DISCHARGE AND EFFICIENCY MEASUREMENTS IN BASSI HYDRO POWER STATION IN INDIA

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ABSTRACT

Bassi Hydro Power station with vertical-shaft Pelton-turbine generating units gets its water from the tail-race discharge of Shanan Hydro Power Station in the state of Himachal Pradesh, India. The four generating units were commissioned during the period of 1970-1981. Reduced generation and excessive vibrations of machines let the station owner to consider its renovation. Possibility of uprating the generating units was also explored. For arriving at a rational decision, the station owner requested the Indian Institute of Technology Roorkee (IITR) to measure the available discharge in the power channel and to evaluate the efficiency of each generating unit. These measurements were made by the authors from IITR. Subsequently, renovation and modernization were carried out by an equipment manufacturer, India. The four units were also uprated from 15 MW to 16.5 MW each. After renovation, efficiency test was repeated by the authors on one of the generating units. This paper presents the details of the methods and instruments used, along with summary of results, of the measurements made before and after renovation works. Uncertainty of both, discharge measurement in the open channel and unit efficiency measurement, are also assessed. As an outcome of renovation, uprating and modernization, the power output of Bassi Hydro Power Station has increased from less than 60 MW to 66 MW. The efficiency of the generating units has gone up by an average of 12.66%. The plant load factor has also improved accordingly.

1. INTRODUCTION

Bassi Hydro Power Station (BHPS), consisting of four generating units of 15 MW each, is located at Joginder Nagar in Himachal Pradesh, a hilly State of India, and owned by State government Himachal Pradesh State Electricity Board (HPSEB). The source of water to the power station is the tail-race discharge of Shanan Hydro Power Station owned by Punjab State Electricity Board (PSEB). The discharge from Shanan Hydro Power Station, which is around 20 m^3/s, is conveyed through a water conductor system and stores in a small balancing reservoir of about 2500 m^3 capacity. The reservoir is used for balancing of the inflow from Shanan Hydro Power Station tailrace and the outflow to BHPS and also works as the forebay tank for the latter. The water conductor system of BHPS, as shown in Figure 1, comprises a cup-shaped (trapezoidal-section) open channel with a total length of 228 m and bottom width of 4.0 m, tunnels (total length 3883 m and internal diameter 3.36 m) and circular pressed RCC ducts (internal diameter 3.36 m).

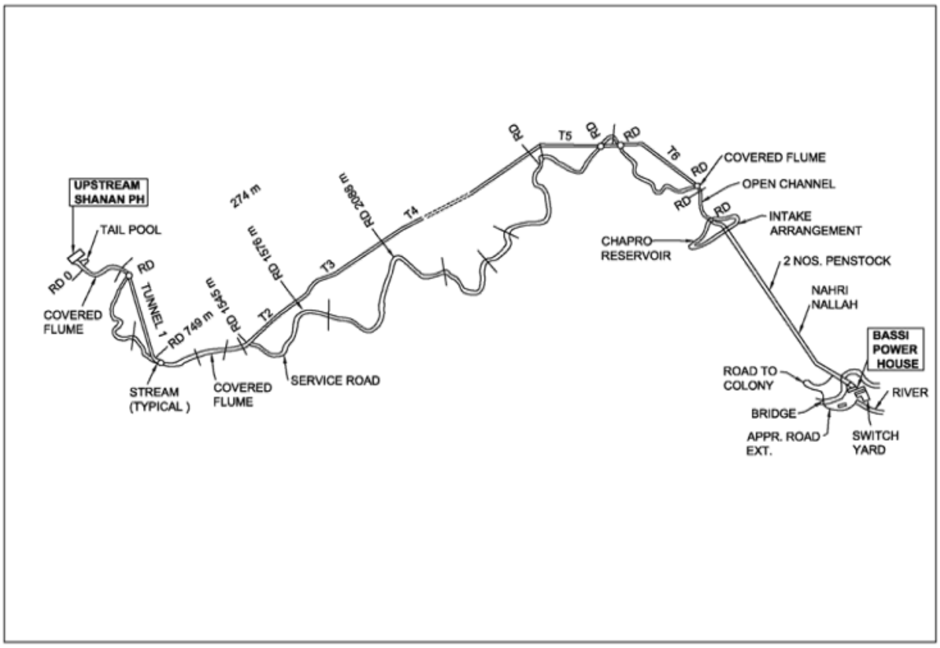

Figure 1 – Schematic of Water Conductor System

The water from the reservoir is fed to the 4 turbines through two penstocks of internal diameter of 1.72 m each; see Figure 2. Each penstock bifurcates into two individual penstocks of internal diameter of 1.226 m each to feed the two turbines each. These 4 individual penstocks at the point of their entry to the power house are shown in Figure 3.

