Report

on

Intra-State

Reserves and Ancillary Services

For Balancing

संतुलन

(SANTULAN)

JANUARY-2020

केन्द्रीय विद्युत विनियामक आयोग
CENTRAL ELECTRICITY REGULATORY COMMISSION

सत्यमेव जयते

के वि वि आयोग
CERC

P. K. Pujari
Chairperson
&
Chairperson
Forum of Regulators

Message

The Forum of Regulators is committed towards nurturing the growth of independent regulation and empowerment of all stakeholders in the Electricity sector. The challenge of real-time balancing has been growing with increasing penetration of intermittent and variable sources of energy in the grid. To address these challenges CERC and SERCs have been creating necessary regulatory framework.
Adequate reserves at the disposal of system operators are very critical for reliable and smooth operation of the power system especially to manage imbalance in supply and demand for energy in real time. Accordingly, I am pleased to share the report "Intra-State Reserves and Ancillary Services for Balancing (SANTULAN)". The report crystallizes the collective wisdom derived from physical visits, deliberations among the practitioners and experts on the subject.

The report emphasizes the need for Essential Reliability Services for functioning of the power system and electricity market. It provides a roadmap for assessment, creation, arrangement, dispatch and settlement of reserves in the grid. The report draws learning from international / national experience on ancillary services and the recommendations have been compiled through a consultative process involving representatives from CERC, SERC, SLDCs, RLDC, NLDC and Academia. The report also includes a Model Regulation on intra-state Essential Reliability Services that could be adapted by the SERCs, while addressing the requirement in their respective States.

The report was endorsed by the Standing Technical Committee in its Meeting on 3rd January 2020 and by the Forum of Regulators in its 70th Meeting on 31st January 2020. The implementation of the recommendations of the FOR reports viz., *SAMAST, CABIL and SANTULAN* at the intra-state level would go a long way in strengthening grid security by establishing sustainable infrastructure, ensuring adequacy and competency of human resources, while creating a robust framework for deploying flexible resources in the Indian power sector.

(P.K.Pujari)

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CENTRAL ELECTRICITY REGULATORY COMMISSION

सत्यमेव जयते

Indu Shekhar Jha
Member

Ensuring load-generation balance in a power system is a rigorous exercise that commences in the planning phase and ultimately culminates in real-time despatch. The mechanisms for balancing in the Indian power system with multi-area and nested control area operation philosophy are still evolving. Formation of the national synchronous grid as well as the introduction of energy markets, non-discriminatory open access in transmission and imbalance settlement mechanism are few of the major endeavors in this direction. In view of India's commitment towards renewable energy, there is an urgent need to ramp up the efforts and introduce instruments for active balancing through reserves and ancillary services along with the established mechanisms of passive balancing through tightening of the frequency band and pricing of imbalance.

The reserve regulation ancillary services operations and the pilot projects on fast response ancillary services, automatic generation control and security constrained economic despatch have provided deep insights that could be utilized to evolve such systems in the intrastate level. The report titled 'SANTULAN' prepared by the FOR standing committee sub-group, shares the practices for power system balancing prevailing in India and other large countries. It provides a roadmap for implementation of reserves and ancillary services at the intrastate level. Sincere efforts towards implementation of the recommendations of SAMAST, CABIL and SANTULAN reports would prepare a fertile ground for a vibrant and robust electricity market. This would also facilitate smooth integration of the envisaged renewables in the Indian grid.

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Foreword

The obligation of providing uninterrupted, quality and economic power supply to the consumers is challenging due to the inherent variability and unpredictability of the instantaneous demand for electricity, availability of generating units, availability of transmission and distribution equipment, generation output and transmission losses. High penetration of variable renewable energy sources adds to this uncertainty. Classical literature and international experience recommend maintaining adequate spinning generation reserves and dispatching them optimally for ensuring reliability. It calls for identification of the various kinds of the reserves and the attributes thereof; dimensioning of the various types of reserves; and establishment of a mechanism for ensuring availability, dispatching and settlement of the services rendered by the provider of those reserves. The definitions and prescription for deployment of reserves is evolving and every power system/market has to charter its own course.

The Indian power system has gained significant experience in this niche area through deployment of the reserve regulation ancillary services, fast response ancillary services, pilot project on automatic generation control and pilot project on security constrained economic dispatch at the national level through a regulated arrangement. The benefits accrued to the overall system have been encouraging. Such systems could be introduced at the intrastate level, provided the basic building blocks are established within the State by implementation of the recommendations of the report on 'SAMAST' and 'CABIL'.The off-line pilot project through the Solver tool inbuilt in the MS Excel,taken up by the SLDCs of Madhya Pradesh, Maharashtra and Gujarat, established that implementation is possible without unsettling the existing contracts. The pilot also revealed the potential benefits to the State system by adoption of algorithmic approach for co-optimization of energy and ancillary services. This report documents the deliberations of the sub-group constituted for the purpose and it suggests a roadmap for implementation of intrastate reserves and ancillary services in India through a regulated mechanism as a transition to a market-based system.

(S. K. Soonee)
Chairman of the sub-group

Acknowledgements

The sub-group members thank the Standing Technical Committee of the Forum of Regulators for constituting the sub-group and creating a platform for deliberating on a very forward-looking terms of reference. Special thanks to Shri. P.K. Pujari, Chairperson CERC & FOR for motivating and guiding the sub-group.

The members acknowledge the extensive support provided by their parent organizations for accomplishing the assignment. The sub-group is grateful to the management of the SLDCs/RLDCs/NLDC who hosted the various meetings of the sub-group even at short notice.

The sub-group would like to thank the FOLD secretariat as well as all the FOLD members for their contributions. It is also indebted to the rich literature by subject experts and reports of all the past committees and Task Forces.A big thanks to the load despatchers (list enclosed) across different LDCs who worked tirelessly behind the scenes.

The sub-group would like to specifically thank Shri Vivek Pandey and Shri Aditya Das from WRLDCfor their assistance in assimilating all the inputs and drafting the sub-group report.

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1.

Contributions

S No.	Name (Mr./Ms.)	Organization	Contributed in
1.	R.A. Sharma	SLDC Madhya Pradesh	Pilot project for Madhya Pradesh
2.	S. S. Patel	SLDC Madhya Pradesh	Pilot project for Madhya Pradesh
3.	Vivek Agrawal	SLDC Madhya Pradesh	Pilot project for Madhya Pradesh
4.	Aarif Ahmad Khan	SLDC Madhya Pradesh	Pilot project for Madhya Pradesh
5.	Piyush Sharma	SLDC Maharashtra	Pilot project for Maharashtra
6.	Avinash C. Dhawade	SLDC Maharashtra	Pilot project for Maharashtra
7.	Vijay S. Kamble	SLDC Maharashtra	Pilot project for Maharashtra
8.	P.B. Suthar	SLDC Gujarat	Pilot project for Gujarat
9.	J D. Trivedi	SLDC Gujarat	Draft regulations, Survey
10.	K.V.N. Pawan Kumar	NLDC	Literature Survey
11	Venkateshan M.	SRLDC	Survey
12.	Sunil Kanojia	NRLDC	Survey
13.	Naga Sudhir	WRLDC	Survey
14.	Srinivas Chitturi	WRLDC	Dimensioning of Reserves

THE REPORT WAS ENDORSED BY THE STANDING TECHNICAL COMMITTEE IN ITS 3RD MEETING ON 3RD JANUARY 2020 AND BY THE FORUM OF REGULATORS IN ITS 70TH MEETING ON 31ST JANUARY 2020.

Executive Summary

Adequate reserves at the disposal of system operators is a well-recognized necessity for imbalance handling and reliable operation of the power system. The National Electricity Policy (NEP) mandates creation of 5% of spinning reserve at national level for grid security and for quality power supply. The growing penetration of renewables (both wind and solar) in India has further highlighted the requirement of flexibility services and system reserves for managing the inherent intermittency and variability of these generation resources.

The reserve requirement is generally a small proportion of the aggregate demand in the system and they have to be ensured all the time through unit commitment when necessary. Reserves are normally pressed into service only for a short duration. Therefore, assessment of the optimal quantum of reserves for the randomly varying system conditions could be quite challenging. Being a niche requirement, the enabling framework for dimensioning and facilitating availability, deployment, performance evaluation and settlement of reserves is equally challenging.

The Central Commission has over the years taken several initiatives to evolve a sustainable mechanism for deployment of reserves. Subsequent to the notification of 'roadmap to operationalize reserves in the country' in Oct 2015, the commission facilitated creation of reserves at regional level through enabling norms [55% technical minimum, upper limit for scheduling, unit commitment] for flexibilization of thermal power stations. Further, reserve regulation ancillary services (RRAS), fast response ancillary services (FRAS), automatic generation control (AGC) and security constrained economic dispatch (SCED) etc. established an enabling mechanism for optimal dispatch of reserves and settlement thereof at interstate level. This report compiles the experience of ancillary services at the interstate level and provides suggestions for implementing such mechanisms at the intrastate level.

The report was deliberated in the 70th Meeting of the Forum of Regulators (FOR) held on 31st January, 2020. As deliberated in the FOR meeting, the reference of 'sub-group' in this report may be read as expert group.

The key recommendations are as under:

1. Establish a robust framework in SLDC for scheduling, metering, accounting and settlement by implementing recommendations of the SAMAST report.
2. Equip the SLDCs with enabling IT infrastructure and adequate human resources by implementing recommendation of the CABIL report.
3. Notify the norms for minimum turn down level, upper scheduling limit and ramp rate for thermal generating units
4. Mandate computation and monitoring of area control error at the state periphery
5. Notify regulations on essential reliability services with following features
    a. A-priori declaration of unit/station level constraints and other details by all essential reliability service providers (viz. DC, start-up time, minimum uptime, minimum down time, ramp rate, energy charge rate etc.)
    b. Periodic assessment of the required reserves
    c. Monitor availability of reserves in real-time and ensure its adequacy through unit commitment over a rolling window.
    d. Specify the criteria for deployment of reserves by SLDC
    e. Adopt a suitable algorithm for optimization of reserves despatch
    f. Create an intrastate virtual ancillary entity to act as a counterparty for scheduling
    g. Suitable compensation mechanism for flexibility / ancillary service providers
    h. Separate regulatory pool account for collection and disbursement of charges related with essential reliability services
6. Suitable mechanism for arranging reserves competitively could be evolved gradually.

A methodology for dimensioning reserves has been suggested. The report documents the pilot project for co-optimization of energy and reserves dispatch in Madhya Pradesh, Maharashtra and Gujarat. A model regulation has also been drafted and the same could be moderated for different States. The report also suggests a roadmap for implementation.

1. Introduction

"We are all tasked to balance and optimize ourselves"

1.1. Formation of the sub-group

In the 22nd meeting of the standing technical committee of the Forum of Regulators (FOR) for implementation of Framework on Renewables at the State level, held on 1st November 2018, it was decided to constitute a sub-group for working on harnessing reserves at state level with appropriate settlement mechanisms. The sub-group comprises of the following members:

1. Sh. S.K Soonee, Advisor, POSOCO - Chairman of the sub-group
2. Sh. P.J. Thakkar, Member (T), GERC (Gujarat) - Member
3. Sh. Prafulla Varhade, Director (EE), MERC (Maharashtra) - Member
4. Sh.Gajendra Tiwari, Director (Tariff),MPERC (Madhya Pradesh) - Member
5. Sh. Umakanta Panda, Secretary, TSERC (Telangana) - Member
6. Sh. B.B. Mehta, Chief Engineer, SLDC Gujarat - Member
7. Sh. Anil Kolap, Chief Engineer, SLDC Maharashtra - Member
8. Sh. R.A. Sharma, Addl. Chief Engineer, SLDC, Madhya Pradesh - Member
9. Sh. P. Suresh Babu SE, SLDC Telangana - Member
10. Sh. V. K. Shrivastava, Executive Director, WRLDC - Member
11. Sh. Abhimanyu Gartia, Executive Director, SRLDC - Member
12. Sh. S.C. Saxena, General Manager, NLDC - Member
13. Sh. Ravindra Kadam, Advisor (RE), CERC - Member/Convener

Co-opted members:

14. Dr. Sushanta Chatterjee, Chief (Reg. Affairs),CERC
15. Prof. Abhijit Abhyankar, IIT Delhi

Special invitee: K.C.V. Ramanjaneyalu, SLDC Karnataka

1.2. Terms of reference of the sub group

The terms of reference of the sub-group were as under:

a) To disseminate the learning from the experience of implementing the reserve regulation ancillary services and fast response ancillary services at the interstate level and recommend the roadmap for implementing similar mechanisms at the state level.
b) To recommend the model regulations for harnessing the flexibility attributes, maintaining the mandated reserves and deploying them under normal and contingent scenario through intra-state reserve regulation ancillary services.
c) Any other recommendation as deemed fit in the context.

The FOR letter regarding constitution of the sub-group and the terms of reference of the sub-group is enclosed as **Annex-I**.

1.3. Methodology

The group conducted physical meetings as well as interactions through video conferencingduring April – December 2019 to deliberate on different issues in line with the terms of reference. Those interactions have been listed below. A consolidation of the discussion summary ofthe meetings is given as **Annex-II**.

Table 1: Sub-group meetings and other interactions

Meeting number	Date	Venue
1	6-May-19	NLDC New Delhi
2	7-Jun-19	SLDC Vadodara, Gujarat
3	26-Jul-19	SLDC Jabalpur, MP
4	30-Aug-19	SLDC Maharashtra
5	31-Oct-19	SRLDC, Bengaluru
6	26-Nov-19	Discussion in FOLD (Through VC)
7	31-Dec-19	Discussions through VC

The group visited four SLDCs and interacted with the personnel working in the area of scheduling, IT, accounting& settlement etc. to understand the existing framework and capabilities. The report of the various expert committees on the subject as well as the prevailing CERC regulations and orders on ancillary services, automatic generation control and security constrained economic dispatch were studied. The group organized online surveys to assess the availability of the basic building blocks for implementation of reserves and ancillary services at state level.

The following aspects were deliberated by the group:

(1) What is the need for intrastate ancillary services?
(2) How is imbalance by intrastate entities handled by the SLDC?
(3) How is imbalance settled within the state?
(4) What are the essential reliability services in the Indian context?
(5) What are the learnings from implementation of RRAS at the regional level?
(6) What are the prevailing methodologies for reserve assessment in the State?
(7) What are the prevailing methodologies for unit commitment in the State?
(8) What are intrastate reserves and ancillary services?
(9) Are the interstate reserves different from intrastate reserves?
(10) Which generators could be eligible for participation in the intrastate ancillary services?
(11) How much reserve should be maintained within the State?
(12) How to assess the available reserve margins in intrastate generators?
(13) How to establish the scheduling limits for intrastate generators?
(14) How to assess the available spinning reserve in the State?
(15) How can the operator visualize the available reserve in the intrastate generators?
(16) How to despatch the available intrastate reserves to regulate deviations from schedule?
(17) How to compensate the generators for delivery of ancillary services?
(18) How to recover the cost of despatched reserves?

(19) Should there be any incentive to generators for providing reserves?

(20) How to replenish the depleted reserves?

Literature survey of the international practices was carried out.

Several interactive sessions for capacity building were conducted for rolling out pilots on reserves and ancillary services. The following table summarizes such programs & interactions:

Table 2: Capacity building initiatives

SN	Date	Description	Remarks
1	25-30 Jun 2019	Interaction between WRLDC & SLDC Gujarat on optimizationtechniques	Teleconference
2	15-20 Jul 2019	Interaction between WRLDC & SLDC MP on optimization techniques	Teleconference
3	7-Aug-2019	Interaction between SLDC Kalwa & WRLDC on scheduling & Optimization	at WRLDC Mumbai
4	13-Aug-2019	Interaction between SLDC Kalwa & WRLDC on scheduling & Optimization	at WRLDC Mumbai
5	19-21 Sep 2019	Capacity building program on ‘*Implementation of Optimization Techniques for Indian Power System Operation’* (in collaboration with IIT-Delhi & NLDC)	at NLDC New Delhi

A summary of the capacity building program is attached as **Annex-III**.

The demo of the existing IT infrastructure at NLDC, created for implementation of RRAS, FRAS and SCED was seen. Pilot project were taken up for three RE rich states of Madhya Pradesh, Gujarat and Maharashtra. Algorithm was developed in MS Excel for dispatching reserves in different scenarios. Summary is compiled as **Annex-V, VI and VII** respectively.

The draft recommendations of the group were presented in the FOLD meeting on 26th Nov 2019. The draft report was circulated among members and the recommendations were finalized during the meeting on 31st December 2019.

2. Ancillary Services – International Practices

"*To go beyond is as wrong as to fall short*" – Confucius

2.1. Ancillary services- definition and deployment

Ancillary services support grid reliability, security and to a large extent power quality. Ancillary Services may include a number of different operations such as frequency support, voltage support, and system restoration. However, there is no universal approach or definition of ancillary services. Rather specification of services and the design of the ancillary service arrangements vary depending upon the overall market design and the technical characteristics of the power system. The definition of Ancillary Services as given by Eric Hirst and Brendon Kirby is "*Ancillary services are those functions performed by the equipment and people that generate, control, transmit, and distribute electricity to support the basic services of generating capacity, energy supply, and power delivery*."

2.2. Range of ancillary services in other countries

Federal Electricity Regulatory Commission of United States vide its Order no. 888 approvedthe following six ancillary services to be included in the open access transmission tariff

- Scheduling,system control and dispatch
- Reactive supply and voltage control
- Regulation and frequency response
- Energy imbalance service
- Spinning reserves
- Supplemental reserves

The various ancillary services deployed by the Independent System Operators in the United States are tabulated below Source: https://publications.anl.gov/anlpubs/2016/01/124217.pdf

In the c**ontinental Europe** the frequency is maintained within the range with the combined efforts of all the TSOs and obligation to have reserves. Reserves are of the following types:

i. Frequency Containment Reserve (FCR) similar to primary control
ii. Frequency restoration Reserves (FRR) similar to secondary control through AGC
iii. Restoration Reserves (RR) to replace FRR similar to tertiary control

The ancillary services available through the **Great Britain** system operation are listed below:

i. Mandatory Frequency Response
ii. Commercial Frequency Response
iii. Reserve
iv. Reactive Power
v. Black start
vi. Demand turn up
vii. Intertrip

Table 3: List of ancillary services in ISOs of United States

	Spinning Reserves	Non-spinning Reserves	Regulation
CAISO	Spinning	Non-spinning	Regulation-up Regulation-down Regulation Mileage-up Regulation Mileage-down
ERCOT	Responsive	Non-spinning	Regulation-up Regulation-down
ISO-NE	Ten-minute Synchronized	Ten-minute Non-synchronized Thirty-minute Operating	Regulation
MISO	Spinning	Supplemental	Regulation
NYISO	Ten-minute Spinning Thirty-minute Spinning	Ten-minute Non-synchronized Thirty-minute Non-synchronized	Regulation
PJM	Synchronized	Primary	Regulation
SPP	Spinning	Supplemental	Regulation-up Regulation-down

The types of ancillary services provided in the **Brazilian** Interconnected power system are:

i. Primary and Secondary frequency control
ii. Primary and Secondary power reserve
iii. Prompt reserve
iv. Reactive power support
v. Black start
vi. Special Protection System (SPS)

The various ancillary services in the **Australian** National Electricity Market are as under:

i. Frequency Control Ancillary Services (FCAS)
ii. Network Control Ancillary Services (NCAS)
iii. System Restart Ancillary Services (SRAS)

The mechanisms used for procurement of ancillary services as well as allocation and recovery of costs of procuring each ancillary service also varies from country to country. Some of the services could be mandated as non-remunerative obligations while others could be procured. "Winning bids for energy and ancillary services are mutually exclusive, but a generator can be compensated for both generation and ancillary service provision in the same period as long as the capacities allocated to each do not overlap."

Source: https://publications.anl.gov/anlpubs/2016/01/124217.pdf

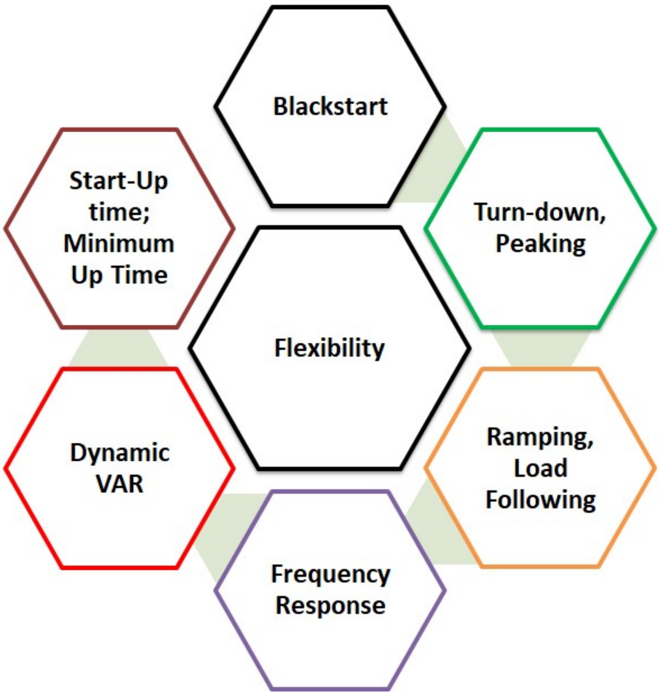


Figure 1: Flexibility attributes

2.3. Essential Reliability Services

The Ancillary Services are more generically termed as Essential Reliability Services (ERS). They are classified into following three categories:

i. Frequency support
ii. Ramping and balancing
iii. Voltage support

Sufficient level of ERS needs to be maintained through a mixture of technological, market, and regulatory approaches.

2.3.1. Frequency support

Immediately after a contingency event (e.g., a generator trip), the kinetic energy is drawn from all remaining synchronous machines to maintain the power balance between production (that has changed due to the generator trip) and consumption (that still remains the same). This withdrawal of kinetic energy is called the synchronous inertial response. As stored kinetic energy is drawn from the generators, they slow down and system frequency therefore declines. Reserves are required to arrest the frequency decline and restore it to the nominal value. Reserves for frequency support are of three types – primary, secondary and tertiary. Primary reserve responds to frequency signals, typically, within 5-10 seconds and ramp up to its full output in 30-60 seconds. Primary reserves aim at stabilizing the system frequency post contingency. The secondary reserves are automatic or deployed online by the system operator to relieve the primary response. Secondary reserves respond in 30-60 seconds and typically take 5-10 minutes to ramp up to its full output.Tertiary reserve has the task of relieving the secondary reserves and are deployed manually. Typically, tertiary reserves respond in 10-15 minutes.

The initial rate at which system frequency declines depends on the amount of inertial response (stored kinetic energy in rotational mass) available at the time of the event, (i.e., the number and size of generators and motors synchronized with the system). With the growing penetration of non-synchronous generators in the grid the system inertia would decline.

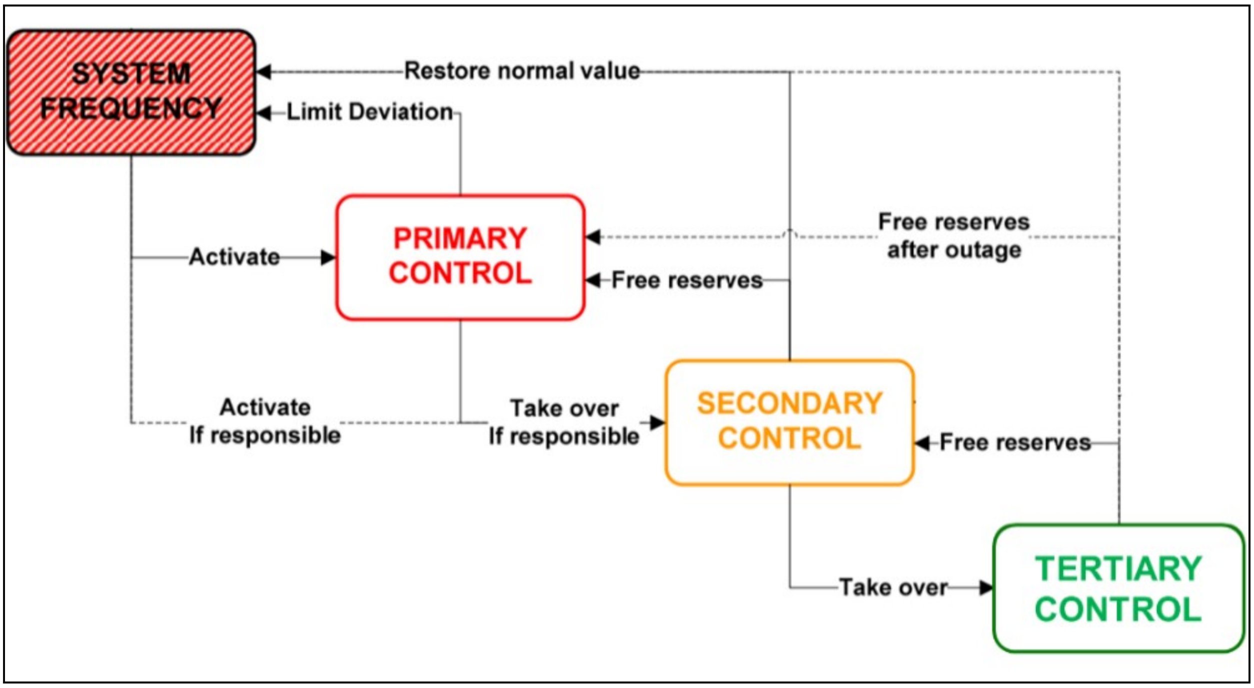


Figure 2: Schematic activation and deployment of reserves (frequency support)

As per the NERC white paper on Essential Reliability Services Sufficiency guideline, published in Dec 2016, the impact of low system inertia could be mitigated by following the alternatives:

i. *Committing additional units for their synchronous inertia, committing different units that have higher inertia, and/or using synchronous condensers*
ii. *Slow down the rate of change of frequency by increasing the rate of primary frequency response of the system in MW/s per Hz*
iii. *Slow down the rate of change of frequency by increasing the speed of frequency response, such as by adding fast frequency response from load resources, storage, synthetic inertia from wind generation, and so forth*

Another approach could be to reduce the magnitude of largest single contingency on the system through re-dispatch.

The report titled 'A survey of definitions and specifications of reserves services' by Yann Rebours and Daniel Kirschen, distinguishes between the attributes of primary, secondary and tertiary control as given in the table below:

Table 4: Attributes of reserves and its deployment

	Primary Control	Secondary Control	Tertiary Control
Why is this control used?	To stabilise the frequency in case of any imbalance	To bring back the frequency	To restore the secondary control reserve, to manage eventual congestions
How is this achieved?	Automatically		Manually
Where is this control performed?	Locally	Centrally	
Who sends the control signal to the source of reserve?	Local sensor	System Operator	System Operator
When is this control activated?	Immediately	Depends on the system	
What sources of reserves can be used?	Partially loaded units, loads, fast-starting units		

Source: [https://labs.ece.uw.edu/real/Library/Reports/Survey_of_Reserve_Services.pdf]

2.3.2. Voltage control

Basic voltage control service is an intrinsic part of power system operation. It is a compulsory provision in most of the countries. However,in few countries voltage control services by operation of generators in synchronous condenser mode are procured either through bilateral contracts or tendering process. The service providers are compensated for reactive energy production or absorption.

2.3.3. Ramping

California Independent System Operator (CAISO) in the United States was among the first independent system operators in North America to implement a separate flexibility ramping product. In November 2016, CAISO implemented flexible ramp up and flexible ramp down ancillary service market products to procure ramp-up and ramp-down capability for 15 minute and 5-minute time intervals. The product is procured in terms of megawatts (MW) of ramping required in a 5 min duration, and any resource capable of fulfilling the ramping requirement can participate. Market participants do not provide bids for this product but are instead compensated according to their lost opportunity cost of providing other services in the ancillary service market.

2.3.4. Types of procurement and remuneration methods

As per the paper “A Survey of Frequency and Voltage Control Ancillary Services- PartII: Economic features” by Rebours, et al., internationally there are four procurement methods to acquire ancillary services: compulsory provision, bilateral contracts, tendering and spot market. Each of these methods have their pros and cons.Remuneration could be according to one of the three types of price: a regulated price, a pay as bid price or a common clearing price. Remuneration for an ancillary service may combine several components that are intended to reflect the various costs that a provider of ancillary services may incur. These components include a fixed allowance (for fixed cost compensation), a utilization frequency price (for actual energy delivery), and a compensation for a possible opportunity cost.

3. Ancillary Services in India

"*Life is like riding a bicycle. To keep your balance, you must keep moving*"- Albert Einstein

3.1. Regulatory provisions for ancillary services in India

CERC Indian Electricity Grid Code Regulations, 2010 (IEGC) define Ancillary Services as below:

"…Regulation 2(1) (b)

Ancillary Services" means in relation to power system (or grid) operation, the services necessary to support the power system (or grid) operation in maintaining power quality, reliability and security of the grid, e.g. active power support for load following, reactive power support, black start etc.;…"

The distinction between the basic services and ancillary services have been deliberated in detail In the Appeal number 202 of 2005 on a reference dated 13th day of December 2006 the Judicial Member of the Appellate Tribunal for Electricity.

[Source: http://aptel.gov.in/judgements/Judgment%20-%20Appeal%20No.%20202%2005(dec).pdf]

Few of the relevant extracts are quoted below:

"30… *Basic - Services" are generation, energy supply and power delivery. Ancillary services are those functions performed to support the basic services of generation, transmission, energy supply and power delivery. Ancillary services are required for the reliable operation of the power system. Automatic generation reserve (spinning and stand-by) load flowing, voltage control and black start capability are some of the commonly recognized, ancillary services. The generators typically provided these ancillary services but it is for a price, either to be agreed or auctioned in a competitive market, as exist in various other countries*."

"*32. Ancillary Services, plainly mean, are those functions performed to support the basic services of generating capacity, energy supply and power delivery. The Ancillary services are split up into different services, e.g. active reserve, reactive reserve and system re-start. Such ancillary services are required for the reliable operation of the power system. The "ancillary services" generally refer to power system services other than the provisions of energy. To be more specific, ancillary services are those functions performed by equipment and people that generate, control, transmit and distribute electricity to support basic services of generation, transmission and distribution.*"

"40. …"Spinning reserve" is the ability of an online generator (load) to increase (decrease) its output (consumption) in a short period of time. In the Grid code "Spinning Reserve" has been described as "Part loaded generating capacity with some reserve margin that is synchronized to the system and is ready to provide increased generation at short notice pursuant to dispatch instruction or instantaneously in response to a frequency drop."

"43. The said author's definition of Spinning Reserve reads thus: "the spinning reserve is the unused capacity which can be activated on decision of the system operator and which is provided by devices which are synchronized to the network and able to affect the active power".

CERC Indian Electricity Grid Code Regulations, 2010 (IEGC) mandates charges for VAR exchanges with the interstate grid as under:

Regulation 6.6 (1):

"The Regional Entity except Generating Stations pays for VAr drawal when voltage at the metering point is below 97%. The Regional Entity except Generating Stations gets paid for VAr return when voltage is below 97%. The Regional Entity except Generating Stations gets paid for VAr drawal when voltage is above103%. The Regional Entity except Generating Stations pays for VAr return when voltage is above 103%."

Regulation 6.6 (2)

"The charge for VArh shall be at the rate of 10 paise/kVArh w.e.f. 1.4.2010, and this will be applicable between the Regional Entity, except Generating Stations, and the regional pool account for VAr interchanges. This rate shall be escalated at 0.5paise/kVArh per year thereafter, unless otherwise revised by the Commission."

Regulation 6.6 (6):

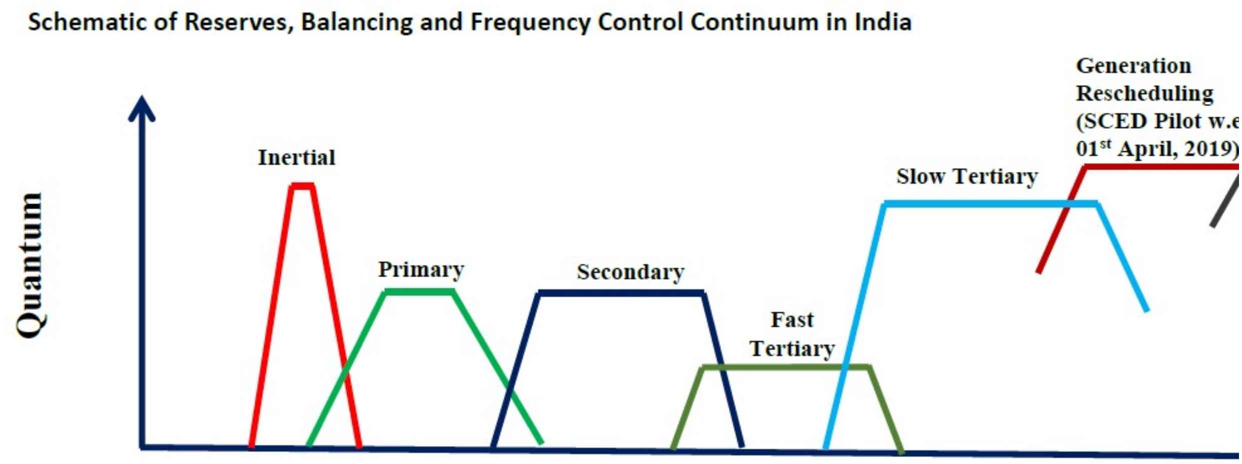
"The ISGS and other generating stations connected to regional grid shall generate/absorb reactive power as per instructions of RLDC, within capability limits of the respective generating units, that is without sacrificing on the active generation required at that time. No payments shall be made to the generating companies for such VAr generation/absorption."

3.2. Frequency continuum in the Indian context

The report of the expert group formed by CERC to review and suggest measures for bringing power system operation closer to National Reference Frequency (Volume-I), states that "Frequency Control in any power system is basically a continuum starting from seconds to a time period of less than an hour. Beyond this time horizon, the problem is basically one of forecasting, unit commitment, scheduling and despatch. Large imperfections in this area would lead to off-nominal frequency or a large quantum of generation reserves requirement which may be suboptimal." The report of the expert group recommends the following frequency continuum.

IEGC 5.2 (f), (g), (h), (i) mandates that all coal fired units of capacity 200 MW and above, gas turbines 50 MW and hydro units of 25 MW and above shall provide primary frequency response.

The salient features of reserve regulation ancillary services for slow and fast ancillary services as well as secondary control through Automatic generation control are described in the following sections.



Response → ↓ Attribute	Inertial	Primary	Secondary	Fast Tertiary	Slow Tertiary	Generation Rescheduling/M:
Time	First few secs	Few sec - 5 min	30 s – 15 min	5 - 30 min	> 15 – 60 min	> 60 min
Quantum	~ 10000 MW/Hz	~ 4000 MW	~ 4000 MW	~ 1000 MW	~ 8000-9000 MW	Load Generati Balance
Local / LDC	Local	Local	NLDC/RLDC	NLDC	NLDC/SLDC	RLDC / SLD
Manual /Automatic	Automatic	Automatic	Automatic	Manual	Manual	Manual
Centralized / Decentralized	Decentralized	Decentralized	Centralized	Centralized	Centralized/ Decentralized	Decentralize
Code /	IEGC / CEA	IEGC / CEA	CERC Order	CERC Order	RRAS	IEGC; CERC O

Figure 3: Frequency continuum

3.3. Evolution of Ancillary services in India

CERC (Unscheduled Interchange) Regulations, 2009 mandated NLDC to provide Ancillary Services. In this direction, in 2010, an Approach Paper on Ancillary Services in Indian Context was submitted by National Load Despatch Centre to CERC.

The approach paper proposed three major categories of Ancillary Services namely

i. Load Generation Balancing Service
ii. Network Control Ancillary Services
iii. System Restart Ancillary Services

The paper recommended the use of un-despatched generation in the form of un-requisitioned surplus (URS). Also, utilization of peaking gas power plants and pumped storage hydro generating stations was envisaged for providing load generation balancing service as well as power flow control. Further, the use of hydro stations as synchronous condenser for providing reactive power support and introduction of black start as an ancillary service for hydro, gas and combined cycle stations which have black start capability was deliberated. In March 2012, CERC Central Advisory Committee (CAC) expressed the need for introduction of ancillary services in India for better security and reliability of grid operation, after due deliberation amongst the stakeholders. A national level workshop was organized in June, 2012 by the Forum of Load Despatchers (FOLD) to explain the various aspects of ancillary services mechanism in Indian context to the stakeholders.

In 2013, CERC floated staff paper on "Introduction of Ancillary Services in Indian Electricity Market".The staff paper discussed about the types of Ancillary Services such as

i. the real power support services or Frequency Support Ancillary Services/ Load following,
ii. Voltage orreactive power support services
iii. Black start support services.

It was envisaged that the generators having surplus capacity, (i.e. either un-requisitioned surplus capacity by the beneficiaries of that capacity or generators who could not sell their capacity in the market and/or surplus captive capacity)may be allowed to bid into the power exchange, in a separate market segment.Pursuant to above, CERC floated draft Regulation on Ancillary Service operation in May, 2015. Some apprehensions were raised by the stakeholders regarding triggering criteria, eligibility of generators, minimum dispatch certainty, pricing considerations, payment security mechanism and incentive & penal provisions etc. There were also reservations from state utilities on implementation of Ancillary Services with the major concern being that it would lead to operation of costly plants leading to rise in electricity prices. After stakeholder consultations, CERC decided that, in order to meet current requirement, tertiary frequency control through utilization of un-despatched surplus capacity available in generating stations at the inter-state level, whose tariff is determined/adopted by CERC, may be introduced as Reserve Regulation Ancillary Service (RRAS) with the following approach.

a. Variable cost of RRAS provider will be considered for merit order despatch.
b. Both fixed charges and variable charges are to be paid to the RRAS providers, which in turn refunds the fixed charges to the original beneficiary in proportion to the power surrendered.
c. The refund of fixed charges to the beneficiary(ies) and mark-up paid to the RRAS provider act as an incentive for the beneficiaries and the RRAS providers respectively.

Ministry of Power, Government of India constituted Technical Committee on large scale integration of renewable energy, need for balancing, deviation settlement mechanism and other associated issues. The Committee in its report also recommended that ancillary services need to be put in place as they provide a framework for operationalizing the spinning reserves, address congestion management issues and facilitate optimization at Regional and National Level and thereby facilitate integration of renewables too. Tariff Policy amended in January 2016, which also envisaged implementation of ancillary services.

CERC (Ancillary Services Operations) Regulations were notified on 13th August, 2015. CERC, in February, 2016, set the mark-up for participation in Regulation 'Up' RRAS at 50 paise/kWh. The detailed procedures were also approved by CERC. Thus, with active support provided by way of policy initiatives by the Ministry of Power and the requisite regulatory framework by CERC, the Ancillary Services were launched by the Nodal Agency i.e. NLDC in coordination with RLDCs on 12th April, 2016.

3.4. Salient features of Reserve Regulation Ancillary Services

The salient features of Reserve Regulation Ancillary Services in India are as follows:

i. All the generators, that are regional entities, and whose tariff for the full capacity is determined or adopted by the CERC have been mandated to provide ancillary services as RRAS Providers.

ii. NLDC, through the RLDCs, has been designated as the nodal agency for ancillary services operations. The nodal agency prepares the merit order stack based on the variable cost of generation.

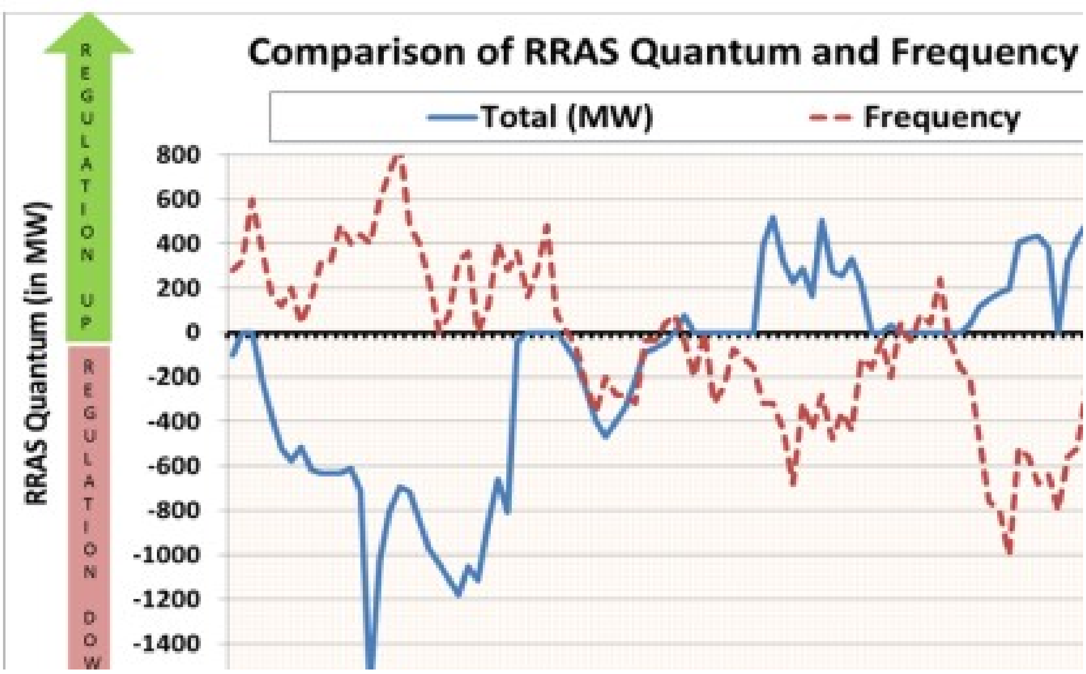


Figure 4: Typical RRAS despatch vs frequency

iii. The triggering events for ancillary services despatch have been defined in the regulations such as extreme weather /special day, generating unit or transmission line outages, trend of load met and frequency, any abnormal event such as outage of hydro generating units due to silt etc., excessive loop flows, trend of computed Area Control Error (ACE) at regional level, and recall by the original beneficiary.

iv. A "Virtual Ancillary Entity (VAE)" has been created in the respective Regional Pool for scheduling and accounting. The quantum of RRAS instruction, by the nodal agency, is being directly incorporated in the schedule of RRAS providers.

v. The RRAS instruction is scheduled to the VAE in one or more regional grids. The deviation in schedule of the RRAS Providers, beyond the revised schedule, is being settled as per the CERC Deviation Settlement Mechanism (DSM) Regulations. The energy despatched under RRAS is deemed delivered ex-bus.

vi. Nodal Agency directs the RRAS Provider to withdraw RRAS, on being satisfied, that the circumstances leading to triggering of RRAS Services have been normalized.

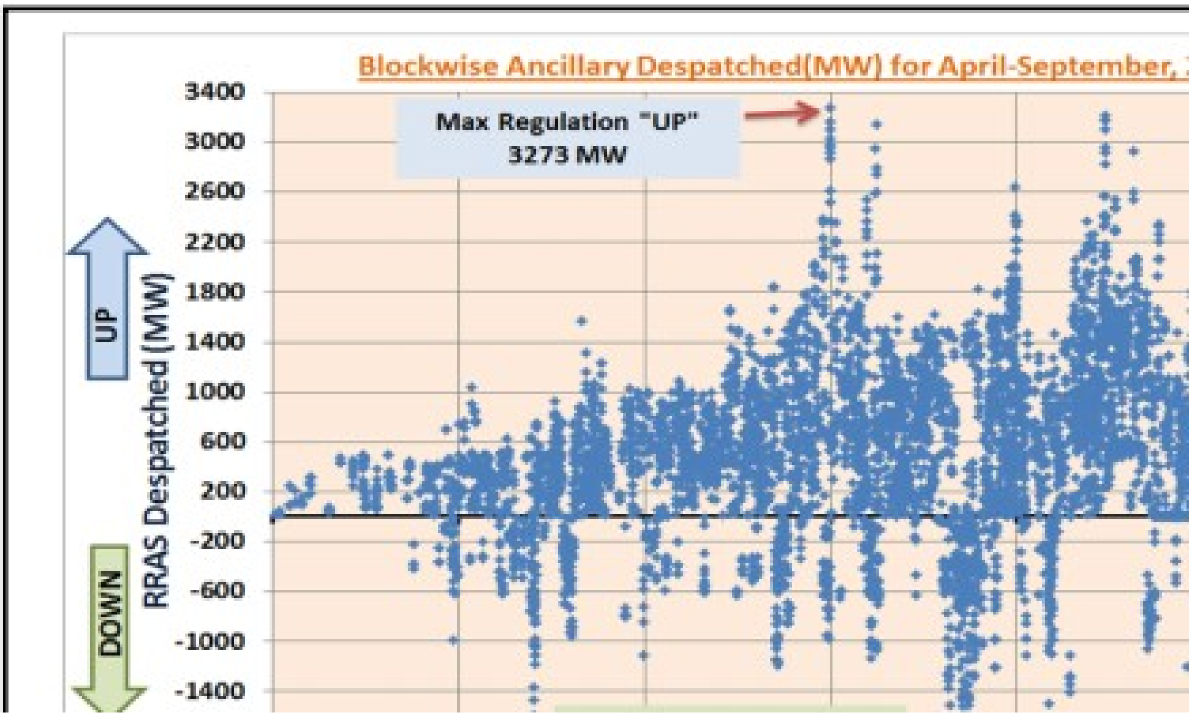


Figure 5: Typical quantum of RRAS despatch

vii. The RRAS Energy Accounting is being done by the respective Regional Power Committee (RPC) on weekly basis along with DSM Account, based on interface meters data and schedule. A separate RRAS statement is being issued by RPC along with Regional DSM Account. Any post-facto revision in rates/charges by RRAS providers is not permitted.

viii. In case of RRAS Up, fixed and variable charges are payable to the RRAS providers from the pool. In case of RRAS Down, 75 percent of the vvariable charges are payable by RRAS providers to the pool and the fixed charges are reimbursed by RRAS providers to the original beneficiaries.

ix. No commitment charges are payable to the RRAS providers. There are penalties for sustained failure to provide RRAS and violation of directions of RLDC.

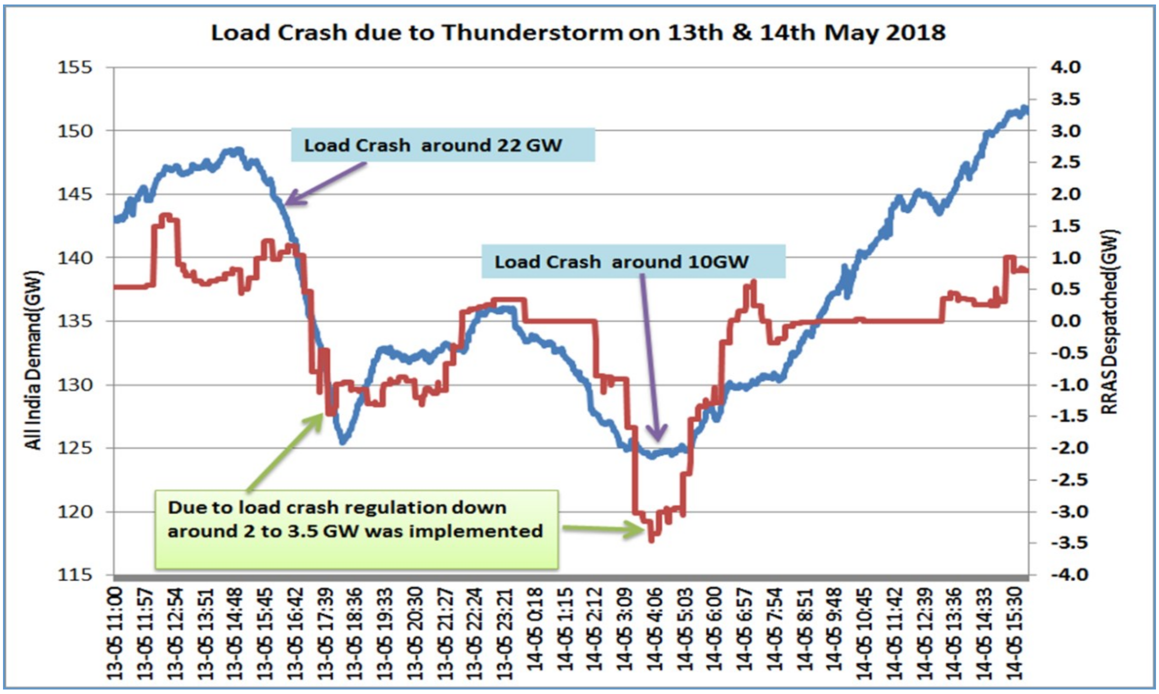


Figure 6: Typical RRAS dispatch during load crash

3.5. Salient features of Fast Response Ancillary Services

RRAS is primarily a framework for slow tertiary reserves at the ISTS level operationalized by National Load Despatch Centre (NLDC) in coordination with Regional Load Despatch Centres (RLDCs). However considering the requirement to mobilise the flexibility rendered by hydro generators viz. overload capability, fast ramping & peaking support etc. Fast Response Ancillary Services for ‘regulation service’ from storage/pondage based hydro stations (e.g. to handle the hour boundary frequency spikes) were conceptualized and implemented. The following attributes of hydro generation were considered for FRAS design:

i. Hydro stations are “energy limited resources” unlike the thermal stations (coal based) which are “ramp limited resources”
ii. Hydro stations are subject to limitations/constraints in terms of water inflows as well as the quantum of water that can be released based on reasons other than power generation requirements
iii. The marginal cost for hydro generation is ‘zero’ and the segregation of fixed and variable charges in case of hydro is only notional.

Accordingly, the Commission vide order in Petition No. 07/SM/2018 (Suo-Motu) dated 16th July, 2018 directed the implementation of pilot project for FRAS covering all Regional Entity hydro generating stations. FRAS was implemented from 26th Nov 2018 to 26th May 2019 on pilot basis. Report was submitted by NLDC to CERC on 30th July 2019 which may accessed at https://posoco.in/wp-content/uploads/2019/08/POSOCO_FRAS_Feedback.pdf.

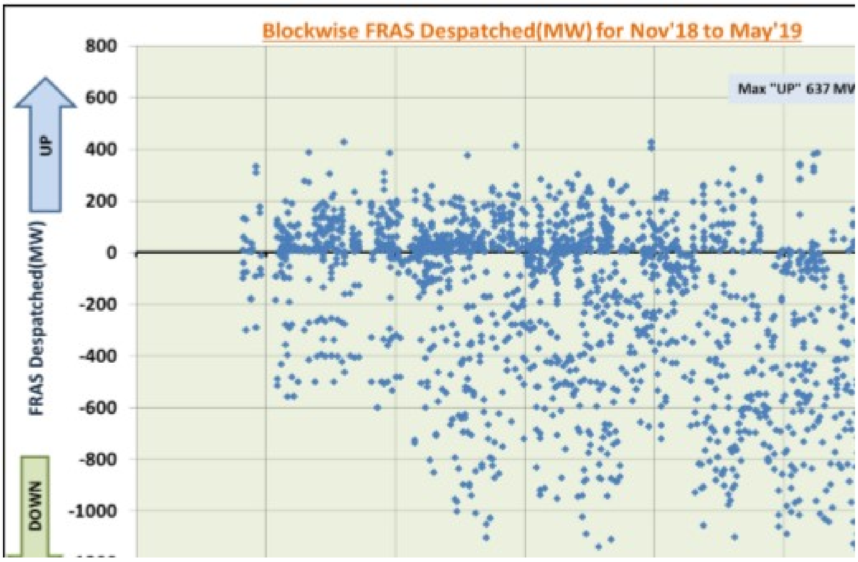


Figure 7: FRAS despatched (Nov-18 to May-19)

The salient features of FRAS were as follows:

i. All constraints declared by the hydro stations are honored. The total energy delivered over the day is maintained as far as possible, as declared by the respective hydro station.
ii. The total energy dispatched under FRAS is attempted to be squared off within the day.
iii. FRAS instructions are triggered based on a stack prepared based on the balance energy available in the hydro station.
iv. The schedules of the beneficiaries are not disturbed in the despatch of FRAS.
v. The respective RPCs issue weekly FRAS accounts along with the RRAS accounts based on the data provided to them by the RLDCs/NLDC.
vi. Incentive is paid from the DSM Pool on mileage basis at the rate of 10 paise per kWh both for 'up' and 'down' regulation provided by the hydro station.

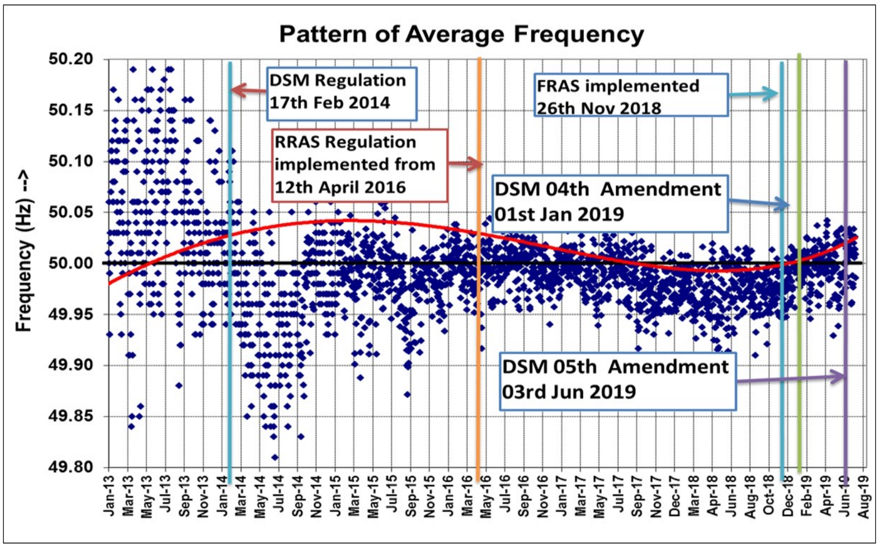


Figure 8: Improvement in frequency profile

3.6. Experience of RRAS and FRAS

Since inception till May, 2019, about 11.6 BU was despatched in Regulation Up (9767 Nos. of instructions) and about 1.4BU in Regulation down (2607 Nos. of instructions) from NLDC through RLDCs.

