Representative plots for plants which are lower in merit (Sasan), mid-merit (Barh) and higher in merit (Dadri-II) have been depicted as scatter plot (in Fig. 12, 14 and 16) and as duration plot (in Fig. 13, 15 and 17) respectively.

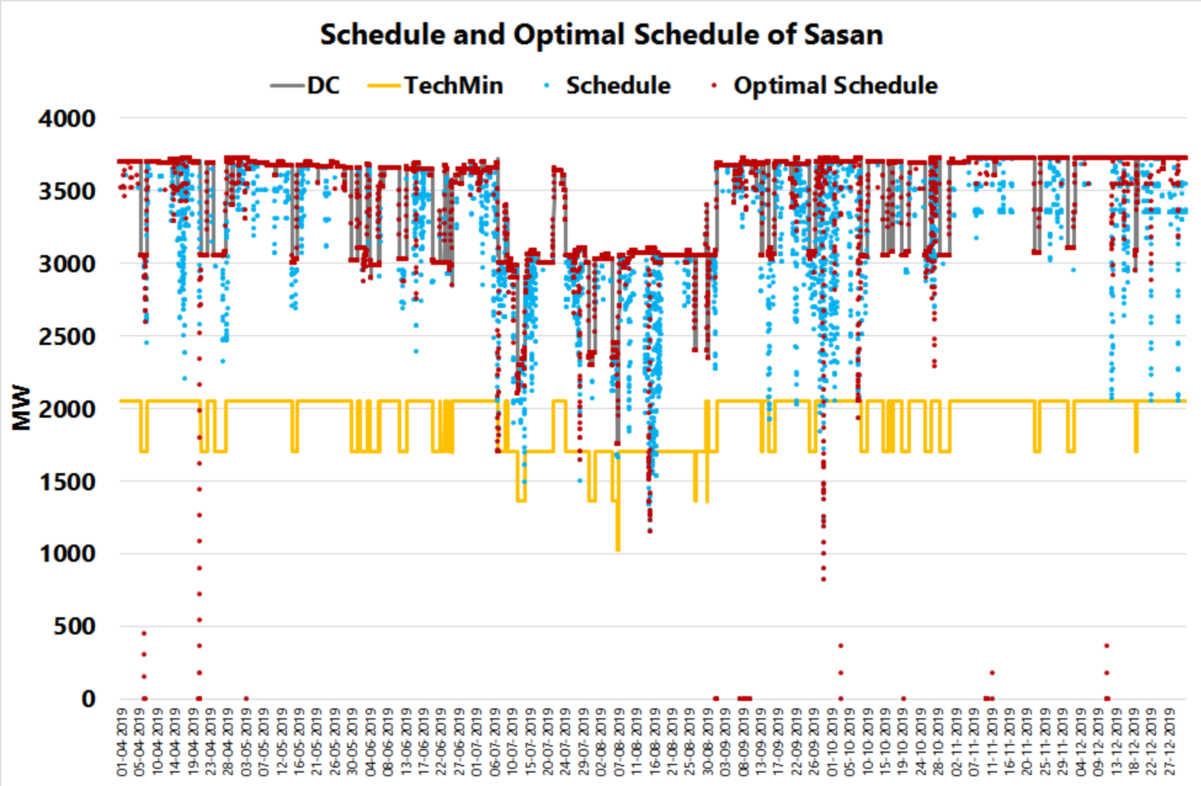


Figure 12: Schedule and Optimal Schedule of Sasan

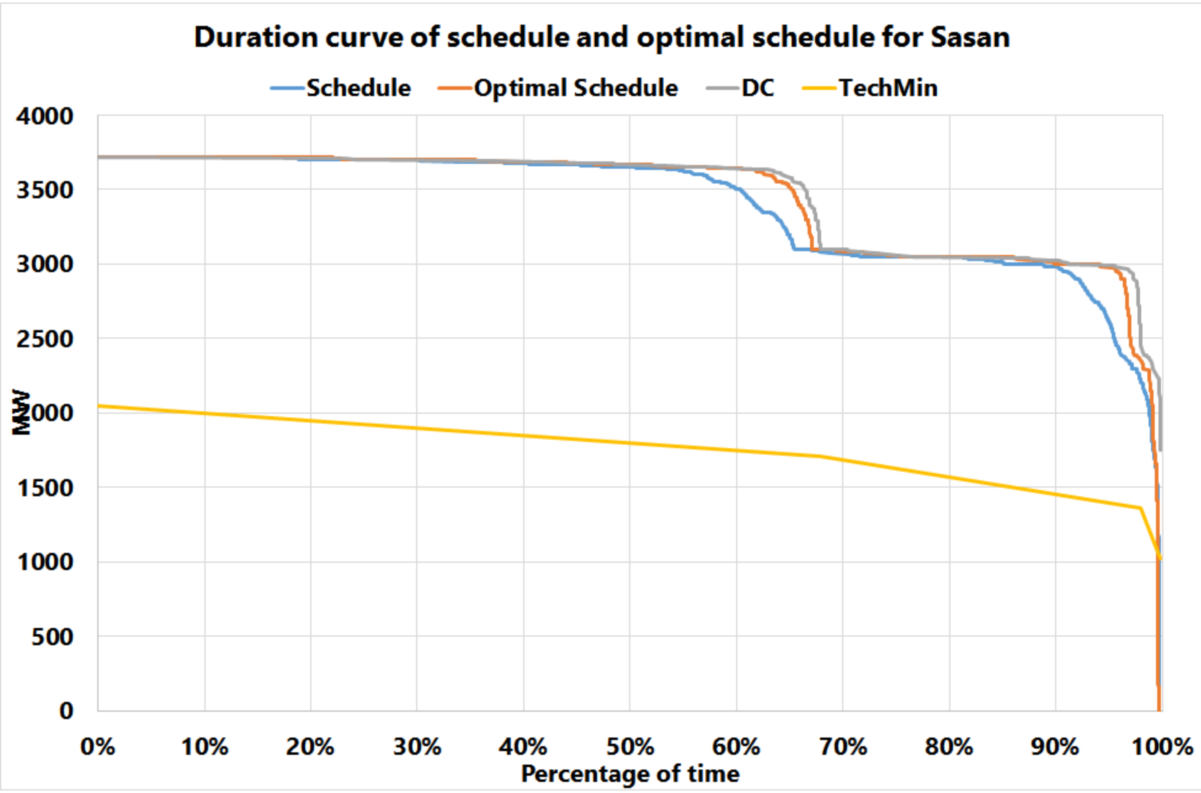


Figure 13: Duration Curve of Schedule and Optimal Schedule of Sasan

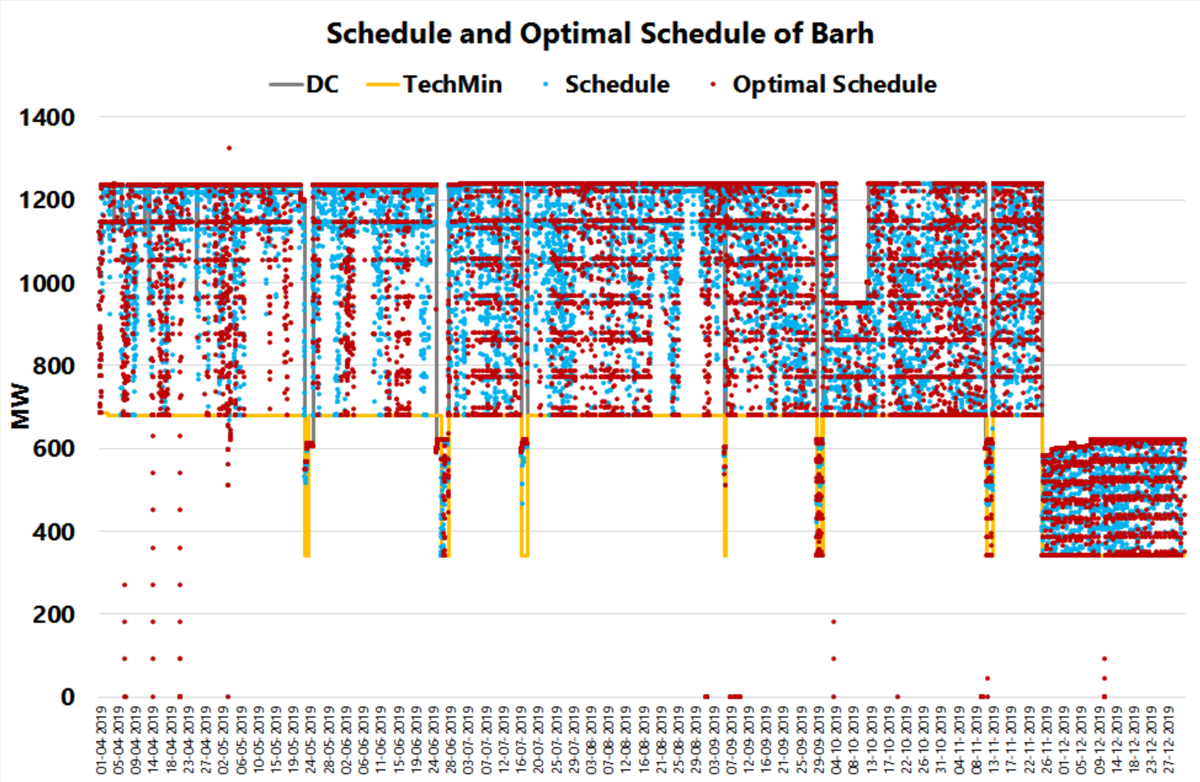


Figure 14: Schedule and Optimal Schedule of Barh

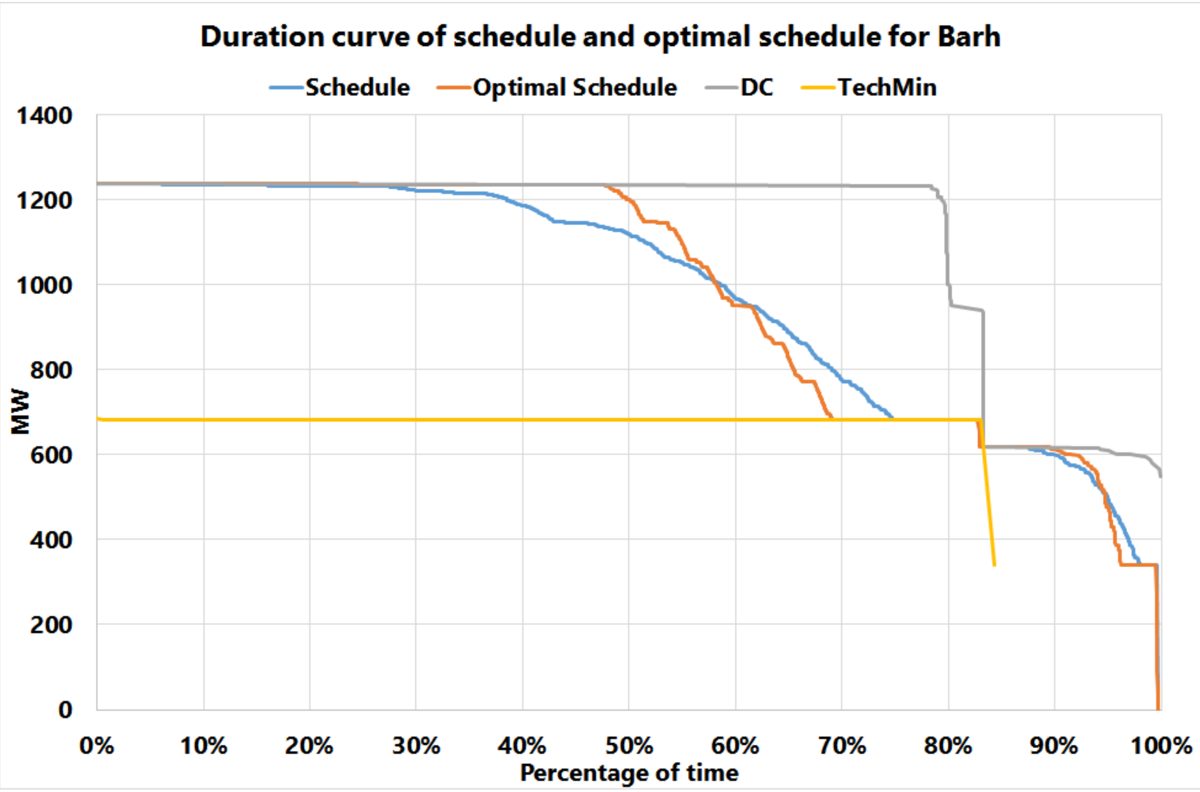


Figure 15: Duration Curve of Schedule and Optimal Schedule of Barh

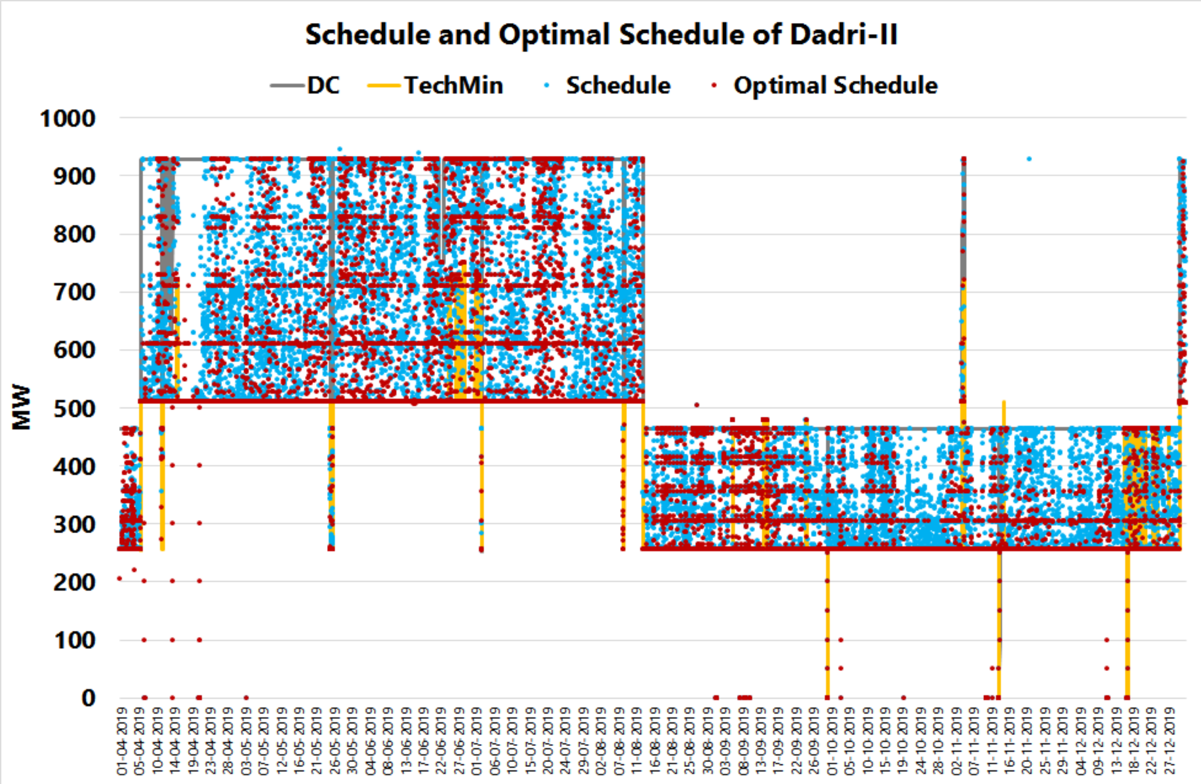


Figure 16: Schedule and Optimal Schedule of Dadri-II

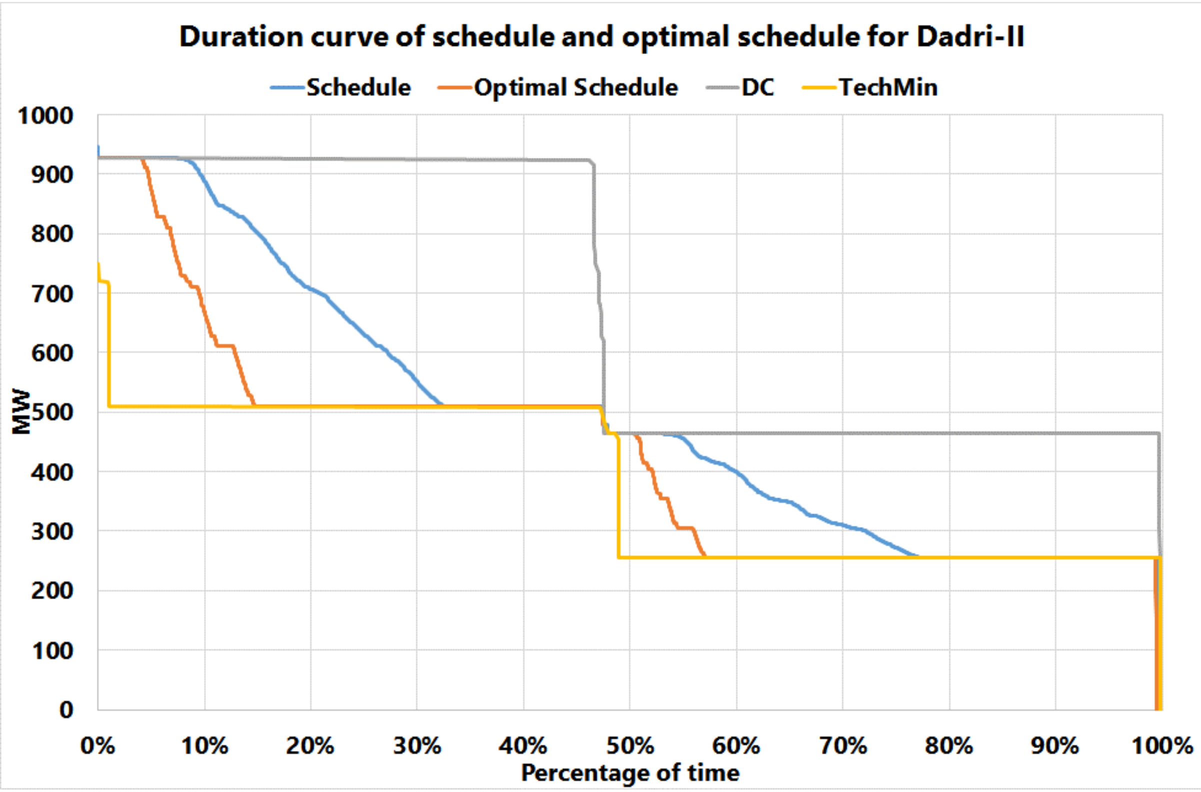


Figure 17: Duration Curve of Schedule and Optimal Schedule of Dadri-II

There were instances early on after the commissioning of SCED application when the optimization had to be stopped for various reasons such as communication problems, data interfacing issues, software upgradation and maintenance activities. It may be noted that the effect of the downtime of optimization activity may reflect in the data visualization, which might translate as outliers in the various plots.

In Fig. 13, 15 and 17 above, the optimal schedule and schedule of Sasan, Barh and Dadri-II plants are depicted along with the technical minimum and DC for every 15 minute time block (Apr to Dec 2019). It can be observed that the generation of the lower variable cost Sasan was increased by SCED and generation at Dadri was decreased by SCED, which has a high variable cost. The mid-merit plant Barh depending on the demand and the time of the day had to increase or decrease its generation. The corresponding duration curves in Fig. 14, 16 and 18 depict the percentage of time for which these power plants were scheduled at various levels before and after SCED.

As observed from the plots, Dadri-II, which is a high variable cost plant, had to generate more than 700 MW for 15% of the time after SCED and would have had to generate at 700 MW or above for 30% of the time without SCED. This is in line with the SCED objective that the higher variable cost generation would be backed down by the SCED resulting in reduction in production cost. Similarly, for Sasan, as it is a lower variable cost plant, there is an increase in the duration at higher generation level. It can also be observed from the duration plots that the certainty of the generators spending time either at DC or at technical minimum has increased after SCED. This can also be seen from the duration curve of Barh at Figure 16.

4.1.2 Ease of Generator Operations

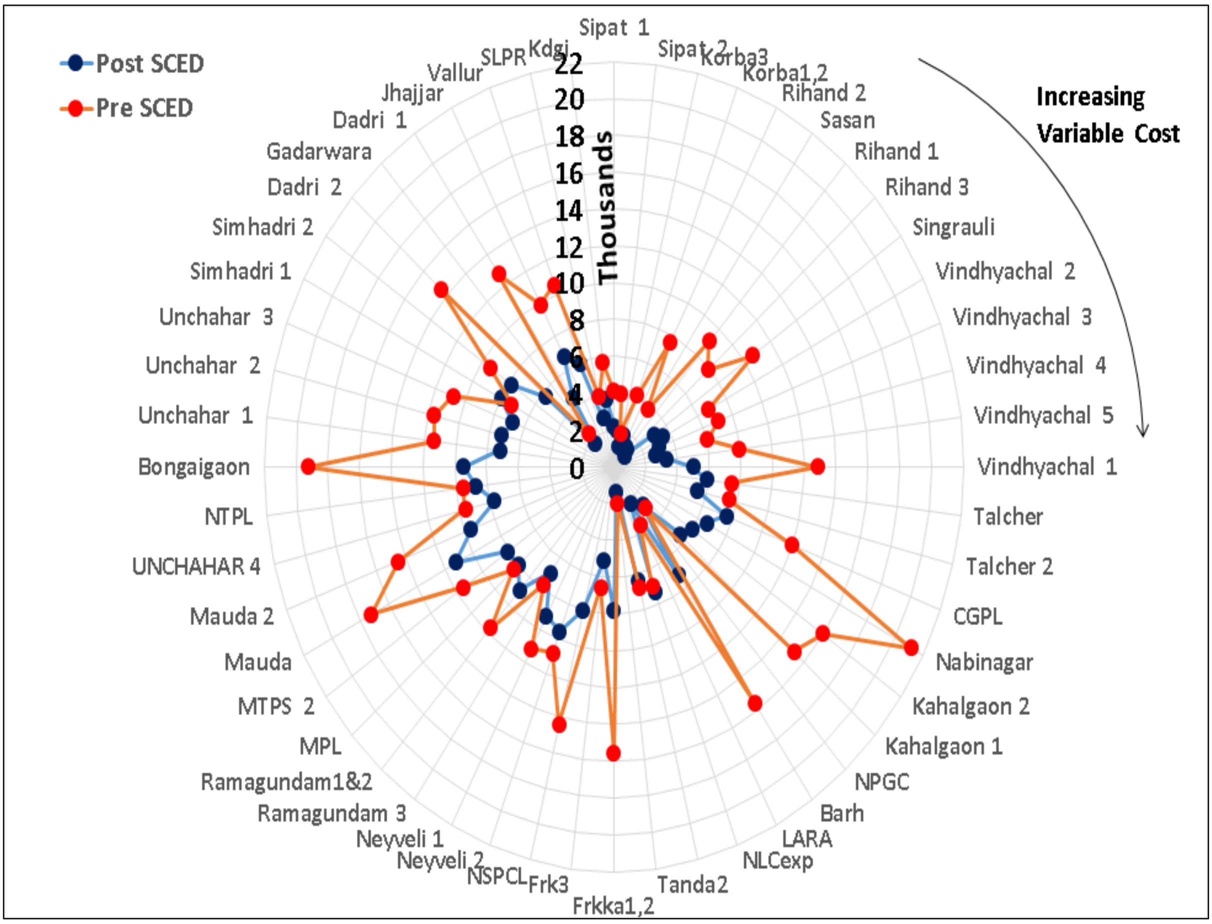


Figure 18: Cumulative change in schedule (MW) with and without SCED

SCED brought more certainty in the dispatch pattern of generators. There is an average decrease of 42 % in the cumulative MW change in schedules (Fig. 18) and average decrease of 29 % in the number of instructions (counting any change in the schedule of the generator by the RLDC as one instruction) to all the generators (Fig. 19) during the period Apr- Dec 2019. It has resulted in increased plant load factor in lower variable cost power stations & vice versa. Therefore, pilot on SCED has facilitated the ease of generators' operations by requiring change in generation schedule less often.

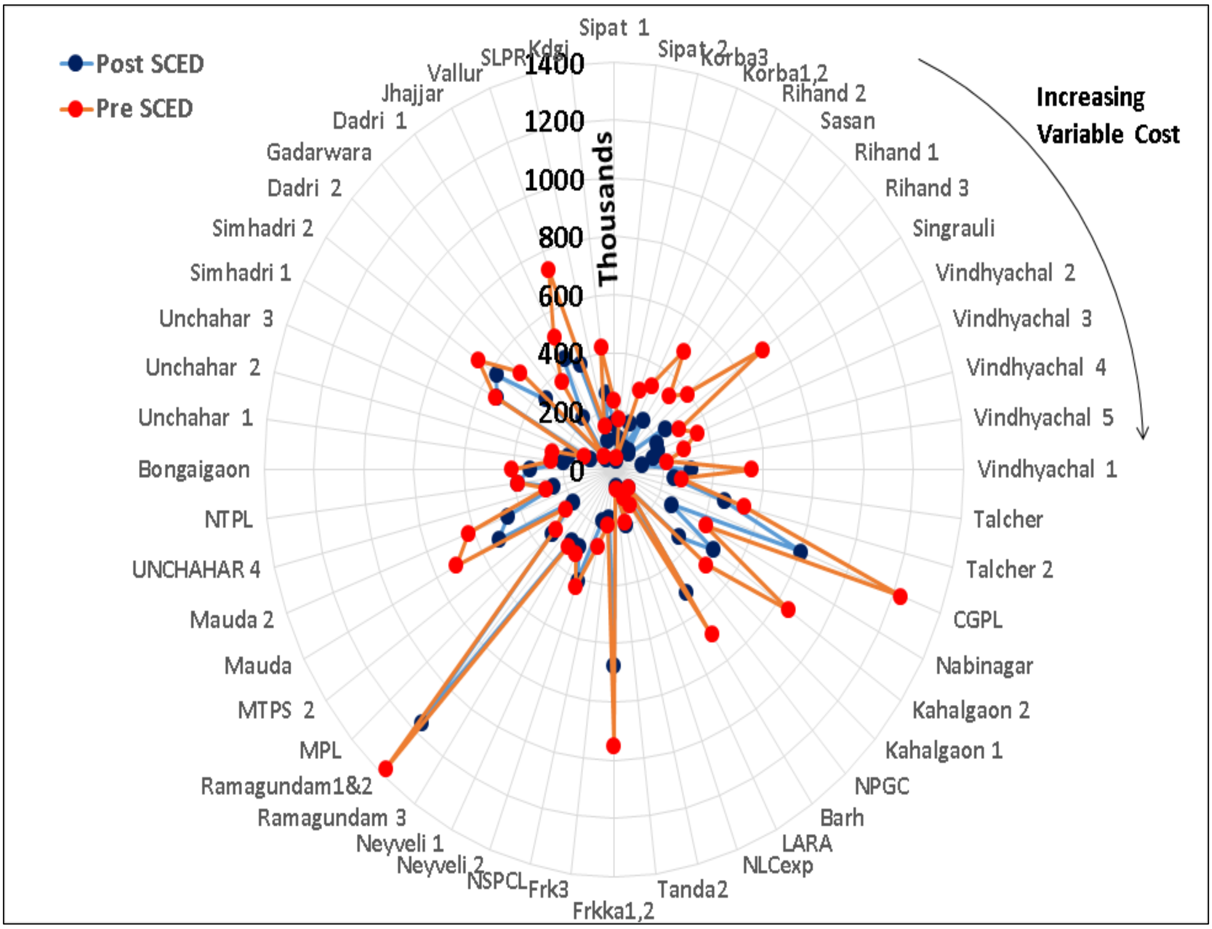


Figure 19: Change in instruction count to generators before and after SCED

The generator-wise Pre-SCED and Post SCED Change in Number of Instructions and cumulative MW change in schedules (Apr'19 – Sep'19) is tabulated as below:

Table 1: Generator-wise change in number of instructions and Delta MW

Generator	VC (p/kWh)	Cumulative Delta MW Post SCED	Cumulative Delta MW Pre SCED	% change in MW	Instruction Count Post SCED	Instruction Count Pre SCED	% change in instructions
Sipat 1	118.2	2213	4110	-46	159354	237525	-32
Sipat 2	121.6	1942	3976	-51	111467	175636	-36
Korba 3	122.2	1151	1855	-37	30684	39388	-22
Korba 1,2	123.7	1803	4130	-56	171790	293452	-41
Rihand 2	131.8	1063	7594	-86	86123	326256	-73
Sasan	132.2	1309	3780	-65	203201	493604	-58
Rihand 1	132.4	1232	9084	-86	89242	336401	-73
Rihand 3	133.3	881	7916	-88	80671	390693	-79
Singrauli	138.6	3042	10648	-71	248126	725050	-65
Vindhyachal 2	148.5	3516	6741	-47	196543	295556	-33
Vindhyachal 3	148.9	3085	7049	-56	187623	355890	-47
Vindhyachal 4	149	2697	6062	-55	160344	289298	-44

Generator	VC (p/kWh)	Cumulative Delta MW Post SCED	Cumulative Delta MW Pre SCED	% change in MW	Instruction Count Post SCED	Instruction Count Pre SCED	% change in instructions
Vindhyachal 5	150.4	3351	7946	-57	111300	212908	-47
Vindhyachal 1	158.7	5002	12812	-60	308893	553189	-44
Talcher	173.3	5915	7501	-21	242708	271230	-10
Talcher 2	173.9	5399	7452	-27	457135	538144	-15
CGPL	180.01	7581	12002	-36	802731	1228125	-34
Nabinagar	194.6	6628	21148	-68	260398	416505	-37
Kahalgaon 2	207.1	5980	15987	-62	486279	850857	-42
Kahalgaon 1	216.7	5578	15154	-63	348083	494124	-29
NPGC	219	2778	3000	-7	86087	86402	0
Barh	221.7	7175	15603	-54	512536	689266	-25
LARA	235	2221	3592	-38	108771	137828	-21
NLCexp 1	235.8	7294	6905	5	115761	106804	8
NLCexp 2	236.2	6407	6777	-5	197039	185138	6
Tanda 2	239	1377	2052	-32	56907	71095	-19
Farakka 1,2	249.4	7830	15570	-49	672812	951269	-29
Farakka 3	250.7	5124	6597	-22	165584	194847	-15
NSPCL	250.9	8018	14398	-44	181243	275021	-34
Neyveli 2	255.2	9583	10830	-11	408014	430725	-5
Neyveli 1	255.2	9168	11170	-17	297908	329886	-9
Ramagundam 3	256.7	7025	7757	-9	299053	323870	-7
Ramagundam1&2	261.9	8938	11681	-23	1162007	1377115	-15
MPL	270	8039	8423	-4	330312	312341	5
MTPS 2	270.7	8148	11514	-29	197140	237077	-16
Mauda	277	11222	17234	-34	519570	712752	-27
Mauda 2	283.2	9621	14510	-33	451974	622187	-27
Unchahar 4	284.6	7729	9603	-19	249752	278760	-10
NTPL	292.4	8745	9556	-8	386772	387500	0
Bongaigaon	301.9	9462	19243	-50	336741	407684	-17
Unchahar 1	307.5	7197	11381	-36	202972	252342	-19
Unchahar 2	307.5	7242	11665	-37	190716	253359	-24
Unchahar 3	307.5	6801	10790	-36	99545	127305	-21
Simhadri 1	322.1	7979	7236	10	529277	536262	-1
Simhadri 2	322.6	7837	9479	-17	571239	657888	-13
Dadri 2	334.6	5704	14558	-60	365322	500971	-27
Gadarwara	345	1722	2364	-27	46013	63059	-27
Dadri 1	356.9	4501	12718	-64	217109	367511	-40
Jhajjar	359.1	6756	9909	-31	427796	514874	-16
Vallur	372.3	5945	10551	-43	384751	733485	-47
Solapur	385.1	2726	3900	-30	104147	153767	-32
Kudgi	400.1	3717	5689	-34	265835	424872	-37
All India		**283399**	**489202**	**-42**	**14883400**	**21227093**	**-29**

4.2 Ramping

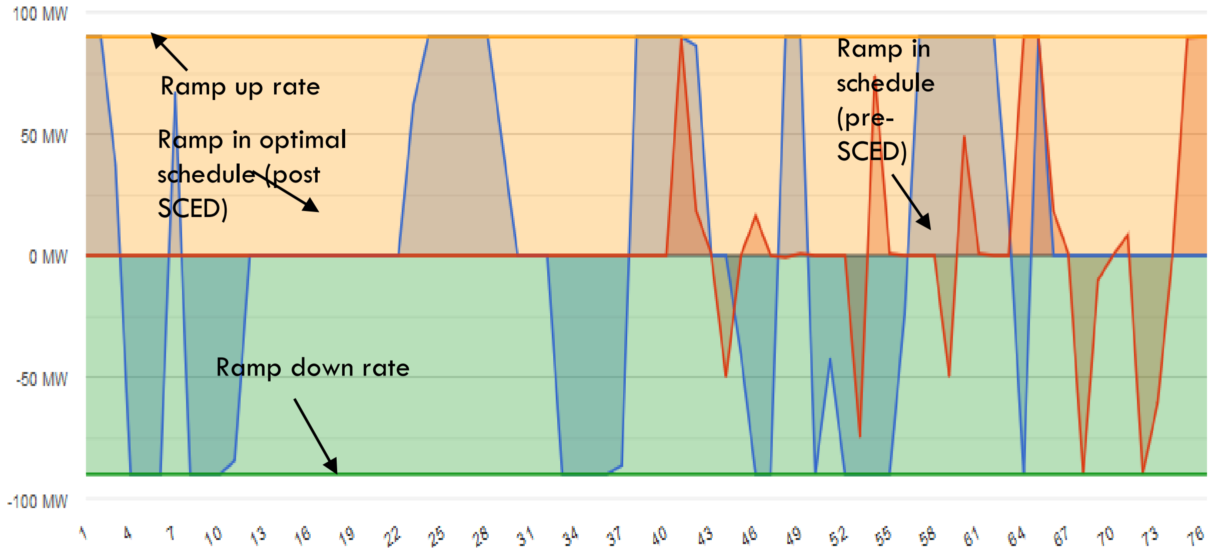


Figure 20: Derivative of Generator Schedule pre and post SCED (Typical Day)

Fig. 20 depicts the block wise ramp in the generator schedule pre and post SCED. It may be noted that the ramp rate declared by the generators itself may be varying during the course of the day. Schedule given by SCED honours the ramp rate declared by the generators at every point of time.

