Introduction of Secondary Frequency Control in Indian Power System

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***Abstract* — Secondary frequency control has been introduced through Automatic Generation Control (AGC) in India in 2018 on a pilot basis. This paper elaborates the various steps that were involved in the introduction of secondary frequency control. Details of the important resources identified for the implementation of AGC at load despatch centre and at power plants are elaborated. Regulatory framework evolved around secondary frequency control is discussed. The authors also present the core ideas around secondary frequency control and its future in India.**

Keywords—Secondary frequency control, Automatic Generation Control, AGC, Indian power system, Ancillary Services, AGC pilot project.

I. Evolution towards Secondary Frequency Control in India

Over the years there is a marked decline in the energy deficit [1]. Along with that, there is a significant improvement in frequency profile of the interconnected Indian grid. Figure-1 depicts the improvement in average grid frequency profile of India since 2004. Apart from growing grid size and interconnections, this improvement has been made possible because of bringing multiple frequency control mechanisms in place supported by strong metering and settlement systems for financial accounting. It was observed that each of the frequency control strategies operate in a different time frame with some overlap. Load and renewable forecast, unit commitment, generation scheduling, manual frequency control ancillary services, automatic secondary and primary frequency control, inertial response and interconnection strength are all essential components of frequency control of any grid. Taking this experience into cognizance, Central Electricity Regulatory Commission (CERC) Expert Group to review and suggest measures for bringing power system operation closer to National Reference Frequency (Volume-I) suggested secondary control as a vital link in the frequency control continuum as depicted in Figure-2 [2]. No single frequency control mechanism alone is sufficient to stabilize the grid frequency in a sustainable manner over the years.

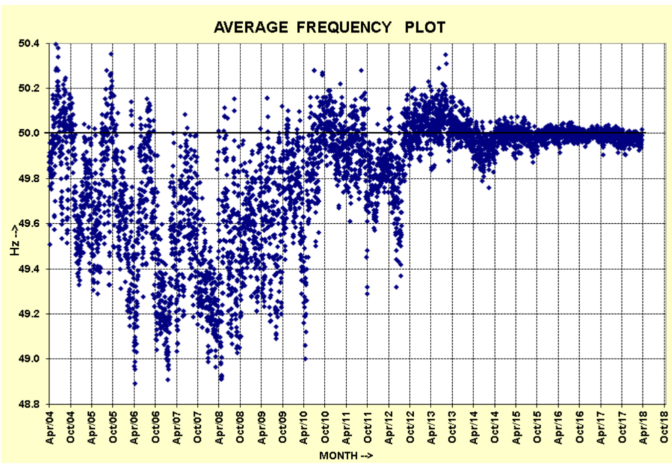

Figure-1: Average grid frequency of India since 2004

Since independence, Indian power system has evolved gradually from state grids to regional grids and now an All India synchronous electricity grid. Within each regional grid, the system is operated in a decentralized manner with each state grid considered as a notional control area. Unlike the practices in power systems elsewhere, there was no compulsion or regulatory mandate for the state control areas to balance themselves 24 x 7. Rather, the imbalances or deviations in net drawal from the schedule by each control area were priced through a frequency and volumetric linked deviation prices. This worked well as long as regional grids operated separately and energy deficits were common. With the interconnection of regional grids between 2003-2013, introduction of open access and an explosion in the growth of Independent Power Producers (IPPs), congestion in the network also came to the fore.

While primary frequency control is already mandated by the Indian electricity grid code on several generators, slow tertiary frequency control as an ancillary service for manually changing the schedules of thermal generators was introduced in 2016. Lack of automatic controls for balancing the system, the rapid expansion in Renewable Energy (RE) generation and the need to successfully integrate these in the grid brought out the need for automatic secondary frequency control in the Indian grid though this technology is in operation since the 1930s as per the 1992 AGC Task force of the IEEE System Control sub-committee [3].

For a large percentage of time every day, it is observed that the inter-state shared generating stations have power reserves available due to non-requisition by the states. Some generators are under reserve shutdown due to less requisition of power from their respective beneficiaries. These reserves have been envisaged to be harnessed for meeting high demand ramps and for minute to minute tracking of load through AGC.