Figure 2 – Two penstocks for Units-1 and 2 and Units-3 and 4

Figure 3 – Individual penstocks for the four Turbines

The four generating units of BHPS, which use vertical-shaft Pelton turbines, were commissioned between 1970 and 1981. By the year 2007, these units were 26 to 37 years old and were not able to generate rated power output; their efficiency was low and had the problem of excessive vibrations. So the option of renovating these machines was considered by the station owner, HPSEB, who decided to evaluate the efficiency of the generating units and to measure the conveying capacity of water conductor system. Since the four generating units were not identical and had worked for different lengths of time under different conditions, it was considered necessary to test the efficiency of each individual unit. Further, HPSEB also decided to ascertain the actual value of discharge available from Shanan Hydro Power Station with a view to examine the possibility of enhancing the station capacity of BHPS. Accordingly, a request was made in 2007 by HPSEB to Indian Institute of Technology Roorkee (IITR) for the followings:

(a) To measure the discharge in the power channel (water conductor system).
(b) To measure the efficiency of each of the four generating units at rated load.

A visit to the BHPS was undertaken, and the methods and locations of various measurements were mutually agreed to by HPSEB and IITR. Measurements were carried out in the year 2007 by the experts (faculty) and technicians of IITR, which were witnessed by the engineers of HPSEB. Based on the results of these measurements and the poor health of the machines, the owner decided to get the four generating units of 15 MW rating each renovated and uprated to 16.5 MW each. The major scope of supply and services under the renovation contract included runners, nozzles and deflectors, bearings, shaft, main inlet valve, governing system, new stator core and windings, pole coils, new static excitation system, control and protection system (Hydro News, 2012). Since all the units after renovation were almost identical, it was decided in the year 2013 to test (past renovation and uprating) only one unit to save resources.

This paper describes the measurements carried out by the authors from IITR before and after the renovation of the power station. The plans, techniques and results of these measurements are presented. The benefits of the renovation, uprating and modernization of the power plant are also briefly discussed.

2. MEASUREMENT PLAN

In order to determine suitable locations for carrying out various measurements, appropriate method of each measurement and site preparation required for the measurements, an advance visit was made in May 2007. The entire water conductor system was meticulously inspected and thence a location on the open channel portion of the power channel was identified for discharge measurement. It was decided to use a battery of propeller current meters (PCMs) fixed to a mounting frame (Gandhi and Verma, 2007). The mounting frame was later designed, fabricated and installed.

The efficiency test of turbine-generator units by head-discharge measurement method involves simultaneous measurement of three major quantities, namely discharge through the turbine, net water head availed by the turbine and electric power output of the generator (IEC-60041, 1991). For the measurement of discharge in the individual penstocks, it was mutually agreed to use an ultrasonic transit-time flow-meter (UTTF) with clamp-on type ultrasonic transducers for the following reasons:

(a) To avoid puncturing of the old penstocks to install intrusion-type ultrasonic transducers.
(b) To save the time and cost of drilling holes and installing intrusion-type transducers.
(c) Lower cost of clamp-on type UTTF as compared to intrusion-type UTTF.

It was decided to fix a high-precision gauge-pressure transmitter at the turbine intake for pressure head measurement and connect a precision-class digital wattmeter at the generator relay and metering panel in parallel to the existing digital multi–function meter for power measurement.

In July 2007, all arrangements for fixing instruments were made under the supervision of IITR. Thereafter, discharge measurement in the open channel and efficiency test on the four old generating units at rated load were carried out.

After the completion of renovation and modernization work, one of the renovated generating unit was tested by using the earlier (2007) agreed procedure by IITR in March 2013. The testing was witnessed by the engineers of the owner as well as the equipment manufacturer.

3. DISCHARGE MEASUREMENT IN POWER CHANNEL

The open power channel alignment is straight from RD of 840 m to 870 m and the flow was reasonably free from disturbances in this channel reach. Therefore, this was considered as the best possible location for discharge measurement in the open channel and a current-meter mounting frame was installed at RD 855 m.