4.2.1 Ramping Comparison in Optimal Schedule and Actual

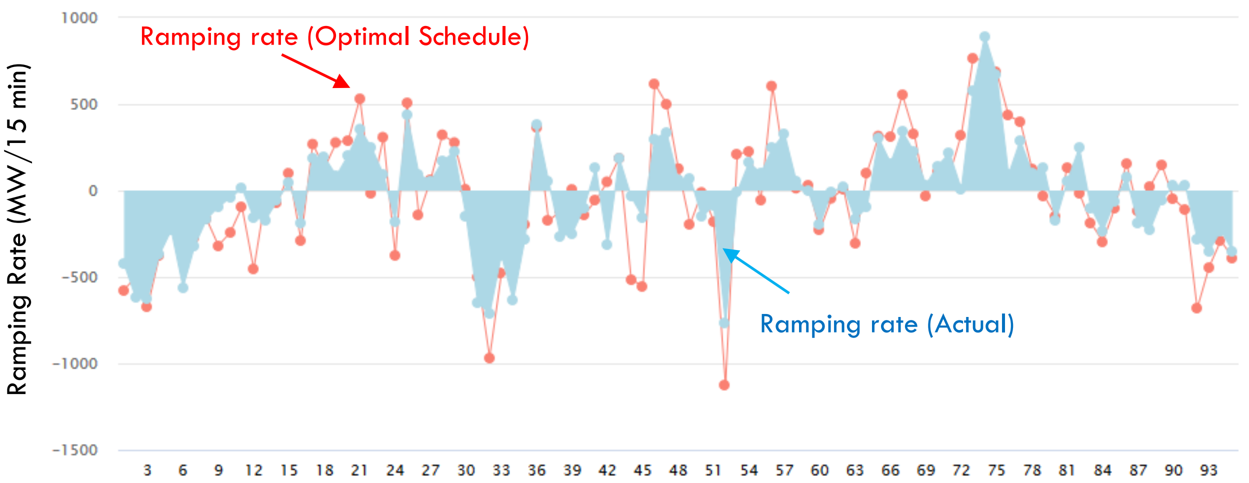


Figure 21: Ramping in Optimal Schedule and Actual (All-India) – Typical Day

In Fig. 21, ramping in optimal schedule depicts the total ramping requirement (in MW/15 min) of the states from all the SCED generators combined, in the next time block compared to the previous time block. Actual ramping that is delivered depends on the thermal power plant performance and can be impacted by multiple factors. This in turn affects the instantaneous frequency of the power system.

It may be noted that the ramp rate limits are declared by the power plants in advance and it might be of concern when the system ramp requirement is not fulfilled. Detailed analysis of the ramp rates provided by the thermal generators in the country was presented in the report by POSOCO released in May 2019[19].

4.2.2 Duration Curve – Ramping in Schedule and Optimal Schedule

As depicted in Figure 22, 23 and 24 below, the duration of time when the plant has to ramp up or down has decreased, in general. Lower variable cost plants tend to remain mostly at the DC and the higher variable cost plants tend to remain at the technical minimum and mid-merit plants are ramped only when the total requisition from SCED generators by states warrants so.

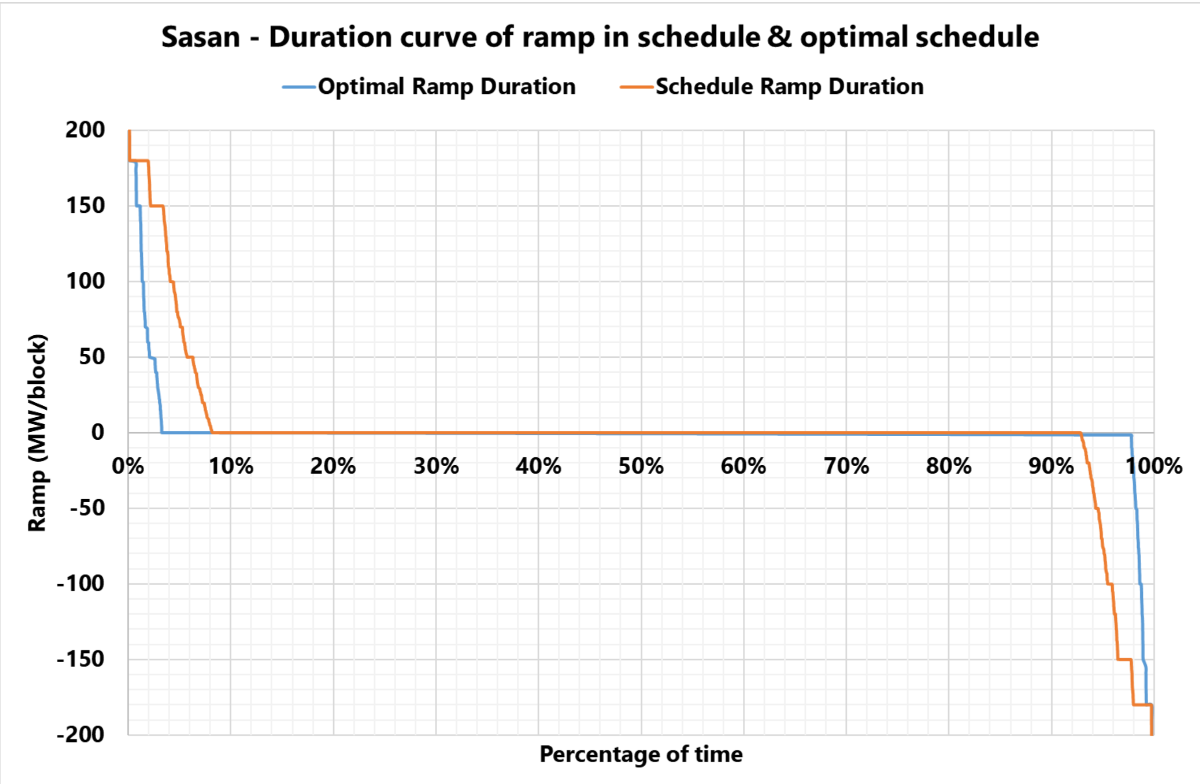


Figure 22: Duration Curve - Ramp in Schedule & Optimal of Sasan

19 POSOCO report on "Analysis of ramping capability of thermal power stations in India"; https://posoco.in/download/analysis-of-ramping-capability-of-coal-fired-generation-in-india/?wpdmdl=23042

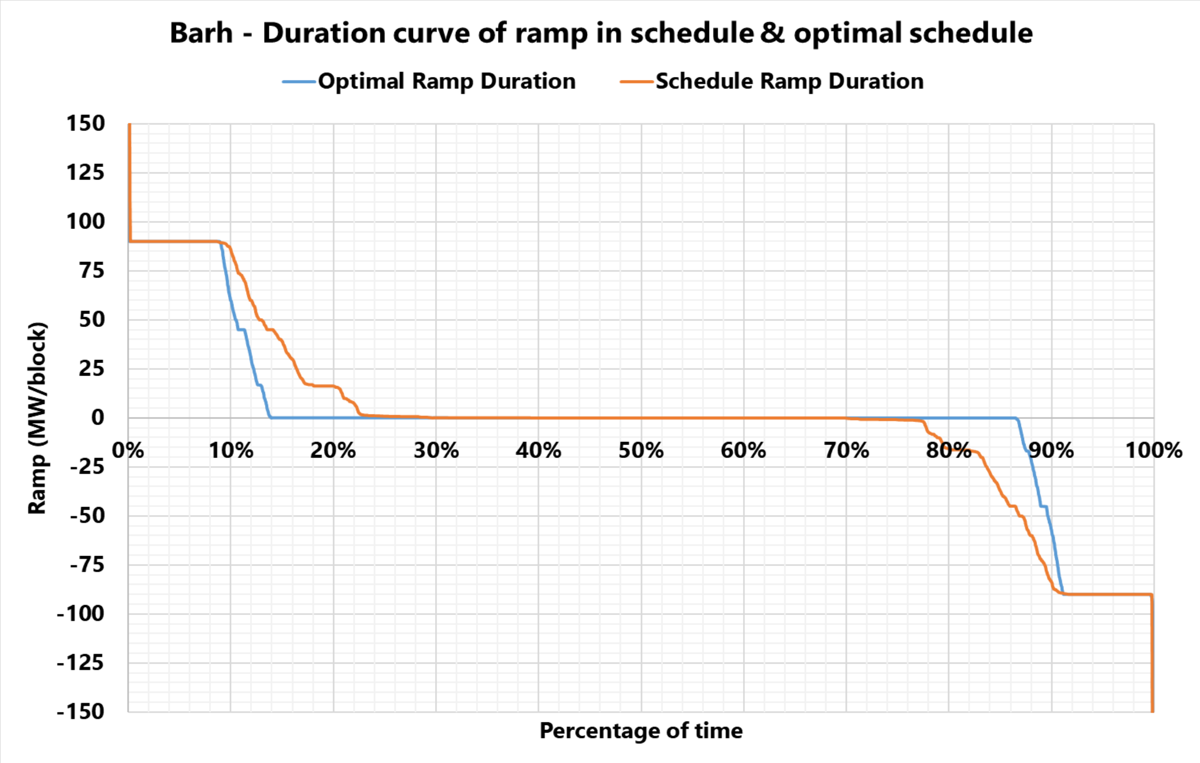


Figure 23: Duration Curve - Ramp in Schedule & Optimal of Barh

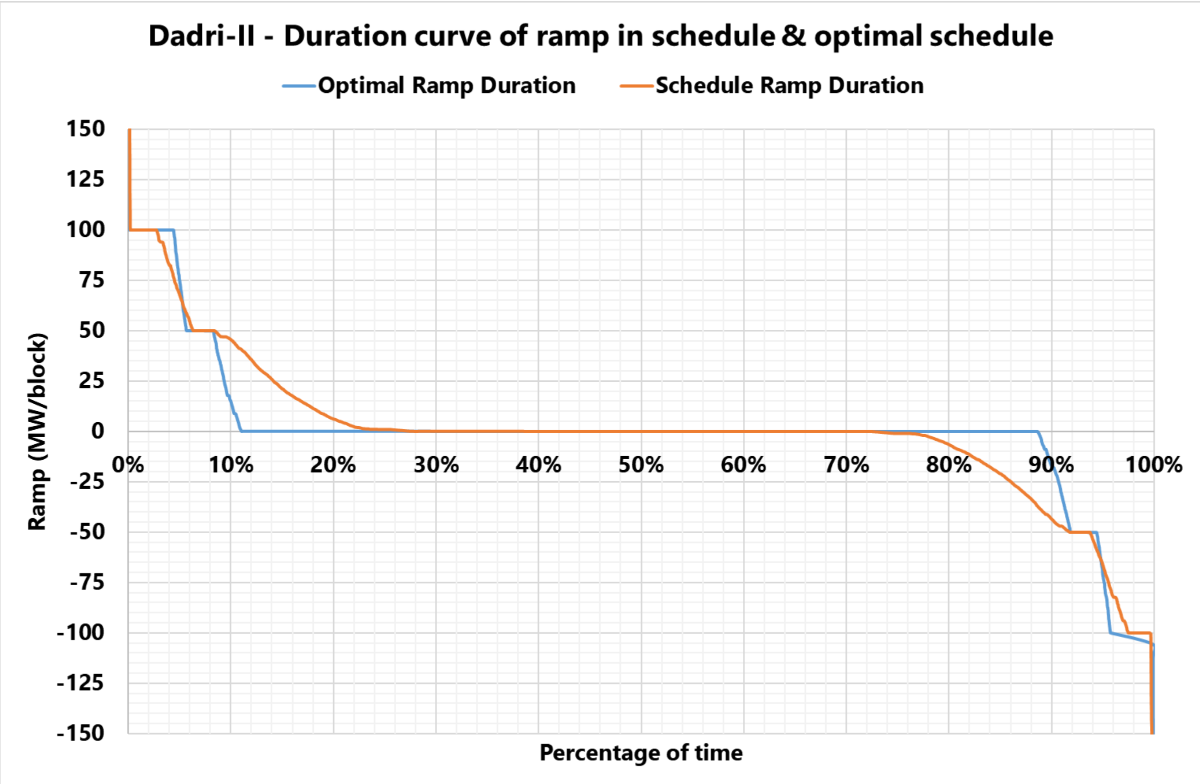


Figure 24: Duration Curve - Ramp in Schedule & Optimal of Dadri-II

4.2.3 Duration Curve – Ramping in Optimal Schedule and Actual

In figures 25, 26 and 27 below, the duration curve of the actual ramp has been superimposed over that of optimal schedule. The changes in the sharpness of the duration curve in post-SCED at the either end with respect to the pre-SCED are self-explanatory.

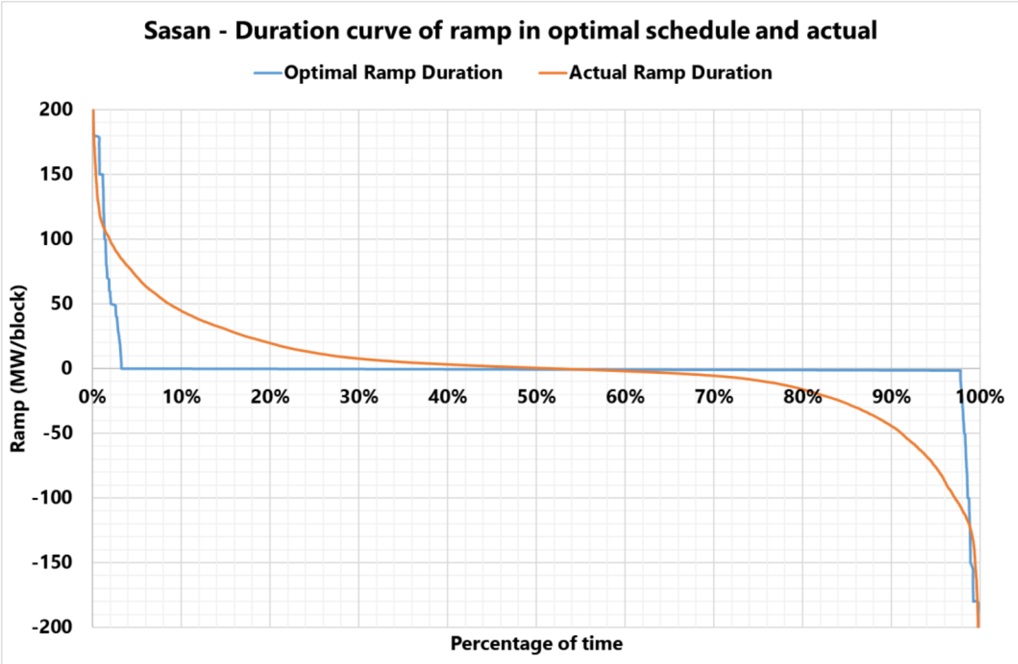


Figure 25: Duration Curve - Ramp in Optimal Schedule & Actual of Sasan

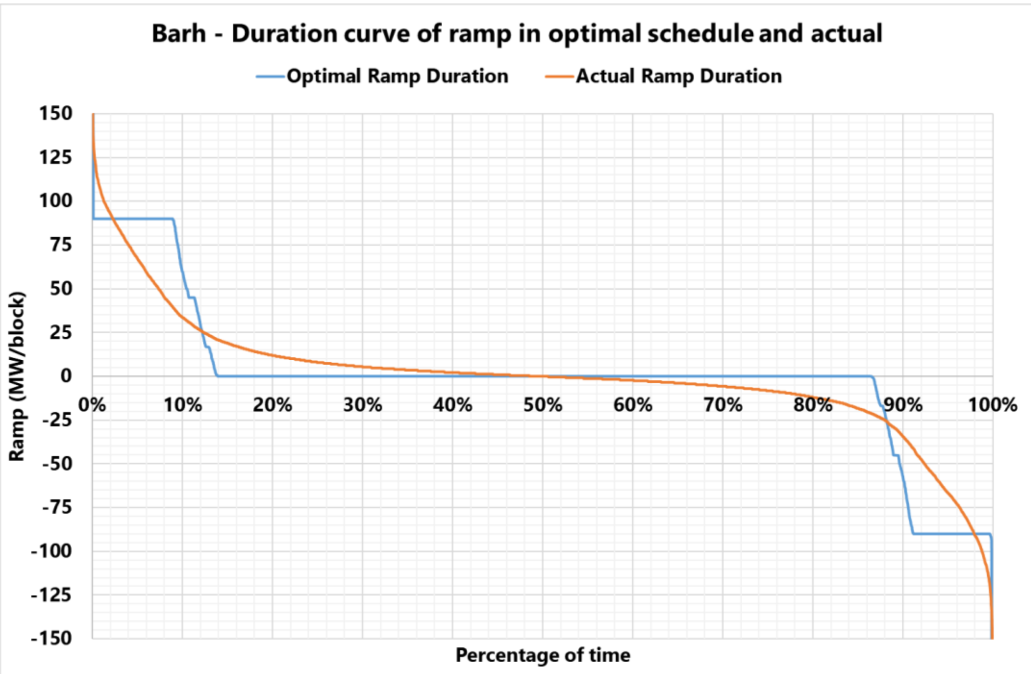


Figure 26: Duration Curve - Ramp in Optimal Schedule & Actual of Barh

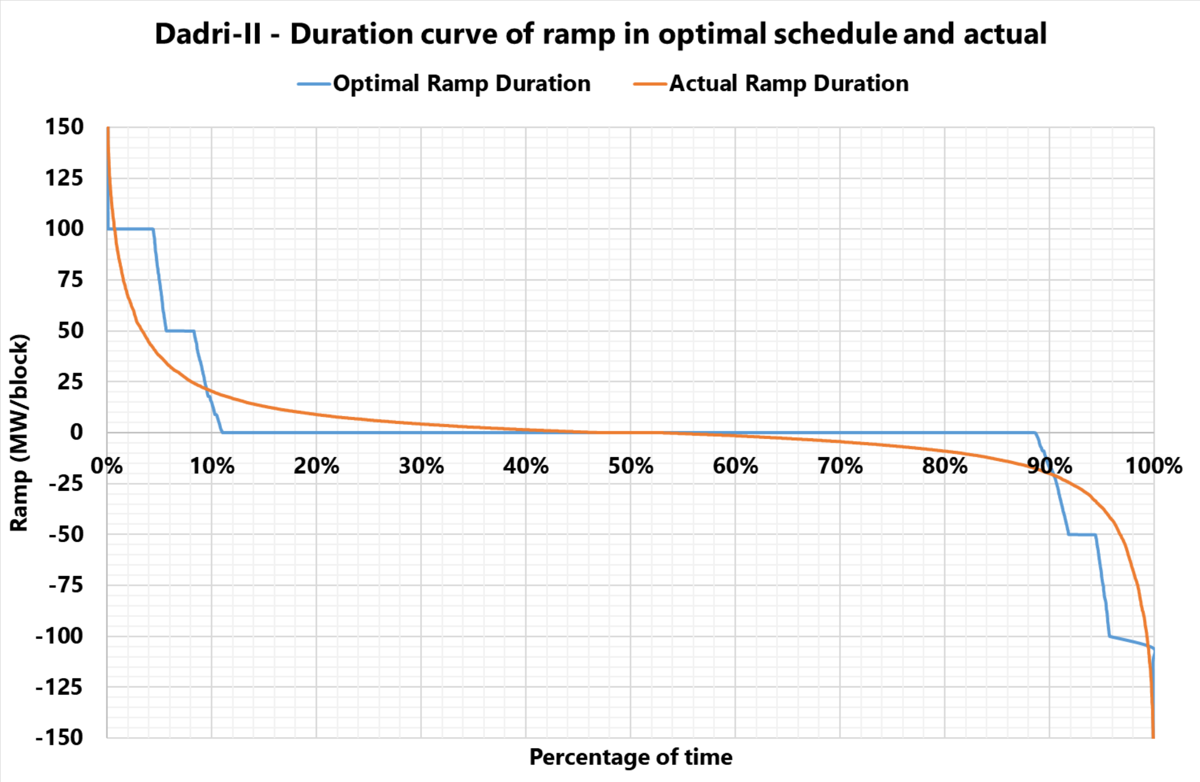
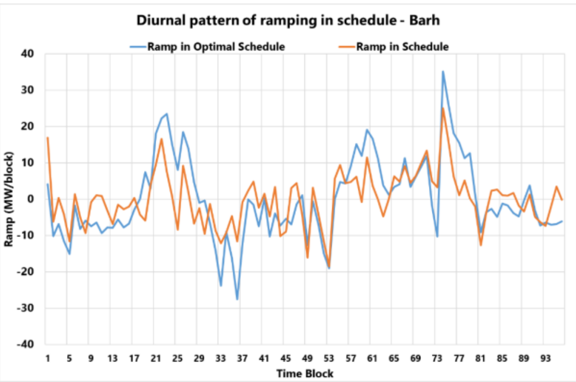


Figure 27: Duration Curve - Ramp in Optimal & Actual of Dadri-II

4.2.4 Diurnal Pattern – Ramping in Schedule, Optimal Schedule & Actual

In the figure 28, 29 and 30, the diurnal pattern (average over 275 days for each time block) of ramping in schedule, optimal schedule and actual over the April – December, 2019 period is depicted for the Barh, Sasan and Dadri-II generating stations.



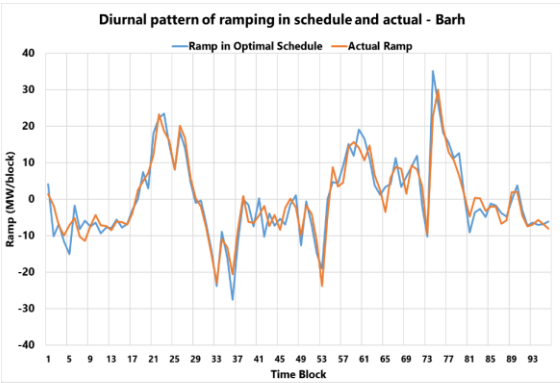
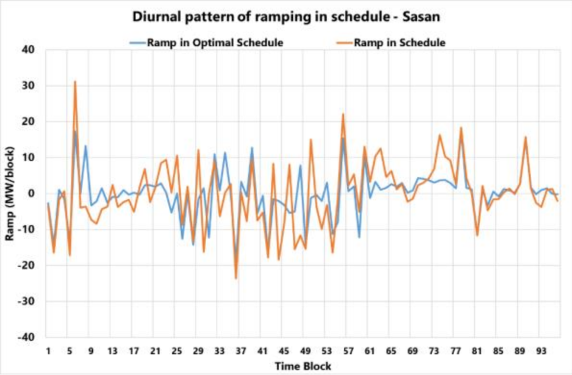


Figure 28: Diurnal Pattern – Ramping in Schedule, Optimal & Actual- Barh



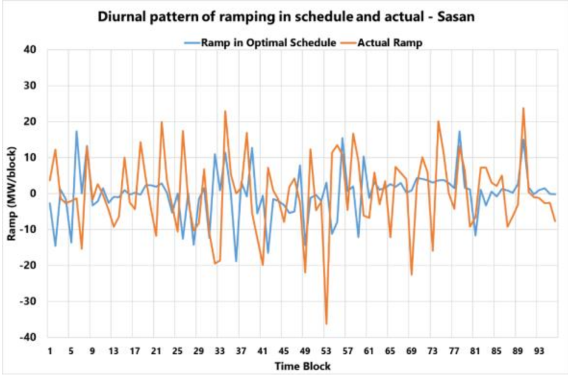
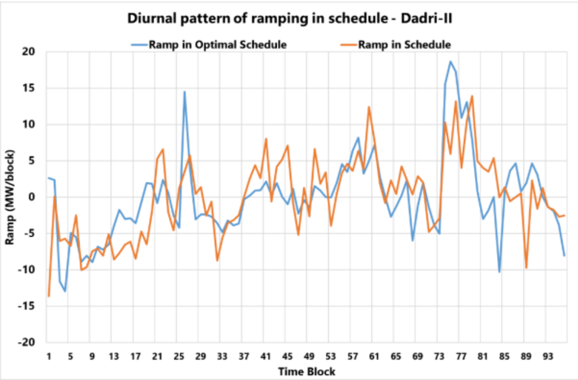


Figure 29: Diurnal Pattern – Ramping in Schedule, Optimal & Actual-Sasan



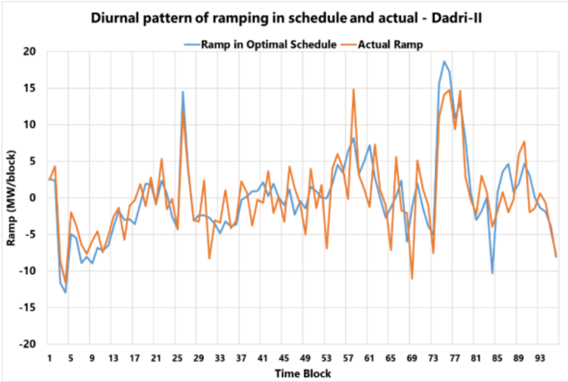


Figure 30: Diurnal Pattern – Ramping in Schedule, Optimal & Actual- Dadri-II

4.3 Performance Monitoring

Actual generation of ISGS, recorded by Special Energy Meters (SEMs) for each 15-minute time block is also being imported into SCED software for performance monitoring. Figure 31 depicts the comparison of the optimal schedule and actual meter reading on All India basis for a sample day. It is observed that, generally, the optimal schedule has been followed by the generating stations pan-India over the April – December, 2019 period.

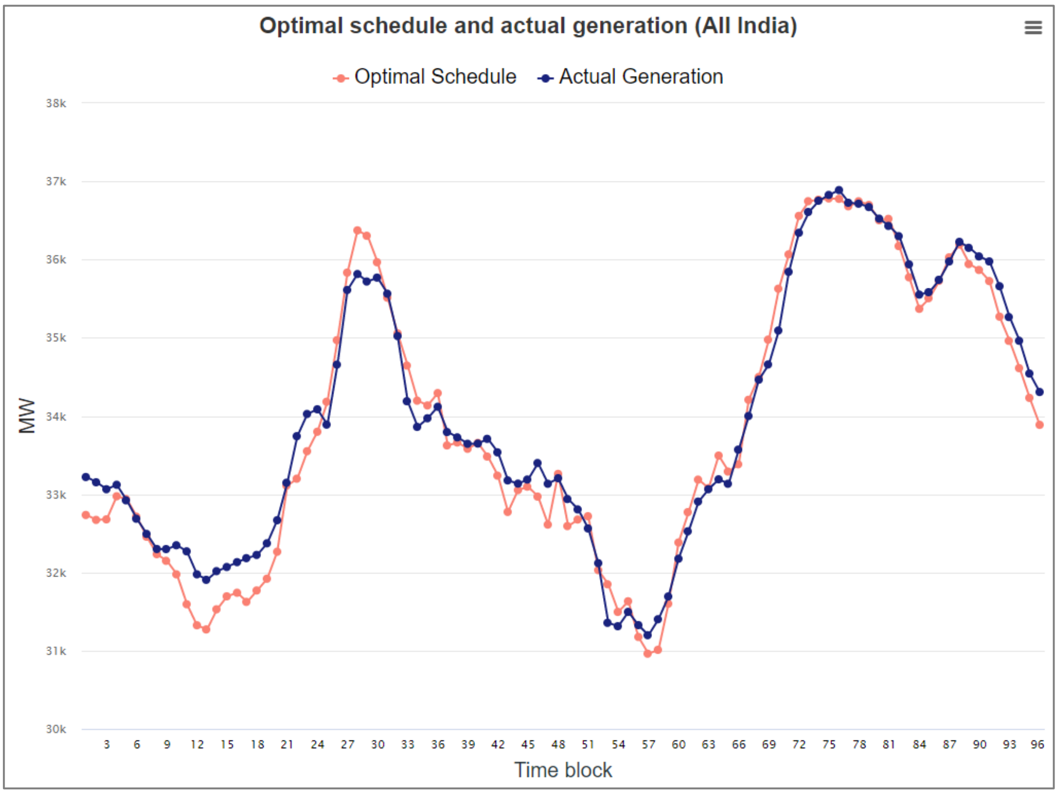


Figure 31: Performance Monitoring - Optimal Schedule and Actual (All India)

Figures 32, 33 and 34 depict optimal schedule versus actual generation over April – December 2019 for the Barh, Sasan and Dadri-II generating stations.

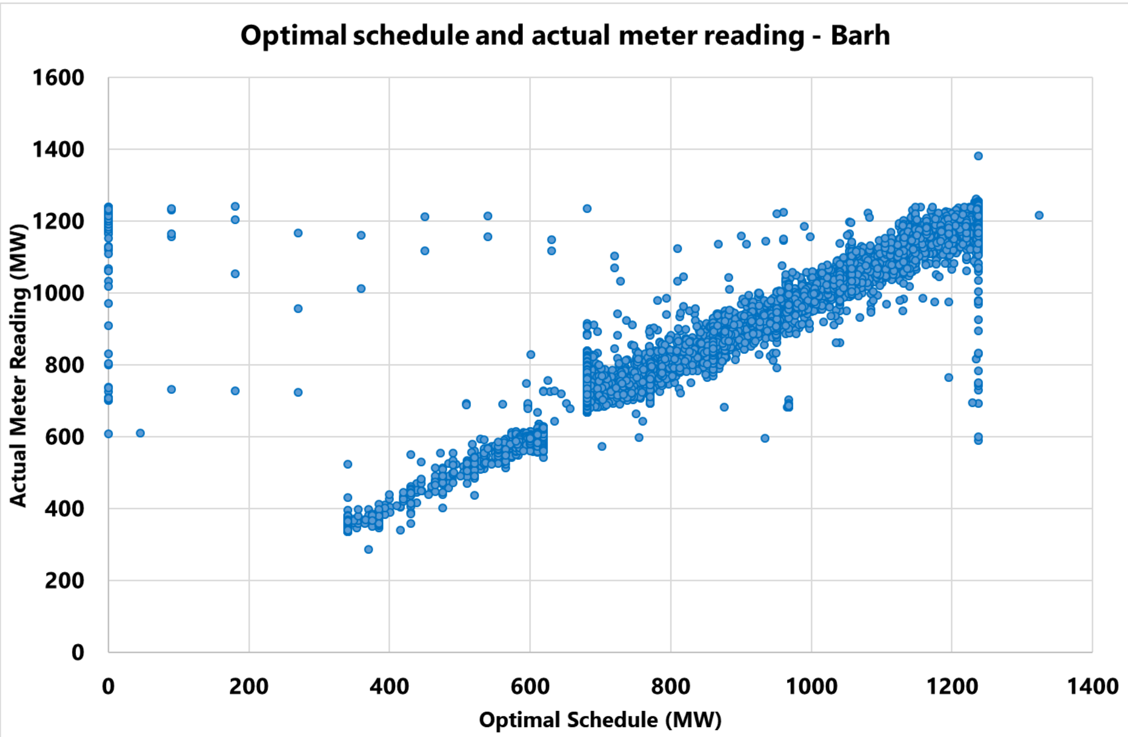


Figure 32: Optimal Schedule and Actual for Barh

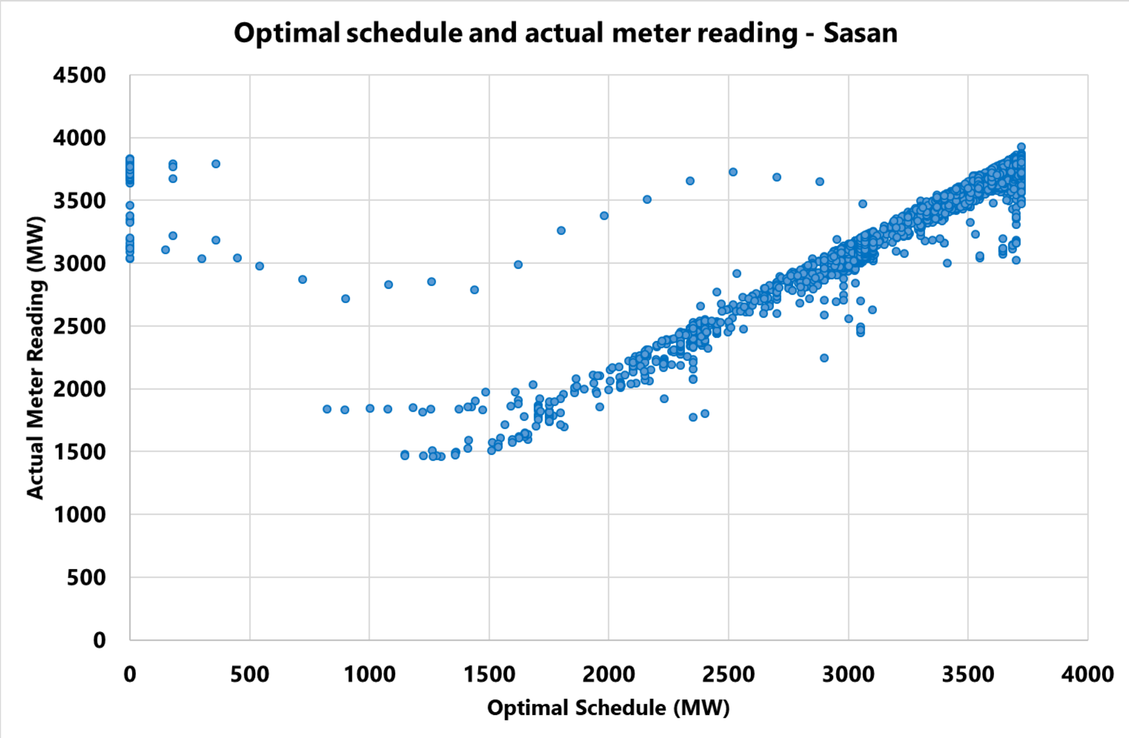


Figure 33: Optimal Schedule and Actual for Sasan

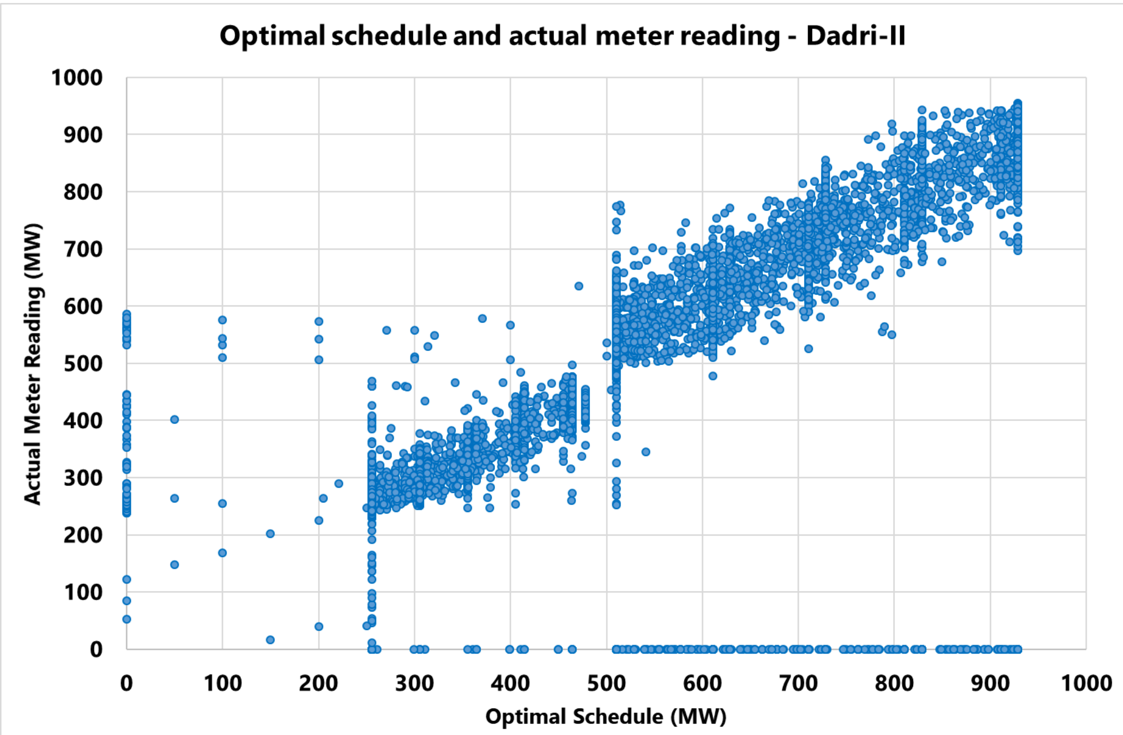


Figure 34: Optimal Schedule and Actual for Dadri-II

4.4 Reserves

Spinning reserves available in thermal ISGS are being monitored in SCED. Up spinning reserve is calculated as the difference between the on bar DC and schedule (pre-SCED); and as that between on bar DC and optimal schedule (post-SCED). Down spinning reserve is calculated as the difference between schedule and technical minimum (pre-SCED); and that between optimal schedule and technical minimum (post-SCED). Total spinning reserve remains unaltered after SCED optimization, as a result of the equality constraint mention in section 3. Figure 35 and 36 show block-wise diurnal pattern of spinning reserves (up and down) during Apr-Dec 2019.