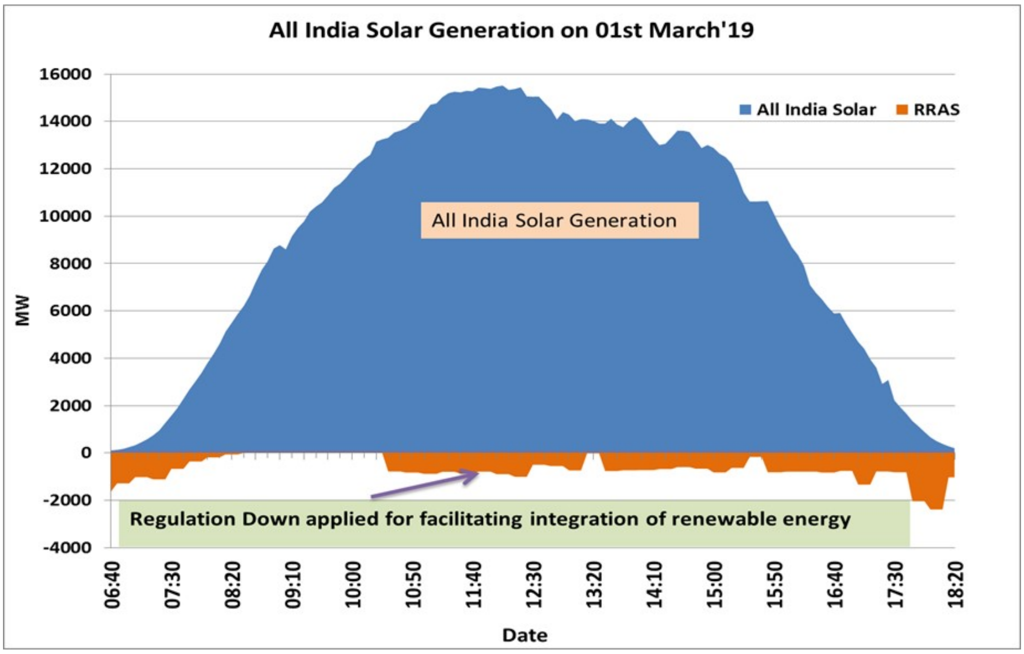


Figure 9: RRAs dispatch to facilitate high solar generation

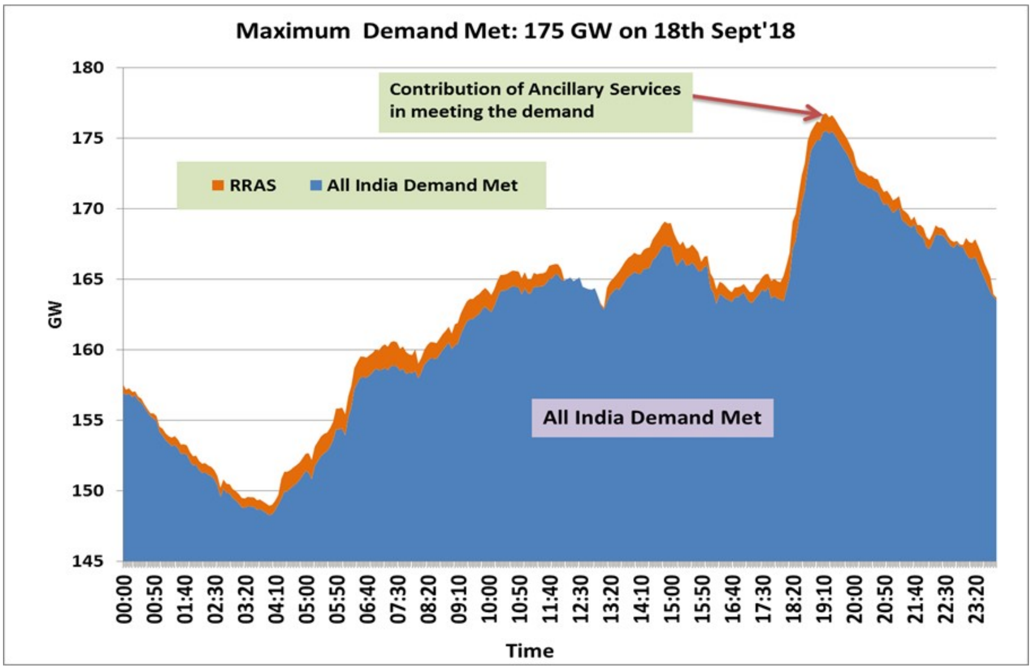


Figure 10: RRAS dispatch during high demand

With the help of in-house development of customized software solution, RRAS helped in improving the frequency profile, congestion management, optimization of reserves dispatch at pan-India level for frequency control, and facilitating integration of renewables. Various challenges have been experienced in the RRAS implementation such as 'gate closure' in the multi-lateral scheduling system, maintaining adequate reserves quantum and forecasting by the utilities for resource adequacy.

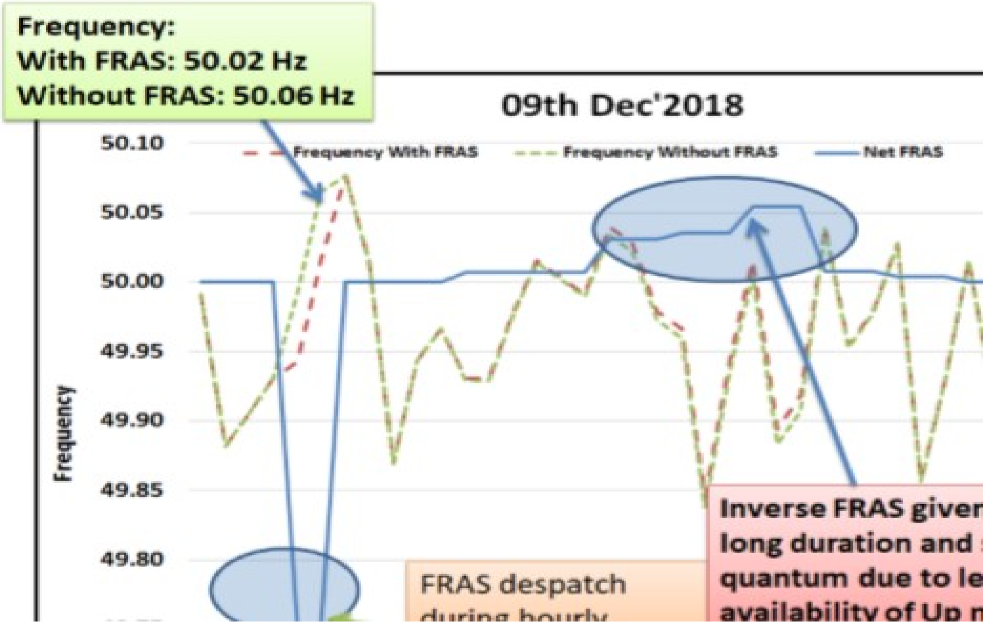


Figure 11: Typical RRAS despatch

FRAS was implemented as ‘fast’ tertiary control to handle frequency spikes at hourly boundary. The required application software was developed in-house at NLDC/RLDCs. 20 hydro stations in Northern, Eastern and North-Eastern regions with aggregate capacity of 8604 MW participated. Approx. 3 to 4 instructions were issued on daily basis. Instructions for total 9.7 MU FRAS up and 41.6 MU FRAS down were issued during the pilot period. The challenges encountered in the FRAS implementation included determination of minimum threshold quantum to be despatched under FRAS, forecasting & availability declaration by hydro station, lead time for communication of instructions, regulation of power supply by FRAS providers, dilemma of reserves in hydro plants, handling residual energy, primary response, automation, information technology infrastructure and manpower requirements. During the FRAS pilot, difficulties were faced in the squaring off of the despatched FRAS energy due to various reasons.

3.7. Salient features of secondary frequency control

Five stations were identified for providing secondary response under the pilot project on Automatic Generation Control (AGC), viz. Dadri-II (NR), Mouda-II (WR), Simhadri (SR), Barh (ER), Bongaigaon (NER). The first pilot project on AGC at NTPC Dadri Stage-II was implemented in January 2018. Thereafter, AGC pilot projects have also been operationalized at NTPC Simhadri Stage-II (on 16th November 2018), NTPC Mauda Stage-II (on 30th January 2019), NTPC Barh (on 23rd August, 2019) and NTPC Bongaigaon (Nov 2019).Highlights are as under:

- AGC pilot project is being operated from NLDC.
- Required hardware and software has been installed at NLDC and the stations under AGC
- The AGC software has been integrated with the existing SCADA system at NLDC
- The five regional grids are considered as a balancing area. The ACE of the regional grid is computed and scaled down to derive the plant AGC set point

- AGC set point is communicated every 2 second to the power station through Inter Control Center Communications Protocol (ICCP)
- The unit Digital Control System (DCS) accepts AGC signal sent by NLDC when the unit is set into “Remote” by the unit operator. When the unit is placed in “Local” mode, the unit DCS only receives the signal but does not act on the signal
- Delta P is the AGC correction is calculated as the difference between plant AGC set point and the reference Unit Load Set Point. The plant operator has the choice to distribute the plant AGC set point in between the two units by a factor.
- Aggregated AGC incremental MW signals over 15 minutes/5 minutes are logged at NLDC and the power station as AGC MWh.
- Deviation in MWh for every 15-minute time block are worked out as: - MWh deviation = (Actual MWh)- (Scheduled MWh)- (AGC MWh); This is settled as per the existing DSM Regulations
- For AGC MWh computed for each 5-minute time block, 50 paise/kWh mark-up is payable to the participating station from the regional DSM pool for both positive AGC MWh generation and negative AGC MWh reduction. Data is submitted by NLDC to respective RPCs in the agreed format on a weekly basis.

Implementation of AGC on hydro and solar power plants is also being undertaken with USAID under Greening the Grid (GtG) RISE project. Karnataka Power Transmission Corporation Ltd. together with USAID has proposed AGC pilot project on Varahi and Sharavathi Hydro Power Plants. Similar pilot projects could be taken up in the RE rich and few of the larger States. CERC vide its order dated 28th August 2019 in Petition No.: 319/RC/2018 directed roll out of AGC pan India. Under phase-I, implementation would be taken up in all regional entity generators whose tariff is approved/adopted by CERC. Implementation in the regional entity generators having merchant capacity shall be taken up in the second phase. The basic infrastructure required for implementation of AGC are as under:

- Reliable wideband communication between SLDC and generating station
- AGC application software in SCADA/EMS at SLDC
- AGC application software at Generating station
- Measurement and computation of Area control error at every 4 seconds

4. Dimensioning of reserves for intrastate Ancillary Services

"Errors, like straws, upon the surface flow, He who would search for pearls must dive below"

4.1. System imbalance due to stochastic factors

Imbalance in the power system could be attributed to the following factors:

i. Forced/unplanned outage (Generation loss or load loss)
ii. Load forecast error
iii. Forecast error of RES (Wind & Solar) generation
iv. Difference between scheduled and actual generation

Deviation of the frequency from the nominal value is a consequence of the above imbalances.

4.2. System imbalance due to deterministic factors

The changes in the physical supply or the demand are generally gradual (except under contingency). However, in the electricity market, the interchange schedules are specified as discreet step functions in hourly or sub-hourly intervals (15-min in India).

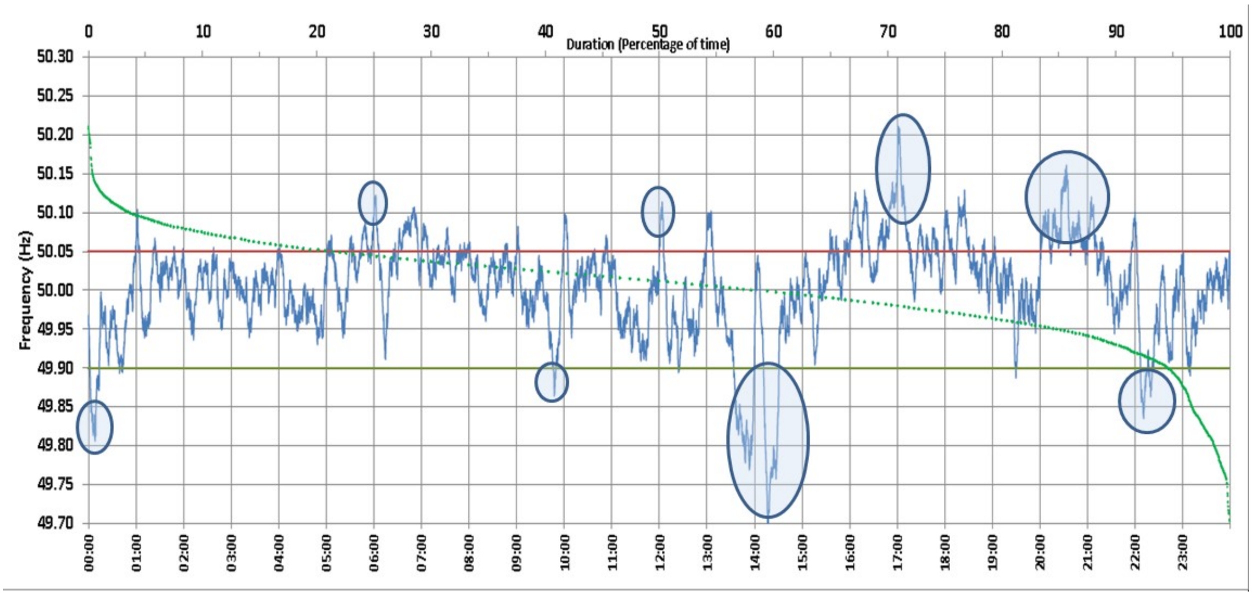


Figure 12:Sharp variations in frequency at 15-min and hourly boundaries on a typical day

This implies that in a given time block, the interchange schedule would never match the demand or supply perfectly – it would either be 'over-scheduled' or 'under scheduled'. Thus, the deviation of actual interchange from the interchange schedule are inevitable in a power system. These deviations are sometimes referred as 'schedule leaps'. Schedule leaps are quite significant at the boundary of the defined time blocks due to step changes in the schedule. The schedule leaps are also reflected in the frequency profile of the grid. [Source:https://www.neon-energie.de/Hirth-Ziegenhagen-2015-Balancing-Power-Variable-Renewables-Links.pdf].

The scheduling and the settlement interval or period are a part of the electricity market design. It influences the way in which the contracts are designed in the electricity market. Therefore, increasing the granularity of scheduling interval could help in regulating the schedule leaps. In fact, the quantum of reserves required for regulation and ramp management would significantly reduce with the reduction in the scheduling interval enhancing market liquidity and enabling access to fast markets. The same is illustrated through the figures extracted from the NREL report on 'operating reserves and variable generation'. (https://www.nrel.gov/docs/fy11osti/51978.pdf.) NITI Aayog in its Report on India's Renewable Electricity Roadmap 2030 [section 3.23 (ii)] also highlighted that the ancillary service requirement would be lower in case of 5-min scheduling.

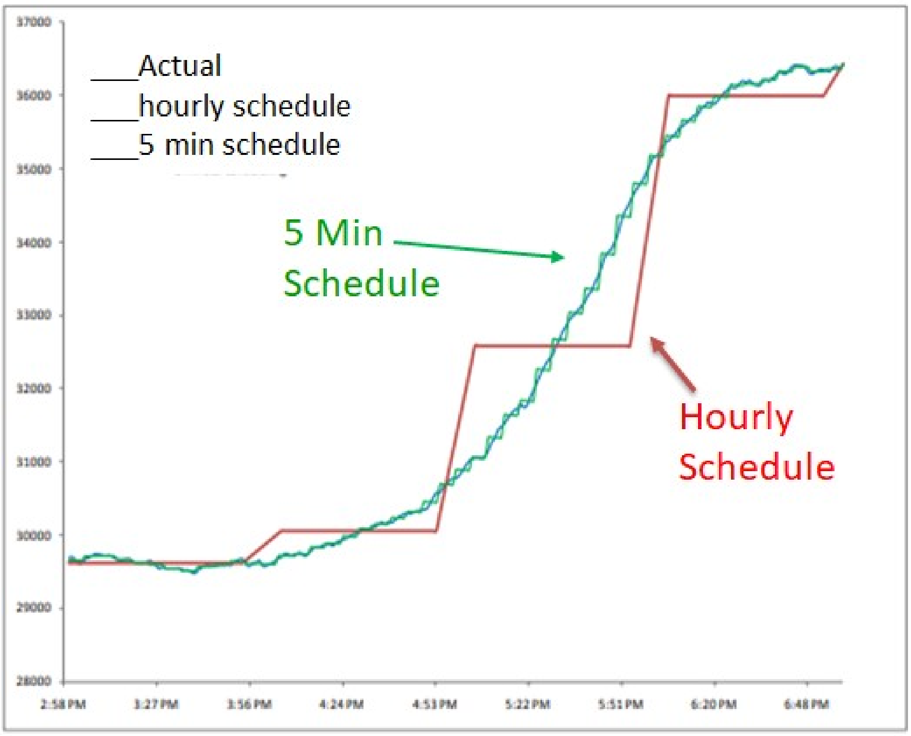


Figure 13: Hourly scheduling vis-a-vis 5-minute scheduling

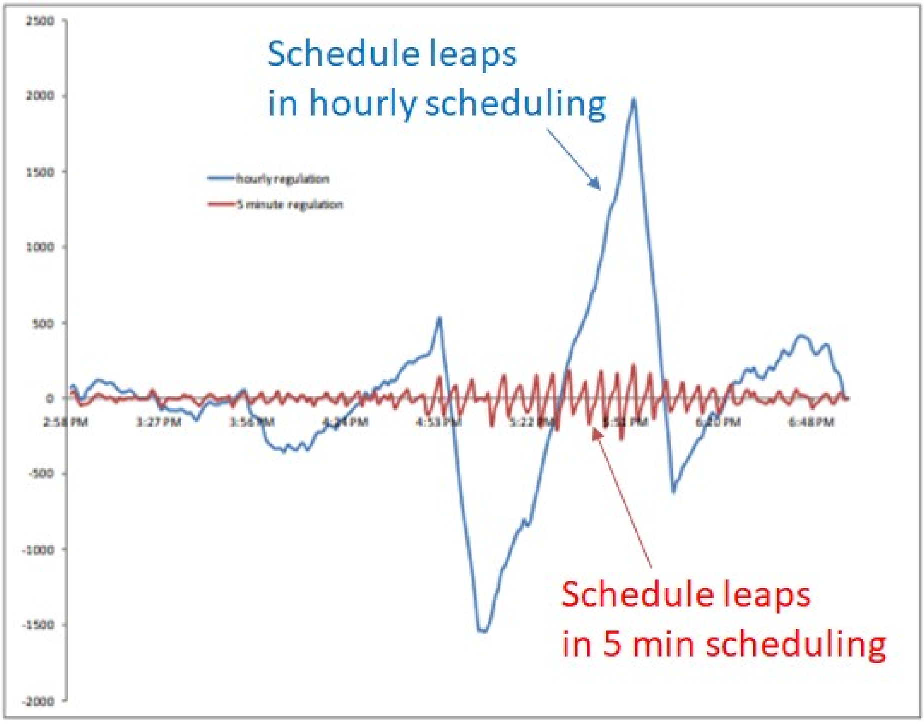


Figure 14: Regulation requirement for hourly scheduling vis-a-vis 5-min scheduling

4.3. Primary reserves as per CERC roadmap

CERC vide its order dated 13th October, 2015 in Petition no 11/SM/2015 envisaged loss of complete power station as a credible contingency for maintaining primary reserve. It states that a minimum primary reserve of 4000 MW shall be maintained to arrest the sudden frequency drop post outage of an Ultra Mega Power Plant or any similar event. This reserve has to be distributed in all India generators to take advantage of diversity. IEGC 5.2 is applicable to intrastate generators as well as interstate generating stations. Thus, the reserves for primary response have to be maintained in all coal-fired units of capacity 200 MW and above, all gas turbines of capacity 50 MW and above and all hydro units of capacity 25 MW and above. All the units on bar would respond as per their droop characteristics to stabilize the frequency post contingency.

In order to ensure adequate reserves for primary response, the injection schedule of the intrastate generating stations issued by the SLDCs should not exceed the capacity on bar less normative auxiliary consumption of the respective stations. It is desirable to have primary reserves distributed over large number of units instead of maintaining it in few units. This could be an effective strategy for ensuring availability of response and avoiding large variation in the power flow across the network due to the primary response during the quasi-steady state.

The respective SERCs could mandate the frequency response obligations of the intrastate entities. The respective SLDCs could compute the frequency response characteristics for different contingencies and compare it with the obligations. The computation could be as per the 'Procedure for Assessment of Frequency Response Characteristic (FRC) of control areas in Indian power system" that was approved by CERC vide its order in petitions 47/MP/2012, 49/MP/2012, 50/MP/2012, 51/MP/2012 and 52/MP/2012.

4.4. Secondary reserves as per CERC roadmap

Secondary reserves are deployed to restore the primary reserves, and keeping the system ready to handle the next contingency. The primary response is required to stabilize the frequency while the secondary reserve is to be deployed to restore the primary reserve and restore the frequency to 50 Hz. Secondary reserve is deployed in the area where the contingency has occurred. The CERC roadmap on reserves, envisaged that each region should maintain secondary reserve equal to the size of the largest unit in the region.The secondary reserves to be maintained at regional level as per the CERC roadmap are tabulated below.These reserves would be available only if there is un-requisitioned surplus power in the ISGS.

Table 5: Secondary reserves recommended in the CERC roadmap

Region	Reserve at regional level (MW)
North	800
East	660
West	800
South	1000
North East	363
Total	**3623**

4.5. Tertiary reserves as per CERC roadmap

Tertiary reserves are required to replenish the secondary reserves. Hon'ble CERC vide its Suo moto order 11/SM/2015 dated 13.10.2015 in the matter of operationalization of spinning reserves envisaged a that "*tertiary reserves should be maintained in a decentralized fashion by each state control area for at least 50% of the largest generating unit available in the state control area.*"Aggregate tertiary reserves at intrastate level computed from the above deterministic approach is tabulated as under:

Table 6: Tertiary reserve recommended in the CERC roadmap

Region	Aggregate tertiary reserves at the intrastate level (MW)
North	1658
East	857
West	1353
South	1343
North east	65
Total	**5218**

4.6. Probabilistic methods for reserve assessment

The reserves required for a control area varies seasonally, daily and time block wise. Methodologies for estimation of reserves can be either deterministic or probabilistic. Reserves based on largest possible generation incident in a control area is a deterministic approach. It is desirable to adopt a probabilistic approach for reserve assessment to account for deviation patterns, size of control area, severe events and their probability. The idea of probabilistic methods is to size the reserve such that a certain, pre-defined level of system reliability is met. These methods estimate the density function of system imbalances and use a cut-off to determine the size of the reserve. Reserves can be determined for long time periods such as one year or more frequent periods depending on the current or expected status of the system. Reserves based on deterministic sizing is usually static whereas probabilistic sizing can be static or dynamic.

In probabilistic methods, different parameters can be considered for estimation of reserves viz. forced outage rates, capacity outage probabilities, forecast errors, area control errors, deviations due to imbalances and combination of above etc. A probabilistic approach called

Graf-Haubrich is used in Germany for dimensioning of secondary and tertiary control reserves. In Graf-Haubrich method different sources of imbalances (load forecast errors, power plant outages etc.) are convoluted to probability density function. The probability density function gives level of significance for required amounts of reserves. The schematic of Graf-Haubrich method adopted in Germany is shown below.

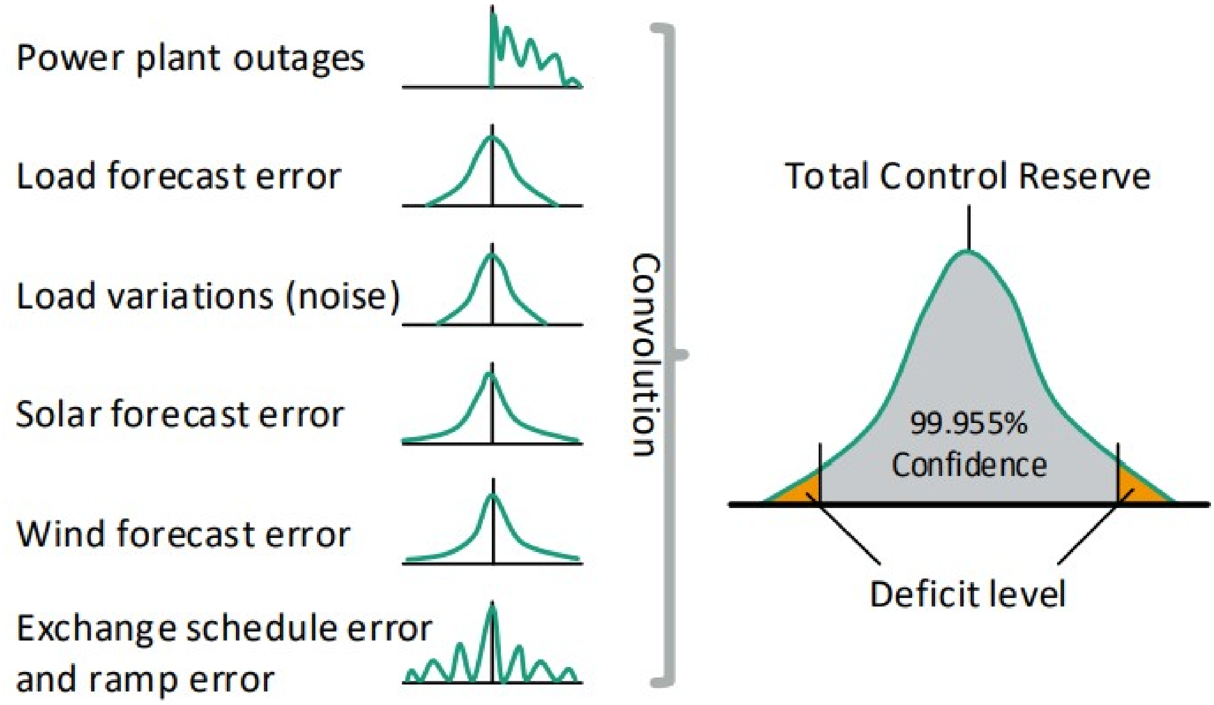


Figure 15: Schematic of Graf-Haubrich method for determination of reserves

4.7. Area Control Error

The imbalance of a control area is generally measured in terms of Area Control Error (ACE). ACE is computed as below.

Area Control Error (ACE) = (Ia - Is) - 10 * Bf * (Fa - 50) + Eσ

Ia = Actual net interchange [-ve for import, +ve for export]

Is= Scheduled net interchange

Bf = Frequency bias coefficient in MW/0.1 Hz, negative value

Fa = Actual system frequency

Eσ= Measurement error

Positive ACE implies over-generation and it causes interconnection frequency to rise while a large negative ACE implies under generation and it causes interconnection frequency to drop. The deviation from schedule on account of power plant outages, load forecast error, load variations, solar forecast error, wind forecast error and scheduling error would be reflected in the Area Control Error. ACE is being computed at all RLDCs by considering10*Bf as 4% of control area load and neglecting measurement error. Thus, the probability density function of ACE could be utilized for probabilistic assessment of balancing reserves. Schematic is illustrated below:

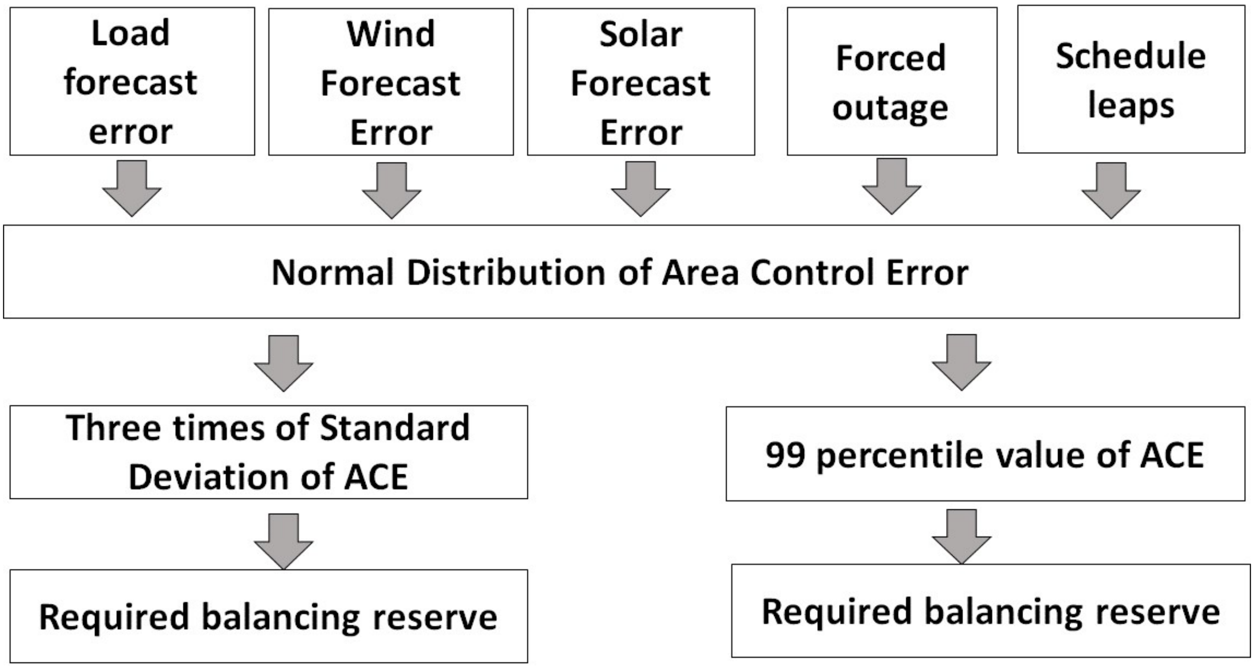


Figure 16: Schematic of probabilistic computation of required reserves

4.8. Reserve assessment from 99 percentile of area control error

Percentiles are used to understand and interpret data. They indicate the values below which a certain percentage of the data in a data set is found. Basically, percentile is a number where a certain percentage of values fall below that number. The nth percentile of a set of data is the value at which n percent of the data is below it. For example, if 99th percentile of data set is 1500 then it means that 99 percentage of values fall below 1500.99 percentile values of ACE computed state wise are tabulated below. As the mean of ACE was not zero, 99 percentile value of ACE will be different for positive and negative ACE. 99 percentiles of ACE could be considered as secondary reserve requirement. [ENTSOE System Operation guidelines suggests this for Frequency Restoration Reserves].Typical values of the 99percentile ACE value of states for the period April 2018 to March 2019 are tabulated below.

Table 7: 99th percentile of ACE of Western Region

Region/State	**99 percentile Positive ACE (MW)**	**99 percentile Negative ACE (MW)**
Maharashtra	640	538
Gujarat	576	625
Madhya Pradesh	636	582
Chhattisgarh	271	362
Goa	85	92
UT Dadra and Nagar Haveli	67	70
UT Daman and Diu	49	50

Table 8: 99th percentile of ACE of Southern Region

Region/State	99 percentile Positive ACE (MW)	99 percentile Negative ACE (MW)
Andhra Pradesh	672	560
Telangana	620	595
Karnataka	638	768
Kerala	240	208
Tamil Nadu	720	630
UT Pondicherry	60	80

Table 9: 99th percentile of ACE of Northern Region

Region/State	99 percentile Positive ACE (MW)	99 percentile Negative ACE (MW)
Punjab	744	660
Haryana	496	640
Rajasthan	718	788
Uttar Pradesh	693	705
Delhi	247	310
Himachal Pradesh	383	273
UT Jammu & Kashmir	382	607
Uttarakhand	337	458
UT Chandigarh	87	79

Table 10: 99th percentile of ACE of Eastern Region

Region/State	99 percentile Positive ACE (MW)	99 percentile Negative ACE (MW)
Bihar	388	545
Jharkhand	194	347
DVC	395	313
Odisha	302	338
West Bengal	466	535
Sikkim	52	61

Table 11: 99th percentile of ACE of North-eastern Region

Region/State	99 percentile Positive ACE (MW)	99 percentile Negative ACE (MW)
Arunachal Pradesh	48	88
Assam	152	208
Manipur	42	50
Meghalaya	62	57
Mizoram	26	44
Nagaland	41	46
Tripura	85	96

4.9. Reserve assessment from standard deviation of area control error

The distribution curve of ACE of a control area could be used to estimate the reserve required for that control area. Three times of standard deviations of the mean of ACE of individual control areas could be considered as the required power balancing reserve for specified hourly time horizon. Normal distribution of ACE would give percentage of values that lie within a band around the mean with a width of one, two and three standard deviations **(σ)**, respectively; more accurately, 68.27%, 95.45% and 99.73% of the values lie within one, two and three standard deviations of the mean, respectively.

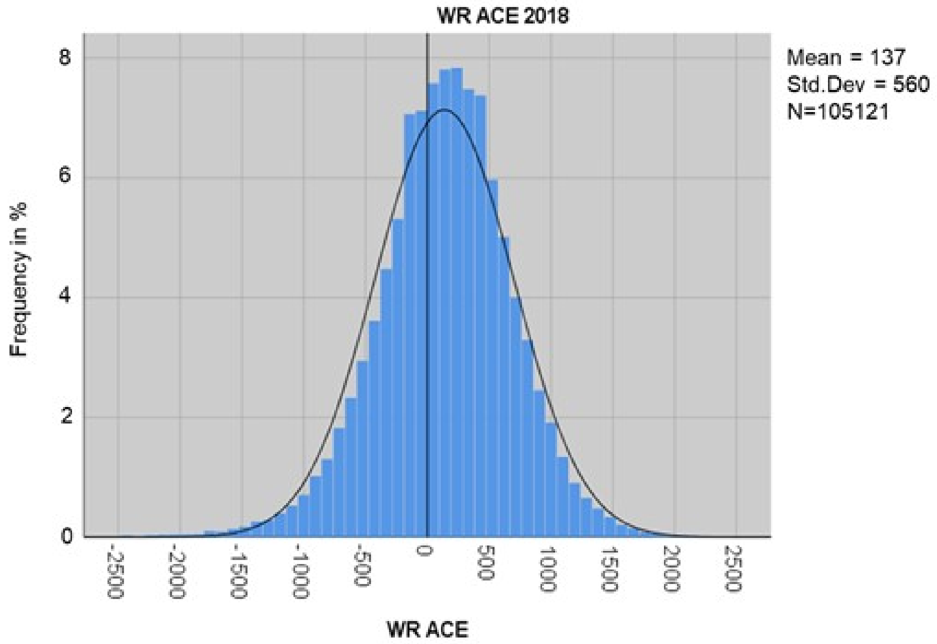


Figure 17: Frequency distribution of ACE of Western Region (Jan-Dec 2018)

As three times of standard deviations of the mean covers 99.73% of values, required sizing of secondary and tertiary reserves for a control area could be considered as three times of standard deviations of the mean of ACE. Based on above approach, three times of standard deviations of the mean of ACE of WR and its constituents were calculated and tabulated below. For computation, ACE values for the year 2018 and 2019 (up to 31st Aug 2019) were considered.

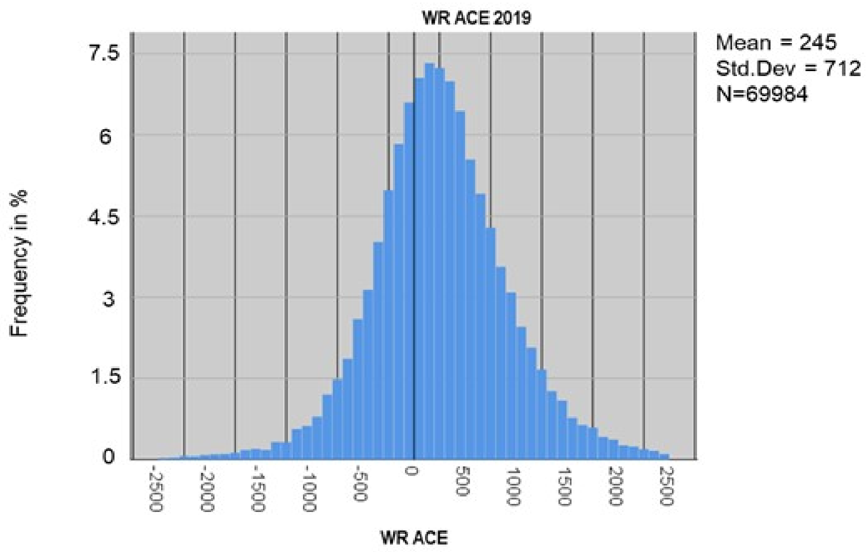


Figure 18: Frequency distribution of ACE of Western Region (Jan-Aug 2019)

Density function plot of ACE for WR and its constituents are enclosed as **Annex-IV**. Summary is as below:

Table 12: Reserve required as per 3sigma method

Region/State	Reserves required (as per CERC roadmap) (MW)	Reserves required (3 times of Standard Deviation)	
		2018 (MW)	2019* (up to 31st Aug) (MW)
Maharashtra	330	759	699
Gujarat	330	660	714
Madhya Pradesh	330	594	675
Chhattisgarh	250	318	372
Goa	-	87	81
UT Daman and Diu	-	75	57
UT Dadra and Nagar Haveli	-	81	72
WR	800	1680	2136

4.10. Monitoring and dispatching active energy reserves

It is recommended that probabilistic approach may be adopted for reserve assessment. The computed reserves may be considered as the total reserves needed for secondary control and tertiary control to be kept inside the control area. Percentage share to secondary control and tertiary control may be varied from time to time or fixed. The amount of reserves can be set on an annual basis and reviewed periodically.

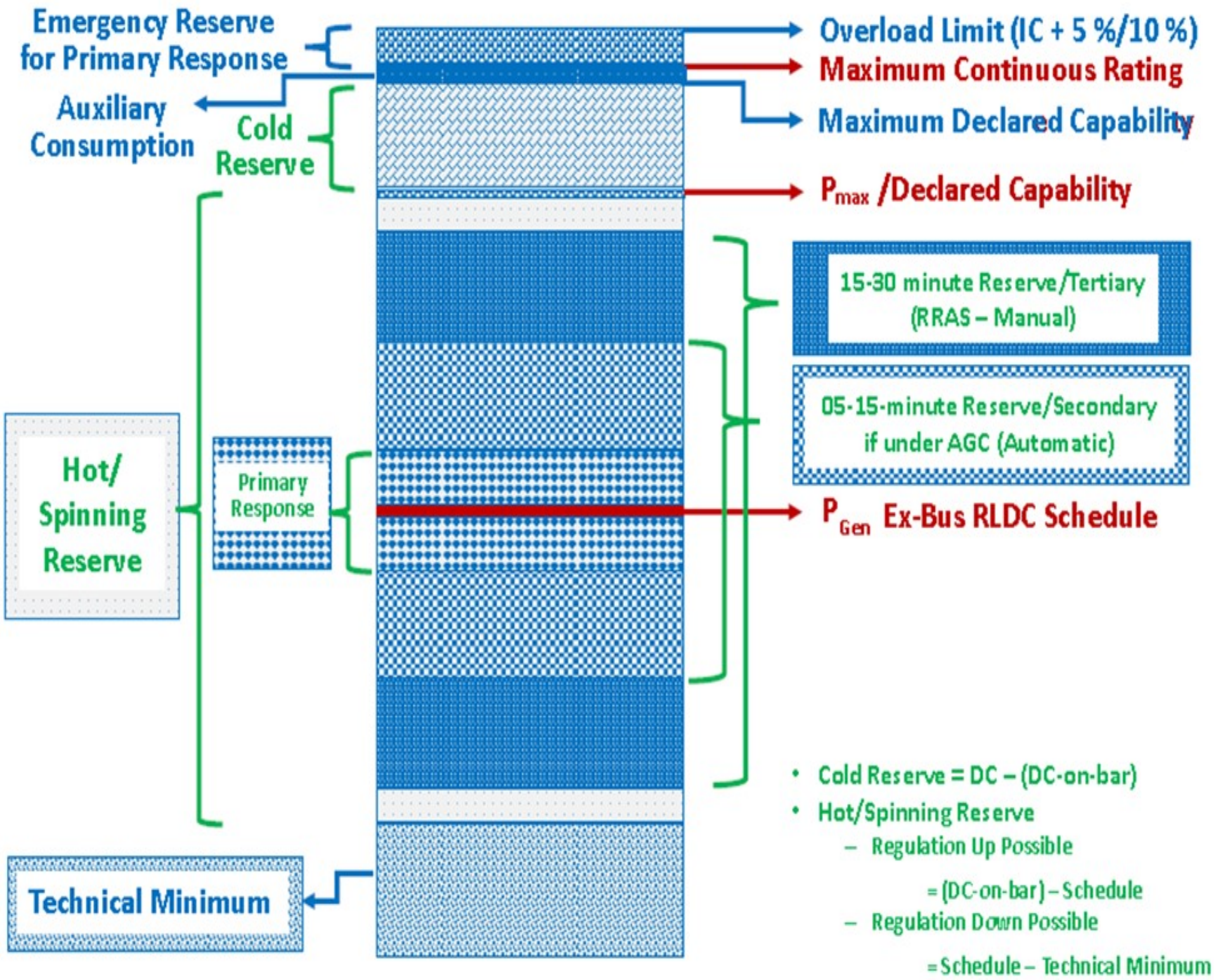


Figure 19: Schematic of reserve margins in a typical unit during a certain time block

The availability of up reserve margin and down reserve margin in all the intrastate generating stations within the State control area and a member in the intrastate DSM pool irrespective of ownership should be computed in real-time and displayed on the operator console in the SLDC control room. This requires notification of norms for Normative Declared Capability, Technical minimum generation capability, ramp up rate, ramp down rate by the SERC. All the intrastate generating stations shall provide the required details to the SLDC. A schematic for reserve margins in a typical unit for a certain time block is illustrated below:

Consequent to the merit order / economic dispatch, the available spinning reserve would get consolidated in the generators having higher variable cost. As a result, the reserves despatch gets constrained by the ramping capability of generation units carrying reserve. The ratio of ramp constrained reserve (that gets despatched) to the total available reserve may vary from 15% to 75%. Reserve available in multiple stations may have to be dispatched simultaneously. In doing so the economy may have to be sacrificed to some extent. The ancillary dispatch instruction could be given to multiple units at a time to exploit the collective ramping capability. It is desirable that suitable incentives may be provided to encourage generators to provide higher ramp rate and number of units providing ramping service is enlarged.

4.11. Economic dispatch vs control area regulation

The dilemma between control area regulation and economic dispatch is well articulated in the classical paper titled 'Considerations in the Regulation of Interconnected Areas', by Nathan Cohn [IEEE Transactions on Power Apparatus and Systems Vol. PAS-86, No. 12 December 1967 pp 1527-1538, https://ieeexplore.ieee.org/document/4073237]. The same is illustrated in figure below.

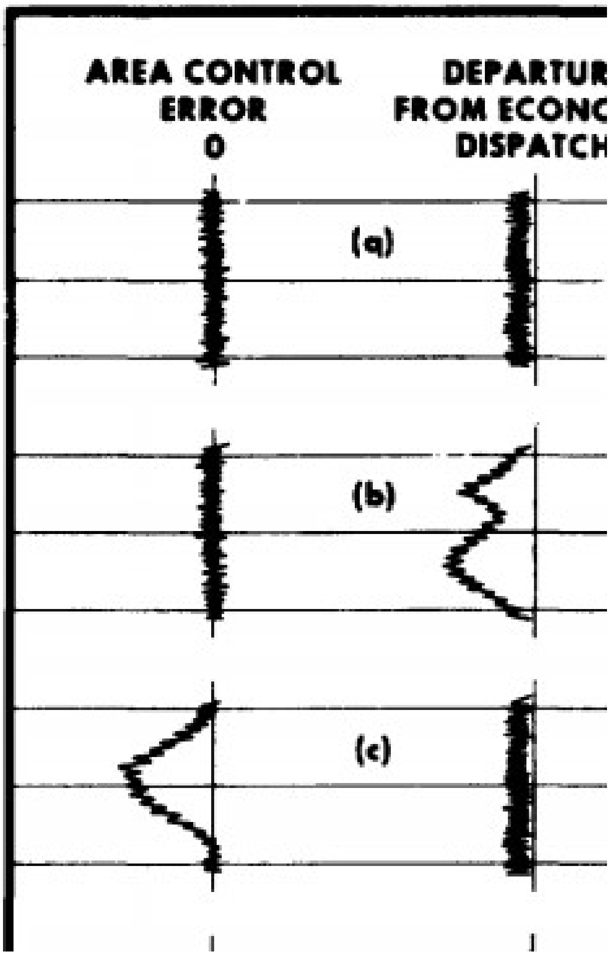


Figure 20: Curves illustrative of control area performance

It states that while pursuing an economic dispatch schedule, the next in line generating source that receives instructions to regulate generation may not have the response characteristics or capabilities or permissible rate of generation change to match the control demand. Also, the control may over-regulate, causing generation changes that exceed the prevailing rate of area load change, with corresponding creation of area control errors.

It may be seen in the figure that good area regulation and optimum economic dispatch are achieved in case (a). In case (b), economic dispatch is sacrificed for good area regulation. In case (c) economic dispatch is achieved at the expense of area regulation. In case (d) neither good area regulation nor economic dispatch are achieved. In view of the above the ramping capability of the units on bar is extremely important. The generating units must be incentivized for declaring a higher ramp rate. The terms and conditions of tariff of central sector generating stations for 2019-24 approved by CERC has mandated a higher return on equity to the generating stations offering a higher ramping capability.

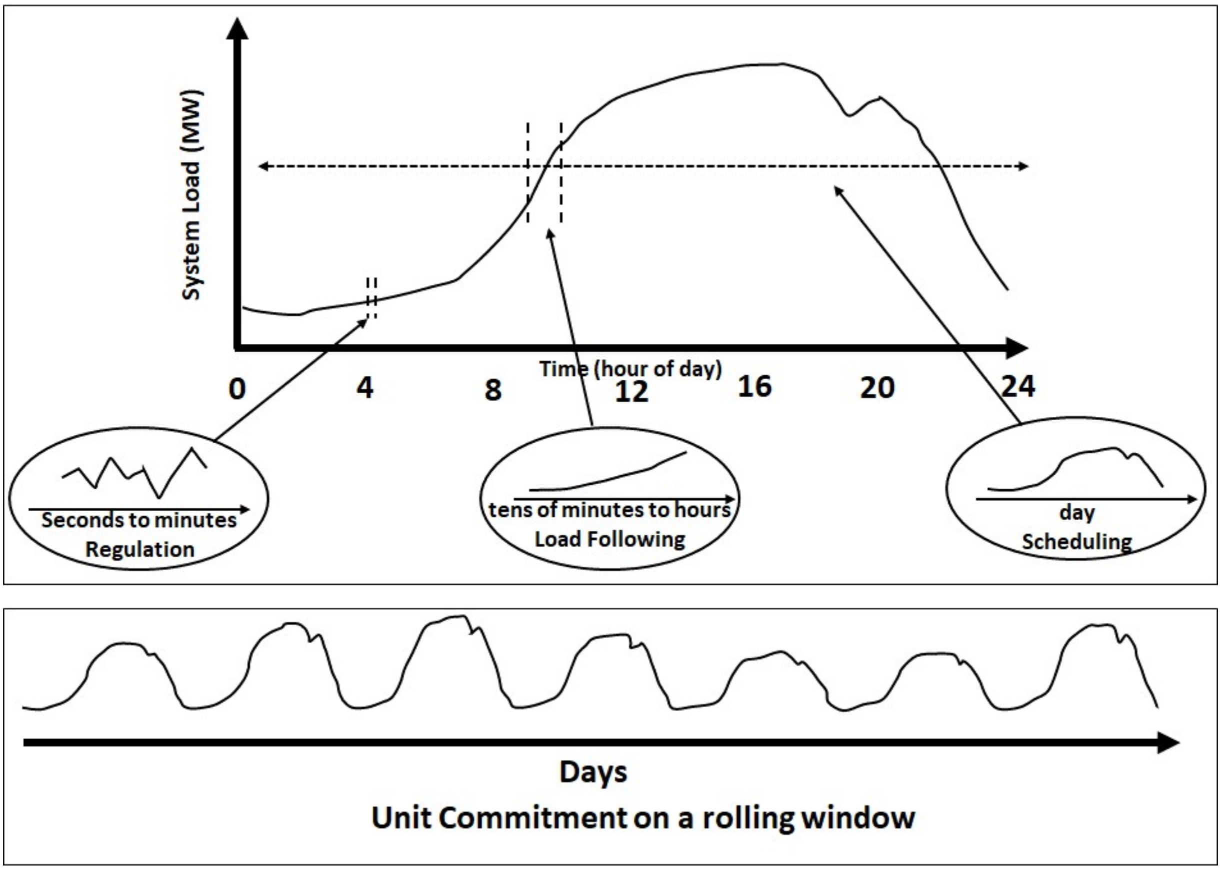


Figure 21: Power system operation time frames

4.12. Unit commitment to ensure reserve adequacy

The depleted reserves would have to be replenished to ensure its adequacy in all time frames. If required, additional units could be brought on bar. Likewise, in case of availability of reserves in excess of the requirement certain units would have to be taken off-bar. This could be accomplished by multi-period optimization of reserves through unit commitment. Thus, unit commitment decision is an integral part of reserve management.

4.13. Voltage Control Ancillary Services in the intrastate system

Adequate availability of static and dynamic sources of reactive power are essential for maintaining voltage profile with the stipulated range. Transmission utilities generally plan shunt compensation in the form of switchable capacitor banks, bus reactors and line reactors. Considering the growing penetration of Variable RE, high capacity evacuation corridors and the large variation in the loading of transmission system the intrastate entities need to be encouraged provide dynamic VAR support for voltage control. At the interstate level the reactive energy exchanges with the grid are charged at 14.5 paise /kVARh if the average voltage during that time block is outside 97% to 103% of nominal. Similar voltage dependent reactive energy pricing could be considered for providing incentives/disincentives reactive energy exchanges with the grid. Considering the capability of VRE to operate in voltage control mode and reactive power control mode and the capability of several hydro units to operate as synchronous condensers. A suitable ancillary service for voltage support could be evolved.

4.14. Black start services in the intrastate system

Black start service is an essential reliability service in power system operation. However very few hydro stations and gas stations have the capability to black start and build the grid post blackout. Regulation 5.8 of the IEGC mandates weekly testing of diesel generators that provide auxiliary supply to black start capable units. Mock trial runs of the system recovery procedure is to be conducted at least once every six months. The model regulation on hydro tariff provides for compensation of the O&M expenses incurred during black start exercise. It also mandates a lumpsum incentive of Rs. 0.5 Lakh for successful demonstration of the black start capability after certification by the SLDC. The above provisions could be suitably considered by the SERCs while drafting the intrastate reserves and ancillary regulations.

5. Survey of preparedness for Intrastate Ancillary Services

"The aim of science is not to open the door to infinite wisdom, but to set a limit to infinite error"

5.1. Survey questionnaire

An online questionnaire was created to assess the availability of the resources and mechanisms for implementation of intrastate ancillary service mechanism. The list of questions is as below:

1. Is intra-State ABT implemented in the State?
2. Does the State have its own grid code?
3. How many government/State owned DISCOMs are there in the State?
4. How many Private DISCOMs are there in the State?
5. How many State-owned generating stations are there in the State and what is their installed capacity in MW?
6. How many private generating (IPP/CPP etc.) stations are there in the State and what is their installed capacity?
7. How many merchant generating stations (without any LTA with the DISCOMs) are there in the State and what is their installed capacity?
8. Does the State follow a common merit order for dispatch instruction for all generators & DISCOMs?
9. In case of private DISCOMs, do they have their own merit order for dispatch?
10. Is there any mechanism to transfer URS power between State owned DISCOMs and private DISCOMs within the state? If yes, how is the settlement done?
11. If need arises, does the SLDC give dispatch instruction to any intra-state generator irrespective of ownership?
12. If need arises, does the SLDC give dispatch instruction to State Owned Generators only?
13. Who prepares merit order?
14. What are the factors considered for preparing the merit-order?
15. Does SLDC have information about fixed cost of all the State generators?
16. Is open access regulation implemented in the State? If yes, up to which voltage level open access is granted?
17. Does SLDC prepare DSM accounts? If Yes, please mention the type of DSM pool?
18. In case of fund generated out of the residual DSM account is maintained, who maintains the fund?
19. What are the criteria to utilize the surplus fund created out of DSM?
20. Who is deciding authority for utilizing the fund created out of DSM?
21. Give details of any other intra-state pool, if any in addition to DSM pool viz State Reactive account pool, Congestion pool etc.
22. What is the norm for technical minimum generation level for state owned thermal generators?

23. Is there any norm specified by SERC for compensation towards part load operation of intra-state thermal stations?
24. Do all the intra-state generators declare DC on day ahead basis?
25. Do all the intra-state generators declare ramp-up and ramp-down rate (in MW/Min)?
26. Do you feel that a more optimized despatch is possible in the state with an algorithm-based approach?
27. Does the State/SLDC do load forecasting?
28. Does the State/SLDC do Renewable (Wind/Solar) generation forecasting?
29. Does the State/SLDC do Renewable (Wind/Solar) generation forecasting?
30. What is the % error (RMSE) in day-ahead demand forecasting?
31. What is the % error (RMSE) in day-ahead Solar forecasting?
32. What is the % error (RMSE) in day-ahead wind forecasting?
33. Have you engaged a forecasting service provider (FSP) for demand/RE forecasting or it is done in-house?
34. Does your forecasting model include weather data in addition to time series data?
35. How does the SLDC do reserve assessment?

5.2. Inferences from the survey responses

Total 22 response were received. Inferences from the survey are as under:

1. Intrastate Grid Code is notified in all the States/Areas.
2. Intrastate ABT in place in 7 States/Areas viz Maharashtra, Madhya Pradesh, Gujarat, Chhattisgarh (in Western Region), Rajasthan, Delhi (in Northern Region) and West Bengal in Eastern Region. In Karnataka, Telangana, Tamil Nadu, Uttarakhand, Himachal Pradesh, Punjab, Bihar and DVCintrastate ABT is either partially implemented or is under progress.
3. 5 States (Tamil Nadu, Uttarakhand, Himachal Pradesh, Punjab and UT of DD) have single government-owned distribution licensee while 13 have multiple distribution licensees. Out of these 13 States, eight states (Odisha, Telangana, Bihar, Karnataka, Madhya Pradesh, Andhra Pradesh, Rajasthan, and Haryana) have only multiple government owned distribution licensees. Kerala has the maximum of 11 distribution licensees- 1 government owned and remaining privately owned.
4. Except Bihar and UT Daman & Diu all 22 States have privately owned generating companies. Nine SLDCs (West Bengal, Maharashtra, Telangana, Gujarat, Karnataka, Chhattisgarh, Andhra Pradesh, Rajasthan and Himachal Pradesh) coordinate the scheduling for merchant IPPs at intrastate level along with generating stations with long-term/medium term PPA.
5. In West Bengal, Gujarat, Kerala, Delhi and DVC the private distribution licensees schedule follows their own merit order while scheduling. Thus, the SLDC presently coordinates the scheduling based on the merit order stack of the contracts entered into only by the government owned distribution licensees within the State.