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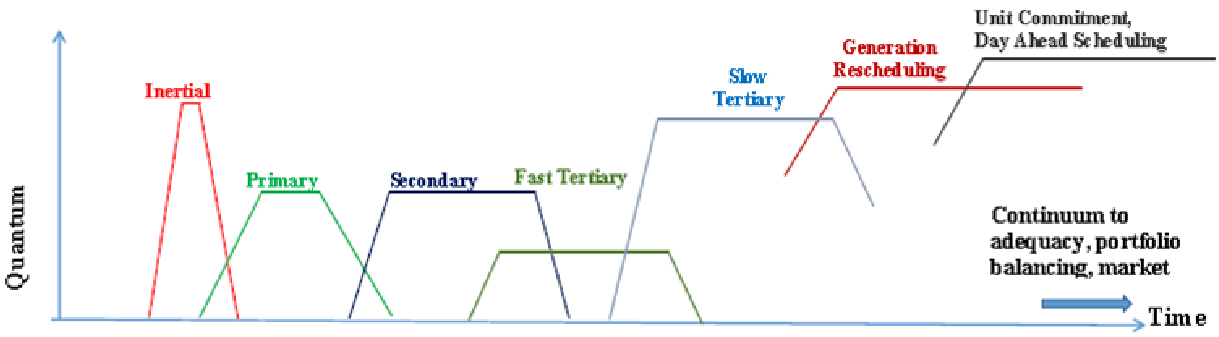

Response → Attribute	Inertial	Primary	Secondary	Fast Tertiary	Slow Tertiary	Generation Rescheduling/Market	Unit Commitment
Time	First few secs	Few sec - 5 min	30 s – 15 min	5 - 30 min	> 15 – 60 min	> 60 min	Hours/ day-ahead
Quantum	~ 10000 MW/Hz	~ 4000 MW	~ 4000 MW	~ 1000 MW	~ 8000-9000 MW	Load Generation Balance	Load Generation Balance
Local / LDC	Local	Local	NLDC / RLDC	NLDC	NLDC / SLDC	RLDC / SLDC	RLDC / SLDC
Manual / Automatic	Automatic	Automatic	Automatic	Manual	Manual	Manual	Manual
Centralized / Decentralized	Decentralized	Decentralized	Centralized	Centralized	Centralized/ Decentralized	Decentralized	Decentralized
Code / Order	IEGC / CEA Standard (?)	IEGC / CEA Standard	Roadmap on Reserves	Ancillary Regulations	Ancillary Regulations	IEGC	IEGC
Paid / Mandated	Mandated	Mandated	Paid	Paid	Paid	Paid	Paid
Regulated / Market	Regulated	Regulated	Regulated	Regulated	Regulated / Market	Regulated / Market	Regulated / Market
Implementation	Existing	Partly Existing	Pilot	Yet to start	Existing	Existing	Existing

Figure-2: Schematic of Reserves, Balancing and Frequency Control Continuum in India [2]

CERC identified Primary, Secondary and Tertiary controls as important components for secure grid operation. A total of 3600 MW of Secondary Reserve was decided necessary by the Commission, corresponding to the largest credible unit outage in each region [4][5]. CERC directed Power System Operation Corporation Limited (POSOCO) to submit a detailed procedure to operationalize reserves in the country. In this connection, an outline procedure was submitted in Dec'15. Section IV of the paper discusses the detailed plan for operationalization of reserves.

In the outline procedure, POSOCO proposed to take up a pilot project with one of the generating plants in a region to identify the necessary software and hardware requirements. In Jan'16, POSOCO organized brainstorming sessions with stakeholders, experts, Energy Management System (EMS) vendors and load despatchers to assess the requirements for AGC.

II. AGC Pilot Project

Following the discussions, Dadri stage-II power plant (2 x 490 MW) in Northern Region (NR) was selected for implementation of the AGC pilot project keeping in view the ease of executing the field level implementation process and considering the high probability of reserve availability in that power station from historical data.

Secondary control considering each of the five regional grids in India as a single balancing area was proposed for operation from National Load Despatch Centre (NLDC), considering the future EMS upgradation project at NLDC. During the course of interaction with the EMS vendors, it was observed that that this type of philosophy (Five AGCs located at a single control centre) is almost first of its kind. The concept of having a region as a balancing area is depicted in Figure-3 and the Area Control Error (ACE) has to be worked out for each area viz. region. The objective of the full-fledged AGC is to drive the regional ACE to zero. Standard industrial grade AGC software was used to process the value of ACE and limits of the power plant through the AGC software to derive the *plant AGC set point*.