However, as a result of optimization, the available up spinning reserve is getting consolidated in the higher variable cost generators and vice versa. The availability of reserve is constrained by the ramping capability of generation units carrying reserve. Therefore, a reduction in the cumulative reserve quantum constrained by ramp is being observed after the SCED optimization process. Figure 37 shows the stack of ramp-constrained reserve for one time-block on a typical day (pre and post SCED), where the reduction in reserve is seen clearly. Figure 38 shows heat-map of plants carrying reserves, sorted by variable cost, pre and post SCED. Figure 39 shows the stack of spinning reserve in a block, pre and post SCED. Typically, ramp constrained reserve is around 20 – 30 % of the total spinning reserve.

4.4.1 Up and Down Spinning reserve – diurnal pattern

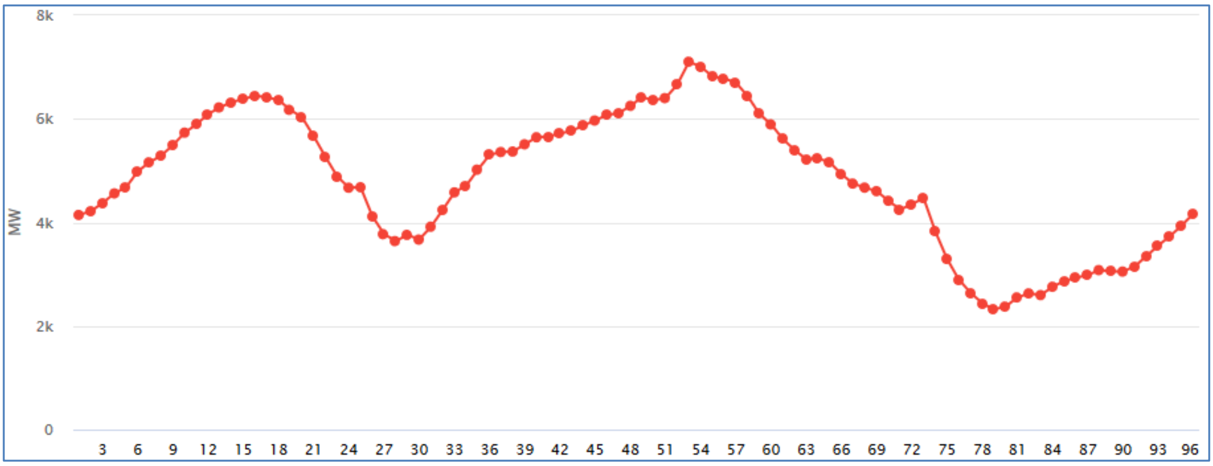


Figure 35: Up Spinning Reserve – Diurnal Pattern

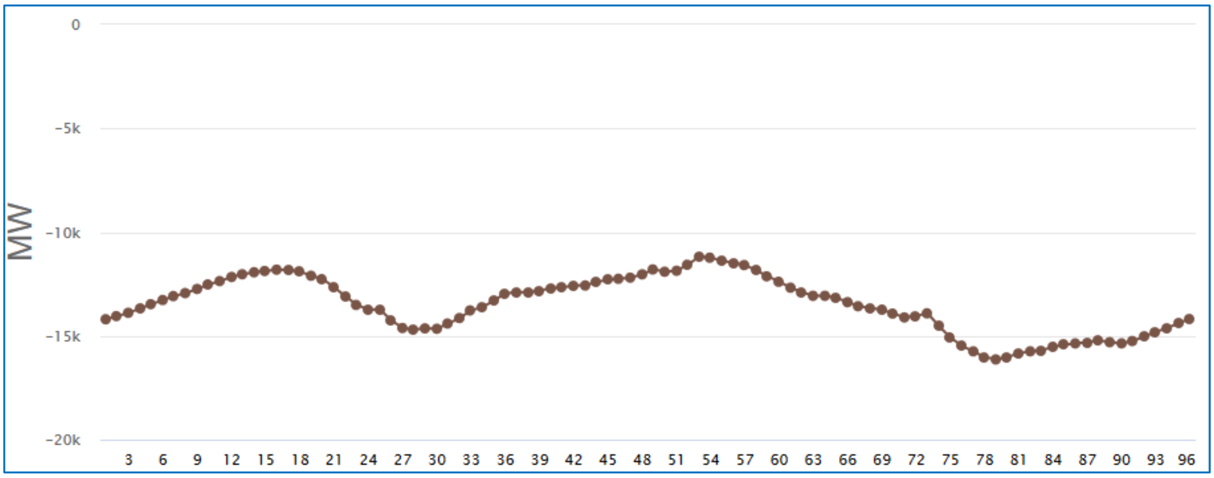


Figure 36: Down Spinning Reserves - Diurnal Pattern

4.4.2 Ramp-constrained reserves

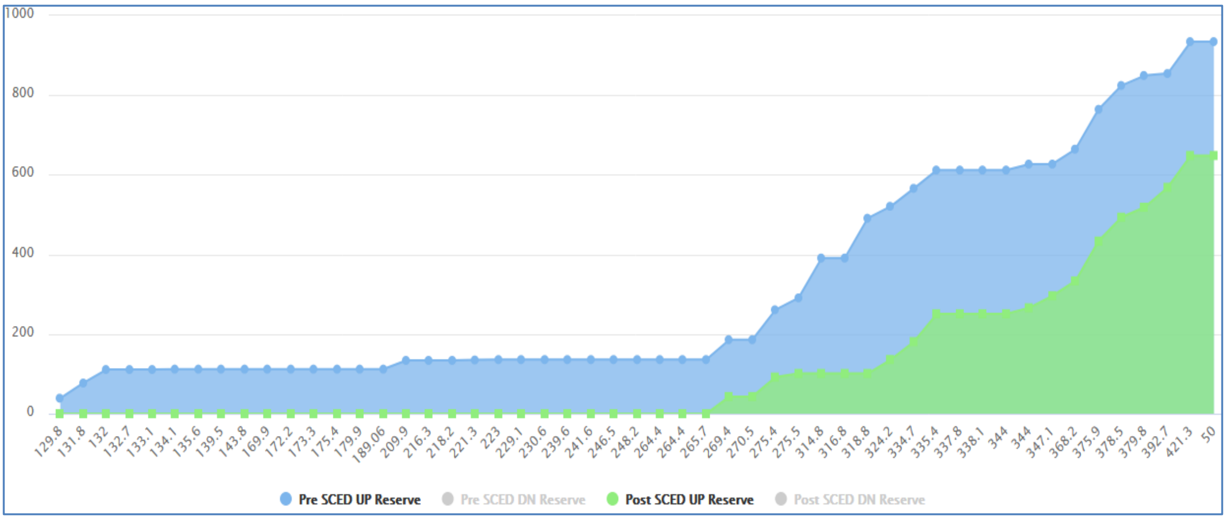


Figure 37: Ramp-constrained Reserves - Typical Day

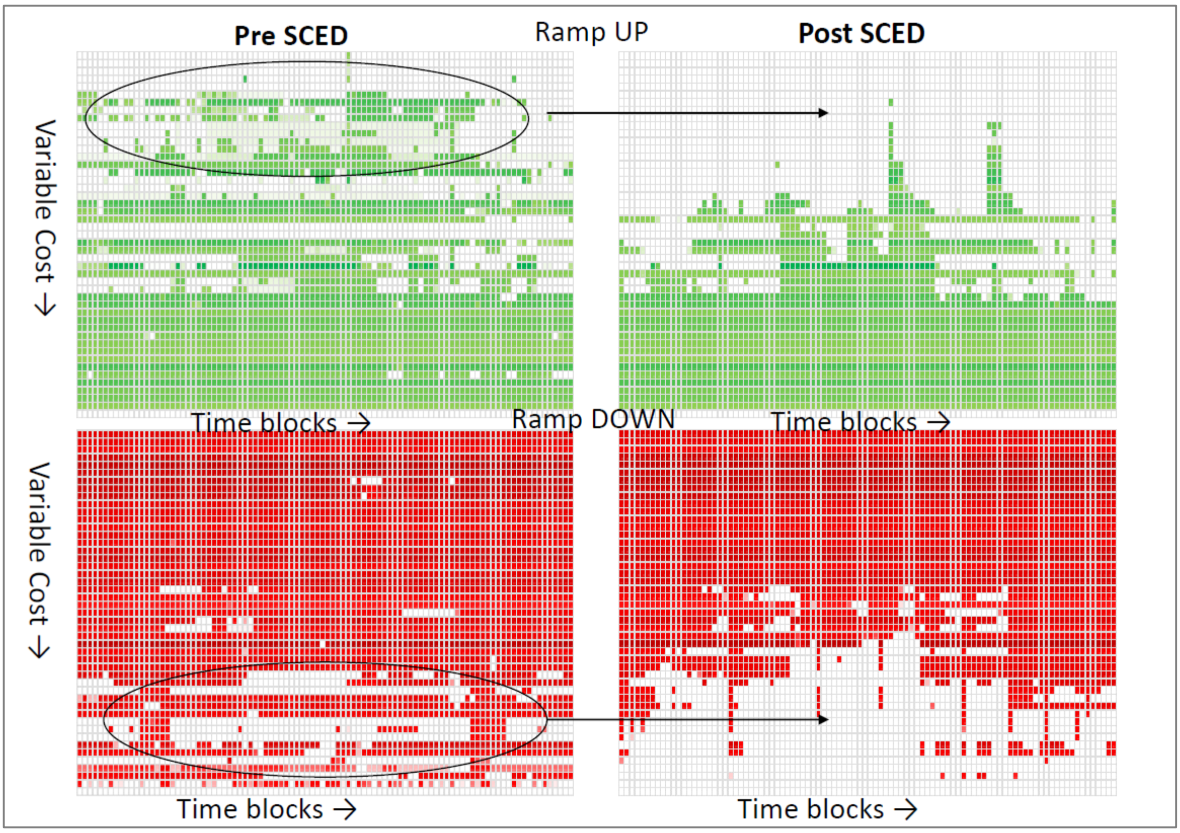


Figure 38: Heat-map of plants carrying reserves – Typical Day

4.4.3 Spinning Reserves

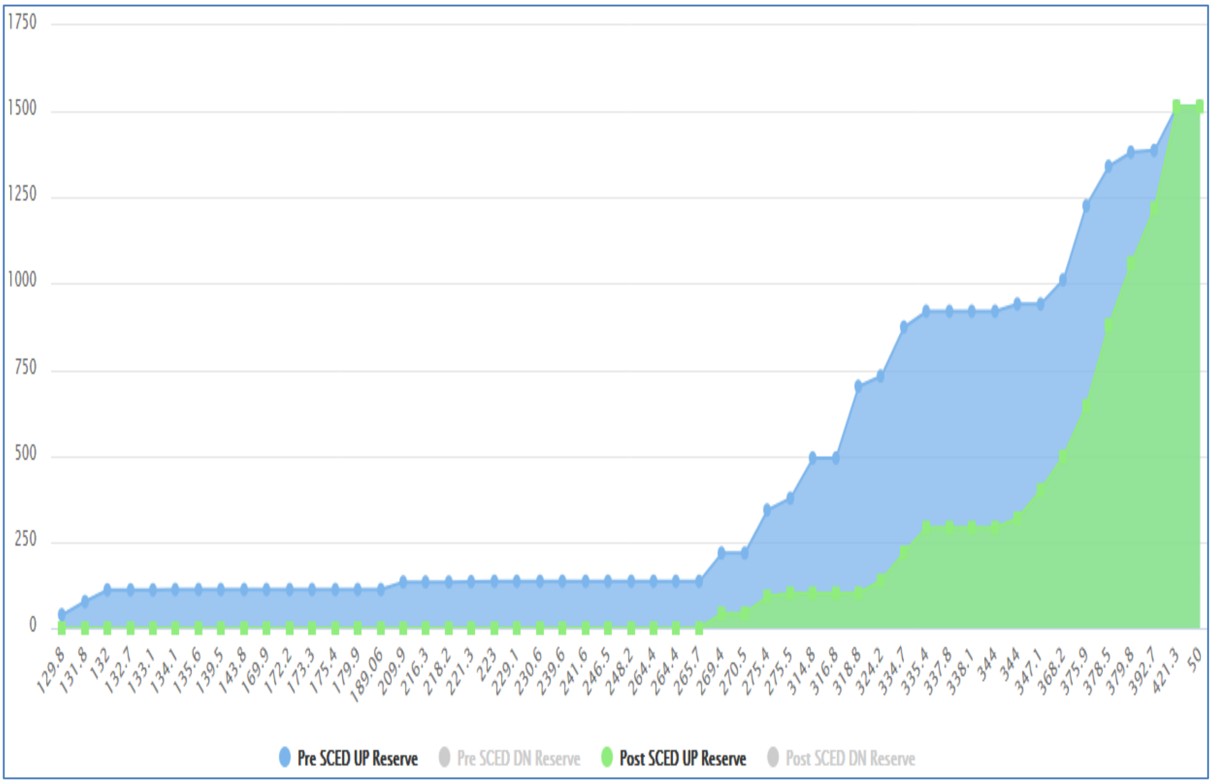


Figure 39: Spinning Reserves - Typical Day

4.4.4 Spinning Reserves - Histogram

Below are the histograms generated for the period Apr- Dec 2019 for Up (Fig. 40) and Down (Fig. 41) ramp-constrained spinning reserves.

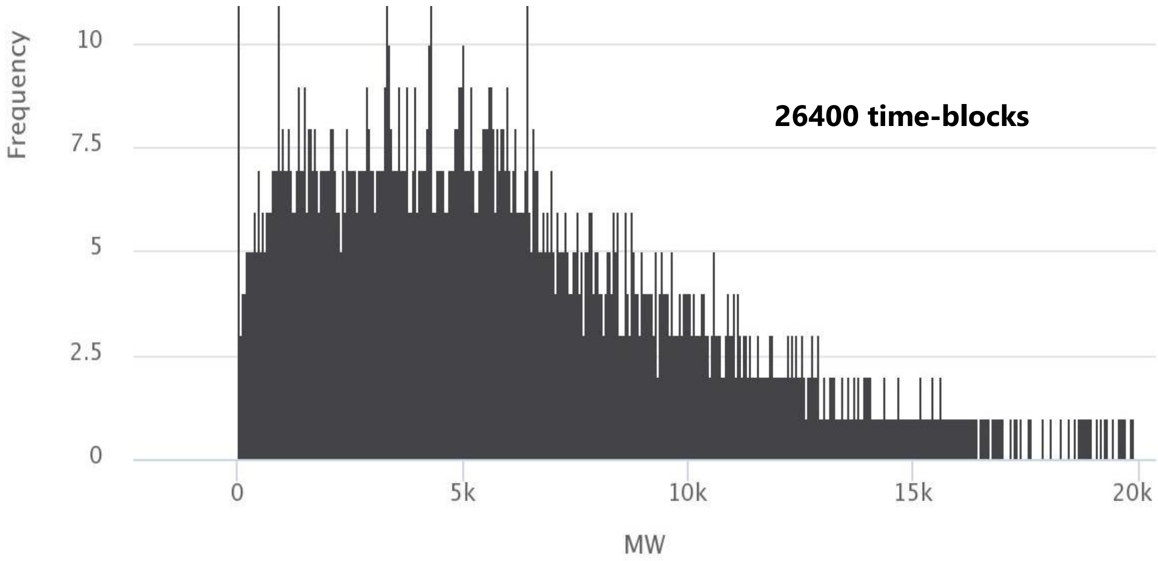


Figure 40: Ramp-constrained Reserve (Up) - Histogram

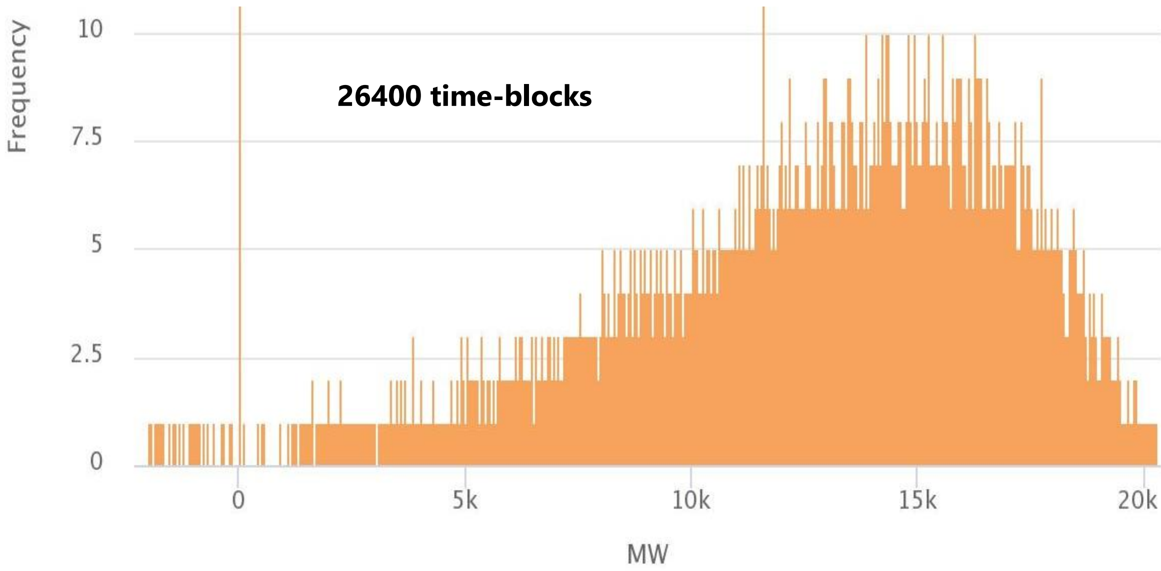


Figure 41: Ramp-constrained Reserve (Down) – Histogram

4.4.5 Cold Reserves (Apr – Dec 2019)

Cold reserves are calculated as the difference between DC and DC on bar of the generators, implying that the generators carrying these cold reserves are under reserve shutdown. The quantum of cold reserves in ISGS during the Apr – Dec'19 period is depicted in Fig. 42.

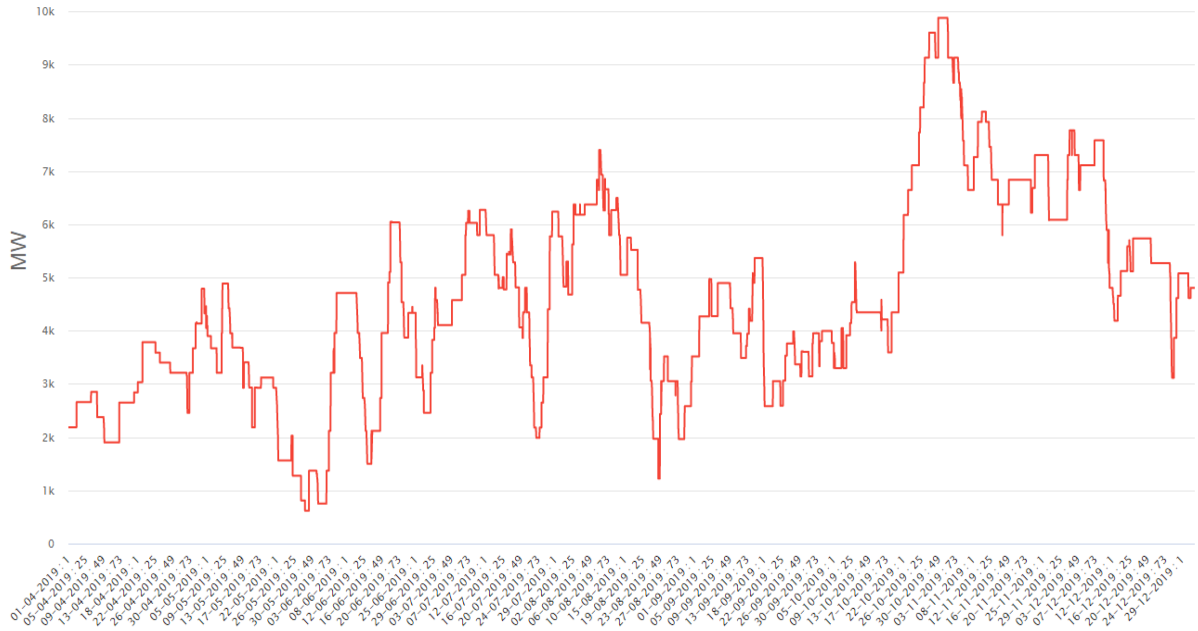


Figure 42: Cold Reserves (Apr'19 - Dec'19)

4.5 Inter-Regional Flows

Base case schedule of generation for each region is prepared such that the resulting scheduled inter regional flows do not exceed the ATC limit. This has to be honored in the case of preparation of optimal schedule also. Figure 43 depicts the sample day inter regional flow pattern of SR, NR and NER, which sometimes experience constraints while importing power from the rest of the grid.

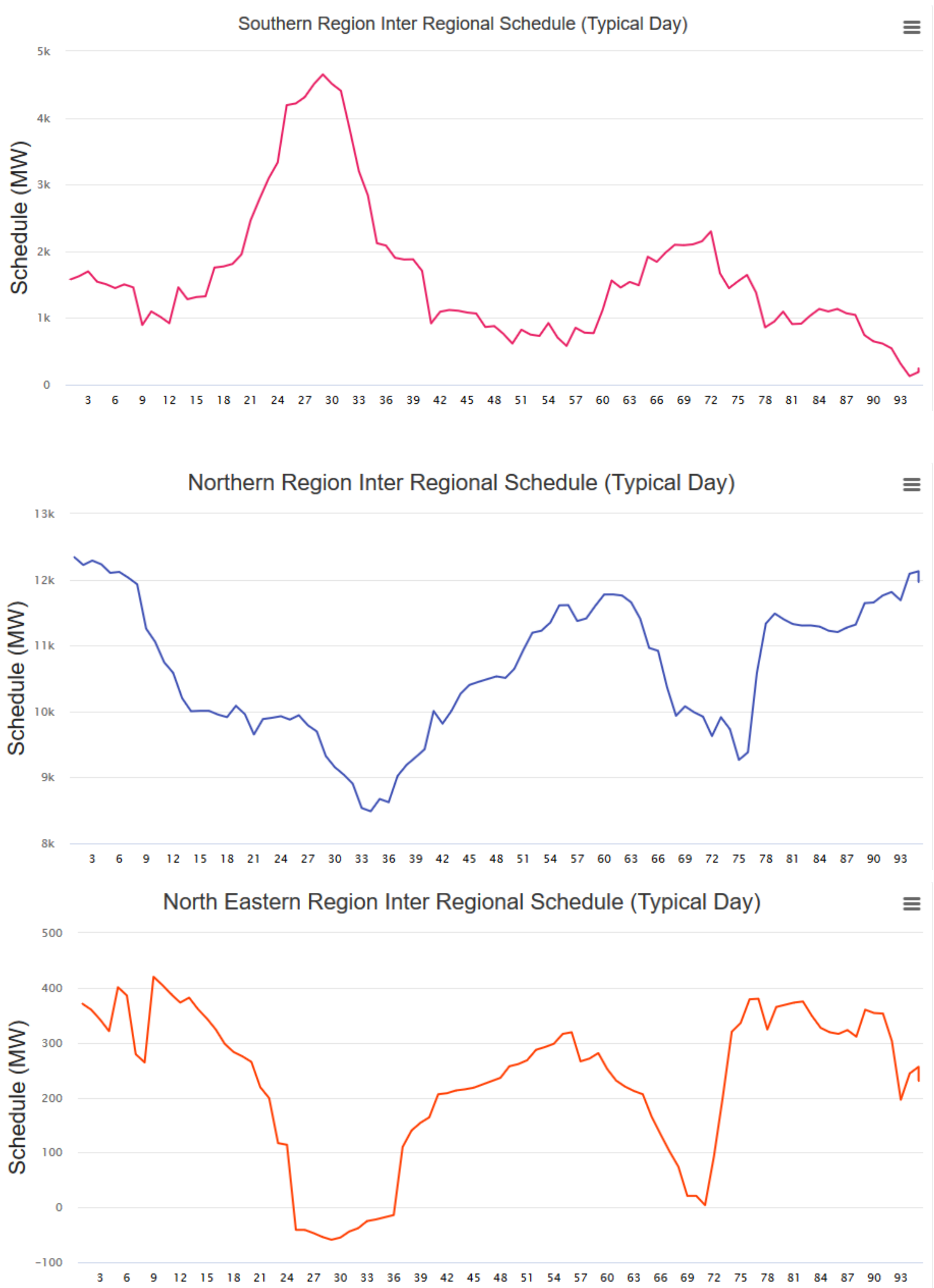


Figure 43: Incorporation of SCED Instructions in Inter-regional corridors

4.6 Variations in the Variable Costs

The monthly variation in the variable charges declared by the participating generators in the SCED for the period April – December, 2019 has been depicted in the heat map. The heat maps of intra-regional and national level spatial distribution of the variable charges are depicted in Table 2 and 3 respectively.

Table 2: Intra-regional Distribution of Variable Charges

Movement of Variable Change of SCED providers - April to December 2019 (paise/kWh)												
Sl No	Region	Plant name	16th Mar to 15th Apr	16th April to 15th May	16th May to 15th June	16th June to 15th July	16th July to 15th Aug	16th Aug to 15th Sept	16th Sept to 15th Oct	16th Oct to 15th Nov	16th Nov to 15th Dec	16th Dec to 15th Jan
1	ER	NPGC							231	227	206	203
2		Talcher-I	167	174	191	210	193	183	218	241	214	205
3		Kahalgaon-II	215	226	209	213	223	208	210	211	207	216
4		BRBCL	195	191	216	219	216	222	223	219	229	227
5		Kahalgaon-I	225	237	221	224	236	220	221	222	219	228
6		Farakka-III	258	239	252	242	212	235	229	236	249	250
7		Barh	221	220	218	226	234	237	247	248	245	252
8		Farakka-I&II	256	237	256	246	216	240	233	241	253	255
9		MTPS-II	271	270	256	272	305	291	276	273	272	266
10		MPL				272	273	274	269	269	267	268
11	NER	Bongaigaon TPP	302	302	322	339	333	318	335	340	327	332
12	NR	Singrauli	139	138	137	144	146	141	134	136	138	140
13		Rihand-III	133	135	129	127	142	133	130	130	133	147
14		Rihand-II	132	133	131	129	144	135	132	131	135	149
15		Rihand -I	132	134	131	129	144	135	132	131	135	150
16		Tanda TPS Stage-II									234	240
17		Unchahar-IV	285	283	303	301	312	322	324	328	322	329
18		Unchahar-I	308	306	322	319	331	342	344	348	342	349
19		Unchahar-III	308	306	322	319	331	342	344	348	342	349
20		Unchahar-II	308	306	325	322	334	345	347	351	345	352
21		IGSTPS-JHAJJAR	359	353	350	369	374	364	376	364	368	370
22		Dadri -II	335	347	364	364	375	379	393	406	411	386
23		Dadri- I	357	378	392	385	401	401	421	443	439	414
24	SR	Talcher-II	168	174	190	208	191	182	216	239	213	203
25		NLC- I Exp	236	248	242	243	241	242	242	243	255	255
26		Ramagundam- III	257	256	264	251	252	266	266	273	258	258
27		NLC- II Exp	236	248	248	248	248	248	248	248	260	260
28		Ramagundam- I & II	262	262	269	255	256	270	271	277	263	262
29		NLC- I	255	269	264	264	264	266	264	264	278	277
30		NLC- II	255	269	264	264	264	266	264	264	278	277
31		NTPL	292	320	345	355	341	315	275	316	278	280
32		Simhadri- II	323	310	332	322	319	317	315	334	325	335
33		Simhadri- I	322	310	336	326	323	320	319	338	329	339
34		Vallur	372	379	381	381	407	391	368	378	376	380
35		Kudgi STPS	400	396	400	373	376	384	379	398	405	381
36	WR	Sasan	132	132	132	132	133	132	133	133	132	132
37		Korba(III)	122	126	125	130	129	125	133	144	136	141
38		Korba(I & II)	124	128	128	133	132	128	136	147	138	144
39		SIPAT-I	118	120	128	127	132	141	140	151	176	147
40		SIPAT-II	122	123	132	131	137	146	144	156	181	152
41		Vindhyachal-IV	149	153	153	154	157	181	170	164	157	167
42		Vindhyachal-III	149	153	155	156	159	183	172	166	160	169
43		Vindhyachal-II	149	153	156	158	160	184	173	168	161	171
44		Vindhyachal-V	150	153	155	156	162	186	175	170	163	173
45		Vindhyachal-I	159	163	162	163	166	191	180	174	167	177
46		Coastal Gujarat PL	180	181	177	197	195	194	189	194	192	189
47		LARA							233	233	230	252
48		GADARAWARA			377	377	373	373	338	326	330	298
49		Mouda-II	283	282	281	318	327	322	338	340	331	312
50		Mouda-I	277	288	290	312	316	328	335	332	326	315
51		NTPC SAIL PCL	251	251	305	357	326	329	380	429	351	318
52		SOLAPUR	385	389	409	435	395	352	317	331	337	330

Table 3: National level Distribution of Variable Charges

Movement of Variable Change of SCED providers - April to December 2019 (paise/kWh)												
Sl No	Plant	Region	16th Mar to 15th Apr	16th April to 15th May	16th May to 15th June	16th June to 15th July	16th July to 15th Aug	16th Aug to 15th Sept	16th Sept to 15th Oct	16th Oct to 15th Nov	16th Nov to 15th Dec	16th Dec to 15th Jan
1	Sasan	WR	132	132	132	132	133	132	133	133	132	132
2	Singrauli	NR	139	138	137	144	146	141	134	136	138	140
3	Korba(III)	WR	122	126	125	130	129	125	133	144	136	141
4	Korba(I & II)	WR	124	128	128	133	132	128	136	147	138	144
5	Rihand-III	NR	133	135	129	127	142	133	130	130	133	147
6	SIPAT-I	WR	118	120	128	127	132	141	140	151	176	147
7	Rihand-II	NR	132	133	131	129	144	135	132	131	135	149
8	Rihand -I	NR	132	134	131	129	144	135	132	131	135	150
9	SIPAT-II	WR	122	123	132	131	137	146	144	156	181	152
10	Vindhyachal-IV	WR	149	153	153	154	157	181	170	164	157	167
11	Vindhyachal-III	WR	149	153	155	156	159	183	172	166	160	169
12	Vindhyachal-II	WR	149	153	156	158	160	184	173	168	161	171
13	Vindhyachal-V	WR	150	153	155	156	162	186	175	170	163	173
14	Vindhyachal-I	WR	159	163	162	163	166	191	180	174	167	177
15	Coastal Gujarat PL	WR	180	181	177	197	195	194	189	194	192	189
16	NPGC	ER							231	227	206	203
17	Talcher-II	SR	168	174	190	208	191	182	216	239	213	203
18	Talcher-I	ER	167	174	191	210	193	183	218	241	214	205
19	Kahalgaon-II	ER	215	226	209	213	223	208	210	211	207	216
20	BRBCL	ER	195	191	216	219	216	222	223	219	229	227
21	Kahalgaon-I	ER	225	237	221	224	236	220	221	222	219	228
22	Tanda TPS Stage-II	NR									234	240
23	Farakka-III	ER	258	239	252	242	212	235	229	236	249	250
24	Barh	ER	221	220	218	226	234	237	247	248	245	252
25	LARA	WR							233	233	230	252
26	NLC- I Exp	SR	236	248	242	243	241	242	242	243	255	255
27	Farakka-I&II	ER	256	237	256	246	216	240	233	241	253	255
28	Ramagundam- III	SR	257	256	264	251	252	266	266	273	258	258
29	NLC- II Exp	SR	236	248	248	248	248	248	248	248	260	260
30	Ramagundam- I & II	SR	262	262	269	255	256	270	271	277	263	262
31	MTPS-II	ER	271	270	256	272	305	291	276	273	272	266
32	MPL	ER				272	273	274	269	269	267	268
33	NLC- I	SR	255	269	264	264	264	266	264	264	278	277
34	NLC- II	SR	255	269	264	264	264	266	264	264	278	277
35	NTPL	SR	292	320	345	355	341	315	275	316	278	280
36	GADARAWARA	WR			377	377	373	373	338	326	330	298
37	Mouda-II	WR	283	282	281	318	327	322	338	340	331	312
38	Mouda-I	WR	277	288	290	312	316	328	335	332	326	315
39	NTPC SAIL PCL	WR	251	251	305	357	326	329	380	429	351	318
40	Unchahar-IV	NR	285	283	303	301	312	322	324	328	322	329
41	SOLAPUR	WR	385	389	409	435	395	352	317	331	337	330
42	Bongaigaon TPP	NER	302	302	322	339	333	318	335	340	327	332
43	Simhadri- II	SR	323	310	332	322	319	317	315	334	325	335
44	Simhadri- I	SR	322	310	336	326	323	320	319	338	329	339
45	Unchahar-I	NR	308	306	322	319	331	342	344	348	342	349
46	Unchahar-III	NR	308	306	322	319	331	342	344	348	342	349
47	Unchahar-II	NR	308	306	325	322	334	345	347	351	345	352
48	IGSTPS-JHAJJAR	NR	359	353	350	369	374	364	376	364	368	370
49	Vallur	SR	372	379	381	381	407	391	368	378	376	380
50	Kudgi STPS	SR	400	396	400	373	376	384	379	398	405	381
51	Dadri -II	NR	335	347	364	364	375	379	393	406	411	386
52	Dadri- I	NR	357	378	392	385	401	401	421	443	439	414

4.7 Price

The diurnal pattern duration pattern and histogram of All India System Marginal Price, for the generators participating in SCED, in the period Apr – Dec’19 has been depicted in the Fig. 44, 45 and 46 respectively. As observed in Fig. 46, there is no SMP in the range of 295 – 300 paisa/kWh which signifies that there is no ISGS plant having variable cost in that range. Further, variable cost is a function of demand (MW) met in that particular time-block and therefore, there are instances where SMP has remained in a particular range for higher number of time-blocks.

