Enabling Fast Response Ancillary Services Using Pumped Storage Hydro Power Projects

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Abstract — Development of Pumped Storage Hydro (PSH) Power Plants is not up to the mark due to various reasons such as No conducive Regulatory framework to access the economic viability of PSH project, No regulatory framework to compensate the PSH for providing ancillary services, No focused efforts by appropriate authorities to promote development of PSH by addressing the technical and environmental issues in development of PSH. As regulatory framework is not conducive, private investment is not being attracted for development of PSH besides having huge potential. If conducive regulatory environment is created, PSH could be game changer as an ideal Source for ancillary services. This Paper deals with the Technical, Commercial and Regulatory aspects of PSH towards its unique offerings in ancillary services market.

Keywords: Pumped storage hydro, ancillary services, regulations

I. Introduction

Indian economy is growing at a very fast rate over the last decade as the economic growth is likely to accelerate in the upcoming years. Energy is the lynchpin of growth in any economy. With Indian economy expected to grow at over 8% annually, energy security of the nation is of prime importance.

In this context it is important to meet the ever-increasing demand of energy which is the driver of the economy. The onus of carving out a path for meeting the ever-increasing energy demand lies on the planners and policy makers. In a bid to plan for catering to the rising energy needs it is vital to strike a balance between energy prices and environmental sustainability. It is of utmost importance to embrace sustainable, reliable and innovative forms of energy to minimize the damages caused to the environment. India faces key challenges of (a) ensuring availability of 24/7electricity to all and (b) progressively moving towards adoption of clean and low-carbon energy systems. It is therefore, advocated to adopt cleaner forms of energy to cater to the electricity demand.

Economies across the world have shown propensity toward increasing the proportion of cleaner forms of energy in their energy mix. India too has committed to enhance its share of installed capacity of renewable sources within overall energy capacity mix to 40% by 2030. The installed RE capacity in India has grown from a mere 0.34 gigawatt (GW) in 1995 to over 42 GW at present, registering more than 100-fold growth during this period. Fueled by Paris Agreement commitments, the Government of India has set an ambitious target of achieving 175 GW of renewable energy capacity by 2022, with a mix of 100 GW from solar, 60 GW from wind, 10 GW from biomass and 5 GW from small hydropower. The addition in wind and solar power capacity from the incumbent levels of 5 GW and 25 GW to the targeted levels is a critical challenge toward achieving the holistic targets and minimizing carbon emissions.

At present, the grid interactive wind energy constitutes around 45% and solar energy constitutes around 34% of the total installed renewable energy capacity in India. The capacity additions to wind and solar energy projects form a significant part of the target with the envisaged capacity of 160 GW from the present capacity of 65 GW in a mere 3 years of time with a CAGR requirement of 35%. Hence, it is important to facilitate the augmentation of wind and solar generation in the country.

The wind farms in India are mostly located in the states that are rich in wind and solar resources, viz. Tamil Nadu (TN), Karnataka, Maharashtra, Gujarat and Rajasthan. Considering the high variability and unpredictability of generation from renewable, efficient and economical grid operation becomes one of the critical challenges in India‘s power system.

The generation pattern from renewable sources is not uniform resulting in intermittency in generation. With the present practice of state boundary as area control centre, the state grid can accommodate small amounts of intermittent electricity generation. However, large-scale penetration requires rebalancing the different elements of electricity system: generation, transmission, demand management, and regulation. At present, the states are using hydro resources, limited gas-based generation with peaking capacity, unscheduled interchange mechanism and load management as tools to deal with variable renewable generation in renewable rich states. The mitigation of intermittency must address both variability and uncertainty. A variable, but predictable resource can be managed with careful day-ahead scheduling.