6. Only Delhi has a mechanism wherein the un-requisitioned surplus power can be scheduled from one intrastate discom to the other intrastate discom by transfer of liability to pay the fixed and variable charge of the corresponding quantum.
7. SLDC Andhra Pradesh, Haryanaand DVC give dispatch instructions only to the State-owned generating companies within their jurisdiction. In order to maintain the grid parameters/deviation at State-regional boundary, SLDC Gujarat gives specific dispatch instructions to only those generators having contracts with GUVNL DISCOMs.
8. Seventeen States have stated that only the variable charges are considered for preparing the merit order stack. SLDC Kerala and SLDC Himachal Pradesh consider both Fixed charges and Variable charges for arriving at the merit order stack. SLDC Telangana and Uttarakhand have stated that composite tariff is considered for preparation of the merit order stack if the breakup is not available.
9. West Bengal and PDD of Jammu and Kashmir have stated that Fixed Charges for State owned generating stations are not available.
10. The DSM pool account is revenue neutral in case of Gujarat, Madhya Pradesh, Maharashtra and Rajasthan whereas in case of Chhattisgarh, West Bengal and Delhi the DSM pool account is non-zero sum (surplus). In case of Himachal Pradesh, DSM account has been created by SLDC and the available surplus amount is transferred to the State Power System Development Fund. In case of Delhi the surplus revenue from the DSM account is maintained by the SERC and is utilized for system Strengthening schemes.
11. Existing practices for technical minimum thermal generation are as under:
    a. Madhya Pradesh (55%)
    b. Maharashtra (70 %)
    c. Gujarat (60-70 % considered as declared by stations, SERC yet to notify)
    d. Chhattisgarh (60 – 70 %)
    e. West Bengal (60-70% considered, SERC yet to notify)
    f. Jharkhand (55 %)
    g. Bihar (55%)
    h. Telangana (65-71 %)
    i. Andhra Pradesh (70%)
    j. Karnataka (70 %)
    k. DVC (As declared by the Station)
    l. Norms are yet to be notified in West Bengal, Gujarat, Tamil Nadu, Kerala, UT J & K, Rajasthan, Uttarakhand
    m. Himachal Pradesh (No thermal generation in the State)
    n. Delhi (70%)
    o. Haryana (65%)
    p. Punjab (As declared by the Stations)

12. All SLDCs have stated that the Declared Capability is available at SLDC. Most of the intrastate generators also submit the ramp rates except in case of Uttarakhand, Chhattisgarh and Jharkhand.
13. Most of the respondents have agreed that a more optimized dispatch is possible through an algorithm-based approach.
14. Maharashtra, Gujarat, Karnataka, Madhya Pradesh have deployed Forecast Service Providers for VRE forecasts.

5.3. Phase wise rolling out intrastate reserves and ancillary services

Based on the survey, and subsequent deliberations the states were placed in the following three groups for rolling out reserves &ancillary services.

Table 13: Roll out of intrastate reserves and ancillary services

Group	States/UTs	Rationale
A	Madhya Pradesh, Maharashtra, Gujarat, Rajasthan, Delhi, West Bengal, Chhattisgarh	Large States SAMAST framework in place
B	Telangana, Karnataka, Andhra Pradesh, Tamil Nadu, Kerala, Uttar Pradesh, Haryana, Punjab, Uttarakhand, Himachal Pradesh, Odisha, Bihar, Jharkhand, DVC	SAMAST framework under implementation
C	NER States, Goa, DD&DNH, Puducherry, Jammu& Kashmir and others	Emerging States and Union territories

6. Simulation model for despatch of reserves

"All models are wrong; the practical question is how wrong do they have to be to not be useful"

6.1. Mandate for scheduling and despatch

The Indian grid is demarcated into several control areas, where the load dispatch centre or system operator of the respective control area controls its generation and/or load to maintain its interchange schedule with other control areas whenever required to do so and contributes to frequency regulation of the synchronously operating system. The regional grids are to be operated with decentralized scheduling and despatch in which the SLDC have the total responsibility for scheduling/dispatching their own generation (including generation of their embedded licensees) and scheduling their drawal from the Interstate generating stations within their share in the respective plant's declared capacity. The SLDCs are responsible for optimum scheduling and despatch of electricity within a State, in accordance with the contracts entered into with the licensees or the generating companies operating in that State. They are also responsible for carrying out real time operations for grid control and despatch of electricity within the State through secure and economic operation of the State grid in accordance with the Grid Standards and the State Grid Code. The Grid code mandates the SLDCs to initiate actions to regulate the drawal of the respective control area from the grid within the net drawal schedule. Thus, the SLDC would have to assess the reserves requirement and ensure its availability and optimal despatch. The role of SLDC would be delineated from distribution licensees while despatching reserves at the state periphery.

6.2. Pilot project using MS Excel Solver

As a pilot project, a simulation model was evolved by using a default optimization tool available in Microsoft Excel Solver for facilitating optimum despatch of reserves. The details of the model are described below.

6.3. Input parameters for the model

i. Installed Capacity
ii. Total Declared capability in MW
iii. Declared capability on-bar (in MW)
iv. Normative Auxiliary Consumption (in %)
v. Schedule in MW
vi. Energy Charge Rate / Variable charge (VC) in Rs/kWh
vii. Ramp-Up rate in (%age of on-bar Capacity) per minute
viii. Ramp-down rate in (%age of on-bar Capacity) per minute
ix. Mandated tertiary reserve to be maintained

6.4. Derived parameters for the model

Based on the above base data, certain derived parameters could be computed and monitored for each time block as under:

i. Regulation Up-reserve = On bar installed capacity – Schedule (fig. in MW)
ii. Regulation Down-reserve = Schedule – Technical Minimum (fig. in MW)
iii. Cold reserve = DC – DC on bar …. (in MW)
iv. Hot spinning reserve = DC on bar – Schedule …. (in MW)
v. Despatchable reserve = Minimum of hot spinning reserve andramping reserve

6.5. Constraints

i. Pmax less than or equal to (On bar installed capacity – Normative auxiliary consumption (in MW))
ii. Pmin less than or equal to Technical Minimum generation (in MW)
iii. Aggregate schedule of all stations equal to total estimated net load
iv. Import capability limits, scheduling limits, Transmission constraints

6.6. Objective function

The objective function could be to “minimize production cost subject to all constraints”. Energy and reserve despatch could be co-optimized. Typical algorithm is attached as **Annex-V.**

6.7. Inferences from the pilot projects taken up in three States

Pilot project was taken up by Madhya Pradesh, Maharashtra and Gujarat. It was inferred that co-optimization of energy and reserves dispatch results in reduction in total production cost and the average per unit generation cost. The exercise also revealed that the dispatchable reserves get limited by ramping constraints. The detail report on the pilot projects are enclosed as Annex-**VI**, **VII** and **VIII**.

7. IT infrastructure required for Intra-state ancillary

“Economists could Engineer, Engineers would Economize”

A robust IT infrastructure would be required for implementation. The typical schematic for IT infrastructure and the information flow is illustrated below.

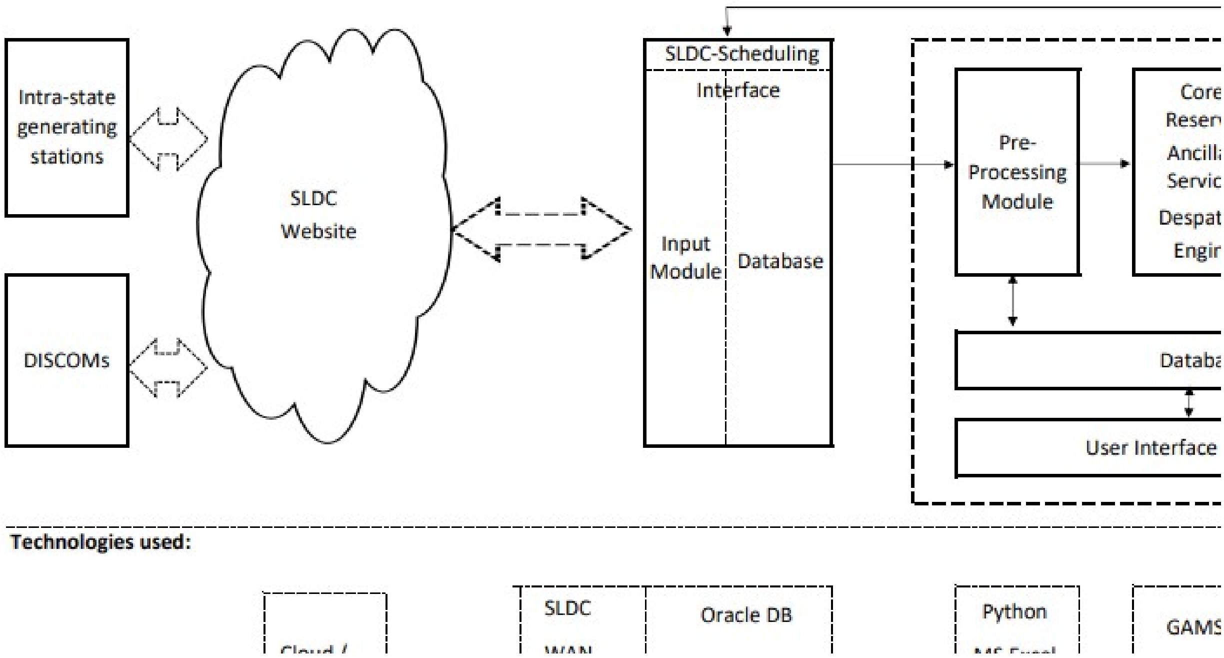


Figure 22: Typical schematic for IT infrastructure and information flow

Writing software requirement specifications(SRS) may be challenging. The application software would evolve organically through a combination of inhouse applications and over-the-shelf external applications deployed with support from a professional system integrator.

A mix of technologies have to be integrated and data exchange has to take place between different layers of technologies at SLDCs and different stakeholders. The infrastructure requirements have to comply with stringent timelines. The scheduling application of respective SLDCs is accessed through public internet by different entities and hence, cyber security and data integrity assumes significant importance. A secure data communication network (Private/Public links) is needed for data exchange between databases in different SLDCs and various stakeholders.

There is a need for application server such as Windows Server with adequate RAM, Disk space, drives and cores. There is also a need for a Database Server (e.g. Oracle DB, .NET, Mongo DB etc.) for data warehousing. The database backup in terms of both physical backup and logical backup assumes significant importance (e.g. SAN - Storage Area Network). There is a need for other technologies including open source ones such as PHP, HTML, CSS, JavaScript, Node.js, Python etc. to interact with the databases, interface with the data and generate user defined reports. The software development is needed SLDCs for seamless data flow for implementation of intra-state ancillary services.

Databases like Oracle DB and Mongo DB could be used in the application development. Oracle DB stores all the sensitive data and for user Interface interaction and graph rendering. Mongo DB is used to keep a replica of data for faster access. This also helps in the keeping the data in Oracle DB safe as the number of data requests from Oracle DB is reduced. The user interface and data analysis web application use Node JS and Python. Node JS is used for web application backend development. Python is used for development of Core-Engine and scripts for fetching data at regular intervals.

The important considerations for the IT infrastructure shall be as under

a. The functional specifications shall be in line with the regulations
b. Test development system
c. Troubleshooting
d. Database applications
e. Data repository
f. Dedicated broadband communication with route diversity
g. Data exchange through API / file transfer
h. Professional optimization engine
i. Cyber security
j. Visualization tools
k. Stakeholder interface
l. Reporting tools
m. Accounting
n. Reconciliation

7.1. Template for Displays /Dashboards

A typical display of available margins in the participating generators in the 96-time blocks is illustrated below. The display should fetch data from the scheduling application and get refreshed after every revision. Similar display could be created for intrastate generating stations.

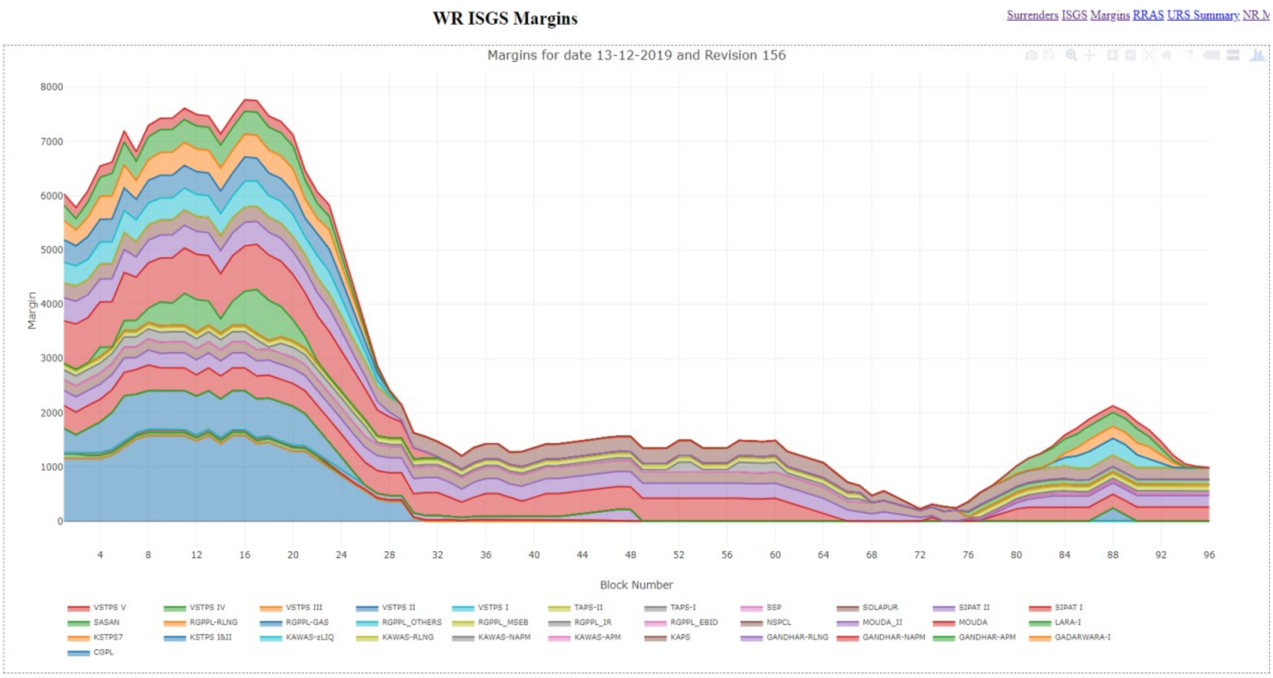
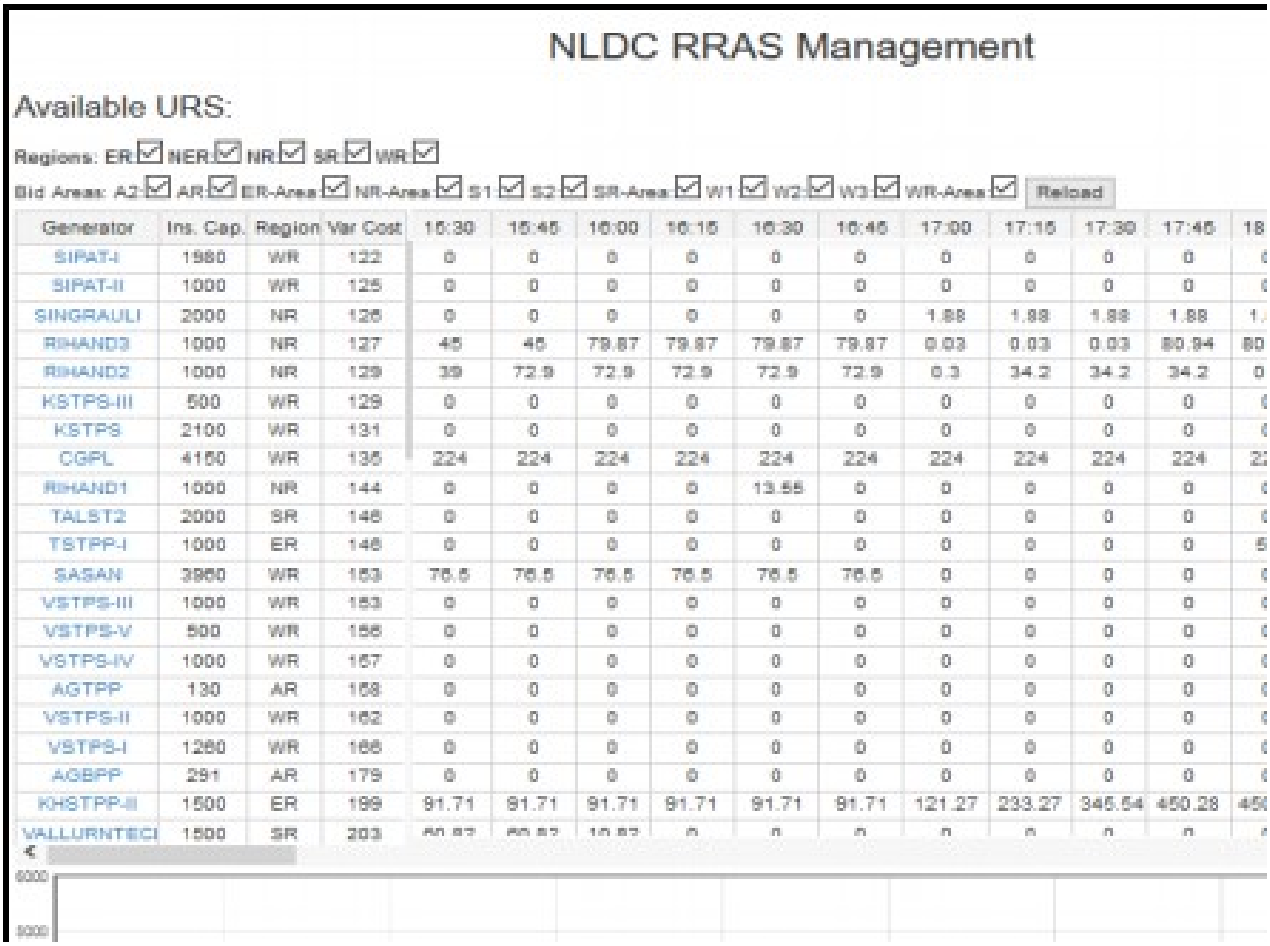


Figure 23: Reserves in western region on a typical day

A typical user interface for dispatching the available reserves is illustrated below.



NLDC RRAS Management

Available URS:

Regions: ER NER NR SR WR

Bid Areas: A2 AR ER-Area NR-Area S1 S2 SR-Area W1 W2 W3 WR-Area Reload

Generator	Ins. Cap.	Region	Var Cost	15:30	15:45	16:00	16:15	16:30	16:45	17:00	17:15	17:30	17:45
SIPAT-I	1980	WR	122	0	0	0	0	0	0	0	0	0	0
SIPAT-II	1000	WR	125	0	0	0	0	0	0	0	0	0	0
SINGRAULI	2000	NR	126	0	0	0	0	0	0	1.88	1.88	1.88	1.88
RIHAND3	1000	NR	127	45	45	79.87	79.87	79.87	79.87	0.03	0.03	0.03	80.94
RIHAND2	1000	NR	129	39	72.9	72.9	72.9	72.9	72.9	0.3	34.2	34.2	34.2
KSTPS-III	500	WR	129	0	0	0	0	0	0	0	0	0	0
KSTPS	2100	WR	131	0	0	0	0	0	0	0	0	0	0
CGPL	4150	WR	135	224	224	224	224	224	224	224	224	224	224
RIHAND1	1000	NR	144	0	0	0	0	13.55	0	0	0	0	0
TALST2	2000	SR	146	0	0	0	0	0	0	0	0	0	0
TSTPP-I	1000	ER	146	0	0	0	0	0	0	0	0	0	0
SASAN	3960	WR	153	76.5	76.5	76.5	76.5	76.5	76.5	0	0	0	0
VSTPS-III	1000	WR	153	0	0	0	0	0	0	0	0	0	0
VSTPS-V	500	WR	156	0	0	0	0	0	0	0	0	0	0
VSTPS-IV	1000	WR	157	0	0	0	0	0	0	0	0	0	0
AGTPP	130	AR	158	0	0	0	0	0	0	0	0	0	0
VSTPS-II	1000	WR	162	0	0	0	0	0	0	0	0	0	0
VSTPS-I	1260	WR	166	0	0	0	0	0	0	0	0	0	0
AGBPP	291	AR	179	0	0	0	0	0	0	0	0	0	0
KHSTPP-II	1500	ER	199	91.71	91.71	91.71	91.71	91.71	91.71	121.27	233.27	345.54	450.28
VALLURNTECI	1500	SR	203	60.87	60.87	10.87	0	0	0	0	0	0	0

Figure 24: User interface for RRAS management

Source: http://www.iitk.ac.in/npsc/Papers/NPSC2016/1570291562.pdf

7.2. Cost Estimate for IT infrastructure

<table>
<tr><th colspan="3">At SLDC Control Centre</th></tr>
<tr><th>S.No.</th><th>Title</th><th>Approximate Cost (in ₹)</th></tr>
<tr><td>1.</td><td>Annual License for Open source, object-oriented web application development platform</td><td>65,000</td></tr>
<tr><td>2.</td><td>Single User Licenses License for High-level Modeling System for Mathematical Optimization with Solver(E.g. GAMS Optimization Software with CPLEX Solver)
Multi-User/Department (MUD) Licenses:
<table>
<tr><td>License</td><td>Users</td><td>Price</td></tr>
<tr><td>small MUD</td><td>up to 5</td><td>twice the price of a single user system</td></tr>
<tr><td>medium MUD</td><td>up to 10</td><td>three times the price of a single user system</td></tr>
<tr><td>large MUD</td><td>up to 20</td><td>four times the price of a single user system</td></tr>
</table></td><td>7,00,000

(USD 9600 as per 04th February, 2019 Standard Price List)</td></tr>
<tr><td>3.</td><td>Database (Oracle DB – Two Processors) –
Perpetual License
Annual Subscription Charge</td><td>Perpetual License – 18,00,000
Software Update – 2,50,000
Support – 1,00,000</td></tr>
<tr><td>4.</td><td>Two Server(s) (Main and Hot Standby) to install all the desired software</td><td>24,00,000</td></tr>
<tr><td>5.</td><td>Two Workstations</td><td>1,70,000</td></tr>
<tr><td>6.</td><td>Rack</td><td>65,000</td></tr>
<tr><td></td><td>Total</td><td>55,50,000</td></tr>
</table>

https://www.gams.com/fileadmin/standard_price_list.pdf

Disclaimer: The prices are subject to competitive tendering process and customized requirement of the respective SLDCs and will be based on budgetary offer after finalization of requirement. These prices are in no manner reference to the actual costs/prices prevalent in the open market and therefore, are only indicative in nature. The costs of software development and communication for the implementation of the above framework are not included.

8. Recommendations

8.1. Balancing paradigms

The paradigms for balancing in the Indian power system have evolved over the years. Policy and regulatory interventions have been towards facilitating interconnection of the State grid, formation of regional grids and the national synchronous grid to harness diversity benefits and enlarging the balancing area. Initiatives have been also taken to facilitate better portfolio management by enabling access to the market through non-discriminatory open access alongside narrowing of the operating band for frequency and passive balancing through the imbalance price signals (UI/DSM vector, gradual coupling with market). With growing adequacy of generation in the States, the Indian power system is under transition from the 'load-follow-generation' mode (due to chronic scarcity) of operation to the 'generation-follow-load' mode of operation.

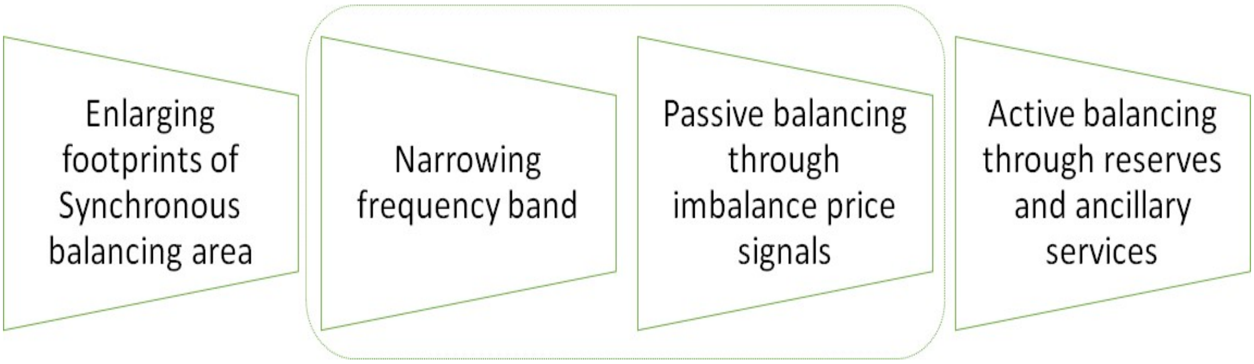


Figure 25: Balancing paradigms

In view of the rise in VRE, it is imperative to take up active balancing through automatic loop controls along with established system of passive balancing. This requires recognition of flexibility attributes (peaking, ramping, load-following, regulation, minimum turn down, overload etc.), assessment of reserve requirement (through deterministic, stochastic techniques), acquiring the reserve capacity (through regulated or competitive route), dispatching reserves optimally through ancillary services and financial settlement of the services rendered.

8.2. Margins in part loaded generators to be considered as reserves

The margins available on part loaded generating units is the spinning reserve to be actuated through different means (primary, secondary or tertiary). Spinning reserves would be created through periodic unit commitment. This would mean that no generating unit would be earmarked exclusively as spinning reserves. Fast starting gas and hydro units could be factored subject to the energy constraints (arising from fuel / water release schedules / reservoir management).

8.3. Distributed primary reserves

It is desirable to have primary reserves distributed over large number of units instead of maintaining it in few units. It would mitigate the risk and ensure availability of primary response. This would avoid large variation in the power flow across the network due to the primary response during the quasi-steady state. The primary reserve for automatic primary response to be maintained in all coal-fired units of capacity 200 MW and above, all gas turbines of capacity 50 MW and above and all hydro units of capacity 25 MW and above. All the units on bar would respond as per their droop characteristics to stabilize the frequency post contingency. In order to ensure adequate reserves for primary response, the injection schedule of the intrastate generating stations issued by the SLDCs should not exceed capacity on bar less normative auxiliary consumption of the respective stations. The primary response could be monitored as per the CERC approved procedure.

8.4. Prerequisites for implementation of essential reliability services

The pre-requisites for implementation of intrastate essential reliability services are as follows:

i. Notification of norms for minimum turn down level, upper scheduling limit and ramp rate
ii. Apriori knowledge of variable charges of intrastate generators
iii. Robust SAMAST system and Intrastate deviation settlement system
iv. Adequacy of human resources and IT infrastructure at SLDC in line with CABIL report
v. Creation of a non-zero and surplus regulatory pool (by design) for deviation settlement pool [through hysteresis and non-linearity in duel, non-reciprocal settlement rate nuances]to take care of default in payments, cash flow

8.5. Computation of area control error

The imbalance of the State control area shall be measured in terms of Area Control Error (ACE) at the state periphery (jurisdiction boundary). ACE shall be computed as below:

Area Control Error (ACE) = (Ia - Is) - 10 * Bf * (Fa - 50) + Eσ

Ia = Actual net interchange [-ve for import, +ve for export]

Is= Scheduled net interchange

Bf = Frequency bias coefficient in MW/0.1 Hz, negative value

Fa = Actual System Frequency

Eσ= Measurement Error

8.6. Dimensioning of secondary and tertiary reserves

The requirement of reserves depends on the forecast errors (demand, RE generation), credible contingencies, scheduling interval and ramping constraints. The reserve requirement shall be assessed periodically with the help of suitable probabilistic method based on historical Area Control Errors. Efforts shall be made to maintain the reserves through unit commitment over a rolling window. The reserve requirement would gradually reduce by the following ways:

- improvement of load forecast
- improvement in wind and solar forecasts
- reduction in frequency of plant outages
- improved intra-day market liquidity allowing better portfolio management
- reduction in scheduling interval
- enhancing market liquidity and access to fast markets
- shorter gate closure

8.7. Pre-requisites for computation of available reserves in real-time

Knowledge of the following scheduling limits is essential for computation of available reserves

i. Normative Auxiliary consumption to obtain the Normative Declared Capacity
ii. Declared ex-bus capacity (Pmax)
iii. Minimum turn down levels (Technical minimum or Pmin) (as % of normative DC)
iv. Ramp-up rate and ramp down rate (% of installed capacity per min)
v. Start-up time
vi. Minimum up time
vii. Minimum shutdown time

The above limits shall be as per the notified norms of operation by the State Electricity Regulatory Commission.

8.8. Implementation of secondary control

Automatic generation control should be implemented particularly in large and renewable-rich states for controlling the area control error. It would require AGC application software at SLDC as well as at the participating generating station; reliable wideband wide band communication system between SLDC and the generating station, measurement and computation of area control error. AGC at the regional level would regulate the output of the participating interstate generating stations while the AGC at the State level would regulate participating intrastate generating stations. Accounting and settlement of residual energy on account of AGC regulation as well as incentive for mileage needs to be evolved.

8.9. Gate closure for dispatching intrastate reserves

In the decentralized scheduling mechanism, the generating stations have the freedom to revise the station declared capacity while the discoms have the freedom to revise their requisitions (in approved long-term and short-term transactions). However, some definite time (ahead of the delivery time) needs to be set aside for enabling the SLDC to assess the available reserve with certainty and to dispatch them in the most optimum manner. This would be possible only with notification of the gate closure time for revision in DC and requisitions and strict adherence to the same by all stakeholders. The gate closure timeline at intrastate level would have to be aligned with the gate closure at the interstate level.

8.10. Sanctity of variable charges or energy charge rate

The merit order stack for dispatching the reserves is prepared from the ex-ante declared energy charge rate. Wherever there is single part generation tariff, the concept of incremental cost may have to be considered. This would get factored in the bids when reserves are arranged competitively. For the purpose of ancillary, post facto revisions should be avoided in the energy charge rate declared ex-ante by the generating station.

8.11. Sanctity of ex-ante DC and injection schedule

Available up-reserves is derived from the DC and the injection schedule. Therefore, no post facto revisions should be allowed in the DC and the injection schedules.

8.12. Computation of available reserves in real time

The reserves available in real-time shall be computed as under:

a. Cold reserve = Total DC minus DC on bar
b. Hot spinning up Reserve = DC_on bar minus Injection Schedule
c. Hot spinning down Reserve = Injection Schedule minus Technical minimum

Schedules ramp rate = (Schedule in block T+1) minus (Schedule in block T)

The dispatchable reserves shall be limited by the maximum station ramp rate.

The tertiary reserves of a State in the interstate generating stations shall be computed separately with reference to the entitlement of that State in the concerned ISGS.

8.13. Monitoring of available reserves

Monitoring availability of reserves in real time assumes importance for its effective deployment in the most optimal way. The mechanisms and tools for facilitation of reserve monitoring & deployment by real time operators at SLDC must enable the operator

a. to see the trend of reserve available for next few time blocks
b. to decide how much reserve is to be pressed in to service
c. to assess the cost of these reserves
d. to ensure most optimal deployment of reserves

Reserve cannot be measured by meters. It is an assessment only. Besides active/reactive power reserves must have following attributes – Energy delivered, time of delivery, cost of carrying reserves, and cost of dispatching. The reserves available in hydro units is energy constrained due to inflows/reservoir levels and water release schedule for storage hydro while the reserves available in thermal units is ramp constrained.

8.14. Unit commitment to ensure reserves

Unit commitment is essential as it would ensure reserves over a rolling window. Under provisioned unit commitment would reduce availability of online reserves as well as the overall cost while over provisioned unit commitment enhances the quantum of online reserves and the overall cost. However, unit commitment is a lumpy decision and there is no unique or simple solution. It calls for information on start-up cost, shut-down costs, start-up time, minimum operating time of units etc. Presently the unit commitment decisions are being taken heuristically. A more rigorous and scientific approach for unit commitment is desirable in future. Further Value of Lost Load becomes important in the context of unit commitment.

8.15. Despatch of reserves

Merit order stack (based on the energy charge rate) of the available reserves shall be prepared by the SLDC. The role of SLDC shall be delineated from discoms in optimizing the dispatch of reserves. The decision regarding the quantum of reserves to be despatched shall be taken based on the following operating conditions: Trend of Area Control Error, Ramping capability of the available vis-à-vis observed ramp in the net load, congestion management etc. Adoption of algorithmic approach for co-optimization of energy and reserves is desirable to minimize the total production cost. Mechanisms to override the infeasibilities observed during the optimal dispatch would evolve with experience.

8.16. Honoring intrastate transmission constraints

The evacuation constraints from the intrastate generators and the transfer capability of different corridors within the intrastate network shall be honored while dispatch of reserves.

8.17. Creation of virtual ancillary entity

Reserves shall be despatched from the ancillary service providers to pool (or vice-versa) without disturbing the underlying power purchase agreements and requisitions. A virtual ancillary entity shall be created within the intrastate scheduling application to convert single entry. The VAE shall be a member of the intrastate deviation pool. It shall act as the counterparty for the schedule prepared for despatch of reserves by the ancillary services providers. For regulation up service, power shall be scheduled from the generating station to the virtual ancillary entity by the concerned nodal agency, until such time the nodal agency gives instruction for withdrawal of service. For regulation down service, power shall be scheduled from the virtual ancillary entity to the generating station, so that effective scheduled injection of the generating station comes down, until such time the nodal agency gives instruction for withdrawal of service.

Scheduling of reserves through VAE will enable scheduling of reserves without unsettling existing contracts. It would also establish a double entry system in the dispatch of reserves and enable check and balance in the mechanism.

8.18. Incentives for essential reliability service providers

Suitable mechanisms for compensating and incentivizing various flexibility services (ramping, reserve regulation, peaking etc.) could be evolved in the State through a consultative process.

8.19. Settlement of despatched reserves through regulatory pool account

The despatched reserves shall be treated as deemed delivered. It shall be subsumed in the injection schedule derived by aggregation of the requisition of all beneficiaries of that station. Thus, the deviation of the station shall be computed by subtracting the measured injection from the scheduled injection (including ancillary). The ancillary service provider shall be remunerated for the energy scheduled at the energy rate approved/adopted by the regulatory commission plus a mark-up to be decided by the SERC. The surplus available in the intrastate imbalance pool could be used for compensating the ancillary service providers. The actual interchange of VAE with the grid would be zero as it is not a physical entity and it is not bounded by meters. The energy despatched under Reserves Regulation Ancillary Services would be deemed as delivered ex-bus. However, VAE would be a member of the intrastate DSM pool. Separate account shall be maintained for collection and disbursement of charges related with reserves dispatch. After gaining sufficient experience the ambit of ancillary service providers could be expanded by evolving suitable mechanism for procuring reserves competitively. The settlement period could initially be 15-min. Settlement at 5-min interval could be considered subsequently when the matching infrastructure for scheduling, energy metering, accounting and settlement is available.

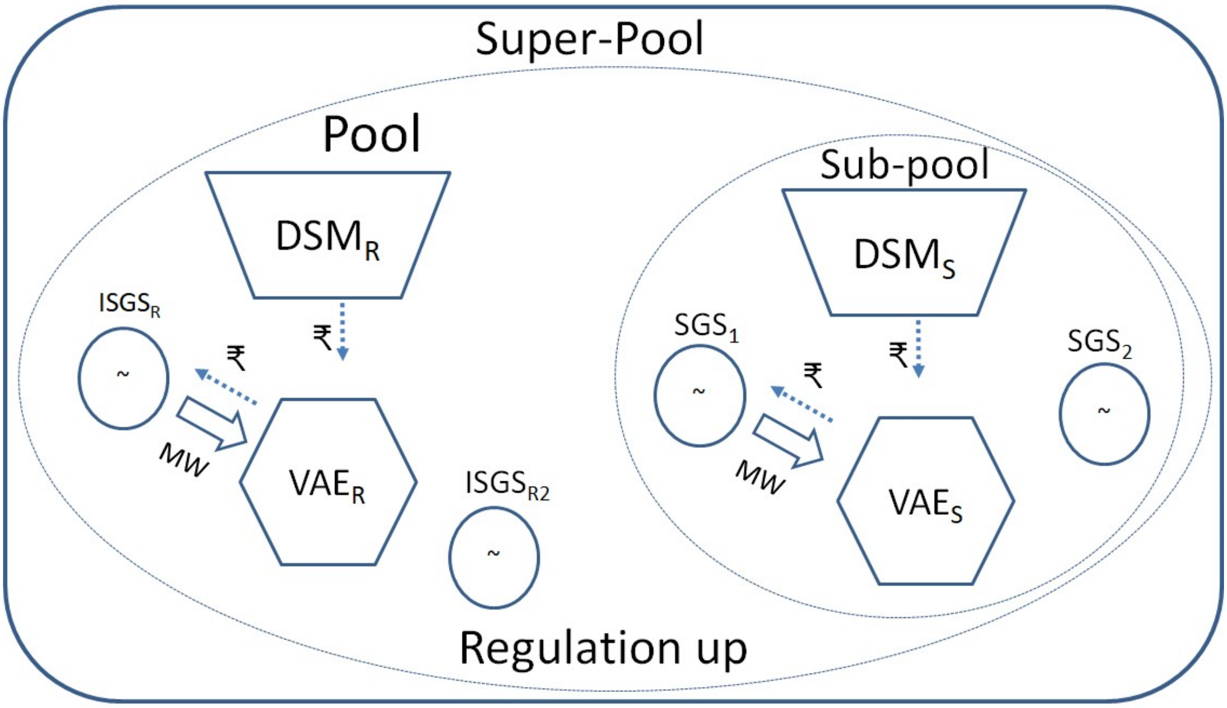


Figure 26: Regulation up service in nested control area

8.20. Information and Communication Technology infrastructure

Assessment, visualization and dispatch of reserves shall be through a robust and versatile optimization algorithm. A reliable and path redundant communication channel shall be provided for ensure the delivery of dispatch instructions the ancillary service providers in the electronic form. In addition, the reserves dispatch shall be posted transparently on the SLDC website for ease of access of the concerned stakeholders.

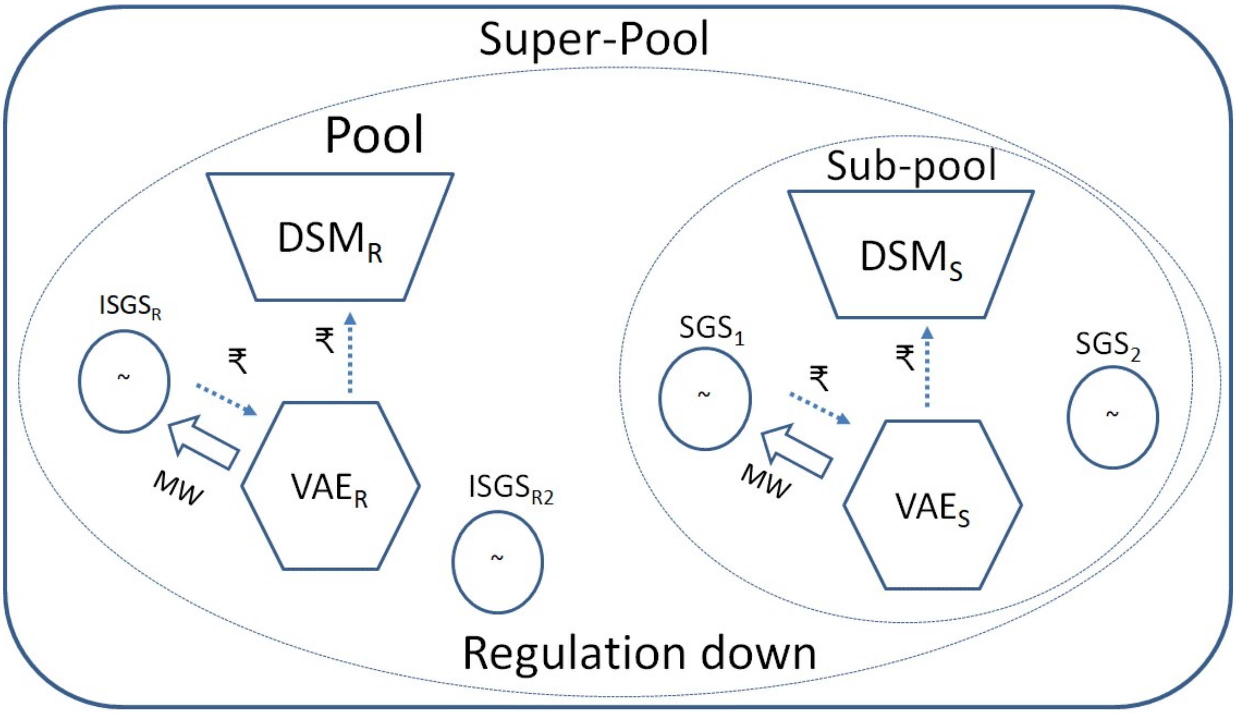


Figure 27: Regulation down service in a nested control area

8.21. Transmission charge and loss administration

Philosophy for application of transmission charges and of transmission losses for the reserves despatched shall be declared in advance. There shall be no post facto truing up transmission charges and losses.

8.22. Capacity building

Suitable initiatives for capacity building in the market simulation, optimization techniques, harnessing of flexibility attributes, reserve assessment and ancillary service shall be taken up in collaboration with industry experts, academia and Forum of Load Despatchers.

8.23. Regulation for intrastate reserves and ancillary services

The draft model regulation for intrastate reserves and ancillary services is enclosed as **Annex-VI**. The regulations could suitably consider deployment of lift irrigation schemes and pumped storage hydro stations under the ancillary services. The procedure for assessment, monitoring, despatch and settlement of reserves shall be prepared in consultation with all stakeholders and approved by the State Electricity Regulatory Commission.

8.24. Periodic review of the progress of implementation

An appropriate committee may be constituted for monitoring the progress of implementation of the recommendation in different States. The committee may provide guidance and enable hand-holding through experience sharing across different States.

9. Road map

The suggested roadmap for implementation of the intrastate reserves and ancillary services is as below:

Table 14: Suggested roadmap for implementation

S No.	Activity	Cumulative time (from zero date)
1	Stakeholder workshop on the SANTULAN report and the Model regulations by SLDC	**15 days**
2	Draft amendment of intrastate Grid Code by SERC for maximum scheduling limit, technical minimum, ramp rate for generating units etc. by SERC	**30 days**
3	Notification of the amendment after stakeholder discussion	**90 days**
4	Publication of the draft regulations on reserves and ancillary services for intrastate grid based on the Model regulations	**100 days**
5	Notification of the regulations on reserves and ancillary services for intrastate grid	**160 days**
6	Submission of a procedure for implementing intrastate reserves and ancillary services by SLDC after stakeholder consultation	**190 days**
7	SERC approval of the Procedure for intrastate reserves and ancillary services after stakeholder consultation	**210 days**
8	Procurement of hardware and development of software by SLDC	**300 days**
9	Furnishing details to SLDC by intrastate reserves and ancillary service providers	**330 days**
10	Go live	**365 days**

The above timeline is only indicative. The actual implementation would depend on the available resources and State specific constraints.

"***An error does not become truth by reason of multiplied propagation, nor does the truth become error because nobody will see it***"-Mahatma Gandhi

10. Bibliography

[1] Central Electricity Regulatory Commission (CERC) Staff Paper on Introduction of ancillary services in Indian Electricity Market, 10th April 2013http://www.cercind.gov.in/2013/whatsnew/SP13.pdf

[2] CERC - Discussion Paper on Re-designing Ancillary Services Mechanism in India, Sep 2018 http://www.cercind.gov.in/2018/draft_reg/DP.pdf

[3] Ministry of Power, GoI, National Electricity Policy 2005 https://powermin.nic.in/en/content/national-electricity-policy

[4] CERC(Indian Electricity Grid Code) 4th Amendment Regulations 2016 http://www.cercind.gov.in/2016/regulation/9.pdf

[5] CERC-Approved procedure for taking units under reserve shut down & compensation mechanism for part load operation and multiple start-stop of thermal generating units, May 2017 http://www.cercind.gov.in/2017/regulation/SOR132.pdf

[6] CERC– Road map to operationalise reserves in the country, October 2015) http://www.cercind.gov.in/2015/orders/SO_11.pdf

[7] CERC - Report of the Committee on Spinning Reserves 17.09.2015 http://www.cercind.gov.in/2015/orders/SO_11.pdf http://www.cercind.gov.in/2015/orders/Annexure-%20SpinningReseves.pdf

[8] National Load Despatch Centre (NLDC) - Detailed procedure for operationalisation of reserves 14th Jul 2017 https://posoco.in/download/detailed-modus-operandi-on-operationalization-of-spinning-reserves/?wpdmdl=13461

[9] CERC (Ancillary Services Operations) Regulations 2015 & revised detailed procedure http://www.cercind.gov.in/2015/regulation/Noti13.pdf ; http://www.cercind.gov.in/2016/regulation/revisedSOR.pdf

[10]CERC Order on AGC pilot project 6th Dec 2017 (Pet 79/RC/2017) http://www.cercind.gov.in/2017/orders/79_rc.pdf

[11]CERC Order on AGC implementation pan India 29th Aug 2019 (Pet 319/RC/2018) http://www.cercind.gov.in/2019/orders/319-RC-2018.pdf

[12]POSOCO – Requirement of equipment for AGC implementation at power plants Sep 2019 https://posoco.in/download/communication-to-power-plants-regarding-agc/?wpdmdl=24784

[13]CERC order (02/SM/19) on implementation of Security Constrained Economic Despatch (SCED) on pilot basis – 31 Jan 2019 http://www.cercind.gov.in/2019/orders/02-SM-2019.pdf

[14]CERC order on extension of Security Constrained Economic Despatch (SCED), Sep 2019 http://www.cercind.gov.in/2019/orders/08-SM-2019.pdf

[15]POSOCO Detailed procedure for implementation of SCED (Rev-01, April 2019 and Rev 02, October 2019) https://posoco.in/download/letter-to-generators-sced/?wpdmdl=24893; https://posoco.in/download/revised-detailed-procedure-w-e-f-01-10-2019/?wpdmdl=25183

[16]POSOCO Interim report on pilot on implementation (Security Constrained Economic Despatch) August 2019 https://posoco.in/wp-content/uploads/2019/09/Interim-Feedback-Report-Pilot-on-SCED.pdf

[17]POSOCO Implementation of pilot project on Hydro as fast response ancillary services – half yearly analysis report, 30th Jul 2019 https://posoco.in/wp-content/uploads/2019/08/POSOCO_FRAS_Feedback.pdf

[18]CERC - Report of Expert Group to review and suggest measures for bringing power system operation closer to National Reference Frequency (Volume-I) (https://posoco.in/download/report-of-expert-group-to-review-and-suggest-measures-for-bringing-power-system-operation-closer-to-national-reference-frequency/?wpdmdl=16059)

[19]POSOCO - Flexibility Requirement in Indian Power System, Jan 2016 (https://posoco.in/download/flexibility_requirement_in_indian_power_system/?wpdmdl=711)
[20]POSOCO Analysis of ramping capability of coal fired stations in India Apr 2019 (https://posoco.in/download/analysis-of-ramping-capability-of-coal-fired-generation-in-india/?wpdmdl=23042)
[21]FOR Sub-group Report on Introduction of five-minute scheduling, metering, accounting and settlement in Indian Electricity Market, Feb 2018http://www.forumofregulators.gov.in/Data/Reports/5.pdf
[22]POSOCO and NREL report, 'Opening Markets, Designing windows, and closing gates: India's Power System Transition - Insights on Gate Closure', Aug 2019 https://www.nrel.gov/docs/fy19osti/72665.pdf

Relevant literature

[23]Y G. Rebours, Daniel S. Kirschen, Marc Trotignon and Sebastien Rossignol, 'A Survey of frequency and voltage control ancillary services-part II: Economic Features', IEEE Transactions on Power Systems, Vol. 22, No. 1, February 2007 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.98.8865&rep=rep1&type=pdf
[24]Y. Rebours and Daniel Kirschen, "A Survey of Definitions and Specifications of Reserve Services", Release 1, the University of Manchester, the 19th of September 2005. https://www.researchgate.net/publication/242170645_A_Survey_of_Definitions_and_Specifications_of_Reserve_Services
[25]Erik Ela, Michael Milligan, and Brendan Kirby, "Operating Reserves and Variable Generation", Technical Report, NREL, August 2011. https://www.nrel.gov/docs/fy11osti/51978.pdf
[26]Eric Hirst and Brendan Kirby, Unbundling Generation and Transmission Services for Competitive Electricity Markets: Ancillary Services, NRRI98-05, National Regulatory Research Institute, Columbus, OH, Jan. 1998 (https://www.researchgate.net/publication/253981336_Unbundling_generation_and_transmission_services_for_competitive_electricity_markets)
[27]Eric Hirst, Brendan Kirby - Allocating Costs of Ancillary Services: Contingency Reserves and Regulation, June 2003 (https://www.researchgate.net/publication/248775533_Allocating_Costs_of_Ancillary_Services_Contingency_Reserves_and_Regulation)
[28]NREL report on Flexibility Reserve Reductions from an Energy Imbalance Market with High Levels of Wind Energy in the Western Interconnectionhttps://www.nrel.gov/docs/fy12osti/52330.pdf
[29]FERC Order 888, https://www.ferc.gov/legal/maj-ord-reg/land-docs/order888.asp
[30]NERC, "Operating manual", 15th of June 2004. (http://quantlabs.net/academy/download/free_quant_instituitional_books_/[NERC]%20NERC%20Operating%20Manual%20-%20June%202004.pdf
[31]NERC, 'Essential Reliability Services - Whitepaper on Sufficiency guidelines', Dec 2016 https://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSWG_Sufficiency_Guideline_Report.pdf
[32]Lion Hirth, Inka Ziegenhagen,' Balancing power and variable renewables: Three links', Renewable and Sustainable Energy Review 50 (2015), pp 1035-1051, Elsevier ScienceDirect https://www.neon-energie.de/Hirth-Ziegenhagen-2015-Balancing-Power-Variable-Renewables-Links.pdf
[33]Marissa Hummon, Paul Denholm, Jennie Jorgenson, and David Palchak, "Fundamental Drivers of the Cost and Price of Operating Reserves", Technical report, NREL, July 2013.(https://www.nrel.gov/docs/fy13osti/58491.pdf)
[34]Bringing Variable Renewable Energy Up To Scale, Options for Grid Integration Using Natural Gas and Energy Storage‟, The Energy Sector Management Assistance Program (ESMAP) Technical

report, February 2015 (https://openknowledge.worldbank.org/bitstream/handle/10986/21629/ESMAP_Bringing%20Variable%20Renewable%20Energy%20Up%20to%20Scale_VRE_TR006-15.pdf)

[35]Understanding Automatic Generation Control - A report of the AGC Task Force of the IEEE PES/PSE/System Control subcommittee‟, August 1992.

[36]CIGRE Technical Brochure no 450: February 2011, Grid Integration of Wind Generation (https://e-cigre.org/publication/450-grid-integration-of-wind-generation

[37]General algebraic modelling systems (GAMS) tutorial (https://www.gams.com/latest/docs/UG_Tutorial.html)

[38]A GAMS TUTORIAL by Richard E. Rosenthal Naval Postgraduate School Monterey, California USA

[39]Narayan S. Rau - Optimization principles Practical Applications to the Operation and Markets of the Electric Power Industry – IEEE Press (ISBN 0-471-45130-4)

[40]Alizera Soroudi – Power System Optimization Modelling in GAMS, © Springer International Publishing (ISBN 978-3-319-62350-4 ebook)

[41]Video tutorials for GAMS (https://www.youtube.com/watch?v=98wJKIuRLPI; https://www.youtube.com/watch?v=OgQbk2dhhyA)

[42]NPTEL videos on optimization techniques (https://www.youtube.com/watch?v=4s3Ks-yNufc&list=PLbMVogVj5nJT8iTaUR8FoWBuJy0vs-Z3C; https://www.youtube.com/watch?v=PHapE1hyxJ8&list=PLbRMhDVUMngct1skDAxoR2xhbIqOnAt0H&index=2)

[43]Video Tutorials for Excel Solver (https://www.youtube.com/watch?v=tJkHxpoX3kU&feature=youtu.be; https://www.youtube.com/watch?v=vWEEdg3tIpY&feature=youtu.be)

[44]Office Journal of the European Union – Part-IV (Load Frequency Control & Reserves) 25.08.2017

Annex-I:Constitution of the sub-group

FORUM OF REGULATORS (FOR)

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Telefax Nos. : 011-23353503/23753920

No.1/14/2015-Reg.Aff.(FSDS)/CER Dated: 22.02.2019

Subject: Constitution of Sub-Group on 'Reserves and Ancillary Services at State Level' under FOR Standing Technical Committee

Reference discussion during the 22^{nd} Meeting of the Standing Technical Committee for "Implementation of Framework on Renewables at the State Level" held on 1^{st} November 2018 at New Delhi, wherein it was decided to constitute a Sub-Group for pilot on Reserves and Ancillary Services for the States. It was also decided that the pilot project could be initiated without waiting for State Regulations on the Reserves and Ancillary and CERC regulation can be used for reference for Pilot Project.

2. Accordingly, a sub-group on 'Reserves and Ancillary Service at State Level' of the Standing Technical Committee of the Forum of Regulators (FOR) is hereby constituted with the following composition:-

1. Shri S.K Soonee, Advisor , POSOCO, - Chairman of the sub-group
2. Representative of GERC (Gujarat) - Member
3. Representative of MERC (Maharashtra) - Member
4. Representative of MPERC(Madhya Pradesh) - Member
5. Representative of TSERC(Telangana) - Member
6. Chief Engineer, SLDC Gujarat - Member
7. Chief Engineer, SLDC Maharashtra - Member
8. Chief Engineer, SLDC Madhya Pradesh - Member
9. Chief Engineer, SLDC Telangana - Member
10. Executive Director, WRLDC, Mumbai - Member
11. Executive Director, SRLDC, Bengaluru - Member
12. Representative of NLDC, New Delhi - Member
13. Representative of CERC/FOR, - Member/Convener

3. The Terms of Reference of the Sub-group are as under:-

i. To disseminate the learning from the experience of implementing the reserve regulation ancillary services and fast response ancillary services at the interstate level and recommend the roadmap for implementing similar mechanisms at the state level.

ii. To recommend the model regulations for harnessing the flexibility attributes, maintaining the mandated reserves and deploying them under normal and contingent scenario through intra-state reserve regulation ancillary services.

i.

iii. Any other recommendation as deemed fit in the context.