Regional ACE is calculated using the *frequency, inter-regional schedule tie line MW* and *actual tie line MW* data as shown in Figure-3. The software is capable of operating in three modes viz., frequency bias, tie line interchange and tie line bias (combination of tie line interchange and frequency bias). References [6] and [7] recommend using frequency response characteristic (FRC) calculated after the after the power and frequency transients have settled, for the *Frequency Bias Setting* used in the ACE equation. Twenty events are adequate for estimating the frequency response characteristic to rule out human error [6]. For around 58 events in the grid since 2015, Frequency response characteristic is archived for all the regions estimated using Phasor Measurement Unit (PMU) data at NLDC.

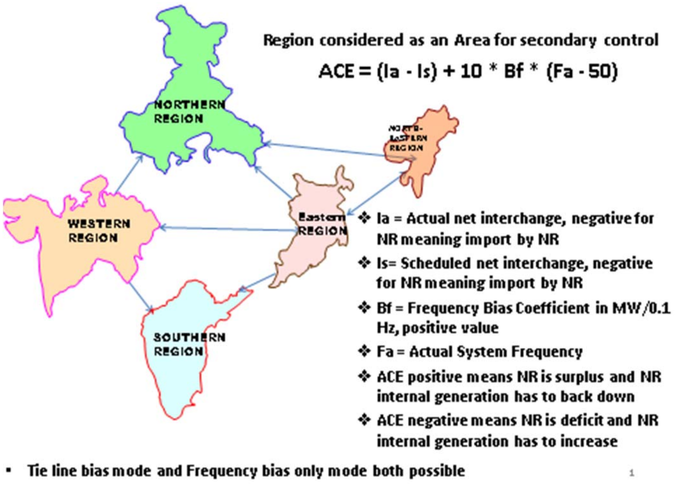

Figure-3: Concept of region as a balancing area

Data is exchanged between the SCADA system at NLDC and AGC application through Inter Control Center Communications Protocol (ICCP). AGC system at NLDC exchanges data two-way with the power plant in IEC 60870-5-104 (IEC 104) protocol. The data flow in AGC project is represented in Figure 4.

Unit Load Set Point (ULSP) of Dadri Stg-II is the gross set point of the plant including auxiliary power consumption, which is fed manually by the plant operator to the unit Digital Control System (DCS). This is taken as an input for the AGC to establish the reference for base set point. AGC software output is the *plant AGC set point* which is communicated every two seconds (configurable 2s-10s) to the power plant.

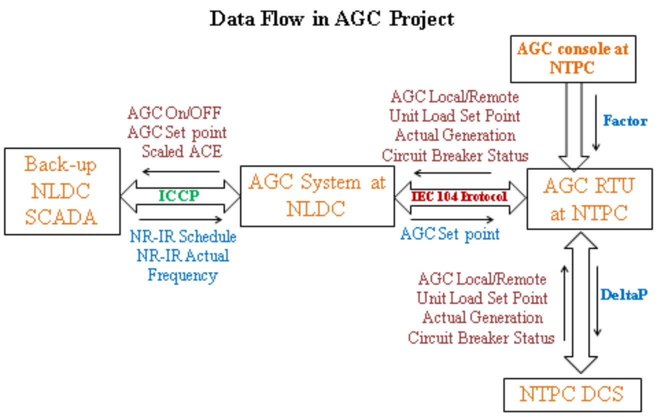

Figure-4: Data flow in AGC pilot project

Delta P is the AGC correction calculated as the difference between *plant AGC set point* and the reference ULSP. The plant operator has the choice to distribute the *plant AGC set point* in between the two units by a *Factor*.

The unit DCS accepts AGC signal sent by NLDC when the unit is set into *Remote* by the unit operator. Similarly the unit DCS only receives the signal but does not act on the signal when the unit is placed in *Local.* Unit circuit breaker status is also collected by the AGC system to update the limits if any unit goes offline.

There are two modes *OFF* and *ON*. When working normally, AGC is in *ON* state. In case the tie line MW data that is telemetered from the Remote Terminal Units (RTUs) is suspect for more than ten minutes, then the AGC program transcends to mode *OFF*. AGC program has to be switched *ON* manually after the quality of telemetry is restored. Also, if there is any break detected in the communication channels to AGC server at NLDC, then the AGC program goes to *OFF* state.

