Implementation of Automatic Generation Control at Hydro Power Plants in Southern India

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***Abstract*— Power system reliability under increased RE penetration is of significant concern to system operators. As of now in India, the regulations on tertiary reserve market exist, and are followed by Regional Load Dispatch Centres (RLDCs). Considering the future growth of RE to meet the Government of India (GoI) targets, regulation reserves have been identified as necessary to compensate variations due to the load and RE in the seconds timeframe. Under the pilot, the AGC facilities are planned to implement at two hydro power plants: Sharavathi hydro power plant (10x103.5 MW) and Varahi Hydro power plant (4x115 MW). The existing AGC module in Energy Management System (EMS) at State Load Dispatch Center (SLDC) is planned to configure to generate the AGC signals for participated hydro units. The paper will analyse the role of ancillary services with focus on secondary control using Automatic Generation Control (AGC).**

Keywords- Automatic Generation Control, Ancillary services, Energy Management System, Hydro power plants

I. INTRODUCTION

USAID/India‘s Greening the Grid (GTG) – Renewable Integration and Sustainable Energy (RISE) initiative (referred to as ―RISE” hereafter), focuses primarily on implementing a set of innovative pilots, which are multi-implementer work programs aimed at testing and evaluating building blocks to improve the integration of high levels of renewable energy (RE) in India‘s state and national power grids. AGC pilot discussed in this paper is one among the pilots proposed under RISE initiative.

The rapid expansion of renewable energy sources gives rise to a number of challenges for power system operators and electricity market participants. The important challenges include: scheduling, system control and dispatch; reactive power supply and voltage control; regulation and frequency response reserve; energy imbalance service; operating synchronized reserve; and operating supplemental reserve.

Karnataka is the largest renewables integrated state in India as on date with 17913 MW of renewables (Wind: 4748 MW, Solar: 6100 MW, Large Hydro: 3670 MW, Mini Hydro & Others: 2675 MW) on the grid. Due to this high renewables in the grid, the ramp variations due to intermittent nature of renewables are reported and system operation is getting more complex. Hence the objective of the AGC pilot is to support the system operation during high ramping of renewables by enabling secondary reserves by AGC in the system operation. At present most of the power plants in India are enabled for one way communication where actual generation of the generation units is communicated to SLDC (State Load Dispatch Center). However power plants are not enabled to receive any signals from SLDC and respond accordingly.

Under this pilot, communication network are planned to enhance at plant side with two way communication facilities to receive the AGC signals from SLDC and observe the response of hydro units as per the AGC signals. The pilot is initiated in the year 2018 and will be in operation for 3 months from Sep 2019 to Nov 2019. The outcomes of the pilot will be analysed to develop the frame work guidelines for ancillary market mechanism focused on secondary reserves in India. This will enable power plants to participate in the secondary reserves as per the market pricing signals.

II. METHODOLOGY

Power system operators are more concerned to ensure system reliability in addition to provide the energy to end-consumers considering the high levels of Renewable Energy (RE) penetration in future. To achieve this, system operators need to maintain an array of ancillary services to ensure it is always possible to balance the supply and demand for energy in real-time.

A subset of these ancillary services is commonly categorized as [1];

- Regulation,
- Spinning, and
- Non-spinning Reserves

Regulation reserves, also referred as secondary reserves, are used to constantly and automatically balance small fluctuations in supply and demand in real time. Generation units that are providing regulation service must be able to respond to Automatic Generation Control (AGC) signals from the system operator and change their output accordingly on very short time scales, typically 2 to 5 seconds.

Operating Reserves are maintained to provide additional generation capacity in the event of load increase or other supply side resources reduce their output or are taken offline. The reserves are typically segmented into two categories, 1) Spinning or synchronized reserves that are provided by generation units that are actively generating and can increase or decrease their output, 2) Non-spinning or non-synchronized Reserves that are provided by generation resources that are not actively generating, but are able to start up and provide generation within a specified timeframe. Operating reserves typically have response times on the order of 10 to 30 minutes and can similarly be provided by demand-side resources that can reduce their load.

In other words, system reserves are the most important services among all ancillary services when RE penetration is high in the system. System reserves include:

- Primary reserves
- Secondary reserves
- Tertiary reserves

The distribution of reserves based on the event type is presented in Figure 1. Large disturbances like large generation outage or high capacity transmission line outage are refereed as ‗event‘. Any disturbance due to load variations and renewable variations are referred as ‗non-event‘. The response time of various reserves are presented in Figure 2.

