SEDIMENT MANAGEMENT IN HYDRO POWER RESERVOIRS

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1. INTRODUCTION

Hydro Power is a Green, Sustainable, and Environmental Friendly source of electricity. Hydro Power Plants are among the Temples of modern India (a term coined by India's first Prime Minister Jawahar Lal Nehru while starting the construction of the Bhakra Nangal Dam to describe scientific research institutes, steel plants, power plants, dams being launched in India after independence to jump-start scientific and industrial progress).

The first Hydro development in India commenced with the commissioning of 130 KW hydropower station at Darjeeling in 1897 by the Darjeeling Municipal body. The electrical power generation capacity at the end of 1950 was only 1712 MW comprising about 1000 MW of Thermal, 560 MW of Hydro and 152 MW of Diesel plants. The present total installed capacity of the country as on 29-02-2020 is about 368989.77 MW comprising 230189.57 MW in Thermal, 45699.20 MW in Hydro, 6780 MW in Nuclear and 86321 MW in other non-conventional sources of energy, viz., wind, biomass, etc. Out of this, In Operation installed capacity as on 29-02-2020 is 45699.20 MW. The category wise operational installed capacity is given in Table 1.1.

Table 1.1: Installed Capacity (Hydro > 25 MW) - Operational category-wise

Sector	RoR		RoR (P)		Storage (S)						Total	
	No.	MW	No.	MW	S(P)		S(MPP)		PSS		No.	MW
					No.	MW	No.	MW	No.	MW		
Central	8	2115	19	6963	6	1725	9	4503	1	40	43	15346
State	14	781	50	7590	32	6434	43	7557	7	4595	146	26958
Private	1	400	13	2547	3	297	0	0	1	150	18	3394
Total	23	3296	82	17100	41	8456	52	12060	9	4785	207	45699
% (Total)	11.5	7	41	38	20.5	19	26	27	4.5	10	100	100

***Abbreviations**: RoR - Run of River, RoR(P) – Run of River with Pondage, S(P) – Storage (Conventional) for Power Generation purpose only, S(MPP) – Storage (Conventional) for Multipurpose Project, PSS – Pumped Storage Scheme*

The Hydro Power Plants, unlike the other resources of power, provide a number of benefits not only to the energy grid but also to the environment and society. Some of the well known benefits of hydropower plants are as follows:

i. Flexibility in operation.
ii. Carbon emission reduction
iii. Longer Life
iv. Benefits of Flood Moderation, Irrigation, Navigation and drinking water.
v. Socio-Economic benefits of education, employment, infrastructure development and economic upliftment of the people.

2. Water Security Issues- Some facts

India has 4% of world's water resources but 18% of world population. The country receives around 4,000 BCM Annual Rainfall out of which 6% (250BCM) is stored in dams. Our water requirement will be around 1093 BCM for the year 2025 and 1447 BCM for the year 2050. In 1951, the annual per capita availability of water of India was 5177 m^3, which reduced to 1342 m^3 by 2000. The fact indicates that India is expected to become 'water stressed' by 2025 and 'water scarce' by 2050. India has 200 m^3 of water storage capacity per person, compared to 2,200 m^3 per person in China and 6,000 m^3 per person in the United States. India's accessible, reliable supply of water amounts to 744 billion m^3, or 29 per cent of its total water resources.

The total live storage capacity of the 120 reservoirs in India is 170.328 BCM which is about 66.06% of the live storage capacity of 257.812 BCM which is estimated to have been created in the country. As per reservoir storage bulletin dated 09.01.2020, live storage available in these reservoirs is 130.282 BCM, which is 76% of total live storage capacity of these reservoirs. More Storage dams are needed for water security and management of storage volume is required for existing dams and future dams. However, Siltation is causing Loss of storage volume. Storage sites are limited and objective should be to convert non-sustainable reservoirs into sustainable infrastructure for future generations.

3. Sediment- Source and associated problems for Hydro Power Plants

Sedimentation embodies the process of erosion, transportation, deposition and the compaction of sediments. Erosion and sedimentation are part of the natural evolution of landscape. Most alluvial rivers have experienced increased sedimentation or bed load deficit; both due to natural processes and series of human interventions in the river catchment or on river itself. Rapid urbanization in flood plains, encroachment of river beds, changes due to human activity and deforestation in catchment area of rivers are causing sedimentation in rivers. Sediment or the silt comprises of solid particles of mineral and organic material that are transported by water. The “suspended sediment load” refers to the fine sediment that is carried in suspension and this can comprise the material picked up from the bed of the river (suspended bed material) and material washed into the river from the surrounding land (wash load). The wash load is usually finer than the suspended bed material. In contrast, the “bed load” comprises larger sediment particles that are transported on the bed of the river by rolling, sliding or saltation. Himalayan rivers carry huge sediment during monsoon seasons with nearly 60 to 65% quartz or Feldspar contents having angular & sub angular structure and hardness of 6 to 7 moh.