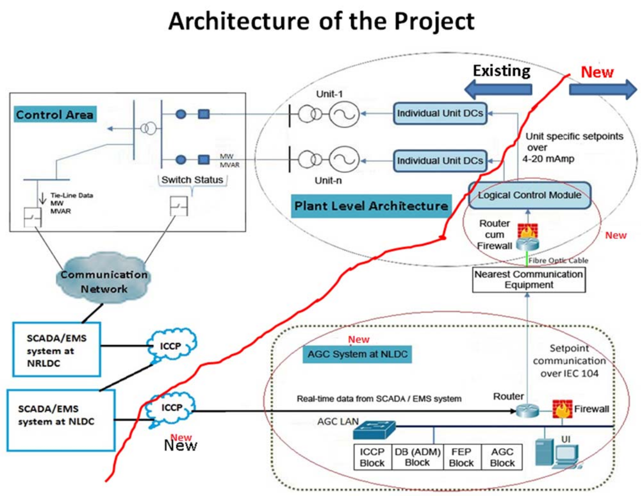

Figure-5: Architecture of the AGC pilot project

The architecture of the project is depicted in Figure-5. AGC server at NLDC has four divisions. They are - i) ICCP block, ii) database block, iii) front end processor block and iv) AGC block.

- ICCP block handles the data exchanges with SCADA.
- Database block contains the information regarding the parameters of the units under AGC.
- Front end processor communicates with the Remote Terminal Unit (RTU) located at the plant under AGC.
- AGC block handles the Proportional Integral (PI) controller related calculations and the power plant limits after taking inputs from other blocks and decides the plant AGC set point.

RTU located at the plant is connected to the nearest wide band communication node through a fibre optic cable laid as a part of the AGC project. The nearest wide band communication node reports to the AGC front end processor located at NLDC through a communication path provided by the optical fiber ground wire (OPGW) cables of the meshed electric grid planned by Central Transmission Utility (CTU). RTU located at the plant is hardwired to the generating unit Digital Control System (DCS). Cyber security is ensured through appropriate router configurations, firewalls and antivirus softwares.

Desired attributes of the RTU are also understood as a part of the pilot project. They are listed hereunder.

- Sizing of the analog and digital input cards are decided based on the number of signals sent and received per generating unit for AGC, with scope for expansion.
- In the first AGC Pilot, no digital outputs were used, but provision was kept for connecting digital devices in future.
- The RTU should be capable of communicating over IEC 60870-5-104 protocol with RLDC/NLDC.
- RTU should also have the capability of performing microprocessor level calculations and accepting logic. In the AGC pilot, arithmetic and logical operations like +,-,*, /, if, else, while, do, AND, OR etc. were used on AGC signals for sanity checking of data.
- GPS clock synchronization facility, operation over the standard DC input voltage of 24-60 V DC, capability of automatic start up following restoration of power after an outage, internal battery backup to hold data and date/time stamp in sequence of events (SOE) buffer memory is needed.
- Communication interfaces should be via insertable serial interface modules for Ethernet.
- The RTU shall be able to store the AGC signals from NLDC/RLDC and mathematically integrate the AGC command over the desired period along with GPS time stamping for accounting purposes.

A mock test was successfully conducted in June'17 by connecting NTPC Dadri stg-II with NLDC through AGC. During the test, signals were sent every two seconds (configurable between 2s-10s) directly from NLDC control centre in New Delhi to NTPC Dadri control centre. The generator responded as per the requirement. Response of the plant during mock test is shown in Figure-6.

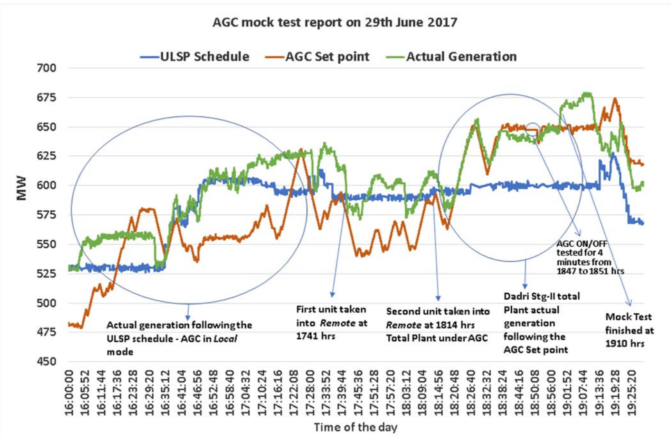

Figure-6: Results of the AGC mock test

Ramp limits of the plant were restricted in the software to +/- 10 MW/min during the test. It was observed that the output of the software had strictly honored the limits. Ramp rate adherence of the *plant AGC set point* is shown in Figure-7. Other important limits like max-min limits of the generating units are also strictly honoured.