4.7.1 System Marginal Price (Apr – Dec 2019)

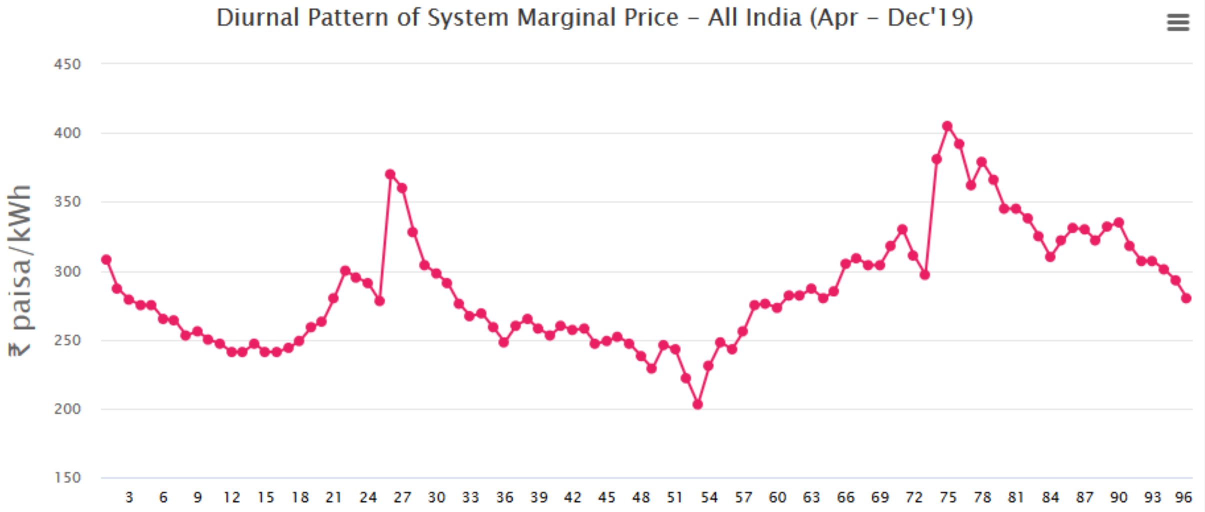


Figure 44: System Marginal Price - Diurnal Pattern

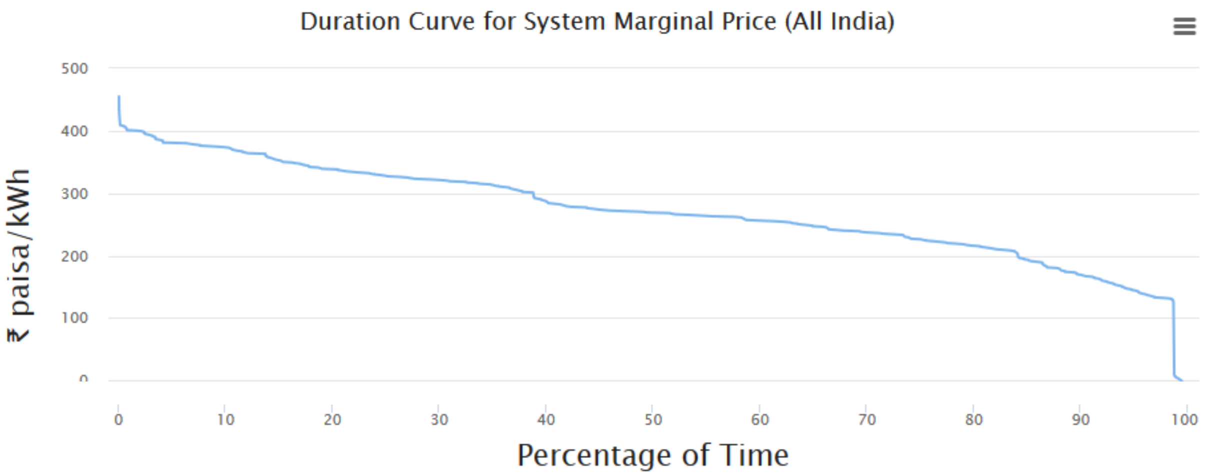


Figure 45: System Marginal Price - Duration Curve

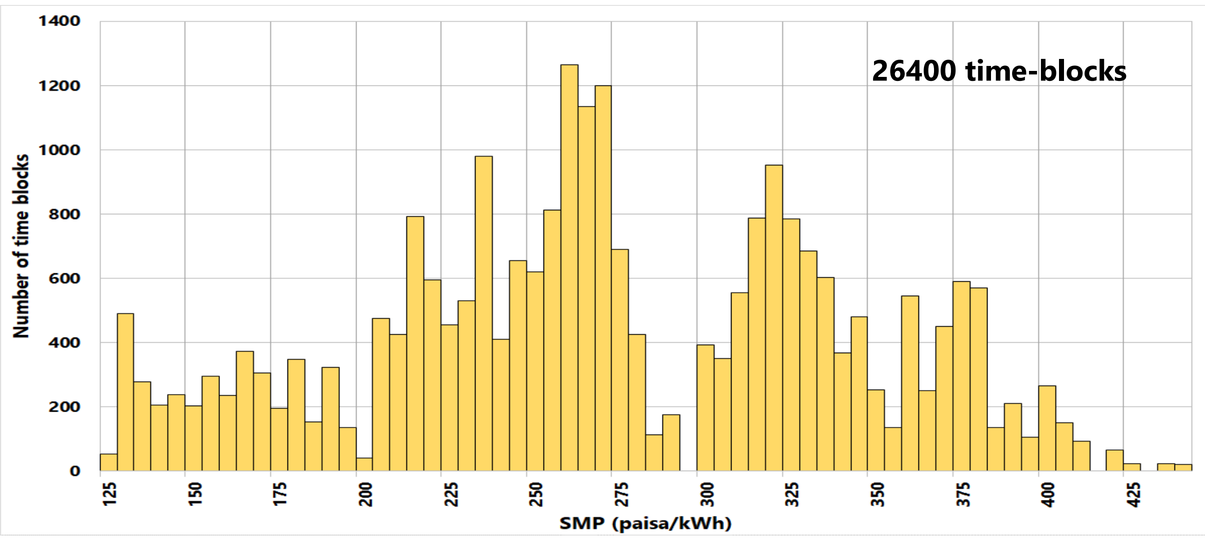


Figure 46: System Marginal Price – Histogram

4.7.2 Average Price (Apr – Dec 2019)

The histogram of the average price (in paisa/kWh) has been depicted in Fig. 47.

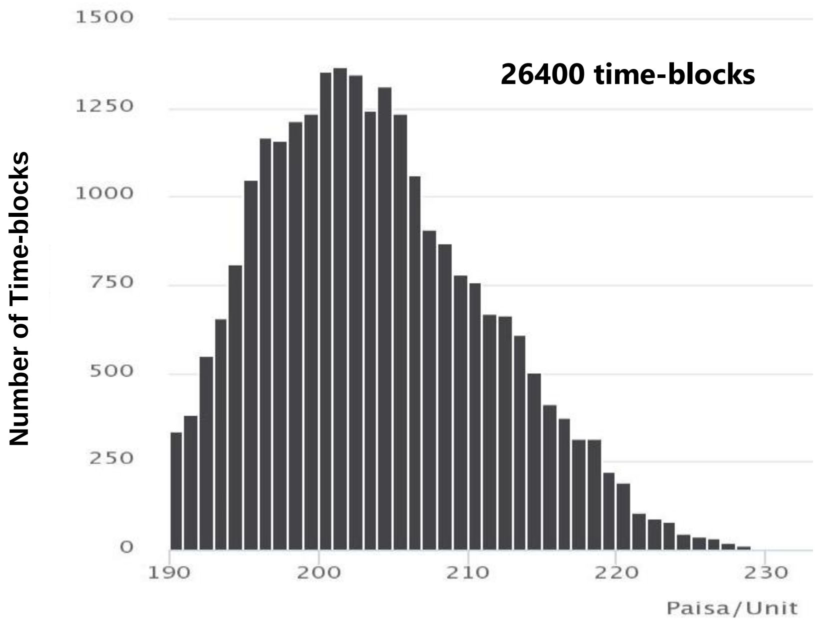


Figure 47: Average Price (Paisa/kWh) – Histogram

4.7.3 Average Cost (Apr – Dec 2019)

The histogram comparing pre-SCED and post-SCED average cost (in ₹ lakhs/hour) has been depicted in Fig. 48.

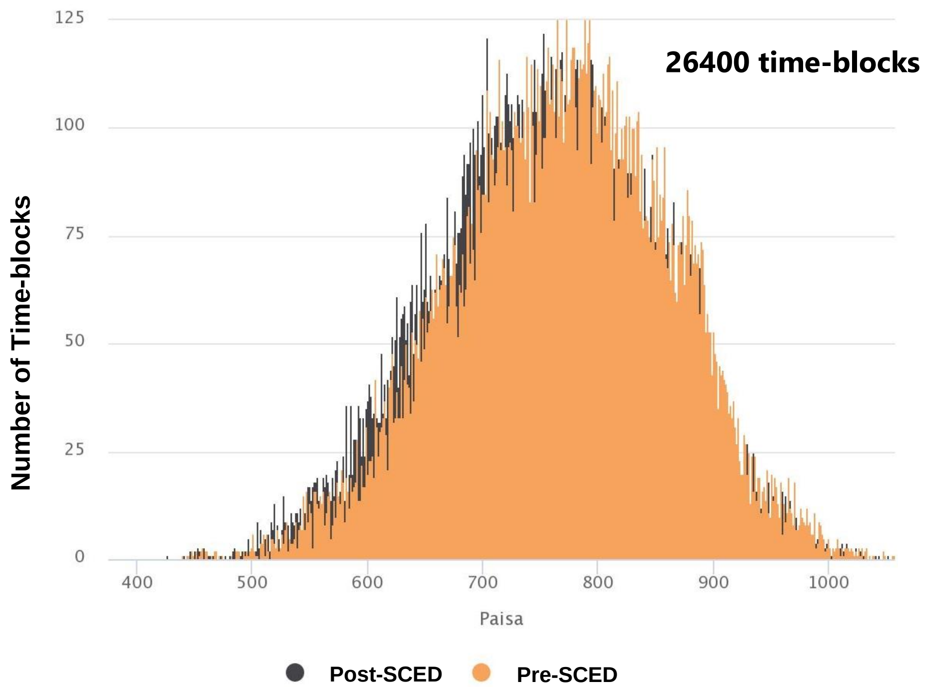


Figure 48: Average Cost (₹ Lakhs/Hour) - Histogram

4.7.4 Market Clearing Price (MCP) vs SMP (Apr – Dec 2019)

The scatter plot of Unconstrained MCP discovered in IEX versus SMP (in paisa/kWh) has been depicted in Fig. 49.

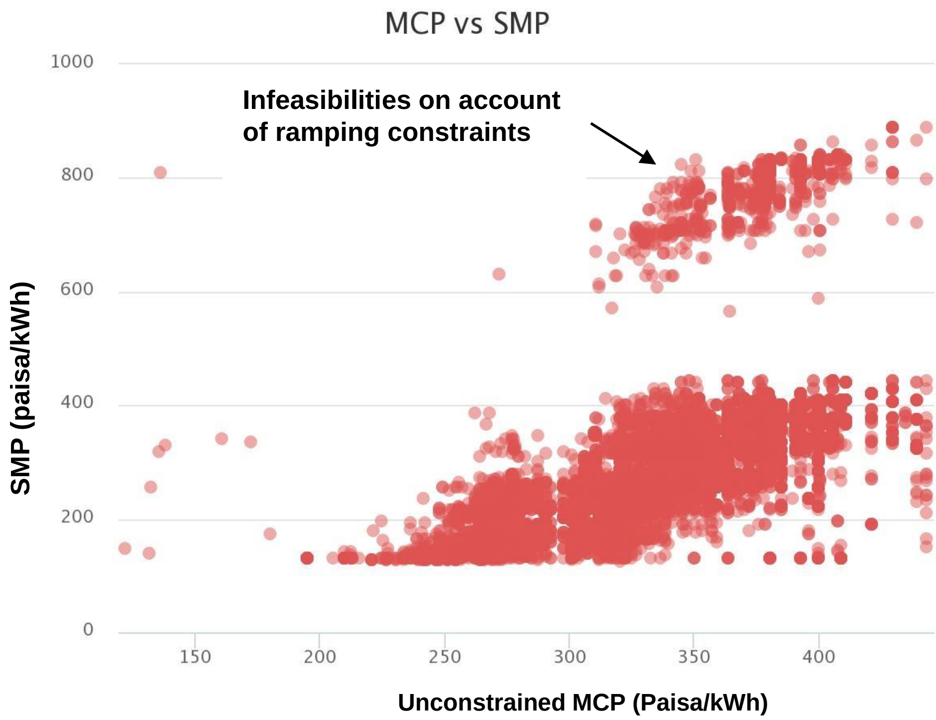


Figure 49: Market Clearing Price (MCP) vs SMP

4.7.5 Perturbation (MW) vs Reduction in Costs (Paisa/kWh)

The scatter plot of Perturbation (MW) vs Reduction in Costs (Paisa/kWh) has been depicted in Fig. 50.

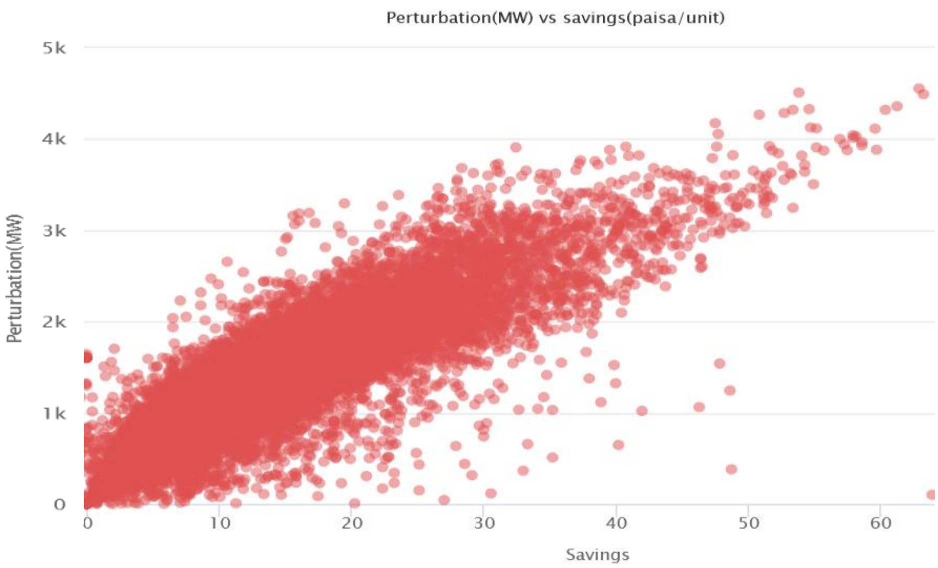


Figure 50: Perturbation (MW) vs Reduction in Costs (Paisa/kWh)

4.8 Infeasibility Ride through analysis

The diurnal pattern of ramping up and ramping down infeasibilities (in MW) is depicted in Fig. 51.

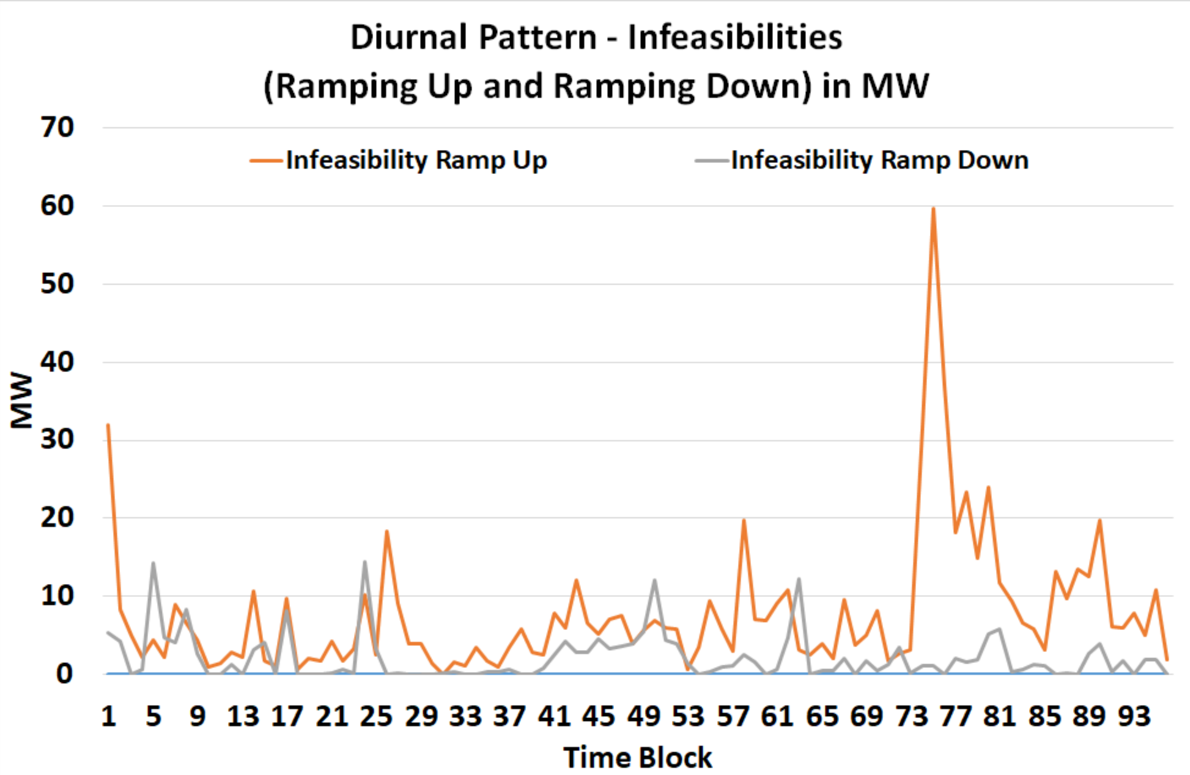


Figure 51: Infeasibilities (Ramp Up/Down) - Diurnal Pattern

The generator-wise count of the ramping up and ramping down infeasibilities encountered during Apr – Dec'19 period is tabulated in Table 4.

Table 4: Infeasibilities Count (Apr'19 - Dec'19)

Generator	Variable Cost (Avg.)	Ramp up count	Ramp down count
Korba-Stage-3	131	3	3
Sasan	132	3	20
Korba STPS Stage 1 and 2	133	4	13
Rihand 3	133	2	8
Rihand 1	134	3	8
Rihand 2	134	4	10
Sipat STPS Stage 1	138	6	13
Singrauli TPS	139	7	6
Sipat STPS Stage 2	142	4	8
Vindhyachal STPS Stage 4	160	6	8
Vindhyachal STPS Stage 3	162	4	13
Vindhyachal STPS Stage 2	163	15	9

Generator	Variable Cost (Avg.)	Ramp up count	Ramp down count
Vindhyachal STPS Stage 5	164	11	15
Vindhyachal STPS Stage 1	170	11	17
CGPL Mundra	189	158	92
Talcher	198	34	14
Talcher Stage 2-NTPC	200	12	12
Kahalgaon Stage 2	212	8	23
Nabinagar	216	31	24
NPGC	219	17	4
Kahalgaon Stage 1	223	8	10
Barh	234	39	16
LARA	235	3	6
Tanda-2	235	5	14
FARAKKA-STAGE-3	239	26	23
Farakka Stage 1 and 2	243	34	13
Neyveli TPS 1 (Expn.)-NLC	244	83	45
Neyveli TPS 2 (Expn.)-NLC	249	78	57
Ramagundam TPS Stage 3	260	36	6
Ramagundam TPS Stage 1&2	264	71	9
Neyveli-I (ISGS)-NLC	266	166	88
Neyveli-II (ISGS)-NLC	266	179	94
MPL	270	170	35
MTPS Stg 2	275	73	12
UNCHAHAR 4	311	96	10
Mauda	313	132	17
NTPL	314	112	15
Mauda 2	315	132	13
Simhadri NTPC Stage 2	322	86	21
Bongaigaon	325	166	35
Simhadri -NTPC Stage -1	325	87	12
Unchahar TPS 1	331	84	6
Unchahar TPS 3	331	51	8
Unchahar TPS 2	333	105	8
NSPCL	334	105	4
Gadarwara-1	345	47	2
Indira Gandhi TPS (Jhajjar)	364	157	9
NTPC SOLAPUR	368	106	13
Dadri Stage 2	377	130	6
Vallur NTECL	381	176	7
Kudgi-1	388	131	11
Dadri Stage 1	405	156	1

4.9 Incremental / Decremental Transmission Losses due to SCED

4.9.1 Transmission Losses due to SCED – Diurnal Pattern

The flow of power from pit head plants to load centers because of SCED also affects transmission losses. Simulation analysis was made on the data of Apr-May 2019 by running multiple power flows with and without SCED generation changes. There was a 0.4 % increase in the transmission losses compared to the losses without SCED. This increase is approximately 0.013% of the total all India transmission losses. One reason for such a low increase in transmission loss because of SCED covers only 50 GW generation capacity in a system size of 180 GW, and also the fact that on an average only 1300 MW generation out of 50 GW available, is perturbed by SCED to achieve the entire reduction in fuel cost.

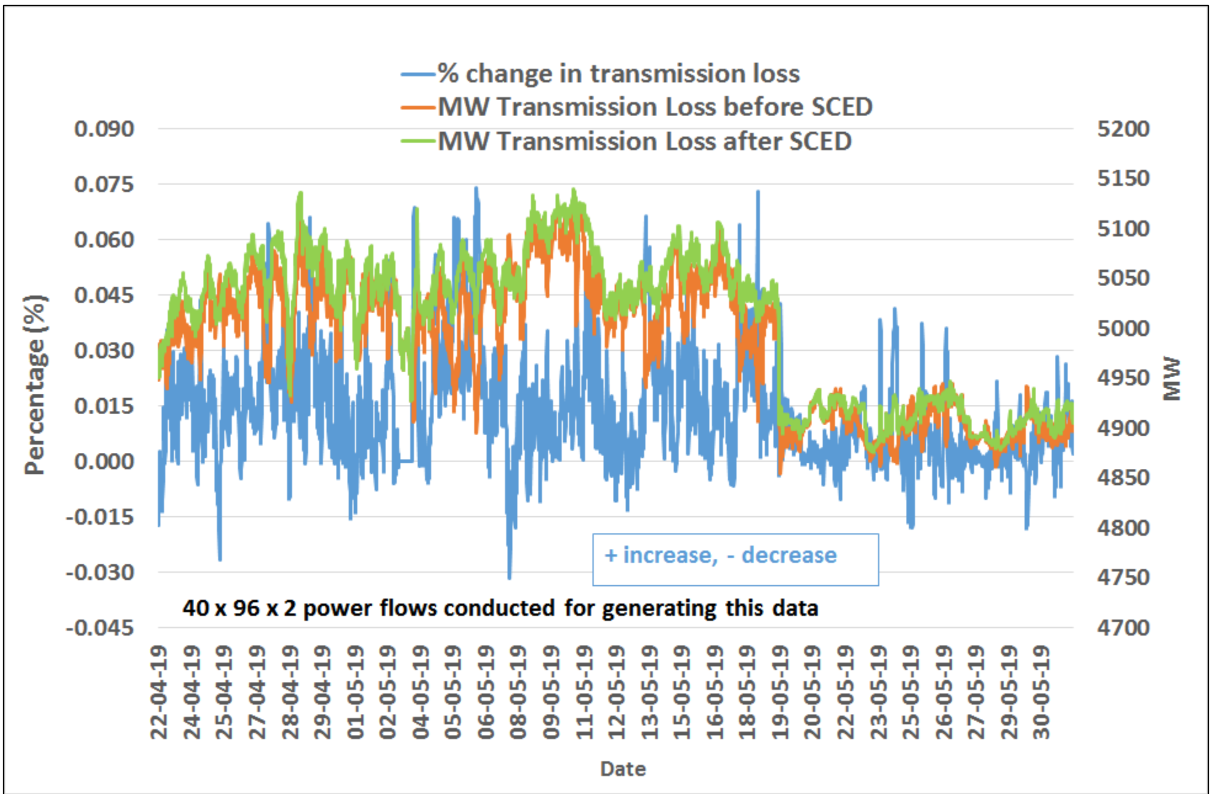


Figure 52: Simulated Loss Percentage before and after SCED

Incremental loss MW caused by SCED is also calculated by applying the Point of Connection (POC) injection charges[20] of generator nodes over the incremental

[20] POC injection loss data available at https://posoco.in/side-menu-pages/applicable-transmission-losses/transmission-losses-2019-20/

generator SED up/down MW. The net average loss for the period during the April-December 2019 period, turns out to be a very small value. Fig. 53 below depicts the duration plot of the MW loss due to SCED.

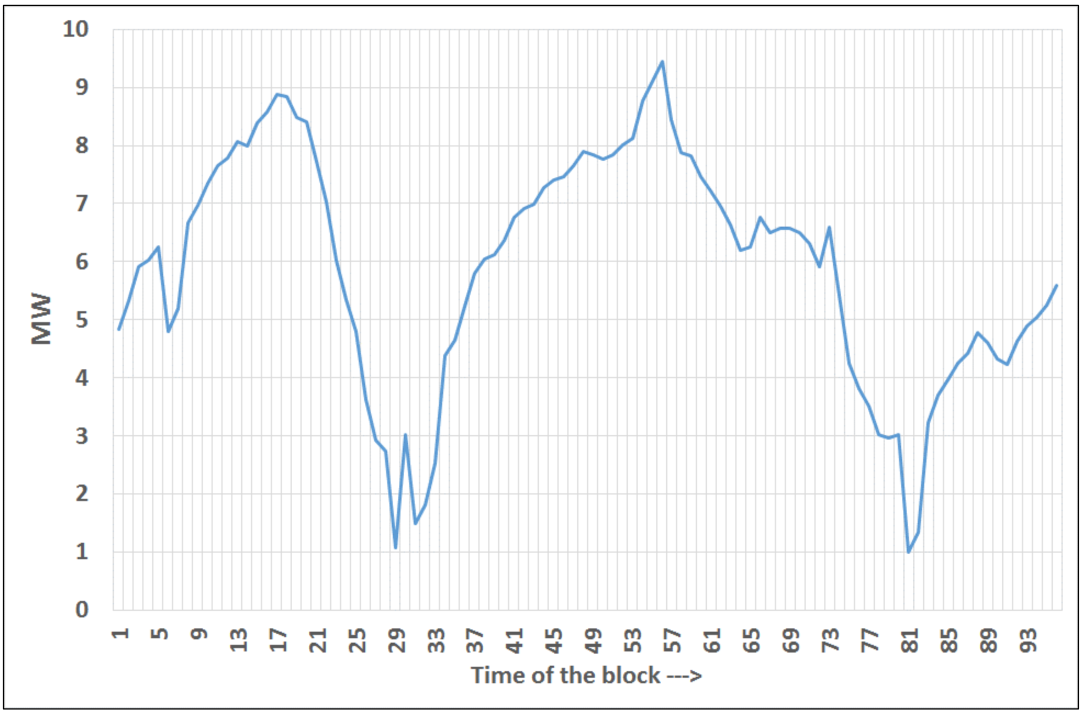


Figure 53: Transmission Losses due to SCED – Diurnal Pattern

4.10 Analysis of Duals

Generation in the southern region (SR) and northern region (NR) of the Indian grid has been decreased by SCED during the period Apr-Dec 2019 causing NR and SR to import more energy from the rest of the grid. This is due to the fact that relatively lower cost pit head plants are located in eastern region (ER) and western region (WR) of India and variable cost of thermal generation in SR is relatively on the higher side.

As can be inferred from Fig. 54 below, this has led to a split in the system marginal price (SMP) of SR and NR from rest of the grid (all India). SMP is calculated by suitably scaling and adding the duals of the binding constraints mentioned in equation 1 and equation 3 in the previous section 3. The split in system marginal price would send signals for investments in new/upcoming transmission system to the planners.

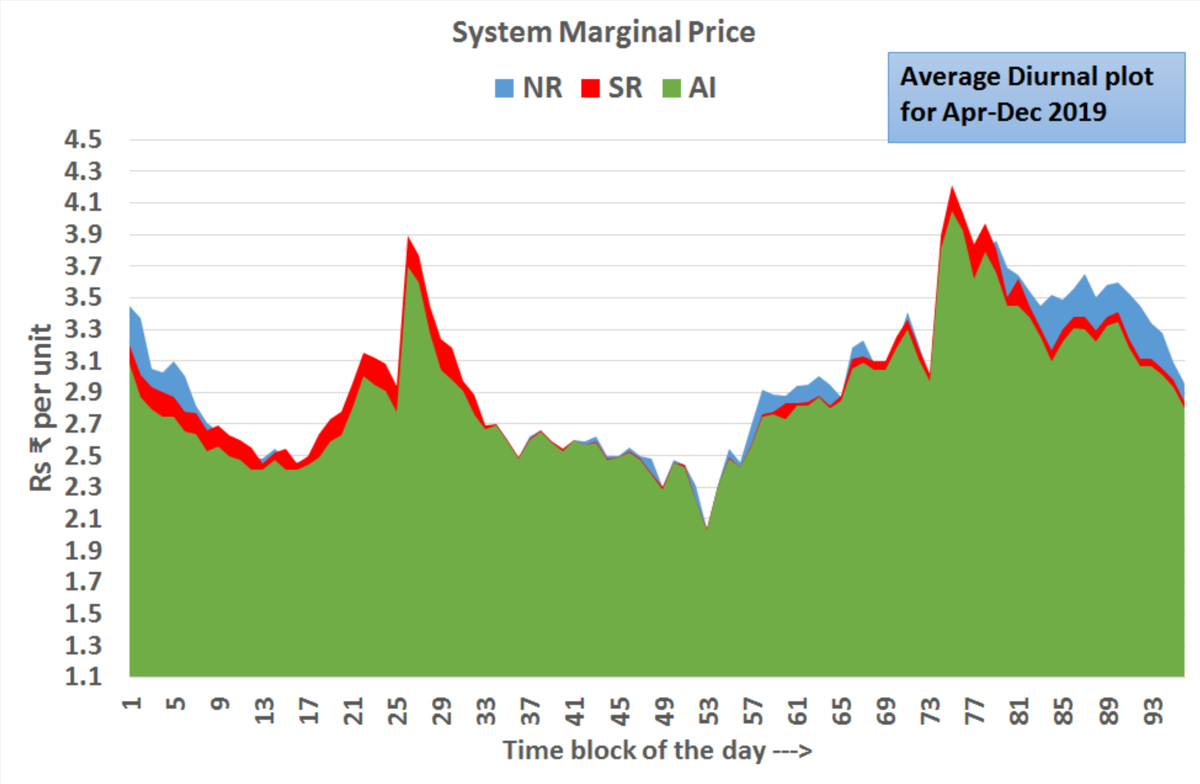


Figure 54: System Marginal Price (Region and All India) – Diurnal Pattern

The dual variables obtained for the constraints in the equations 4, 5, 6 and 7 in chapter 3 are analyzed in Fig. 55 (Count Ramp Up %), Fig. 56 (Count Ramp Down %), Fig. 57 (Count Pmax %), Fig. 58 (Count Pmin %) respectively to gather insights regarding where the value lies in investment regarding increase in ramp up or ramp down rates, decreasing technical minimum etc. The consolidated duals of ramp up, ramp down, Pmax and Pmin in percentage of time is depicted in Fig. 59.

The data is analyzed for 26400 nos. of 15-minute time-blocks spanning from Apr-Dec 2019 period. The figures below show the percentage of time for which the equations for the respective plants (represented by variable cost) have become binding in the optimal solution. It appears that reducing technical minimum turn down level from the present (55% DC on bar) to a lower value, at least for all the higher variable cost plants, can be a good technological intervention to take up. Mid merit power plants may have to do more ramp up and ramp down duty. Investing on these aspects can yield more economy.

