SILT EROSION

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ABSTRACT

Silt is a big problem for hydro plants. Not only it erodes and damages the plant components, it reduces efficiency of machinery and ultimately affects the generation capacity of a plant. O&M cost of plants increases and more time is taken in repair and maintenance of the plant. Availability of the plants also gets affected. The problem of silt erosion is exacerbate by the favorable head and topography of many of the rivers which, at least during parts of the year, carry high particle content. Hydro-abrasive erosion of hydraulic turbines in these regions is an ongoing problem and needs to be solved or at least mitigated. Plants tend to be in mountainous regions, which imply a high head leading to a relatively low construction cost per kilowatt and have fewer environmental and resettlement problems. However, these economic advantages tend to be somewhat negated if the development requires large expenditures on extensive settling chambers or long periods of diminished generation due to a seasonal high particle load in the river. So the R&D in this field needs to be continued and improved upon to understand the silt problem and make the components wear resistant by way of development of new material/alloys as well coating techniques etc.

1. Introduction

Many hydro project sites in the Himalayan range in northern India, and in the northeastern region of the country, face severe silt erosion problems. Several existing hydroelectric power stations located in these regions have confirmed the severity of silt on the critical underwater parts of turbines and other components of the power station.

Some of the Power Stations facing silt erosion problem are Maneri Bhali-I, Maneri Bhali-II, Nathpa Jhakri, Bariasul, Dehar, Salal, Machkund, Chilla, Periyar, Kundah-IV and Umtru. These power plants are facing regular damages due to excessive silt in water and facing number of operation and maintenance problems e.g. frequent choking of strainers, damage of guide-vanes, runner blades and other components of the turbine.

Silt has not only damaged/eroded the components of these plants but resulted in a steep fall in efficiency of the affected machinery, which can only be rectified if timely and thorough repairs are carried out. Silt has resulted in increased operation and maintenance costs and reduced availability of these stations for power generation.
Some of the most attractive hydro sites remain closed due to silt at certain times of the year. Silt erosion of the hydraulic turbines at these sites is typically controlled by upstream settling chambers and turbine protective coatings; however, further work is needed to better predict and control silt erosion.

Many of India’s potential hydroelectric sites are in the north of the country and are fed by run-off water from melting glaciers and rivers carry substantial quantities of particles.

2. Characteristics of Silt

High concentrations of silt are associated with floods. In the monsoon period the issue of silt becomes increasingly critical. For judging the danger of silt erosion it is important to note the quality of silt (the percentage and shape of the quartz contents and other hard materials) and the amount of silt.

a. Size and Shape of Particles

The intensity of erosion is directly proportional to the size of particles. Particles sizes above 0.2 to 0.25 mm are extremely harmful. It has been found that the large size particle (above 0.25 mm) even with hardness lesser than 5 on Mohr’s scale cause wear. Fine silt particle even less than 0.05 to 0.1 mm, containing quartz wears out the underwater parts. The fine silt can also be dangerous if the turbine is operating under high head. Sharp and angular particles cause more erosion in comparison to rounded one. The shape of the particles is especially relevant for gouging erosion where the particle adopts a cutting action. A sharp-edged, irregular particle can have a far greater deleterious effect on the surface than a well-rounded or spherical particle.

b. Hardness of Particles

The intensity of erosion is also directly proportional to the hardness of particle. The particles with Mohr’s hardness above 5 are considered harmful. Himalayan silt in India is 90% Quartz which is 7 on Mohr’s scale against 10 of diamond.

c. Silt Concentration

Silt concentration is the most dominating factor influencing erosion intensity, linearly. Particle concentration is usually expressed in grams per liter (g/l). However, often parts per million (ppm) by weight is used, with the approximation of 1,000 ppm equal to 1 g/l being normal usage.