4. The sub-group may co-opt any other member, as deemed fit.

Yours Faithfully,

Sd/-
(Rashmi Somasekharan Nair)
Deputy Chief (RA)

Copy to:

Members of the Sub-Group (as above)

Copy for information to:

PPS to Chairperson, CERC /FOR
Sr. PPS to Secretary, CERC
PS to Joint Chief (RA)

Annex-II: Consolidated discussion summary of subgroup meetings

1st meeting- 06 May 2019, NLDC New Delhi

1. Advisor (RE), CERC, as Member-Convenor, welcomed the participants to the meeting. It was highlighted that the regulatory framework on reserves and ancillary services at inter-state level have facilitated secure and reliable system operation. The regulatory framework on reserves and ancillary services are also required to be implemented at intra-state level which would facilitate better and flexible system operation, especially in case of renewable rich states.
2. The chairman of the sub-group gave a brief background on the constitution of the sub-group and stressed on the need for Reserves and Ancillary Services in large grids like India. The sub-group would focus on harnessing reserves at state level with appropriate settlement mechanisms. While report preparation is one of the tasks, the sub-group would attempt to create, test and implement a real-time on-the-ground pilot on reserves and ancillary services in some of the states.
3. The Chairman of the sub-group read out the ToR and sought suggestions to co-opt any other expert(s) in the sub-group. SLDC (Guj.) representative opined that a member from academia may be co-opted. The Chair also suggested co-opting Sh. S K Chatterjee JC(RA), CERC as an expert in market design aspects to which all members agreed. Further, Ancillary Services are being increasingly recognized as Essential Reliability Services world-wide and accordingly, Ancillary Services may be renamed as “Essential Reliability Services”. These suggestions were agreed to by all the members.
4. A presentation was made by member representative from NLDC, POSOCO regarding experience gained in implmentation of Reserve Regulation Ancillary Service (RRAS) and Fast Response Ancillary Services (FRAS). A copy of the presentation is attached at **Annex – 2**. The main points presented include, inter-alia, System Balancing Continuum, Key Statistics, Analysis of RRAS & FRAS Despatch Instructions, Frequency Improvement, Real Time Case Studies and Key Learnings.
5. The key design needs for implementation of reserves/ancillary services were recognized as follows:
   - Tariff of Intra-state Generation Plants (Single-part/Multi-part)
   - Mechanism for Declaring Capability, Ramp Rates, Technical Minimum
   - Scheduling and Despatch
   - Imbalances and Settlement thereof
   - Computation of Reserves Quantum
   - Compensation Mechanism for Reserve
   - Incentive/Mark-up

- Settlement Systems
- Recovery for Sustainable Mechanism

6. In the context of FRAS from hydro, it was mentioned that intra-state hydro stations have water release and other constraints as per irrigation requirement and there may be difficulty in participation in ancillary services. The Chair clarified that after satifsfying all constraints, we can try to harness the flexibility of hydro. There is a need for mathematical formulation and validation of all legacy constraints. The computation and visualization of reserves (DC_on bar minus Schedule) in real-time is the starting point. There is a need for dashboard for the operator to see the merit order stack, up reserve, down reserve, maximum ramp up, maximum ramp down etc.
7. The member representative from Gujarat, SLDC made a presentation on state level ancillary services. The copy of the presentation is placed at **Annex – 3.** It was mentioned that SLDC may be appointed as Nodal agency for implementation. Nodal agency may be empowered to operate/trigger Ancillary services in pre-specified conditions.
   - All the state generating stations to be covered under this mechanism.
   - Generator to declare Fixed and Variable cost
   - Common merit order to be prepared and displayed on the website for the ancillary services.
   - Ancillary services be triggered based on merit order except in case of transmission constraints.
   - Hot and Cold reserves may be used as per requirement.
   - In case of original beneficiary requisites URS back, then schedule under ancillary may be dispatched from the next generator as per merit order for ancillary services,
   - In case of specific scheduling under ancillary service, that particular entity has to pay all (FC + VC) charges. FC to be compensated back to the original beneficiaries.
   - In case of settlement through the pool, generator may be paid FC+VC. FC to be compensated back to the original beneficiaries.
   - In case of backing down, generator need to pay to pool @ VC to the extent of backing down.
   - Technical minimum requirement of generation to be ensured.
8. The member representative from GERC opined that common merit order would have to be prepared for the state as a whole including MPPs/IPPS. The member representative from MPERC stated that provisions in PPAs may have to be factored as the tariff is not determined/adopted by the ERCs. The member representative from SLDC Maharashtra enquired on payment of variable charges to the pool upon backing down by the generator. Advisor (RE), CERC stated that part load compensation would also have to be factored. The ambit of ancillary services could be expanded to include Demand response and Energy storage in future. The member representative from SLDC, Gujarat suggested that this pilot on ancillary services would pave the way forward for integration of battery storage in the future.

9. The Chair emphasized that reserves/ancillary services have many flavours and variations worldwide. As a first step, computation of reserves available is required to be done based on Declared Capability, Schedule and Technical Minimum. Further, the quantum of despatchable reserve is limited by ramp constraints.
10. The member representative from SLDC, Telangana made a presentation to the sub-group. The copy of the presentation is placed at **Annex – 4.** The salient points were as follows:
    - The tariff of Intra-state generation plants is two part i.e. Fixed Charges and Variable charges
    - All intra state generators are declaring availability block wise on Day Ahead Basis. Revised availability declaration duly considering the tripping / Synchronization of units is being furnished by the Generators.
    - Reserve assessment is based on trend analysis (previous day, weather forecast and day of the week) load forecast on day ahead basis is carried out. The total availability considering the declarations furnished by all the generators (LTA & MTOA) is assessed along with quantum of power available from all Short term contracts. Hydel availability is also assessed considering any discharge instructions issued by KRMB.
    - There is no separate mechanism for Harnessing Reserves in the State. Load Generation Balance is being carried out as per existing IEGC and State regulations.
    - 500 MW Spinning Reserve is being maintained to meet any contingency in the form of hydro generation when Hydro resources are available.
    - When Hydro resources are not available , spinning reserve is being maintained in the form of back down of thermal generators as per Merit Order.
    - During surplus power conditions pumping mode of operation is being carried at srisailam and Nagarjuna'sagar hydel stations. It is being utilised during peak demand period and contingencies.
    - Settlement of intrastate generators is being carried out through a mutual accepted procedure which is approved by TSERC. There is no separate incentive mechanism for despatch of Reserves.
11. The member representative from SLDC, Telangana emphazized that there is need for ABT at intra-state level. Advisor (RE), CERC enquired about inter-state banking contract under overarching agreement. SLDC, Telangana stated that this arrangement was used on few occassions with bilateral contracts through RLDCs.
12. ED, WRLDC highlighted that in view of ABT mechanism in place in states of Gujarat and MP, there is a clear case for a pilot project. Maharashtra would also have ABT from 2020 onwards and hence, it would also be able to operationalize in future. ED, SRLDC stated that there is no ABT implementation in any of the five states of southern region.
13. The demonstration of reserves under RRAS and FRAS was made by member representative from NLDC, POSOCO. The Chair emphasized the need for similar mechanism for computation of reserves. The need for primary reserves was also emphasized.

14. The Chair observed that there are international standard techniques for reserve assessment and compensation. It was agreed that international literature survey would be carried out. Gujarat, SLDC volunteered to prepare a questionnaire on various aspects of reserves and ancillary services. The Chair emphasized the need for actual control room experience with implementaion of a pilot project in any of the willing states. The member from Gujarat SLDC graciously offered to host the next meeting at SLDC, Vadodara in the last week of May, 2019.
15. **Key Decisions Taken**
    - All member representatives to be added in SANTOLAN WhatsApp and Google groups to facilitate smooth communication.
    - SLDC Gujarat to prepare a questionnaire for survey of states regarding reserves & despatch.
    - Generators views/suggestions to be invited in the series of meetings in States.
    - A representative from Academia and Dr. S K Chatterjee, JC(RA), CERC to be co-opted as experts.
    - Next meeting to be held in last week of May, 2019 at Vadodara, Gujarat.

2nd meeting -07 Jun 2019, SLDC Gujarat

1. The Second meeting of the sub-group on 'Reserves and Ancillary Services at State Level' was held on 7th June 2019 under the Chairmanship of Shri S. K Soonee, Advisor, POSOCO. At the outset the member convener and Advisor (RE), CERC welcomed all the members and participants connected over VC from NLDC, SLDC Maharashtra, SLDC Madhya Pradesh, SLDC Telangana, SRLDC Bangalore and WRLDC Mumbai to the 2nd meeting of the FOR technical committee sub-group. The Member Conveyor thanked Chief Engineer (SLDC), Gujarat for organising the meeting and conveyed special thanks to the Member, GERC, Director (MERC) and Director (MPERC) for gracing the occasion with their presence. The meeting started with review of progress since the first meeting and the following points were deliberated
2. **Confirmation of the minutes of the first meeting:** The minutes of the first meeting held on 06.05.2019 were confirmed by all members.
3. **Progress review**:

    (1) It was informed by the Chairman that as per the decision in the first meeting Shri S K Chatterjee, Chief (RA) CERC and Professor Abhijit Abhayankar, IIT Delhi had been co-opted in the sub-group.

    (2) It was intimated by CE, SLDC Gujarat that survey questionnaires have been circulated by SLDC Gujarat & filled by SLDC Madhya Pradesh.

    (3) NLDC informed that the basic information on intra-state generators (Installed capacity, Pmax, Pmin, Variable charges) had been received from SLDC Gujarat & SLDC Madhya Pradesh.

4. **Chairman of the sub-group** emphasized on the need for taking up a pilot project in Western Region to create a success story and pave way for formulating the regulations for intrastate reserves and ancillary service. He also mentioned that the learning derived from the interstate level could be used by the States to leapfrog. The introductory presentation given by the Chairman is enclosed as **Annexure-2**.

The following points emerged to plan out the future course of action:

i. What is the tariff structure of intra-state power stations?
ii. What is the mechanism for conveying information on Declared Capability (DC) by the power stations to SLDC for scheduling?
iii. Is the fixed charge (FC) recovery linked with plant availability factor (PAF)?
iv. Can the PAF be verified by SLDC through the DC submitted by the generators?
v. What is the mechanism for imbalance handling & settlement within the state?
vi. Is there any intra-state regulation on computation & despatch of spinning reserves?
vii. How is the intra-state reserve being computed?
viii. Is the operator able to see the trend of reserve available for next few time blocks?
ix. Is operator confident as to how much reserve is to be pressed in to service?
x. Is operator able to assess the cost of these reserves?
xi. Is there a settlement system to pay for the reserve, utilised or unutilised?
xii. Is there a mechanism to establish that the most economic operation is followed?
xiii. Should we have a mechanism for compensating the power station for reserves?
xiv. Should we have a cost recovery mechanism for ensuring long term sustainability of the essential reliability services viz. reserves?
xv. Should there be any incentive to generators for providing reserves?
xvi. Should there be a formal mechanism to replenish the depleted reserve?

Basic Data

The basic set of data required for computing & monitoring intra-state reserves at SLDC was discussed & it emerged that the following information must be made available at SLDC for every time block for each power station:

(1) Declared capability in MW
(2) Declared capability on-bar (in MW)
(3) Schedule in MW
(4) Pmax = On bar installed capacity – Normative Auxiliary Consumption (in MW)
(5) Pmin = Technical Minimum generation (in MW)
(6) Variable charge (VC) in Rs/Kwh
(7) Ramp-Up rate in (%age of on-bar Capacity) per minute
(8) Ramp-down rate in (%age of on-bar Capacity) per minute

Derivable parameters:

Based on the above base data, certain derived parameters could be computed & monitored for each time block as under:

- Regulation Up-reserve = On bar installed capacity – Schedule (fig. in MW)
- Regulation Down-reserve = Schedule – Technical Minimum (fig. in MW)
- Cold reserve = DC – DC on bar …. (in MW)
- Hot spinning reserve = DC on bar – Schedule ….(in MW)
- Despatchable reserve = Minimum (Hot spinning reserve & Regulation Up Reserve)

5. **GM NLDC** presented a sample optimisation module using 'MS Excel Solver' based on some basic data for intra-state generators of Gujarat. The solver used the objective function of minimising production cost while honouring all extant technical & commercial constraints as under:
    - Objective Function: $\sum Schedule * VC = Minimum$
    - Equality Constraint(s): ***Total schedule = Total demand of the state***
    - Inequality constraint(s): ***Pmin ≤ Station schedule ≤ Pmax;***
6. **CE, SLDC Gujarat** appreciated the algorithm based approach toward reserve computation & despatch. He suggested that the sample excel solver sheet may be shared by NLDC team with SLDCs for further exploration and customization.
7. **CE SLDC Telangana** stated that all the data would be shared for initiating the pilot project on optimization. He also offered to provide IT support. He suggested that implementation of SAMAST should be pursued in all States.
8. **Notification of Technical Minimum of coal fired Generating stations**

Concerns were raised by State representatives regarding part load operation of old/small-size thermal units and compensation for degradation of station heat rate, auxiliary consumption, and secondary fuel oil consumption. Concerns were also raised with regards to inadequate support from OEMs for flexible operation.

CE, SLDC Maharashtra stated that enabling regulatory framework is required for reserves and ancillary in the state level.

ED, WRLDC emphasized that notification of technical minimum norms for intrastate generators in line with CERC regulations is the first step for implementation of reserves and ancillary services. He proposed that a uniform approach could be adopted initially and exceptions could be dealt separately on case-to-case basis by the appropriate commission.

Chairman, shared that flexibilization of coal-fired units has become a key agenda globally.

WRLDC representative shared the performance of central sector thermal units of 210 MW, 500 MW, 660 MW and 830 MW units over the last one year to demonstrate successful part load operation of those units.

Addl. CE, SLDC Madhya Pradesh stated that technical minimum level needs to be mandated in the regulations for wider acceptance.

Director MPERC opined that detailed methodology could be provided in the procedure.

After deliberation it emerged that either the technical minimum level should be lowered or the machines would be required to perform two shift operations. It was decided that all technical constraints of the generating units should be factored in the optimization model that was being developed.

Member GERC stated that procedures could be developed by the respective SLDCs based on the regulations notified by the appropriate Commission.

ED, SRLDC stated that mock exercise could be taken up in MS Excel to start with.

Director, MERC stated that deviation settlement mechanism, merit order despatch, technical minimum levels and compensation mechanism must be harmonized for implementation of intrastate reserves and ancillary services. He requested for devising a common philosophy for all States.

9. Other inferences drawn from the deliberations:
   i. Intra State reserve and ancillary services mechanism presupposes implementation of intrastate ABT and SAMAST framework
   ii. Ramp-up / Ramp down constraints were the key limiting constraints during the implementation of SCED (security constrained economic despatch at central level).
   iii. CERC (Terms & Conditions of tariff) Regulations have devised specific norms for ramping services from thermal generators.
   iv. Merit order stack should be visible to the operators in real time for despatching. Post facto moderation in the MOD stack would defeat the purpose.
   v. Quantum of reserves requirement would vary from State to State
   vi. Well defined norms for technical minimum and compensation, Scheduled based payments and double entry system through a Virtual Ancillary Entity could simplify scheduling and settlement of reserves
   vii. Adoption of causer-pays principle would enable the Intra-State pool account be self-sustainable
   viii. Weekly settlement of ancillary despatch is desirable.
   ix. Adequate provision for IT, communication infrastructure and HR resources is essential
   x. Inclusion of stations multi-purpose shared hydro stations and gas fired stations having multiple modes of operation (Open cycle, combined cycle) and multi-fuel options (APM, NAMP, RLNG, Liquid) would increase the complexity of the optimization model. Hence, inclusion of gas and hydro stations could also be considered after gaining some experience with optimization of coal fired stations.

10. Constitution of working groups at SLDCs

CE, SLDC suggested constitution of teams for experimenting with the optimization model developed by NLDC.

11. It was decided that teams comprising of members conversant with scheduling, commercial regulatory, IT could be formed in the respective SLDCs to run the optimisation module for the respective state. The team could then share their feedback with the sub-group.
12. It was also decided that the team would carry out gap analysis for different States on the following aspect:

- Tariff Structure
- Scheduling & Despatch, Imbalance
- Declaration of technical parameters & variable charge
- Reserves – Mandate, availability, computations, despatch,
- Metering, Accounting & Settlement Systems
- Sustainable recovery & payment mechanism for reserves, any incentives
- Availability of technology platform
- Manpower adequacy, skillsets needed

13. **Schedule for Next Meeting**

It was decided that the 3rd meeting would be help in July 2019 at Jabalpur and the 4th meeting would be tentatively held in August 2019 in Maharashtra.

14. Member convener thanked Chairman, all members of the sub-group and other participants for their contribution in the meeting.
15. The meeting ended with a vote of thanks to the Gujarat SLDC.

3rd meeting- 26 Jul 2019, SLDC Madhya Pradesh

1. The third meeting of the sub-group on 'Reserves and Ancillary Services at State Level' was held on 26th July 2019 under the Chairmanship of Shri S. K Soonee, Advisor, POSOCO. At the outset, Chief Engineer (SLDC, Jabalpur) formally inaugurated the meeting. The member convener and Advisor (RE), CERC welcomed all the members and participants connected over VC from SLDC Maharashtra, SLDC Gujarat, SLDC Telangana, SRLDC Bangalore and WRLDC Mumbai to the 3rd meeting of the FOR technical committee sub-group. The Member Conveyor thanked Chief Engineer (SLDC), Madhya Pradesh for organising the meeting.
2. **Confirmation of the minutes of the first meeting:** The minutes of the second meeting held on 07.06.2019 were confirmed by all members.
3. **Chairman** of the sub-group gave a briefoverview of the progress made so far. He expressed satisfaction over the work done by SLDC Jabalpur & SLDC Gujarat viz. constitution of internal teams with SLDC to work on schedule optimisation using excel solver. He commended the active involvement of SLDCs in recent past in bringing out some key documents viz. the SAMAST and the CABIL reports under the aegis of the Forum of Regulators (FOR) which provided a robust framework for implementing major reforms at intra-state level. He said that the next desirable step could be devising a mechanism for causing overall economy at state-level. He expressed that reserves & flexibility in conventional generation are key ingredients for successful integration of renewables, for which the following points would be necessary:
   - Groundwork for implementation of framework for reserves at intra-state-level factoring all state-specific constraints
   - Pilot implementation for creating a success story
   - Inter-SLDC groups for optimization to cause economy

- Academia support for learning the fundamentals & latest tools
- Procurement of optimization software viz. GAMS
- Sanctity of variable charge computation should not act as a hinderance
- Information on ramping capability is a vital input for reserve assessment
- Identifying other states which could be taken in fold so as to give feed-back to regulatory commissions for necessary intervention

ED SRLDC proposed to consider co-opting KarnatakaSLDC as a member for implementation of intra-state reserves & ancillary services. It was agreed to send a formal invitation to SLDC Karnataka in this regard.

Chief Engineer, SLDC Gujarat expressed that SLDC Gujarat team shall prepare a draft model regulation for operationalisation of reserves and ancillary at state level. The same would be shared with the sub-group for further refining & finalisation. Presentation made by Gujarat SLDC during the meeting is attached as **Annexure –III**.

4. **GM, NLDC** informed that a google form based online survey portal has been created with help of the questionnaire shared by SLDC Gujarat in previous meeting. The online survey could be remotely filled by the members with help of the following web-link: https://forms.gle/zZ8r4NdPJayqzXow5.

   He also expressed that the operational experience of security constrained economic dispatch (SCED) at national level shall be shared with the members.

   Chief Engineer SLDC Gujarat urged all members to share their input (if any) on the survey questionnaire so as to finalize & freeze the survey form.

5. **Shri Vivek Agarwal, EE SLDC** Madhya Pradesh gave a presentationon 'intra-state generation tariff, forecasting, scheduling, merit order dispatch (MOD), intra-state reserves, unit-commitment criteria, metering & settlement system etc. prevalent in the state of Madhya Pradesh. (**Annexure-II**) Key highlights of the discussion are summarized below**:**

   a) MPERC (Terms & Conditions of Tariff) Regulations 2015 is the guiding regulation for intra-state generation tariff. MPERC determines tariff of intra-state generators, IPPs vide MYT orders.

   b) A 2-Part tariff structure comprising of fixed charge (FC) & variable charge (VC) is in place in Madhya Pradesh.

   c) SLDC computes & certifies plant availability factor (PAF) & scheduled energy on monthly basis for payment of FC & VC respectively to intra-state generators

   d) Monthly PAF computation is linked to DC as given under:

$$\mathbf{PAF = 10000 \times \sum_{i=1}^{N} DC_i \,/\, \{ N \times IC \times (100\text{-}AUX_n) \}\%}$$

Where,

IC = Installed Capacity of the generating station in MW,

DCi = Average declared capacity (in MW) for the ith day of the period.

N = Number of days during the period, and

AUXn = Normative Auxiliary Energy Consumption as a %age of gross generation;

e) MOD is prepared by the holding Distribution Company (MPPMCL) based on VC as per latest (last month's) bill issued by the state generators. MOD is submitted by MPPMCL to SLDC on monthly basis by 10th -15th day of every month. The VC of ISGS stations used in MOD preparation factors in the point of connection (POC) transmission loss component.

f) Scheduling is done as per MP State Grid Code (MPEGC) and Balancing and Settlement Code (BSC) 2015

g) All power allocation from Government are made to MPPMCL. MPPMCL re-allocates the power among the 3 state DISCOMs based on day-ahead demand forecast for each time block. There are no private DISCOMs in the state. MPPMCL is allowed to revise the allocation to the state-DISCOMs on the actual day of operation based on load-generation balance requirement. MPPMCL runs the MOD and unit commitment (UC) software. During low demand period reserve shut down decision is taken by MPPMCL in consultation with MP-SLDC.

The Chairman said that unit commitment decisions are being presently taken heuristically and a more rigorous and scientific approach for unit commitment would be desirable in future.

ED WRLDC, expressed that MOD preparation should be coordinated by SLDC. Since presently there is no private DISCOM in MP, MOD preparation by MPPMCL is going on smoothly. However, in future with IPPs & private DISCOMs entering the intra-state market, a neutral body viz. SLDC would be required to prepare the intra-state-MOD.

h) As per 20th FOLD recommendations, SLDC MP has engaged Indian Institute of Information Technology, Jabalpur for Development of a load forecasting model for daily, weekly, monthly, seasonal and annual load forecasting. Weather data from RLDC/NLDC would be desirable for better forecast.

Chairman of the Sub-Group expressed that load & RE forecasting need to be done by SLDC for grid security & by MPPMCL for containing deviation & associated commercial implications.

ED WRLDC suggested that it would be prudent to take input from multiple professional weather forecast service providers in stead of being solely dependent on IMD. He commended the initiatives taken by Madhya Pradesh in handling imbalances by taking 1-2 MW golden share in ISGS stations of NR which they use for managing imbalances by availing URS during contingency.

i) **400-500 MW** reserve is always maintained by under-requisitioning in hydro & thermal stations for meeting contingency during real time operation. Reserve availability in ensuing blocks is manually computed by real time shift engineers.

j) Hydro generators are out of the ambit of ABT & MOD. SLDC-MP dispatches hydro based on grid conditions. Renewable generation is treated as must run & their variability is handled by dispatching reserve margin available in hydro power stations.

k) Intra-state ABT has provided for meters at each T-D(transmission-distribution) inter-face point. Presently 1081 inter-face energy meters are in place in the state. Deviation (DSM) and reactive energy (RE) charges for intra-state entities are computed based on main meter data.

l) AMR system is in place at each interface point (G-T, T-D) & at SLDC which facilitates meter-data downloading at SLDC. Missing meter data is retrieved using local meter reading instruments (MRI) & sent by mail upon intimation by SLDC on monthly basis.

CE, SLDC MadhyaPradesh said that redundancy in energy meter data & SCADA data is essential. He stated that based on a recent review of state grid code (MPEGC 2005) under leadership of MP-SLDC, State Commission (MPERC) has notified MP Electricity Grid Code 2019 on 21st June 2019 which has addressed several issues raised by SLDC-MP. The new state grid code has provisions for check meters in addition to main & standby meters. He informed that norms for **technical minimum** generation level have been specified by MP-ERC for the intra-state generators**.**

MP Power Generating Company (MPPGCL) representative said that new units of 250 MW and above size are capable of operating at 50% of capacity.

m) Procurement of check meters & meters capable of recording at 5-minute interval are being taken up with MPPTCL. PSDF funding approval has been obtained for the same.

n) State energy accounting (SEA) is being done by SLDC in a dispute-free manner since 2009. SLDC has started deviation charge computation for 10 MW & above wind generators and 5MW & above solar generators since Aug 2018 following the MP-ERC notification of DSM regulations for intra-state Wind/solar plants.

Chief Engineer SLDC-MP stated that Intra State Deviation pool was changed from non-zero to zero sum pool due to accumulation of surplus amount.

6. Case studies on Optimization

An excel solver module for generation cost optimisation was shared by GM NLDC in the 2nd meeting on which SLDC Madhya Pradesh & SLDC Gujarat representatives did further customisation in consultation WRLDC team. They shared a number of case studies based on their experience with the Solver Module. The members commended the efforts taken by MP-SLDC & Gujarat SLDC teams in running the optimisation module and expressed satisfaction at the sample results. The solver output gave vital information viz. system marginal price, optimised generation cost for each representative time block.

Inference from the discussion on Solver Case studies:

- MS Excel Solver could be used for day-ahead purchase decisions, ancillary despatch, economic despatch, estimation of reserve carrying cost.
- The optimization results could be converted into graphs for comprehension
- Database is required to save various scenarios and their results
- Following steps would be involved for running the Solver model for 96-time blocks: - *fetch data from the scheduling Software > Run Solver Model > Push the results back to the scheduling s/w;*
- Reliability of communication system would be critical for continuous & automatic operation of the optimization program
- Despatchable reserves is limited by ramping constraints, hence reserves need to be distributed over multiple units. Having more units on bar helps in improving the despatchable reserves volume.
- For realistic results, the must run stations (wind/solar/run-of-the river hydro) and must take (STOA) contracts could be kept out of optimization module by making Pmax = Pmin.

  It was appreciated by all members that this tool can be effectively used for decision making on day ahead basis on matters like taking units under RSD, planning for short term power procurement.

GM NLDC suggested that the current level of familiarisation with Solver module needs to be scaled up to the next level to run it continuously for all 96 blocks in a day; to factor in several other constraints; under-standing higher concepts viz. infeasibilities etc. He suggested that more powerful database software like MySQL, Mongo.db, etc. could be used along with python / visual basic scripts for further automation of the process. He expressed that the experience of NLDC team in running in-house optimisation engine for SCED implementation could be gainfully utilised by the members. He demonstrated the different out-puts and displays of the SCED software to explain the visualisation tools that would be necessary for reserve monitoring. He agreed to share some basic reference material on Optimisation techniques and the General Algebraic Modelling System (i.e. GAMS). He advised to refer to solver manuals (available at solver.com) for more insight on different terminology and other solver add-ons. The members of the Sub-Group suggested that a training session on optimisation using GAMS may be facilitated by POSOCO.

7. Suggested Regulatory interventions

It was suggested that the following Regulatory Interventions would be necessary for implementing Essential Reliability Services at state level.

- Notification of Technical minimum generation level
- Notification of ramping capability norms for generators
- Notification of methodology for computation of Variable Charges
- Notification of Regulations for intra-state ancillary services
- Notification of spinning reserves to be maintained at State level

- Amendment to intra- state open access (OA) regulations in line with CERC amendments to inter-state open access regulations.

CE, SLDC-MP stated that a detailed report for AGC implementation (at Shri Singhaji TPS) is being prepared by SLDC which will be submitted to MPERC for approval. He informed that MPERC is examining for resolution of some issues raised by qualified coordinating agencies (QCAs) and RE generators through suitable amendment in intra-state RE-DSM regulations.

The **Chairman** informed that another sub-group constituted under FOR Standing Technical Committee is working on roles & responsibilities of QCAs for RE integration.

8. Other inferences/discussions

a. Computation on Variable charge of thermal generators by different states need to be examined. VC is a quadratic function & depends upon factors viz. station heat rate, gross calorific value, auxiliary energy consummation, secondary fuel oil consumption etc. The document of CEA on this topic could be a good reference material.

b. Scientific approach based on algorithmic solutions is desirable for reserve computation & monitoring.

c. The following basic capability would be required for running & monitoring optimized dispatch: (i) Familiarity with state power system (ii) Fundamentals of resource optimization (iii) Optimization software (iv) Software interface for front line operators (v) Database management

9. Decisions taken for future work:

The following action plan was decided for the ensuing months:

- More case studies to be done in MS Solver
- Must run stations / Must take contracts to be excluded from optimization module
- Net load Forecast to be considered instead of Demand forecast
- Inter SLDC-RLDC working teams to be formed to work on the optimization modeling
- Free version of GAMS to be downloaded
- Transmission constraints to be considered in the optimization model
- GAMS manual to be circulated by NLDC
- Capacity building workshop to be planned by NLDC

10. Schedule for Next Meeting

It was decided that the 4th meeting would be help in August 2019 at SLDC Maharashtra.

11. Member convener thanked Chairman, all members of the sub-group and other participants for their contribution in the meeting. The meeting ended with a vote of thanks to SLDC Madhya Pradesh team.

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4th meeting- 30 Aug 2019, SLDC Maharashtra

1. The fourth meeting of the sub-group on 'Reserves and Ancillary Services at State Level' was held on 30th August 2019 under the Chairmanship of Shri S. K Soonee, Advisor, POSOCO. At the outset, Chief Engineer (SLDC, Maharashtra) welcomed the Chairperson, Director MPERC (Shri G Tiwari) and Dy Director-Technical MERC (Shri A. Khandare) & other members and participants to the meeting. The member conveyor thanked Chief Engineer (SLDC), Maharashtra for organizing the meeting. The Chairperson acknowledged the active interest & participation of SERC members / staff and the heads of SLDCs in various sub-group meetings. He expressed that the presence of SERC staff would add value to deliberations of the sub-group. Other participants joined the meeting over VC from SLDC Madhya Pradesh, SLDC Gujarat & SRLDC Bangalore.

2. **Confirmation of the minutes of the 3rd meeting:** The minutes of the third meeting held on 26.07.2019 were confirmed by all members.
3. **Chairman** of the sub-group gave a briefoverview of the progress made so far and said that the sub-group shall demonstrate the results in the form of successful pilot projects while the report would be a biproduct of the experience. He commended the hard work done by the internal working groups in SLDC-MP, Gujarat & Maharashtra in understanding & running the solver-based optimization tool which marked synergy & convergence of ideas. He expressed that the success of security constrained economic dispatch (SCED) & fast response ancillary services (FRAS) pilot projects at national level has given the confidence to roll-out a doable framework at intra-state level by duly factoring all state-specific constraints & dynamics. It is the inhouse teams at SLDCs who understand the complexities & dynamics of the intra-state system better than any out-side vendor/consultant. Thus inhouse capacity building within SLDCs is imperative for moving further towards implementing a sustainable frame-work of intra-state reserves & ancillary services.

   He said that a 3-day tutorial in being planned to be conducted in Delhi in mid-September in association with academia for capacity development of the sub-group members and the young enthusiasts at SLDCs.

   GM NLDC informed that the 3-day tutorial s likely to be held during 12-14 September 2019 and the participants are expected to bring their cases & laptops for doing hands-on sessions after learning the basics on GAMS optimization module.

   Chief Engineer, SLDC Gujarat said that he recently attended a meeting at MoP wherein four states have been proposed for implementation of intra-state SCED viz. Gujarat, Karnataka, West Bengal & Uttar Pradesh (UP). Accordingly, it is desirable to rope-in SLDC Uttar Pradesh & SLDC West Bengal in the sub-group. He also expressed that SLDC Gujarat may be entrusted with the task of compiling survey responses on behalf of the sub-group.

   Addl. Chief Engineer, SLDC Madhya Pradesh proposed that the sub-group may consider roping in one SLDC from each region.

   After deliberations, it was proposed to co-opt members from following 3 SLDCs

   - SLDC Uttar Pradesh (NR)
   - SLDC West Bengal (ER)
   - SLDC Assam (NER)

It was proposed by member convener (and agreed by all) that the above matter could be proposed in the forth coming FOR technical committee meeting & based on their advice a decision would be taken.

4. **Shri Abinash Dhawade, Dy Executive Engineer, SLDC** Maharashtra gave a presentationon 'intra-state generation tariff, scheduling procedure, merit order dispatch (MOD), intra-state reserves assessment method, metering & settlement system etc. prevalent in the state of Maharashtra (**Annexure-II**) Key highlights of the discussion are summarized below**:**

Tariff Structure:

a) MERC (Multi-Year-Tariff) Regulations define norms for generation tariff in the state.

b) 2-Part tariff structure comprising of fixed charge (FC) & variable charge (VC) is in place

c) The tariff regulations have provisions for computation of plant availability factor (PAF) linked to DC declared by generators & plant load factor (PLF) linked to scheduled energy on monthly basis for payment of fixed charge (FC) & variable charge (VC) respectively to intra-state generators

d) SLDC computes & certifies PAF, PLF, scheduled energy and actual energy for all intra-state generators.

Scheduling & Despatch

e) Merit Order Despatch is the least cost approach to meet demand from the contracted capacity of the respective Distribution Licensee. MOD is prepared on day-ahead basis by SLDC based on VC as per the MERC guidelines. It was clarified that the VC considered for MOD preparation is the landed-up cost at state periphery. Further, it is a flat cost irrespective of generator loading & the nature of heat curve.

f) Decision on zero schedule / reserve shutdown (RSD) is taken by DISCOMs with 24 hours advance notice after consultation with SLDC. Minimum RSD period is 72 hours.

g) A new scheduling software (MiDss) developed by M/s. PRDC Bangalore is in operation since 01.01.2019.CE(LD), Maharashtra said that of cloud-based solution for an integrated scheduling accounting, settlement software has proven to be more cost efficient.

Reserve Assessment:

h) Presently, there in no regulatory mandate from SERC for reserve assessment. However SLDC monitors & dispatches incidental reserves available in the form of margin available in intra-state generators after running MOD program and the quantum margin created after generation backing down in real time, un-scheduled hydro generation, generation taken under RSD during low demand period etc.

Metering & Settlement system

i) Intra-state ABT is in place since August 2011 as per MERC order in case 42 of 2016. The imbalance settlement method is known as Final Balancing & Settlement Mechanism (FBSM). Unlike the CERC (DSM) regulations, the FBSM based imbalance settlement rate is linked to weighted average system marginal price. 1118 ABT meters capable of recording energy at every 15 minute are used for weekly settlement of deviations from schedules.9 DISCOMs & 9 merchant generators are covered under the FBSM. The state pool is a zero-balance pool by design.

Chief Engineer SLDC Maharashtra, said that:

- The MERC has notified intra-state DSM regulations (similar to CERC regulations) which would be effective from 1.4.2020.
- The MERC has notified a MOD guide line that mandates a spinning reserve of 660 MW (~ highest size generator in state) to be maintained at state level. However, more clarity is required whether to keep such reserve at a single generator or at multiple units in a distributed manner.
- Considering hydro generation as a reserve has certain limitations since the hydro projects are multipurpose projects which serve several obligations such as drinking water supply, irrigation etc. as mandated by respective water tribunals.

The Chairperson emphasized on the following aspects:

- Need for adopting a multi-part tariff comprising of FC, VC, Deviation charge, Congestion charge, mark-up for Ancillary Services etc. to factor all aspects of electricity market design.
- PLF calculation could be based on two aspects viz. scheduled energy & actual energy.
- A dedicated section in the report could be written on variable charge computation in states.
- Post the functioning of electricity markets, there is a need for thinking beyond MOD which is a legacy of the pre-market era and economy may be brought through optimization.
- Settlement system should be simple, implementable and dispute free.
- Keeping reserve is a role of system operator (viz. SLDC). It need to be booked to the pool (not to any specific state entity) and settlement is to be done with the pool. Spinning reserve in a power system is similar to the 'reserves & surplus' kept in financial books of accounts. Spinning reserve should be planned & kept by system operator such that it is dependable, distributed and duly factor the network constraints, generator ramp limitations, forecasting errors (error % would be different for RE rich & non-RE rich states).
- Operationalization of reserve & ancillary shall provide an opportunity for co-optimization of energy & ancillary.
- A clear mandate from SERC is necessary in this regard for enabling the SLDCs to keep reserves. Further, the SERC may classify the reserve as cold reserve, hot spinning reserve, fast/slow reserve, ramp limited reserve, dispatchable reserve etc.to bring more clarity. Spinning reserve would always be preferred over cold reserve.

5. Case studies on Optimization

The solver based module which was developed & shared by GM-NLDC was used to run optimization cases by SLDC Maharashtra. They shared a number of case studies on different scenarios (viz. max demand, min demand, high RE, low RE etc.) and gave a comparative analysis on actual dispatch vs optimized dispatch in each case & summarized the results indicating overall economy achievable through optimization. The following table shows the summary of the cases which indicates reduction in average cost post optimization.

Cases	Production cost before Optimization	Production cost After Optimization	Total Saving	Average Cost before Optimization	Average Cost After Optimization	SMP rate
	(Rs Lakhs)	(Rs Lakhs)	(Rs Lakhs)	(Rs/Unit)	(Rs/Unit)	(Rs/Unit)
Case 1: Maximum Demand	515	484	31	2.54	2.49	3.29
Case 2: Minimum Demand	366	320	46	2.45	2.27	2.81
Case 3: Maximum Wind	375	350	25	2.47	2.31	2.96
Case 4: Minimum Wind	361	349	12	2.3	2.26	3.69
Case 5: Maximum Surrender	284	276	8	2.54	2.51	2.52
Case 6: Minimum Surrender	507	483	24	2.59	2.41	30

6. **Presentation by SLDC Madhya Pradesh:** Shri Rishabh Nayak, AE, MP-SLDC presented an advanced version of the solver module by running the optimization for all 96 blocks is a day in a sequential manner. He informed that AGC at intra-state level is being proposed for Shri Singhaji thermal power station in Madhya Pradesh. The members commended the efforts taken by SLDC internal teams in running the optimization modules and expressed satisfaction at the progress. Presentation given by MP-SLDC is attached as **Annexure-III**.

   GM NLDC said that the current level of familiarity of SLDC teams with excel solver and appreciation of optimization results had effectively established proof of concept. It would be necessary to raise it to the next level by running optimization for all 96 blocks in one shot & doing it continuously for all time blocks. In block-by-block sequential running of solver the futuristic constraints viz. MWH limit for hydro, expected ramping during peak etc. may not be reflected correctly. Hence a multi-period continuous running of optimization would be desirable. Similarly, the current solver model won’t be able to address issues like infeasibility This would require an advanced tool (viz. GAMS) since excel solver had several limitations viz. max. number of constraints etc.

Addl. CE (SLDC MP) informed that they had filed a petition before SERC for a zero balance DSM pool since managing huge pool surplus was a challenge since there is no PSDF counter-part for the state.

The Chairman of the sub-group stated that there are certain disadvantages of a zero balance pool viz. (i) lack of buffer for handling pool deficit scenario; (ii) fund constraints for rolling out any new reform mechanism by system operators viz. AGC, ancillary services; (iii) no latitude for doing system improvement viz. PMU/WAMS pilot project etc. Thus, it is preferable to have a positive pool balance by design. Excess surplus situation might be handled by having provision for ceiling. He stated that the next logical step would be planning out the modalities for pilot implementation of reserves in the states for which an order from SERC would be desirable.

Shri SS Patel, SE(SLDC-MP) said that additional resources & infrastructure (viz. hardware/software etc.) would be required for pilot implementation of intra-state reserves & ancillary services.

Director (Commercial), SERC Madhya Pradesh, said that it would be preferred if a petition is filed by SLDC in this matter. **Dy Director (Technical), MERC** also expressed similar concerns.

The Chairperson stated that it would be better if a suo-moto order comes in line with the CERC order on SCED by citing reference to the National Electricity Policy and CERC road map on reserves. GM NLDC stated that as envisaged in the Electricity Act, SERCs may initiate suo-moto petition for promoting market development towards causing overall economy.

7. **Draft Model Regulation: SLDC** Gujarat team shared a draft model regulation for intra-state reserves & ancillary services (copy enclosed as **Annexure-IV)**& the same was deliberated. The desirable features of the model regulation which emerged after the deliberation are summarized under:
   - The term Reserve need to be clearly defined & duly classified as fast, slow etc. Terms like MOD may be suitably replaced to avoid legal dispute.
   - Co-optimization concept need to be introduced suitably.
   - Incentive for ancillary (Up/Down) may be properly defined. In principle, only VC (& not FC) may be marked up. The appropriate commission may decide the mark-up quantum.
   - Ancillary despatch should not create any perverse incentive towards inaction by players.
   - Pool design (zero balance vs positive balance) to be suitably deliberated.
   - Reserve Up & Down (RRAS) instruction could be issued by system operator (SO) from Generator to pool & vice versa.
   - It would be a regulatory dispatch instruction from SLDC & additional contract need not be created in this process. SLDC can execute a contract rather than causing one.
   - The suo-moto rescheduling provision of grid code could be suitably used when the default by an entity gets established.

- The model regulation need to leave ample room for SERCs to factor state-specific issues.

It was decided that a revised draft would be shared by SLDC Gujarat team after incorporating inputs from all the members.

8. Decisions taken for future work:

The following action plan was decided for the ensuing month:

- Feedback to FOR Technical Committee on the progress made by the sub-group.
- Tutorial on Optimization using GAMS at Delhi tentatively during 12-14 September 2019
- Next meeting of sub-group at Bangalore

9. Schedule for Next Meeting

It was decided that the 5th meeting would be help in September / October 2019 in southern region.

10. Member convener thanked Chairman, all members of the sub-group and other participants for their contribution in the meeting. The meeting ended with a vote of thanks to SLDC Maharashtra team.

5th meeting -31 Oct 2019, SRLDC Bengaluru

1. The fifth meeting of the sub-group on 'Reserves and Ancillary Services at State Level' was held at SRLDC Bengaluru on 31st October 2019 under the Chairmanship of Shri S. K Soonee, Advisor, and POSOCO. SLDC Madhya Pradesh, SLDC Gujarat, SLDC Maharashtra, Telangana and WRLDC Mumbai were connected through video conference.
2. Executive Director (SRLDC) welcomed all the members of the FOR sub-group and other participants to the meeting.
3. Member convener thanked SRLDC for hosting the meeting. He welcomed representative from SLDC Karnataka as a special invitee.
   Chairperson acknowledged the active interest & participation of SERC members / staff and the heads of SLDCs in various sub-group meetings.
4. **Confirmation of the minutes of the 4th meeting**: The minutes of the third meeting held on 30.08.2019 were confirmed by all members.
5. **SLDC Karnataka** gave a brief presentation on challenges faced by the state and the need for reserve ancillary services. A copy of his presentation is attached as **Annexure-II**. Key highlights are given under:
   a. Total Renewable generation Capacity in Karnataka is 13900 MW out of which Solar, 6448 MW (46%) is Solar, 4852 MW (35%) is Wind, 1731 MW (12%) is cogeneration and rest is biomass and mini hydro.
   b. Power supply for irrigation pump sets was being given during day time to utilize Solar generation

c. This year Karnataka observed a maximum must run generation of 9000 MW (8000 MW from RE + 1000 MW from overflowing hydro) while the demand reduced to 6000 MW from a peak of 12000 MW. Under such conditions even after backing down ISGS generation to its technical minimum and closing down of intrastate thermal units, Karnataka had a surplus of around 4000 MW which was sold in the day-ahead market.
d. 10x103.5 MW Sharavathy (Pelton wheel) and 4x115 MW Varahi (Pelton wheel) were being used as spinning reserves for handling load and RE variability
e. Tail race hydro plants (Kadra-3x50MW, Kodsahally-3x40MW and STRP-4x60MW) were being dispatched during Non-solar peak period
f. Development of pumped storage scheme is envisaged at Sharavathy and Varahi
g. The development of real-time market would enable the States to dispose the surplus power.
h. Deviation volume limit and must-run status for RE during high penetration could be reviewed

6. **Chief (Regulatory Affairs)**, CERC stated that
   a. The CERC, through its various orders and regulations had made it amply clear that the grid does not generate electricity. It cannot be considered as a source or sink of electricity. Hence raising the deviation limit militates against the basic principle of maintaining load-generation balance.
   b. CERC passed an order in 2015 charting out roadmap for reserves including primary, secondary and tertiary reserves requirement for system reliability. Subsequently the Commission mandated primary response by directing RLDCs to restrict the schedules to Maximum Continuous rating of the units at bar minus the normative auxiliary consumption.
   c. Pilot project for Secondary control (Automatic Generation Control) were initiated through the CERC roadmap for reserves. He also updated about the recent Order by the Hon'ble CERC regarding AGC enablement being mandatory for Inter-State Generators.
   d. Tertiary control through reserve regulation ancillary services (RRAS) & fast response ancillary services (FRAS) mechanisms in administered mode have been implemented at regional level
   e. Co-optimizated dispatch of energy and reserves with market based approach is required.
   f. Complementary initiatives for development of real-time market are being taken up. A staff paper on real time market (RTM) was floated followed by draft amendments to relevant Regulations to roll out RTM.
   g. The expectation from sub-group is to evolve a common minimum framework for assessment, procurement, despatch and settlement of reserves for implementation at the intrastate level.
   h. The sub-group is expected to evolve model regulations for enabling assured availability of mandated quantum of reserves and its deployment under contingencies. The model

regulations could be suitably adapted by respective SERCs to suit the requirements of the respective states.

7. The draft report of the sub-group (**Annexure-III**)was deliberated in detail the following suggestions made by the sub-group members were agreed for inclusion in the draft report:
    a. Primary response has to be mandated through the grid code. The upper and lower bounds for scheduling are to be mandated through the regulations for ensuring availability of adequate margins in a distributed manner across all intrastate generating stations.
    b. Implementation of SAMAST framework is required to enable implementation of robust scheduling, metering, accounting and settlement of transactions in electricity.
    c. SAMAST implementation inter alia includes implementation of intrastate ABT. The system would bring in transparency, accountability and discipline on the part of the generating stations as well as its procurers.
    d. SERCs to notify the technical minimum limit of 55% and ramp rates (of at least 1 % per min) in line with the CERC norms for thermal generation to enable computation and monitoring of reserves in real-time.
    e. SERC to mandate submission of various details for participating in ancillary services (Fixed charges, Energy charge rate, minimum turn down level, minimum operating hours after bring the unit on bar, shut down/start up cost etc.)
    f. The members also agreed that the transition towards market-based procurement of reserves and ancillary services could be in a phased manner.
    g. The assessment of reserve could be estimated as thrice of the standard deviation of the historical area control area.
    h. Reserve assessment could be done on a rolling window of seven days. In case of inadequacy of available reserves additional units to be brought on bar. In case of surplus availability of reserves, the decision for taking one or more units under reserve shutdown to be taken.
    i. A schematic to explain the MCR, DC, Scheduling limits, spinning reserve, primary reserve, ramping reserve (up/down) etc. to be included in the report
    j. The criteria for triggering the ancillary services could be included in the regulations
    k. The stacking of reserves shall be as per their energy charge rate.
    l. The ancillary service providers to be compensated for flexibility services
    m. Mechanism for reserve monitoring in different time horizons
    n. The scheduling and settlement of ancillary dispatch to be 15minute to start with. A faster dispatch interval of say 5 minutes could be considered in future.
    o. Gate closure is required, to enable the SLDCs to assess the available reserves at the State level with certainty, ahead of the delivery time. The time line to be aligned with the gate closure and real-time market at the interstate level

p. A virtual ancillary entity shall be created to enable reserve despatch to/from the pool. Only energy charges plus mark up to be paid for the reserves despatched by the SLDC. Suggested mark-up is 10 to 25 paise/unit.

q. The ancillary dispatch received by a generating station shall be subsumed in the injection schedule and the deviation from schedule would be computed with reference to the total schedule including the ancillary despatch.

r. Secondary control through Automatic Generation Control could be implemented in few of the larger States.

s. Robust communication system with path redundancy needs to be established between the SLDC and the generating stations as well as between the SLDC-RLDC-NLDC for fast and reliable exchange of exchange of scheduling data.

t. Other essential reliability services viz. voltage control ancillary service and black start ancillary service etc. shall be suitably incorporated in the report considering the present scope & future requirements.

u. A road map for implementation starting with publication of draft regulations on intrastate reserves and ancillary by respective SERC within 1 year shall be devised

8. Following **decisions** were also taken in the meeting:

a. The revised draft report shall be compiled and recirculated to the sub-group members for the review and comments

b. The draft model regulations and the implementation roadmap shall be redrafted and circulated for review

c. The revised draft report of the sub-group shall be presented in the next FOLD meeting for wider consultation with the SLDCs

d. The 6th meeting of the sub-group could be scheduled in Delhi in the last week of November 2019 for finalization of the report for presentation in the next FOR standing technical committee meeting

9. The Chairman thanked all the members for their valuable contributions.

10. Member convener thanked the Chair.

Annex-III: Summary of the Capacity building program

As decided in the 4th meeting of the FOR technical committee sub-group on intra-state reserves & ancillary services, a capacity building programme on Implementation of *'Optimization Techniques for Indian Power System Operation'* was conducted at NLDC New Delhi on 19-21 Sep 2019 in collaboration of NLDC & IIT Delhi. The programme was attended by senior officials as well as working groups on optimisation from different SLDCs, NLDC, RLDCs including Chairman of the FOR subgroup, the member convenor (Advisor (RE), CERC, Director (SO) POSOCO, Chief Engineer (SLDC) Gujarat. Key highlights of the programme are as given under:

Day-1 (19-Sep-2019):

1. **Session-1: Introduction to Optimization**:
   - Optimization problem formulation;
   - Different types of optimization problems (LP, NLP, MILP, MINLP)
   - Objective Function,
   - Equality & Inequality Constraints
   - Decision Variables, Dual variables (Lagrange multipliers)
   - Popular Optimization packages viz. GAMS (General Algebraic Modeling System, AMPL (A mathematical Programming Language), MATLAB tool box etc.
   - History & Evolution of Optimisation techniques
   - Classification of Optimisation Problemsbased on constraints, nature of variables, nature of equations, objective type etc.
2. **Session-2: Introduction to Excel as Optimization Solver EXCEL**
   - Illustrations with sample examples
   - Interpretation of Excel solver output & typical terms viz. sensitivity report, Answer report, allowable increase/decrease, shadow price, binding & non-binding constraints etc.
3. **Session-3: Economic Load Despatch (ELD)**
   - Introduction to economic load dispatch
   - Problem formulation
   - Solution by Method of Lagrange Function
   - Solution Techniques
   - ELD with network losses
   - Examples
   - ELD when unit limits are considered

Day-2 (20-Sep-2019)

4. **Session-4: Unit Commitment Problem**
   - Introduction to Unit Commitment
   - ELD & Unit Commitment
   - Issues

- Problem formulation
- Examples

5. **Session-5: Introduction to General Algebraic Modelling System (GAMS)**
    - Introduction – What is GAMS,
    - Types of problems solved by GAMS
    - The basic components of GAMS model
    - Algebraic Representation
    - Mathematical Modelling
    - Structure of a GAMS model – Sets, List, Table, Scalar, Assignment, Variables, bounds, equations, model statements, solve statements, Conditional Operators, logical operators, data transfer tools etc.
    - GAMS Solvers viz. CPLEX
    - Sample Example – Transportation problem
6. **Session-6: Hands on Session on GAMS**
    - Writing & running GAMS code
    - Error detection
    - Interpretation of GAMs output (.lst) file
    - Solving the ELD & UC problems of Day-1 & Day-2 using GAMs
    - Comparing GAMS solution with Excel Solver solution in Unit Commitment case – limitations of excel solver in changing unit status from 0 to 1 leading to suboptimal solution

Day-3 (21-Sep-2019)

7. **Session-7: Orientation programme on SCED Module being operated at NLDC**
8. **Session-8: Learning & Feedback:**

Key Learnings from the program:

(1) Basics of optimization, ELD, UC and GAMS

(2) Solving Optimization problems through MS Excel solver, GAMS Modelling Tool and MS Excel limitations

(3) Handling of glitches, implementation complexities and modelling strategies for state specific optimization formulation

(4) Sharing of Practical Implementation experience by NLDC for optimization and Roadmap for implementation of SCED

(5) Requirements and Key design elements required in the Regulatory framework for initiating optimization at intra-state level.