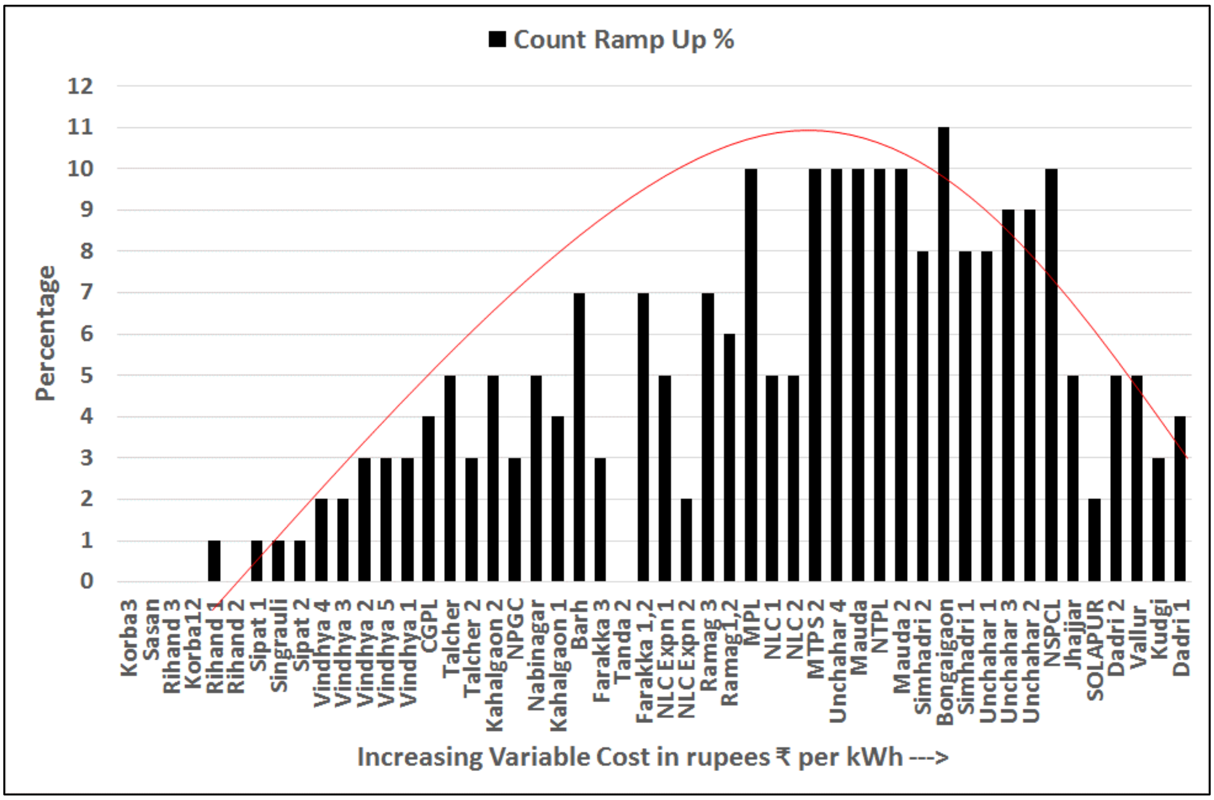


Figure 55: Dual Count Ramp Up (in % of time)

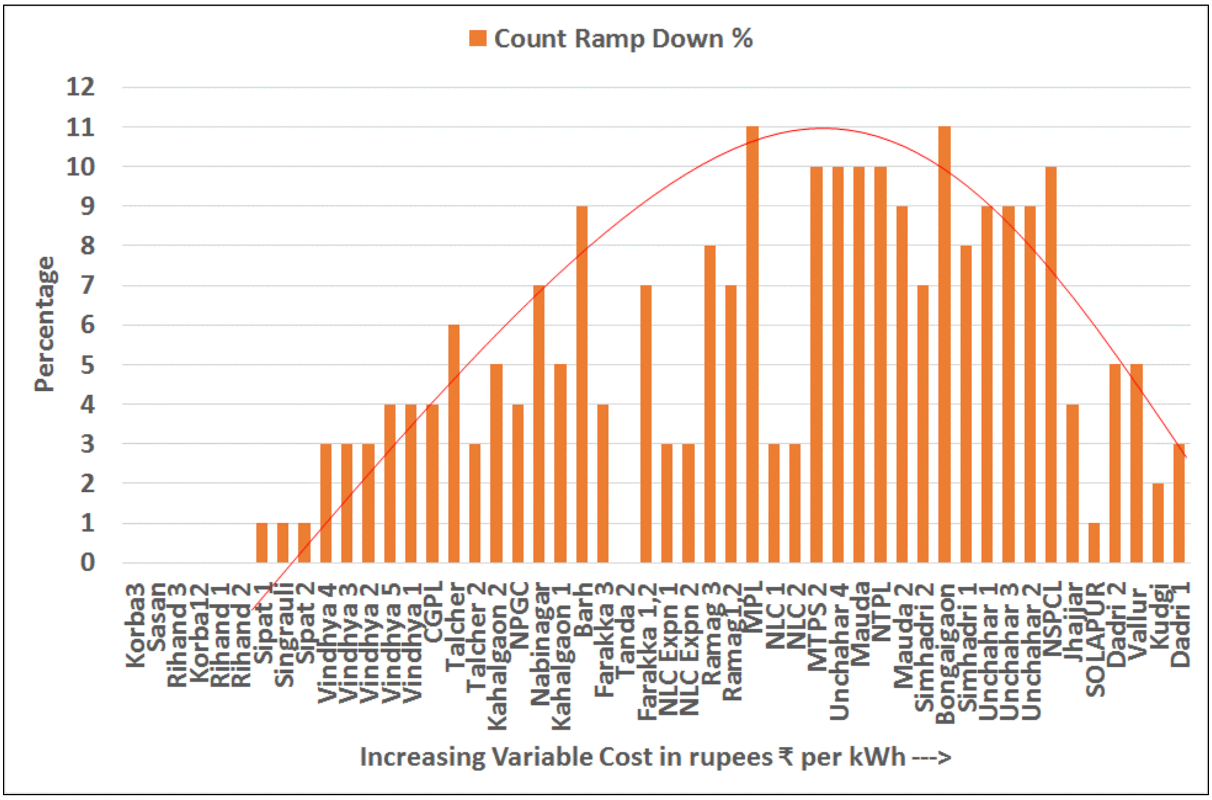


Figure 56: Dual Count - Ramp Down (in % of time)

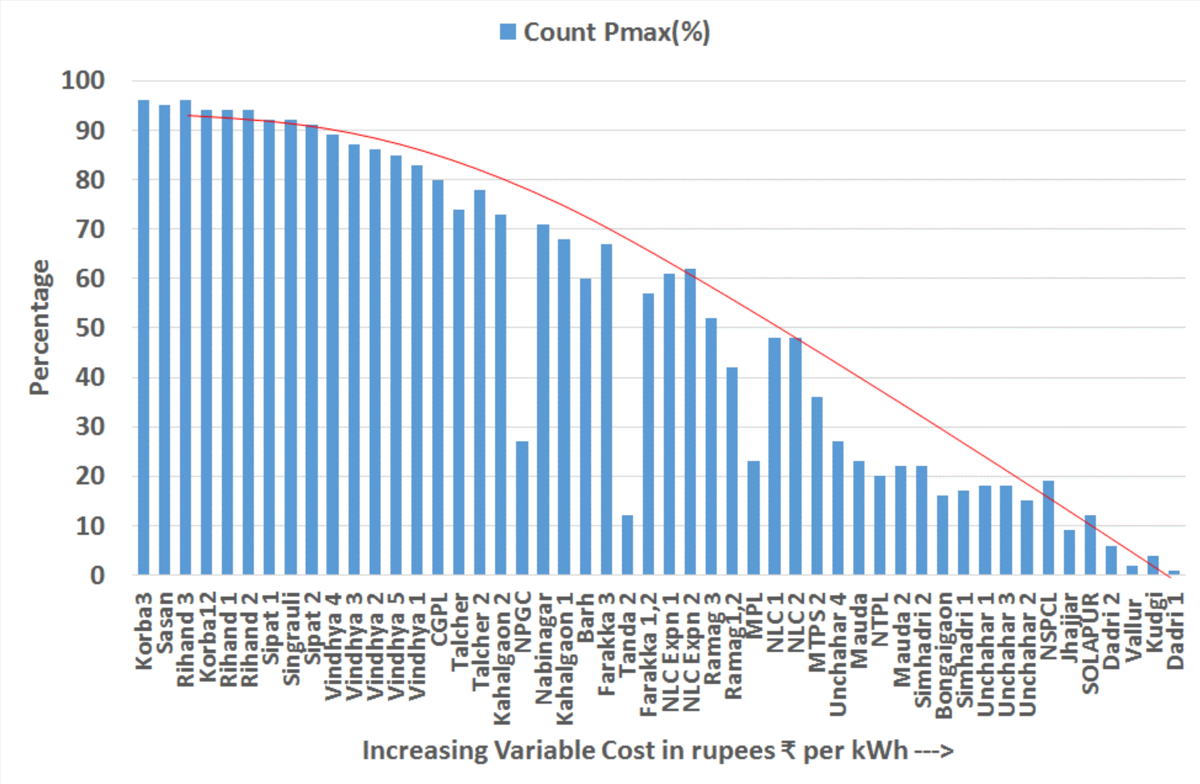


Figure 57: Dual Count - Pmax (in % of time)

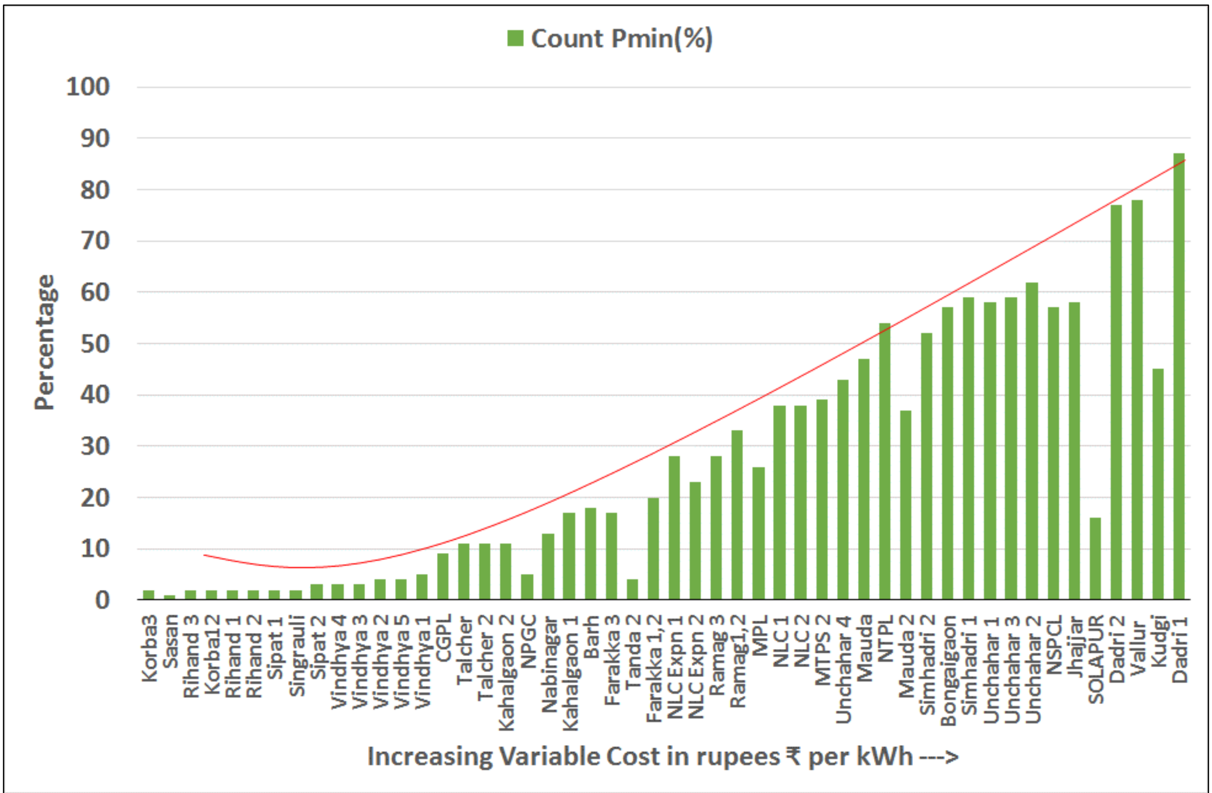


Figure 58: Dual Count Pmin (in % of time)

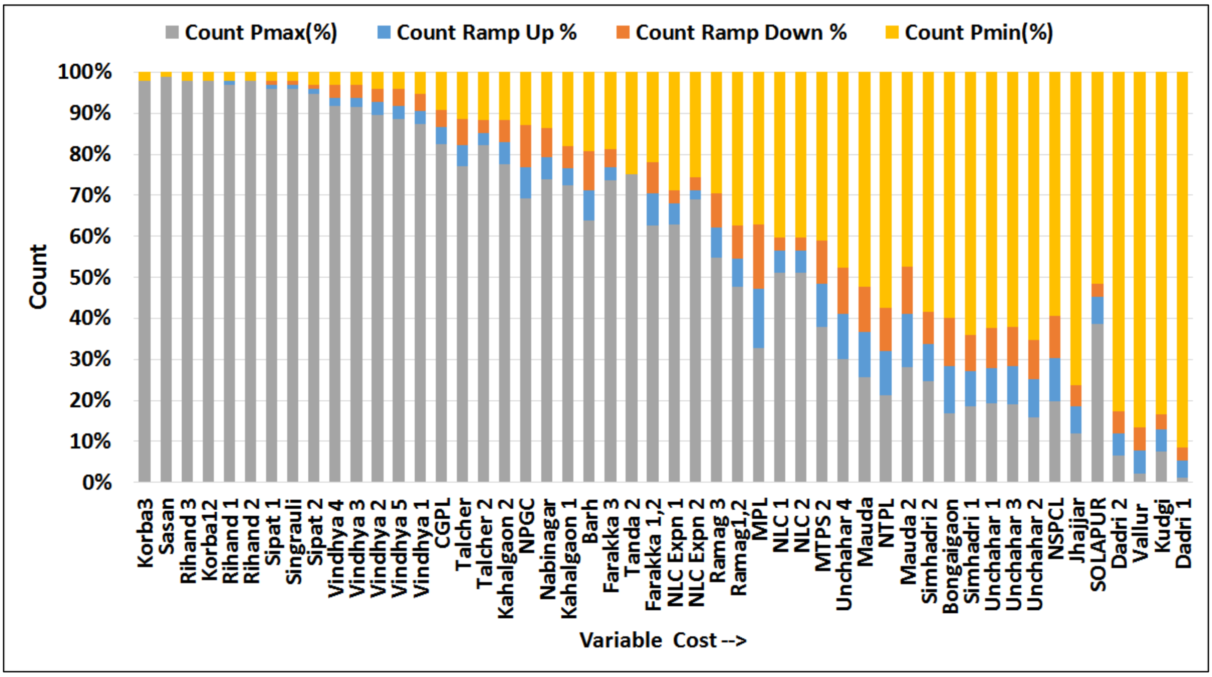


Figure 59: Dual Count all Pmax, Pmin, Ramp Up and Ramp Down (in % of time)

In Table 5, generator wise duals of ramp up, ramp down, Pmax and Pmin are tabulated. Some of the higher variable plants have been made to go under reserve shut down for a significant duration during the pilot.

Table 5: Generator-wise Dual Analysis

S.NO.	GENERATOR	VC (Avg.)	Count Rup %)	Count Rdn (%)	Count Pmax (%)	Count Pmin (%)
1	Korba-Stage-3	131	0	0	96	2
2	Sasan	132	0	0	95	1
3	Rihand 3	133	0	0	96	2
4	Korba STPS Stage 1 and 2	133	0	0	94	2
5	Rihand 1	134	1	0	94	2
6	Rihand 2	134	0	0	94	2
7	Sipat STPS Stage 1	138	1	1	92	2
8	Singrauli TPS	139	1	1	92	2
9	Sipat STPS Stage 2	142	1	1	91	3
10	Vindhyachal STPS Stage 4	160	2	3	89	3
11	Vindhyachal STPS Stage 3	162	2	3	87	3
12	Vindhyachal STPS Stage 2	163	3	3	86	4
13	Vindhyachal STPS Stage 5	164	3	4	85	4
14	Vindhyachal STPS Stage 1	170	3	4	83	5
15	CGPL Mundra	189	4	4	80	9
16	Talcher	198	5	6	74	11
17	Talcher Stage 2-NTPC	200	3	3	78	11

S.NO.	GENERATOR	VC (Avg.)	Count Rup %)	Count Rdn (%)	Count Pmax (%)	Count Pmin (%)
18	Kahalgaon Stage 2	212	5	5	73	11
19	Nabinagar	216	5	7	71	13
20	NPGC	219	3	4	27	5
21	Kahalgaon Stage 1	223	4	5	68	17
22	Barh	234	7	9	60	18
23	Tanda-2	235	0	0	12	4
24	FARAKKA-STAGE-3	239	3	4	67	17
25	Farakka Stage 1 and 2	243	7	7	57	20
26	Neyveli TPS 1 (Expn.)-NLC	244	5	3	61	28
27	Neyveli TPS 2 (Expn.)-NLC	249	2	3	62	23
28	Ramagundam 3	260	7	8	52	28
29	Ramagundam 1&2	264	6	7	42	33
30	Neyveli-I (ISGS)-NLC	266	5	3	48	38
31	Neyveli-II (ISGS)-NLC	266	5	3	48	38
32	MPL	270	10	11	23	26
33	MTPS Stg 2	275	10	10	36	39
34	UNCHAHAR 4	311	10	10	27	43
35	Mauda	313	10	10	23	47
36	NTPL	314	10	10	20	54
37	Mauda 2	315	10	9	22	37
38	Simhadri NTPC Stage 2	322	8	7	22	52
39	Bongaigaon	325	11	11	16	57
40	Simhadri -NTPC Stage -1	325	8	8	17	59
41	Unchahar TPS 1	331	8	9	18	58
42	Unchahar TPS 3	331	9	9	18	59
43	Unchahar TPS 2	333	9	9	15	62
44	NSPCL	334	10	10	19	57
45	Jhajjar	364	5	4	9	58
46	NTPC SOLAPUR	368	2	1	12	16
47	Dadri Stage 2	377	5	5	6	77
48	Vallur NTECL	381	5	5	2	78
49	Kudgi-1	388	3	2	4	45
50	Dadri Stage 1	405	4	3	1	87

4.11 Reduction in Costs

4.11.1 Pre-SCED and Post-SCED Cost

The duration plot of pre and post SCED cost in ₹ lakhs/hour is depicted in Fig. 60.

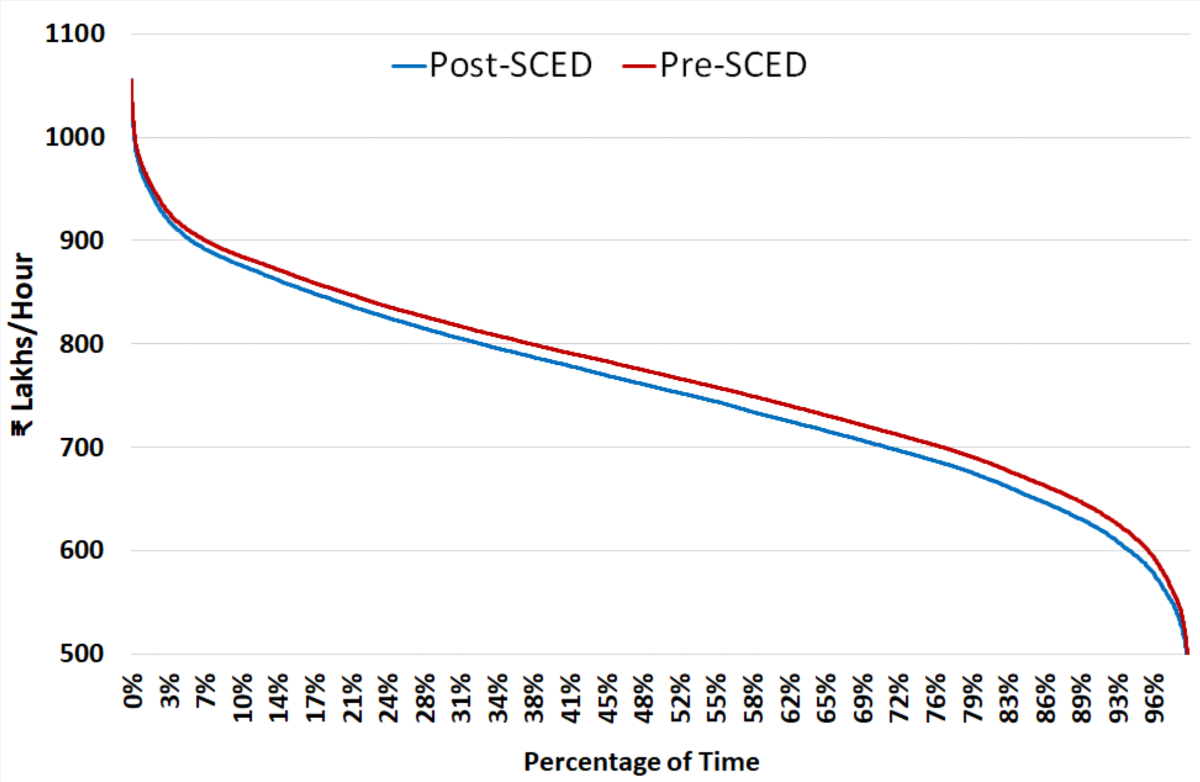


Figure 60: Optimal Cost and Present Cost – Duration Plot

The diurnal plot of present cost and optimal cost in ₹ lakhs/hour pre and post SCED is depicted in Fig. 61.

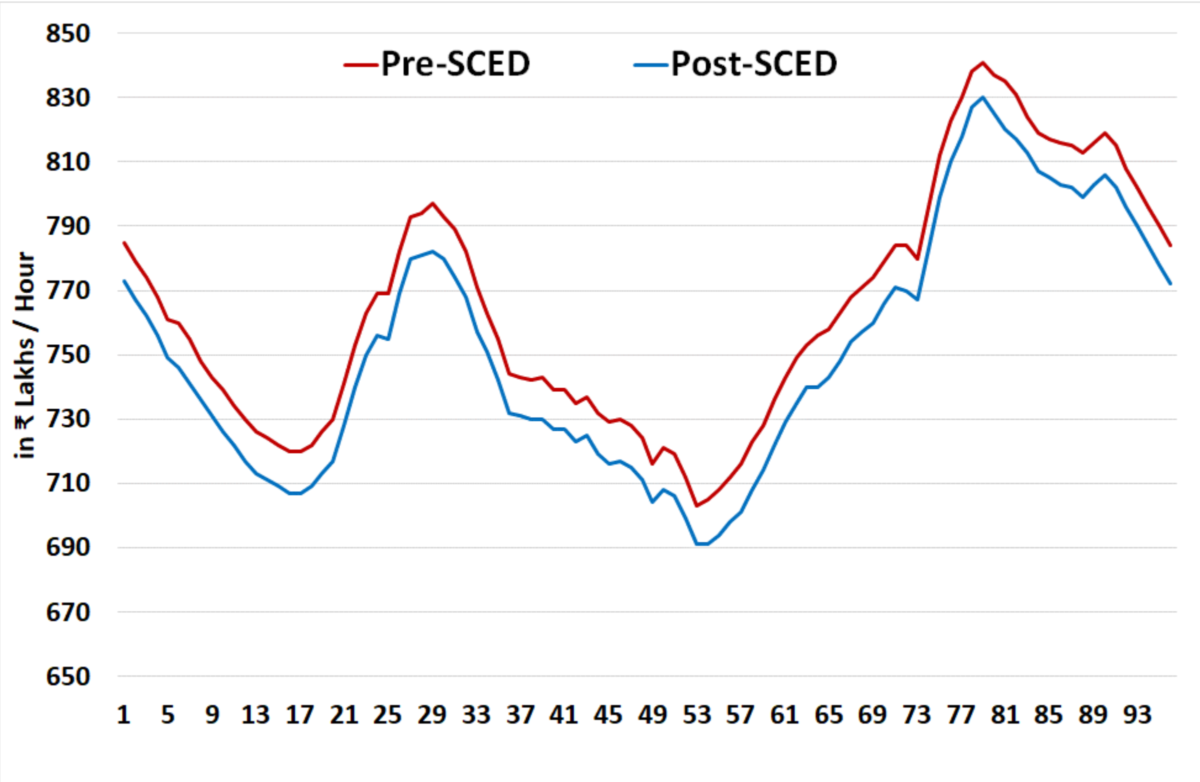


Figure 61: Optimal Cost and Present Cost – Diurnal Pattern

The pre and post SCED cost in paisa/kWh for Apr – Dec'19 is depicted in Fig. 62.

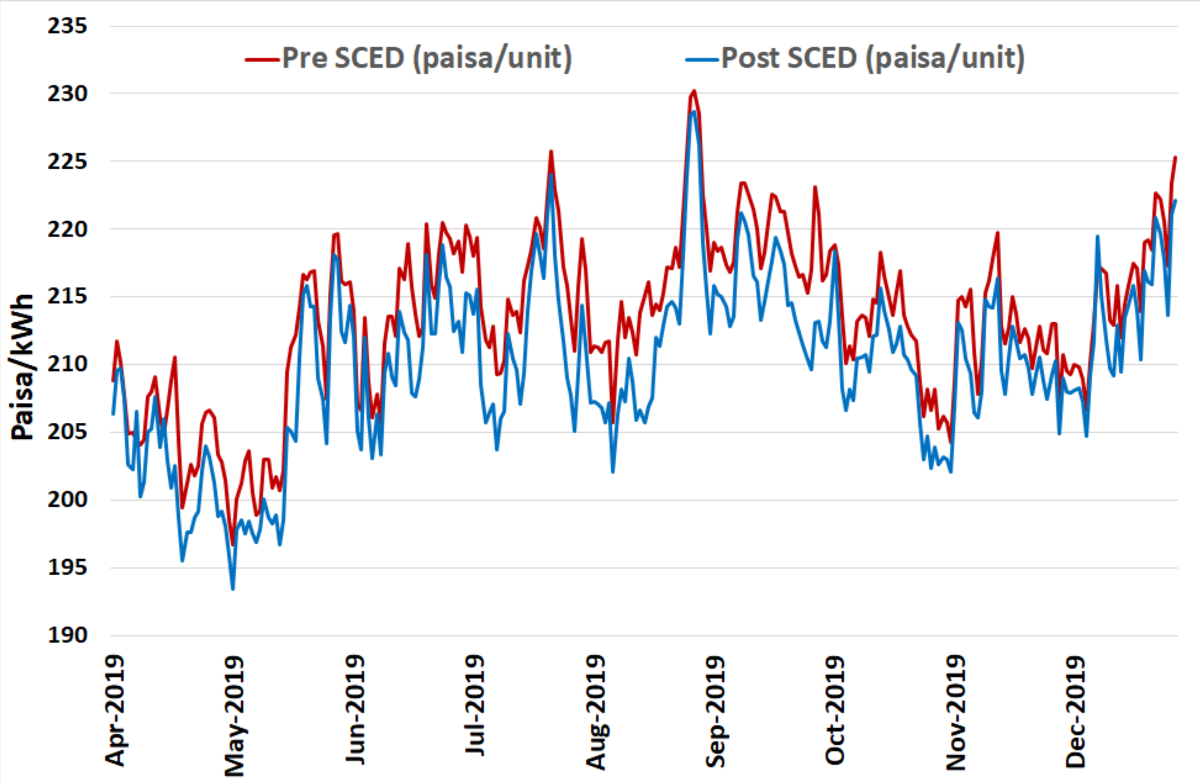


Figure 62: Pre-SCED and Post-SCED (paisa/kWh)

4.11.2 Reduction in Cost

The diurnal pattern and histogram of reduction in costs (₹ lakhs/hour) for the period Apr – Dec'19 is depicted in Fig. 63 and 64 respectively.

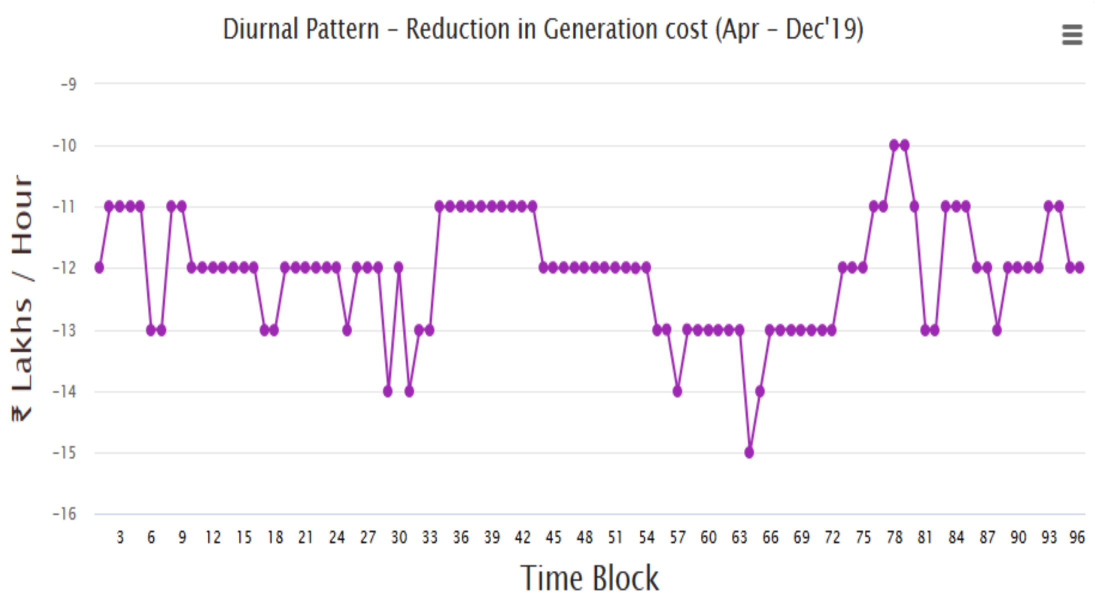


Figure 63: Reduction in Costs (₹ Lakhs/hr) - Diurnal Pattern

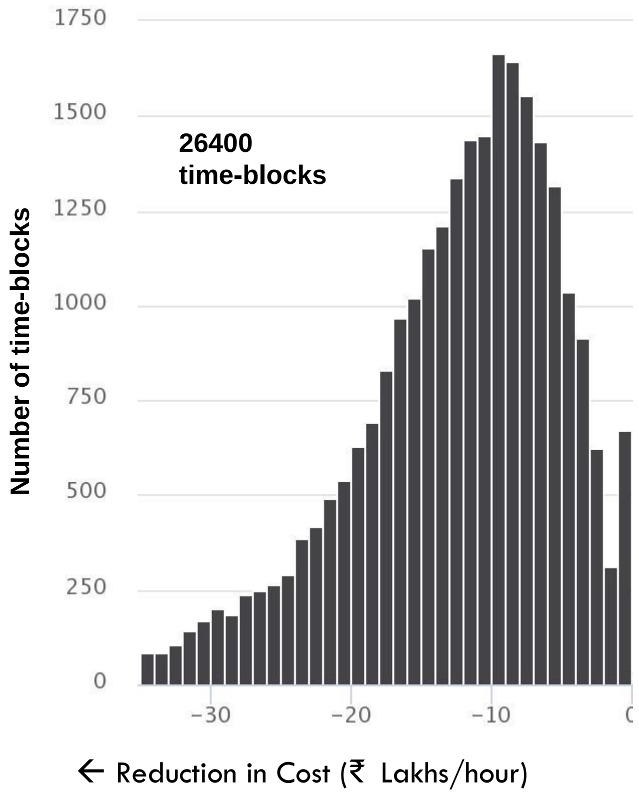


Figure 64: Reduction in Costs (₹ Lakhs/hr.) – Histogram

The scatter plot of MW versus Reduction in Production Costs (paisa/kWh) for a typical month is depicted in Fig. 65. It may be inferred that as the MW increases, the scope for reduction in cost decreases.

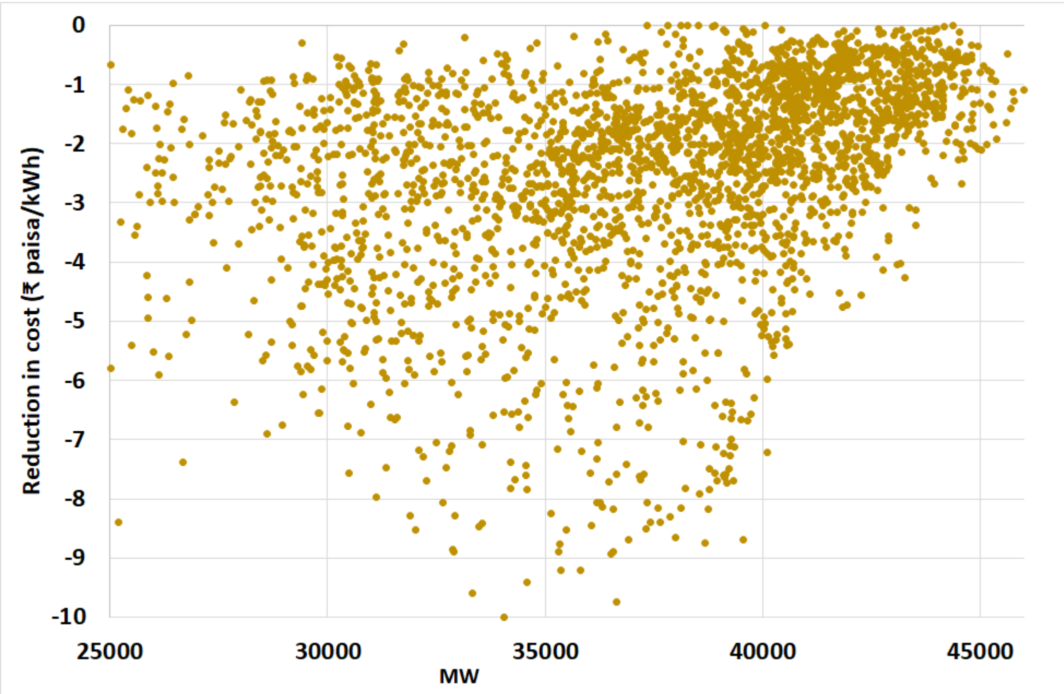


Figure 65: MW vs Reduction in Production Costs (paisa/kWh) – Typical Month

The scatter plot of MW vs Average Price (paisa/kWh) for a typical week is depicted in Fig. 66. It may be inferred that the reduction in cost post SCED with respect to pre-SCED is non-linear in nature. The non-linearity on either side is due to constraints like Pmax, Pmin, Ramp and above all, the combination of unit commitment.

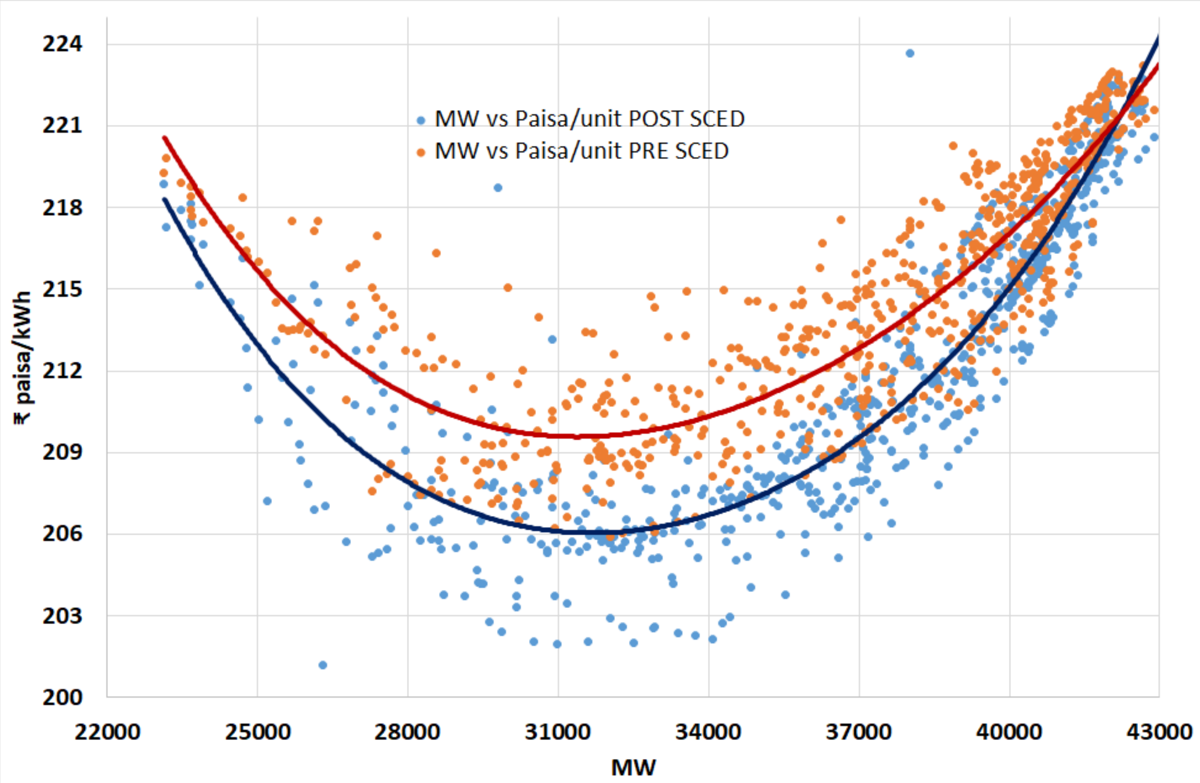


Figure 66: MW vs Average Price (paisa/kWh) – Typical Week

4.12 Supply and Demand Effect in SCED

The typical plot of merit order stacked cumulative DC of ISGS in SCED and Requisition (shadow of supply-demand curve) during Night Lean Hours, Morning Peak Hours and Evening Peak hours in a time-block for a typical day is depicted in Fig. 67, 68 and 69 respectively.

It can be inferred that during the lean hours, the requisition is met at the variable cost of 250 – 300 paisa/kWh whereas during the peak hours, the requisition is met at the variable cost of 300 – 350 paisa/kWh which rises further in case of evening peak hours. These figures are only for the purpose of demand supply crossing using merit order stacking. The actual SMP could be lower or higher than these values due to various other constraints such as technical minimum, ramp rate, ATC etc.