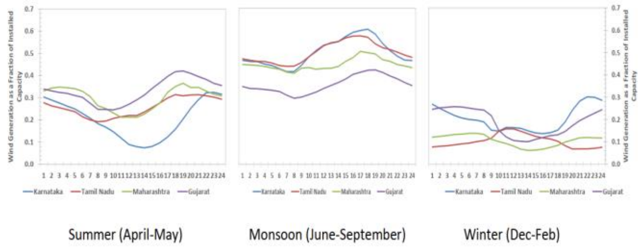


Figure 1: Average daily wind generation curve in key states

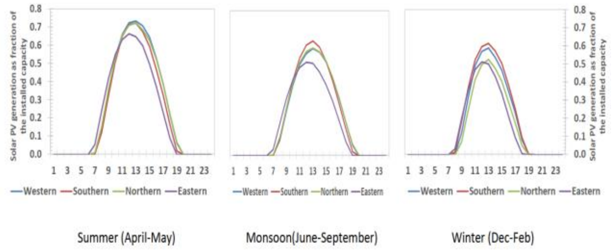


Figure 2: Average daily solar generation curve in India

(Source: LBNL Publication)

In August 2014, the Central Commission promulgated amendments to Indian Grid Code Regulations (IEGC), 2010, Deviation Settlement Mechanism Regulations and introduced Forecasting and Scheduling mechanism for inter-state transactions. Since majority of the wind generators are located at the state level, the Forum of Regulators (FOR) come up with the model forecasting and Scheduling and Deviation Settlement Regulations for the States in November,2015. It is advocated that a robust forecasting and scheduling mechanism, deviation settlement mechanism, imbalance handling and settlement mechanism, and metering and generator payment mechanism be formulated at the state level. The above will entail 100% metering, a clear institutional framework and establishment of robust telemetry system to increase the visibility of the wind generation at the SLDCs.

To increase the flexibility in operation of Thermal Power Plants, Central Commission has reduced the technical minimum to 55% as against 70% for interstate generators and specified compensation mechanism towards the increased use of secondary oil consumption. State Regulators are also coming up with similar directives of lowering technical minimum for Intra-State Generators.

Further, the Central Commission revised its Deviation Settlement Mechanism (DSM) to introduce stringent provisions like volume limits for Buyers and Sellers, Zero Crossing or Sign Change in specific time blocks and also tightened the frequency band in the revised range of 49.9Hz to 50.05Hz by amending the provisions of the grid code to increase the grid stability. State Regulators are also introducing similar provisions within State to improve the intra-state grid stability.

Stringent conditions of regional Deviation Settlement Mechanism have increased complexity and financial burden on the states. To tackle such challenges System Operators requires flexibility in the generation sources to maintain the load-generation balance and deviation within limits.

II. Need of Ancillary Services

Ms. Sally Hunt in her famous book "Making Competition Works in Electricity" defines the 4 Pillars of the Electrical Market Design namely, Scheduling and despatch, congestion management, imbalance handling and ancillary services. [1] These pillars are essential to maintain security and reliability of power system which also helps in developing market in electricity sector.

Ancillary Services is one of the most vital pillars of 'Electricity Market'. Ancillary services provide necessary support to the power system for maintaining system reliability with the unsurpassed system efficiency. Ancillary services, being one of the techniques adopted by many countries to maintain the reliability of the grid and avoid disturbance in power system operation, would play a vital role for such integration. Because of its successful operation in developed countries, adopting such techniques and their market at "larger level" would be next Paradigm shift in Indian Electricity Sector.

III. Types of Ancillary Services

Ancillary Services are categorized in 3 services in current system operation as below:

1. Frequency control ancillary services
2. Network control ancillary services
   i) Voltage control ancillary services
   ii) Power flow control ancillary services
3. System restart (black start) ancillary services

1. Frequency control ancillary services

Frequency control refers to the need to ensure that the grid frequency remains within a specific range of the nominal frequency. Mismatch between electricity generation and demand causes variations in frequency, so control services are required to bring the frequency back to its nominal value and ensure it does not vary out of range. Three levels of Frequency Control are generally used to maintain the balance between generation and load i.e. Primary Frequency Control, Secondary Frequency Control, Tertiary Frequency Control. Three levels differ as per their time of response to a fluctuation and the methodology adopted to realize the fundamental operating philosophy of maintaining reliability and overall economy.