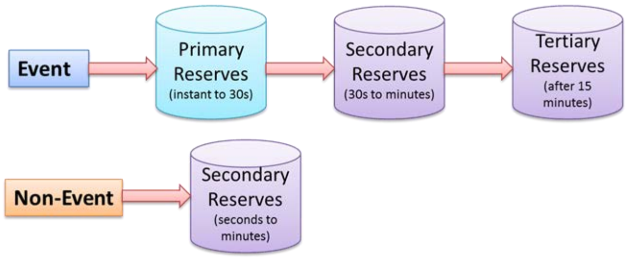

Figure 1: Event based reserves

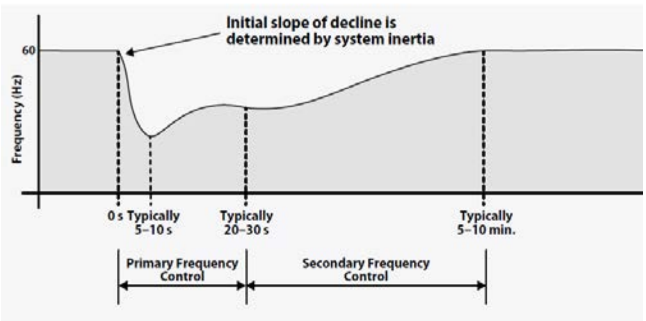

Figure 2: System reserves and their operating times [2]

Two methods can be adopted for system reserve calculation,

- Deterministic and Probabilistic calculations
- Simulation method using power system transient/ dynamic models

The convergence of above two methods will determine the required reserves.

A. Deterministic and Probabilistic calculations

Determination of primary and secondary reserves based on the deterministic analysis is presented in Figure 3.

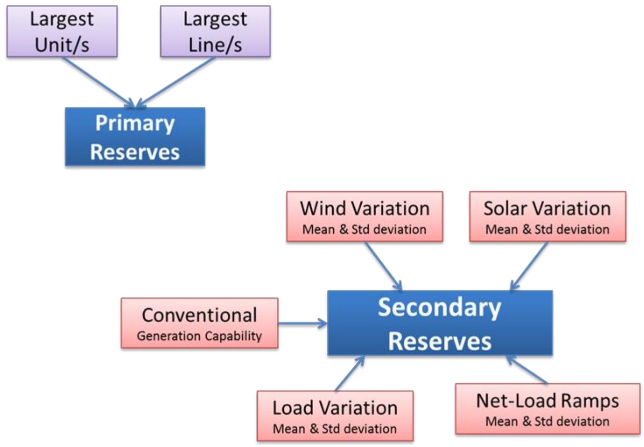

Figure 3: Parameters to be considered for calculation of reserves

B. Simulation method

Calculation of primary and secondary (AGC) reserves using simulation models is presented in Figure 4 and Figure 5.