CERC in its order in Dec'17 approved the Commissioning of the AGC Pilot Project between NLDC and NTPC Dadri Stage-II [8]. The Commission observed that development of secondary reserves in the country will lead to grid security and reliability. The Commission also directed that similar pilot projects may be replicated by NLDC, in at least one other regional grid of the country.

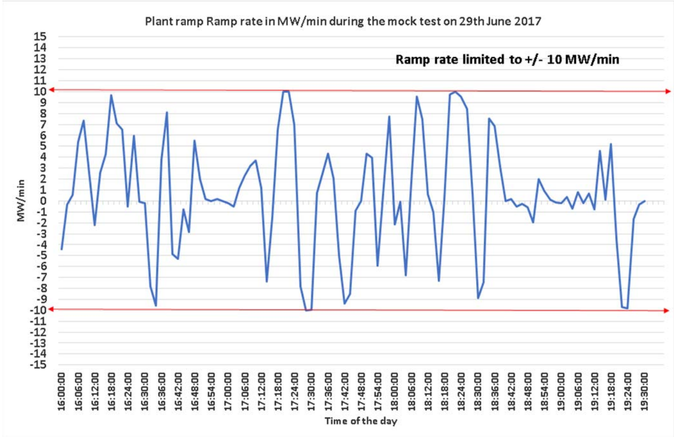

Figure-7: Ramp rate of the *plant AGC set point*

The country's first AGC set up at NTPC Dadri stg-II and NLDC has been successfully operationalized from Jan'18. Further areas from the pilot such as frequency bias mode operation, frequency plus tieline bias mode operation besides configuring additional units on AGC is also being studied.

III. METERING, ACCOUNTING AND SETTLEMENT OF SECONDARY CONTROL SERVICES

While several methods exist worldwide for compensating generating stations providing secondary regulation services through AGC considering opportunity costs, a simple method is required considering that the power plant is under CERC's jurisdiction as far as tariff is concerned, its fixed cost liability is being shared by the beneficiaries and little opportunity cost is involved in bringing this plant under AGC.

Accounting and settlement of energy and services is being done as per the orders of the regulatory commission mentioned above. Schematic of signals archived for accounting and settlement is given as Figure-8. Aggregated *Delta P* MW signals over 15 minutes and 5 minutes are logged in MWh at NLDC and power plant as *AGC MWh*. Power plant sends its *AGC MWh* account every week to NLDC for cross verification. *AGC MWh* logs are forwarded to Northern Regional Power Committee (NRPC) secretariat on weekly basis through Northern Region Load Despatch Centre.

Deviation in MWh for every 15-minute time block would be worked out as

$$\begin{aligned}\text{Pant MWh deviation}\\ &= (\text{Plant Actual MWh})\\ &- (\text{Plant Scheduled MWh})\\ &- (AGC\ MWh)\end{aligned}$$