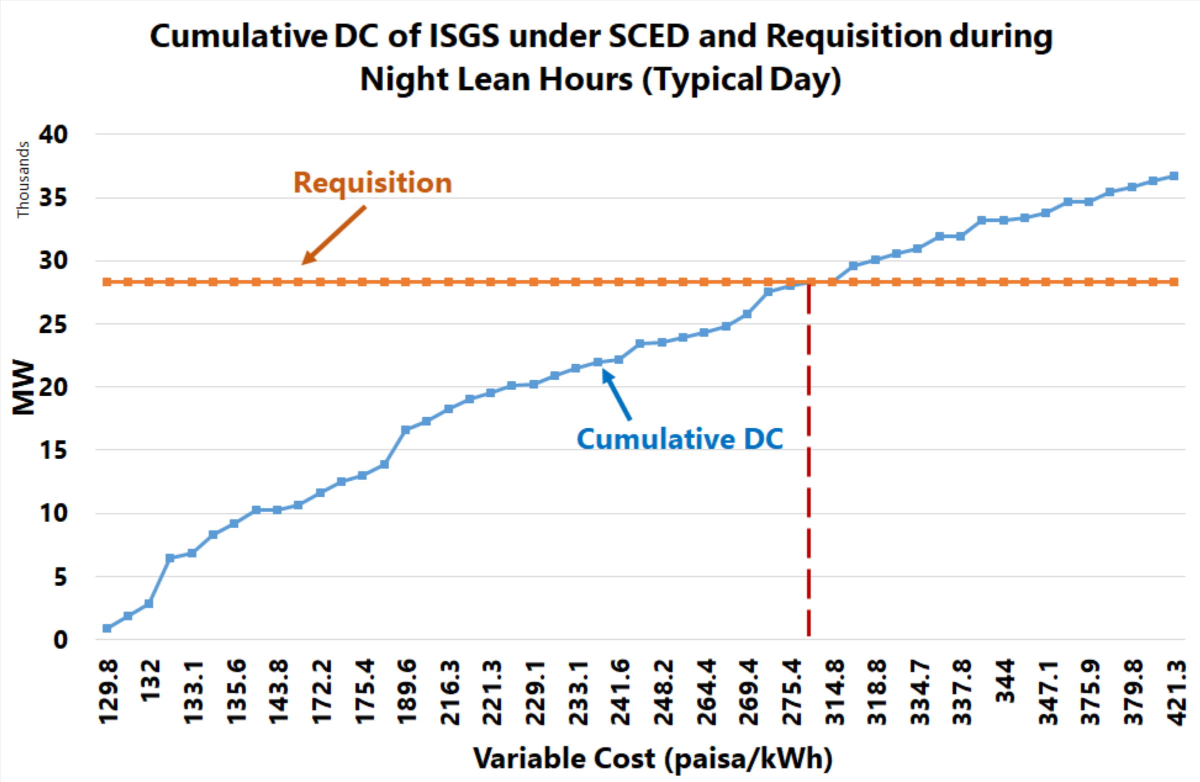


Figure 67: Cumulative DC of ISGS in SCED and Requisition during Night

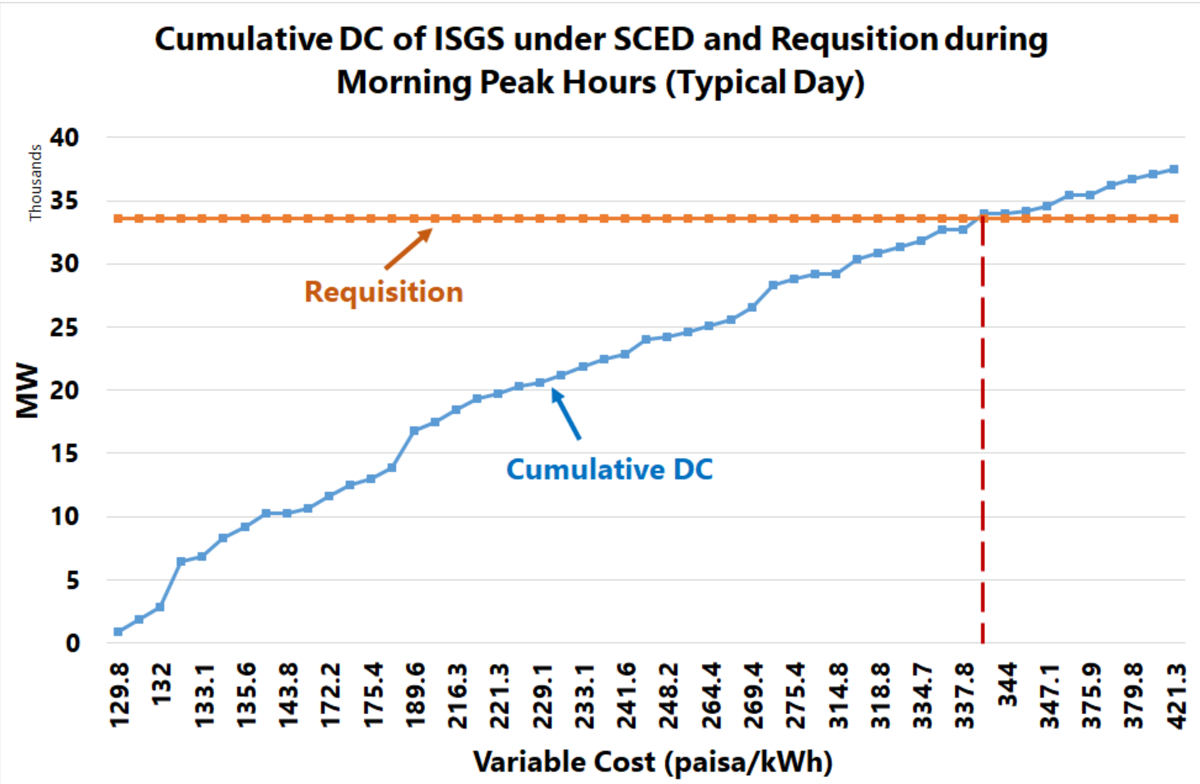


Figure 68: Cumulative DC of ISGS in SCED and Requisition during Morning

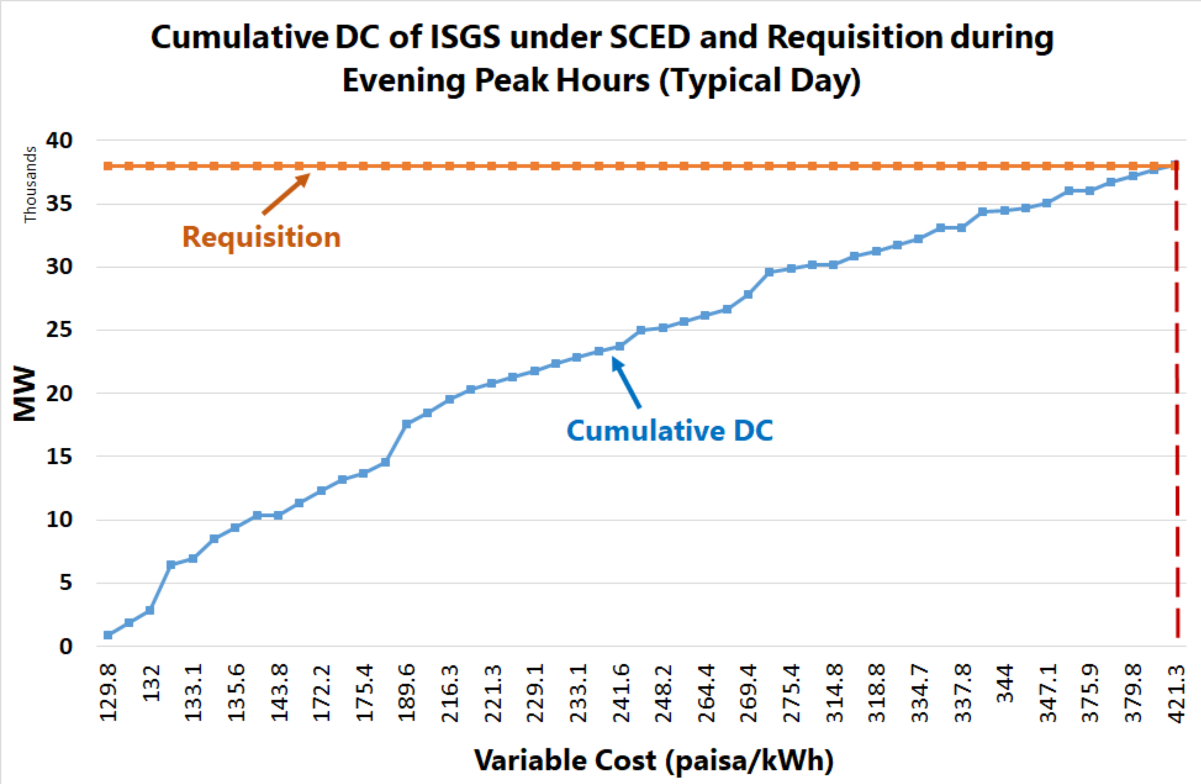


Figure 69: Cumulative DC of ISGS in SCED and Requisition during Evening

4.13 Emissions

The impact on emissions by SCED was also analyzed using the CO2 baseline database for the Indian power sector[21]. The specific emissions for 2017-18 (tCO2/MWh) and Variable Cost is depicted in Fig. 70. It was observed that the average 1300 MW perturbation from SCED doesn't cause any significant change in CO2 levels with respect to pre-SCED condition. It was further observed that there was a 0.19 % reduction in CO2 emissions, during the studied May 2019 period, on account of SCED. The estimated block-wise change in CO2 emissions due to SCED in May, 2019 in terms of percentage and quantum (t CO2) has been depicted in Fig. 71 and 72 respectively. For the sake of simplicity, the estimation doesn't take into account the heat rate changes at different loading levels.

[21] CDM - CO2 Baseline Carbon Dioxide Emission Database, Central Electricity Authority, Govt. of India. http://cea.nic.in/tpeandce.html

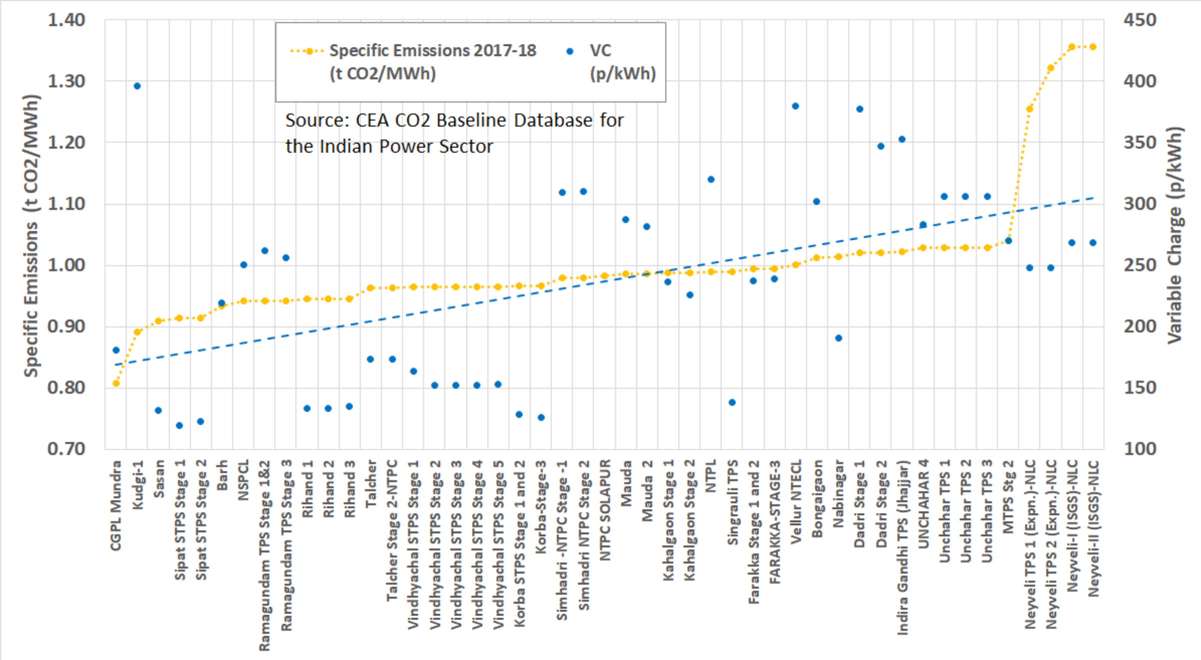


Figure 70: Specific Emissions 2017-18 (tCO2/MWh) and Variable Cost

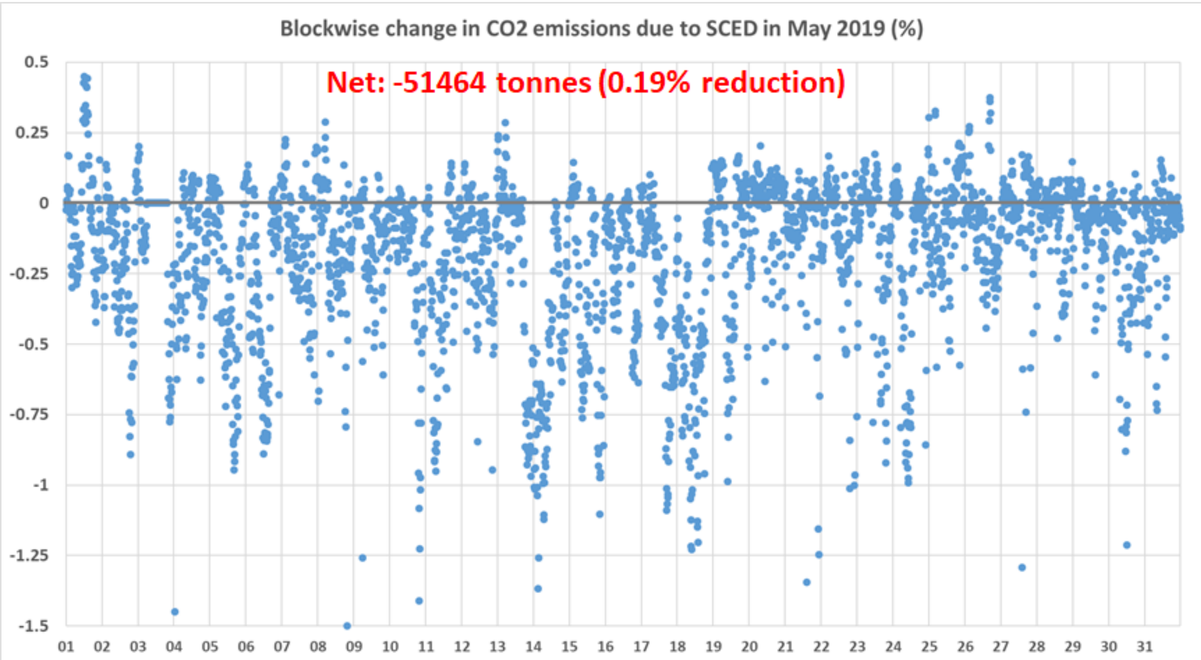


Figure 71: Estimated Blockwise Change in CO2 emissions in May, 2019 (%)

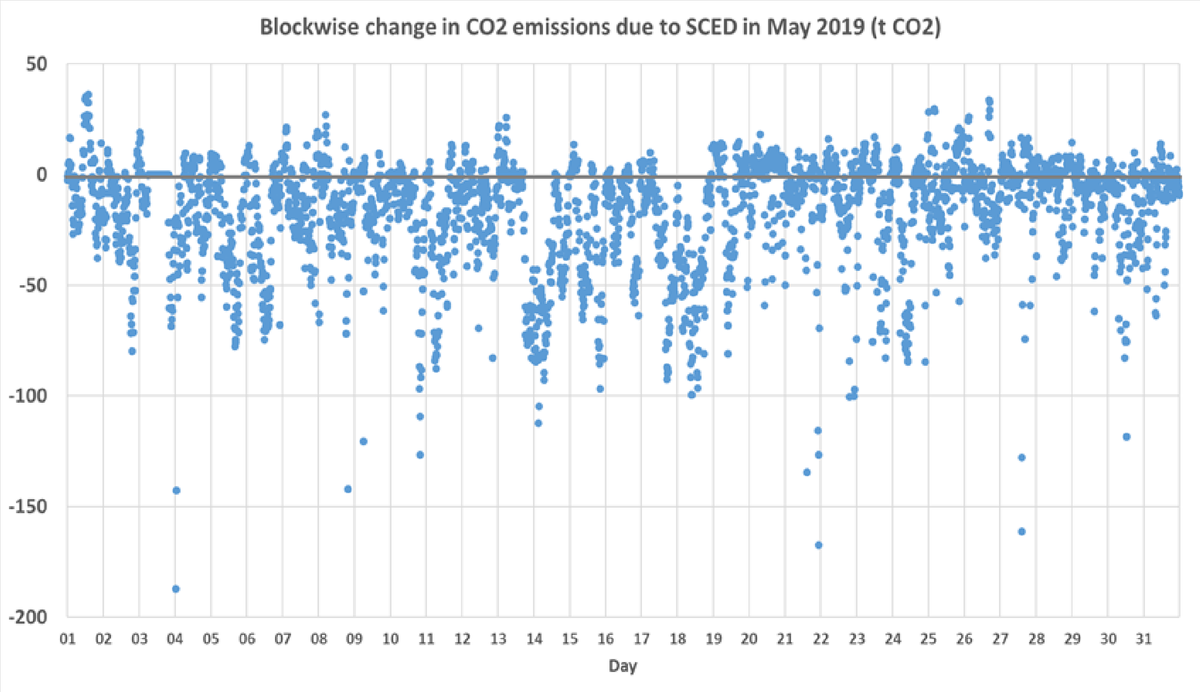


Figure 72: Estimated Blockwise Change in CO_2 emissions in May, 2019 (t CO_2)

5 ACCOUNTING & SETTLEMENT

5.1 Accounting System

The pilot on SCED has been implemented w.e.f 01st April, 2019 in all the thermal ISGS which are regional entities and whose tariff is determined or adopted by the CERC for their full capacity. The plants participating under SCED are also participating in Reserve Regulation Ancillary Services (RRAS). The RRAS providers are furnishing the variable charge and other details to respective RPCs on monthly basis. These details submitted by RRAS providers are applicable from 16th of every month to 15th of next month. The variable charge declared by plants for RRAS is being considered for despatch in SCED.

As per the Central Commission order, a separate regulatory account namely "National Pool Account (SCED)" has been constituted. All payments on account of SCED to/from the generators participating in pilot on SCED are settled through this regulatory account only. In case of any increment in the injection schedule on account of SCED, the payment is made to the SCED providers at the rate of their variable charge from the National Pool Account (SCED). In case of any decrement in the injection schedule on account of SCED, the payment is made by the SCED providers at the rate of their variable charge after discounting compensation due to part load operation as certified by RPC in accordance with the IEGC provisions. Based on the incremental/decremental SCED schedule, the plant-wise net injection schedule is prepared.

5.2 Virtual SCED Entity

In order to maintain proper checks and balances, the well-recognized double entry accounting system has been adopted. In each of the five regions, Virtual Security Constrained Economic Despatch (VSCED) entity has been created in the WBES application as counter beneficiary of all SCED instructions.

The summation of all the SCED instruction at ex-bus of SCED generators is normally zero. However, due to application of POC transmission losses, the summation of VSCED is non zero. In case of SCED Up instruction, applicable POC injection loss of the concerned generating station and normal PoC slab loss of the region where generating station is located is factored to schedule SCED Up to VSCED. In case of SCED Down instruction, twice the normal POC loss slab of the concern region where generator is located is factored to schedule SCED Down to VSCED.

5.3 Weekly National SCED Statement

The respective RPCs have been given responsibility of publishing the respective regional SCED accounts on weekly basis along with the DSM, RRAS, FRAS and AGC accounts based on the data provided to them by RLDCs. Based on the Regional SCED account published by respective RPCs, NLDC publishes the consolidated "National SCED Weekly Statement" comprising payment and receipts to/from all generators participating in the pilot on SCED.

The concerned SCED Generator would pay the indicated charges for SCED decrement within seven (07) working days of the issue of statement of SCED by the RPC to the 'National Pool Account (SCED)'. The concerned SCED Generator shall be paid the indicated charges for SCED increment within ten (10) working days of the issue of consolidated "National SCED Monthly Statement" by the NLDC from the 'National Pool Account (SCED)'. The payments against SCED are not adjusted against any other payments by the SCED Generator.

All RPCs have issued SCED account statements[22] up to 31st December, 2019. A total of **₹ 1715 Crore** has been paid to SCED generators for incremental generation on account of SCED. A total of **₹ 2560 Crore** has been paid by the SCED generators on account of decrement in generation on account of SCED. The week-wise "National

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[22] https://nrpc.gov.in/commercial-category/sced-account/?lang=en; http://www.wrpc.gov.in/Commercial_rras_chrg.asp; http://www.srpc.kar.nic.in/html/all_uploads.html; http://erpc.gov.in/ui-and-deviation-accts/; http://nerpc.nic.in/SCED_statement.php;

SCED Weekly Statement”[23] is available in NLDC-POSOCO website. A sample ""National SCED Weekly Statement” is given below in Table 6:

Table 6: National SCED Weekly Statement – Sample Month

NLDC "National SCED Weekly Statement”

For Week 01.07.2019 to 07.07.2019

Dated: 07-Aug-2019

Sl.No.	SCED Generator	Region	Increment due to SCED scheduled to VSCED (MWHr) (A)	Decrement due to SCED scheduled to VSCED (MWHr) (B)	Charges To be Paid to SCED Generator from National Pool (SCED) (in ₹) (C) = (A) x V.C.	Charges To be Refunded by SCED Generator to National Pool (SCED) (in ₹) (D) = (B) x V.C.	Net Charges Payable (+) / Receivable (-) (in ₹) (E)* =(C) – (D)
1	BARH	ER	9,819.14	11,639.69	22,230,522	26,352,247	-4,121,725
2	BRBCL	ER	4,350.60	2,678.37	9,532,165	5,868,309	3,663,856
3	FTSPP-I&II	ER	18,439.18	8,593.26	45,397,255	21,156,612	24,240,643
4	FTSPP-III	ER	0.00	0.00	0	0	0
5	KHSTPP-I	ER	6,759.86	4,756.71	15,169,131	10,674,046	4,495,085
6	KHSTPP-II	ER	13,662.08	2,460.06	29,072,896	5,234,997	23,837,899
7	MTPS-II	ER	1,662.13	2,351.97	4,522,649	6,399,704	-1,877,055
8	TSTPS-I	ER	1,041.68	5,856.55	2,183,361	12,275,324	-10,091,963
9	MPL	ER	1,390.27	10,633.85	3,782,925	28,934,713	-25,151,788
10	Ramagundam Super Thermal PowerStation (U1-6)	SR	3,373.69	21,418.92	8,589,408	54,532,558	-45,943,150
11	Ramagundam Super Thermal PowerStation (U7)	SR	750.83	4,714.21	1,886,836	11,846,803	-9,959,967
12	Simhadri Super Thermal PowerStation Stage II	SR	1,541.62	13,689.43	4,960,917	44,052,578	-39,091,661
13	Talcher Super Thermal PowerStation Stage II	SR	1,098.09	5,681.57	2,288,409	11,840,392	-9,551,983
14	Vallur Thermal Power Station	SR	187.26	35,377.75	714,565	135,001,494	-134,286,929
15	NLC TPS-II Stage I	SR	851.74	3,326.48	2,247,748	8,778,574	-6,530,826
16	NLC TPS-II Stage II	SR	967.14	3,798.53	2,552,276	10,024,327	-7,472,051
17	NLC TPS-I Expansion	SR	796.70	2,567.14	1,935,178	6,235,589	-4,300,411
18	NLC TPS-II Expansion	SR	0.00	0.00	0	0	0
19	NTPL	SR	492.13	8,285.32	1,745,594	29,388,039	-27,642,445
20	Simhadri Super Thermal PowerStation Stage I	SR	3,178.41	2,349.32	10,361,625	7,658,791	2,702,834
21	Kudgi Super Thermal PowerStation Unit I	SR	198.23	12,530.94	740,191	46,790,521	-46,050,330
22	CGPL	WR	29,495.65	1,672.51	57,976,650	3,287,491	54,689,159
23	KSTPS I&II	WR	6,927.37	2,717.84	9,206,468	3,612,003	5,594,465
24	KSTPS7	WR	979.69	145.33	1,276,539	189,365	1,087,174
25	MOUDA	WR	11,535.51	5,939.11	35,990,783	18,530,015	17,460,768
26	MOUDA_II	WR	7,737.16	2,306.73	24,627,380	7,342,314	17,285,067
27	NSPCL	WR	272.79	18,731.29	972,479	66,777,058	-65,804,579
28	SASAN	WR	9,191.92	1,644.73	12,133,331	2,171,047	9,962,284
29	SIPAT I	WR	7,278.11	0.00	9,250,478	0	9,250,478
30	SIPAT II	WR	3,410.47	426.83	4,467,712	559,147	3,908,565
31	SOLAPUR	WR	0.00	0.00	0	0	0
32	VSTPS I	WR	25,091.70	24.56	40,899,471	40,025	40,859,446
33	VSTPS II	WR	6,690.59	139.00	10,577,815	219,755	10,358,060
34	VSTPS III	WR	13,957.13	363.60	21,773,115	567,208	21,205,907
35	VSTPS IV	WR	10,818.37	88.67	16,649,464	136,467	16,512,997
36	VSTPS V	WR	6,325.23	8.37	9,854,712	13,040	9,841,672
37	GADARAWARA	WR	0.00	0.00	0	0	0
38	DADRI TPS	NR	40.83	24,525.18	157,186	94,421,953	-94,264,767
39	DADRI-II TPS	NR	883.36	14,411.91	3,211,023	52,387,284	-49,176,261
40	IGSTPS-JHAJJAR	NR	4,161.45	7,596.35	15,347,418	28,015,320	-12,667,902
41	RIHAND STPS	NR	5,200.91	0.00	6,724,770	0	6,724,770
42	RIHAND-II STPS	NR	5,143.40	0.00	6,634,986	0	6,634,986
43	RIHAND-III STPS	NR	9,652.61	0.00	12,287,773	0	12,287,773
44	SINGRAULI STPS	NR	14,794.78	1,010.54	21,319,274	1,456,192	19,863,083
45	UNCHAHAR-I TPS	NR	1,174.13	3,231.52	3,750,179	10,321,475	-6,571,296
46	UNCHAHAR-II TPS	NR	970.06	2,143.83	3,125,533	6,907,404	-3,781,871
47	UNCHAHAR-III TPS	NR	1,302.54	1,503.50	4,160,321	4,802,163	-641,842
48	UNCHAHAR-IV TPS	NR	4,280.66	2,296.70	12,884,772	6,913,075	5,971,697
49	BONGAIGAON	NER					
	All India	**Total**	**257,877.14**	**253,638.13**	**515,173,283**	**791,715,419**	**-276,542,134**

Notes:

1.SCED Account issue dates by respective RPCs for week 01.07.2019 to 07.07.2019 are as follows:

Region	Revision-0
SR	16-07-19
NR	19-07-19
WR	16-07-19
ER	29-07-19
NER	Yet to publish

2.*(+) means payable from the National Pool Account (SCED) to SCED Generator/
(-) means receivable by National Pool Account (SCED) from SCED Generator

3.Compensation for heat rate degradation shall be paid separately to the respective generators after issuance of Heat Rate Degradation Account by the concerned RPCs

5.4 Generator-wise SCED Accounting and Settlement

As per the variable cost of SCED generator, technical details and grid condition, SCED Up and Down instruction are issued. The plant wise details are mentioned in Table 7. Total reduction in production cost for the period 01st April’19 to 31st December’19 is **₹ 845 Crore**. The mentioned figure is without considering the compensation for heat rate degradation.

[23] https://posoco.in/national-sced-settlement-statement/

Table 7: Generator-wise SCED Accounting (Apr – Dec 2019)

S. No.	SCED Generator	Variable cost (Paisa/kWh)	Sum of Increment due to SCED scheduled to VSCED (MU) (A)	Sum of Decrement due to SCED scheduled to VSCED (MU) (B)	Sum of Charges To be Paid to SCED Generator from National Pool (SCED) (in ₹ Crs.) (C) = (A) x V.C.	Sum of Charges To be Refunded by SCED Generator to National Pool (SCED) (in ₹ Crs.) (D) = (B) x V.C.	Sum of Net Charges Payable (+) / Receivable (-) (in ₹ Crs.) (E)* =(C) – (D)
1	KSTPS7	129.6	9.0	1.1	1.2	0.1	1.0
2	KSTPS I&II	132.2	115.1	21.2	15.6	2.9	12.7
3	SASAN	132.3	345.8	6.4	45.8	0.9	44.9
4	RIHAND-III STPS	134.8	312.8	4.0	41.8	0.6	41.3
5	RIHAND-II STPS	136.5	250.1	5.3	33.6	0.8	32.9
6	RIHAND STPS	136.9	267.4	4.0	36.0	0.6	35.4
7	SINGRAULI STPS	141	609.3	10.4	84.9	1.5	83.5
8	SIPAT I	144.1	115.3	31.3	16.4	5.1	11.3
9	SIPAT II	148.5	84.3	22.6	12.3	3.7	8.6
10	VSTPS IV	161.1	165.6	19.9	26.8	3.2	23.5
11	VSTPS V	163.4	138.2	14.1	23.3	2.4	21.0
12	VSTPS III	163.7	200.5	25.1	32.9	4.1	28.8
13	VSTPS II	164.5	154.0	33.3	25.9	5.6	20.4
14	VSTPS I	170.8	370.5	32.1	64.1	5.6	58.6
15	CGPL	190.29	759.7	100.3	143.1	18.9	124.2
16	Talcher 2	194.8	143.1	158.2	28.5	33.3	-4.8
17	TSTPS-I	196.7	108.7	109.7	23.0	22.6	0.5
18	NPGC	212.5	43.7	70.6	9.7	15.8	-6.2
19	KHSTPP-II	214.7	503.0	79.9	107.1	17.4	89.7
20	KHSTPP-I	226.4	216.9	94.2	48.8	21.3	27.4
21	BRBCL	232	291.3	90.5	62.6	19.8	42.7
22	TANDA-II STPS	239.4	65.5	9.9	15.4	2.3	13.1
23	FTSPP-III	247.4	72.6	40.6	17.5	9.8	7.7
24	FTSPP-I&II	252.1	437.0	275.4	106.2	65.9	40.2
25	NLC TPS-I Expansion	254.6	27.0	62.6	6.6	15.2	-8.7
26	NLC TPS-II Expansion	259.3	8.1	13.8	2.0	3.4	-1.4
27	Ramgundam 7	259.3	83.7	155.8	21.9	40.5	-18.6
28	Ramgundam 1-6	262.7	279.0	580.2	74.0	153.7	-79.6
29	MPL	265.6	118.3	387.9	32.0	105.0	-73.1
30	LARA	270.6	60.5	33.5	14.2	7.8	6.4
31	MTPS-II	274.1	142.3	88.3	38.6	24.6	14.0
32	NLC TPS-II Stage I	277.6	48.0	69.3	12.7	18.4	-5.7

S. No.	SCED Generator	Variable cost (Paisa/kWh)	Sum of Increment due to SCED scheduled to VSCED (MU) (A)	Sum of Decrement due to SCED scheduled to VSCED (MU) (B)	Sum of Charges To be Paid to SCED Generator from National Pool (SCED) (in ₹ Crs.) (C) = (A) x V.C.	Sum of Charges To be Refunded by SCED Generator to National Pool (SCED) (in ₹ Crs.) (D) = (B) x V.C.	Sum of Net Charges Payable (+) / Receivable (-) (in ₹ Crs.) (E)* =(C) – (D)
33	NLC TPS-II Stage II	277.6	63.4	90.6	16.8	24.1	-7.3
34	BARH	285.2	353.2	312.2	83.0	73.7	9.3
35	NTPL	291	178.3	197.5	54.0	63.6	-9.6
36	GADARWARA	292.5	4.2	40.8	1.6	15.3	-13.7
37	MOUDA_II	306.9	138.9	362.8	41.6	113.8	-72.2
38	MOUDA	310.9	150.5	332.5	45.9	104.3	-58.4
39	SOLAPUR	327.5	6.5	98.0	2.2	34.3	-32.1
40	UNCHAHAR-IV TPS	329.4	157.5	85.2	48.4	26.6	21.8
41	NSPCL	332.8	19.0	500.7	5.6	172.0	-166.4
42	BONGAIGAON	338.6	141.7	310.1	46.2	102.2	-55.9
43	Simhadri 2	347.9	115.1	295.2	37.1	95.0	-57.8
44	UNCHAHAR-I TPS	349.5	51.5	165.1	16.5	55.4	-38.8
45	UNCHAHAR-III TPS	349.5	33.1	72.4	10.7	24.2	-13.5
46	Simhadri 1	352.3	92.1	373.7	29.8	121.9	-92.2
47	UNCHAHAR-II TPS	352.6	38.5	165.4	12.5	55.7	-43.2
48	IGSTPS-JHAJJAR	358.7	51.0	308.2	18.5	111.8	-93.2
49	Kudgi 1	369.9	9.1	365.3	3.5	141.7	-138.2
50	DADRI-II TPS	377	22.7	467.9	8.1	174.7	-166.6
51	Vallur	402.9	10.8	698.2	4.1	265.9	-261.8
52	DADRI TPS	420.6	11.6	377.4	4.3	151.1	-146.8
	Grand Total		8194.9	8270.7	**1714.9**	**2560.1**	**-845.2**

Ideally, Net SCED Up and Down should be zero. However, due to various reasons such as ramp constraints, local or inter-regional constraints or machine related constraints, sometimes, it is non zero. The net positive SCED despatch indicates that there was some additional generation injected compared to the total generation before SCED. This means some additional payment made from the National Pool Account (SCED). The net negative SCED despatch indicates that there was some less generation compared to the total generation before SCED. This means some additional savings in the National Pool Account (SCED).

5.5 Heat Rate Compensation Statement

For any decrement in schedule on account on SCED, the SCED generator shall pay to the National Pool Account (SCED) at the rate of its variable charge after discounting compensation due to part load operation as certified by RPC as per the provisions of IEGC. The RPCs are given responsibility for issues of "Statement of Compensation due to Part Load Operation on Account of SCED" on monthly basis. Based on the RPCs statement "National Statement of Compensation due to Part Load Operation due to SCED" is prepared by NLDC. All the RPCs i.e. SRPC (upto Dec'19), NRPC (Upto June'19), WR (upto Sep'19), ERPC (upto Oct'19) and NER (upto Oct'19) have issued the compensation statement.

Based on the RPCs statement, NLDC issue monthly "National Statement of Compensation due to Part Load Operation on Account of SCED". Total **₹ 134 Crore** is paid to SCED generator for Compensation due to Part Load Operation on Account of SCED till date as different RPCs have issued statements for different periods. The plant wise detail is mentioned in Table 8. Sample NLDC statement is shown in Fig. 73.