High concentration of silt load in water passing through turbine hits the underwater parts at high velocities like bullets thus detaching the parent metal of the components causing high hydro-abrasive erosion due to gouging or hammering by the coarse silt particles. Additionally, silt also acts like a grinding paste on these under water metallic surfaces causing low hydro-abrasive erosion due to rolling or sliding of medium & fine silt particles over the surface thus causing metal loss/ thinning of components. Thus, water with high silt content, if allowed to pass through underwater components of hydro power stations including turbines, cooling water system, etc., would not only reduce the operating useful life of such equipment and component but also reduce operational efficiency and regularly cause high recurring cost on maintenance of these items. However, the rate of hydro abrasive erosion caused by silt particles largely depends on the silt characteristics i.e. concentration, size, shape and hardness as well as the velocity and angle of impact of the silt particles.

The gravity of problems associated with silt varies depending upon the type of the hydro project and the extent of sediments carried by the river. In case of projects with large storage reservoirs, the silt tends to settle down quickly and relatively clear water is available for generation. Moreover, these projects are often designed taking into consideration the New Zero Level after 70/ 100 years of sedimentation. However, dam construction creates an impounded river reach characterized by extremely low flow velocities and sediment trapping. The impounded reach will accumulate sediment and lose storage capacity. Declining storage reduces the capacity for flow regulation and with it all water supply and flood control benefits, besides benefits that depend on releases from storage such as hydropower, navigation, recreation and environmental.

On the other hand, the ROR projects have negligible storage compared to the river flows and management of the silt is a bigger challenge in such projects. The suspended sediment load in these reservoirs is trapped in the desilting chambers and relatively clear water is available. However, during the flood seasons, some rivers carry extensive sediment load which may damage the runner and other under water parts and a number of measures are taken to reduce the silt load as well as to mitigate its impact on the project operation.

During high silt periods, generating units are shut down to protect them from silt damages which leads to loss of generation. The average loss in generation on account of such shutdowns has been estimated to be around 1% of the overall generation. Apart from loss in MU generation, the shutdown of hydro power stations to avoid operating under such conditions also leads to loss of peaking (MW) availability. It also indirectly impacts the power grid and involves issues of grid security in handling such operational matters arising out of big capacity at single location or in cascade operation going out of operation.

In the next Section, various techniques for silt management adopted in Hydro Electric Projects are discussed.

4. SILT MANAGEMENT TECHNIQUES

Silt management in hydropower project needs to be done both at ‘Planning and design stage’ as well as ‘Operational stage’. We discuss them, one by one, in subsequent sub-sections.

Silt management techniques at Planning and Design Stage

These techniques are applied during the design of the Hydro Electric Project and its components. Various techniques during planning and design stage are given below.

i. In case of reservoir based projects, to fix the reservoir levels and corresponding storage capacity such as Active Storage Capacity, Live Storage Capacity, Dead Storage etc. amount of silt in the water needs to be taken into account to estimate new zero elevation of the reservoir for 50/70 years of operation. This can be done by collecting long term silt management data and then calculating average sediment load from the catchment and using it in determining the different reservoir levels mentioned above.

ii. In case of ROR and canal-hydel projects, necessary arrangements are normally provided for exclusion of sediments larger than a particular size (usually 0.2mm) from the water entering into turbines. In such projects, when silt load is very heavy, sediment exclusion should be done by sediment excluders and ejectors, which form part of the head works in the river. At present, devices like sediments excluders and extractors are designed using thumb rules and model studies which give only qualitative information. As a result, even though some excluders and extractors are working satisfactorily, the performance of others is unsatisfactory. Hence, there is need for rationalizing their design procedures taking into account the theory of sediment transport. Desilting Chambers, also known as Silting Tanks, Settling Basins, Sediment Traps, Decantation Chambers are also used for removing sediments larger than the required size, which enter into the water conductor system wherever, the silt issues are envisaged during operation of the project. Further, desilting chambers could, however, be made more effective by automatic operational flushing valve by placing load sensors etc.

iii. The chemical analysis of water and silt data including the petrographic analysis needs to be taken into consideration while designing the turbine, main inlet valve and other auxiliary equipment susceptible to abrasive effects of silt.