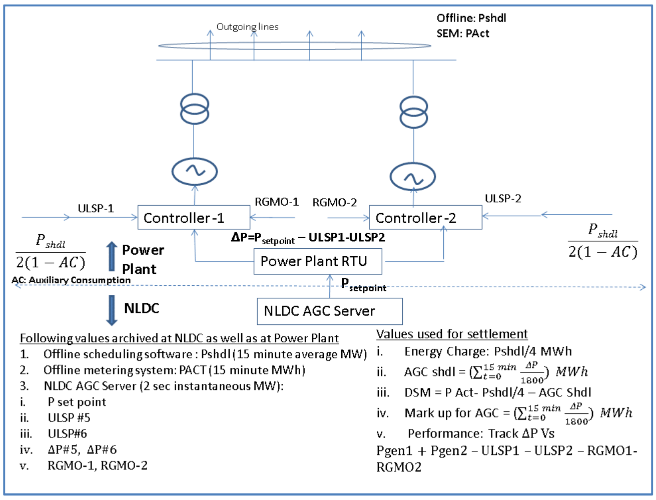

Figure-8: Schematic of the metering and accounting system

Plant Actual MWh & Plant Scheduled MWh are always positive. *AGC MWh* can be either positive or negative. This Plant MWh deviation would be settled as per the existing Deviation Settlement Mechanism (DSM) Regulations [9]. For positive *AGC MWh* computed during every 15-minute time block, energy charge payment would be made from the regional DSM pool to the power plant. For negative *AGC MWh,* which means reduction in generation from the scheduled set point, computed during a 15-minute time block, power plant shall pay as per the same variable charges above to the regional DSM pool. For *AGC MWh* computed for each 5-minute time block, 50 paise/kWh mark-up is being paid to power plant from regional DSM pool for both positive *AGC MWh* and negative *AGC MWh*. Same is depicted in Figure-9.

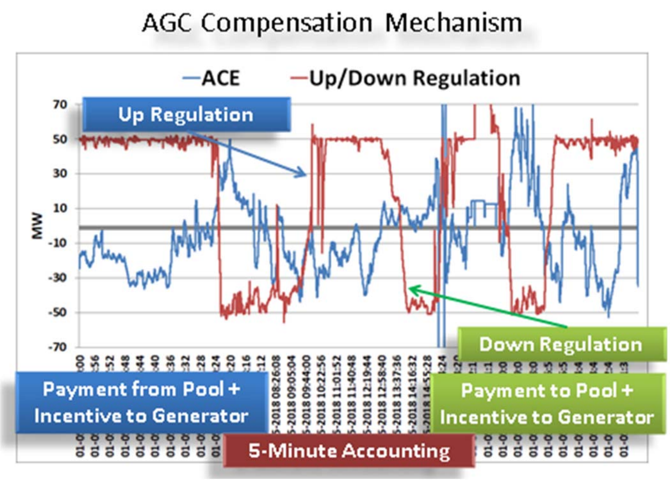

Figure-9: Payment mechanism for secondary control services

The markup of 50 paise/kWh was arrived at considering the half yearly feedback on Ancillary Services submitted to CERC [10]. Based on the experience with the implementation of Ancillary Services, it was observed that the generators participating in the Ancillary Services were retaining approximately 50 paise/kWh as incentive on an average after all payments as per the Ancillary Service regulations [11]. The secondary control energy account is prepared by the Regional Power Committee (RPC) on weekly basis along with Deviation Settlement Mechanism (DSM) Account and the Reserve Regulation Ancillary Services (RRAS) account. There are no opportunity charges payable to the secondary control generators as only the unused power reserves are being used for AGC.

IV. Implementation Plan for Secondary Frequency Control

A detailed plan was submitted to CERC by POSOCO in July'17 for the implementation of secondary frequency control. Secondary Control was recommended to be added as an Ancillary Service [12]. As per the detailed plan, all the ISGS generators whose tariff is regulated / adopted by CERC will be brought under secondary control in the first phase (Phase-I). It was observed from historical statistics that Northern Region (NR) and Western Region (WR) have considerable un requisitioned surplus on bar in their ISGS for 90% of the time. Substantial generation capacity addition is expected in Southern Region (SR) in the near future. To improve the availability of Reserves all Regional Entity generating stations scheduled by RLDCs over and above the phase-I power stations are proposed to be brought under secondary control in phase-II.

Considering the excellent controllability of power electronic devices and the nominal cost of the AGC setup, RE resources like wind and solar also might be wired for AGC. This would be useful for regulation in cases of extreme dispatch scenarios when system runs out of secondary reserves and/or emergencies if RE is to be curtailed. Tehri Pumped storage plant may also be operational by 2019 and it can also be included in the AGC project. In case of the generators which are part merchant and part regulated in India, to participate in the secondary control process, it was recommended that they shall share their Declared Capability and total schedule like other ISGS generators on a day ahead basis. Subsequent revisions in the same must also be shared with RLDCs. The generating units should have working control systems for turbine, boiler and governor to participate in the present AGC mechanism. Governor response plots/graphs of past incidents have to be submitted to RLDC as a proof. The existing communication backbone from NLDC/RLDC to the nearest wideband node has to be made available through coordination with Central Transmission Utility (CTU). IEC104 protocol will be used for two way communication from RLDC/NLDC to the plant unit control system in the AGC project. Data is being transferred till date through IEC 101 protocol to RLDC/NLDC from the field. Cyber Security will be ascertained through appropriate router configurations, firewalls and antivirus software.