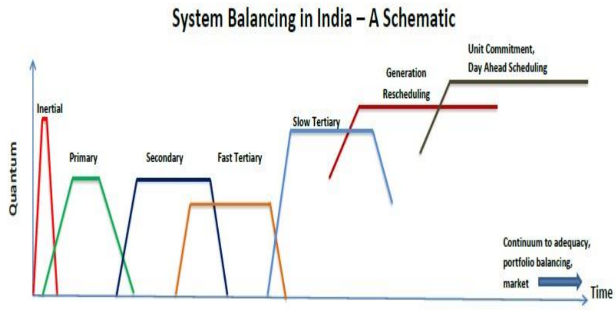
2. Network control ancillary services

a) Voltage support ancillary services: It describes the ability of a system to provide near constant voltage over a wide range of load condition. Reactive control is an important tool for voltage regulation and for optimizing available power utilization.

b) Power flow control ancillary services: This refers to injection/withdrawal of reactive power to maintain system voltage within a prescribed range. Voltage fluctuations are a result of the changes in the loading condition. When the line is lightly loaded transmission lines generate more reactive power and hence voltage increases and when it is heavily loaded then due to inductive effect it consumes more of reactive power and so voltage drops.

3. System restart (black start) ancillary services

This refers to services used to restore the system after a full or partial blackout. Black start is a vital but inexpensive service. Its cost is primarily the capital cost of the equipment used to start the unit, the cost of the operators, the routine maintenance and testing of equipment and the cost of fuel when the service is required. The CERC Report for categorizes the Ancillary Services as shown in the figure 3 below: [2]



Response → Attribute ↓	Inertial	Primary	Secondary	Fast Tertiary	Slow Tertiary	Generation Rescheduling	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	Yet to start	Yet to start	Existing	Existing	Existing

Figure 3. Different types of Ancillary Services available in India [2]

IV. Regulatory Development

The Central Commission has introduced Ancillary Services at regional level to increase the flexibility in the system operation and maintain system reliability. The Central Commission defines the Ancillary Services as *"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;"* [3]

The Central Commission has notified Ancillary Services operations regulations in 2015. The objective of these regulations is to restore the frequency at desired level and to relieve the congestion in the transmission network. MoP vide revised Tariff Policy also insisted on introduction of Ancillary Services to support the power system or grid operation for maintaining power quality, reliability and security of the grid. As per the provision of the CERC Ancillary Services framework, POSOCO is the nodal agency for implementation of the Ancillary Services at the regional level. The Central Commission has also approved the procedure for implementation of Ancillary Services in April 2016. Pricing mechanism set under these regulations is given below:

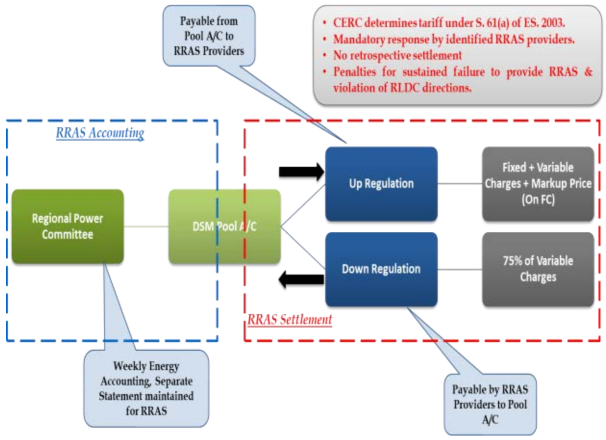


Figure 4. Pricing Mechanism of Ancillary Service Operation

POSOCO has set procedure to operate Ancillary services at Regional Level [4]. Existing Ancillary Service framework is applicable only to Inter-State thermal power plants for which tariff is regulated by central commission. As per the compensation mechanism specified under Ancillary Services Regulations, the "Reserves Regulation Ancillary Services Provider (RRAS Provider) shall be paid at their fixed and variable charges, with markup on fixed cost, as decided by the Commission through a separate order from time to time (presently 50 paisa/kWh) in case of Regulation Up services for the quantum of RRAS scheduled, from the Regional Deviation Pool Account Fund. For Regulation Down service, the RRAS Provider(s) shall pay back 75% of the variable charges corresponding to the quantum of Regulation Down services scheduled, to the Regional Deviation Pool Account Fund.