Suggestions for Future Programs/Tutorials

(1) Formulation of Optimization Problems to incorporate near term challenges such as Renewables

(2) Interfacing requirements with EMS and State Estimation

(3) Metrics for Performance Monitoring

(4) Specifications for the IT infrastructure and Overview of development of Web based Software and User Interface
(5) Financial Accounting and Settlement for Economic Despatch and Pool Accounts
(6) Need for closer to real life problem solving and case studies

Interfacing of MS Excel, Python, MATLAB, PSSE or any other software with the GAMS Modelling tool for optimization

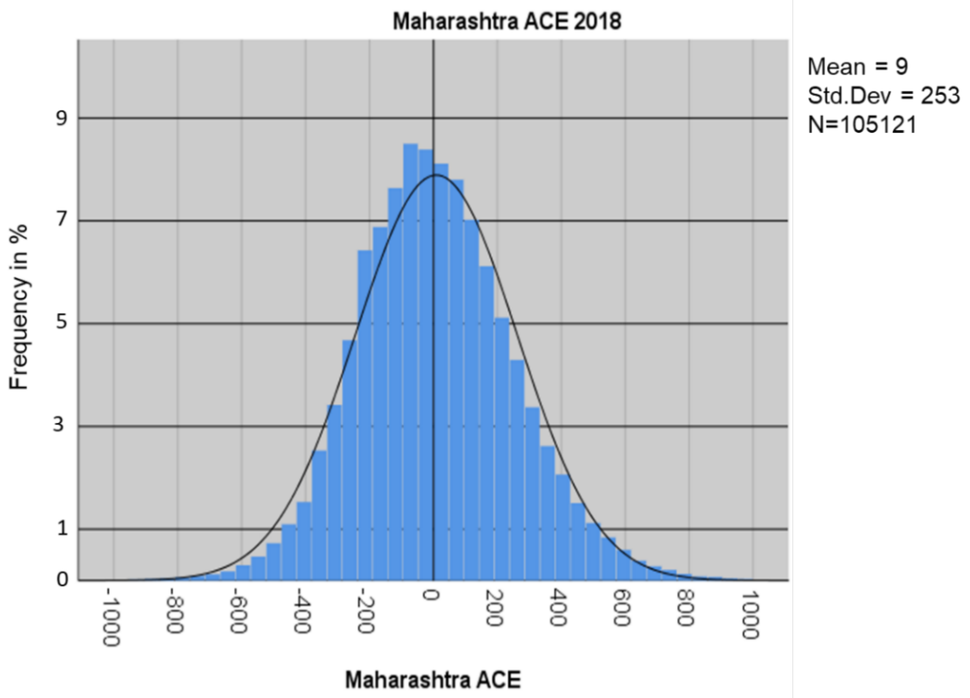
9. **Deliberation of Future Action Pointsby the sub-group**: Further, the following points were discussed on 20-Sep-2019 in presence of the teams from SLDC Madhya Pradesh, SLDC, Gujarat, SLDC Maharashtra, WRLDC & NLDC so as to decide future course of action by the FOR sub-group.
(1) A draft outline of the report was proposed & deliberated
(2) It was proposed that the report would have
    - a dedicated chapter on pilot projects at each of the 3 states viz. Madhya Pradesh, Gujarat, Maharashtra
    - A new chapter on steps/ roadmap for a new state to rollout ancillary services
    - Necessary intervention from regulatory commissions viz. regulations on technical minimum level, compensation for part load operation, ramp-rate declaration by generators etc.
    - Need for a pilot order for implementation of ancillary
(3) The 3 SLDCs (GJ, MP, MH) who have extensively used excel solver for optimisation shall attempt to scale it up using GAMS software
(4) The report to mention & explain the need for an ERC order for pilot implementation & gradual improvement based on experience gained thereof
(5) NPTEL courses on optimisation provide a good learning opportunity
(6) SLDC Gujarat & Maharashtra teams expressed that they already have a system of economic load despatch in place and thus they would like to have a framework for assessment & despatch of reserves

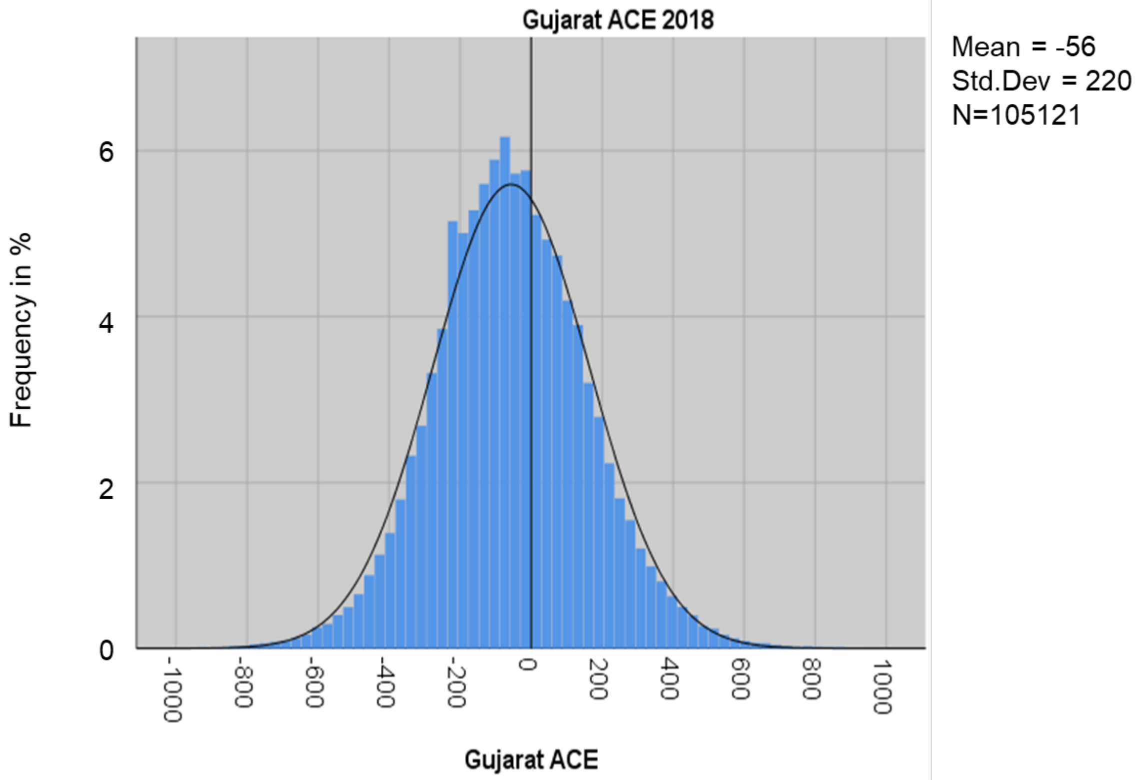
Annexure-1: List of Participants

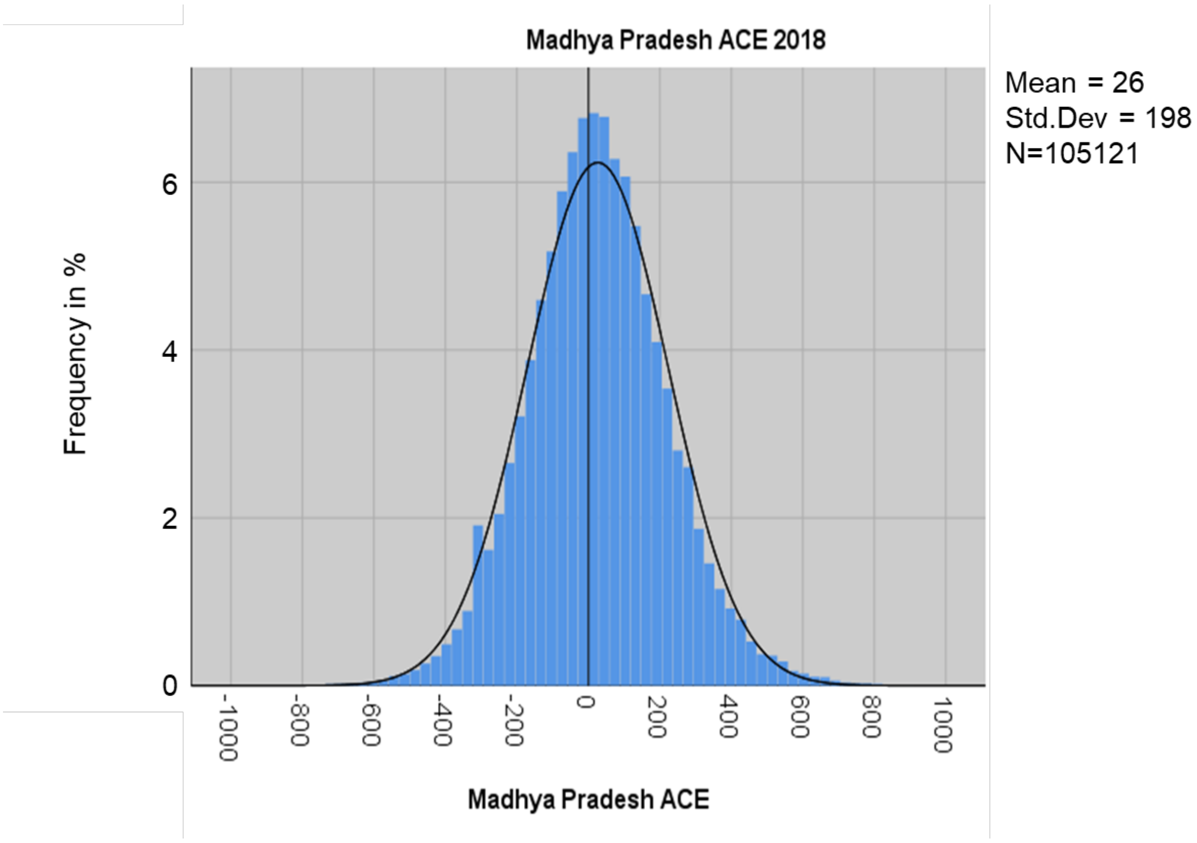
S.N.	Name	Designation	Organization
1	Prof. A R Abhyankar	Professor	IIT-Delhi
2	Dr. Shri Ram Vaishya	Post Doctoral Fellow	
3	Ms. Shruti Ranjan	Ph.D Student	
4	Ms. Megha Gupta	Ph.D Student	
5	Ms. Shaziya Rasheed	Ph.D Student	
6	Ms. Meenakshi Khandelwal	Ph.D Student	
7	Sh. Ambuj Gupta	M.Tech Student	
8	Sh. Ravi Kadam	Advisor	CERC
9	Sh. J D Trivedi	Dy. Engineer	SLDC - Gujarat
10	Sh. P B Suthar	Dy. Engineer	
11	Sh. A J Gami	Dy. Engineer	
12	Sh. B B Mehta	Chief Engineer	

Annexure-1: List of Participants			
S.N.	**Name**	**Designation**	**Organization**
13	Sh. Avinash C. Dhawade	DYEE (Operations)	SLDC-Maharashtra
14	Sh. Vijay S. Kamble	AE (Operations)	
15	Sh. Aarif Ahmad Khan	JE	SLDC-Madhya Pradesh
16	Sh. V.K Agrawal	EE	
17	Sh. Rishabh Nayak	AE	
18	Sh. L Sarveshwar	AE	SLDC-Telangana
19	Sh. Naveen	AE	
20	Sh. Chandan Mallick	Dy. Manager	ERLDC
21	Ms. Sugata Bhattacharya	Executive Trainee	
22	Sh. MP Nath	Chief Manager	NERLDC
23	Sh. Rohit Tulasiyan	Executive Trainee	NRLDC
24	Sh. Ashutosh Kr Pandey	AM	
25	Sh. Ankit Gupta	DM	
26	Sh. Bheemesh	JE	SRLDC
27	Sh. Vivek Pandey	Sr. DGM	WRLDC
28	Sh. Aditya Prasad Das	DGM	
29	Sh. Naga Sudhir	Dy. Manager	
30	Sh. S.R.Narasimhan	Director (SO), POSOCO	NLDC
31	Sh. S.K. Soonee	Advisor	
32	Sh. Debasis De	ED	
33	Sh. Phanishankar	Dy. Manager	
34	Sh. Saif Rehman	Dy. Managaer	
35	Sh. Harish Rathour	DGM	
36	Sh. Mohneesh Rastogi	Manager	
37	Sh. S C Saxena	GM	
38	Sh. K.V.N Pawan Kumar	Manager	
39	Sh. Anupam kumar	Manager	
40	Sh. Shubham Verma	ET	
41	Sh. Laxman Singh	ET	
42	Ms. Anamika Sharma	CM	
43	Sh. Sharat Chandra	Manager	
44	Sh. Anuj Kumar	AM	
45	Sh. Sudheer Talluri	Manager	
46	Sh. N. Nallarasan	Sr. DGM	

Annex-IV: Area Control Error: Frequency distribution






Madhya Pradesh ACE 2018
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Std.Dev = 198
N=105121
Frequency in %
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4
6
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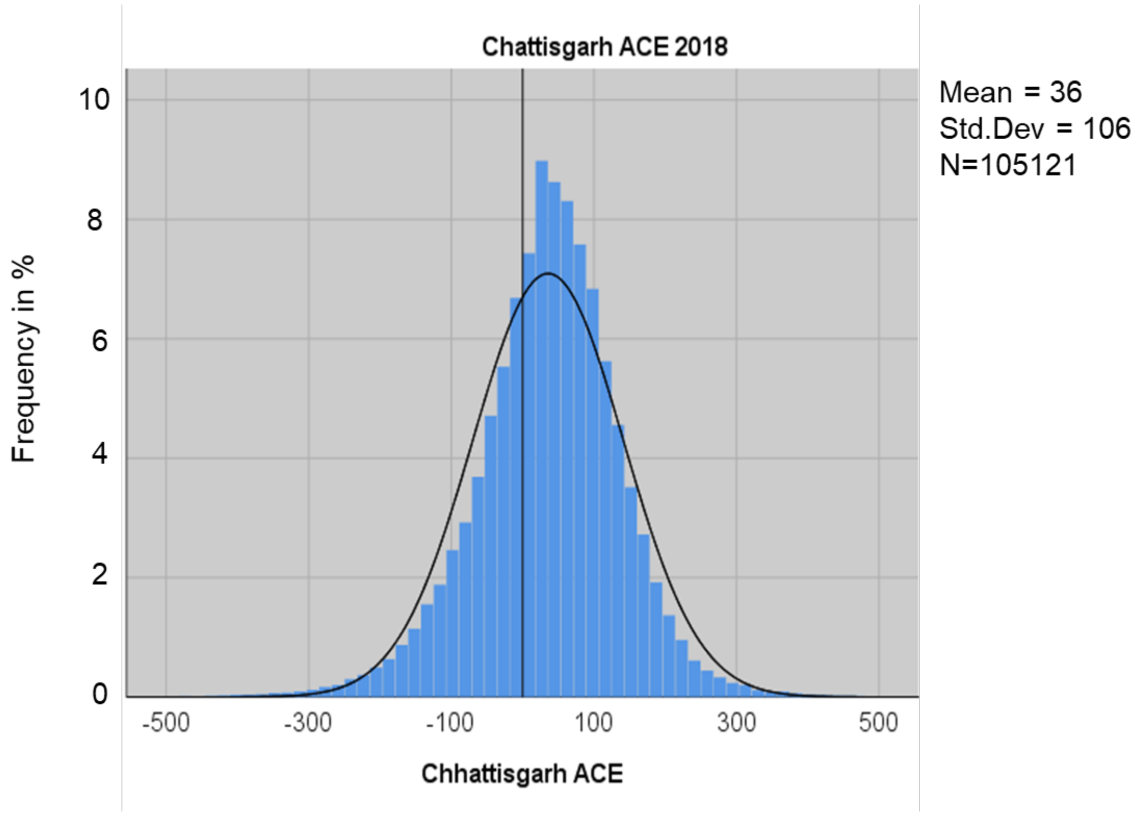
-600
-400
-200
0
200
400
600
800
1000
Madhya Pradesh ACE


Chattisgarh ACE 2018
Mean = 36
Std.Dev = 106
N=105121
Frequency in %
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8
10
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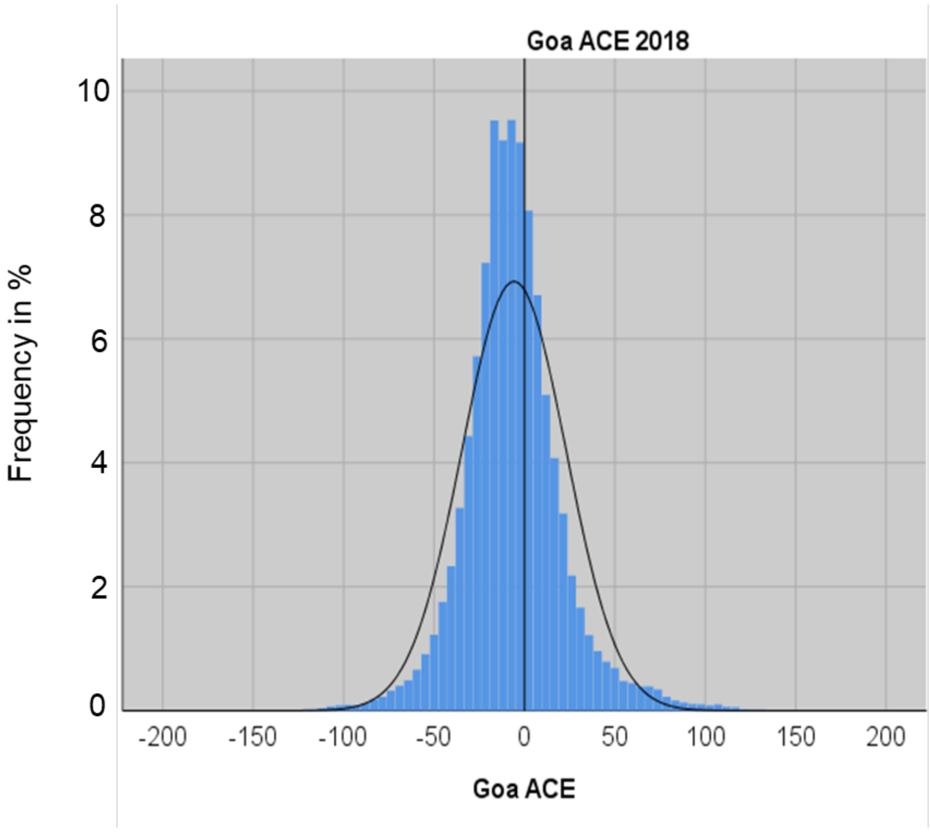
100
300
500
Chhattisgarh ACE



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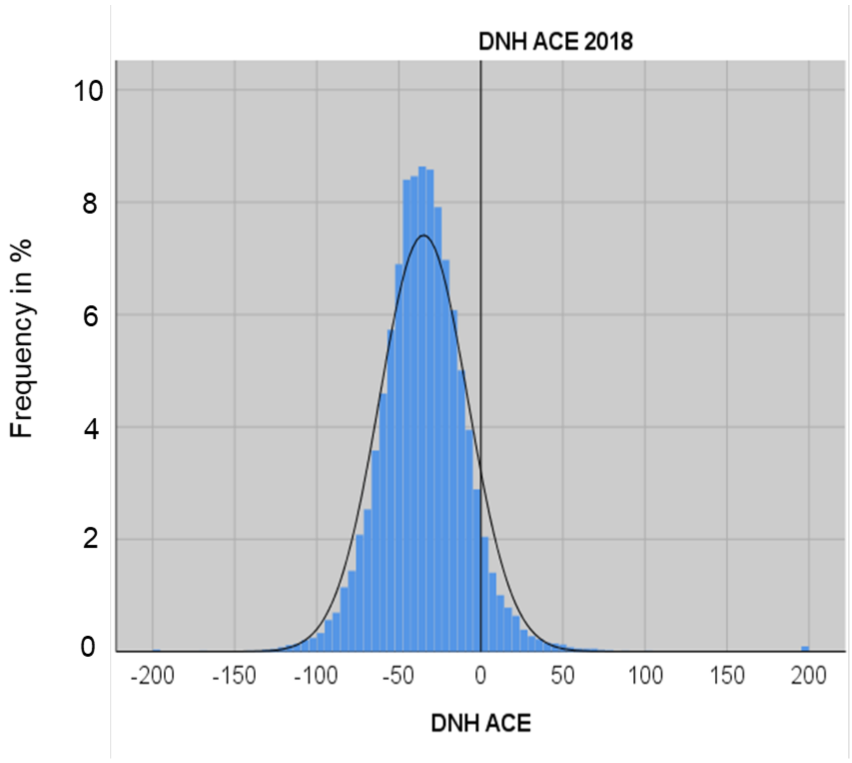

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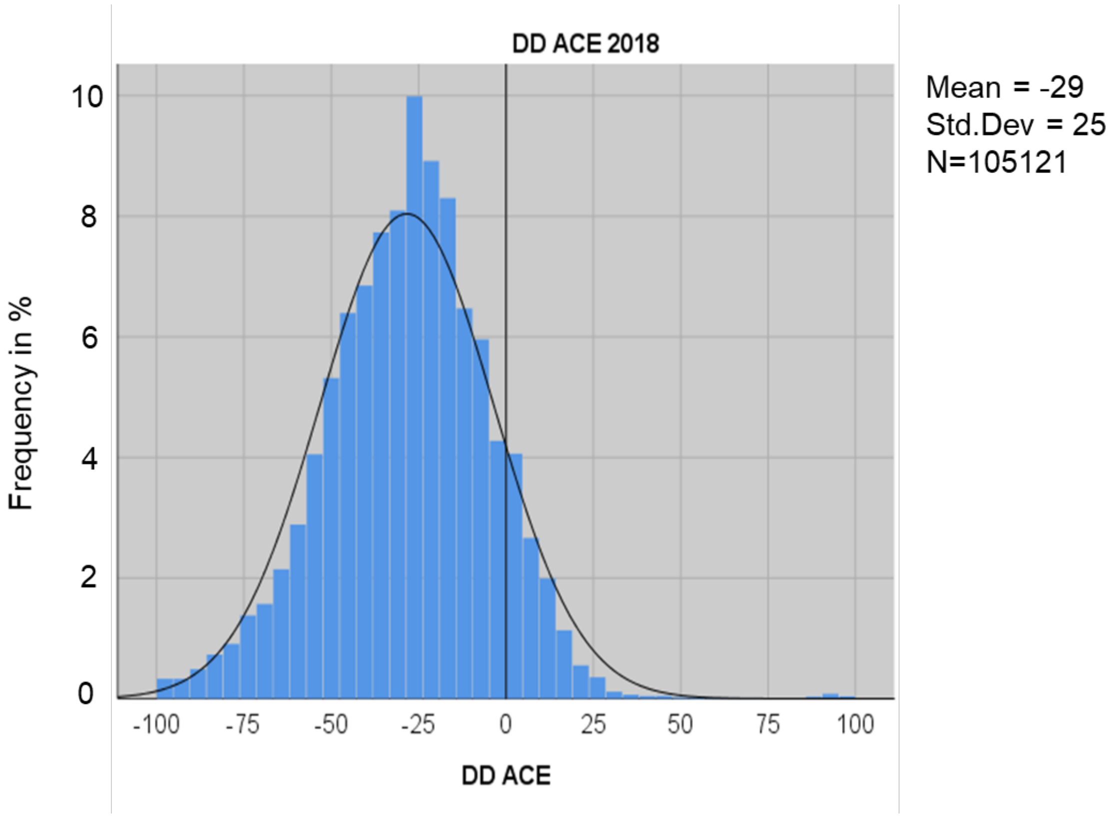
DD ACE 2018
Frequency in %
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75
100
DD ACE
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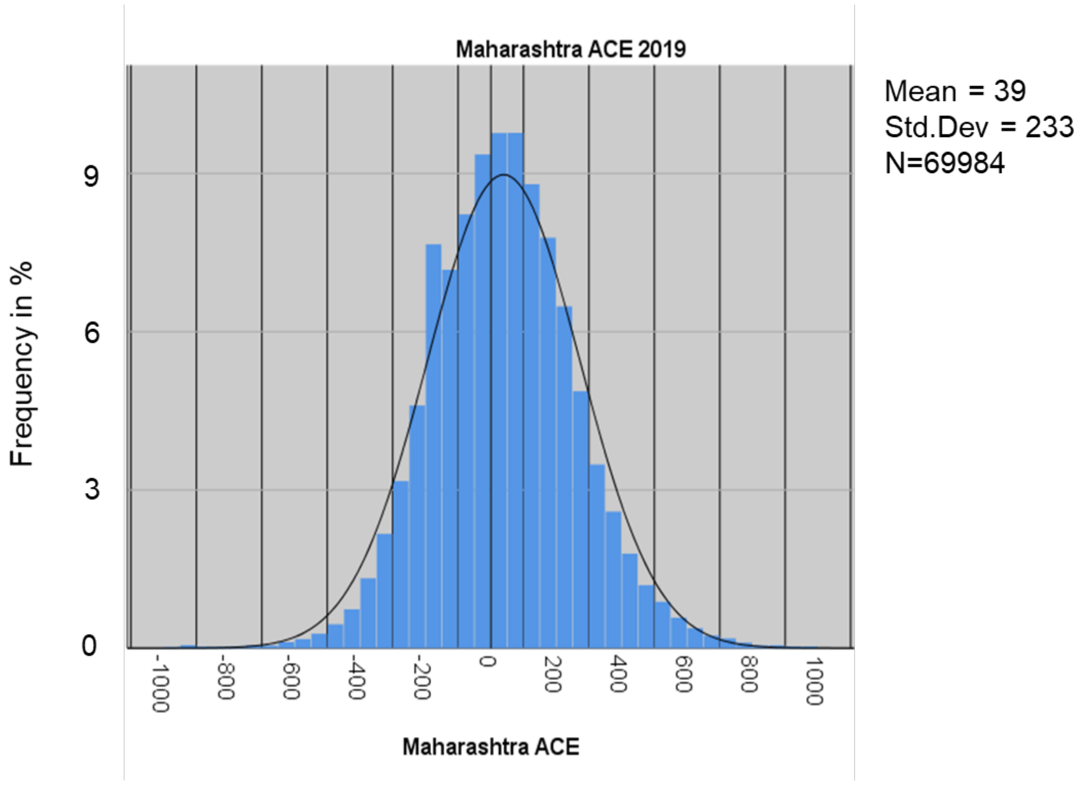
N=105121


Maharashtra ACE 2019
Frequency in %
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6
3
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400
600
800
1000
Maharashtra ACE
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Std.Dev = 233
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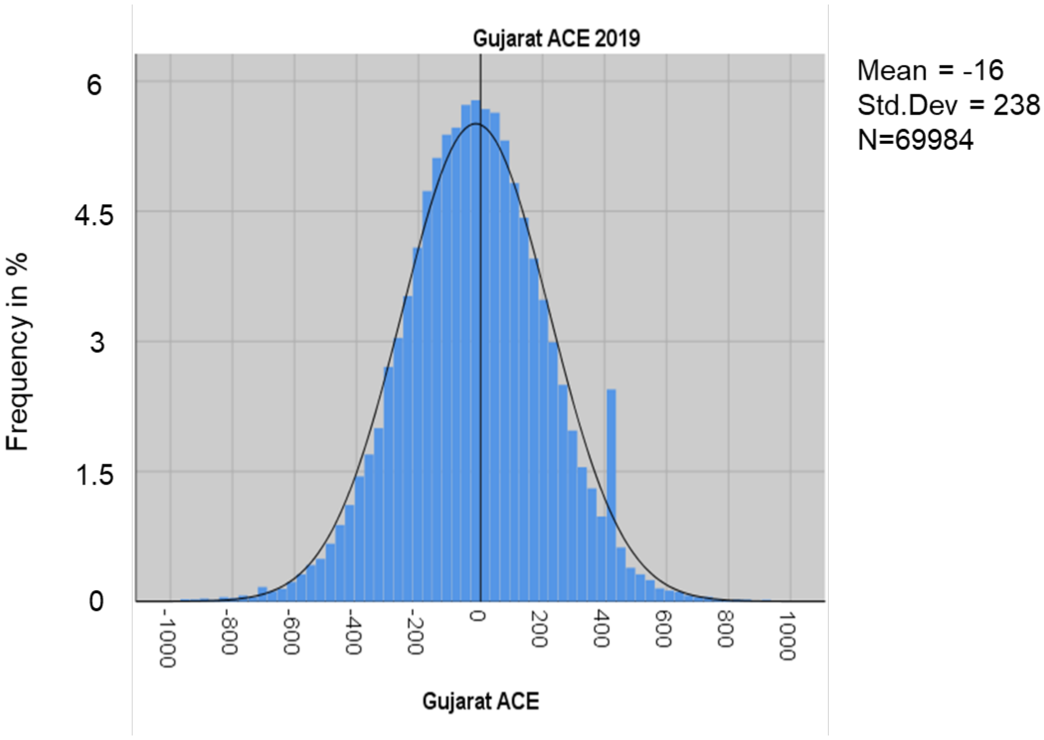

Gujarat ACE 2019
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Std.Dev = 238
N=69984
Frequency in %
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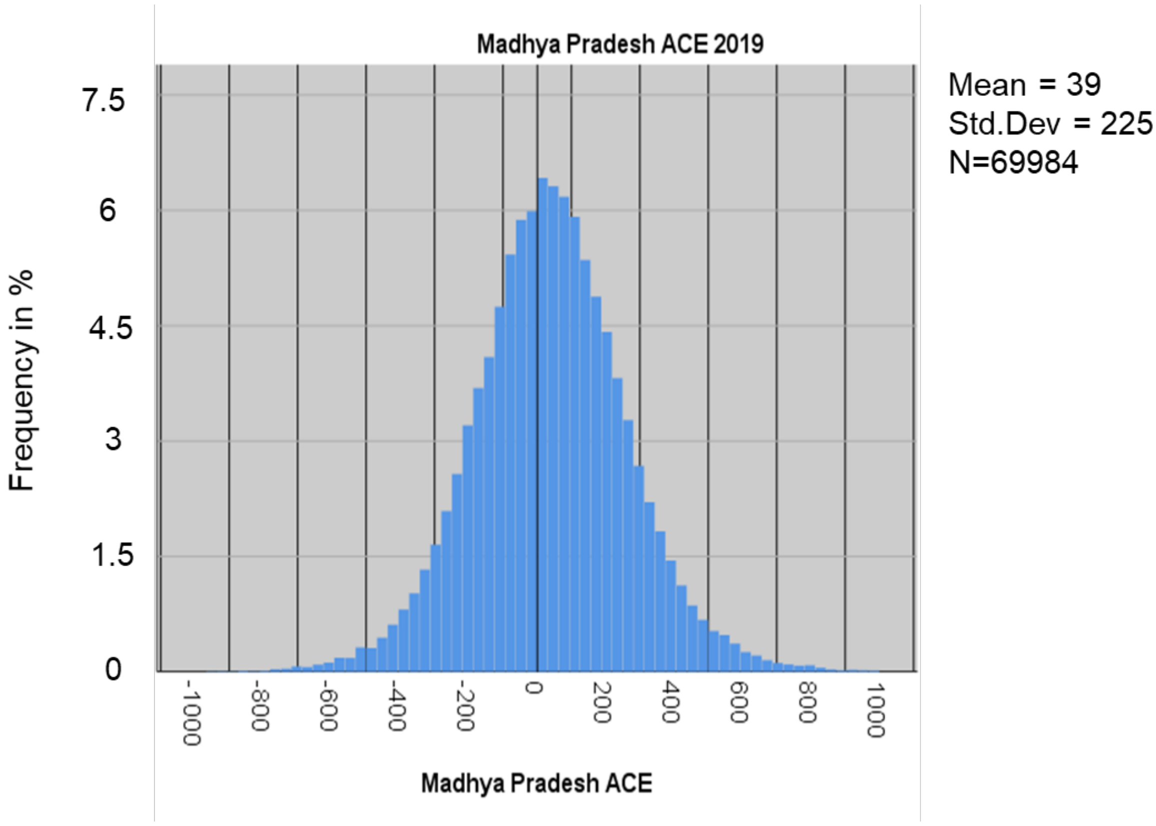
600
800
1000
Gujarat ACE



Madhya Pradesh ACE 2019
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Std.Dev = 225
N=69984
Frequency in %
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6
4.5
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1.5
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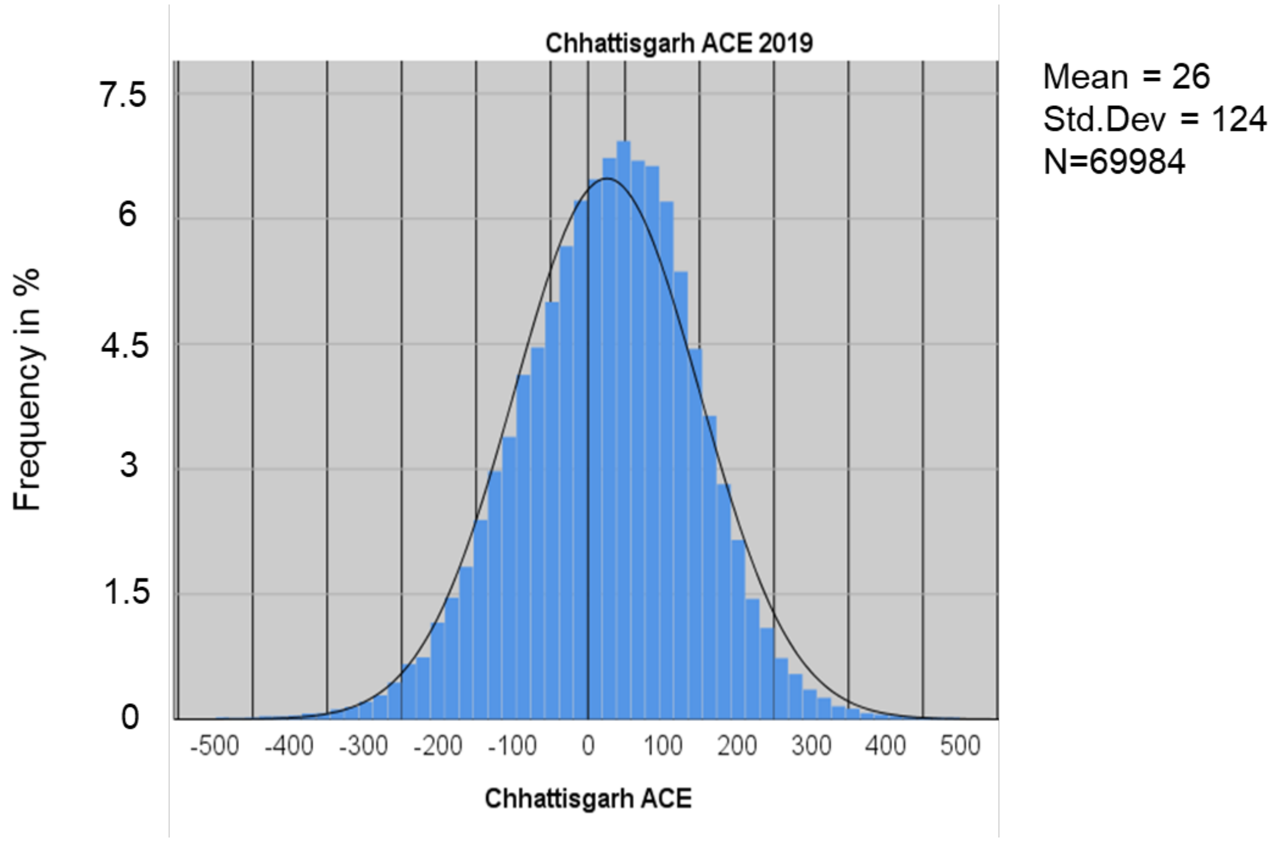
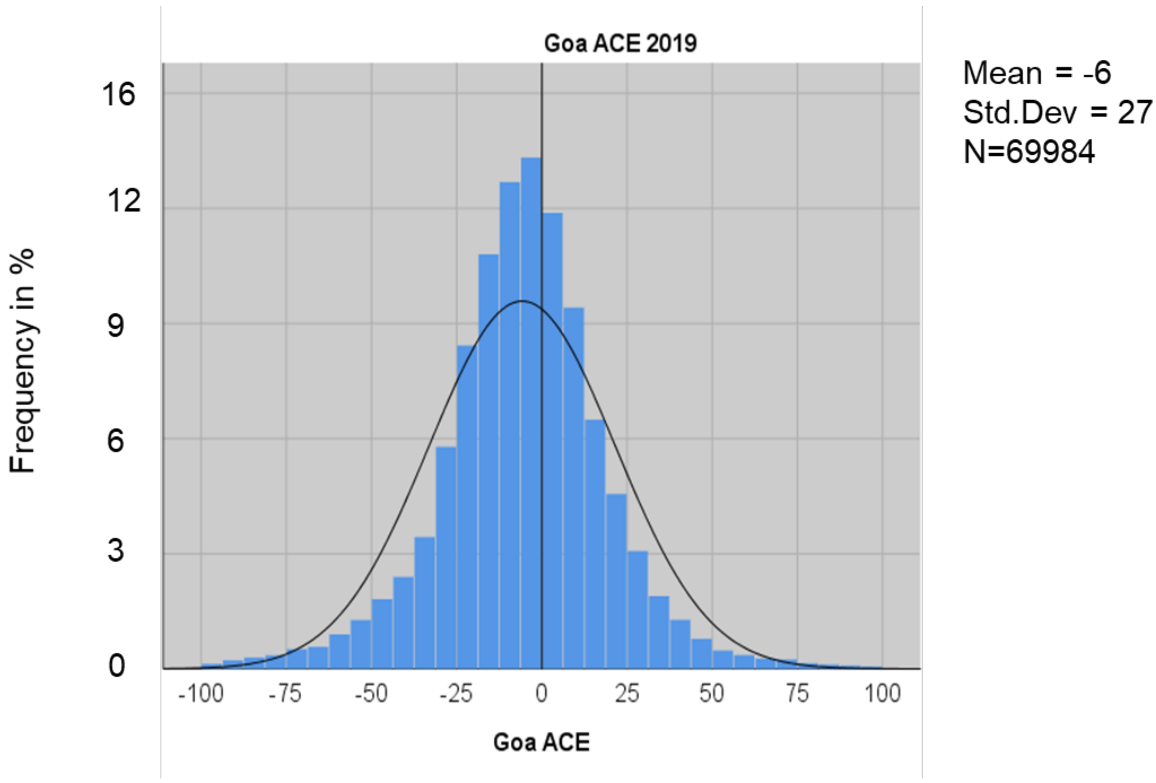
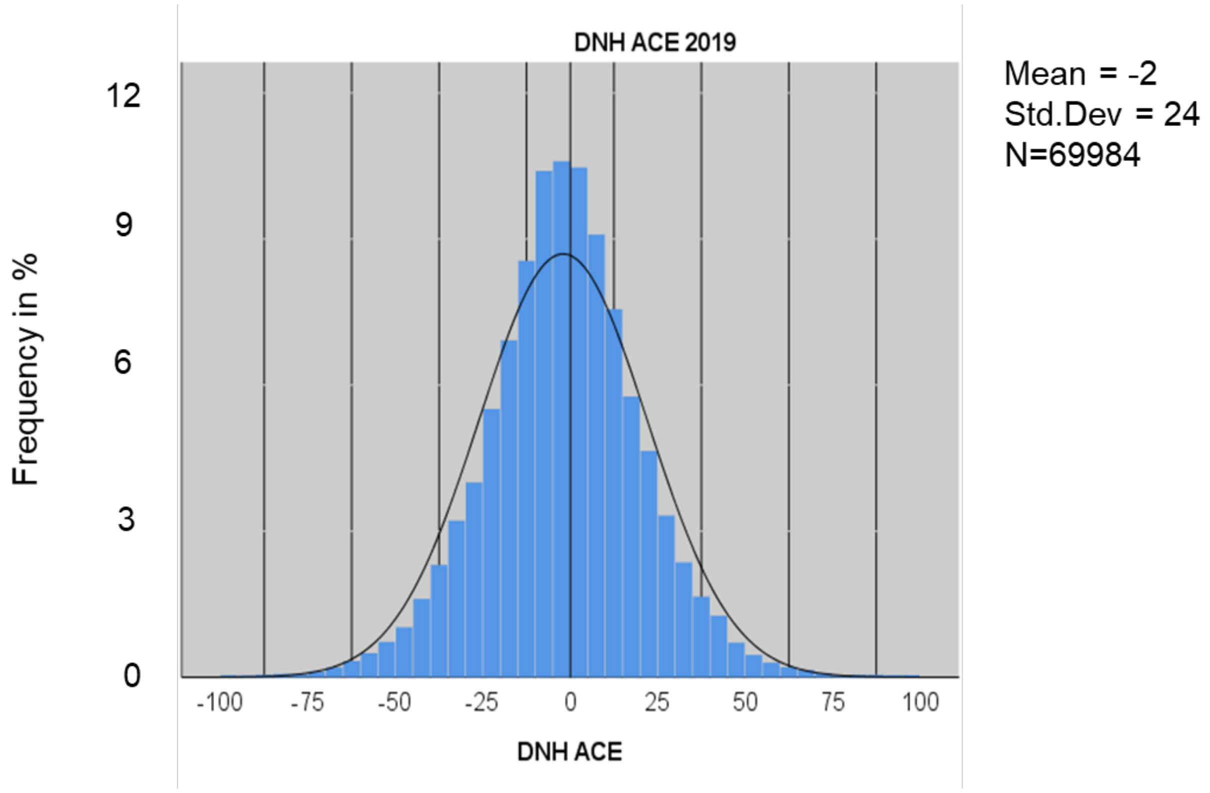
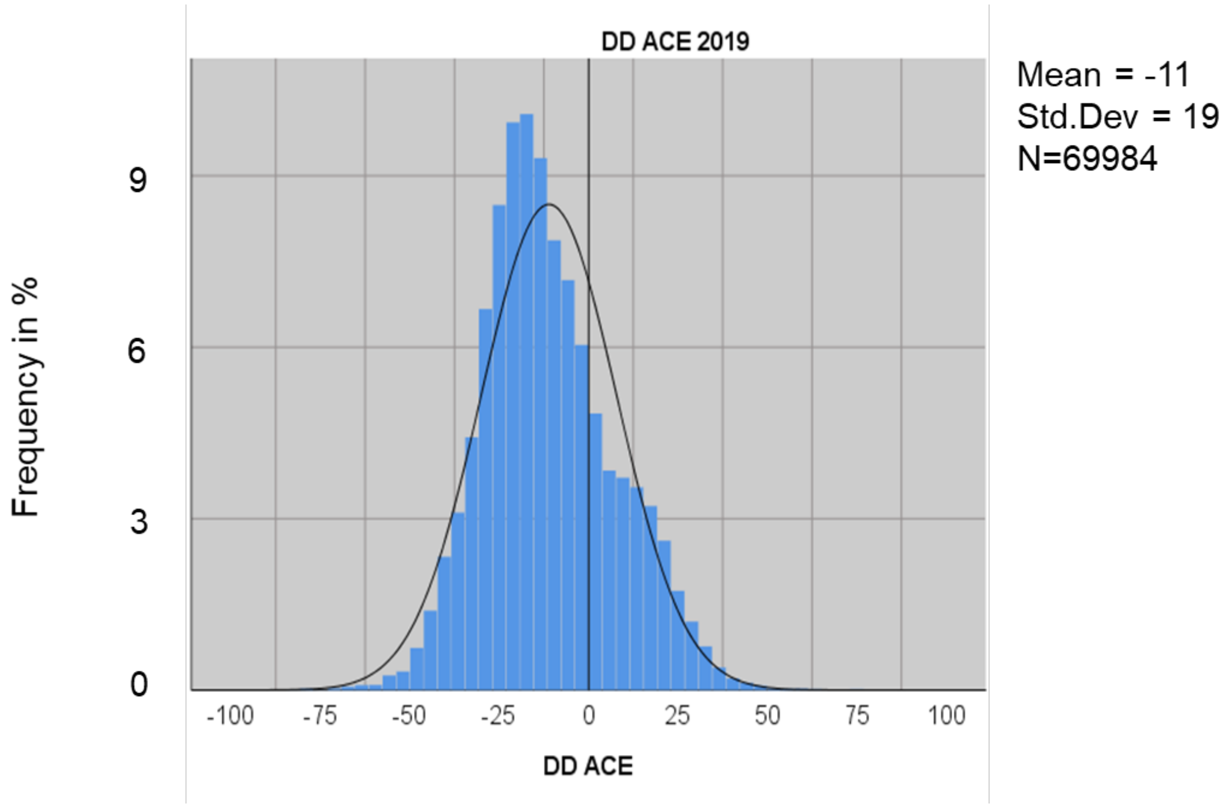
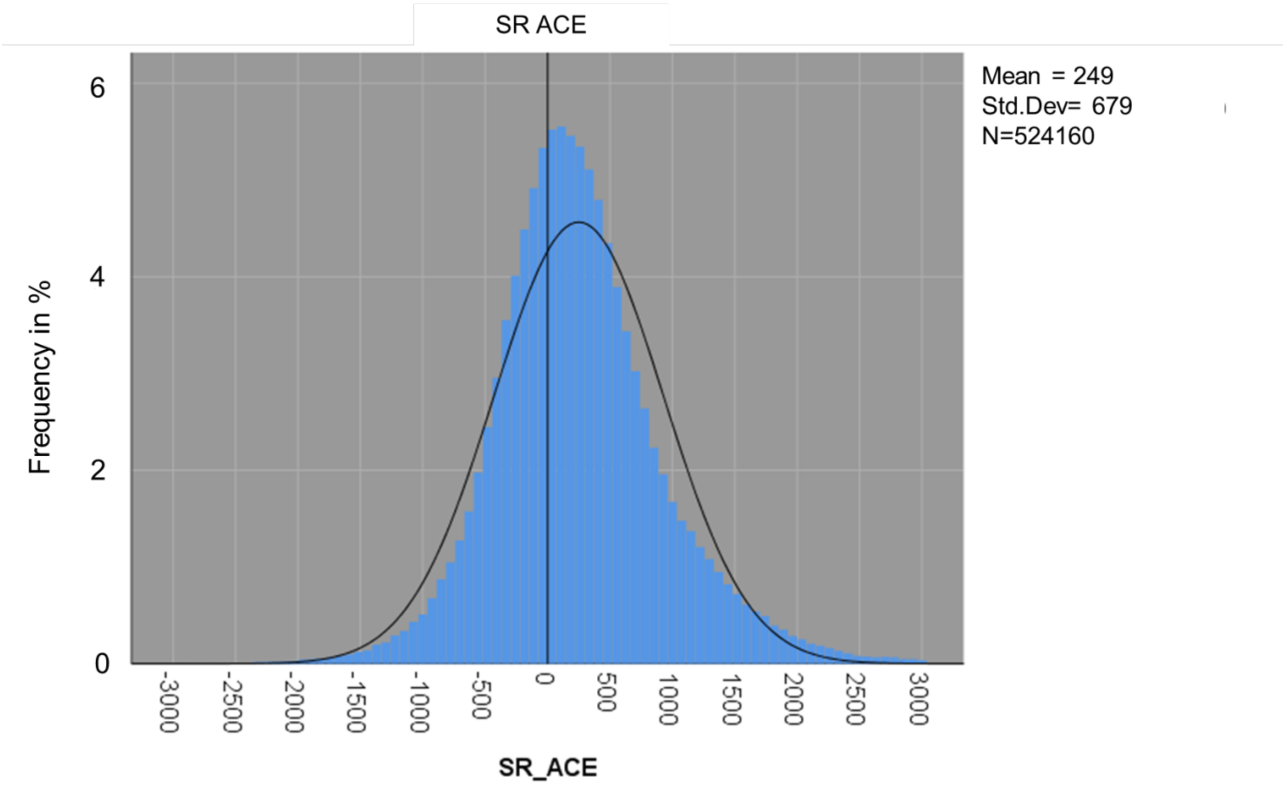
600
800
1000
Madhya Pradesh ACE


Chhattisgarh ACE 2019
Frequency in %
7.5
6
4.5
3
1.5
0
-500
-400
-300
-200
-100
0
100
200
300
400
500
Chhattisgarh ACE
Mean = 26
Std.Dev = 124
N=69984

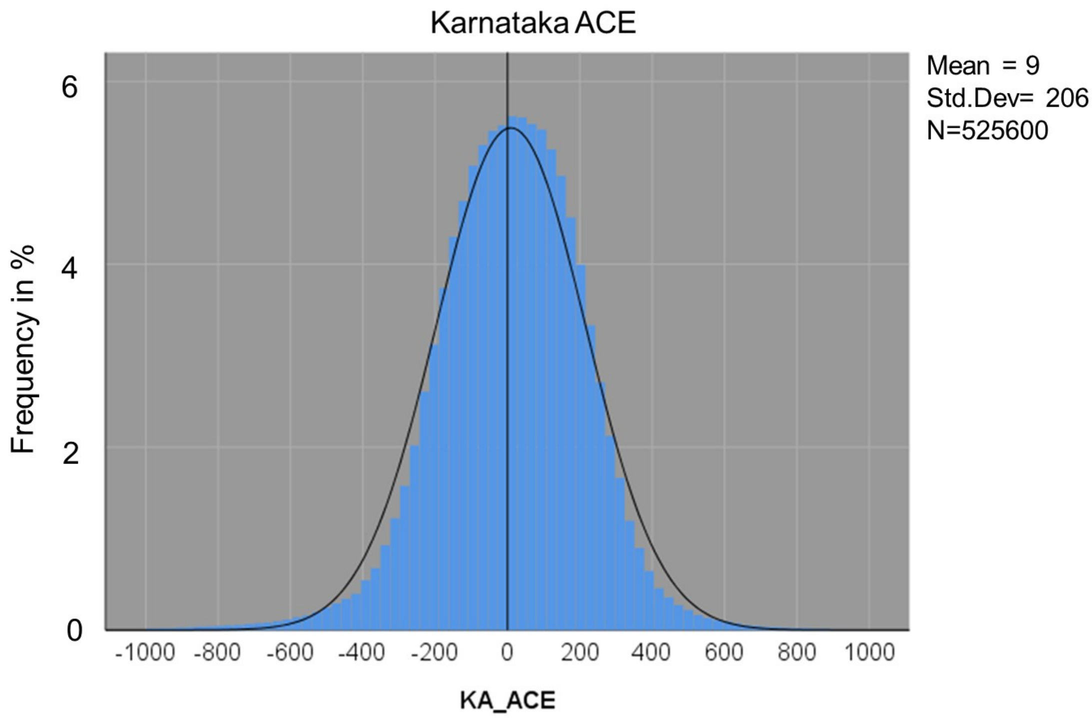

Goa ACE 2019
Frequency in %
16
12
9
6
3
0
-100
-75
-50
-25
0
25
50
75
100
Goa ACE
Mean = -6
Std.Dev = 27
N=69984


DNH ACE 2019
Mean = -2
Std.Dev = 24
N=69984
Frequency in %
12
9
6
3
0
-100
-75
-50
-25
0
25
50
75
100
DNH ACE

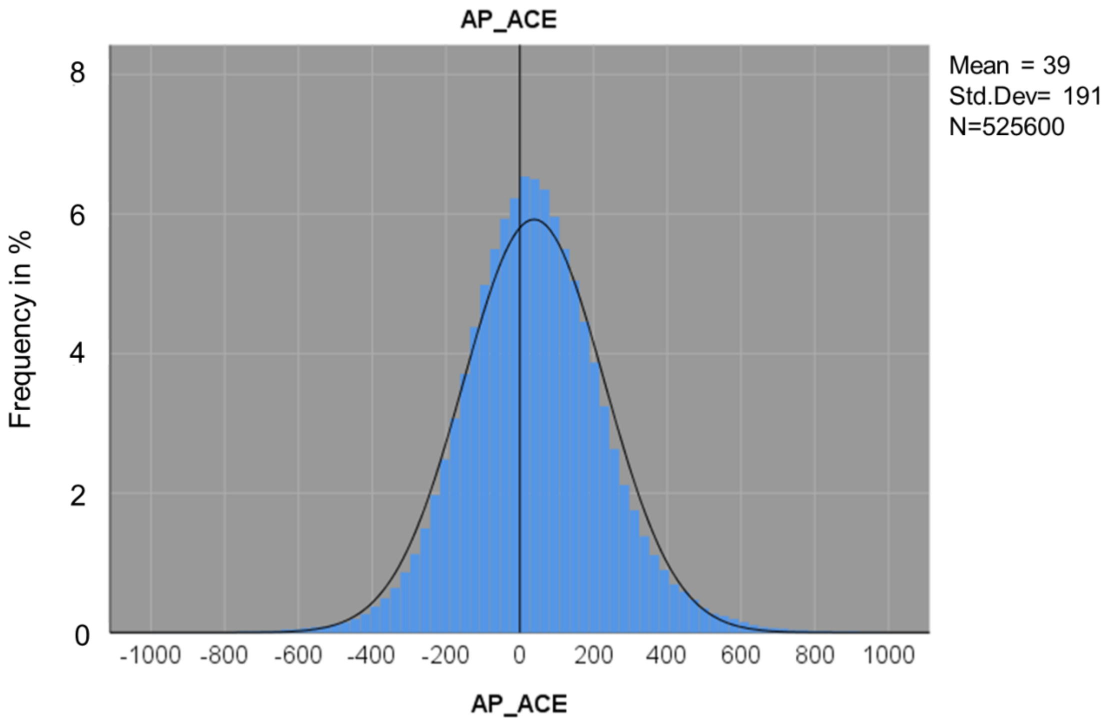

DD ACE 2019
Mean = -11
Std.Dev = 19
N=69984
Frequency in %
9
6
3
0
-100
-75
-50
-25
0
25
50
75
100
DD ACE



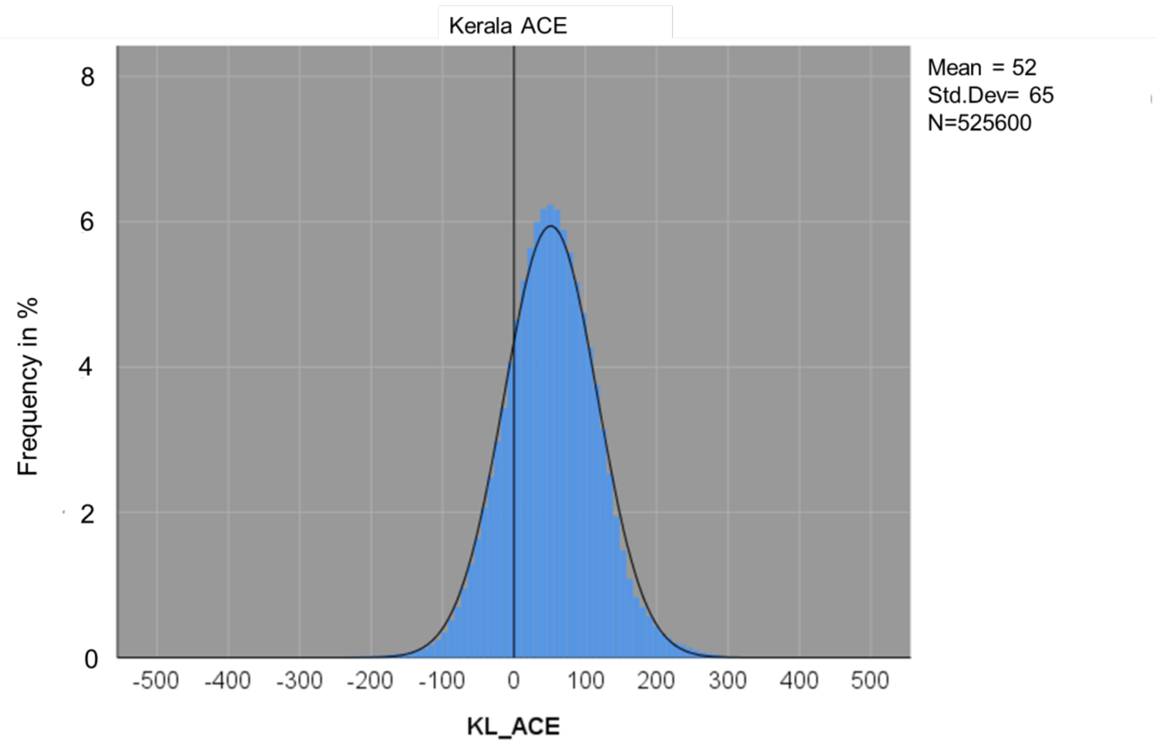
SR ACE
Mean = 249
Std.Dev= 679
N=524160
Frequency in %
6
4
2
0
-3000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
3000
SR_ACE



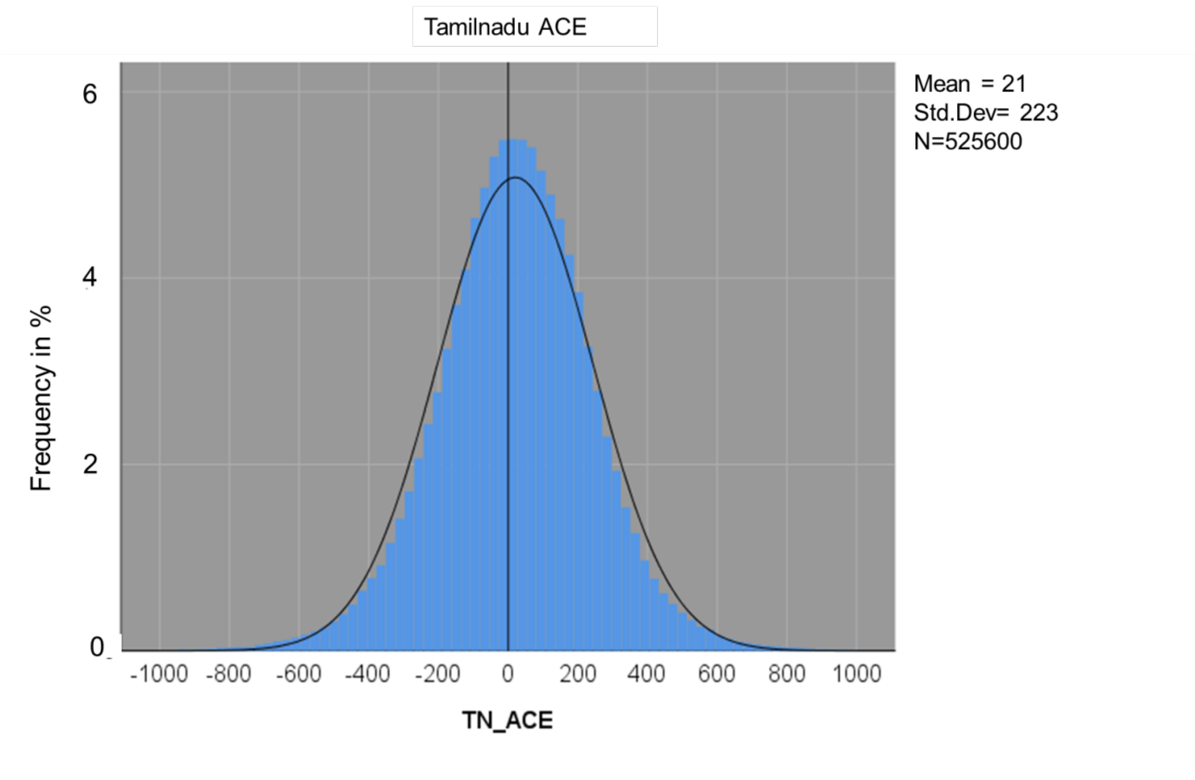
Karnataka ACE
Mean = 9
Std.Dev= 206
N=525600
Frequency in %
6
4
2
0
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
KA_ACE