With regard to AGC at state level, report of CERC Expert Group [2] suggests that AGC at the intra state level, particularly for large and renewable rich states, can be implemented in line with directions by the State Electricity Regulatory Commissions (SERCs). Forum of Regulators approved SAMAST report [13] for intra-state accounting and settlement system. A robust metering, accounting and settlement system is a must to implement any ancillary service. Investment for the envisaged implementation of AGC is minor considering the impact AGC shall have on frequency and grid security of Indian power system. The total cost of the proposed implementation is comparable to $1/10^{th}$ (one tenth) of the indicative cost of a 765 kV double circuit transmission line of 300 km length. Secondary control is suggested to be a fast response Ancillary Service, which will become an additional revenue stream for the conventional generators after large scale penetration of renewables.

After successful testing and implementation, this technology is planned to be spread across India for around 100 power generation plants. A total of around 65000 MW is envisaged to be brought under AGC. The full scale project, planned by 2022, shall enable efficiency and grid security in the India power system, making it ready to handle the 175 GW of renewables targeted by 2022. It is felt that even if the secondary frequency control service is procured from the market at a later date, the generators need to be ready with the necessary infrastructure. NLDC SCADA upgradation started from Oct'17 and is scheduled to be completed by mid-2019. AGC integration work involving software modelling, hardware and communication work also has to be done in parallel. NLDC AGC set up by 2021-22 is envisaged to be capable of sending and receiving AGC signals to all the Regional Entity generating stations to start with, for the first time in India.

V. Conclusion

All the frequency control strategies should be given equal importance. Successful implementation of secondary frequency control in India requires several resources. Software and hardware at plant and load dispatch center are a must. A strong metering, accounting and settlement system is essential supported by regulations. Incentive for participating in secondary frequency control is recommended for gathering power reserves. Lastly, regulatory support for all the above activities enables hassle free implementation and operation. Different agencies are involved in the full project, which makes the implementation of secondary control in India unique.

Acknowledgment

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References

[1] Growth of Electricity Sector in India from 1947-2017, Central Electricity Authority, May 2017. [online] http://www.cea.nic.in/reports/others/planning/pdm/growth_2017.pdf

[2] Report of CERC Expert Group to review and suggest measures for bringing power system operation closer to National Reference Frequency (Volume-I). [online] http://cercind.gov.in/2018/Reports/50%20Hz_Committee1.pdf

[3] N. Jaleeli, L. S. VanSlyck, D. N. Ewart, L. H. Fink and A. G. Hoffmann, "Understanding automatic generation control," in IEEE Transactions on Power Systems, vol. 7, no. 3, pp. 1106-1122, Aug. 1992.

[4] Central Electricity Regulatory Commission, Report of the Committee On Spinning Reserve, 17th September, 2015. [online] http://www.cercind.gov.in/2015/orders/Annexure-%20SpinningReseves.pdf

[5] CERC order on Roadmap to operationalise Reserves in the country, October, 2015. [online] http://www.cercind.gov.in/2015/orders/SO_11.pdf

[6] IEEE Task Force Report. 2017. "Measurement, Monitoring, and Reliability Issues Related to Primary Governing Frequency Response," Technical Report PES-R-24, October.

[7] P. Kundur, Power System Stability and Control, Chapter 11, McGraw-Hill, New York, 1994.

[8] CERC order in the matter of Automatic Generation Control (AGC) pilot project. [online] http://www.cercind.gov.in/2017/orders/79_rc.pdf

[9] Central Electricity Regulatory Commission (Deviation Settlement Mechanism and related matters) Regulations, 2014. [online] http://www.cercind.gov.in/2014/regulation/noti132.pdf

[10] Reserve Regulation Ancillary Services (RRAS) Implementation in Indian Grid - Half Year Analysis and Feedback by POSOCO, November, 2016. [online] https://posoco.in/download/half-year-feedback-to-cerc/?wpdmdl=8916

[11] Detailed Procedure For Ancillary Services Operations, POSOCO, March 2016. [online] http://cercind.gov.in/2015/regulation/DAS.pdf

[12] Detailed Modus Operandi on operationalization of Spinning Reserves by POSOCO, July 2017. [online] https://posoco.in/download/detailed-modus-operandi-on-operationalization-of-spinning-reserves/?wpdmdl=13461

[13] Forum of Regulators 'SAMAST' Report. [online] http://www.forumofregulators.gov.in/Data/WhatsNew/SAMAST.pdf