After implementation of RRAS in system, POSOCO prepared half yearly report on the experience, performance of system and improvements in system performance from which it has been identified that ancillary services are helpful in maintaining grid stability and reliability and it has improved overall system frequency in well manner. [5] After successful implementation of ancillary services mechanism from coal and gas-based power plants, POSOCO is taking initiative to introduce Hydro power plants in ancillary services operation. POSOCO in its report has mentioned that, run of the river and pondage based hydro stations have constraints/limitations to draw on or cushion in reservoir capacity to conserve water. However, reservoir based hydro power plants can also provide Ancillary Services. With Tehri Pumped Storage plant (PSP) expected in the near future, utilization of PSP under Ancillary Services also needs to be formulated suitably to capture both 'generating' and 'pumping' modes of operation.

Further, POSOCO has presented how operation of hydro power plants as ancillary services will be beneficial. The Central Commission has suggested to run a pilot project for operation of hydro power plants as ancillary services. [6] Based on experience of pilot project, the Central Commission would take further steps. The present paper focuses on various features of Pumped Storage Hydro (PSH) suitable for offering Ancillary Services required for large scale RE integration in the grid.

V. OPERATION OF PSH AND VARIABLE SPEED PSH

A. Principle of operation of PSH

PSH is a modified use of conventional hydropower technology to store and manage the electricity. As shown on Figure 5, PSH operates by exploiting the difference in height between two water reservoirs to store energy. Energy is stored by pumping water from the lower reservoir to the upper reservoir and is recovered by releasing the stored water from the upper reservoir. It is the most commonly used and most commercially viable large scale electricity storage technology and currently accounts for 99% of the total storage capacity globally.

In the generation mode, a conventional synchronous speed PSH can typically operate over a range of heads from about 65% to about 125% of the rated net head, where the rated net head is the head that generally corresponds to the head at which full power is achieved. The best efficiency point is always above the maximum operating head because of the necessary compromise between pumping and generating.

As the upper and lower reservoirs fluctuate during the course of a generating cycle, the head will be progressively reduced, and the amount of water to produce a given amount of power output will increase in response to this reduction in head and the associated reduction in the operating efficiency.

Similarly, a conventional synchronous speed PSH can typically operate over a range of flows down to about 50% of the rated discharge, where the rated discharge is the discharge that produces the power to match the generator rating at the rated head. Normally the unit would be designed so it produces the rated power output when the wicket gates are near or at 100% open. If the unit has been sized according to this rule, then the discharge would need to be curtailed to produce rated generator power at heads greater than the rated head. Operation of typical PSH in these modes is shown in figure 5.