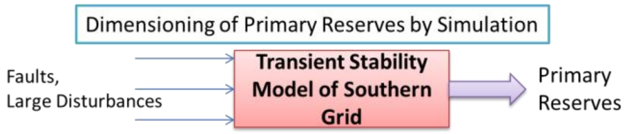

Figure 4: Transient model for primary reserves calculation

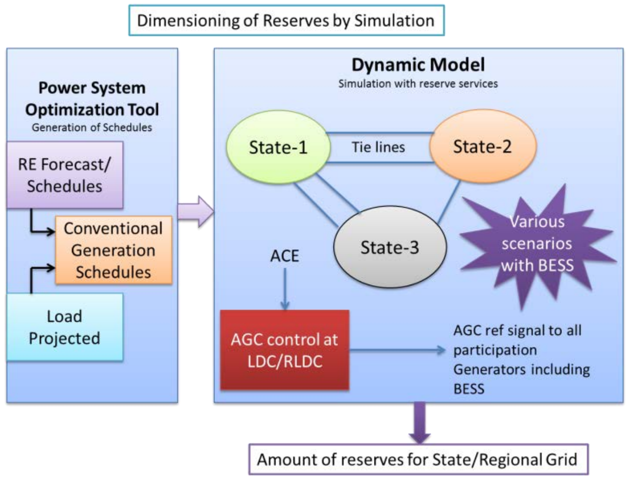

Figure 5: Transient model for secondary reserves calculation

III. Simulation Studies

In a modern AGC system, three inputs are received through telemetry channels, i.e. power output of each committed unit, power flow over tie-line and system frequency. The AGC logic is the combination of ACE logic, generation allocation logic and unit control logic. The ACE and unit error outputs are summed and passed through an integrator with gain K. The value of this gain K must be chosen wisely, as it may cause the system to diverge instead of attaining the desired set point of tie-line power or frequency [5]. The output of the integrator is passed to the generation allocation logic whose output is then passed to the unit control logic for computation of unit error, based on which a *raise* or *lower* request will be sent through telemetry channels to the governor to properly control the valves or gates. The AGC block diagram is presented in Figure 6.

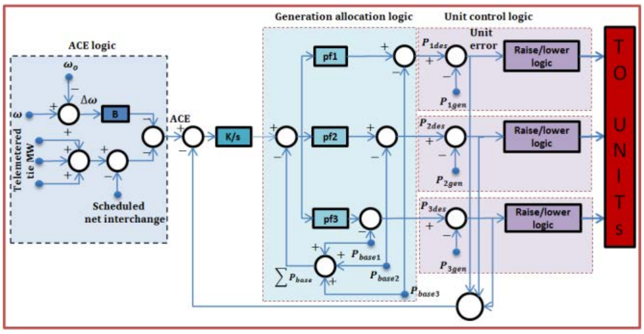

Figure 6: Block diagram of AGC

In this paper, a system with four generating units i.e. Unit A, B, C and D has been considered, with Plant-A: 1720MW (7×210MW + 1×250MW), Plant-B: 1700MW (2×500MW + 1×700MW), Plant-C: 1035MW and Plant-D: 460MW.

The comprehensive power system analysis package ‗MiPower' has been used to model the network, including the AGC control system block, and to perform load flow and dynamic studies as shown in Figure 7.

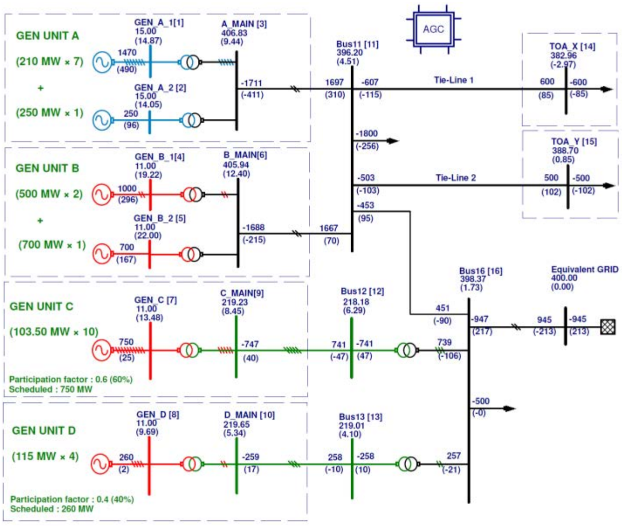

Figure 7: Typical two area system simulated in MiPower [6]

The simulation study is performed by increasing the load at Bus 16 from 500 MW and 900 MW and the frequency response of the grid is plotted in Figure 8.

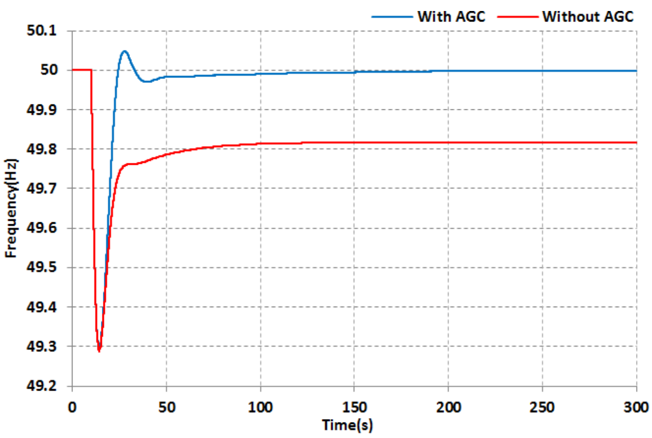

Figure 8: Frequency response with and without AGC under loading less than maximum generation limit

From Figure 8, it can be observed that the frequency will starts falling and stop at 49.3 Hz due to system inertial offered by rotating machines. Later, the frequency is recovered to 49.8 HZ and stabilizes with application of primary reserves. Please note that primary control will stabilizes the grid frequency but not at 50 Hz. Hence the application of secondary control will bring the frequency back to 50 Hz. Hence by simulating various scenarios, one can determine the required primary and secondary reserves for the system using simulation studies. The benefits with Battery Energy Storage System (BESS) in ancillary services domain can also be evaluated with the proposed methodology.