iv. To minimize effect of damage to underwater parts of HE station due to high silt content in the river water, suitable materials, protective hard coating (i.e. Tungsten Carbide) by High Velocity Oxy Flame (HVOF) spray method or any other state of the art technology should be employed to resist silt abrasion, wherever required, as per the site conditions. The abrasion resistant coating on the underwater parts of turbine, often, gets eroded due to water silt content of abrasive nature during the course of operation. As such, this coating needs to be reapplied in case it is found eroded during visual inspection or according to established maintenance practice of the utility based on operational experience. This technique has been applied in SJVN project Nathpa Jhakri (1500 MW) and JSWHEL project Karcham Wangtoo (1000 MW).

v. Gates at desilting arrangements require appropriate features suitable for exclusion of silt and control of discharges under high heads. These gates require sealing and bearing arrangements such that constant flow of silt loaded water has no long term detrimental effects on the gate components. These gates are quite often of small size and are required to be operated under partial open conditions. Due to heavy silt load, these gates require frequent operation. Considering these, hydraulic hoists for the operation of various gates in power station including desilting chambers should be encouraged, wherever possible since drum hoists are often found inconvenient and modern installations adopt hydraulically operated gates for maintaining partial operation.

vi. The need for installation of sediment removal system at hydro projects using a Hydro Suction System could be envisaged/ suitably explored at planning and design stage. The system allows sediment dredging in reservoir by hydro-suction without input of power of any kind and utilizes excess water during monsoon season, so no water is lost for production.

vii. The possibility of providing low level sluices needs to be explored in the new projects since it is an effective solution for carrying out flushing of reservoir in run-of-the-river projects.

viii. In case of the projects planned in the high silt-affected areas, provision for providing requisite blank panels during monsoon at the intake crest level should be made based on hydraulic model studies to restrict silt ingress in water conductor system. This technique has been successfully applied in projects like Nathpa Jhakri Hydro Electric Project.

In the next sub-section, we discuss various techniques for silt management, which could be applied at operational stage.

5. Operational Stage silt management Techniques

Every hydroelectric project is a unique entity and has different set of problems. Generation utilities should prepare project specific guidelines and standard operating procedures for management of sediments for each of the project based on their operational experience. Various techniques that could be used for silt management during operational stage are given below.

i. Sediment rating curves, discharge v/s suspended sediment load, should be prepared for every medium and major hydroelectric project on monthly basis for the monsoon season. Rating curves may also be prepared for non-monsoon period. Based on the above and the operational experience of the developer, plant should be shut down if the silt content measurement in water upstream of power house increases beyond pre-defined limit of silt content in the river which is for example 5000 ppm in case of Nathpa Jhakri. Efforts should also be made by the utility for forecasting of the flows in the upstream for planning in advance of the operational measures in the eventuality of the shutdown of the station due to high level of silt.

ii. Wherever, hydroelectric projects having diversion structure with small storage capacity or projects where live storage capacity has been reduced considerably due to sedimentation, utilities should prepare detailed instructions for carrying out flushing operations during monsoon season to prolong the useful life of the project and for its desired performance.

iii. In order to reduce siltation of live storage capacity in case of run-of-the river schemes or projects having small storage capacities, operation of reservoirs at/ near MDDL during monsoon/ high flow periods, while discharges are more than the design discharge, could be considered. This would ensure sediment free environment in front of power intake as well as sediment balance between upstream and downstream of dam/barrage is maintained and thus natural river regime remains close to original profile. This practice is being used in the HEPs in Himalayan region.

iv. For projects in cascade lying in close vicinity of each other, flushing could be carried out to the extent possible in tandem so that the sediment flushed out from the upstream reservoir are not allowed to settle in the downstream reservoir. A co-ordinated and synchronized silt flushing approach should be studied based on river slope and its sediment carrying capacity and the flushing/guildlines need to be prepared for the project accordingly. The last reservoir flushing shall normally be carried out at the end of high flow seasons with coordination of upstream project to avoid any accumulation of silt in the reservoir so that it does not affect the performance of the machines during the balance month of entire lean season. Such an arrangement has been made between Naptha Jhakri and Karcham Wangtoo HEPs. A joint protocol for reservoir flushing has been signed between JSWHEL, NRLDC and SJVNL for regulating generation and shut down of the units followed by reservoir flushing.

v. Depending upon type and size of deposited sediments in the reservoir and tributaries meeting the river/reservoir, dredging could be carried out.