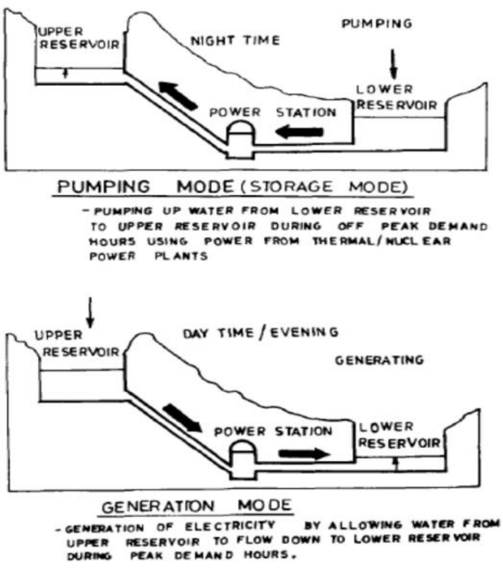


Figure 5: Operation of Typical PSH

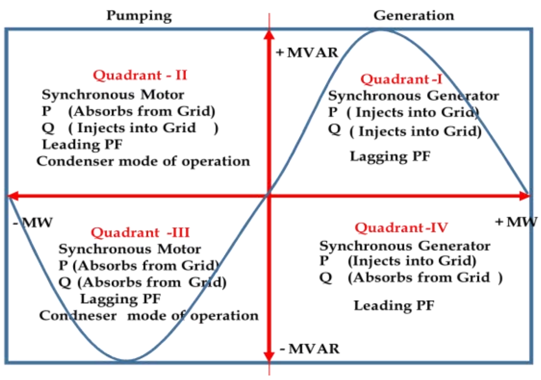
B. Variable Speed PSH

Typical PSH in pumping mode, are constrained and cannot adjust their pumping load requirements. Typically, it is operated at no load or full load. Further, operating efficiency of fixed speed PSH is not near to its maximum efficiency. To address these issues variable or adjustable speed PSH are introduced. A variable speed PSH project does not have this limitation and can be adjusted over a load range of 50 to 60% of rated pumping power. This would help to better integrate variable RE generation such as wind/solar generation. In the generation mode, the capabilities of an adjustable speed unit are quite similar to a single speed unit, except that the operating efficiency can be optimized by adjusting the speed for the prevailing head and desired power output. For example, with adjustable speed it would be possible to operate at the point of maximum turbine efficiency, which is normally at a head that is above the normal operating range for a fixed-speed pump-turbine.

Adjustable speed machines can provide frequency control in both generating and pumping modes. There are two control components. One is the turbine governor controlling the wicket gate position of the turbine and the other is the inverter controlling the rotor currents of the generator /motor. With these two control elements in turbine mode, two quantities can be controlled independently.

With an adjustable speed machine, the response rate is faster than that of a conventional unit under speed governor control. A PSH with adjustable speed generator/motors can use the rotating inertia of the machine and modulate instantaneous (short time) power fluctuations. However, for longer time fluctuations in the adjustable speed machine, a frequency governor (which controls rotor speed by way of excitation frequency and rotor current) is provided, in addition to a speed governor to control the wicket gates. Because rotor speed can be controlled by the cycloconverter exciter, the machine can change speed and modulate power output.

kinetic energy stored in the rotor (inertia) can be utilized in the event of load variations or short circuits by changing the rotor speed. Since the rotor speed can be changed by varying the frequency of the rotor currents (and not only by changing the turbine flow), response time is faster than for a conventional synchronous power generator. Typical four quadrant operation of PSH is shown in the figure below:



(Source: WRLDC workshop)

Figure 6: Typical four quadrant operation of PSH

VI. PSH AS ANCILLARY SERVICES

PSH can provide various services envisaged under ancillary services operation. PSH can adjust their output very quickly upwards or downwards having very high Ramp Up or Ramp Down rate. If the PSH is in pumping mode, it can offer incremental reserve by reducing the pumping power and thus reducing overall system load. Being in generating mode, PSH can offer decremental reserve by deactivating the turbine and thus absorbing the power surplus. Furthermore, PSH being in off-line mode can supply incremental non-spinning reserve within minutes by opening gates for water and starts operating in generating mode.

PSH serves the grid with wide range of services which can be considered as ancillary services. Some of the major services are summarized below:

i. **Peak shaving:** PSH can be used to meet the highest demands in short period of time with very high Ramp rate to the tune of 200 MW/Min

ii. **Load balancing:** Load leveling usually involves storing power during period of light loading (off peak hours) on the system and delivering it during periods of high demand.

iii. **Frequency regulation:** PSH contributes to maintain the frequency within the given margins by continuous modulation of active power. PSH can be operated in Pumping mode when frequency is higher than 50Hz which can help to bring down the frequency to 50 Hz whereas when frequency is lower than 50 Hz, PSH can be operated in generation mode to provide necessary load relief to the grid.