To understand the response of participated plants for AGC control, the response of unit-C and Unit-D ((hydro) are plotted in Figure 9.

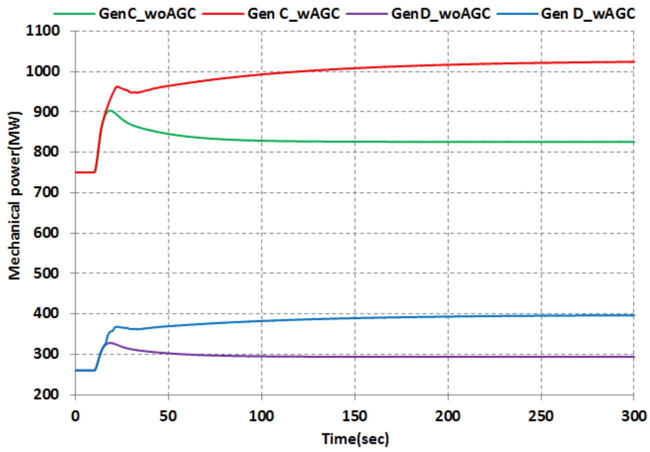

Figure 9: Mechanical input to of the unit C and D under loading less than the maximum generation limit

IV. PILOT IMPLEMENTATION

AGC pilot is implementing in two stages in Karnataka. In first stage the existing AGC module in EMS system at SLDC will be configured to generate AGC control signals. In second stage the facilities at hydro power plants will be enhanced to implement AGC control.

A. *AGC Pilot Implementation at SLDC*

The pilot on AGC for secondary control shall be implemented with time interval of 4 seconds with configurable time intervals from 2 to 12 seconds. At initial state, the time interval can be more, to test the AGC operation and system operators as well as generation unit personnel will be trained to bring it down to 4 seconds time interval later.

In general, AGC signals will be generated by observing the deviation in frequency and tie-line flows at balancing authorities. Balancing authority (RLDC) generates an ―Area Control Error" (ACE) signal,

$$ACE = -\Delta P_{tie} - B\Delta f$$

where B is the frequency bias factor in MW/Hz, ΔP_{tie} is change in tie line flow, Δf is change in frequency.

The ACE will then be passed to the subsequent section of the control system, which will direct the governors of the various participating generators to take the necessary actions for increasing or decreasing generation [3].

However, for the present AGC system at SLDC, Karnataka, ACE signals are available from SRLDC (Southern Regional Load Dispatch Center), hence the calculation of ACE considering tie-lie power flows and/or frequency may not be required. The available ACE signal can be directly used in AGC module available as part of EMS application.

The control mechanism of AGC at SLDC is presented in Figure 10. Considering the availability of ACE, ACE calculation portion can be by-passed and AGC module can receive the ACE signal directly. Once ACE signal is available, the normal AGC control blocks have to be processed to generate AGC set point signals. The participation factors are to be determined to limit the contribution from participated hydro plants instead of responding to ACE of the State.

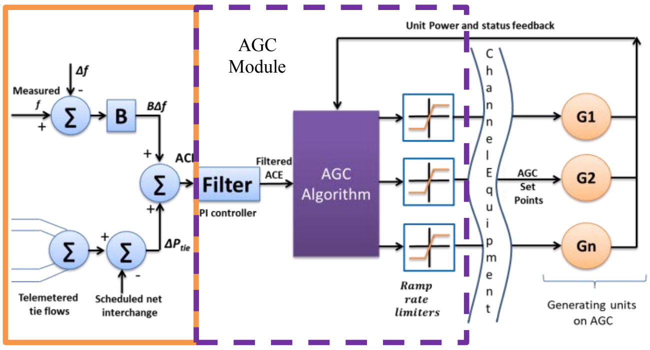

Figure 10: AGC configuration during pilot [4]

AGC module at SLDC will be configured to operate in two modes based on the operating mechanism enabled at hydro power plants.