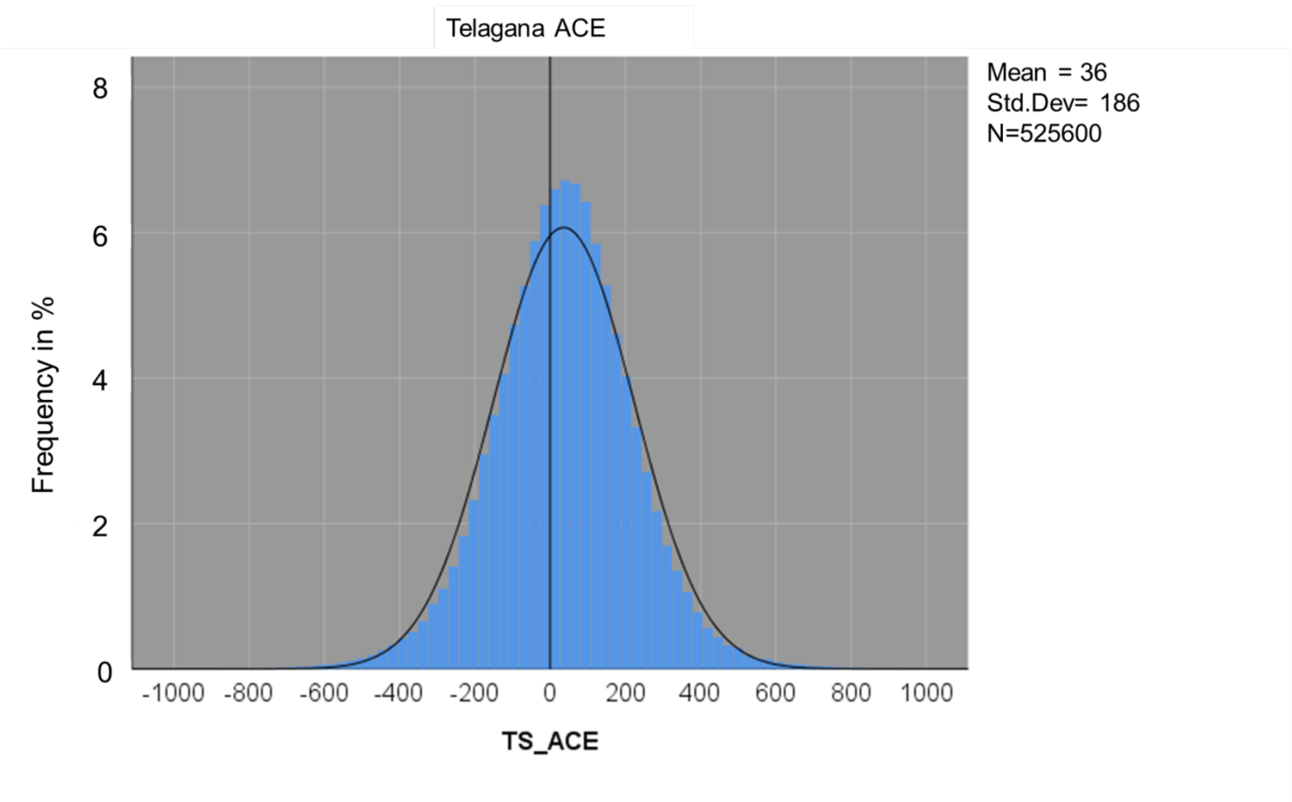


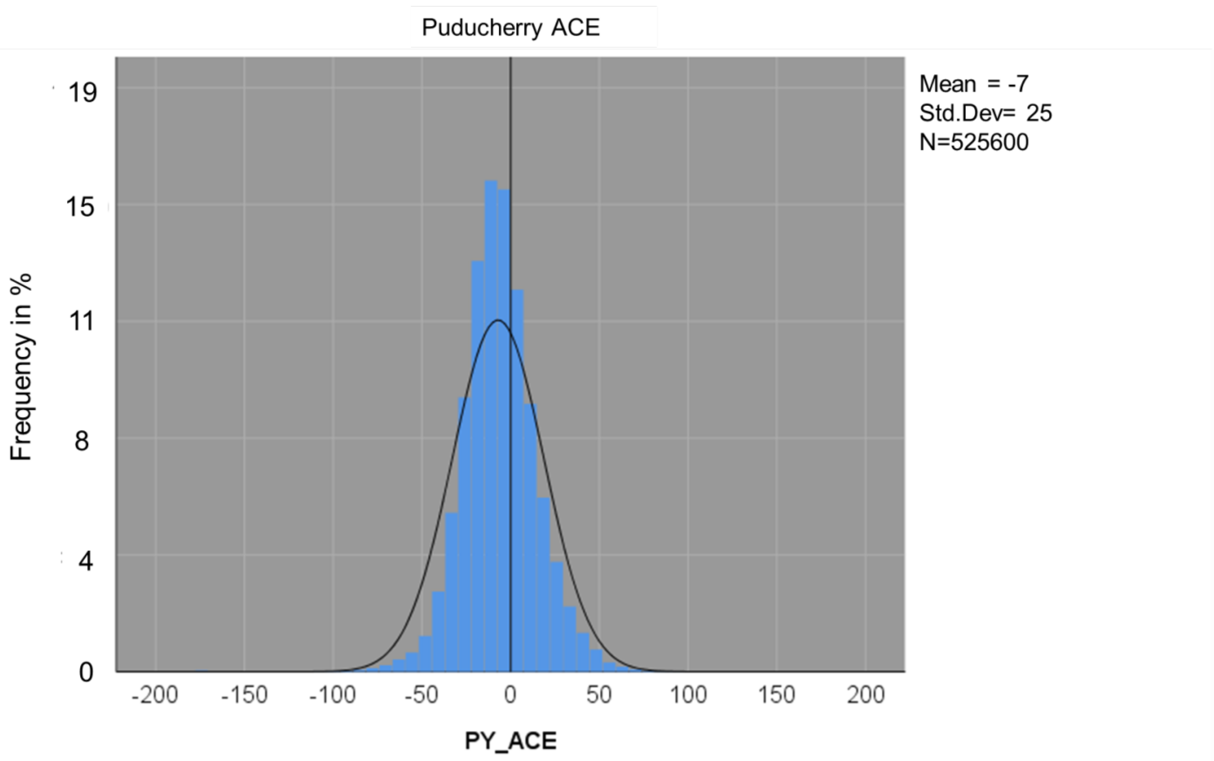
AP_ACE
Mean = 39
Std.Dev= 191
N=525600
Frequency in %
8
6
4
2
0
-1000 -800 -600 -400 -200 0 200 400 600 800 1000
AP_ACE

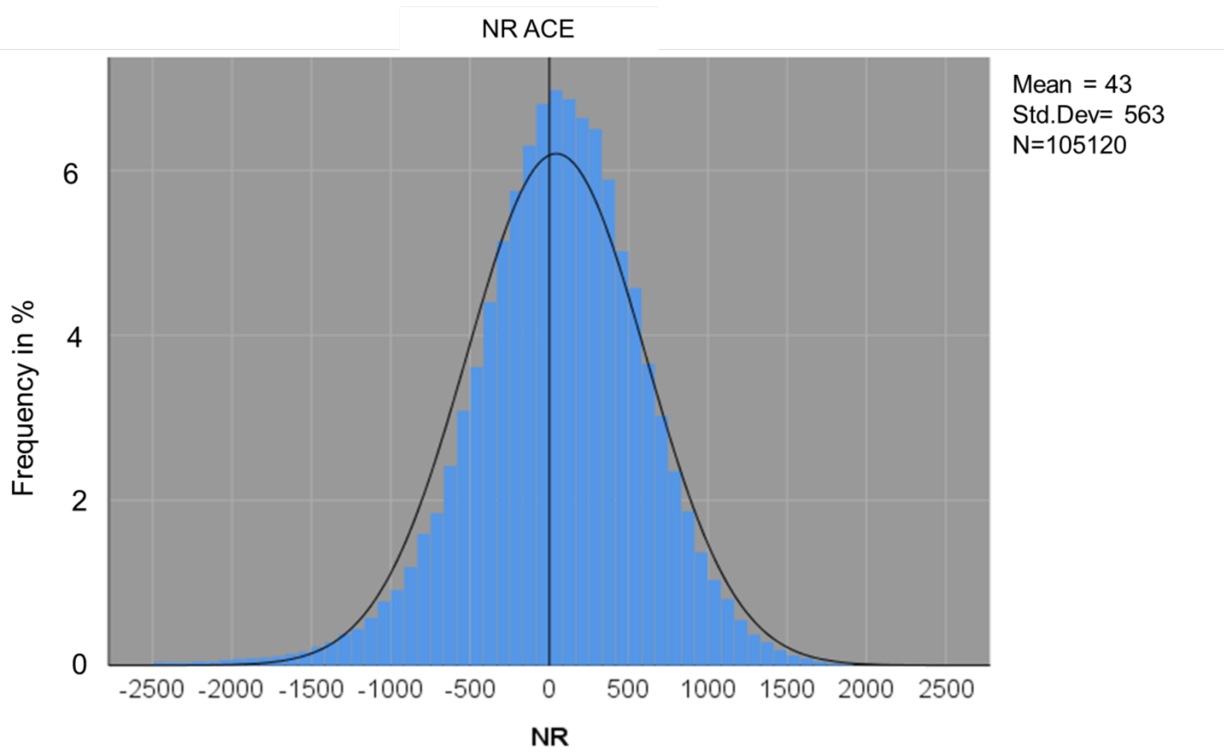


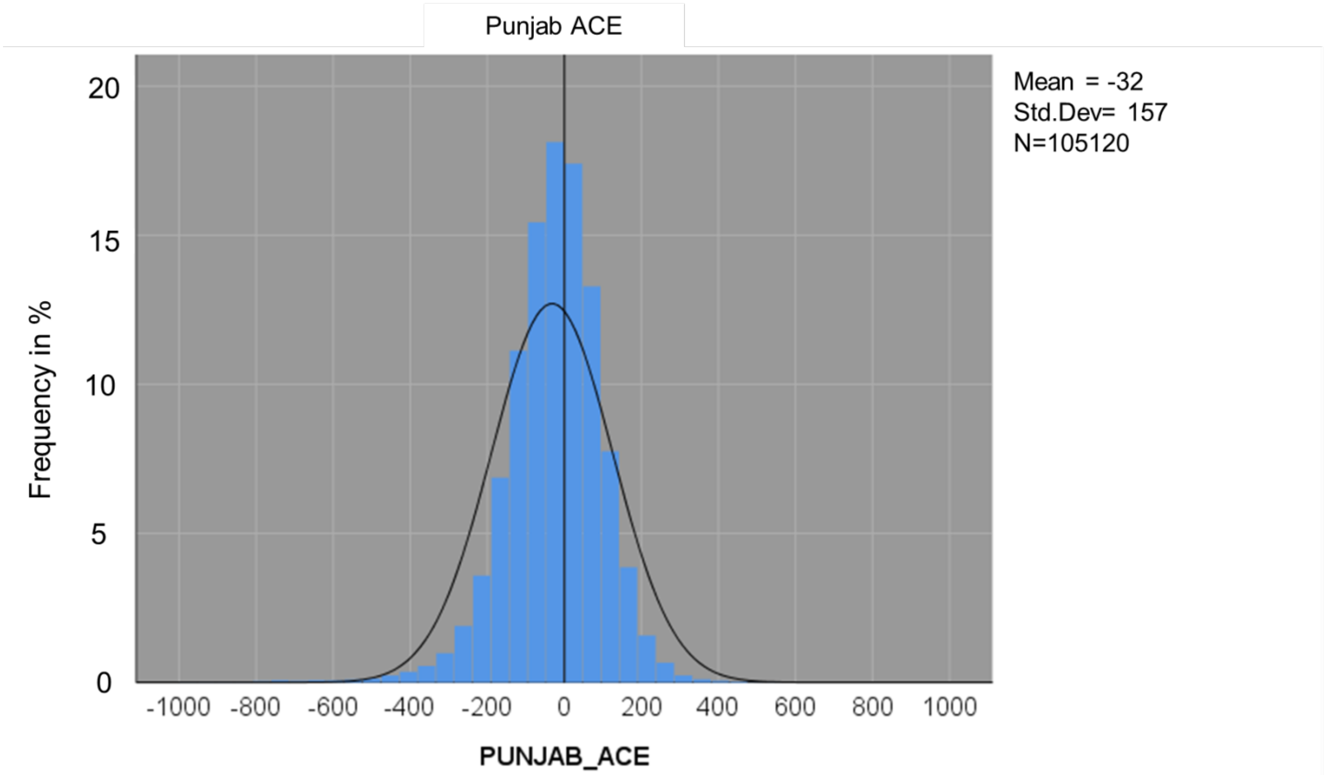
Kerala ACE
Mean = 52
Std.Dev= 65
N=525600
Frequency in %
8
6
4
2
0
-500 -400 -300 -200 -100 0 100 200 300 400 500
KL_ACE

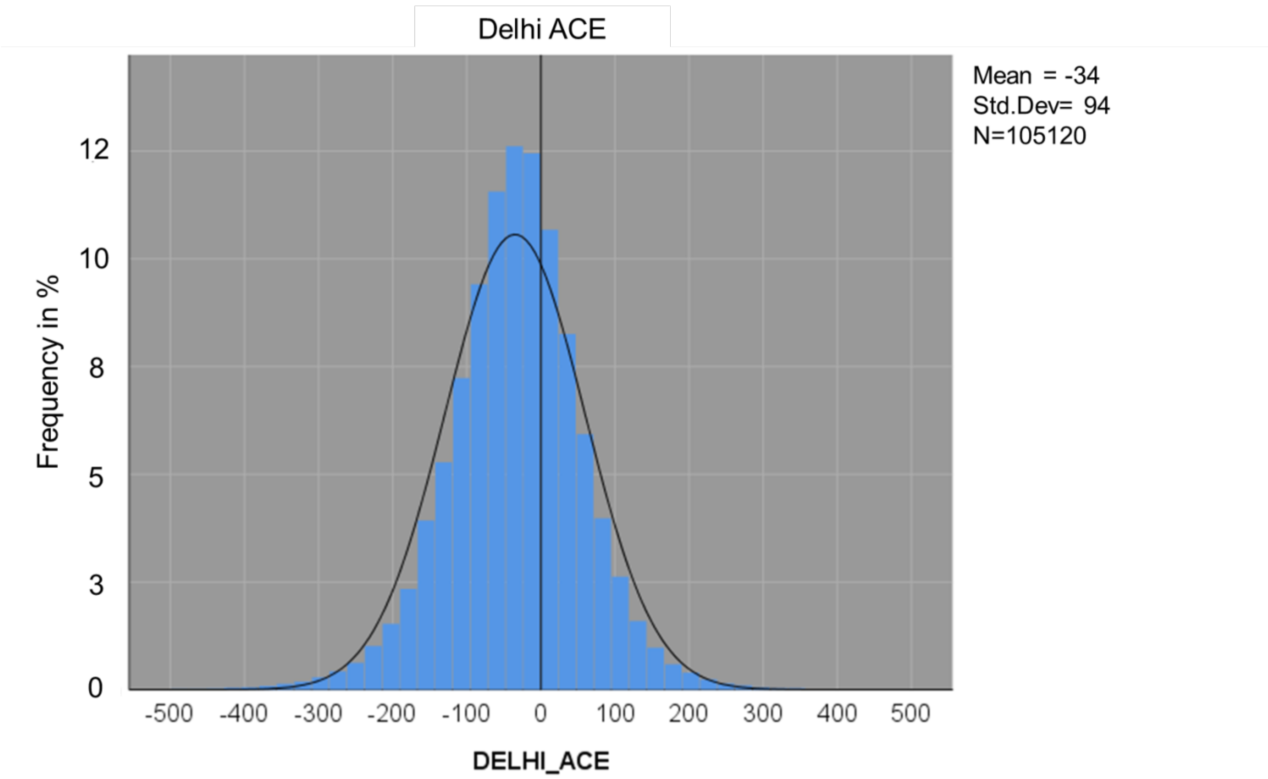

Tamilnadu ACE
Mean = 21
Std.Dev= 223
N=525600
Frequency in %
6
4
2
0
-1000 -800 -600 -400 -200 0 200 400 600 800 1000
TN_ACE

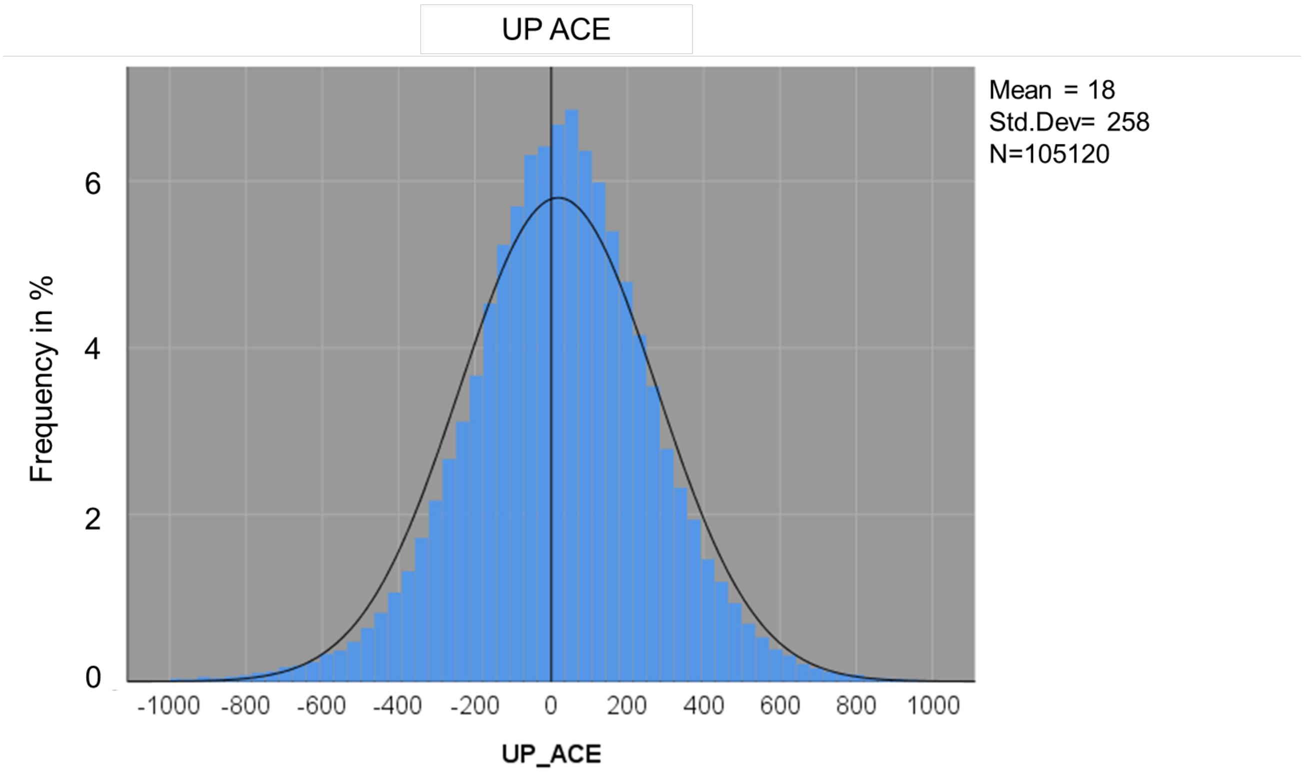

Telagana ACE
Mean = 36
Std.Dev= 186
N=525600
Frequency in %
8
6
4
2
0
-1000 -800 -600 -400 -200 0 200 400 600 800 1000
TS_ACE

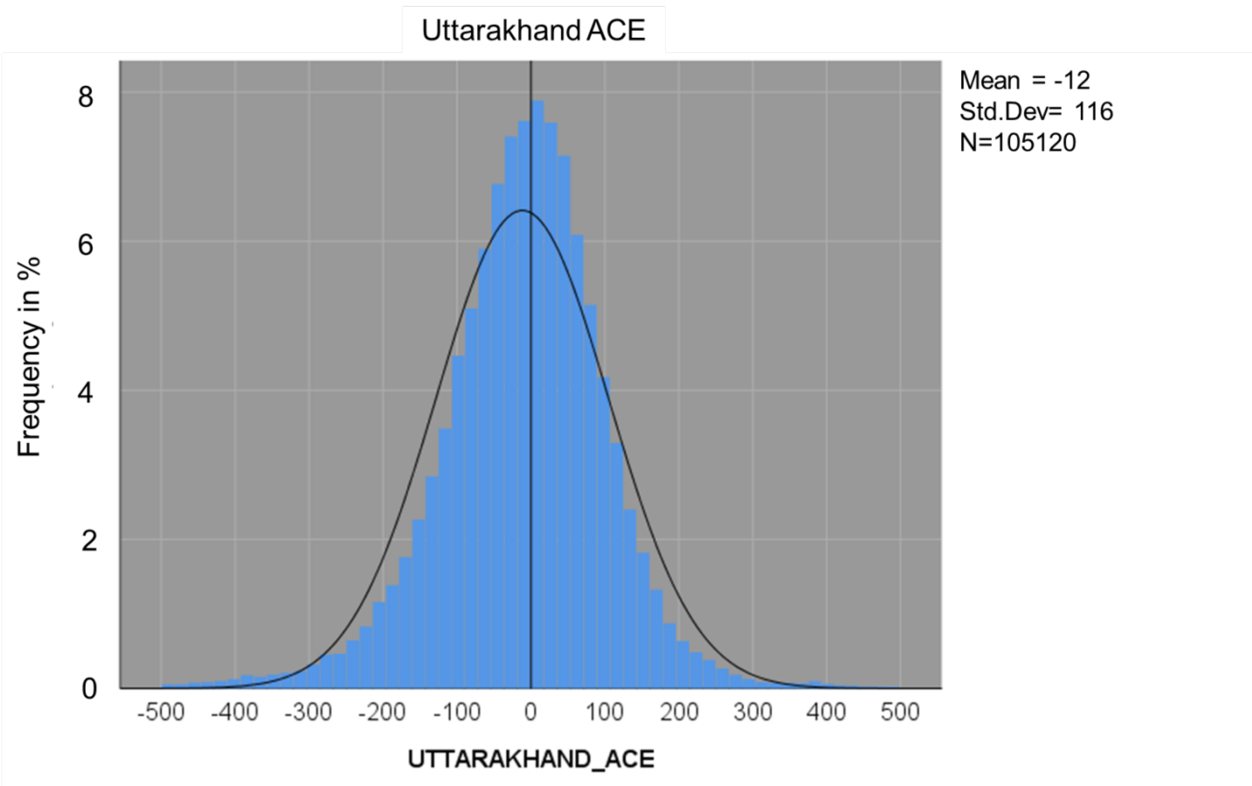

Puducherry ACE
Mean = -7
Std.Dev= 25
N=525600
Frequency in %
19
15
11
8
4
0
-200
-150
-100
-50
0
50
100
150
200
PY_ACE

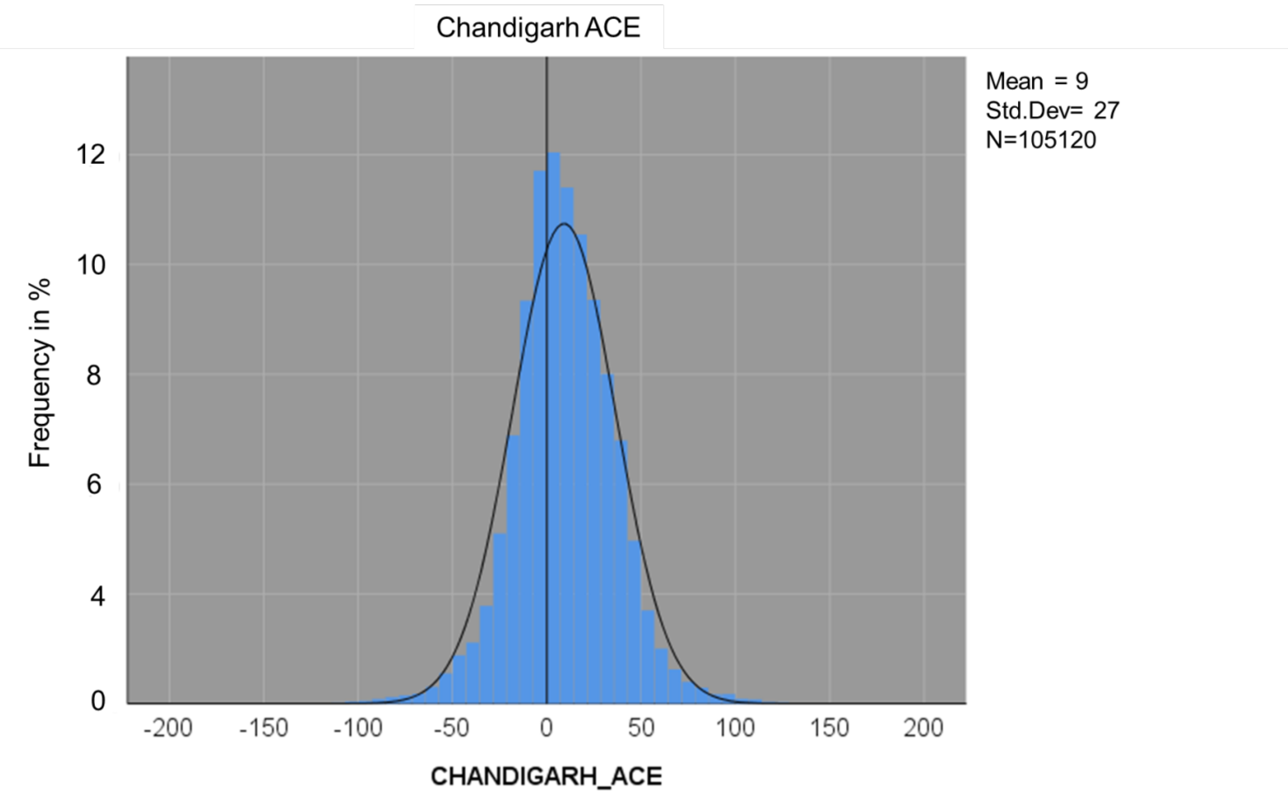

NR ACE
Mean = 43
Std.Dev= 563
N=105120
Frequency in %
6
4
2
0
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500
NR

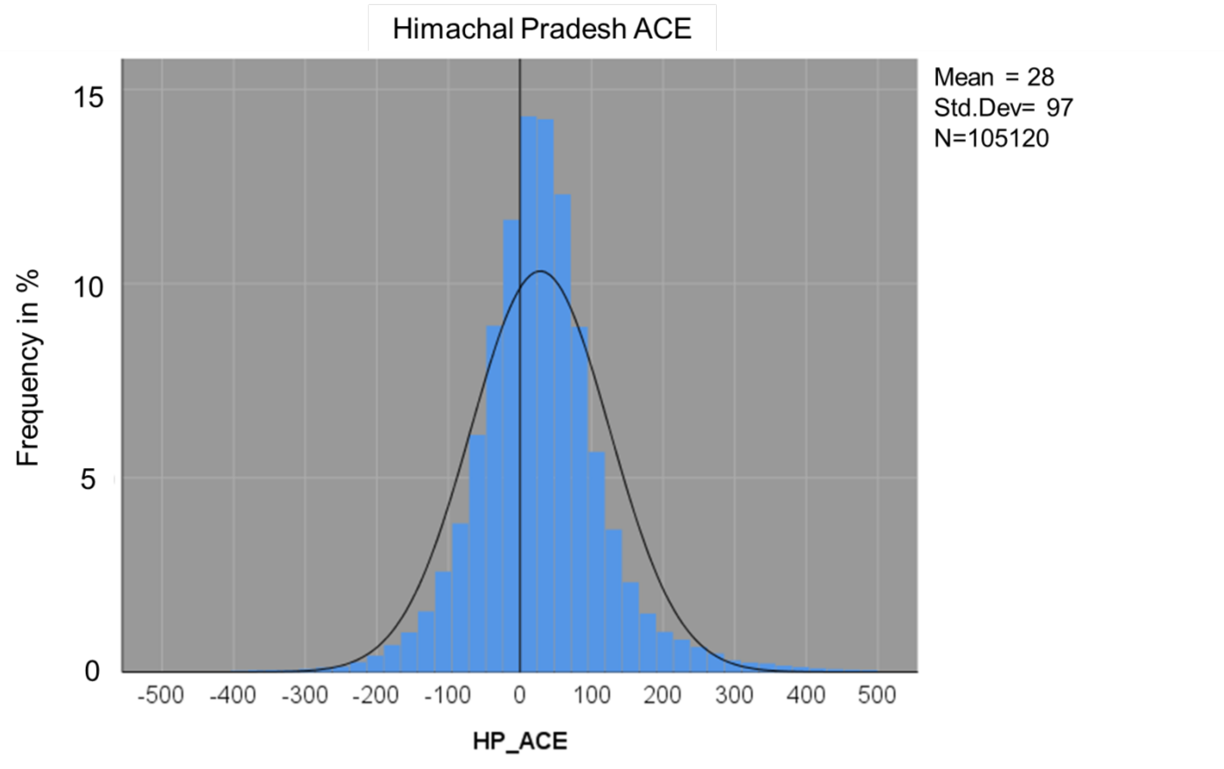

Punjab ACE
Mean = -32
Std.Dev= 157
N=105120
Frequency in %
20
15
10
5
0
-1000 -800 -600 -400 -200 0 200 400 600 800 1000
PUNJAB_ACE

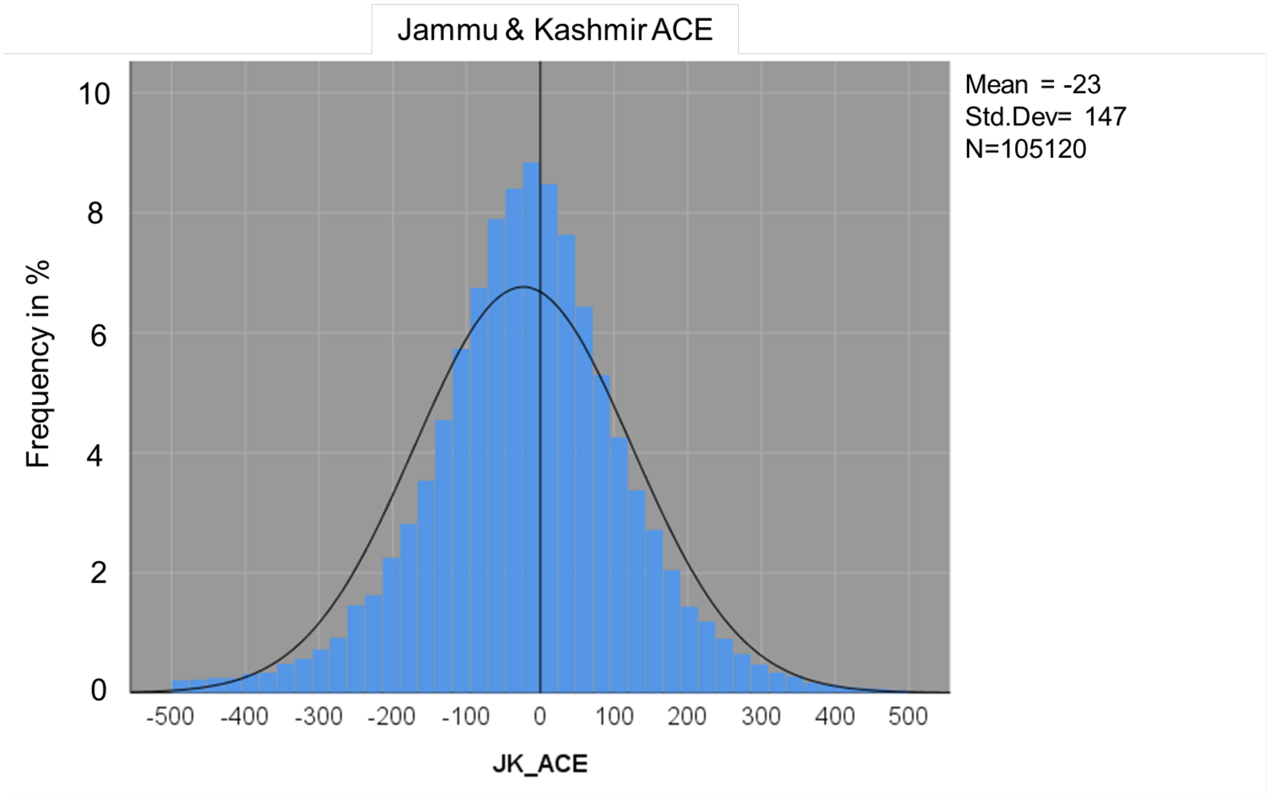

Delhi ACE
Mean = -34
Std.Dev= 94
N=105120
Frequency in %
12
10
8
5
3
0
-500 -400 -300 -200 -100 0 100 200 300 400 500
DELHI_ACE

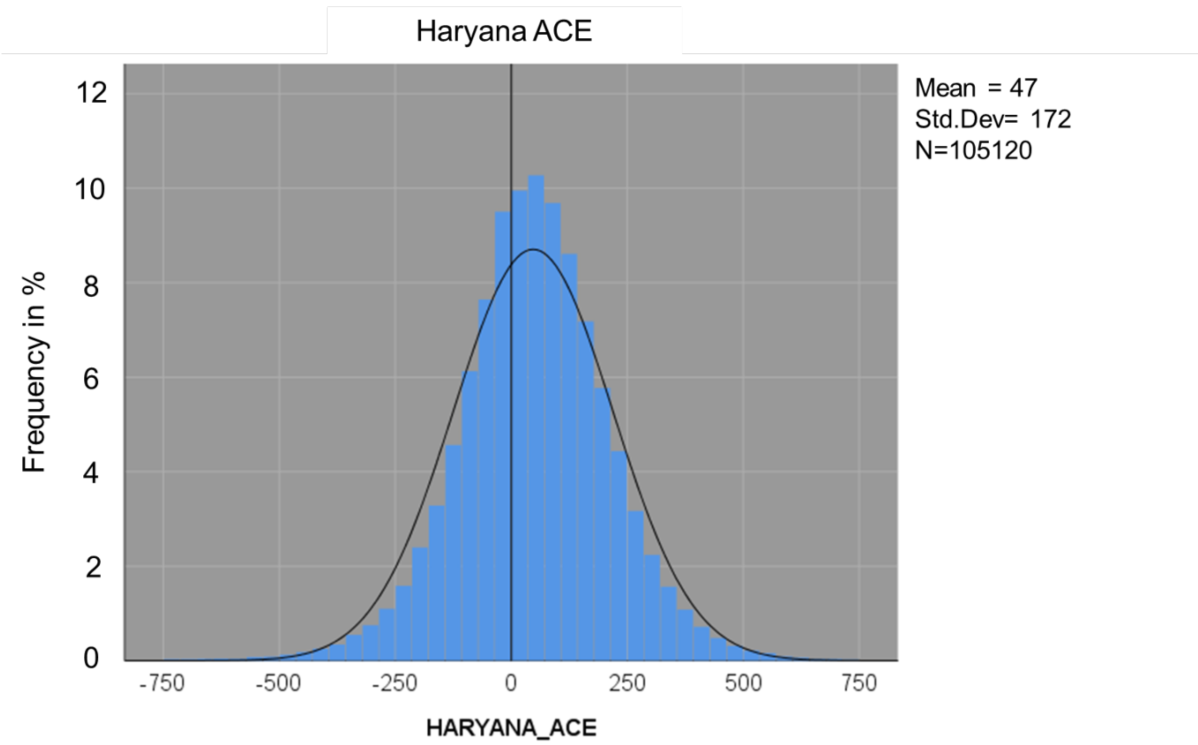

UP ACE
Mean = 18
Std.Dev= 258
N=105120
Frequency in %
0
2
4
6
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
UP_ACE

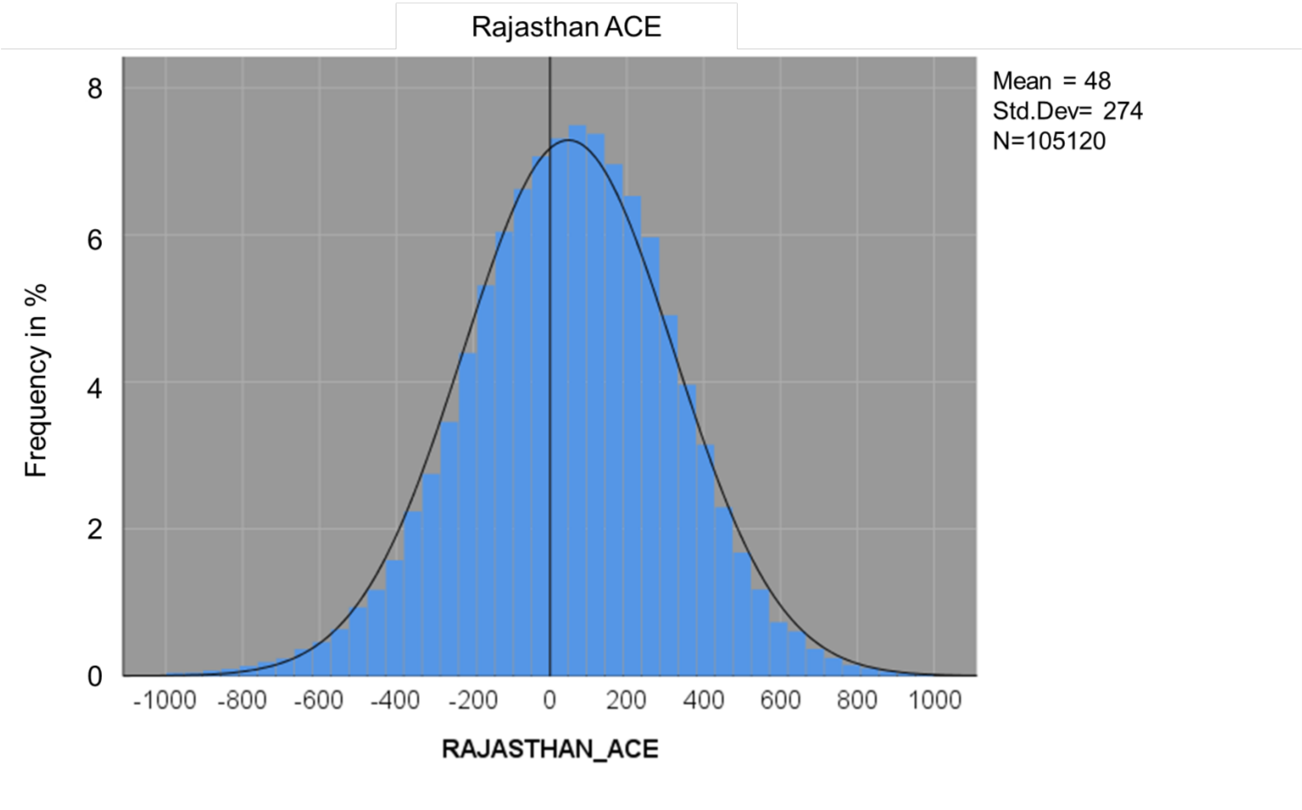

Uttarakhand ACE
Mean = -12
Std.Dev= 116
N=105120
Frequency in %
0
2
4
6
8
-500
-400
-300
-200
-100
0
100
200
300
400
500
UTTARAKHAND_ACE

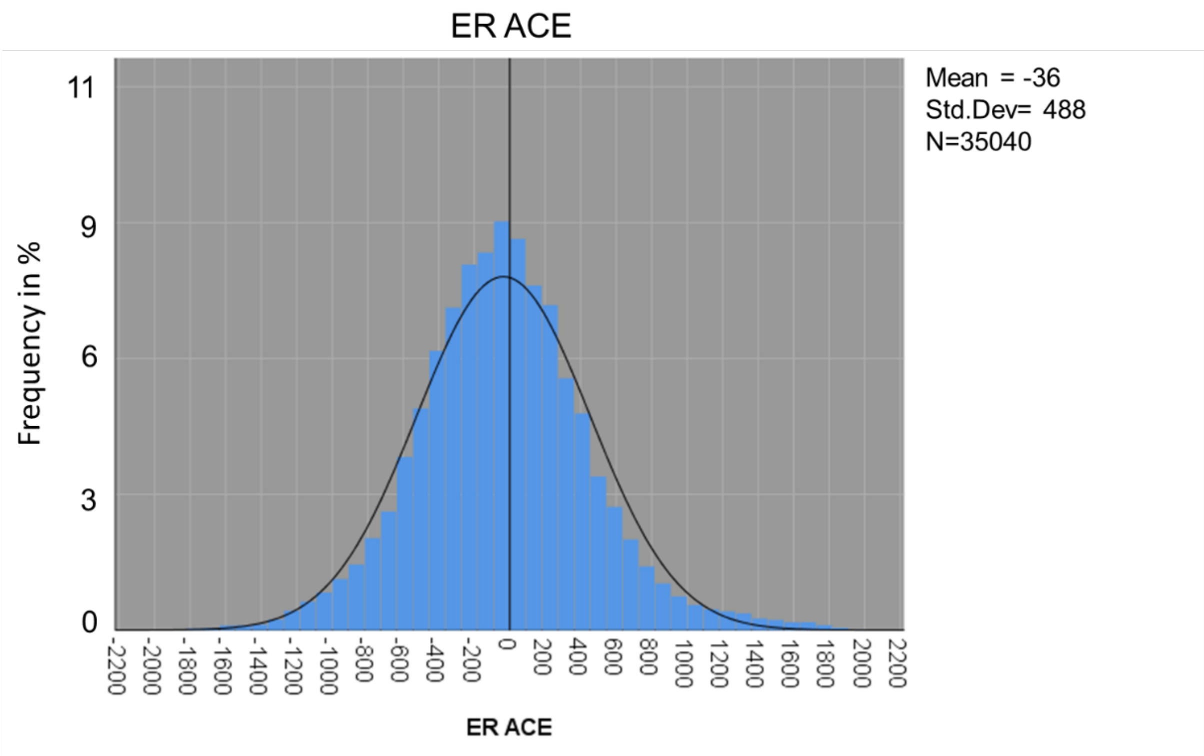

Chandigarh ACE
Mean = 9
Std.Dev= 27
N=105120
Frequency in %
12
10
8
6
4
0
-200
-150
-100
-50
0
50
100
150
200
CHANDIGARH_ACE

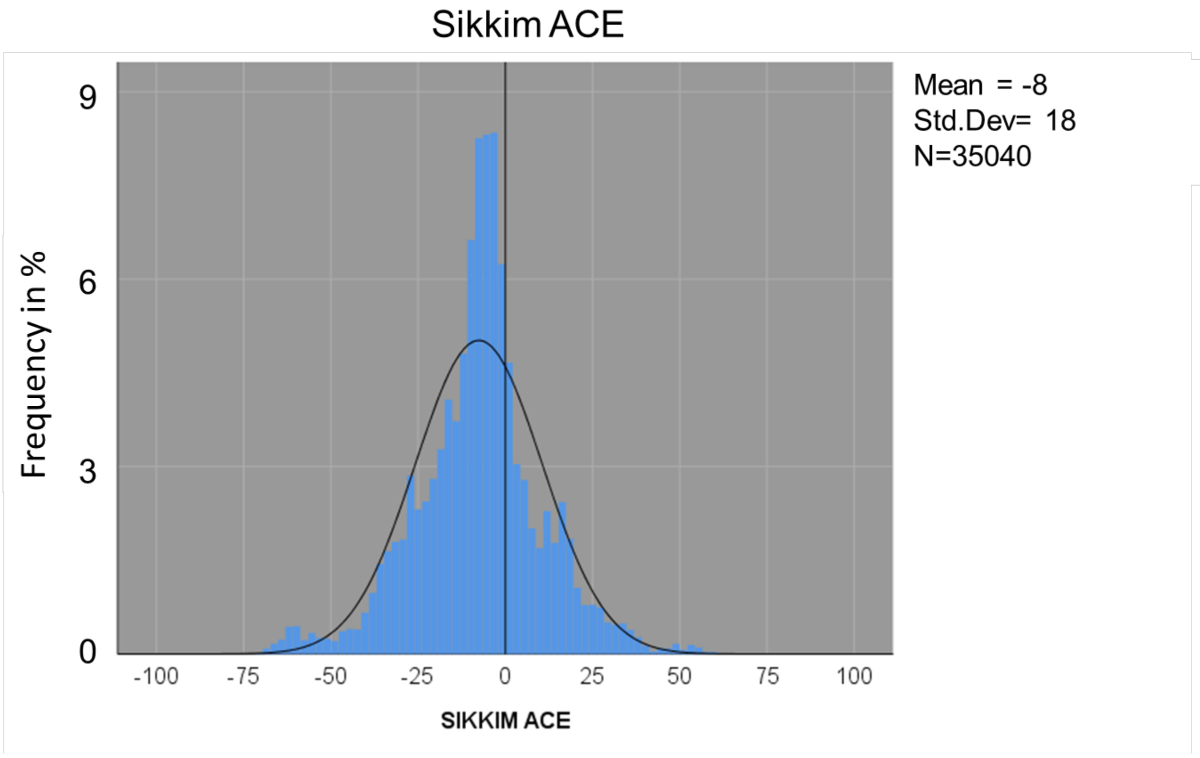

Himachal Pradesh ACE
Mean = 28
Std.Dev= 97
N=105120
Frequency in %
15
10
5
0
-500
-400
-300
-200
-100
0
100
200
300
400
500
HP_ACE

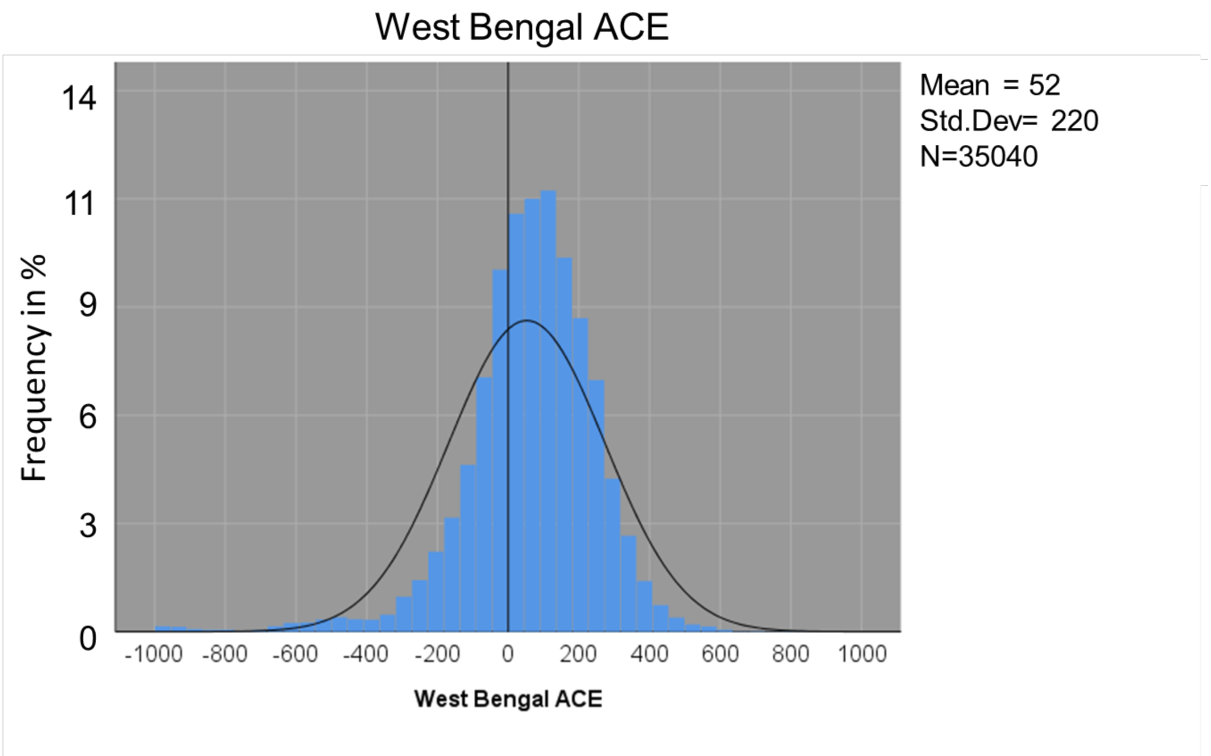

Jammu & Kashmir ACE
Mean = -23
Std.Dev= 147
N=105120
Frequency in %
10
8
6
4
2
0
-500
-400
-300
-200
-100
0
100
200
300
400
500
JK_ACE

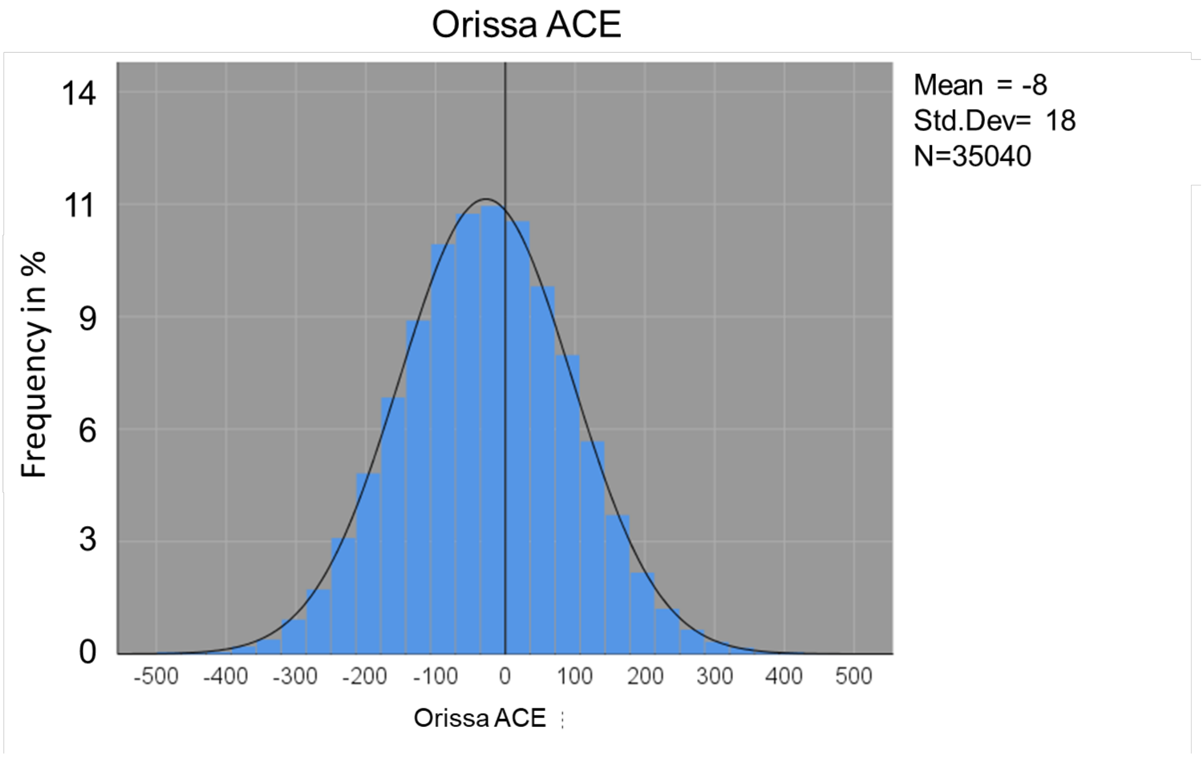

Haryana ACE
Mean = 47
Std.Dev= 172
N=105120
Frequency in %
12
10
8
6
4
2
0
-750
-500
-250
0
250
500
750
HARYANA_ACE

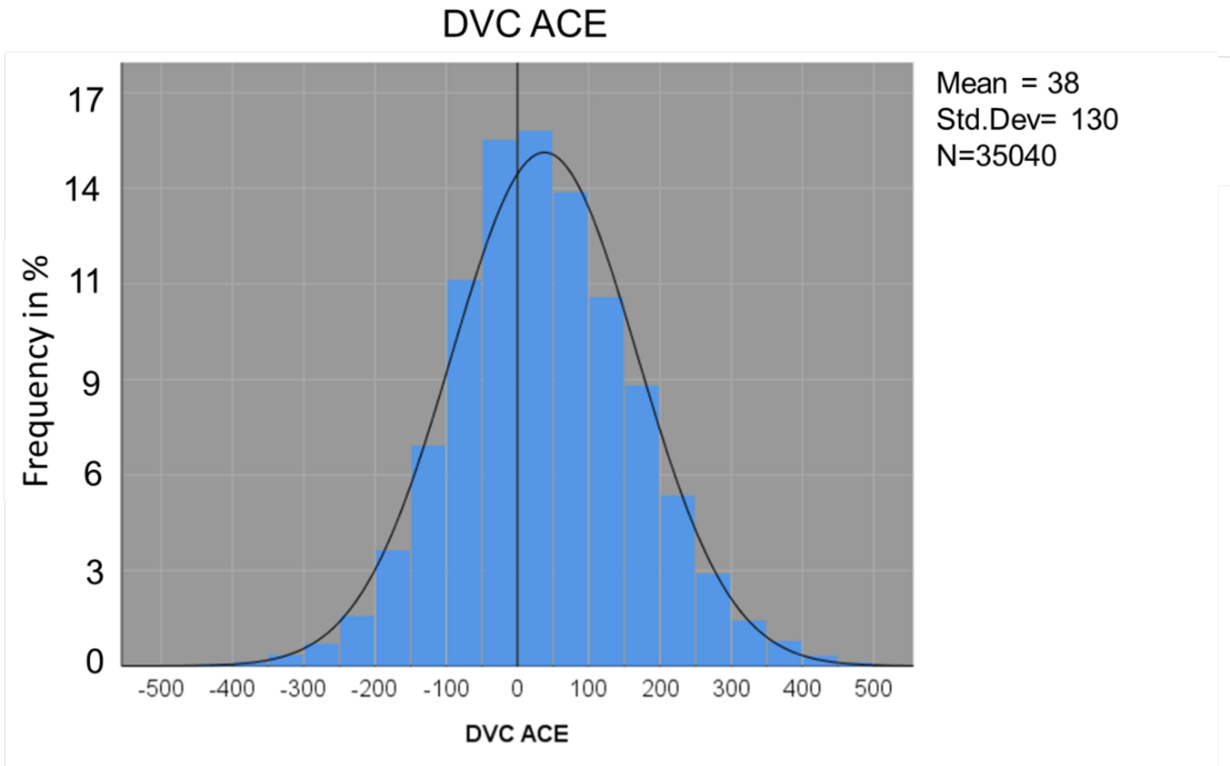

Rajasthan ACE
Mean = 48
Std.Dev= 274
N=105120
Frequency in %
8
6
4
2
0
-1000 -800 -600 -400 -200 0 200 400 600 800 1000
RAJASTHAN_ACE