iv. **Back-up reserve, spinning reserve:** PSH can be operated as back up reserve or spinning reserve with its high ramping rate. PSH can be operated in either of the mode in case of sudden outage of any generator or sudden failure of any load in the grid.

v. **Quick start capability:** PSH generation could be set up in just a few minutes. It is much less than that of other types viz. gas turbines which takes 30 min to 1 hour, or a few hours of the steam generation.

vi. **Black start capability:** If upper reservoir of PSH is full and PSH is ready for generation cycle, it can be used for energizing the grid in case of cascade tripping.

vii. **Voltage control:** As for frequency, voltages must be kept within design tolerances. Regulating voltage involves balancing supply and demand of power, although in this case, it involves balancing reactive power, measured as VARs (Volt-Ampere Reactive power), rather than real power. An imbalance in the supply and demand of VARs causes voltage to rise or drop across the power system. In both pumping and generation modes, voltage control is performed through the voltage regulator which is part of the excitation system. The machine voltage is adjusted by changing the field current via the excitation system. PSH can be operated in lead or lag mode to meet the requirement of reactive power of the grid. PSH can be also operated in Synchronous condenser mode to improve the system power factor.

With above various benefits of the PSH, it can be concluded that, conventional as well as variable speed PSH are best suitable for providing all the services envisaged under Ancillary Services operation. The Table below provides the summary of the Ancillary Services that can be provided by PSH /variable speed PSH. The table also provides that the economic benefits of such services can be quantified.

Table 1: Summary of Ancillary Services by PSH

Sr. No.	Services	Possible services	Economic Benefit of Services
1	Peak Energy	✓	✓
2	Voltage stabilization, Supply of reactive power	✓	✓
3	Frequency stabilization (primary, secondary reserve)	✓	✓
4	Negative and positive balancing energy	✓	✓
5	Energy Storage (off peak from renewables)	✓	✓
6	Standalone Starting (recovery from a grid breakdown (black out))	✓	✓
7	Increases in efficiency of thermal power plants	✓	✓

VII. POTENTIAL AND INSTALLED CAPACITY OF PSH IN INDIA

As per Central Electricity Authority's (CEA) report the Potential of PSH in India is 96,535 MW out of which current installed capacity is 4785.6 MW (Out of this, only 2600 MW is operating in pumping mode). The details of Potential and Installed capacity are shown in the charts below:

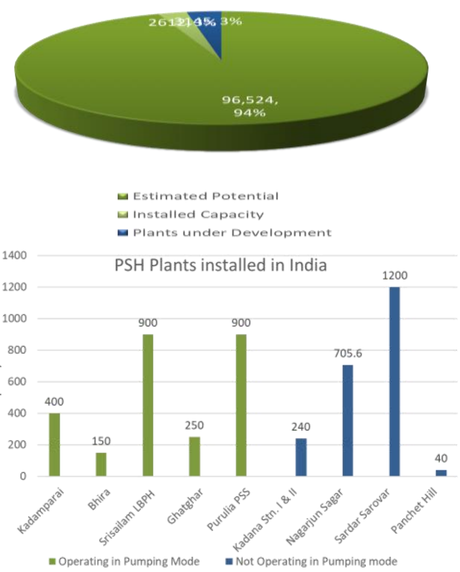
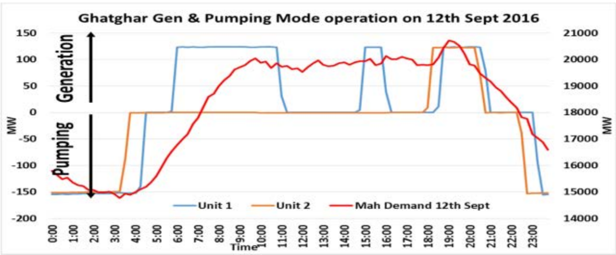


Figure 7: Potential and Installed Capacity of PSH in India.