Table 8: Consolidated Heat Rate Compensation

Sl.No.	SCED Generator	Company	Region	Decrement due to SCED (MU)	Compensation Amount Payable from National Pool Account (SCED) to SCED Generator (in ₹ Cr)
1	BARH	NTPC	ER	0	0
2	BRBCL	BRBCL	ER	0	0
3	FTSPP-I&II	NTPC	ER	0	0
4	FTSPP-III	NTPC	ER	0	0
5	KHSTPP-I	NTPC	ER	0	0
6	KHSTPP-II	NTPC	ER	0	0
7	MTPS-II	KBUNL	ER	0	0
8	TSTPS-I	NTPC	ER	59	17
9	MPL	MPL	ER	528	9
10	NPGC	NPGC	ER	0	0
11	Ramagundam (1-6)	NTPC	SR	125	0
12	Ramagundam (U7)	NTPC	SR	40	0
13	Simhadri Stage II	NTPC	SR	31	11
14	Talcher Stage II	NTPC	SR	15	0

Sl.No.	SCED Generator	Company	Region	Decrement due to SCED (MU)	Compensation Amount Payable from National Pool Account (SCED) to SCED Generator (in ₹ Cr)
15	Vallur	NTECL	SR	131	41
16	NLC TPS-II Stage I	NLC-II	SR	-1	0
17	NLC TPS-II Stage II	NLC-II	SR	-5	0
18	NLC TPS-I Expansion	NLC-I EXP	SR	-7	0
19	NLC TPS-II Exp.	NLC-II EXP	SR	-2	2
20	NTPL	NTPL	SR	-13	1
21	Simhadri Stage I	NTPC	SR	132	14
22	Kudgi Unit I	NTPC	SR	-12	10
23	CGPL	CGPL	WR	0	0
24	KSTPS I&II	NTPC	WR	0	0
25	KSTPS7	NTPC	WR	0	0
26	Lara-I	NTPC	WR	0	0
27	MOUDA	NTPC	WR	152	9
28	MOUDA_II	NTPC	WR	185	4
29	NSPCL	NSPCL	WR	0	0
30	SASAN	SASAN	WR	0	0
31	SIPAT I	NTPC	WR	0	0
32	SIPAT II	NTPC	WR	0	0
33	SOLAPUR	NTPC	WR	73	0.1
34	VSTPS I	NTPC	WR	0	0
35	VSTPS II	NTPC	WR	0	0
36	VSTPS III	NTPC	WR	0	0
37	VSTPS IV	NTPC	WR	0	0
38	VSTPS V	NTPC	WR	0	0
39	GADARWARA	NTPC	WR	36	0.1
40	DADRI	NTPC	NR	122	2
41	DADRI-II	NTPC	NR	186	6
42	IGSTPS-JHAJJAR	APCPL	NR	122	2
43	RIHAND	NTPC	NR	0	0
44	RIHAND-II	NTPC	NR	0	0
45	RIHAND-III	NTPC	NR	0	0
46	SINGRAULI	NTPC	NR	0	0
47	TANDA-II	NTPC	NR	0	0
48	UNCHAHAR-I	NTPC	NR	17	0.1
49	UNCHAHAR-II	NTPC	NR	43	0.8
50	UNCHAHAR-III	NTPC	NR	5	0.003
51	UNCHAHAR-IV	NTPC	NR	0	0.00
52	BONGAIGAON	NTPC	NER	132	5
	All India		**Total**	**2,095**	**134**

NLDC "National Statement of Compensation due to Part Load Operation on Account of SCED"

For Month : May'19

Dated: 04-Jul-2019

Sl.No	SCED Generator	Region	Decrement due to SCED (MWHr)	Compensation Amount Payable on account of SCED from National Pool Account (SCED) to SCED Generator (in ₹)
1	BARH	ER		
2	BRBCL	ER		
3	FTSPP-I&II	ER		
4	FTSPP-III	ER		
5	KHSTPP-I	ER		
6	KHSTPP-II	ER		
7	MTPS-II	ER		
8	TSTPS-I	ER		
9	Ramagundam Super Thermal Power Station (U1-6)	SR	35,378	0
10	Ramagundam Super Thermal Power Station (U7)	SR	10,736	0
11	Simhadri Super Thermal Power Station Stage II	SR	63,541	32,793,385
12	Talcher Super Thermal Power Station Stage II	SR	0	0
13	Vallur Thermal Power Station	SR	140,157	74,007,863
14	NLC TPS-II Stage I	SR	7,645	0
15	NLC TPS-II Stage II	SR	9,134	0
16	NLC TPS-I Expansion	SR	7,754	0
17	NLC TPS-II Expansion	SR	1,817	0
18	NTPL	SR	35,881	20,531,908
19	Simhadri Super Thermal Power Station Stage I	SR	45,570	32,501,910
20	Kudgi Super Thermal Power Station Unit I	SR	59,647	12,342,891
21	CGPL	WR		
22	KSTPS I&II	WR		
23	KSTPS7	WR		
24	MOUDA	WR		
25	MOUDA_II	WR		
26	NSPCL	WR		
27	SASAN	WR		
28	SIPAT I	WR		
29	SIPAT II	WR		
30	SOLAPUR	WR		
31	VSTPS I	WR		
32	VSTPS II	WR		
33	VSTPS III	WR		
34	VSTPS IV	WR		
35	VSTPS V	WR		
36	DADRI TPS	NR		
37	DADRI-II TPS	NR		
38	IGSTPS-JHAJJAR	NR		
39	RIHAND STPS	NR		
40	RIHAND-II STPS	NR		
41	RIHAND-III STPS	NR		
42	SINGRAULI STPS	NR		
43	UNCHAHAR-I TPS	NR		
44	UNCHAHAR-II TPS	NR		
45	UNCHAHAR-III TPS	NR		
46	UNCHAHAR-IV TPS	NR		
47	BONGAIGAON	NER		
	All India	**Total**	**417,261**	**172,177,957**

Notes:

1. Statement of Compensation due to Part Load Operation on Account of SCED by respective RPCs for month May'19 are as follows:

Region	Revision-0	Revision-1
SR	24.06.19	28.06.19
NR	Yet to publish	Yet to publish
WR	Yet to publish	Yet to publish
ER	Yet to publish	Yet to publish
NER	Yet to publish	Yet to publish

Figure 73: National Statement of Compensation due to Part Load Operation

5.6 Reconciliation

The RPCs are publishing the Regional SCED Weekly Statement. As per details mentioned in RPCs statement the SCED generators pay to National Pool Account (SCED) for net SCED decrement schedule. As per the "National SCED Weekly Statement", SCED providers are paid at the rate of its variable charge for net increment in the injection schedule on account of SCED from the National Pool Account (SCED). "National Pool Account (SCED)" is operated by NLDC accordingly all payment to SCED generator are done by NLDC.

In order to have smooth dispute free settlement, monthly reconciliation is carried out by NLDC with all the SCED generators. The Reconciliation statement consist details of payment received and paid from "National Pool Account (SCED)".

5.7 Cash flow

The SCED statements are issued by respective RPCs on weekly basis. Based on the weekly statement the SCED generators pay the indicated charges for SCED decrement, within seven (07) working days of the issue of statement of SCED by the RPC to the 'National Pool Account (SCED)'. However, the SCED generators are recovering the variable charge of the schedule energy to their beneficiary after the issues of monthly Regional energy account. This means SCED generator undergoing SCED decrement has to pay the variable charge in advance in National Pool Account (SCED), however, the variable charge is recovered with time gap of around one month. Sometimes, this may lead to cash flow issue for SCED generator.

In order to address this issue, the Procedure for Pilot on SCED for Inter State Generating Stations pan India was revised. The revised procedure is effective from 01st October, 2019. All the SCED weekly settlements are changed to monthly settlement system from October, 2019.

5.8 Distribution of Regional VSCED in Inter-regional Flows

Inter-regional schedules are prepared by incorporating all the transactions, which are schedule to/from one region to another region. Based on the inter-regional scheduled, beneficiary/generating station injection or drawing from inter-regional link. Since SCED generators generates as per the schedule prepared after incorporating the SCED Up/Down instruction. This SCED Up/Down instruction has impact on inter-regional flow of power. In a time-block, when net VSCED of a region is positive, the import from interregional line shall reduce and if net VSCED of a region is negative then import from interregional line shall increase. Based on the sensitivity of inter-regional line flows, the net regional VSED is notionally distributed amongst inter-regional links and further added in implemented inter-regional schedule.

5.9 SCED Benefits Distribution

CERC through Suo-Motu Petition No. 08/SM/2019, order dated 11th September, 2019 extended the pilot project on SCED Up to 31st March, 2020. Hon'ble commission has also directed to share the net benefit accrued in the National Pool Account (SCED) on account of SCED in the ration of 50:50 between the SCED generator and the concerned beneficiaries on monthly basis, after adjusting compensation for part load operation of the generators.

50 % of the total net SCED Benefit shall be shared by the beneficiaries in proportion to their final schedule from the SCED generator on a monthly basis as per the Regional Energy Account (REA) published by respective RPCs.

50 % of the total net SCED Benefit shall be distributed in the ratio 60:40 between the SCED generators receiving SCED Up and SCED Down respectively. This shall be based on the block wise SCED Up and SCED Down energy accumulated on monthly basis.

In compliance with above order, SCED procedure was revised and RPCs were requested to provide the REA and SCED data for publishing the "National net SCED Benefits Distribution Statement" for SCED Generator and Beneficiary.

Based on the data available at NLDC, provisional "National net SCED Benefits Distribution Statement" for SCED Generator and Beneficiary is prepared and made available in POSOCO website under following link

https://posoco.in/nation-sced-benefit-sharing-statement/

In order to disburse the net SCED benefits, Beneficiaries were requested to provide the bank details. Based on the provisional "National net SCED Benefits Distribution Statement" for April'19 month, benefit was credited to those Beneficiaries who have submitted the bank details. Sample National net SCED Benefits Distribution Statement is given in Table 9 for SCED generator and Table 10 for beneficiaries.

As per the data available with NLDC, provisional calculation were carried out for National net SCED Benefits Distribution Statement (from Apr'19 to Sep'19). The details for SCED Generator and Beneficiaries is given in Table 11 and 12 respectively. Average benefit to SCED generator for the perturbed quantum due to SCED comes out in the range of 17 -23 paisa/kWh (before heat rate compensation).

Table 9: Provisional National Net SCED Benefits Distribution (Generator)

Format SCED8:NLDC " Provisional National net SCED Benefits Distribution Statement"- SCED Generator*

For the Month: April,2019 Dated 09-10-2019

Total Saving for the month (Rs.) (A)	Heat Rate Compensation (Rs.) (B)	Net Saving for the month (Rs.) (C)	Net Benefit sharing for generators (Rs.) (D=50% of C)	For SCED UP (Rs.) (E=60% of D)	For SCED Down (Rs.) (F=40% of D)
962561767.3	1635,91,697	7989,70,070	3994,85,035	2396,91,021	1597,94,014

Sl.No.	SCED Generator	Region	SCED UP Energy (MWH) (A)	For SCED UP (Rs.) (B)	SCED DOWN Energy (MWH) (C)	For SCED Down (Rs.) (D)	Total Benefit Distribution (Rs)
1	BARH	ER	29459.20	76,37,733	21883.24	37,40,523	113,78,256
2	BRBCL	ER	52677.61	136,57,448	5421.89	9,26,768	145,84,216
3	FTSPP-I&II	ER	61022.13	158,20,889	30219.01	51,65,364	209,86,254
4	FTSPP-III	ER	16370.57	42,44,313	12386.08	21,17,165	63,61,478
5	KHSTPP-I	ER	33636.28	87,20,704	9222.83	15,76,466	102,97,170
6	KHSTPP-II	ER	53545.26	138,82,401	6374.80	10,89,651	149,72,052
7	MTPS-II	ER	20374.56	52,82,406	12251.98	20,94,243	73,76,649
8	TSTPS-I	ER	9081.14	23,54,419	11341.66	19,38,641	42,93,060
9	Ramagundam Super Thermal PowerStation (U1-6)	SR	24274.34	62,93,482	63298.44	108,19,663	171,13,144
10	Ramagundam Super Thermal PowerStation (U7)	SR	5440.00	14,10,401	13684.78	23,39,152	37,49,553
11	Simhadri Super Thermal PowerStation Stage II	SR	4984.12	12,92,207	54409.96	93,00,347	105,92,554
12	Talcher Super Thermal PowerStation Stage II	SR	8375.56	21,71,487	8738.60	14,93,697	36,65,184
13	Vallur Thermal Power Station	SR	1333.41	3,45,705	126784.47	216,71,390	220,17,095
14	TPS-II Stage I	SR	4893.92	12,68,821	15226.36	26,02,657	38,71,478
15	TPS-II Stage II	SR	8224.46	21,32,314	19239.34	32,88,599	54,20,913
16	TPS-IExpansion	SR	1044.84	2,70,891	9844.04	16,82,650	19,53,541
17	TPS-IIExpansion	SR	454.33	1,17,791	3557.13	6,08,024	7,25,815
18	NTPL	SR	2118.94	5,49,367	36146.54	61,78,563	67,27,930
19	Simhadri Super Thermal PowerStation Stage I	SR	16415.91	42,56,068	45639.16	78,01,145	120,57,213
20	Kudgi Super Thermal PowerStation Unit I	SR	1142.03	2,96,088	97289.76	166,29,831	169,25,919
21	CGPL	WR	90159.13	233,75,088	22165.97	37,88,851	271,63,939
22	KSTPS I&II	WR	4608.75	11,94,887	1233.69	2,10,876	14,05,763
23	KSTPS7	WR	918.69	2,38,183	464.57	79,410	3,17,593
24	MOUDA	WR	21633.27	56,08,744	52172.26	89,17,854	145,26,598
25	MOUDA_II	WR	21083.24	54,66,141	73955.06	126,41,209	181,07,350
26	NSPCL	WR	3494.81	9,06,081	26620.51	45,50,270	54,56,351
27	SASAN	WR	37231.11	96,52,715	1097.40	1,87,579	98,40,294
28	SIPAT I	WR	2912.26	7,55,047	1028.41	1,75,786	9,30,833
29	SIPAT II	WR	1999.61	5,18,429	562.22	96,101	6,14,530
30	SOLAPUR	WR	0.00	-	0.00	-	-
31	VSTPS I	WR	24029.94	62,30,116	2471.16	4,22,398	66,52,514
32	VSTPS II	WR	7370.41	19,10,887	2819.66	4,81,967	23,92,854
33	VSTPS III	WR	10221.41	26,50,053	2997.71	5,12,401	31,62,453
34	VSTPS IV	WR	9532.45	24,71,430	2988.60	5,10,844	29,82,274
35	VSTPS V	WR	5711.95	14,80,908	1322.85	2,26,117	17,07,024
36	DADRI TPS	NR	7296.33	18,91,682	18449.41	31,53,575	50,45,257
37	DADRI-II TPS	NR	7289.92	18,90,018	37408.19	63,94,218	82,84,236
38	IGSTPS-JHAJJAR	NR	1373.60	3,56,125	19716.50	33,70,160	37,26,285
39	RIHAND STPS	NR	45807.63	118,76,305	719.38	1,22,964	119,99,269
40	RIHAND-II STPS	NR	39662.85	102,83,181	454.44	77,677	103,60,859
41	RIHAND-III STPS	NR	60561.19	157,01,385	654.98	1,11,956	158,13,341
42	SINGRAULI STPS	NR	99625.86	258,29,477	970.43	1,65,877	259,95,354
43	UNCHAHAR-I TPS	NR	10482.23	27,17,673	9309.60	15,91,298	43,08,971
44	UNCHAHAR-II TPS	NR	8362.83	21,68,187	10701.88	18,29,282	39,97,470
45	UNCHAHAR-III TPS	NR	4815.21	12,48,413	4901.47	8,37,812	20,86,225
46	UNCHAHAR-IV TPS	NR	24682.54	63,99,312	6636.97	11,34,464	75,33,776
47	BONGAIGAON	NER	18766.98	48,65,618	30062.00	51,38,527	100,04,145
	All India Total		**924502.78**	**2396,91,021**	**934845.35**	**1597,94,014**	**3994,85,035**

*Final statement shall be published after receipt of data from RPCs

Table 10: Provisional National Net SCED Benefits Distribution (Beneficiary)

Format SCED9:NLDC " Provisional National net SCED Benefits Distribution Statement"- SCED Generator*

For the Month: April,2019 **Dated** **09-10-2019**

Sl No	State	REGION	Total schedule Energy(Mwh)	Total sharing in (Rs)
1	BIHAR	ER	17,26,212	247,25,266
2	ORISSA including ODISHA coal Power	ER	6,53,675	93,62,871
3	JHARKHAND	ER	2,68,807	38,50,240
4	DVC	ER	56,513	8,09,467
5	WEST BENGAL including COAL POWER - Rajasthan	ER	4,82,119	69,05,594
6	SIKKIM	ER	44,443	6,36,574
7	POWERGRID(PUSAULI)	ER	554	7,928
8	POWERGRID (ALIPURDUAR)	ER	442	6,334
9	NVVN BANGLADESH	ER	1,53,280	21,95,495
10	GOA (SR)	SR	58,116	8,32,417
11	ANDHRA PRADESH	SR	10,85,340	155,45,791
12	KARNATAKA	SR	17,63,861	252,64,532
13	KERALA	SR	8,00,627	114,67,722
14	TAMILNADU	SR	20,28,170	290,50,336
15	TELANGANA including NSM II	SR	10,24,709	146,77,348
16	PUDU CHERRY	SR	2,26,882	32,49,729
17	PGCIL HVDC (SR)	SR	3,347	47,945
18	GUJARAT GUVNL	WR	28,87,242	413,55,189
19	MADHYA PRADESH Including RAJGARH SOLAR	WR	25,95,517	371,76,691
20	VINDHYACHAL HVDC	WR	309	4,428
21	CHATTISGARH Including NVVN coal & SAIL Bhilai	WR	8,12,749	116,41,348
22	Maharashtra Including NVVN coal	WR	31,14,437	446,09,396
23	GOA (WR)	WR	2,53,785	36,35,072
24	Daman and Diu DD	WR	1,42,638	20,43,061
25	Dadra and Nagar HaveliDNH	WR	3,36,838	48,24,670
26	HVDC CHAMPA	WR	1,027	14,711
27	BHADRAWATI HVDC	WR	666	9,544
28	DELHI	NR	13,03,118	186,65,113
29	UTTAR PRADESH	NR	18,10,424	259,31,465
30	CHANDIGARH	NR	22,041	3,15,703
31	HIMACHAL PRADESH	NR	1,08,497	15,54,050
32	J & K	NR	3,38,077	48,42,419
33	PUNJAB	NR	10,64,685	152,49,941
34	RAJASTHAN	NR	11,41,869	163,55,474
35	UTTARAKHAND	NR	2,09,050	29,94,311
36	HARYANA	NR	9,17,608	131,43,282
37	RAILWAYS_UP_ISTS	NR	8,568	1,22,729
38	PG-AGRA	NR	1,515	21,702
39	PG-BALLIA	NR	618	8,852
40	PG-BHIWADI	NR	529	7,581
41	PG-KURUKSHETRA	NR	1,493	21,387
42	PG-RIHAND	NR	477	6,827
43	ARUNACHAL PRADESH	NER	46,394	6,64,520
44	ASSAM	NER	2,94,543	42,18,859
45	MANIPUR	NER	17,971	2,57,401
46	MEGHALAYA	NER	-	-
47	MIZORAM	NER	23,279	3,33,440
48	NAGALAND	NER	27,675	3,96,402
49	TRIPURA	NER	28,896	4,13,892
50	HVDC BNC	NER	697	9,988
		All India	27890331	399485035

*Final shall be published after receipt of data from RPCs

Table 11: Net SCED Benefits Distribution - Beneficiaries (Apr'19 - Sep'19)

SL. No.	State	REGION	Total schedule Energy (MU)	Total sharing in (Rs) Crore
1	Maharashtra Including NVVN coal	WR	17355.9	29.3
2	GUJARAT	WR	15945.2	26.7
3	MADHYA PRADESH Including RAJGARH SOLAR	WR	13881.1	22.5
4	UTTAR PRADESH	NR	12340.8	21.1
5	BIHAR	ER	10328.4	17.5
6	TAMILNADU	SR	9779.0	16.0
7	DELHI	NR	8727.8	14.8
8	KARNATAKA	SR	7717.7	12.5
9	ANDHRA PRADESH	SR	6582.5	11.5
10	RAJASTHAN	NR	6777.5	11.4
11	PUNJAB	NR	6205.1	10.5
12	TELANGANA including NSM II	SR	5348.8	8.9
13	HARYANA	NR	5287.6	8.7
14	CHATTISGARH Including NVVN coal & SAIL Bhilai	WR	5047.4	8.5
15	KERALA	SR	4774.6	8.1
16	ORISSA including ODISHA coal Power	ER	3438.4	5.7
17	WEST BENGAL including COAL POWER - Rajasthan	ER	3247.5	5.5
18	J & K	NR	2259.8	3.7
19	HIMACHAL PRADESH	NR	1616.8	3.2
20	Dadra and Nagar Haveli DNH	WR	1879.8	3.1
21	ASSAM	NER	1641.4	2.7
22	JHARKHAND	ER	1539.8	2.6
23	GOA (WR)	WR	1410.5	2.4
24	UTTARAKHAND	NR	1282.0	2.2
25	PUDU CHERRY	SR	1255.3	2.1
26	NVVN BANGLADESH	ER	878.9	1.5
27	Daman and Diu DD	WR	862.6	1.5
28	DVC	ER	655.7	1.2
29	GOA (SR)	SR	359.7	0.6
30	SIKKIM	ER	236.1	0.4
31	ARUNACHAL PRADESH	NER	176.7	0.3
32	CHANDIGARH	NR	146.4	0.2
33	NAGALAND	NER	144.8	0.2
34	TRIPURA	NER	143.1	0.2
35	MANIPUR	NER	105.9	0.2
36	MIZORAM	NER	99.1	0.2
37	MEGHALAYA	NER	55.0	0.1
38	RAILWAYS_UP_ISTS	NR	38.2	0.1
39	PGCIL HVDC (SR)	SR	18.9	0.03
40	PG-KURUKSHETRA	NR	8.9	0.01
41	PG-AGRA	NR	8.4	0.01
42	HVDC CHAMPA	WR	6.6	0.01
43	BHADRAWATI HVDC	WR	4.5	0.01
44	HVDC BNC	NER	4.3	0.01
45	POWERGRID (ALIPURDUAR)	ER	3.9	0.01
46	POWERGRID(PUSAULI)	ER	3.7	0.01
47	PG-BHIWADI	NR	3.4	0.01
48	PG-BALLIA	NR	3.5	0.01
49	PG-RIHAND	NR	3.0	0.01
50	VINDHYACHAL HVDC	WR	1.8	0.003
	Grand Total		**159644**	**268**

Table 12: Net SCED Benefits Distribution - Generators (Apr'19 - Sep'19)

Sl. No.	SCED Generator	Region	SCED UP Energy (MU) (A)	For SCED UP Rs. Crore	SCED DOWN Energy (MU) (C)	For SCED Down Rs. Crore	Total Rs. Crore
1	CGPL	WR	760	21.1	100	1.9	23.0
2	FTSPP-I&II	ER	340	9.4	198	3.6	13.1
3	Ramagundam (U1-6)	SR	216	6.0	371	6.8	12.9
4	SINGRAULI STPS	NR	416	11.5	6	0.1	11.6
5	BARH	ER	245	6.9	211	4.0	10.8
6	Vallur Thermal Power Station	SR	8	0.2	533	9.5	9.7
7	KHSTPP-II	ER	281	7.8	71	1.3	9.1
8	MOUDA_II	WR	104	2.7	289	5.4	8.1
9	MOUDA	WR	113	3.0	265	4.9	8.0
10	VSTPS I	WR	256	7.3	16	0.3	7.6
11	DADRI-II TPS	NR	22	0.6	367	6.7	7.3
12	SASAN	WR	246	7.1	3	0.1	7.1
13	Simhadri II	SR	90	2.5	243	4.3	6.8
14	NSPCL	WR	16	0.4	341	6.4	6.8
15	RIHAND-III STPS	NR	236	6.6	2	0.0	6.6
16	DADRI TPS	NR	11	0.3	335	6.3	6.5
17	Kudgi I	SR	9	0.2	347	6.3	6.5
18	MPL	ER	68	2.0	208	4.0	6.0
19	BONGAIGAON	NER	95	2.6	178	3.2	5.8
20	RIHAND STPS	NR	205	5.7	3	0.0	5.8
21	NTPL	SR	101	3.0	154	2.7	5.7
22	Simhadri I	SR	73	2.0	197	3.6	5.6
23	BRBCL	ER	168	4.5	53	1.0	5.5
24	KHSTPP-I	ER	134	3.7	72	1.3	5.0
25	IGSTPS-JHAJJAR	NR	45	1.3	205	3.7	5.0
26	RIHAND-II STPS	NR	164	4.6	2	0.03	4.6
27	UNCHAHAR-IV TPS	NR	112	3.1	66	1.2	4.3
28	VSTPS III	WR	139	3.9	14	0.3	4.2
29	MTPS-II	ER	91	2.5	65	1.2	3.7
30	Ramagundam (U7)	SR	63	1.8	95	1.8	3.5
31	Talcher II	SR	88	2.4	61	1.1	3.5
32	NLC TPS-II Stage II	SR	63	1.8	91	1.7	3.4
33	VSTPS II	WR	101	2.9	14	0.3	3.2
34	VSTPS IV	WR	101	2.8	11	0.2	3.0
35	UNCHAHAR-I TPS	NR	45	1.2	96	1.8	3.0
36	UNCHAHAR-II TPS	NR	33	0.9	104	1.9	2.8
37	NLC TPS-II Stage I	SR	48	1.3	69	1.3	2.6
38	VSTPS V	WR	85	2.4	7	0.1	2.6
39	FTSPP-III	ER	63	1.7	34	0.6	2.3
40	KSTPS I&II	WR	75	2.1	11	0.2	2.3
41	TSTPS-I	ER	42	1.1	64	1.2	2.3
42	NLC TPS-I Expansion	SR	27	0.8	63	1.2	1.9
43	SIPAT I	WR	57	1.6	4	0.1	1.7
44	UNCHAHAR-III TPS	NR	29	0.8	44	0.8	1.6
45	SIPAT II	WR	52	1.5	4	0.1	1.6
46	SOLAPUR	WR	3	0.1	76	1.5	1.5
47	GADARWARA	WR	4	0.1	41	0.7	0.9
48	NPGC	ER	11	0.3	10	0.2	0.5
49	NLC TPS-II Expansion	SR	8	0.2	14	0.3	0.5
50	KSTPS7	WR	9	0.2	1	0.02	0.3
	Total		**5771**	**160.8**	**5829**	**107.2**	**268**

6 KEY LEARNINGS

6.1 Optimization of Generation based on Merit Order

It is being observed that generally, the lower variable cost pit head generation is being increased in Western Region and Eastern Region whereas the higher variable cost generation is being decreased in Northern and Southern Region. Further, the ramping from the higher variable cost generators is being done only when absolutely needed. Therefore, the pilot on SCED has led to optimization of the generation across India thereby saving production costs.

6.2 Reduction in Fuel Costs

Around ₹ 845 Crore reduction in fuel cost for April – Dec'19 period has been facilitated by pilot on SCED. Considering a base of approx. ₹ 50,000 Crore, around 1.5 % reduction in generation cost (without considering heat rate compensation) has been observed. There is reduction of about 3 paisa from 206 paisa to 203 paisa in the average variable cost of generation during the April – December, 2019 period.

6.3 Ease of Generators' Operations

There has been 29 % decrease in the number of instructions (counting any change in the schedule of the generator by the RLDC as one instruction) in the injection schedules of participating generators and 42 % decrease in the cumulative MW schedule change. Therefore, pilot on SCED has facilitated the ease of generators' operations.

6.4 Movement in Plant Load Factor

A shift has been observed in the plant load factor (PLF) post SCED. As depicted in Fig. 74, the PLF of the lower variable cost generators has gone up whereas that of relatively costlier power plants has gone down.

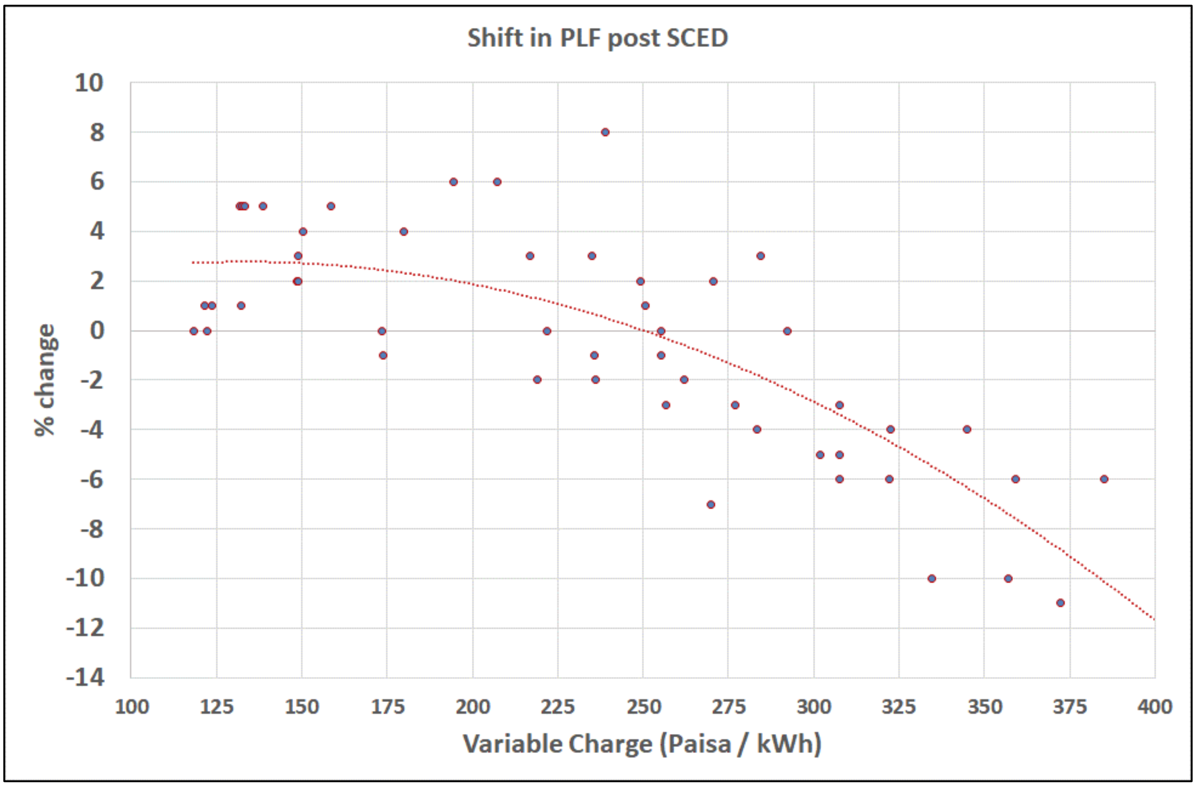

Figure 74: Shift in PLF post SCED

6.5 Increasing Reliability

In addition to optimizing the generation dispatch for limited set of generators, the pilot on SCED has also helped address system reliability operation as a part of the 'security constrained' feature of SCED. SCED by design has control over the power imports of the regions, subject to the reserve availability in the importing region. In case of any sudden reduction in transfer capability due to line / equipment outage in the real time, thereby reducing the available transfer capability below the inter regional schedule, SCED can quickly and automatically increase generation in the next time block in the importing region to relieve congestion, subject to reserve availability and ramp constraints.

6.6 Harnessing Diversity

It has been observed that, generally, during the holidays / weekends time period, there is increased reduction in fuel costs. Further, during extreme weather conditions, load crash results in schedule revised to technical minimum within the region and therefore, diversity of the generation mix pan-India is harnessed. The split in regional system marginal prices represents periods of transmission congestion.

6.7 Expanding the Ambit

Two generating plants were included in the SCED software application in the pilot from 01st April, 2019 – 30th September, 2019. The details are as follows:

- Tata Power Maithon Power Ltd. (MPL) - 2 x 525 MW – 1050 MW (12th June, 2019)
- NTPC Gadarwara – 1 x 800 MW (03rd June, 2019)
- NPGC Nabinagar – 1 x 660 MW (06th September, 2019)

The generators were seamlessly integrated into the RLDC WBES and NLDC SCED Software application. Hon'ble Commission, vide Suo-Motu order in Petition No. 08/SM/2019 dated 11th Sep'2019 extended the Pilot on SCED of ISGS Pan India up to 31st March, 2020. In the aforesaid order it was mentioned that 'willing' generators shall participate under SCED. Post 01st October, 2019, the following new plants of about 1460 MW capacity have been added under the SCED:

- NTPC Lara-1 (800 MW) - variable charge of 233.1 Paisa/kWh (w.e.f. 1 Oct 2019)
- NTPC Tanda-2 (660 MW) - variable charge of 233.6 Paisa/kWh (w.e.f. 7 Nov 2019)

Five generating stations of total capacity 6540 MW have opted out from SCED below:

- Coastal Gujarat Power Ltd (4150MW) with variable charge of 193.98 Paisa/kWh
- NLC TPS - I Exp (420 MW) with variable charge of 242.60 Paisa/kWh
- NLC TPS - II Exp (500 MW) with variable charge of 248.10 Paisa/kWh
- NLC TPS – I (630 MW) with variable charge of 264 Paisa/kWh
- NLC TPS – II (840 MW) with variable charge of 264 Paisa/kWh

During the pilot, the multi-fuel combined cycle gas power plants were kept out of the ambit. Further, the north-eastern region has a significant capacity of combined cycle gas plants operating on a single fuel viz. gas. However, considering period of open cycle operation, these have been kept out.

7 CHALLENGES

7.1 Information Technology

The in-house development of software application for pilot on SCED was undertaken by the team of people pan-India across NLDC/RLDCs. Validation of the data exchange and information protocols was done on day to day basis. A robust and seamless communication was established between RLDCs and NLDC. Hardware augmentation and strengthening was undertaken at NLDC and RLDCs. Hardware elements such as RAM for Application Server and Database Servers using SQL and Non-SQL database with sufficient processor cores. Sufficient Disk space for archival and storage was also added. Both Windows and Linux based servers were used. Suitable backups of applications and codes were created in SAN, physical, logical, in-place and git domains.

7.2 Communication and Integration of Scheduling pan-India

Internet and dedicated communications links are being used for communication with RLDCs in SCED with inter-se priority. SCED is designed as an automatic process with little or no manual intervention. Integration of WBES across all RLDCs with automatic schedule preparation in each time-block was done as a precursor for SCED. The synchronization of ISGS schedules pan-India required development of Application Programming Interface (API) at NLDC to exchange data with WBES of all 5 RLDCs. With the tight data exchange & processing timelines, the hardware and software across all RLDCs/NLDC had to be upgraded.

WBES was upgraded with visibility of the SCED data to the stakeholders on a real time basis. NLDC provides processed data to RLDCs' WBES after carrying out several checks in the SCED software. This helps to save processing time and avoids any further load on WBES. The complete optimization process and data communication had to be repeated every time block in a time bound manner. More than 180,000 parameters are being handled by SCED on daily basis.