vi. For effective operation of the Desilting chambers in existing stations, the possibility for automation of the operation of flushing valves, depending upon sediments deposition inside the desilting chambers by placing the load sensors, should be examined by the utilities, which would minimize choking of the desilting chambers and would also optimize water requirement for flushing operations. The frequency of the operation of the desilting chamber valves would, however, depend on the incoming sediment load during the monsoon and non-monsoon period and need to be estimated by the utility based on their operational experience.

vii. Wherever possible, efforts could be made for real-time coordination among different hydro generating utilities, in order to have effective regulation and to supplement the peak generation from projects having diurnal storage or large volume storage especially during the period of closure of plant(s) due to heavy silt load.

viii. For effective management of sediments, feasibility of lowering of spillway crest and converting them into low level sluices, in the existing dams, by cutting body of the dam or any modifications by suitable techniques (wire-line cutting technology etc.) could be explored on case-to-case basis.

ix. A temporary channel may be excavated through which the sediment can be poured into dead storage using force of inflow. This technique has been applied in the Takase Dam of Japan. Especially when flood is forecasted, the water level of the Takase Dam is set near Minimum Water Level before the flood occurs. The stronger the flood, the more effective this technique is, i.e., more effectively the sediment is poured into the dead storage.

x. Hydrographic survey of the reservoir should be carried out every year at fixed locations, which shall permanently be marked along the reservoir length by constructing concrete pillars duly marked with reach lengths. Power utilities should carry out systematic and quantitative budgeting of sediments by taking into account, inflow sediment load, sediments deposited in the reservoir, flushing of sediments, dredging of sediments and sediments passing through the turbines.

The effectiveness of Catchment Area Treatment Plans need to be assessed from time-to-time by the generating utility and requisite works identified to restore the old treatment works as well as new ones should be taken up on priority to reduce the sediment yield. Efforts should be made to reduce the sediment yield from catchment area of the project. Generation utilities need to follow the methodology of catchment area treatment, including construction of small check dams, plantation/ forestation along river embankments to check soil erosion, embankment protection works to check landslide debris at identified/ prone weaker geological zones, etc. The effectiveness of these treatment plans needs to be assessed from time to time.

In the next Section, we discuss a new model, which may be used to forecast sediment in the reservoir.

6. A NEW MODEL FOR SEDIMENT FORECASTING

The proposed model incorporates forecasting both the weather system and land structure as given below:

i. Weather Forecasting System: It predicts the quantum of rainfall in the upstream catchment area of the river on which the HEP is located. The sediment created out of the erosion is directly related to the amount of rainfall. Thus, amount of sediment can be anticipated by a better weather forecasting system located on the upstream of the river. For this a localized weather model needs to be developed.

ii. Inflow Forecasting System: To get an estimate of the amount of inflow at the project site 'Automatic Weather Stations (AWS)' on the catchment of the River and Gauge site on its upstream may be installed. AWS will measure the amount of precipitation on the catchment of the River and Gauge sites on the upstream of the river at suitable locations will measure the amount of inflow at the site of its installation. Suitable mathematical models developed on the basis of the data will help predict the inflows at the Dam site.

iii. **Rock Structure Forecasting:** The forecasting of rock structure will help in understating the stiffness/hardness of rock on the upstream of the river. This information will help in predicting the amount of erosion by the river which forms the sediment. For this an inventory of the landslides happened in the area needs to be created and the existing land use and soil data needs to be reviewed and updated by using the satellite images. The rock cutting activities that have occurred in the area also needs to be looked into. The run-off that will occur in the catchment area of the Dam also needs to be reviewed by driving the inputs received from the satellite images.

The combined forecasting model incorporating the above discussed models may help in predicting the amount of sediment in the river in advance which would further help in better silt management in the hydro power plants in terms of generation forecasting/scheduling of power by generating utilities/load despatchers. To make it economically viable, the cost of developing the localized silt prediction model can be shared by all the project proponents operating in cascade in the river. One similar kind of model is being presently developed by NRSC, ISRO for NHPC Project TEESTA IV, a 520 MW run of the river project located in Sikkim on river Teesta.

REFERENCES

1. "Standard Operating Procedure for management of Silt in Hydro Electric Project", by Central Electricity Authority, Ministry of Power.
2. "Executive Summary on Power Sector" by Central Electricity Authority, Ministry of Power.
3. Article on "R&M in Hydro Power Plant- Historical Background, Present & Future", by Sanjay Srivastava, Rakesh Kumar, K.K. Neema and Deepak Choudhary, Published in CEA Technical Papers on Renovation, modernization, Uprating & Life Extension of Hydro power Plants in December 2016.
4. Various data from official site of CEA.