(Source: CEA)

VIII. Case study of Ghatghar PSH in Maharashtra

Government of Maharashtra Water Resources Department (GoMWRD) has installed Ghatghar PSH (2X125MW) near Nasik I Maharashtra in 2010-11. Two PSH units when operates in Pump mode it provides load of (2X150MW). The PSH is planned for 6 hours of generation and 7 hours of pumping during a day for 6 days of week and balance water is to be pumped on Sunday. The water Turbines are Francis turbine with fixed speed operation. The Ghatghar PSH is operated as per the institutions of SLDC. The Team of WRLDC and SLDC carried out the study of operation of Ghatghar PSH. The summary of study is as below:



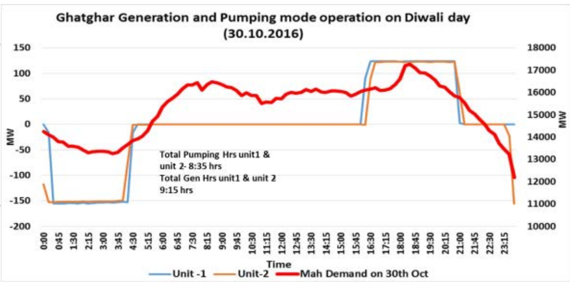


Figure 8: Operation of Ghatghar PSH on typical day

(Source: WRLDC workshop)

Ghatghar PSH is operated in accordance with the instruction of SLDC to manage the load-generation balance of State, however it is not operated as an Ancillary Service discussed above. The commercial arrangement of Ghatghar PSH is not conducive for its operation as Ancillary Services.

IX. Commercial arrangement of Gharghar PSH

Ghatghar PSH is operated by MAHAGENCO under lease arrangement with GoMWRD. GoMWRD receives annual lease rent from MAHAGENCO against ownership of the PSH. MAHAGENCO and MSEDCL has MoU for procurement of power generated from PSH. The State Regulator has allowed barter arrangement for arranging off peak power by beneficiary and receiving peak power from PSH. Accordingly, MSEDCL arranges off peak power for Pumping the water for Gharghar PSH. Considering normative cycle efficiency of 75% for PSH operation, MSEDCL provides "X" unit of energy for Pumping and MSEDCL receives "0.75X" units of generation from PSH.

The existing commercial arrangement is as per the Regulatory provisions specified by State Regulator as below:

"50 Pumped Storage Hydro Generating Stations:

50.1 The mechanism for billing for existing pumped storage hydel stations shall be in accordance with the Power Purchase Agreement already approved by the Commission and shall not be in accordance with this Regulation.

50.2 The fixed cost of pumped storage hydel generating stations achieving COD after April 1, 2016 shall be computed on annual basis, based on norms specified under these Regulations, and recovered on monthly basis as Capacity Charge.

50.3 The Capacity Charge shall be payable by the Beneficiaries in proportion to their respective allocation in the saleable capacity of the generating Station:

Provided that during the period between the date of commercial operation of the first Unit of the generating Station and the date of commercial operation of the generating Station, the annual fixed cost shall be worked out based on the latest estimate of the completion cost for the generating Station, for the purpose of determining the Capacity Charge payment during such period.

50.4 The Capacity Charge payable to a pumped storage hydel generating Station for a calendar month shall be

(AFC x NDM / NDY) (in Rupees), if actual Generation during the month is greater than or equal to 75 % of the Pumping Energy consumed by the Station during the month, and

{(AFC x NDM / NDY) x (Actual Generation during the month during peak hours/ 75% of the Pumping Energy consumed by the Station during the month) (in Rupees)}, if actual Generation during the month is lower than 75 % of the Pumping Energy consumed by the Station during the month.

Where,

AFC = Annual fixed cost specified for the year, in Rupees;

NDM = Number of days in the month;

NDY = Number of days in the year:

Provided that there would be adjustment at the end of the year based on actual generation and actual pumping energy consumed by the Station during the year.