7.3 Self-healing / Ride-through Attributes

The SCED software application had to be robust enough to run continuously in real time environment with self-healing / ride-through attributes within the given constraints in case of infeasibility. SCED software is designed with a guiding principle that there would be little or no manual user intervention. In this direction, an improved optimization algorithm was formulated and the updated version of the software was deployed w.e.f 14:45 hours of 18th April, 2019. The revised Detailed Procedure was also uploaded on POSOCO website.

7.4 Operational Flexibility Provisions in SCED

During certain contingencies in the system, facilitating operational requirements of the generators as well as regulatory compliances, and to improve the reliability of the power system, operational flexibility provisions were incorporated in the SCED application. One underlying design aspect of the application was that SCED should be flexible enough to quickly incorporate any new requirements that can come along the way of operation. One such requirement has been presented below as a case study. Also, three generators which were commissioned after 1st April 2019, totalling to 1460 MW capacity have been added into SCED without interrupting the SCED process, within a very short span of time.

Some use cases include:

- As depicted in Fig. 75, on 1st April 2019, after the inaugural start of SCED at 1300 hrs, there were high tie lines flows towards southern region (SR), because SCED had decreased the costly generation in the southern region and increased the lower cost generation available in the rest of the grid. Figure below illustrates the inter-regional flow pattern on the said date. This led to a situation where the inter-regional flows towards SR were touching/crossing the ATC limits continuously. So, to enhance reliability of the grid, a flexibility provision was created by 1700 hrs to restrict the limits of generation backing down in the regions to a user defined level. This flexibility provision proved useful when the entire Vijayawada power station (6 x 210 MW) tripped at 2258 hrs of 1st April 2019 because of electrical problems at 220 kV side. System operators could maintain reliability of the power system despite a sudden power in rush towards SR, as they were maintaining a 500 MW margin from ATC using the flexibility provision prior to the incident to brace against the uncertainties.

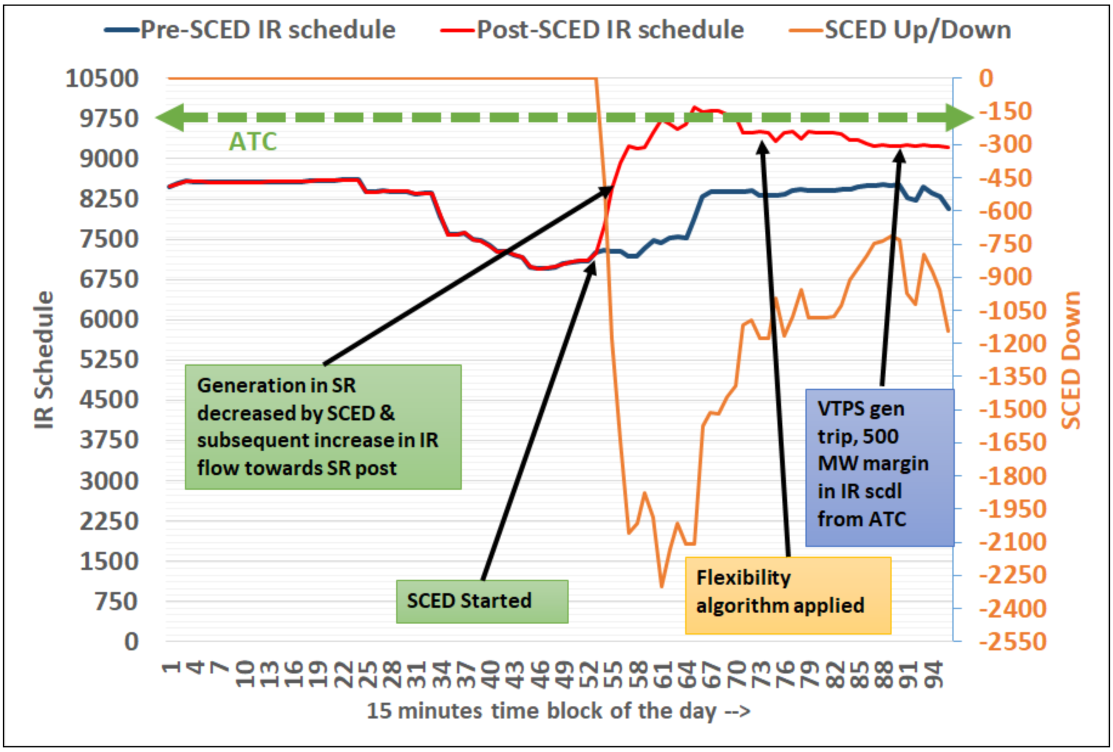

Figure 75: Case study for creating flexibility provision in SCED

- All SR Generators were excluded from SCED application w.e.f. 23:00 hrs on 2nd May 2019 till 1930 hrs of 3rd May 2019 in anticipation of forced outages of major links in ER-SR Corridor due to Cyclone "FANI". Exclusion of generators would cause Pmax = Pmin = Schedule. Thus preventing
- Performance guarantee tests were facilitated by increasing technical minimum in SCED at BRBCL (18 Apr 2019), Kudgi (4-10 Apr 2019) and Bongaigaon (29 Apr – 1 May 2019)
- Technical minimum was increased at Dadri-II for facilitating boiler modification works (24-26 Apr 2019)
- Technical minimum increased at MPL for facilitating PSS tuning (19 Jun 2019)

- Facilitated implementation of CERC Order in the petition number 144/MP/2017 by increasing technical minimum for NLC units.

7.5 Effect of SCED on Ramping Reserves

In the pilot on SCED, it has been observed that the available spinning reserve is being consolidated in the higher variable cost generators. The availability of reserve is being constrained by the ramping capability of generation units carrying reserve. Therefore, a reduction in the cumulative reserve quantum constrained by ramp is being observed after the SCED optimization process. It is being observed that typically, ramp constrained reserve is approximately one third of the total spinning reserve.

7.6 Impact of SCED Instructions on Inter-Regional Schedules

Presently, corridor wise path specific scheduling is carried out by the RLDCs. Inter-regional schedules are also being reconciled by the neighbouring regions. Deviations from schedules in the actual power flows are computed based on the energy meter readings and are accounted for in the regional energy accounts. Presently, optimization is done considering the net import capability constraints.

NLDC is computing the impact of SCED schedules on the inter-regional schedules using a sensitivity based method for all regions. The sensitivity is based on the actual corridor wise flows into or out of the region. The incremental change in the inter-regional schedules is being communicated by NLDC to the respective RLDCs for incorporation in the net inter-regional schedules being given to the RPCs for the purpose of accounting.

7.7 Interruptions

On 7th April'19 communication of non-plausible values to the generators was observed and SCED software was manually stopped. Suspected reason for this was excessive usage of hardware resources. To overcome this, a process crash detection module was inserted in the software with an 'auto -stop' feature. Execution logs were strengthened to identify the root-cause. Hardware resource monitoring logs were installed and CPU and RAM usage logs are set up for monitoring.

On 14th April'19, SCED software 'auto-stopped' after data exchange issues. Input data could not be fetched from the database. Safeguard placed on 7th April'19 was modified to 'auto-stop' the SCED software based on the error generated by the log.

On 21st April'19 - SCED process crashed after database read / write issues were identified. The safeguards deployed on 7th April'19 worked. Reason was pinpointed to slowed down data exchange by the WBES server due to inefficient data retrieval techniques from data base employed in some situations. Same were rectified.

Some other interruptions for short durations also happened on account of non-punching of essential data in the WBES. The same were tackled through administrative means and increased awareness/training of personnel. Installation process of third party licensed supporting software updates also led to short interruptions.

Apart from the above there can be system crashes also because of unforeseen conditions leading to problems for the power system. Literature survey[24] indicates that such instances are not uncommon, and must be handled carefully. One such instance from NERC is described below.

A process conflict during a normal data transfer process resulted in undesirable unit commitment outputs from security-constrained economic dispatch unit commitment software. System operators intervened by identifying and blocking the undesirable dispatches; however, some of the instructions could not be blocked or overridden. This caused the Balancing Authority to experience a reduction in generation output that caused its area control error (ACE) and system frequency to deviate for almost 20 minutes.

Notwithstanding all the above interruptions on account of various factors explained above, the non-availability of the SCED software application during the pilot phase was around 2 % of the time.

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[24] NERC - lesson learned
https://www.nerc.com/pa/rrm/ea/Lessons%20Learned%20Document%20Library/LL20170401_Dispatched_Reduction_in_Generation_Output_Causes_Frequency_Deviation.pdf

7.8 Handling Infeasibilities

There is always some probability of infeasibility when solving mathematical models because of various reasons. To prevent infeasibility of the model, artificial variables were added to the model as given in equation 1-7 of previous section 3.

Artificial variables are added, factoring the variable cost of highest cost generator (1/3rd in case of ramp violation and twice in case of inter-regional transmission violation). The model is made feasible through classical BIG-M techniques as the generators cannot physically provide output/ramp more than their declared limits. SCED output later gets clamped to the plant limit before getting scheduled, to avoid problems for the plant. Clamping also results in under/over delivery to the system. The infeasibilities were encountered for around 3 % of the time on account of various constraints. The residual that gets accrued because of the clamping also gets included into the monthly accounts which is of the order of 5-6 %. On an average, a dozen infeasibilities are encountered on a daily basis considering 96 time-blocks and 52 plants. The ramp violations during the start-stop has also to be suitably factored to avoid infeasibilities. The procedures of declaration during the unit commitment by plants as well as algorithm has to be evolved to reduce the occurrence of infeasibility to the extent possible. There were prominently three conditions observed which caused infeasibilities which are as follows:

A. **Total available ramp rate falling short of system ramp rate (National)**

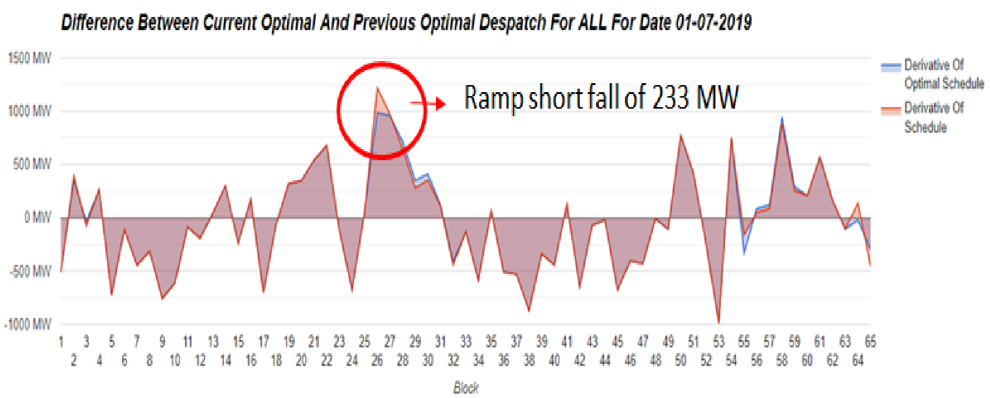

Figure 76: Infeasibility Case Study – System Ramp (National)

System Ramp Rate for SCED is determined by the total ramp rate required by all the beneficiaries from the ISGS. Required System Ramp Rate can be very high for few blocks, sometimes more than 2000 MW in a time block. As depicted in Fig. 76, it is observed that the required system ramp rate can be very high during morning and evening peak, resulting in a short fall from the 'available ramp reserve' and creating infeasible conditions to the model. This is handled through inserting artificial variables.

As per the CERC (Terms and Conditions of Tariff) Regulations, 2019, coal fired units under regulated tariff mechanism have been mandated to provide minimum 1% per minute ramping with a graded incentive scheme for providing higher ramping. This would be implemented with effect from 1st April, 2020 and would help to mitigate the ramping issue to some extent.

B. IR schedule exceeding transfer capability limits with finite reserves (Regional)

Interregional schedules may exceed Transfer Capability limits for a limited time frame during sudden outages of lines. It might take the beneficiaries upto 4 time blocks to revise the schedules to bring the inter-regional schedules within ATC limit. Till such time SCED algorithm reschedules the available generation to in such a manner to increase the generation in the ATC violating region and correspondingly decreases generation elsewhere taking merit order into consideration. As depicted in Fig. 77, at pre-processing stage in SCED, the generation reserves in ATC violating region are scheduled limited by reserve quantum available. If sufficient reserves are not available in the region, the same is corrected only to extent of reserve availability in that region.

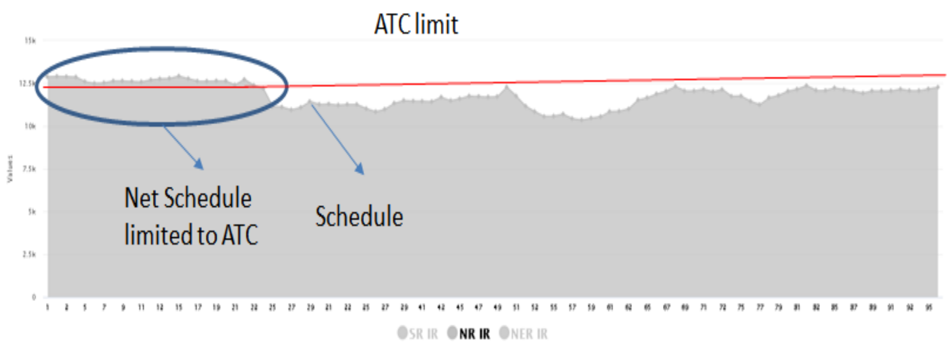

Figure 77: Infeasibility Case Study – Inter-regional Schedule (Regional)

C. Individual generator ramp rate (Local)

Individual plant Pmin or Declared Capability on bar might vary over a period of the day, exceeding its own declared ramp rate. This is done by the power plants typically in order to honour technical minimum, by exceeding their own declared ramp rate. Start up and shutdown conditions were cited to lead to such self-contradictory input data by the generators. This also gives the clue that start up and shutdown ramp rates declared by the power plants should be different from the ramp rates declared for normal operation. Apart from the above, communication issues can also result in such local infeasibility conditions. When communication is lost between the power plant /scheduling software / RLDCs and SCED, then it may result in old/non-updated data being used by the SCED for the sake of continuity. Once the communication is restored, there can be discrepancy in SCED schedule & RLDC/power plant schedule. These infeasibility conditions were also handled by inserting artificial variables. This aspect has been depicted in Fig. 78.

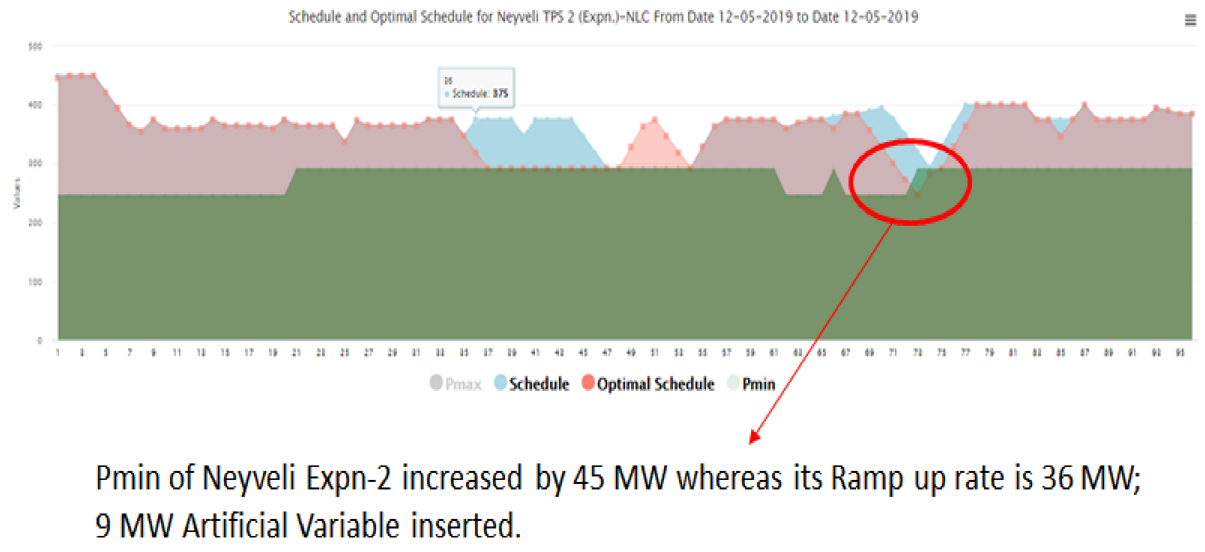

Figure 78: Infeasibility Case Study – Generator Ramp Rate (Local)

8 WAY FORWARD

8.1 Need for Incremental Heat Rate Curves

Accurate input data collection is a subject that has to be pursued. Unit input-output curves and valve point loading effects can be considered in the optimization process as and when they are made available for every plant. Coupling the heat rate information and granular emission data might yield more insights.

8.2 Expanding the Ambit

It is recognized that expanding the ambit of SCED would lead to better scope for optimisation & causing economy while at the same time improving the overall ramping capability available in the system. To begin with, a possibility may be explored for including all the thermal regional entity generating stations in SCED whose scheduling is done by RLDCs. Suitable regulatory provisions have to be made to handle multiple rates for different types of contracts at different times of the day as entered into by the regional entity generating station.

In SCED, there is a need for single variable charge for optimization based on the merit order and other constraints. The regulatory framework has to facilitate upfront declaration of the variable charges along with major technical parameters such as total Declared Capability (DC), Technical Minimum, Ramp-up/down rates etc. by each regional entity generating station. In the absence of regulation for giving heat rate compensation for IPPs (tariff not covered under Electricity Act Section 62 & 63), special regulatory provisions have to be explored for SCED down cases.

Hon'ble Commission, vide Suo-Motu order in Petition No. 08/SM/2019 dated 11th Sep'2019 extended the Pilot on SCED up to 31st March, 2020. In the aforesaid order it was directed to implement the SCED pilot for the thermal ISGS that are willing to participate in the SCED, for the period from 1st October, 2019 to 31st March, 2020. Post 01st October, 2019, the two new plants of about 1460 MW capacity have been added under the SCED and five generating stations of about 6540 MW capacity have opted out from SCED. However, the opted-out plants continue to participate under RRAS and are getting mark-up for Regulation Up/Down despatch.

Moreover, Declared Capacity of Plants participating under SCED is automatically getting tested based on the SMP without the need for commensurate requisition from the beneficiaries. It is worthwhile to mention here that it may be difficult to verify the declared capacity of plants that have opted out of SCED.

Korba-III (500 MW) and Farakka-III (500 MW) were withdrawn from SCED from 27th September, 2019 onwards due to expiry of PPA for merchant quantum and resulting share allocation for partial capacity only. NTPC vide communication dated 13th November,2019 has communicated that it is willing to accept despatch under SCED for Farakka-III. It has also stated that the variable cost of the merchant portion is to be taken the same as per the tariff determined by CERC for the rest of the capacity. Accordingly, Farraka-III has been included under RRAS and SCED w.e.f 14th Nov., 2019.

8.3 Mechanism to Utilize Residuals

Hon'ble Commission directed to share the net benefit accrued in the National Pool Account (SCED) on account of SCED in the ration of 50:50 between the SCED generator and the concerned beneficiaries on monthly basis. Further the benefits to the beneficiaries/Discoms shall be shared in proportion of the schedule energy from the from the SCED generator on monthly basis as per Regional Energy Account (REA).

In the interest of the Indian power system, it is suggested that the residuals in 'National Pool Account (SCED)' accrued due to reduction in fuel costs of generators on account of optimization process through SCED may be shared to the following stakeholders:

1) **State Utilities** - The state utilities may be given a share in proportion to the total drawl schedule or entitlements by the beneficiaries from the generating company which is also in line with the formulation by MoP policy. (Refer Ministry of Power Scheme on "Flexibility in Generation and Scheduling of Thermal Power Stations to reduce the cost of power"

2) **Generation ISGS** – The respective generation ISGS may also be given a share based on performance and the heat rate compensation. The incentive can be based on higher ramp (>1 %/min) and lower technical minimum (< 55 %). (Refer CERC (Terms & Conditions of Tariff) Regulations, 2019)

3) **Transmission ISTS** – Adequate transmission is a key enabler to the economy caused through the SCED optimization process. The insights obtained from SCED may be used to give a share to encourage development of efficient transmission planning and secure grid operation through simulation tools, modelling infrastructure and related hardware.

4) **Innovation and Research** – Ultimately, there is a need to foster a systematic and data-driven process to strengthen human resources, learning, and skills development in the country for development of economic despatch faculty in power systems. Therefore, a share of the residuals towards promoting institutional building and strengthening[25] may also be given.

8.4 Need to Increase Minimum Turn-Down Level

The minimum turn-down level refers to the operation of despatchable generators at low levels. It is observed that during periods of low demand, there is a need for generators that can turn down output to low levels but remain available to rise again quickly.

CEA Technical Standards for Construction of Electric Plants and Electric Lines, 2010 defines 'control load' for coal or lignite based thermal generating units which means the lowest load at which the rated steam temperature can be maintained under auto control system. This is generally taken as 50 % of the Maximum Continuous Rating (MCR). CERC has mandated 55 % technical minimum for all inter-state

[25] FOR CABIL Report
http://www.forumofregulators.gov.in/Data/Reports/FOR%20Report%20CABIL.pdf

generating stations. Further, CERC has allowed compensation for degradation of heat rate and auxiliary consumption for operation below 85% of maximum capacity[26].

If the minimum turn-down levels are further improved, there would be more scope for optimization and consequent, further reduction in costs as revealed in the Dual analysis in the previous sections.

8.5 Further Streamlining the Scheduling Process at all Levels

In the present framework, revision of schedules by the market participants is permitted and as per the 'Scheduling and Despatch Code' under the Indian Electricity Grid Code (IEGC), the schedules can be revised by giving a notice of four (4) time blocks (each of 15-minutes). Given the large number of participants, there are requests for revisions in schedule on an almost continuous basis. This also poses problems in real time assessment of the available 'hot' and 'cold' reserves available in the system.

In the CERC 'Proposed framework for Real-Time Market for Electricity', Real-Time Market has been proposed as a half hourly market. The concept of gate closure is also proposed to be introduced, with timeline in consonance with half hourly market. The introduction of gate closure will bring in more certainty of despatch especially in terms of reserves requirement & activation thereof. The time available for the plants is one time block or sometimes even less which is a challenge to the plant.

8.6 Need for Robust and Seamless communication

The integration of scheduling software across all regions with automatic schedule preparation in each time-block needed robust and seamless communication infrastructure. As and when the ambit of SCED is expanded to include more entities, the synchronization of entity schedules pan-India assumes significant importance. With the tight data exchange & processing timelines, the hardware and software had across all RLDCs/NLDC has to be enhanced in addition to addressing cyber security vulnerabilities.

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[26] CERC, Indian Electricity Grid Code, 2010 (4th Amendment)
http://www.cercind.gov.in/2016/regulation/124_1.pdf

8.7 Spinning (Hot) and Non-Spinning (Cold) Reserves

It is observed that spinning (hot) reserve is depleted during the evening peak hours. Cold reserves, comprising of generating units available but not synchronized, need to be brought on bar under such circumstances. As the time required for thermal units to come on bar is high, such units also need to be kept running at technical minimum levels during the other hours of the day. This is in effect also means out of merit generation despatch with the objective of maintaining adequate reserves for reliable and secure operation of the grid.

CERC has given a roadmap for maintaining reserves vide Suo-Motu Order dated 13th October 2015. From an enforcement perspective, a mandate for reserves in the appropriate Regulations/Grid Code is needed for maintaining reserves and calling cold reserves into service as and when needed.

8.8 Ramping Requirements

Presently, the ramp rates declared by the generating stations participating in SCED are lesser than 1 %. In the pilot on SCED, it has been observed that the available spinning reserve is being consolidated in the higher variable cost generators. The availability of reserve is being constrained by the ramping capability of generation units carrying reserve. Therefore, a reduction in the cumulative reserve quantum constrained by ramp is being observed after the SCED optimization process.

Regulation 7(4) of the CEA (Technical Standards for Construction of Electrical Plants and Electrical Lines) Regulations 2010 specifies the generating units shall have a minimum rate of loading or unloading of 3% per minute above the control load (i.e., 50 % MCR). Indian Electricity Grid Code (IEGC) provides that a minimum of 1% ramp rate shall be provided by the generators. Further, CERC (Terms & conditions of Tariff) Regulations, 2019 has provided that in case of a thermal generating station, with effect from 1.4.2020, rate of return on equity shall be reduced by 0.25% in case of failure to achieve the ramp rate of 1% per minute. An additional rate of return on equity of 0.25% shall be allowed for every incremental ramp rate of 1% per minute achieved over and above the ramp rate of 1% per minute, subject to ceiling of additional rate of return on equity of 1.00%. Detailed procedure under preparation may also consider these inputs from SCED.

8.9 Inter-Regional Scheduling

Presently, optimization is done considering the net import capability constraints. NLDC is computing the impact of SCED schedules on the inter-regional schedules using a sensitivity based method for all regions. The sensitivity is based on the actual corridor wise flows into or out of the region. The incremental change in the inter-regional schedules is being communicated by NLDC to the respective RLDCs for incorporation in the net inter-regional schedules being given to the RPCs for the purpose of accounting.

Hence, for implementation of the optimization process, it is necessary to change the scheduling methodology from corridor wise scheduling to net-injection/net-drawal for each region. This would require amendments to the 'Scheduling and Despatch Code' under the Indian Electricity Grid Code (IEGC). With the implementation of net-injection/net-drawal based scheduling for each region, a 'National Deviation Settlement (DSM) Pool' is needed to be maintained and operated by NLDC as a Regulatory Pool Account. The respective Regional DSM pools may interact with the National DSM Pool only.

8.10 Co-optimization of Energy and Ancillary Services

In order to bring efficiency and certainty in scheduling and despatch of the spinning reserves, so that spinning reserves are fully utilized for frequency control when needed, a method on co-optimization was explored. A basic co-optimization model was prepared in GAMS and segregated SCED and RRAS dispatch notionally in May 2019. Relevant communication was sent to central regulator on possible way of co-optimization in June 2019.

Several models were prepared and discussed with the academia & industry experts and multiple scenarios were tested. More emphasis was placed on segregation of SCED and RRAS. Co-optimization of SCED and RRAS might help in utilising full spinning reserve (limited by ramp) when extremely needed. But, for reaping this approximately 500 MW 'lost reserve', many changes are needed in the existing set up. Gas plants are dispatched in RRAS and not in SCED. Recently, some generators have opted out of SCED or did not qualify for SCED because of part merchant status. So, there is no single database for SCED and RRAS participants for co-optimization. After running the co-optimization code, segregation of SCED and RRAS quantum is a major challenge.

Suitable regulatory interventions are needed for achieving the co-optimization objective in order to bring efficiency and certainty in scheduling and despatch of the spinning reserves.

8.11 Statement of Station Heat Rate Degradation Compensation

NLDC has been mandated to issue the monthly Statement for heat rate degradation compensation on account of SCED on monthly basis as per the format SCED4 of "Procedure for Pilot on Security Constrained Economic Despatch for Inter State Generating Stations pan India". CERC order in Suo-Motu Petition No. 08/SM/2019 dated 11th Sep'2019 directed issuance of all account statements in timely manner to facilitate smooth disbursement and settlement. CERC has also given the methodology for disbursing the SCED benefits accrued in the pool due adjusting compensation for part load operation of the generators.

In absence of Statement for heat rate degradation compensation on account of SCED due to delay in issuance of the same by different RPCs, it is becoming difficult to prepare "National net SCED Benefits Distribution Statement" for SCED Generator and their respective Beneficiary.

8.12 Factoring Impact on Emissions

One of the major objective of SCED is not to cause increase in emissions. SCED directly impacts the emissions by systematically increasing the use of the most economic generation units leading to better fuel utilization, lower fuel usage, and reduced air emissions. With the large geographic and electrical diversity integrated under unified SCED pan-India, there is an increased scope for reduction in emissions. For best results, the data on emissions has to be accurate and verified.

8.13 Need for Security Constrained Unit Commitment (SCUC)

SCUC is the exercise to assure that the appropriate resources will be operational when they are needed for economic despatch. It is envisaged that SCUC produces energy, regulation, and reserve schedules for generators and loads for each time-block in a dispatch day. SCED coordinates the production levels of available resources to meet loads in a grid secure fashion in real time, and SCUC increases the likelihood that the most cost effective and reliability-supportive resources will be available to be dispatched. SCUC would pave the way forward to make the processes more efficient. Suitable regulatory framework, both at central as well as state level would smoothen the process and cause further economy.

Presently, unit commitment is being handled as per the operating procedure approved by CERC for taking units under reserve shut down. While schedules are based on the requisitions by the states, "operationally reasonable" schedules for generators must be given by the concerned RLDC. For ensuring operationally reasonable schedules, technical minimum, ramp rates and other generator parameters need to be honoured. The allocation of power to the beneficiaries is fragmented with multiple states having shares in multiple stations. The allocation is also skewed with some states having large quantum of share from one station e.g., UP in Dadri (Th) and Karnataka in Kudgi. In such stations the quantum allocated to other beneficiaries is small and unless the larger states requisition power, generating units are taken under reserve shut down. The decision to commit/de-commit a generating unit is contingent upon the requirements of the major beneficiary in the station.

Therefore, it is proposed that NLDC, in coordination with RLDCs, may perform the SCUC at the National level, for regional entity generating stations, in order to meet total power requisitioned by regional entities/beneficiaries at optimal cost, maintaining adequate spinning and ramping reserves subject to security constraints as per applicable CERC regulations.

8.14 Implementation of SCED at Intra State level

The following aspects learnt during the implementation at inter-state level may be emulated at intra-state level as follows:

- Robust Scheduling, Metering, Accounting and Settlement (SAMAST) framework
- Visibility of Merit order stack to the operators in real time for despatching
- Well defined norms for technical minimum and compensation
- Ramp-up / Ramp down constraints need to be factored
- Simplifying scheduling and settlement of reserves through schedule based payments (vis-à-vis actual based) – Need for double entry system
- Adoption of causer-pays principle to enable state pool to be self-sustainable
- Weekly settlement of ancillary despatch
- IT, communication infrastructure and skilled human resources

The minimum basic set of data required for economic despatch for every time block for each power station are

- Declared capability in MW
- Declared capability on-bar (in MW)
- Schedule in MW
- Pmax = On bar installed capacity – Normative Auxiliary Consumption (in MW)
- Pmin = Technical Minimum generation (in MW)
- Spinning Reserve = Declared capability on-bar (in MW) - Schedule (in MW)
- Cold Reserve = Declared capability (in MW) - Declared capability on-bar (in MW)
- Variable charge in Rs/kWh
- Ramp-Up and Ramp-Down rates in (% of on-bar Capacity) per minute

9 THE TEAM

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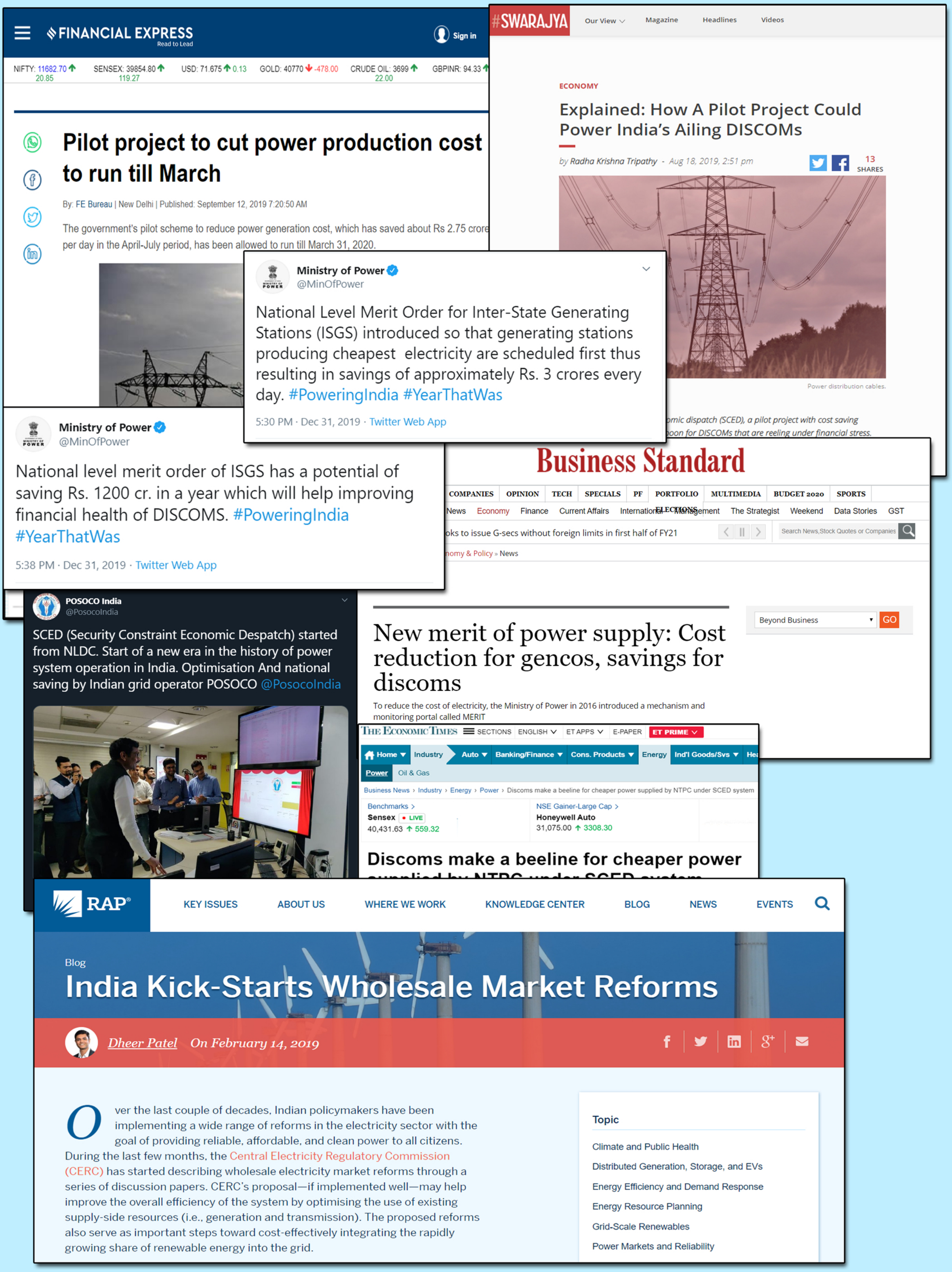
12 REMARKS BY SENIOR OFFICIALS

"I visited POSOCO office today and was given a presentation on Implementation of the "Security Constrained Economic Despatch". I must complement team of POSOCO led by Sh. Baba, CMD and all younger contributors at HQ, NLDC and RLDCs for making it a success. I am told it has led to saving of about Rs 90 crores in the month of April.
Keep it up."

Sh. A.K. Bhalla
(Secretary, Ministry of Power)
15.05.2019

"POSOCO as an institution has always been highly active and energetic. The implementation of SCED as a successful pilot was possible only because POSOCO took extraordinary initiatives. POSOCO should continue its efforts to make the grid more robust and secure.
All the best to POSOCO. CERC always supports the initiatives of POSOCO."

Sh. P. K. Pujari
(Chairperson, CERC)
03.07.2019



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