Greater the concentration, the higher the erosion rate and hence lesser time to equipment failure. At many facilities, concentration is measured and operation of the units ceases when the particle concentration exceeds a pre-determined value. Erosion rate is essentially proportional to concentration over the practical operating range for a hydropower unit, but
3. **Mechanisms of hydro-abrasive erosion**

Particles above 1,000 micrometers (µm) in diameter will not follow the hydraulic contour, and even at relatively low velocity will impact upon and damage the hydraulic surface.

Particles with diameters between 100 µm and 1,000 µm will tend to be channeled along the outer hydraulic contour, and their propensity for damage will be progressively less.

Particle diameters below 100 µm, the surface damage increases considerably. This is because small particles become entrained in the turbulent boundary layer, which encases all hydraulic surfaces, and results in a sand blasting of the surface.

Overall erosion from fine particles, if in sufficient quantity, can be as great as that from large particles. Due to flow separation, the inside bends surface (suction side of a Francis turbine blade) experiences a steady increase in damage as the particle size decreases.

The effect of particle density is similar to that of size. A particle of greater density will have greater momentum and thus be more inclined to reach the surface in the case of larger particles and less inclined to be entrained in the boundary layer in the case of smaller particles. A particle can only appreciably damage a softer surface; a particle hardness of 5 Mohr’s scale is generally considered the cutoff value for hydraulic turbines. As a general rule, the base materials used for hydraulic components in a hydro-abrasive environment should be as hard as possible.

A particle’s angle of attack to the hydraulic surface gives rise to two distinct erosion mechanisms. A particle approaching nearly normal to the surface will produce impact damage in which the surface is initially cracked, subsequently loosened with further impacts, and finally excavated as the already cracked and loosened particle is removed by another impacting particle. A particle approaching parallel to the surface will scratch and gouge the surface similar to that of mechanical grinding. For angles between the two extremes, the erosion mechanism will be a combination of both.
This hydro-abrasive particle damage on the trailing edge of a high-head Francis turbine runner occurred after only a few months of operation in a heavily particle-laden river.

The effect of particles on cavitation in hydraulic reaction turbines is two fold. Particles 50 µm in diameter or less provide nuclei for cavitation bubbles, leading to premature commencement of incipient higher than in pure water. Cavitation bubble development similarly reflects the premature commencement of cavitation. The second, equally serious effect of hydro-abrasive erosion is that it locally changes the hydraulic contour, which, in turn, disrupts the flow and increases both the propensity for and intensity of the cavitation bubble implosion. The impacts from the implosion of the cavitation bubbles fatigue and loosen the hydraulic surface, adding to the erosion damage and making it easier for the impacting particles to remove damaged material.

The combination of cavitation and erosion is referred to as a “synergistic” effect, the damage resulting from the combination of the two being far greater than the sum of each acting alone.

4. **Turbine components affected by hydro-abrasive erosion**

The relatively low stream velocity in the casing of a Pelton unit means that it is minimally affected by hydro-abrasive erosion. Nozzles, however, suffer greatly; the nozzle spear erodes badly, with a resulting decrease in overall turbine efficiency. The inside of Pelton buckets suffers considerable erosion. Splitters tend to suffer impact erosion and the buckets a mixture of impact and gouging. Turbine efficiency is compromised, especially as a result of erosion of the splitter.

As with Pelton units, because of relatively low velocities, the scroll casing of a Francis unit is typically immune from hydro-abrasive erosion. The nose of the stay vanes can be damaged by impact erosion, but usually this a not a major concern. Wicket gates suffer from both impact damage and gouging erosion. Top and bottom cover cheek plates and runner labyrinth seals sustain considerable damage from gouging erosion. Francis runners experience major damage at the leading edge due to impact erosion and equally severe loss of material along the length of the blades from a combination of gouging erosion and impact erosion. Trailing edges, because of their initial thinness, are particularly prone to damage.
Erosion of all the above mentioned components eventually means a considerable loss of efficiency. Losses include volumetric efficiency due to increase in labyrinth seal and guide vane clearances, form efficiency due to the change in hydraulic profile of the wicket gates and runner blades, and increase in frictional losses resulting from roughening of the hydraulic surfaces. Paradoxically, the initial erosion of the trailing edges can produce an increase in efficiency due to widening of the flow path; however, this is short-lived as the other detrimental effects of erosion come into play. Likewise, erosion from small particles can grind and hone the surface, leading to an initial reduction in friction. This advantage is soon swamped by a loss in efficiency resulting from deleterious changes in the hydraulic profile.