1 Unit control mode
2 Plant control mode

Either in unit control or plant control mode, SLDC can enable/disable the number of units/plants to be participated in AGC control.

In unit control mode, the following aspects to be configured in the AGC module at SLDC,

1 ACE signal available at SLDC to be mapped with AGC module as input parameter.
2 All AGC enabled units (here Sharavathi and Varahi hydro units) shall be configured in AGC module.
3 All parameters required to configure unit characteristics in AGC modules like unit capacity, ramp rates etc. shall be provided by KPCL. PRDC will coordinate to obtain these values.
4 Real time generation of each unit shall be considered in the AGC module as a feedback signal while generating the AGC set points to respective units.
5 The AGC set point signals have to be generated after processing of ramp rate limiters wherein given participation factors are configured for the units based on the generation schedules. Generation schedules with 15 minute intervals shall be provided manually by SLDC for every day. However, the options to configure both participation factor and generation schedules are to be cross verified as per the AGC module of ABB.
6 The processed set point signals from AGC module will be transferred to the respective units considering their ramp and other characteristics in AGC module.
7 Once the AGC signals are available at AGC module, SLDC will take care of communication of AGC set point signals to plant.
8 As part of this pilot, 10 units of Sharavathi and 4 units of Varahi will be configured in the AGC module.
9 AGC module shall have the provision to enable and disable the configured units from AGC operation. No AGC set point signal will be generated for disabled units.
10 AGC module shall have the provision to configure the AGC set point frequency from 2 seconds to 12 seconds. If user configures 4 seconds, AGC signals to be generated for every 4 seconds with the above procedure.

When hydro plants are operating in plant mode operation, AGC module at SLDC will also generate the signals at plant level similar to the above procedure but change in unit/plant configuration.

1 Plant characteristics of Sharavathi and Varahi will be modeled as normal units.
2 All the input parameters to model these two plants as virtual units will be provided by KPCL/PRDC.
3 The procedure defined in unit model AGC will be followed for all activities.

B. AGC Pilot Implementation atHydro plants

B.1 Selection of Generation Plants for AGC pilot:

RISE team had a series of meetings with KPTCL (Karnataka Power Transmission Corporation Ltd) and KPCL (Karnataka Power Corporation Ltd) on selection of generation units in Karnataka for AGC pilot. The following points are considered for selection of generation units.

1. Water Availability: It is essential to meet the main criteria for any generation units as generation unit need to operate above or below limits of operating point. Hence storage based hydro plants are most suitable for AGC operation as compared to run of river plants or irrigation based hydro units.

2. Plant Operation: The other important aspect is control of generation output. The main purpose of multipurpose hydro plants is for irrigation or drinking water supply and electric power generation will be generally a secondary product. Hence multipurpose hydro plants not selected for this pilot.

Hence considering the above two options, three hydro plants in Karnataka are identified for AGC pilot.

- Sharavathi hydro power plant (10x103.5 MW)
- Varahi hydro power plant (4x115 MW)
- Nagjhari hydro power plant (5x150+1x135 MW)

3 Turbine Technologies: Turbine technology is an important technical aspect for AGC operation as the turbine needs to vary its output as per the frequent AGC signal from SLDC. Pelton turbines can be operated with more bandwidth between its maximum and minimum operating points and same is not possible with Francis turbines. Sharavathi and Varahi hydro plants are Pelton type and Nagjhari is Francis type turbine.

Hence Sharavathi and Varahi hydro plants are short listed for AGC pilot operation. The selection process is presented in Table 1.

TABLE 1: SELECTION OF HYDRO POWER PLANT FOR AGC PILOT

S. No	Hydro Plant Name	Installed Capacity (MW)	Reservoir type	Turbine type	AGC control (MW)	Selected Yes/No	Remarks
1	Sharavathi	10x130.5	Dam based	Pelton	Approx. 100 MW	Yes	Selected for pilot
2	Varahi	4x115	Dam based	Pelton	Approx. 100 MW	Yes	Selected for pilot
3	Nagjhari	5x150+ 1x135	Dam based	Francis	---	No	Not selected

Presently, at Sharavathi and Varahi hydro power plants, operators are changing the generator output set points manually as per the information from SLDC, Bangalore over tele-communication. The following are facilities are envisaged to implement the AGC facilities at hydro power plants based on the site visits to hydro plants.