50.5 The energy charge shall be payable by every Beneficiary for the total energy scheduled to be supplied to the Beneficiary in excess of the design energy plus 75% of the energy utilized in pumping the water from the lower elevation reservoir to the higher elevation reservoir, at a flat rate equal to the average Energy Charge Rate of 20 paise per kWh on ex power plant basis.

50.6 Energy charge payable to the Generating Company for a month shall be:

= 0.20 x {Energy generated (ex-bus) for the month in kWh – (Design Energy for the month (DEm) + 75% of the energy utilized in pumping the water from the lower elevation reservoir to the higher elevation reservoir for the month)},

Where,

DEm = Design energy for the month specified for the hydel generating Station, in kWh:

Provided that in case the energy generated in a month is less than the Design Energy for the month plus 75% of the energy utilized in pumping the water from the lower elevation reservoir to the higher elevation reservoir of the month, then the energy charges payable by the Beneficiaries shall be zero."

The existing Regulatory framework ensures the recovery of the fixed cost of the PSH; however, it does not take into account the benefits of the Ancillary Services offered by PSH.

1. **Operation of PSH in pumping mode:** SLDC is expected to instruct the PSH for pumping operation when there is surplus power in the grid i.e. frequency is above 50 Hz. The real time rate of energy consumed for pumping operation needs to be determined by some alternative method. There can be typically 2 options available to determine the rate of energy consumed for pumping.

   a. **Market based energy rate:** Presently in India there is real time electricity market in operation. The present power exchange provides only one opportunity for buying and selling on day ahead basis. More frequent market clearing as well as new products such as real time markets (i.e. the opportunity to buy and sell power about two hours ahead) may provide a platform for selling surplus power or buying power when in deficit. PSH can purchase the power from exchange during least demand period and operate in Pumping mode to store the water in the upper dam. This will provide the load to the grid and also minimize the pumping cost. Similarly, the PSH can utilize the water in the upper dam for generation when there is highest demand of the electricity. The electricity generated by PSH can be compared with highest demand rate during those time blocks. Though the energy consumed by PSH is more than the energy generated by PSH due to the cycle efficiency in the range of 75% to 85%, the difference in the peak and off peak rate of power exchange would provide the reasonable economic viability of PSH operation.

   b. **Corresponding time block wise Deviation Settlement (DSM) rate:** In the absence of real time market rate, the rate of DSM can be considered for economic viability of PSH. PSH is expected to undertake Pumping operation when the frequency of the grid is higher, and as per DSM framework, when frequency is more than 50 Hz, over drawal upto volume limits by buyer is encouraged by reducing the price vector. Typically, at frequency 50.05Hz, the DSM rate is zero. The PSH is expected to operate in pumping mode at this frequency and utilize the cheapest power available in the grid to store the water in the upper dam.

   However, existing Regulatory framework is not conducive for such type of operation of PSH.

2. **Operation of PSH for reactive power compensation:** Similarly, PSH can operate for voltage stabilization and reactive power compensation. However, existing regulatory framework does not encourage PSH's reactive power compensation by providing per kVAr based tariff for PSH.

X. Conclusion and Way Forward

With the above discussions and case study of Ghatghar PSH, it can be concluded that –

- PSH are capable for providing all the services envisaged under Ancillary Services.
- PSH with variable speed technology can be more suitable to provide the Ancillary services to the Grid.
- Large scale RE (wind/solar) penetration is feasible with operation of PSH as storage device.
- Regulatory environment is not conducive for PSH operating for Ancillary Services.
- Development of Intra-day or real time electricity Market is necessary for operation of PSH as Ancillary Services.
- The entire financial viability of PSH depends upon the differential tariff between Peak and off-Peak period.
- High gestation period (about 10 to 15 years) for PSH as it includes construction of upper and lower reservoirs lead to cost overrun and time overrun.
- With proper regulatory framework and market based Ancillary Services, the private investment can be attracted for development of PSH in India.

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[10] Market Opportunities and Challenges for Pumped Hydro in an Evolving Power Grid by Greg Stark National Renewable Energy Laboratory

BIOGRAPHICAL INFORMATION

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