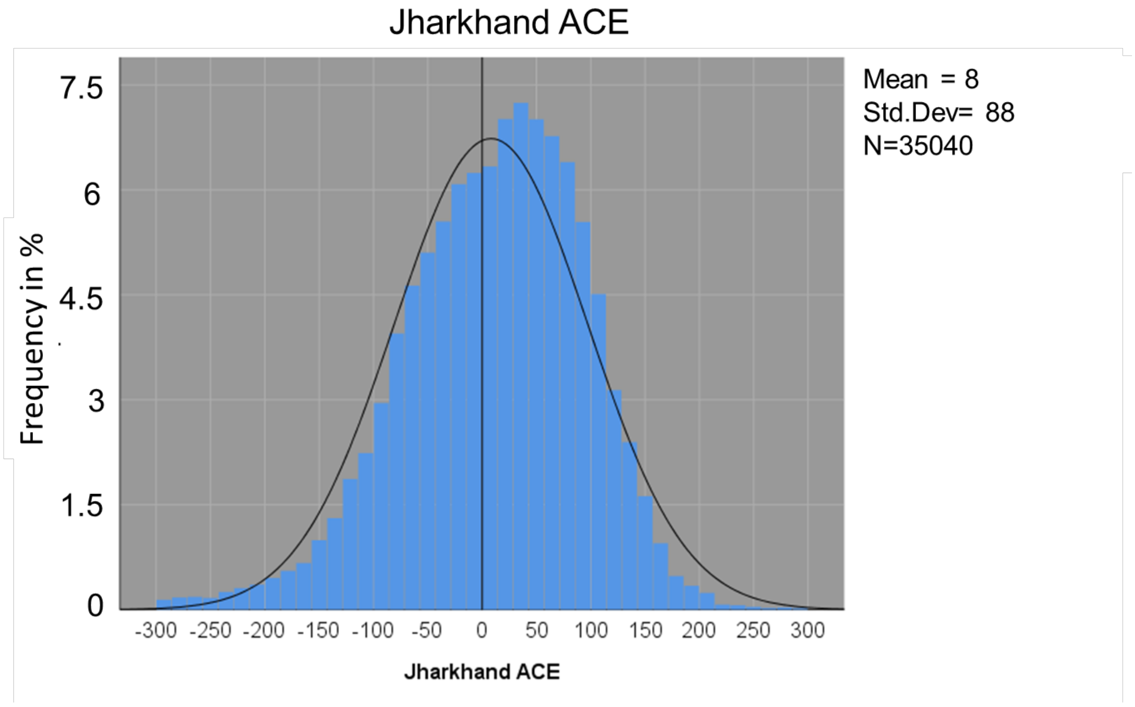

ER ACE
Mean = -36
Std.Dev= 488
N=35040
Frequency in %
11
9
6
3
0
-2200 -2000 -1800 -1600 -1400 -1200 -1000 -800 -600 -400 -200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200
ER ACE

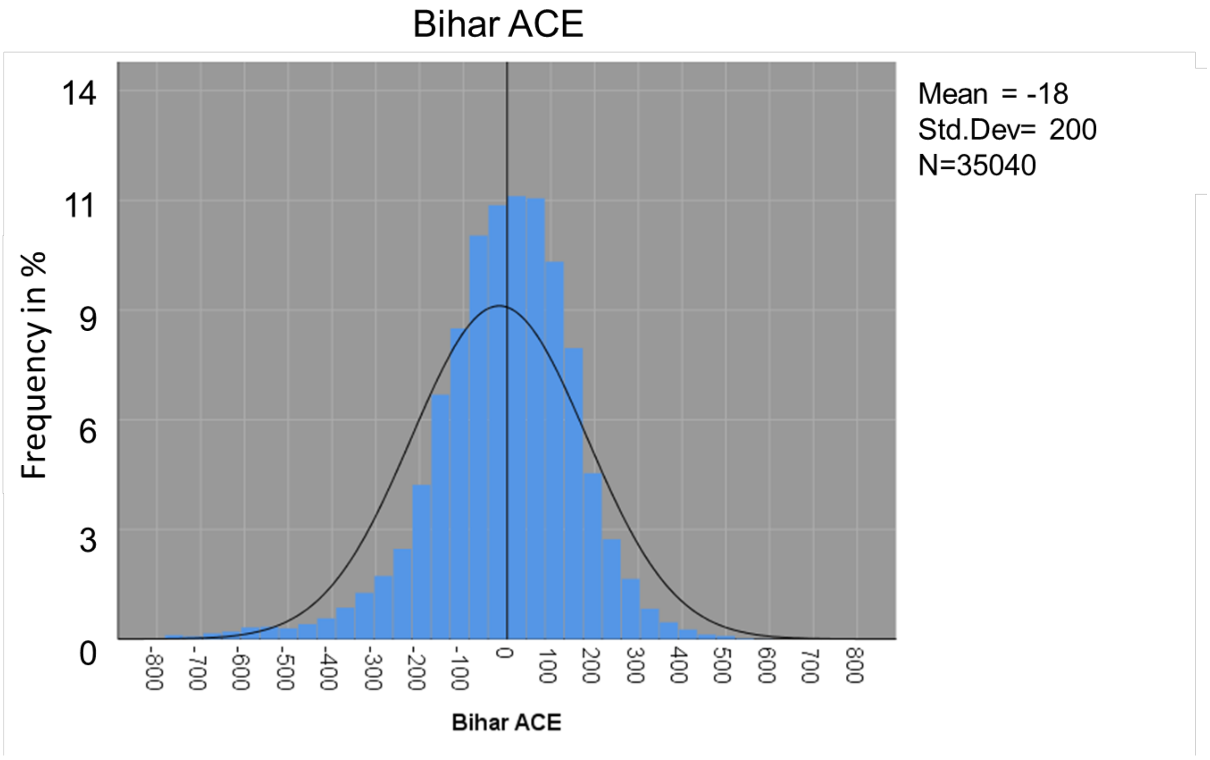

Sikkim ACE
Mean = -8
Std.Dev= 18
N=35040
Frequency in %
9
6
3
0
-100
-75
-50
-25
0
25
50
75
100
SIKKIM ACE

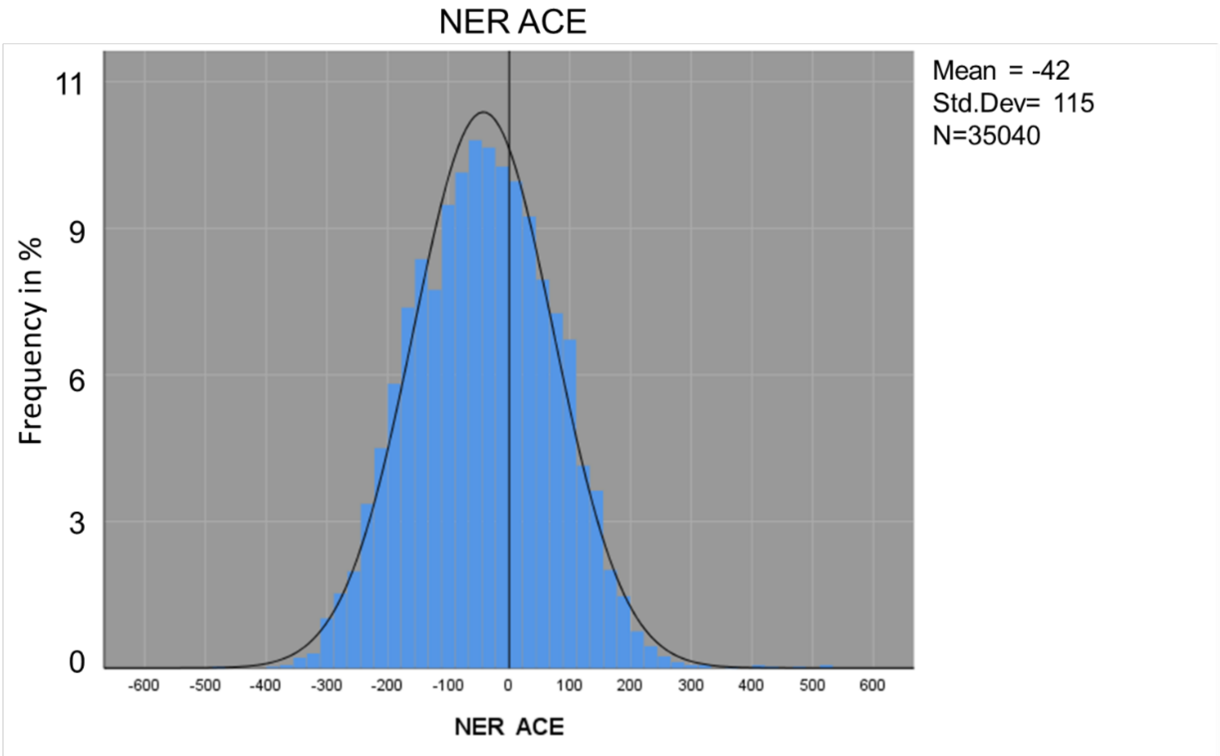

West Bengal ACE
Mean = 52
Std.Dev= 220
N=35040
Frequency in %
14
11
9
6
3
0
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
West Bengal ACE

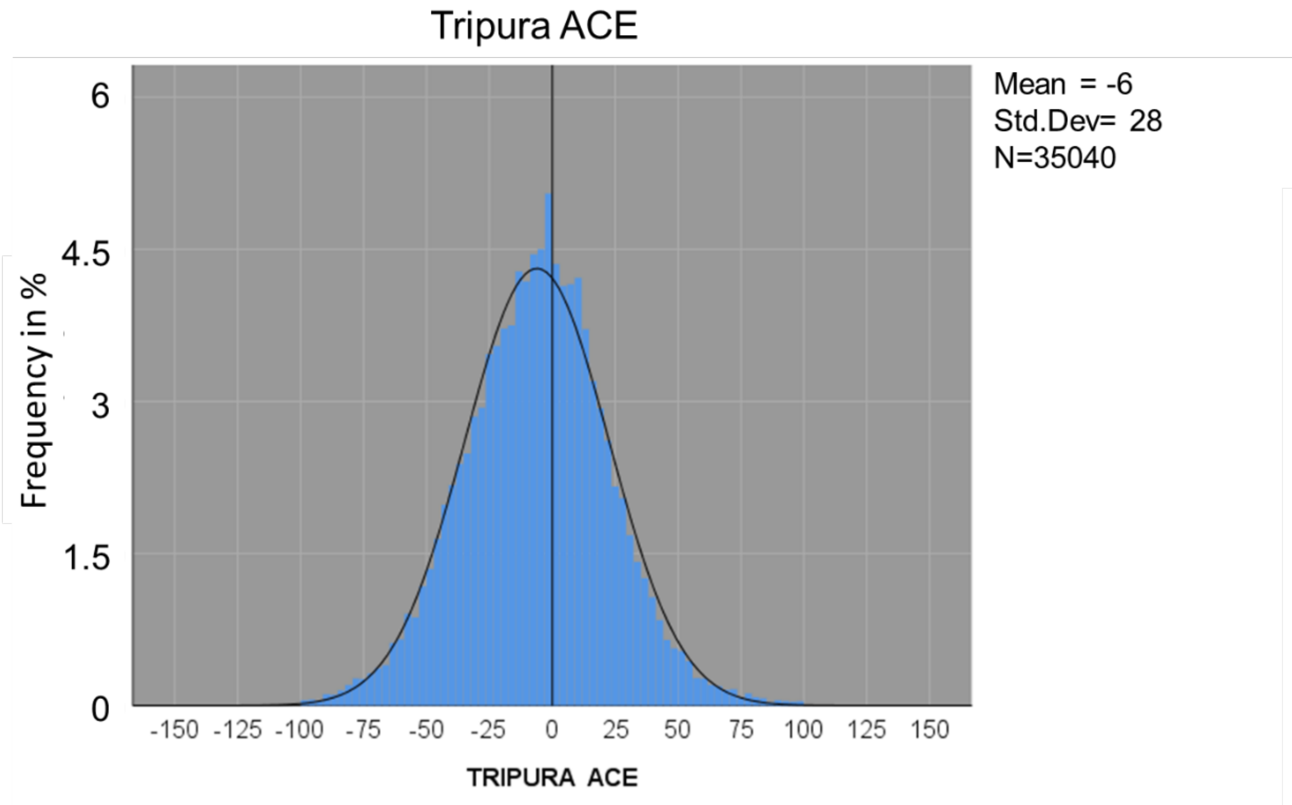

Orissa ACE
Mean = -8
Std.Dev= 18
N=35040
Frequency in %
14
11
9
6
3
0
-500
-400
-300
-200
-100
0
100
200
300
400
500
Orissa ACE

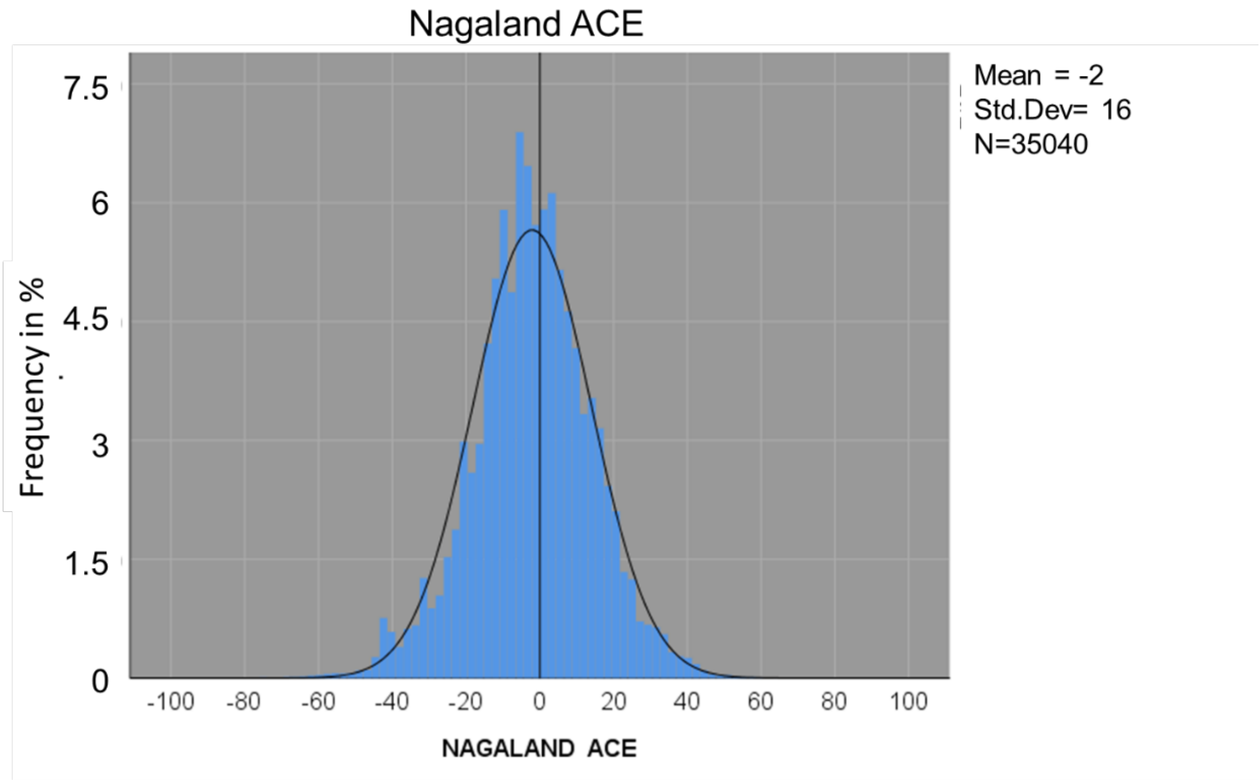

DVC ACE
Mean = 38
Std.Dev= 130
N=35040
Frequency in %
17
14
11
9
6
3
0
-500
-400
-300
-200
-100
0
100
200
300
400
500
DVC ACE

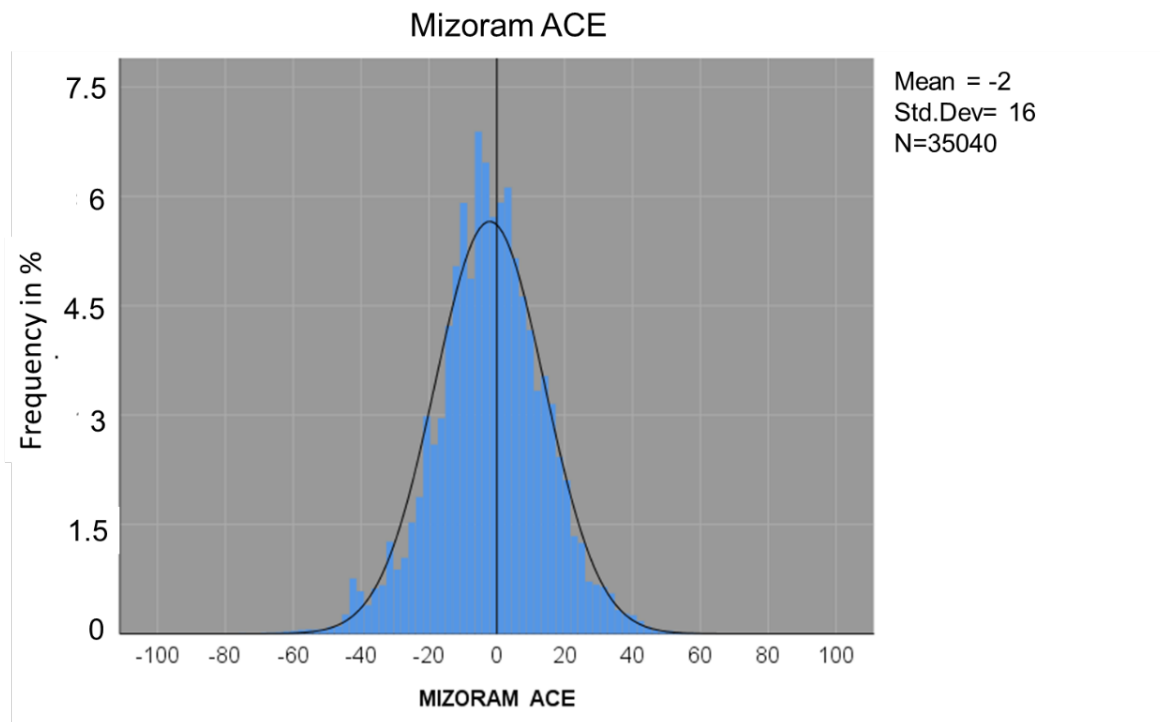

Jharkhand ACE
Mean = 8
Std.Dev= 88
N=35040
Frequency in %
7.5
6
4.5
3
1.5
0
-300 -250 -200 -150 -100 -50 0 50 100 150 200 250 300
Jharkhand ACE


Bihar ACE
Mean = -18
Std.Dev= 200
N=35040
Frequency in %
14
11
9
6
3
0
-800 -700 -600 -500 -400 -300 -200 -100 0 100 200 300 400 500 600 700 800
Bihar ACE

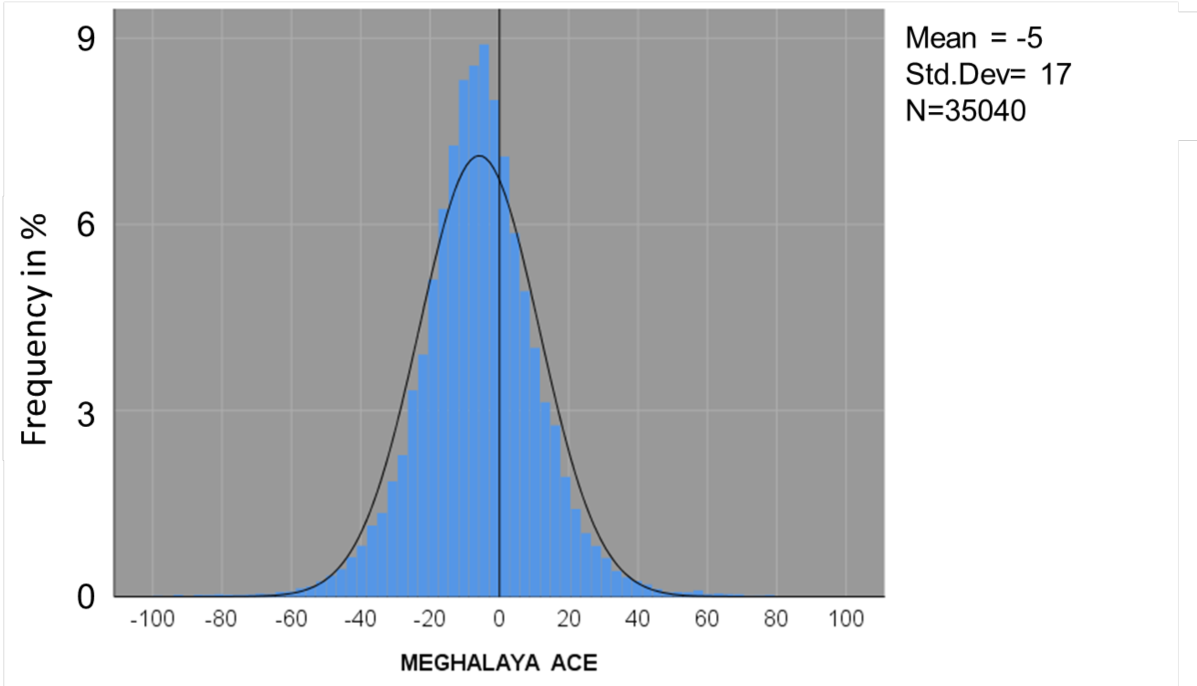

NER ACE
Mean = -42
Std.Dev= 115
N=35040
Frequency in %
11
9
6
3
0
-600
-500
-400
-300
-200
-100
0
100
200
300
400
500
600
NER ACE


Tripura ACE
Mean = -6
Std.Dev= 28
N=35040
Frequency in %
6
4.5
3
1.5
0
-150
-125
-100
-75
-50
-25
0
25
50
75
100
125
150
TRIPURA ACE

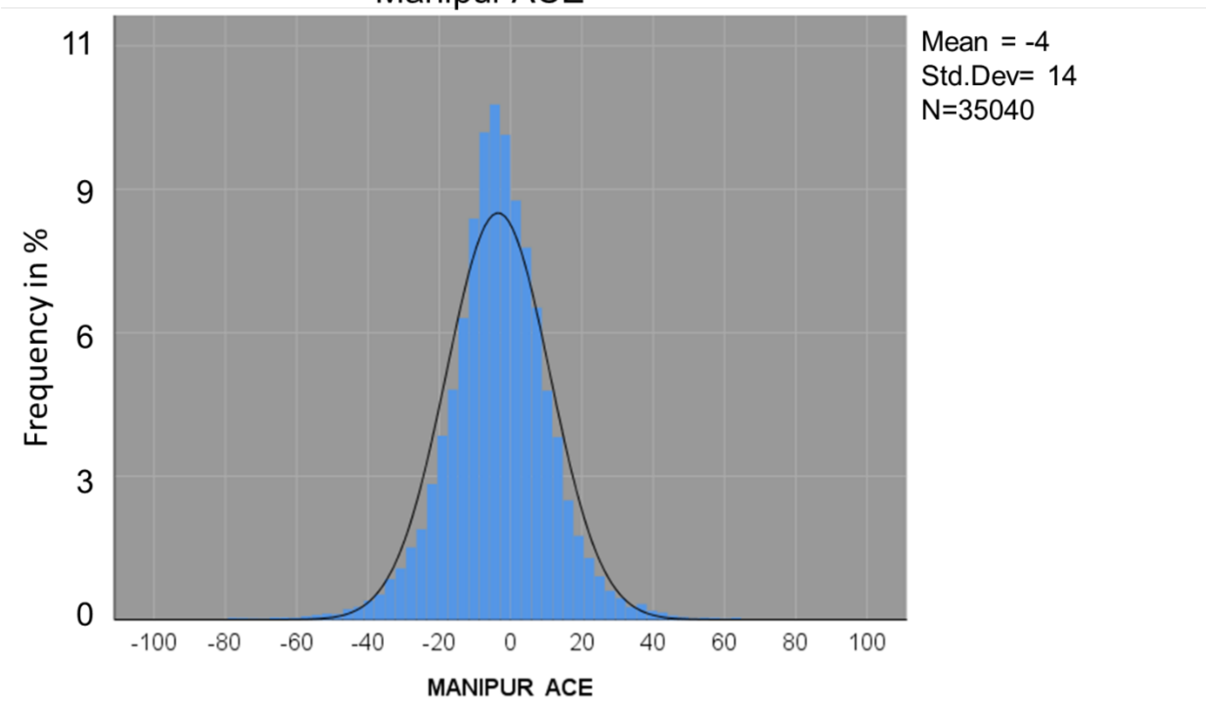

Nagaland ACE
Mean = -2
Std.Dev= 16
N=35040
Frequency in %
7.5
6
4.5
3
1.5
0
-100
-80
-60
-40
-20
0
20
40
60
80
100
NAGALAND ACE

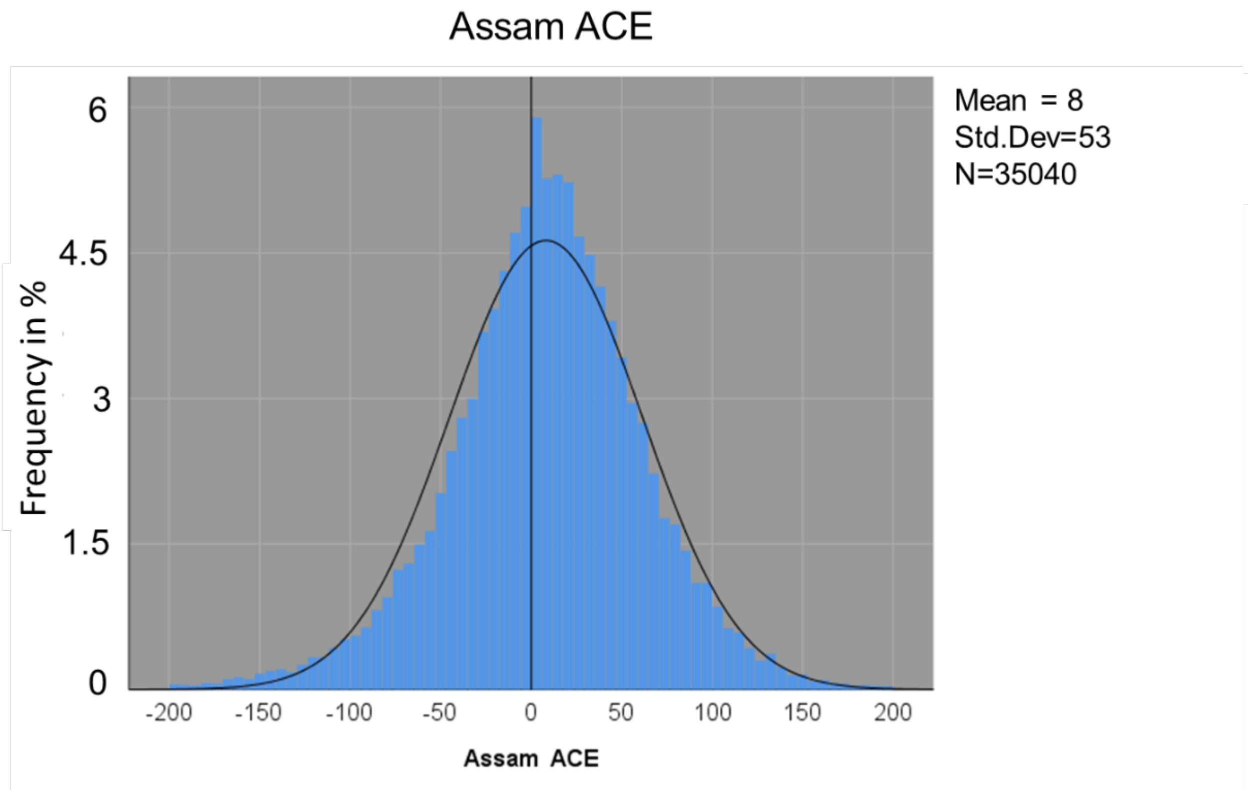

Mizoram ACE
Mean = -2
Std.Dev= 16
N=35040
Frequency in %
7.5
6
4.5
3
1.5
0
-100
-80
-60
-40
-20
0
20
40
60
80
100
MIZORAM ACE

Meghalaya ACE

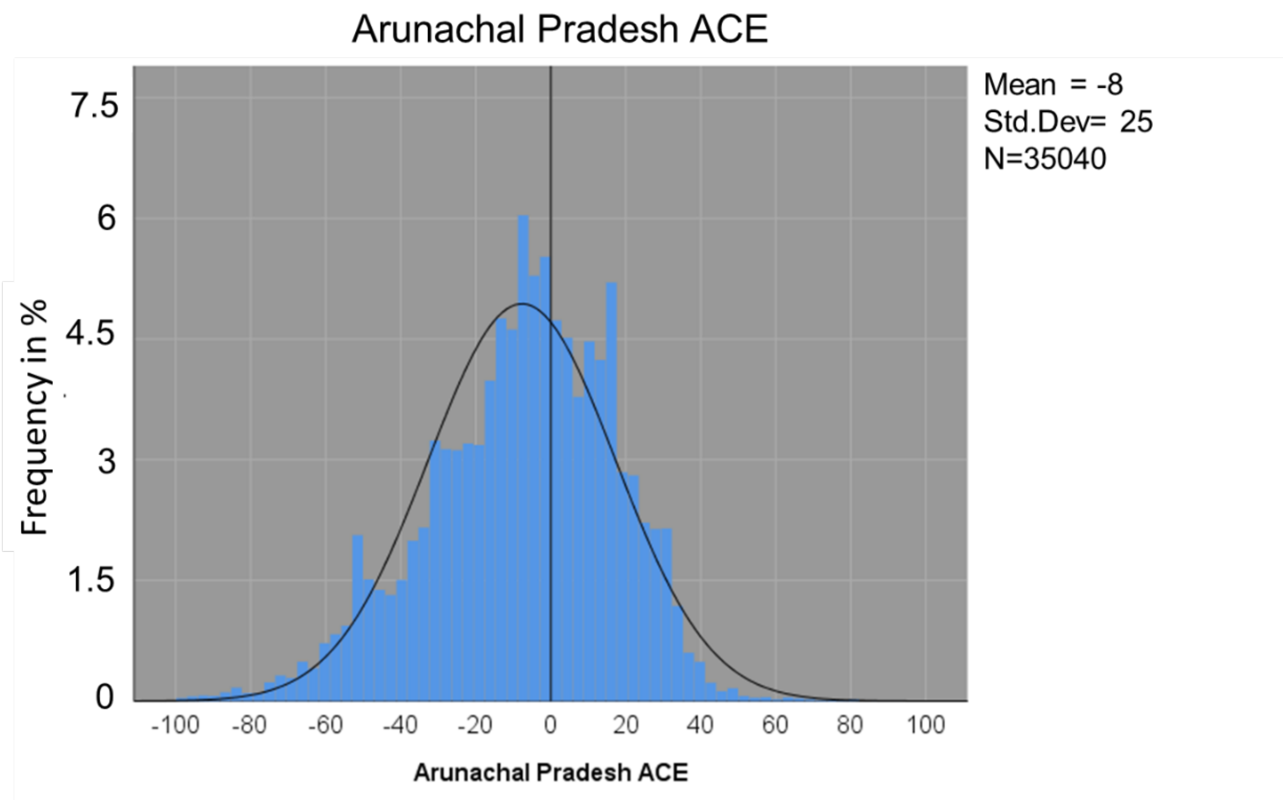


Manipur ACE





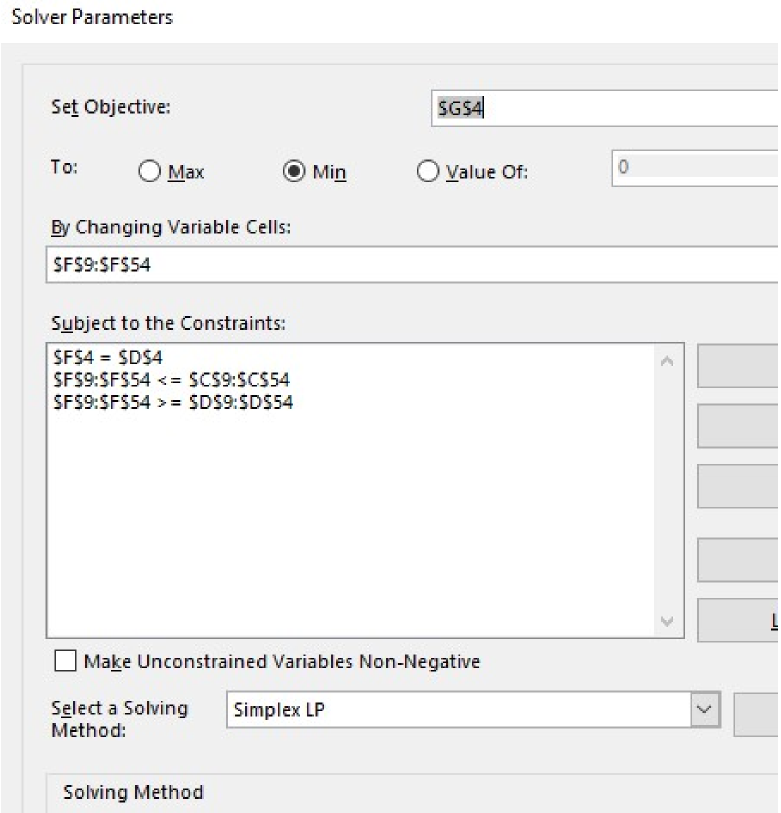
Assam ACE
Mean = 8
Std.Dev=53
N=35040
Frequency in %
6
4.5
3
1.5
0
-200
-150
-100
-50
0
50
100
150
200
Assam ACE



Arunachal Pradesh ACE
Mean = -8
Std.Dev= 25
N=35040
Frequency in %
7.5
6
4.5
3
1.5
0
-100
-80
-60
-40
-20
0
20
40
60
80
100
Arunachal Pradesh ACE

Annex-V: Optimization model developed in Microsoft Excel Solver

	A	B	C	D	E	F	G	H
1	Reserves / Ancillary Services		Despatch Model :	Madhya Pradesh		Total Schdl	Total Cost (Rs.Lac per hour)	Average Rate (R
2			Forecast Demand	4363			83	1.77
3			Reserve	330			Total Cost (Rs./hour)	SMP
4	17.06.19	50 block	Total Demand	4693		4693	8283965	3.33
5			Tech. Min (%)	0.70				
6	Column Name -->		A	B	C	D	E=C*D	F
7	Column Totals -->		7964	3004		4693		4758
8	S No	Station Name	P Max	Pmin	Variable Charge	Schedule for Block 'T'	Production Cost	Schedule for Blo
9	1	JP Nigrie	417.28	277.20	64	417.28	267075	417.28
10	2	Rihand III (NR)	2.36	0.00	132	2.36	3113	2.36
11	3	SIPAT I	105.48	0.00	133	105.48	140149	105.48
12	4	Rihand II (NR)	1.08	0.00	134	1.08	1451	1.08
13	5	Rihand I (NR)	1.94	0.00	134	1.94	2600	1.94
14	6	SIPAT II	158.02	0.00	137	158.02	216346	158.02
15	7	KSTPS-III	71.51	0.00	139	71.51	99751	71.51
16	8	KSTPS	405.31	0.00	142	405.31	573850	405.31
17	9	Sasan	1366.88	956.81	145	1366.88	1986890	1366.88
18	10	Singrauli (NR)	3.59	0.00	150	3.59	5371	3.59
19	11	ATPS (210MW) Chachai	193.00	135.00	160	193.00	308800	193.00
20	12	VSTPS-IV	266.21	0.00	175	56.21	98095	126.21



Optimization Algorithm

Objective Function

Minimize the Statewide Total Variable Cost

Subject to Constraints

Meeting Total Requisition by Discoms from various sources

Technical Minimum of Plants

Maximum Generation (DC-on-bar)

Ramp up

Ramp down rates

Minimise $\sum_{i=1}^{k} C$ ....(1)

- *k* *total number of Plants*
- *Where is the variable per unit cost of the Plant*
- *is the optimised scheduled power of the Plant*

Subject to

- $\sum_{i=1}^{k} P_i = \sum_{i=1}^{k}$ + *Reserve to be despatched through ancillary*. (2)
- $P_i \leq P_{i,m}$ ....(3)
- $P_i \geq P_{i,t}$ ....(4)
- $P_{i,t} \leq P_{i,t-1} + \text{Ramp up ra}$ ....(5)
- $P_{i,t} \geq P_{i,t-1} - \text{Ramp down ra}$ ....(6)

$\text{Reserve availa} \geq$ Stipulated reserve (Through Unit commitment)

- *S* -is the scheduled power
- *t* -represents time block for which optimization is being carried out
- $P_{i,max}$ is max generation limit (DC on bar)
- $P_{i,t}$ is the *technical minimum* for thermal power plants (normally considered at 55% DC on bar)
- Reserve is the quantum of ancillary which is to be despatched for that period

Annex-VI: Pilot Project in Madhya Pradesh

Brief power profile of the State

As on October 2019, the state of Madhya Pradesh has an installed generation capacity of 23995 MW including state generation, independent power producers (IPPs) in the state and the state's share in central sector generation and jointly owned interstate generators. Out of the total generation capacity (~24 GW), 63% (15 GW) is coal-based generation, 20% (4.8 GW) renewable energy-based (RE) generation & 13% (3.2 GW) is hydro generation. In terms of annual energy generation in MUs for 2018-19, 85% of the generation energy came from thermal (coal+gas+nuclear) units, 6% from wind, 5% from hydro and 4% from solar units.

The state demand follows a seasonal pattern wherein the peak demand (~ 13-14 GW) season typically falls in winter (December to February) where-as lean demand is registered in the monsoon season (July-September). Typically, the state demand undergoes a diurnal variation (i.e. difference between intra-day max. and min. demands) of 5000-6000 MW during winter and 1500-2000 MW during the summer. A maximum state demand ramp of ~ 200 MW per block has been observed during onset of morning peak. Daily energy consumption varies between 220 MUs in lean demand period to 270 MUs during peak demand period. With an installed renewable generation capacity of 4.8 GW Madhya Pradesh is considered a renewable rich state which has so far witnessed a maximum RE penetration of 48% in terms of %age of instantaneous state generation. RE generation contributes to 9.4% of net annual energy consumption by the state. Maximum intra-day wind generation variation (Max-Min) stood at 1563 MW on 25.05.18. Typically, the daily wind generation pattern follows the demand pattern during April to September where as the wind generation follows a reverse pattern to demand during the of the period (October to March).

Forecasting

As per 20th FOLD recommendations, SLDC MP has engaged Indian Institute of Information Technology, Jabalpur for Development of a load forecasting model for daily, weekly, monthly, seasonal and annual load forecasting.

Scheduling

MP-SLDC computes schedule for the intra-state entities. As on August 2019 the different category of intra-state entities scheduled by SLDC Madhya Pradesh are given below.

Table 15: Entities scheduled by SLDC Madhya Pradesh

S No	Category	Number
1	Distribution Licensees	5
2	Open Access Customers	6
3	Thermal Power Stations	10
4	Hydro Stations	12
5	Solar Power stations	48

6	Wind Power stations	62
	Total	**143**

Contracts scheduled by SLDC, Madhya Pradesh for a typical day are summarized below:

Table 16: Contracts scheduled by SLDC Madhya Pradesh (2019)

S.No.	Type	Number	MW / MU		Maximum in a Day	
Inter State (+ve : Import; -ve : Export)						
1	Long Term PPA	32	7226	MW		
2	Long Term (Hydro+RE)	6	1470	MW		
3	Short Term Inter-state (Typical transactions in a Day)					
	1. 23.08.19	26	-231.53	LU	-1507	MW
	2. 23.05.19	13	-170.25	LU	-1027	MW
	3. 02.01.19	19	245.38	LU	2143	MW
Intra State						
1	Long Term PPA	10	5781	MW		
2	Long Term (Hydro+RE)	20	6654.14	MW		
3	Short Term (Typical in a Day)					
	1. 23.08.19	4	6.52	LU	28.15	MW
	2. 23.05.19	3	6.40	LU	27.65	MW
	3. 02.01.19	1	1.30	LU	5.4	MW

Scheduling Time line

Day ahead & real time scheduling coordination is done by SLDC with intra-state entities and WRLDC as per a specified time line in line with MP state grid code & Balancing and Settlement Code (BSC) 2015. The following table summarizes the different time lines followed for scheduling activities at SLDC.

Table 17: Scheduling Time line (SLDC Madhya Pradesh)

D-1 day (hh:mm)	Activities on Day-ahead horizon
10:00	15 minute time block wise Capability declaration (DC) for next day by Intra-state generators/IPPs/Shared plants; ISGS entitlements taken from WRLDC website
10:30	Entitlement Computation by SLDC MP for state DISCOMs; The state DISCOMS convey their requsition / forecast demand for next day to MPPMCL
11:00	MPPMCL aggregates the forecast demand & cumputes likely surplus / deficit for nexy day and decides on the position (buy/sale) to be taken in the PX.
13:30	MPPMCL after receiving provisional transaction report from PX and runs merit order dispatch module for next day followed by DISCOM wise power allocation from different power stations/PX.
14:00	MPPML informs SLDC, the DISCOM wise Ex-PP requistion from each power plant including LTA, MTOA & STOA contracts

15:00	SLDC MP intimates WRLDC the composite requisition of the state at regional boundary
17:00	WRLDC intimates the 15 min wise drawal schedule of Madhya Pradesh for next day
17:30	After receipt of the final transaction report, MPPMCL runs the MOD & allocates power time block wise to each state DISCOM as per their demand forecast & entitlement;
18:00	MP-SLDC issues ex-PP injection schedule to generators & ex-STU periphery drawal schedule to DISCOMs (R0)
21:30	State Generators, IPPs inform any foreseen revision in their availability for next day
22:00	SLDC MP intimates WRLDC revised requisition for the state for next day (if any)
23:30	Revised Schedule (R-1) for next day issued by SLDC for all generators and DISCOMs
D-Day	**Activities on the day of operation**
00-24 hrs	MPPMCL initiates revisions (if any) as requested by the DISCOMs; State Generators initiate DC revision (if any); SLDC-MP incorporates these accordingly;
	Activities after the day of operation
By D'+3	**MP-SLDC issues final implemented schedule for D-day after receipt of implemented schedule from WRLDC (on D' day)**
NB:	All Hydro Power Stations of Madhya Pradesh Power Generating Company Limited furnish day ahead DC as per MPERC (Terms and conditions for determination of Generation Tariff) Regulations, 2012 and amendments thereof;

Merit Order Dispatch (MOD) & Unit Commitment:

- MOD stack is prepared by the holding Distribution Company (MP Power Management Company Ltd - MPPMCL) on behalf of the state discoms, based on VC as per latest (last month’s) bill issued by the state generators.
- MOD is submitted by MPPMCL to SLDC on monthly basis by 10th -15th day of every month. The VC of ISGS stations used in MOD preparation factors in the point of connection (POC) transmission loss component.
- MPPMCL is allowed to revise the allocation to the state-DISCOMs on the actual day of operation based on load-generation balance requirement.
- MPPMCL runs the MOD & the unit commitment (UC) software.
- During low demand period reserve shut down decision is taken by MPPMCL in consultation with MP-SLDC.

Generation Tariff Structure

MPERC (Terms & Conditions of Tariff) Regulations 2015 is the guiding regulation for intra-state generation tariff. MPERC determines tariff of intra-state generators, IPPs vide MYT orders.
Some highlights of generation tariff are given under:

- 2-part tariff structure comprising of Fixed Cost (FC) & Variable Cost (VC)
- SLDC computes & certifies plant availability factor (PAF) & scheduled energy on monthly basis for payment of FC & VC respectively to intra-state generators
- Monthly PAF computation is linked to DC similar to central sector generators

Intra-state ABTand Deviation settlementmechanism are operational since October 2009 which is applicable to all intra-state entities including DISCOMs, Open Access Customers and a few hydro stations. The scheduling & DSM for intra-state wind and solar generators is governed by the MPERC (Forecasting, Scheduling and Deviation Settlement) mechanism regulation 2018.

Metering

Intra-state ABT has provided for meters at each T-D (transmission-distribution) inter-face. Presently, 1081 inter-face energy meters are in place in the state. Deviation (DSM) and reactive energy (RE) charges for intra-state entities are computed based on main meter data. AMR system is in place for each interface (G-T, T-D and at SLDC which facilitates automatic meter-data downloading at SLDC. Missing meter data is retrieved using local meter reading instruments (MRI) & sent by mail upon intimation by SLDC on monthly basis. Procurement of check meters & meters capable of recording at 5-minute interval are being taken up with MPPTCL under a PSDF approved scheme.

Imbalance handling in real-time:

The SLDC real time operator has many tools for balancing and deviation control in real-time.

- Hydel and thermal generations of state owned Generating plants are regulated as per system requirement.
- Schedule from Inter-state generators (ISGS) is also regulated as per MOD if required.
- Under extreme contingencies or multiple outages in Generating units during the real time operation, after exhausting contingency reserves MP try to avail unrequisitioned surplus (URS) power from ISGS Power Stations of WR / NR / ER to adhere to grid discipline.
- MP always keeps some contingency reserve margin while preparing requisition on day ahead basis.
- While performing day ahead scheduling activities, if it is observed that there is no contingency margin for the next day, MPPMCL purchases adequate quantum of power through exchange to ensure availability of contingency margin.
- During the lean demand period, sudden drop in demand due to weather conditions or to absorb sudden rise in RE generation, grid discipline is mostly maintained by regulating hydro generation as an immediate measure.
- Subsequently schedule in state generating stations, ISGS and IPP Generating stations is revised as per MOD stack according to the requirement of the grid and hydel generation is again brought back to normal levels.

- Most of the hydro generators are out of the ambit of ABT & MOD. SLDC-MP dispatches hydro based on grid conditions. Renewable generation is treated as must run & their variability is handled by dispatching reserve margin available in hydro units.
- Since 2013 there is no load shedding in MP, therefore, load shedding option has not been required and not being exercised by system operator.

Intra-state deviation pool: Till December 2018 the pool was of a non-zero sum (surplus) type pool similar to the regional DSM pool. In January 2019, SLDC, MP has filed a petition before the Hon'ble MPERC wherein a zero-balance pool is proposed.

Key success factors for implementation of ancillary services

With the foregoing back ground the keys success factors for implementation of ancillary services in the state are summarized below:

Adequate Generation Capacity

Madhya Pradesh being a power surplus state, have adequate generation capacity at both thermal as well as hydel units. In view of sufficient thermal generation capacity SLDC-MP always have a scope to optimize the generation according to the MOD stack. After day ahead scheduling there is always chance to optimize the scheduling during intra-day operations. Based on the prevailing conditions during the real time operation rescheduling & redispatch can be initiated by SLDC to bring in further economy.

Thus, a framework of ancillary services for state of MP shall definitely be beneficial to both generators and beneficiaries to optimally dispatch the available generation & reserve capacity.

Multipart Tariff structure

The intra-state generation tariff has a multipart structure comprising of fixed cost component linked to plant availability & energy charge component linked to scheduled energy. Summary of Intrastate generating stations having two-part tariff and whose tariff for the entire capacity is determined/adopted by the SERC.

Table 18:MP State Generators with two-part tariff (2019)

S.N	Name of Station	n x MW	MW	FC (Rs/kwh)	VC (Rs/kwh)
1	Amarkantak (ATPS)	1X210	210	1.49	1.77
2	Satpura Ph. 2&3 (STPS_II&III)	1x200 3X210	830	0.83	2.78
3	Satpura Ph. 4 (STPS_IV)	2X250	500	2.04	2.33
4	Sanjay Gandhi 1&2 (SGTPS_I&II)	4X210	840	0.84	2.08
5	Sanjay Gandhi 3 (SGTPS_III)	1X500	500	1.15	1.91
6	Singaji 1 (SSTPS_I)	2X600	1200	1.54	2.84
7	Singaji 2 (SSTPS_II)	2X660	1320	1.42	2.68
Total			**5400**		

Norm for Technical minimum generation

MPERC has mandated for Technical minimum as 55% of MCR for intra-state generators also compensation for RSD and part-load operation of state generators.

Availability of URS power

There exists significant scope for dispatching the incidental reserves in the form of un-requisitioned surplus (URS) power in intra-state generators. The typical URS power availability at Intra-state generators for atypical day in summer/winter/monsoon season is given under.

Presently, there is no provision for dispatching URS power available in intra-state generators.

Pilot Optimization exercise with Excel Solver

Based on the FOR sub-group deliberation it was appreciated by the MP SLDC team that a scientific approach based on algorithmic solutions is desirable for reserve computation & monitoring and optimal dispatch thereof. Accordingly, a pilot exercise on constrained optimization technique was carried out by SLDC Madhya Pradesh to optimize the total production cost for a given sets of load-generation scenarios. The formulation used for optimization for a representative time block using MS excel solver is as given under:

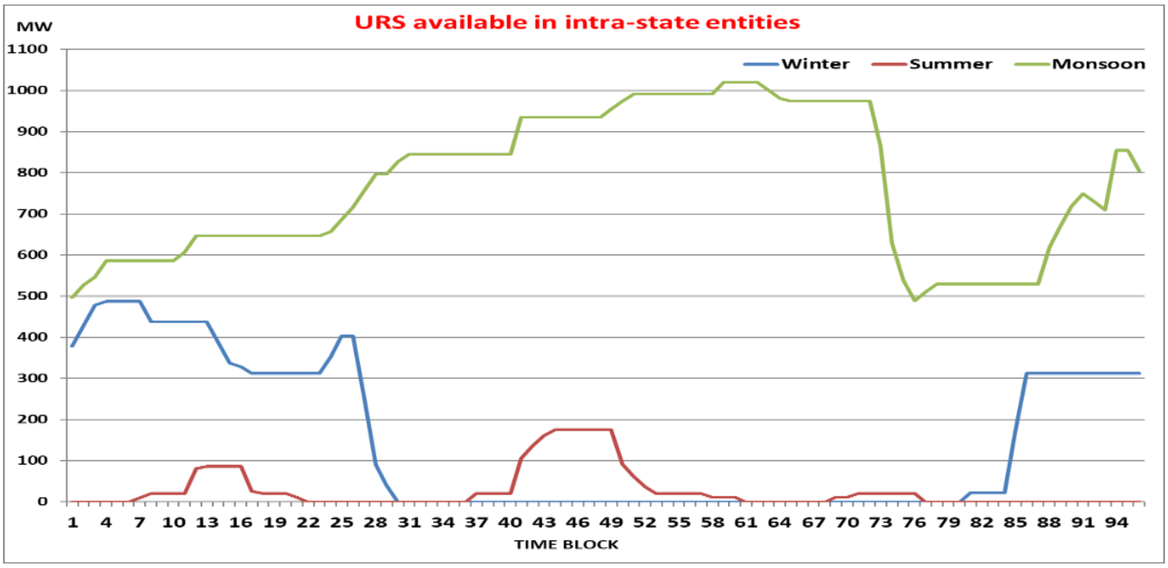


Figure 28: URS power in intra-state generators in MP for a typical day

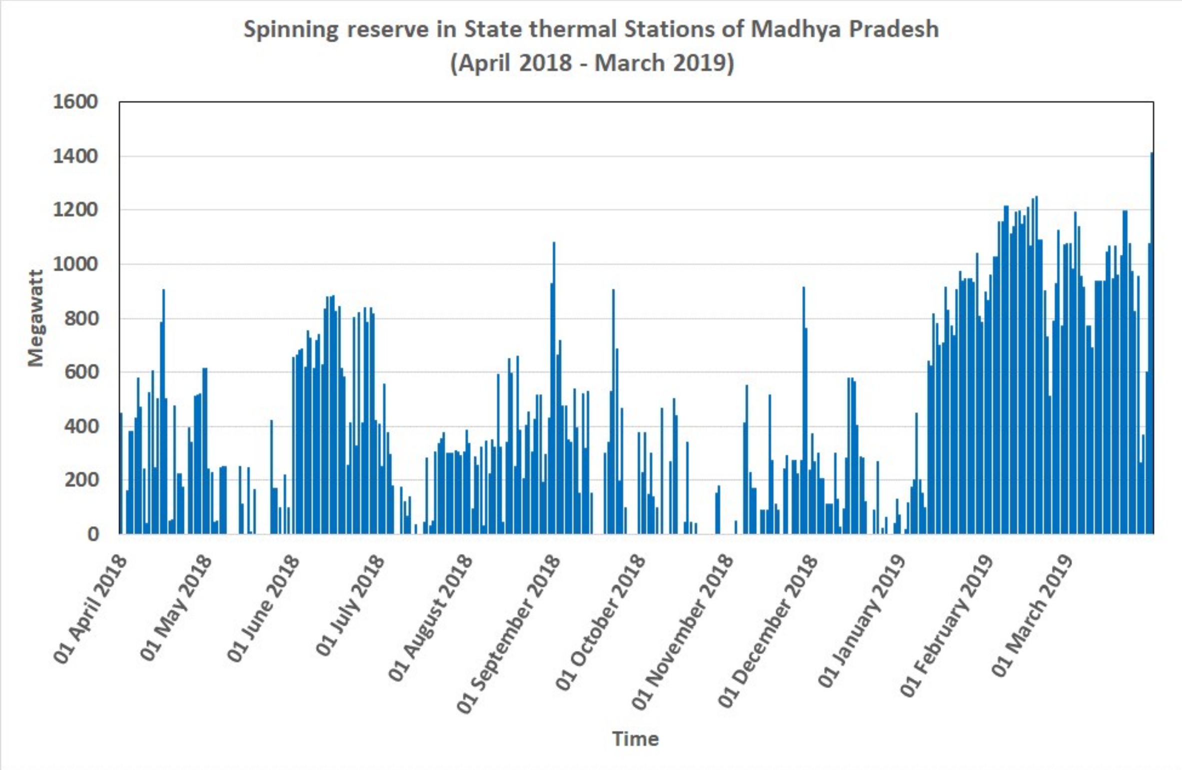


Figure 29:Spinning reserves in MP thermal stations

Input Data for each generator (for a time block):

(1) Declared capability in MW
(2) Declared capability on-bar (in MW)
(3) Schedule in MW
(4) Pmax = On bar installed capacity – Normative Auxiliary Consumption (in MW)
(5) Pmin = Technical Minimum generation (in MW)
(6) Variable charge (VC) in Rs/Kwh
(7) Ramp-Up rate in (%age of on-bar Capacity) per minute
(8) Ramp-down rate in (%age of on-bar Capacity) per minute

Derivable parameters for the generator (for a time block)

(1) Regulation Up-reserve = On bar installed capacity – Schedule (fig. in MW)
(2) Regulation Down-reserve = Schedule – Technical Minimum (fig. in MW)
(3) Cold reserve = DC – DC on bar …. (in MW)
(4) Hot spinning reserve = DC on bar – Schedule ….(in MW)
(5) Dispatchable reserve = Minimum of (Hot spinning reserve & Regulation Up Reserve)

Formulation of the Optimization Problem

- To minimize the Objective Function: $\underline{\sum \boldsymbol{Schedule * VC = Minimum}}$
- Equality Constraint(s): ***Total schedule = Total demand of the state + Reserve***
- Inequality constraint(s): ***Pmin ≤ Station schedule ≤ Pmax;***

- Decision Variables: Schedule of each power plant to be despatched

Summary of the scenarios studied

Seven different system scenarios were studied by running the solver module for a single representative time block, based on above formulation for the state. The results are summarized under at table-

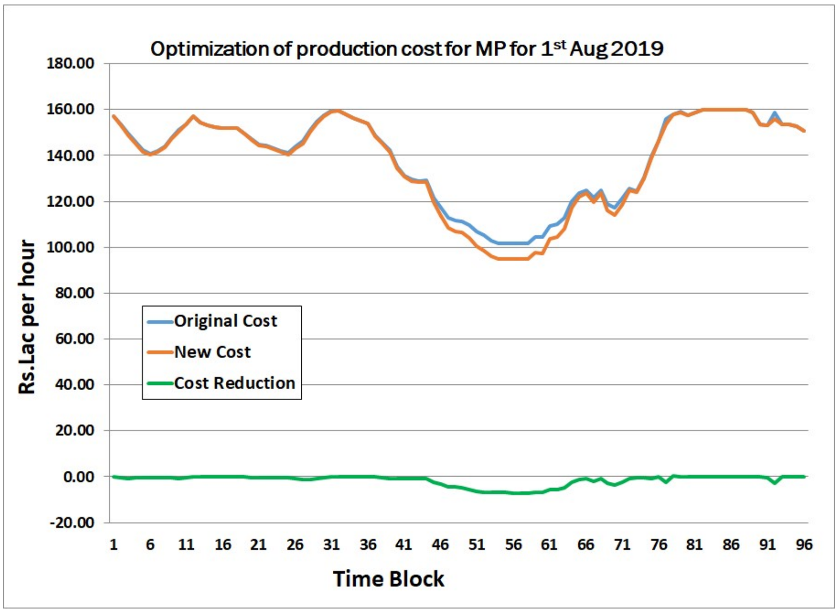
Table 19:Optimization Results for MP for different scenarios (for one time block in Jun 2019)

Senario	Total Production Cost in Rs		Avg. per unit cost		SMP	Up Resereve MW		Down Reserve MW	
	Pre-Optimized	Optimized	Pre-Optimized	Optimized	in Rs/unit	Apparent	Ramp Limited	Apparent	Ramp Limited
Morning Max demand	159.2	157.89	2.12	2.1	3.93	289	106	4510	2328
Morning Min demand	104.8	102.59	1.78	1.74	2.57	1887	794	3256	1798
Evening Demand (Max)	152.01	152.01	2.04	2.04	5.92	0	0	4432	2496
Evening Demand (Min)	103.45	99.89	1.78	1.72	2.57	1846	662	3180	1848
Max Surrender	82.84	80.56	1.77	1.72	1.76	3271	1312	1689	1173
Min. surrender	146.9	146.9	1.98	1.98	5.92	0	0	4773	2352
Maximum RE	86.38	84.19	1.76	1.72	1.77	3074	1243	1897	1273

Going further ahead, SLDC MP ran the optimization module all 96 blocks of a day. Due to limitations of the Excel solver software, the results of one block were considered as input to the next block in this sequential run of optimization. Based on this learning, it was decided to run simultaneous multiperiod optimization for all 96 blocks in one shot followed by continuous running in subsequent time blocks so as to take it to the next higher level for full-fledged implementation by SLDC. For further scaling up the need was felt for more efficient professional optimization software viz. the General Algebraic Modelling System

Observation & Inferences from the optimization exercise

- The optimization exercise gave vital decision tools viz. (1) plant wise optimum schedule, (2) system marginal price, (3) Up reserve (4) Down Reserve (5) Ramp limited reserves for a given time block
- Significant saving was seen in terms of net production cost and average per unit generation cost for all cases barring two scenarios viz. maximum evening demand and minimum central sector share surrender in a day.
- Apparently, these are the cases where there are very few chances of improvement as full on bar power was scheduled in both the cases.
- While running optimization sequentially for all 96 blocks of a day (01st Aug 2019), total cost benefit observed was to the tune of Rs. 1 crore 52 lacs.