B.2 AGC Facilities at Sharavathi hydro power plant

Generation parameters of unit details such as real time generation output in MW etc., are communicating to SLDC. Automation of generation output set points from LDC center, Bengaluru needs to be facilitated from the existing AGC module (software) at LDC.

The requirement for AGC implementation at Sharavathi and Varahi hydro power plants are presented in Figure 11 and Figure 12.

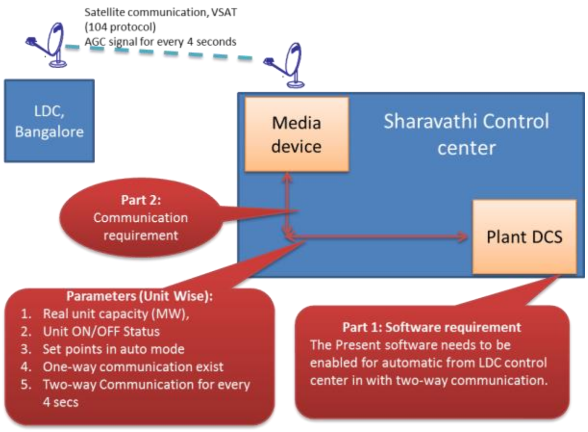

Figure 11: Requirements at Sharavathi hydro power plant

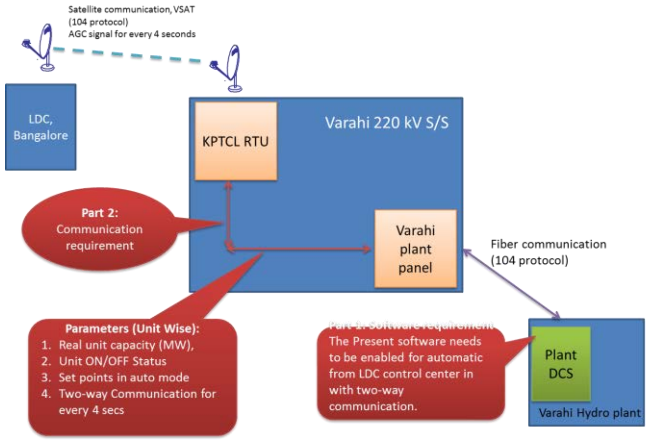

Figure 12: Requirements at Sharavathi hydro power plant

The following facilities need to be provided at hydro power plants to operate the plant in AGC operation.

1. To enable the set point control of hydro unit generation from manual control to auto control mechanism.
2. The auto set point control shall be unit wise or plant wise as per the plant operator selection
3. The set point change shall be implemented in existing DCS system of Sharavathi power plant.
4. The plant DCS system shall be designed to receive the auto signals about set point changes from SLDC with frequency of 4 seconds
5. The plant DCS system shall provide the signals like unit ON/OFF status, operating capacity of each unit on real time to SLDC
6. Configuration of two way communication between Plant and SLDC
7. After configuration of communication channels, plant shall receive the SLDC set point signals and forward to plant DCS. Plant DCS shall operate the hydro plant as per the set point signals received from LDC centre.

V. CONCLUSIONS

From the methodology and simulation results presented, it is demonstrated that the reserves in the system namely primary and secondary reserves can be calculated for state or regional system by using dynamic simulation studies. As the reserve markets are at initial stage in India, Utilities can adopt the presented methodology to determine the required reserves and enable the reserves in the grid to operate the grid with high renewable generation.

Under the AGC pilot, the detailed requirements at power plants and Load Dispatch center are presented. This will help the utilities to draft the technical requirements to implement AGC facilities. At present most of the power plants in India are enabled for one way communication where actual generation of the generation units is communicated to SLDC. Hence, two communication requirements are highlighted to enable AGC operation.

The outcomes of the pilot will be analysed to develop the frame work guidelines for ancillary markets focused on secondary reserves in India. This will enable power plants to participate in the secondary reserves as per the market pricing signals.

The project team also working to enable AGC operation at NTPC's 250 MW solar power plant located in NP Kunta, Andhra Pradesh.

ACKNOWLEDGMENT

The authors would like to thank United States Agency for International Development (USAID) for the funding and support in realization of this work. The authors are also grateful to Karnataka Power Corporation Ltd) and Karnataka Power Transmission Corporation Ltd who operates SLDC, for their invaluable support in providing technical data required for this work.

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