5. Method to overcome the adverse effect on the Hydro Plant

Cavitations and silt erosion of water borne parts of the machine, especially the runner, guide vanes, labyrinth seals, nozzle and needle assemblies, and main inlet valve seals are regarded as the most serious problems for large capacity high head turbines. So following measures should be taken for planning a power station where silt is a potential threat:

- The first weapon against hydro-abrasive erosion is to try to remove it before it reaches the hydro facility. The most efficient method of removing particles is to provide a large head water reservoir which, if of great enough volume and length, will settle out all harmful particles. However, although very effective, it must be remembered that unless provided with effective bottom outlets, a reservoir is only a delaying device. Eventually it will fill and, given adverse topography, deposited particles will reach the turbine inlets.

- Many mountainous hydroelectric facilities do not lend themselves to large upstream reservoirs. In these cases, the only viable solution is settling chambers with flushing facilities. The design of such chambers is well established, and their efficiency in removing particles greater than 1 millimeter (mm) is universally recognized. For convenience, incoming load can be divided into three categories: coarse (>200 µm); medium (75 µm to 200 µm); and fine (<75 µm). Reservoirs are efficient in removing all particles down to the upper fine size but settling chambers have their limitations. Although they remove virtually all coarse particles, depending on incoming concentration, they can pass about 80 percent of fine particles. For medium particles, removal effectiveness is a function of particle size, falling between the two extremes. As hard, sharp particles as small as 50 µm in large quantities can cause damage to hydraulic turbines, it is important for designers to acknowledge that, even with settling chambers, in heavily particle-laden rivers (up to a 20 g/l peak concentration in some Himalayan rivers).

- Selection of right turbine with
  - Civil cost, structure cost comparison of Pelton turbine and Francis Turbine installation.
  - Design energy comparison of Pelton turbine and Francis Turbine installation.
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- Initial investment cost comparison of Pelton turbine and Francis Turbine installation.
- Comparison of Repair maintenance cost and down time of machines for repair and maintenance for the entire life of plant of Pelton turbine and Francis Turbine installation.
- Cost benefit Analysis with selection of Dam, Barrage, Turbine, Design Energy
  - For high head, silt prone hydro power schemes, the theoretical annual design energy should be calculated taking into account the probable annual energy loss due to forced shutdowns imposed by repairs on underwater components.
  - Cost benefit and socio-economic analysis comparison with big sedimentation chamber/dam and with small sedimentation chamber/barrage
  - Selection of Profile with State-of-the-art computational fluid dynamics (CFD) methods are employed to further understand the mechanics of hydro-abrasive erosion and, in particular, to design erosion-resistant hydraulic profiles.
- Protective coatings

6 Conclusion

Hydro-abrasive erosion of hydraulic turbines is an ongoing problem and needs to be solved or at least mitigated as the plants tend to be in mountainous regions, which imply a high head leading to a relatively low construction cost per kilowatt and have fewer environmental and resettlement problems. However, these economic advantages tend to be somewhat negated if the development requires large expenditures on extensive settling chambers or long periods of diminished generation due to a seasonal high particle load in the river. So the R&D in this field needs to be continued and improved upon to understand the silt problem and make the components wear resistant by way of development of new material/alloys as well coating techniques etc. Unless research and development efforts are undertaken in this area, lasting solutions will continue to be a distant dream.

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