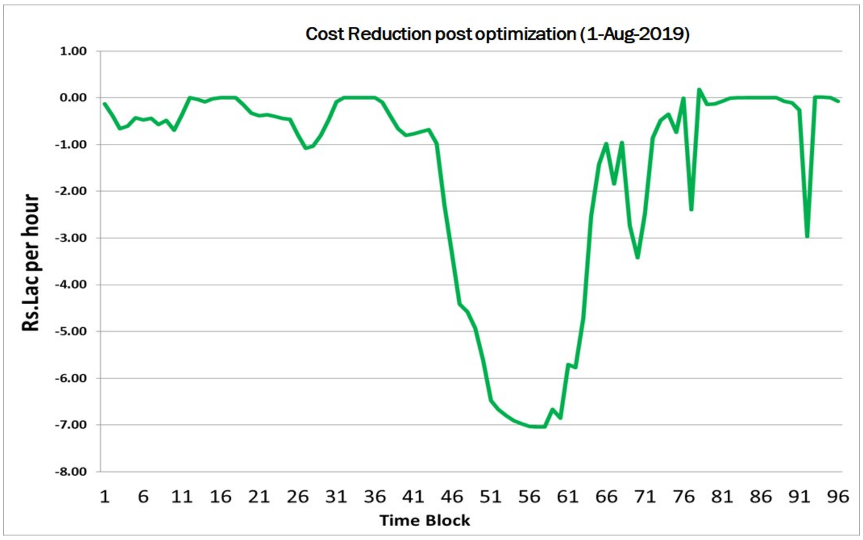


Figure 30: Production cost reduction post optimization exercise for MP for 1-Aug-19

Other generic inferences:

- Optimization tools could be used for day-ahead purchase decisions, ancillary despatch, economic despatch, estimation of reserve carrying cost.
- The optimization results could be converted into graphs for comprehension
- Database is required to save various scenarios and their results
- Following steps would be involved for running the Solver model: (1) *fetch data from the scheduling Software > (2) Run Solver Model > (3) Push the results back to the scheduling s/w;*
- Reliability of communication system is critical for continuous operation of the optimization program
- Dispatchable reserves is limited by ramping constraints, hence reserves need to be distributed over multiple units. Having more units on bar helps in improving the despatchable reserves volume.

- For realistic results, the must run stations (wind/solar/run-of-the river hydro) and must take (STOA) contracts could be kept out of optimization module with formulation Pmax = Pmin
- Net load forecast to be considered instead of demand forecast for realistic results
- Transmission constraints need to be considered in the optimization model
- Operationalized dispatch, assessment of reserves & its dispatch through ancillary services shall pave way for co-optimization of energy & ancillary.

Suggested actions for implementation of intrastate ancillary services:

Based on the learning from the above optimization exercise & deliberations in the FOR subgroup the following action plan is suggested for rolling out intra-state ancillary services

(a) A mandate from MPERC on the following aspects would be necessary to implement reserves framework and the reserve regulation ancillary services in MP:

- Notification of Technical minimum generation level
- Notification of ramping capability norms for generators
- Notification of methodology for computation of Variable Charges
- Notification of spinning reserves to be maintained at State level
- Method for assessment & monitoring of reserves by the SLDC
- Classification of the reserve as cold reserve, hot spinning reserve, fast/slow reserve, ramp limited reserve, dispatchable reserve etc. to bring more clarity.
- Notification of Regulations for intra-state ancillary services to facilitate despatch tertiary reserve
- Regulation for implementation of secondary reserves through AGC
- Amendment to intra- state open access regulations in line with the CERC inter-state open access regulations.

(b) Technology up gradation for seam-less integration of the software for reserves monitoring& ancillary services dispatch with the existing scheduling soft ware at SLDC & RLDC;

(c) Capacity building programs for SLDC personnel for end-to-end implementation of the reserves and ancillary services framework within the state.

Annex-VII: Pilot Project in Maharashtra

Brief profile of Maharashtra power system

As on October 2019, the state of Maharashtra has an installed generation capacity of 43717 MW (source: www.cea.nic.in) including state generation, independent power producers (IPPs) in the state and the state's share in central sector generation and jointly owned interstate generators. Out of the total generation capacity (~44 GW), 61% (27 GW) is coal-based generation, 21% (9.3 GW) is renewable energy-based (RE) generation, 8% (3.5 GW) is gas based generation and rest 8% (3.3 GW) is from hydro generation. In terms of annual energy generation in MUs for 2018-19, 61% of the generation energy came from intra state thermal (coal+gas) units, 30% from central sector units, 5% from wind, 3% from hydro and 1% from solar units.

The state demand follows a seasonal pattern wherein the peak demand (~ 23-24 GW) season typically falls in winter (October-December for rabi load) summer (April-May) where-as lean demand is registered in the monsoon season (July-September). Typically, the state demand undergoes a diurnal variation (i.e. difference between intra-day max. and min. demands) of 3000-4000 MW during winter and summer and 1000-2000 MW during the monsoon. A maximum state demand ramp of ~ 250-300 MW per block has been observed during onset of morning peak. Daily energy consumption varies between 400-430 MUs in lean demand period to 500-520 MUs during peak demand period.

With an installed renewable generation capacity of 9.3 GW Maharashtra is considered a renewable rich state which has so far witnessed a maximum RE penetration of 26% in terms of %age of instantaneous state generation and 14% in terms of daily energy consumption (MUs) on 13.06.18. RE generation contributes to 6% of net annual energy consumption by the state. Intra-day wind generation variation (Max-Min) stood at 1366 MW on 04.07.18 which witnessed maximum wind generation (3157 MW) in the state. Typically, the daily wind generation pattern follows the demand pattern during July - December where as the wind generation follows a reverse pattern to demand during rest of the of the period (viz. Jan to March).

Demand Forecasting

Demand forecasting is done by SLDC Maharashtra in line with the grid code. Maharashtra Electricity Regulatory Commission (Forecasting, Scheduling and Deviation Settlement for Solar and Wind Generation) Regulations, 2018 stipulates norms for forecasting of intra-state renewable (wind and solar) generation.

Scheduling

Maharashtra-SLDC computes schedule for the intra-state entities. As on August 2019 the different category of intra-state entities scheduled by SLDC Maharashtra are given below at Table:-

Table 20: Entities scheduled by SLDC Maharashtra

S No	Category	Number
1	Distribution Licensees	9
2	Generating Companies	8*
	Total	**17**

Table 21: Discoms & Generating Companies scheduled by SLDC Maharashtra

SN	Distribution Licensees	Generating Companies
1	MSEDCL	MSPGCL (State owned Genco)
2	Tata Power Distribution Ltd	Adani Power Maharashtra Ltd.
3	Adani Distribution (Mumbai)	Adani Power (Dahanu)
4	BEST Mumbai	Tata Power Co. Ltd Mumbai
5	Indian Railway (Deemed Discom)	JSWEL Ratnagiri
6	Mindspace Business Park	Ratan India (Amravati)
7	Gigaplex Electricity	Dhariwal Infrastructure Ltd (stg-1)
8	Nidar Utilities Panvel Pvt Ltd	-
9	KRC Infrastructure Pvt Ltd	-

A new scheduling software (MiDss) developed by M/s. PRDC Bangalore is in operation since 01.01.2019. Different categories of scheduling contracts coordinated by SLDC, Maharashtra for a typical day are summarized below.

Table 22: Contracts scheduled by SLDC Maharashtra (2019)

S No.	Type	No.	MW
1	Long / Medium term PPA - intrastate	27	8171
2	Long / Medium term PPA – intrastate (Hydro/RE)	114	4369
3	Short-term bilateral intrastate (Typical in a day)	40	570
4	Long / Medium term PPA -interstate	24	7100
5	Long / Medium term PPA – interstate (Hydro/RE)	5	270
6	Short term bilateral contracts-interstate (Typical in a day)	22	1537
7	Short term contracts-PX (Typical in a day)	26	733
	Total	**258**	**22750**

Scheduling Time line

Day ahead & real time scheduling coordination is done by SLDC with intra-state entities and WRLDC as per a specified time line given in the grid code. The following table summarizes the different time lines followed for scheduling activities at SLDC.

Table 23: Scheduling Time line (SLDC Maharashtra)

Time	Description	Coordinated by
09:00	Availability of ISGS Station wise ex-power plant MW and MWh capabilities foreseen for the next Day	WRLDC (available on website)
10:00	Consent for ISGS capacities by beneficiaries	Intra-state Beneficiary
10:00	Buyers to furnish MSLDC with time block wise drawal schedule for next day	Buyers
10:00	Open Access Consumers furnish time block wise drawal schedule for next day	Open access consumers
12:00	Target despatch schedule for seller and target drawal schedule for buyers.	MSLDC
14:00	Revised demand forecast and availability forecast	Beneficiaries/Generators
15:00	ISGS drawal schedule of beneficiaries	MSLDC
17:00	"Net drawal schedule" of the State in MW and MWh for the next day	WRLDC (available on website)
18:00	IEX power purchases/sales and revised drawal schedule for next day against bilateral power and IPP requisition they have contracted in short term and long-term basis.	Buyers & MSLDC coordinate & incorporate
22:30	Revised ISGS drawal schedule by beneficiaries	MSLDC & WRLDC
23:00	Final load generation balance	MSLDC (through website)
23:00	Final despatch schedules for sellers and drawal schedules for buyers	MSLDC

Merit Order Dispatch (MOD):

Merit Order Despatch is the least cost approach to meet demand from the contracted capacity of the respective Distribution Licensee. MOD module is run day-ahead basis by SLDC based on VC. A monthly 'Merit Order Stack' is prepared on monthly basis based on the Variable charge (energy charge) using the following input data as per the MERC guidelines (order in Case No 42 of 2006).

a) Intra-state generators having long term contract with distribution licensees whose their tariff is determined by MERC submit the variable charge (VC) to SLDC by 10^{th} of every month.
b) Distribution licensees submit variable cost of power purchase from IPPs /ISGS as per PPA.
c) Intra-state STOA transaction (50MW and Above) are considered in merit order stack and are subjected to curtailment as per merit order up to 70 % on the basis of price of transaction [as per decision of state power committee (MSPC)].
d) Central sector generating station variable cost is submitted by MSEDCL and incorporated in state merit order stack.
e) Merit order stack gets effective from 00:00Hrs of 12th day of every month to 11th day of next month.
f) Revision is allowed in MOD Stack in same month for reasons such as change in law, change in rate due to change in POC loss/state transmission loss, addition or expiry of short-term bilateral contract considered in MOD, COD of intra-state generating stations or Central sector generating station etc.

Generation Tariff Structure

Maharashtra Electricity Regulatory Commission (Multi Year Tariff) Regulations, 2019 stipulates norms for intra-state generation tariff. MERC determines tariff of intra-state generators vide MYT orders. Some highlights of generation tariff are given under:

- 2-part tariff structure comprising of Fixed Cost (FC) & Variable Cost (VC)
- SLDC computes & certifies plant availability (PAF), plant load factor(PLF), scheduled energy and actual energy for all intra-state generators
- Monthly PAF computation is linked to DC similar to central sector generators

Imbalance handling by SLDC

As per the MERC order in case 42/2006 dated 17.05.2007, intra-state imbalance settlement mechanism (Final Balancing & Settlement Mechanism - FBSM) was implemented w.e.f. August 2011 which. The FBSM follows a 15-minute settlement period & weekly settlement cycle. Imbalance/Deviation charge is calculated post facto based on weighted average system marginal price (SMP). The deviation charges are not linked to frequency.

- 9 Discoms (4 Distribution licensees + 5 Deemed distribution licensees) and 12 merchant generators fall under FBSM mechanism.
- Generators with long term contract with DISCOMs are not subjected to imbalance pool charges.
- Entire state generation and aggregated demand forecast of DISCOMs are balanced by operating centralized (State wide) MOD.

Maharashtra Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) Regulations, 2019 was notified on 01.03.19 with provisions similar to the CERC regulations on deviation settlement. This is expected to be effective from 1.4.2020. The scheduling & DSM for intra-state wind and solar generators is governed by the MERC (Forecasting, Scheduling and Deviation Settlement of wind & solar generators) regulation 2018.

Imbalance handling in real-time:

Imbalance handling in real time operation is done by SLDC as under:

- During low demand conditions, costlier intra-state generators are backed down as per implemented MOD stack so that central sector drawal is maintained within permissible limits as per IEGC.
- Available hydro generation in the state are utilized as per system requirement.
- Available URS power from ISGS is utilized as per system requirement.

Metering

1118 special energy meters (ABT meters) capable of recording energy at every 15 minutes are used for weekly settlement of deviations from schedules. Special Energy Meters (ABT meters) with 15 min recoding facility are used at all interfaces (boundaries) for the SPPs (state pool participants) including all DISCOMs except MSEDCL in view of large number of customers. For MSEDCL the interchange is calculated based on rest of the meters.

Intra-state deviation pool

The state pool is a zero-balance pool by design. SLDC prepares weekly deviation account. Typical deviation volume for 4 weeks in Jan 2019 are given under for reference.

Deviation volume from 01 to 28 Jan 19						
Dates	**Drawl (Mus)**	**Schedule (Mus)**	**Deviation (Mus)**	**UI-charges (Rs lakh)**	**Cap UI (Rs. In Lakhs)**	**Addl. UI (Rs. In Lakhs)**
01 Jan-19 to 07 Jan-19	601.51	604.62	3.11	-102.89	119.74	115.36
08 Jan-19 to 14 Jan-19	726.68	730.17	3.50	-23.25	74.45	127.58
15 Jan-19 to 21 Jan-19	851.89	852.83	0.94	-25.21	40.78	58.50
22 Jan-19 to 28 Jan-19	808.62	812.90	4.29	-33.39	73.14	149.00
Total	**2988.70**	**3000.53**	**11.84**	**-184.74**	**308.11**	**450.43**

Key success factors for implementation of ancillary services

With the foregoing back ground the keys success factors for implementation of ancillary services in the state are summarized below:

Adequate Generation capacity & diversity

A framework of ancillary services shall be beneficial to both generators and beneficiaries to optimally dispatch the available generation & reserve capacity in view of the following factors as to generation adequacy & diversity in generation technology.

1. Maharashtra has adequate generation capacity including thermal, gas, hydro and renewables.

2. The state has allocation in all major inter-state generators of Western Region.
3. The state has a significant number of merchant generators
4. Similarly, it is a renewable rich state with high penetration (~20-25%) of variable renewable generation which are must run stations & hence need to be absorbed.

Thus, the SLDC has a scope for optimizing the generation dispatch as per requirements of reliability & economy (w.r.t.MOD stack). Based on the prevailing real time conditions rescheduling & redispatch can be initiated by SLDC to bring in further economy. Thus, a framework of ancillary services shall help in optimally dispatching the available generation & reserve capacity for handling imbalance and facilitating absorption of renewable generation.

Multipart Tariff structure

The intra-state generation tariff has a multipart structure comprising of fixed cost component linked to plant availability & energy charge component linked to scheduled energy. Summary of Intrastate generating stations having two-part tariff and whose tariff for the entire capacity is determined/adopted by the SERC.

Table 24: Maharashtra State Generators with two-part tariff (2019)

Name of Generating Station	Owner	No of Units x MW Size	TOTAL (MW)	Fixed Cost (Rs/Unit)	Variable rates (Rs/kWh)
NASIK U-3,4 & 5	MSPGCL	3*210	630	0.9500	4.0981
KORADI U-6 & 7	MSPGCL	2*210	420	0.9500	4.0180
BHUSAWAL U-3	MSPGCL	1*210	210	0.8400	3.7883
VIPL U-1 & 2	VIPL	2*300	600	2.2200	3.7193
DTPS U-1 & 2	DTPS	2*250	500	0.8700	3.6998
TPC U-5	TATA	1*500	500	1.3800	3.6974
TPC U-8	TATA	1*250	250	1.5600	3.6066
KHAPERKHEDA U- 1 TO 4	MSPGCL	4*210	840	0.6900	3.5770
PARAS U-3 & 4	MSPGCL	2*250	500	1.3600	3.4333
PARALI U-6 &7	MSPGCL	2*250	500	1.3300	3.3821
PARALI U-8	MSPGCL	1*250	250	1.6300	3.3515
RATTANINDIA U-1 TO 5 (PPA-1200 MW)	IPP	5*270	1200	1.1000	3.3375
CHANDRAPUR U-3 TO 7	MSPGCL	2*210 & 3*500	1920	0.5700	3.2967
CHANDRAPUR U-8 & 9	MSPGCL	2*500	1000	2.9000	3.2063
BHUSAWAL U-4 & 5	MSPGCL	2*500	1000	1.4900	3.1883

KHAPERKHEDA U-5	MSPGCL	1*500	500	1.3800	3.1511
KORADI U-8 ,9 &10	MSPGCL	3*660	1980	2.4300	2.9286
TPC U-7 (APM)	TATA	1*180	180	2.51	2.8931
ADANI (TIRODA 440 MW PPA) U 1,4 & 5	IPP	440	Coal	1.366	2.7779
ADANI ,TIRODA U-1, 4 & 5 (PPA-1200 MW and 125 MW)	IPP	1325	Coal	1.326	2.7179
ADANI ,TIRODA U-2&3 (1320 PPA)	IPP	1320	1325	1.1130	2.7179
JSW-Ratnagiri U-1	IPP	1*300	300	0.8000	2.5523

Evolving Regulatory framework for reserves

The intra-state regulatory framework is gradually evolving to set aside a specific margin towards spinning reserve. The MERC has notified a MOD guideline (in 08.03.19) that envisages a spinning reserve equivalent to highest thermal size generator in state (i.e. 660 MW at present) to be maintained at state level. Relevant extracts are given under:

"7.2……………………………………………….In order to meet system contingencies MSEDCL may keep hydro capacity equivalent to the capacity of largest thermal unit as a spinning reserve. MSEDCL to ensure that the hydro capacity to be kept as spinning reserve should be a mix of hydro units from different generating companies (….) instead if hydro units from a single generating station or hydro units of one generating company."

Thus, Maharashtra is getting gradually oriented for adopting a full-fledged framework on reserves & ancillary services.

Norm for Technical minimum generation

The MOD guidelines of MERC dated 08.03.2019 has provisions for Technical minimum as 55% of MCR for intra-state thermal generators. Similarly, it mandates for preparation of a detailed procedure by SLDC for compensation for RSD and part-load operation of state generators

URS power

Unscheduled power of intra-state generator is utilized for its contracted buyer only. Presently, there is no provision for dispatching un-requisitioned surplus (URS) power available in intra-state generators.

Pilot Optimization exercise with Excel Solver

Based on the FOR sub-group deliberation it was appreciated by the SLDC Maharashtra team carried out, a pilot exercise on constrained optimization technique to optimize the total production cost for a given sets of load-generation scenarios. The formulation used for optimization for a representative time block using MS excel solver is as given under:

Input Data for each generator (for a time block):

- 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)
- Variable charge (VC) in Rs/Kwh
- Ramp-Up rate in (%age of on-bar Capacity) per minute
- Ramp-down rate in (%age of on-bar Capacity) per minute

Derivable parameters for the generator (for a time block)

- Regulation Up-reserve = On bar installed capacity – Schedule (fig. in MW)
- Regulation Down-reserve = Schedule – Technical Minimum (fig. in MW)
- Cold reserve = DC – DC on bar …. (in MW)
- Hot spinning reserve = DC on bar – Schedule ….(in MW)
- Dispatchable reserve = Minimum of (Hot spinning reserve & Regulation Up Reserve)

Formulation of the Optimization Problem

- To minimize the Objective Function: $\underline{\sum Schedule * VC = Minimum}$
- Equality Constraint(s): ***Total schedule = Total demand of the state + Reserve***
- Inequality constraint(s): ***Pmin ≤ Station schedule ≤ Pmax;***
- Decision Variables: Schedule of each power plant to be despatched

Summary of the scenarios studied

Seven different system scenarios were studied by running the solver module for a single representative time block, based on above formulation for the state. The results are summarized under at table-

Table 25:Optimization Results for Maharashtra (one time block for each case in Jul 2019)

Scenarios	Total production cost in Rs lakh		Average Production cost (Rs/Unit)		System Marginal Price (Rs/Unit)	Up reserve available (MW)		Down reserve available (MW)	
	Pre-Optimized	Optimized	Pre-Optimized	Optimized		Apprent	Ramp limited	Apprent	Ramp limited
Case 1:Maximum Demand	515	484	2.54	2.49	3.29	871	300	9043	1082
Case 2: Minimum Demand	366	320	2.45	2.27	2.81	2339	382	6592	526
Case 3: Maximum Wind	375	350	2.47	2.31	2.96	1609	90	7347	570
Case 4: Minimum Wind	361	349	2.3	2.26	3.69	307	134	7468	809
Case 5: Maximum Surrender	284	276	2.54	2.51	2.52	5479	759	3452	149
Case 6: Minimum Surrender	507	483	2.59	2.41	3	2871	721	7043	661

For further scaling up the need was felt for more efficient professional optimization software viz. the General Algebraic Modelling System. The observations and inferences from the optimization exercise are as under:

- After optimization total production cost and average production cost in Rs/Unit have reduced.
- Up reserve margin and down reserve margin along with ramp limitation is available for each block to operator for any real time contingencies and operation.
- Allowable increase and allowable decrease in demand figures so that SMP will not get change is readily available from the solver output.
- Using this tool economic or optimal despatch/schedule can be given to generators.
- Optimization tools could be used for day-ahead purchase decisions, ancillary despatch, economic despatch, estimation of reserve carrying cost.
- The optimization results could be converted into graphs for comprehension
- Database is required to save various scenarios and their results
- Following steps would be involved for running the Solver model:
    - (1) *fetch data from the scheduling Software*
    - *(2) Run Solver Model*
    - *(3) Push the results back to the scheduling s/w*
- Reliability of communication system is critical for continuous operation of the optimization program
- Dispatchable reserves is limited by ramping constraints, hence reserves need to be distributed over multiple units. Having more units on bar helps in improving the despatchable reserves volume.
- For realistic results, the must run stations (wind/solar/run-of-the river hydro) and must take (STOA) contracts could be kept out of optimization module with formulation Pmax = Pmin
- Net load forecast to be considered instead of demand forecast for realistic results
- Transmission constraints need to be considered in the optimization model
- Operationalized dispatch, assessment of reserves & its dispatch through ancillary services shall pave way for co-optimization of energy & ancillary.

Suggested actions for implementation of intrastate ancillary services:

Based on the learning from the above optimization exercise & deliberations in the FOR subgroup the following action plan is suggested for rolling out intra-state ancillary services

(a) A mandate from MERC on the following aspects would facilitate implementation of reserves framework and the ancillary services in Maharashtra given the fact that MERC has already come out with a guideline for technical minimum (55%) and spinning reserves in March 2019.

- Notification of ramping capability norms for generators
- Notification of methodology for computation of Variable Charges
- Method for assessment & monitoring of reserves by the SLDC
- Classification of the reserve as cold reserve, hot spinning reserve, fast/slow reserve, ramp limited reserve, dispatchable reserve etc.to bring more clarity.

- Notification of Regulations for intra-state ancillary services to facilitate dispatch tertiary reserve.
- Approximately 5% margins in thermal generating station of costlier station would be desirable. For fast response reserve margins are to be kept in hydro generators in the state.

(b) Technology upgradation for seam-less integration of the software for reserves monitoring & ancillary services dispatch with the existing scheduling soft ware at SLDC & RLDC;

(c) Capacity building programs for SLDC personnel for end-to-end implementation of the reserves and ancillary services framework within the state.

Annex-VIII: Pilot Project in Gujarat

Brief power profile of the State

As on October 2019, Gujarat has an installed generation capacity of 34545 MW (source: www.cea.nic.in) including state generation, independent power producers (IPPs) in the state and the state's share in central sector generation and jointly owned interstate generators. Out of the total generation capacity (~35 GW), 48% (16 GW) is coal-based generation, 29% (10 GW) renewable energy-based (RE) generation & 19% (6.5 GW) is gas based generation. In terms of annual energy generation in MUs for 2018-19, out of the total state consumption of 122 billion units (BUs), 47% (57 BUs) came from intra-state thermal (coal+gas+nuclear) units, 34% (42 BUs) from central sector generation, 11% (14 BUs) from renewable generation (Wind & Solar), 8% (9 BU) from hydro generation.

The state demand follows a seasonal pattern wherein the peak demand (~ 16-17 GW) season typically falls in winter (Oct-Dec) & summer (Apr-May) where-as lean demand (~ 12 GW) is registered in the monsoon season (Jul-Sep). Typically, the state demand undergoes a diurnal variation (i.e. difference between intra-day max. and min. demands) of the order of 6000-MW during winter and 2000-3000 MW during the summer. Typically, state demand ramp of 100-150 MW per time block takes place during onset of morning peak in winter (Oct-Dec). Average daily energy consumption varies between 330 million units (Mus) in lean demand period and 390 MUs during peak demand period.

Gujrat is a renewable rich state in WR with an installed renewable generation capacity of 13.7 GW (as of October 2019). The state has so far witnessed a maximum RE penetration of 40% in terms of %age of instantaneous state generation (in MW) in July 2018. Similarly, max. RE penetration in terms of %age of total daily energy consumption stood at 33% in July 2018. RE generation contributes to 11% of net annual energy consumption by the state. Maximum intra-day wind generation variation (Max-Min) of 1000-1200 MW has been observed in high wind season viz. June-July. Typically, the daily wind generation pattern to an extent follows the demand pattern during April to September where as the wind generation follows a reverse pattern to demand during the of the period (October to March).

Forecasting Scheduling & Deviation Settlement

Forecasting

Forecasting is done as per the state grid code & the GERC (Forecasting, Scheduling, Deviation Settlement and Related Matters of Solar and Wind Generation Sources) Regulations, 2019.

Scheduling

Intra state ABT is implemented in Gujarat since 2010. As on August 2019, the different entities whose scheduling is coordinated by SLDC Gujarat are given below at Table-1.

Table 26: Entities scheduled by SLDC Gujarat

S No	Category	Number
1	Distribution Licensees	9
2	Intra-State Generators	18
3	Inter-State Generators	27
4	Solar Power stations	116
5	Wind Power stations	79
6	Independent Power Producers	16
	Total	**265**

SLDC is the nodal agency for scheduling of intra-state short term open access (STOA) transactions. In addition to STOA all the LTA, MTOA and wheeling contract are scheduled by SLDC. Different categories of contracts handled by SLDC Gujarat is shown below at Table-2:

Table 27: Contracts scheduled by SLDC Gujarat (2019)

S.N.	Contract Type	Number
1	Long Term Inter state	20
2	Long Term Interstate (RE)	1
3	STOA Interstate (01/10/19)	256
4	Long Term Intrastate	27
5	Medium term Intrastate	107
6	STOA Intrastate (1/10/19)	11
	Total	**422**

Scheduling Time line

The scheduling procedure followed by SLDC Gujarat is very similar with that given in IEGC scheduling code. The time line for different key activities in day-ahead scheduling is given under at Table-3.

By 9 to10 hours all state generators upload their DC through on line scheduling web portal of SLDC. After checking the input figures, the entitlement for the DISCOMs and MTOA contract details are published. By14.00 hours the requisition is submitted by the discoms and MTOA customer. By16.00 hours, collective transaction cleared report is received by SLDC. Based on all these and applying merit order dispatch the original schedule (version R0) for next day is published by 18.00 hours. The merit order dispatch (MOD) is prepared based on variable cost of the generators. The real time balancing is done by backing down or peaking up of thermal power stations. In case of contingency gas turbine generators are taken on bar and contingency power purchase is also explored as per requirement.

Table 28: Scheduling Time line (SLDC Gujarat)

D-1 day (hh:mm)	Scheduling Activities on Day-ahead horizon
10:00	Capability declaration (DC) for next day by Intra-state generators/IPPs/Shared plants; ISGS entitlements taken from WRLDC website
14:00	Entitlement and MTOA contract details published by SLDC for state DISCOMs;
16:00	SLDC compiles the collective transactions cleared in the Power Exchanges.
18:00	SLDC Gujarat issues ex-PP injection schedule to generators & ex-STU periphery drawal schedule to DISCOMs (R0) after considering state MOD.

Generation Tariff: A multi-part tariff structure comprising of fixed charge & variable charge is in place for most of the intra-state generators.

Merit Order Dispatch (MOD): MOD stack is prepared by the holding Distribution Company (Gujarat Urja Vikas Nigam Ltd. - GUVNL) on behalf of the state DISCOMs (viz. Uttar Gujarat Vij Company Ltd. (UGVCL),Dakshin Gujarat Vij Company Ltd. (DGVCL), Madhya Gujarat Vij Company Ltd.(MGVCL),Paschim Gujarat Vij Company Ltd. (PGVCL) based on VC of generators. A typical merit order based on VC as on 15.10.2019 is given under:

Table 29: Typical MOD stack of Gujarat Intra-state generators (15-Oct-2019)

S. No.	Power Station	Capacity (n*M)	FC (Rs./unit)	VC (in Rs/unit)
1	Ukai Hydro	4x75	Must run	0.17
2	ACB India Ltd	2x100	1.46	0.74
3	AKRIMOTA	2x125	0.79	1.33
4	GIPCL -MANGROL LIGNITE SLPP Expansion	2x125	1.53	1.44
5	GIPCL -MANGROL LIGNITE SLPP	2x125	0.73	1.44
6	ONGC - ANKLESHWAR	1x5	CPP (free power)	1.9
7	ONGC - HAZIRA	1x5		1.9
8	ONGC - HAZIRA	1x5		2.25
9	Dhuvaran CCPP-I & II(GSECL) on GAIL(APM)	2x107	0.72	2.45
10	BLTPS	2x250	2.63	2.6
11	KLTPS 4	1x75	1.95	2.66
12	Dhuvaran CCPP I & II on ONGC WO	2x107	0.72	2.71
13	KLTPS 1-3	3x75	1.5	2.85
14	Adani Power Limited (Mundra) Unit-1-4 (1000 MW)	4x250	1.21	3.01
15	Essar Vadinar	2x500	1.09	3.02

S. No.	Power Station	Capacity (n*M)	FC (Rs./unit)	VC (in Rs/unit)
16	Adani Power Limited (Mundra) Unit-1-4 (200 MW)	4x50 (add.)	1.21	3.06
17	GIPCL-I ON GAS - HVJ	2x37	0.34	3.18
18	UKAI - TPS- 6	1x500	1.69	3.24
19	SIKKA 3-4	2x250	1.58	3.25
20	GIPCL-I ON GAS - Gandhar	2x37	0.34	3.27
21	Utran-II (High Sea Sale)	1x375	0.98	3.59
22	GSEG, Expansion (High Sea Gas)	1x351	1.15	3.61
23	Dhuvaran CCPP-III (High Sea Sale)	1x376	1.11	3.61
24	GPPC (High Sea Sale)	2x351	0.76	3.61
25	UKAI - TPS 3-5	3x210	0.37	3.68
26	Dhuvaran CCPP-I & II (High Sea Sale)	2x107	0.72	3.8
27	GSEG Hazira (High Sea Gas)	2x78	0.46	3.9
28	WANAKBORI TPS # 7	1x210	0.6	4.07
29	GANDHINAGAR TPS #5	1x210	0.63	4.08
30	WANAKBORI TPS # 1-6	6x210	0.47	4.19
31	GANDHINAGAR TPS # 3,4	2x210	1.08	4.22
32	GSEG, Expansion (GSPC Spot Gas)	1x351	1.15	4.48
33	Utran-II (GSPC Spot Gas)	1x375	0.98	4.48
34	Dhuvaran CCPP-III (GSPC Spot Gas)	1x376	1.11	4.5
35	GPPC (GSPC Spot Gas)	2x351	0.76	4.5
36	Dhuvaran CCPP-I & II (GSPC Spot Gas)	2x107	0.72	4.74
37	GSEG, Hazira (GSPC Spot Gas)	2x78	0.46	4.84
38	GIPCL-I ON GSPC SPOT GAS	2x37	0.34	5.95
39	Dhuvaran CCPP-I & II (GAIL Spot Gas)	2x107	0.72	7.15
	Total	**13205**		

Private DISCOMs viz. Torrent (TAECO-Ahmedabad, TSECO-Surat, Dahej-SEZ) having long/medium term PPA with intra-state IPPs viz Sugen, Uno-Sugen, DGEN etc. submit their mutually agreed consolidated requisition which is incorporated in the schedule by SLDC Gujarat.

Imbalance handling by SLDC

Intra-state ABTand Deviation settlementmechanism are operational in Gujarat since 2010 which is applicable to all intra-state entities including DISCOMs and open access customers. The scheduling & DSM for intra-state wind and solar generators is governed by the Gujarat

Electricity Regulatory Commission (Forecasting, Scheduling, Deviation Settlement and Related Matters of Solar and Wind Generation Sources) Regulations, 2019.

SLDC Gujarat maintains deviation (DSM) accounts for all intrastate entities. It is a zero-sum account as per GERC (Deviation Settlement Mechanism) regulations.

Preparation of DSM accounts for the wind and solar Generators has since been commenced in Gujarat after notification of GERC (Forecasting, Scheduling, Deviation Settlement and related matters of Solar and Wind generation sources) Regulations, 2019. All wind and solar generators give their forecast and available capacity (AVC) and revise in real time as per GERC regulations. A summary of intra-state DSM account of Gujarat for four weeks of July 2019 are given under for reference.

Table 30: Gujarat Intra-state DSM account for July 2019

Week	Date (From / To)	Deviation energy (in MWH)	Deviation charge (in Rs)
14	01.07.19 TO 07.07.19	83336	82612477
15	08.07.19 TO 14.07.19	81796	104056770
16	15.07.19 TO 21.07.19	82142	135214739
17	22.07.19 TO 28.07.19	90625	91177680

Key success factors for implementation of ancillary services

The keys success factors for implementation of ancillary services in the state are summarized below:

Favorable Generation Mix & high RE penetration

Gujarat has adequate generation capacity including thermal, gas, hydro and renewables. The state has allocation in all major inter-state generators of Western Region. The state has a significant number of merchant generators (viz. 2x660 MW Adani Power Stage-II Mundra, 2x150 MW Bhadreswar Vidyut Pvt. Ltd. Kutchh). Gujarat has a considerable volume of gas-based merchant generation (viz. 630 MW CLPIPL-Gas station etc.) which can be dispatched under ancillary services. Similarly, it is a renewable rich state with high penetration (~30%) of variable renewable generation which are must run stations & hence need to be absorbed. Thus, the SLDC has a scope for optimizing the generation dispatch as per requirements of reliability & economy (w.r.t.MOD stack). Based on the prevailing real time conditions rescheduling & redispatch can be initiated by SLDC to bring in further economy. Thus, a framework of ancillary services shall help in optimally dispatching the available generation & reserve capacity for handling imbalance and facilitating absorption of renewable generation.

Multipart Tariff structure

The intra-state generation tariff has a multipart structure comprising of a fixed charge (FC) component linked to plant availability & a variable charge (VC) component linked to scheduled energy. Thus, two-part tariff structure along with intra-state ABT & DSM mechanisms provide a conducive framework for rolling out intra-state ancillary services.

Norm for Technical minimum generation

GERC is yet to give a mandate for Technical minimum for intra-state generators. However, the technical minimum is generally considered as 60-70% of MCR for thermal generators based on vintage & capacity.

Availability of URS power

There exists significant scope for dispatching the incidental reserves in the form of un-requisitioned surplus (URS) power in intra-state generators. Reserve monitoring in real time is done by SLDC operators through the web-based scheduling software. The URS power available in real time can be despatched by SLDC operator under a framework of ancillary services.

Pilot Optimization exercise with Excel Solver

Based on the FOR sub-group deliberation it was appreciated by the SLDC team that a scientific approach based on algorithmic solutions is desirable for reserve computation & monitoring and optimal dispatch thereof. Accordingly, a pilot exercise on constrained optimization technique was carried out by SLDC Gujarat to optimize the total production cost for a given sets of load-generation scenarios with help of an excel solver tool devised by NLDC team. The formulation used for optimization for a representative time block using MS excel solver is as given under:

Input Data for each generator (for a time block):

- 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)
- Variable charge (VC) in Rs/Kwh
- Ramp-Up rate in (%age of on-bar Capacity) per minute
- Ramp-down rate in (%age of on-bar Capacity) per minute

Derivable parameters for the generator (for a time block)

- Regulation Up-reserve = On bar installed capacity – Schedule (fig. in MW)
- Regulation Down-reserve = Schedule – Technical Minimum (fig. in MW)
- Cold reserve = DC – DC on bar …. (in MW)
- Hot spinning reserve = DC on bar – Schedule ….(in MW)
- Dispatchable reserve = Minimum of (Hot spinning reserve & Regulation Up Reserve)

Formulation of the Optimization Problem

- To minimize the Objective Function: $\underline{\sum \boldsymbol{Schedule * VC = Minimum}}$
- Equality Constraint(s): ***Total schedule = Total demand of the state + Reserve***
- Inequality constraint(s): ***Pmin ≤ Station schedule ≤ Pmax;***
- Decision Variables: Schedule of each power plant to be despatched

Summary of the scenarios studied

Five different scenarios were studied by SLDC Gujarat running the solver module for a single representative time block, based on above formulation for the state. Results are summarized at Table-7. As can be seen, there is potential for saving in most of the cases studied during the above optimization exercise. For further scaling up the need was felt for more efficient professional optimization software viz. the General Algebraic Modelling System with which the optimization can be run for all 96 blocks on continuous basis.

Table 31: Optimization Results for Gujarat for different scenarios (each case for one time block)

Scenarios		Total production cost in Rs lakh		Average Production cost (Rs/Unit)		System Marginal Price (Rs/Unit)	Up reserve available (MW)		Down reserve available (MW)	
Day	Block	Pre-Optimized	Optimized	Pre-Optimized	Optimized		Apprent	Ramp limited	Apprent	Ramp limited
20-Jun-19	89	347	340	2.97	2.94	1.99	66	N/A	216	N/A
21-Jul-19	61	400	392	3.16	3.11	3.67	11	N/A	228	N/A
21-Jul-19	80	321	318	2.94	2.94	3.67	14	N/A	112	N/A
22-Jul-19	21	411	387	3.17	3.11	3.33	54	N/A	145	N/A
22-Jul-19	61	386	386	3.15	3.13	3.84	44	N/A	126	N/A

The observation &inferences from the optimization exercise are as under.

- The optimization exercise gave vital decision tools viz. (1) plant wise optimum schedule, (2) system marginal price, (3) Up reserve (4) Down Reserve (5) Ramp limited reserves for a given time block
- The above optimization was done with demand of GUVNL (state owned DISCOMs) only (without considering the demands of other private DISCOMs). There is likelihood of more saving if the entire state demand with all DISCOMs is considered.
- Optimization tools can be used for day-ahead purchase decisions, economic despatch, ancillary despatch, estimation of reserve carrying cost.
- The optimization results can be converted into graphs for comprehension
- Database is required to save various scenarios and their results
- Necessary steps involved for running optimization module:
    - (1) *fetch data from the scheduling Software >*
    - *(2) Run Solver Model*
    - *(3) Push the results back to the scheduling s/w;*
- Reliability of communication system is critical for the optimization program
- Dispatchable reserves is limited by ramping constraints, hence reserves need to be distributed over multiple units.
- Having more units on bar helps in improving the despatchable reserves volume.
- For realistic results, the must run stations (wind/solar/run-of-the river hydro) and must take (STOA) contracts could be kept out of optimization module with formulation Pmax = Pmin
- Transmission constraints need to be considered in the optimization model

Suggested actions for implementation of intrastate ancillary services:

Based on the learning from the above optimization exercise & deliberations in the FOR subgroup the following action plan is suggested for rolling out intra-state ancillary services

a. A mandate from SERC on the following aspects would be necessary to implement reserves framework and the reserve regulation ancillary services in Gujarat:

- Notification of Technical minimum generation level & gate closure
- Notification of ramping capability norms for generators
- Notification of methodology for computation of variable charge
- Notification of spinning reserves to be maintained at State level
- Method for assessment & monitoring of reserves by the SLDC
- Classification of the reserve as cold reserve, hot spinning reserve, fast/slow reserve, ramp limited reserve, dispatchable reserve etc.to bring more clarity.
- Notification of Regulations for intra-state ancillary services to facilitate dispatch of tertiary reserves

b. Infrastructure for seam-less integration of the software for reserves monitoring & ancillary services dispatch with the existing scheduling software at SLDC & RLDC;

c. Capacity building programs for SLDC personnel for end-to-end implementation of the reserves and ancillary services framework within the state.

Draft Model Regulation on Intra-State Essential Reliability Services

Notification

No. XX / XX/20XX Dated: DD.MM.20XX

In exercise of the powers conferred under sections 42, 61, 66, 86(1) (e) and 181 of the Electricity Act, 2003 (Act 36 of 2003) and all other powers enabling it in this behalf, and after previous publications, the ……………………(Name of State) Electricity Regulatory Commission hereby makes the following Regulations for the Intra-State Essential Reliability Services Operations:

1. Short Title and Commencement

i. These Regulations may be called the ………………(Name of State) Electricity Regulatory Commission (Intra-State Essential Reliability Services Operations) Regulations, 20XX

ii. These Regulations may come into force from the date of their notification in the Official Gazette

iii. These Regulations shall extend to the whole of the State of……..

2. Definitions and Interpretations

i. In these Regulations, unless the context otherwise requires,

a) "Act" means the Electricity Act, 2003 (36 of 2003) and subsequent amendments thereof;

b) "actual drawal" in a time-block means electricity drawn by a buyer, as the case may be, measured by the interface meters;

c) "actual injection" in a time-block means electricity generated or supplied by the seller, as the case may be, measured by the Interface meters;

d) "beneficiary" means a person who has a share in an Intra-State Generating Station;

e) "Commission" means the ……………….(Name of State) Electricity Regulatory Commission constituted under the Act;

f) "Congestion" means a situation where the demand for transmission capacity exceeds the Available Transfer Capability;

g) "Detailed Procedure" means the procedure issued under regulation 14;

h) "Deviation" in a time-block for a seller means its total actual injection minus its total scheduled generation and for a buyer means its total actual drawal minus its total scheduled drawal;

i) "Essential Reliability Services or ERS" means Ancillary Services that consist of either Regulation Down Service or Regulation Up Service;

j) "Essential Reliability Services Provider or ERS Provider" means the Intra-State Generating Stations eligible to participate in the ERS, for providing Regulation Up or Regulation Down service;

k) "Grid Code" means the Grid Code specified by the ....(Name of State) Commission under the Act;

l) "interface meters" means interface meters as defined by the Central Electricity Authority under the Central Electricity Authority (Installation and Operation of Meters) Regulations, 2006, as amended from time to time;

m) "Load Despatch Centre" means ....(Name of State) Load Despatch Centre, responsible for coordinating scheduling in accordance with the provisions of Grid Code;

n) "Nodal Agency" means the System Operator, namely ....(Name of State) Load Despatch Centre who shall be responsible for implementation of the essential reliability services operations at the intra-state level.

o) "Regulation Down Service" means an ERS that provides capacity that can respond to signals or instruction of the Nodal Agency for decrease in generation, within the technical limit and time limit, to respond to changes in area control error or congestion in the system;

p) "Regulation Up Service" means an ERS that provides capacity that can respond to signals or instruction of the Nodal Agency for increase in generation, within the technical limit and time limit to respond to changes in area control error or congestion in the system;

q) "state entity" means a person whose metering and energy accounting is done at the state level;

r) "Scheduled generation" at any time or for a time block or any period means schedule of generation in MW or MWh ex-bus given by the concerned Load Despatch Centre;

s) "Scheduled drawal" at any time or for a time block or any period time block means schedule of drawal in MW or MWh ex-bus given by the concerned Load Despatch Centre;

t) “Security Constrained Economic Despatch” or “SCED” means operation of generation facilities to produce energy at lowest cost to reliably serve the consumers, recognizing any operational and technical limits of generation and transmission facilities;

u) ‘Security Constrained Unit Commitment’ or ‘SCUC’means committing/de-committing generating units while respecting limitations of the transmission system and unit operating characteristics;

v) "Time-block" means a time block of 15 minutes each for which special energy meters record values of specified electrical parameters with first time block starting at 00.00 hrs;

w) "Un-requisitioned surplus" means the reserve capacity in a generating station that has not been requisitioned and is available for despatch, and is computed as the difference between the declared capacity of the generation station and its total schedule under long-term, medium-term and short-term transactions, as per the relevant regulations of the Commission.

x) "Virtual Ancillary Entity" means a virtual entity participating in the ………………..(Name of State) Deviation Pool, as operationalized under State Electricity Regulatory Commission Regulations, which shall act as the counterparty for the schedule prepared for despatch of essential reliability services providers (to convert single entry to a double entry system);

ii. All other words and expressions used in these Regulations, although not specifically defined herein above, but defined in the Act, shall have the meaning assigned to them in the Act. The other words and expressions used herein but not specifically defined in these Regulations or in the Act but defined under any law passed by the Parliament applicable to the electricity industry in the State shall have the meaning assigned to them in such law.

3. Objective

i. The objective of these regulations is to balance the supply and demand in the state, relieve the congestion in the Intra-State transmission system and to optimize the despatch of electricity incorporating reserves.

4. Scope and applicability

i. These regulations shall be applicable to the Intra-State Entities (other than Hydro & Renewable generators) involved in the transactions facilitated through short-term open access or medium-term open access or long-term access.

5. Eligibility for participation for Intra-State Essential Reliability Services

i. All ………………..(Name of State) Generating Stations and whose tariff is determined or adopted by the Commission for their full capacity shall provide Intra-State ERS.

ii. All other State Generating Stations whose tariff is not determined or adopted by the commission may also be considered for Intra-State ERS. The consolidated tariff may be considered as 303.04 Paise/kwh.

6. Control period

i. The Regulations shall come into force from the date of notification in the Official Gazette.

7. Role of Nodal Agency

i. Nodal Agency shall prepare merit order stack of Intra-……………..(Name of State) Generating Stations as stipulated in regulation 7 (ii) and take despatch decision.

ii. For Regulation-Up, the Nodal Agency shall prepare stack of un-requisitioned surplus capacities available in respect of Intra-……………..(Name of State) Generating Stations from lowest variable cost to highest variable cost in each time block, and taking into account ramp up or ramp down rate, response time, transmission congestion and such other parameters as stipulated in the Detailed Procedure. For Regulation-Down, a separate merit order stack from highest variable cost to lowest variable cost incorporating technical parameters as above shall be prepared.

iii. Nodal agency shall prepare merit order stack factoring intra- state transmission constraints, if any.

iv. Nodal Agency shall monitor the area control error, violation of transfer capability limits etc.

v. Nodal agency shall direct the selected ERS Provider(s) based on the merit order for economical despatch for Regulation Up and Regulation Down, as and when requirement arises in the system on account of any of the following events:

a) Extreme weather forecasts and/or special day;
b) Generating unit or transmission line outages;
c) Trends of area control error;
d) Any abnormal event such as outage of hydro generating units due to silt, coal supply blockade etc.;
e) Excessive loop flows leading to congestion; and
f) Such other events.

vi. Nodal agency shall direct the selected ERS Provider(s) to withdraw their services after the circumstances leading to triggering of ERS no longer exist. The time-frame for withdrawal of service shall be determined as per the Detailed Procedure.

8. Role of Intra-State Essential Reliability Services Provider (ERS Provider)

i. The ERS Provider shall on monthly basis submit the following to the Nodal Agency.

a) Maximum possible ex-bus generation (MW) including overload if any (P_{max})
b) Minimum turn down level (MW) (P_{min})
c) Type of fuel
d) Fixed cost (paise/kWh upto one decimal place)
e) Energy charge rate (paise/kWh upto one decimal place)
f) Ramp up rate (MW/min) for each unit
g) Ramp down rate (MW/min) for each unit

h) Start up time from cold start (in minutes)
i) Start up time from warm start (in minutes)
j) Minimum up time for a unit after synchronization (in minutes)
k) Minimum down time for a unit after desynchronization (in minutes)
l) Maximum number of units that can be started up simultaneously
m) Any other information / constraints

ii. The ERS Provider shall inject or back down generation as per the instruction of the Nodal Agency for Regulation Up and Regulation Down respectively.

9. Despatch of ERS

i. In the real time, Security Constrained Economic Despatch (SCED) shall be implemented by the SLDC for co-optimization of energy and reserves.
ii. Generation under the ERS shall be scheduled to the Virtual Ancillary Entity as decided by the Nodal Agency.
iii. Once the time period as specified by the Nodal Agency in the scheduled procedure starts, ERS shall be deemed to have been triggered.
iv. The schedules of the ERS Provider(s) shall be considered as revised by the quantum scheduled by the Nodal Agency under ERS.
v. Any deviations in schedule of ERS Provider(s) beyond the revised schedule shall be treated in accordance with the -……………….(Name of State) Regulations.

10. Withdrawal of ERS

The Nodal Agency, having been satisfied that the circumstances leading to triggering of ERS no longer exist, shall direct the ERS Provider(s) to withdraw with effect from the time block as specified in the Detailed Procedure.

11. Scheduling of ERS

i. The quantum of generation dispatched shall be directly incorporated in the schedule of respective ERS Provider(s).
ii. For Regulation Up Service, power shall be scheduled from the generating station to the Virtual Ancillary Entity by the concerned Nodal Agency, until such time the Nodal Agency gives instruction for withdrawal of service.
iii. For Regulation Down Service, power shall be scheduled from the Virtual Ancillary Entity to the generating station, so that effective scheduled injection of the generating station comes down, until such time the Nodal Agency gives instruction for withdrawal of service.
iv. Separate statement shall be maintained along with State Deviation Settlement Account for ERS.
v. The energy despatched under ERS shall be deemed as delivered ex-bus.

12. Energy Accounting

i. Energy Accounting shall be done by the Nodal Agency on weekly basis along with State Deviation Settlement Account based on interface meters data and schedule.

ii. The Nodal Agency shall issue an Ancillary Services Statement along with the State Deviation Settlement Mechanism Account.

13. ERS Settlement

i. The settlement shall be done by the Nodal Agency under the State Deviation Settlement Pool Account under separate account head of ERS.

ii. The payment to ERS Provider(s) shall be from the State Deviation Settlement Pool Account Fund. There can be two types of pool. One is ZERO balance pool and other is pool having residual amount after settlement.

iii. In case of ZERO balance (also known as revenue neutral) pool, payment under ERS from or to State DSM pool to be considered as a part of pool balancing and accordingly payable and receivable to be made equal.

iv. In case of Non-ZERO balance pool, settlement towards ERS is to be done directly with the pool. In case of a deficit pool, dispatch under ERS is not envisaged.

v. The ERS Provider(s) shall be paid at their variable charges, with mark-up, as decided by the Commission through a separate order from time to time in case of Regulation Up services for the quantum of ERS scheduled from the pool.
Provided that, the variable charges allowed by the Commission and as applicable at the time of delivery of ERS shall be used to calculate the payment for this service and no retrospective settlement of variable charges shall be undertaken even if the variable charges are revised at a later date.

vi. For Regulation Down service, the ERS Provider(s) shall pay back the variable charges corresponding to the quantum of Regulation Down services scheduled, to the pool. Loss due to sub-optimal operation may be factored.

vii. Any deviation from the schedule given under ERS shall be in accordance with the State Electricity Regulatory Commission Regulations, 2014

viii. Sustained failure to provide the ERS (barring unit tripping) by ERS Provider(s) shall attract penalties on account of gaming. Violation of directions of Nodal Agency for ERS shall also make the ERS Provider(s) liable for penalties in terms of section 30 of the Act.

ix. No commitment charges shall be payable to the ERS Provider(s) for making themselves available for the ERS.

14. Detailed Procedure

i. The Nodal Agency shall, after obtaining prior approval of the State Commission, issue the Detailed Procedure within a period of 3 months of notification of these regulations.

ii. The Detailed Procedure shall contain the guidelines regarding operational aspects of ERS including scheduling and dispatch and any residual matter.

15. Power to give directions

i. The Commission may from time to time issue such directions and orders as considered appropriate for implementation of these Regulations.

16. Power to relax

i. The Commission may by general or special order, for reasons to be recorded in writing, and after giving an opportunity of hearing to the parties likely to be affected, may relax any of the provisions of these Regulations on its own motion or on an application made before it by an interested person.

17. Power to amend

i. The Commission may from time to time add, vary, alter, suspend, modify, amend or repeal any provisions of these Regulations.

18. Power to remove difficulties

i. If any difficulty arises in giving effect to the provisions of these Regulations, the Commission may, by an order, make such provisions, not in consistent to the provision of the Act and these Regulations, as may appear to be necessary for removing the difficulty.

(Secretary)