3.1 Simultaneous Measurement of Flow Velocities using Current-Meters

Six propeller current meters were used for simultaneous measurement of flow velocity in the measurement section. As the channel is trapezoidal section, the current meters were placed at equidistance from the centerline of the channel. Two current meters were fixed to a fixed platform near the banks of the channel, while another four current meters were fixed to a movable frame as per dimensional drawing shown in Figure 4.

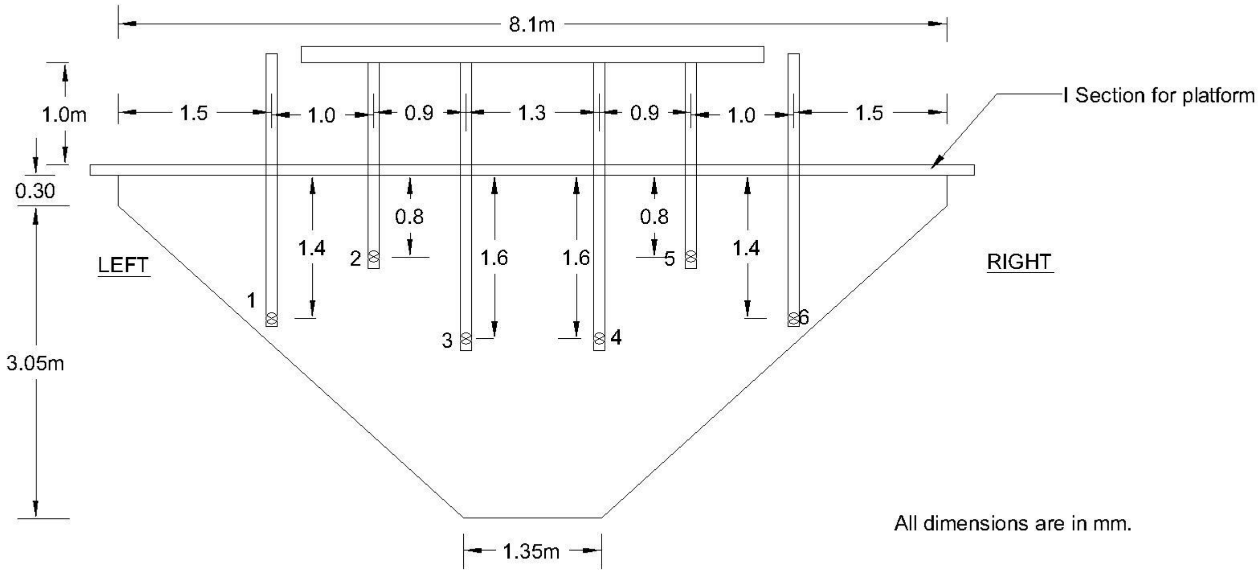

Figure 4 – Mounting Frame for Current Meters

The movable portion of the frame was moved vertically to measure the velocities at different water levels. It resulted in measurement of velocity at 22 points in the measurement section of the channel. The flow velocities were observed to vary in the range of 1.6-2.8 m/s. It can be noted from the Figure 4 that the two current meters at the center were moved to 6 different depths and the other two were moved to only 4 depths because of the trapezoidal cross section of the channel. A photo view of the current-meter structure is shown in Figure 5.

Figure 5 – Current Meter Mounting Structure used at Power Channel for Discharge Measurement

The readings (number of revolutions) of the current meters were recorded simultaneously on a microcontroller-based data logger. The data logger was fed with the calibration equation of each current meter. At the end of each 120-second integration period, the data logger computes average velocity of water during that period at each point along a horizontal plane and stores the same in its memory. Several records were taken at each depth during the measurement process for the purpose of averaging out any random error.

3.2 Result of Discharge Measurement

At the end of the velocity measurement process, the average-velocity data was downloaded from the data logger to a computer. Based on this data, the discharge was calculated by velocity-area segmentation method (IEC 60041, 1991). The value of discharge through the power channel was found to be 24.193 m^3/s.

The discharge in the power channel was also measured simultaneously by using ultrasonic/ acoustic instruments, namely a Horizontal-beam and a Vertical-beam acoustic Doppler current profiler (ADCP). The result of discharge measurement using currentmeters as above was found in good agreement with that of the ADCPs (Patnaik et al., 2011).

3.3 Assessment of Uncertainty of Discharge Measurement

Uncertainty of velocity measurement by a PCM	= ± 1.0 %
Uncertainty of velocity-area segmentation method	= ±1.5 %
Uncertainty of cross-sectional area and geometry of channel section	= ±1.5 %

Therefore, total uncertainty of discharge measurement is

$$f_q = \sqrt{1.0^2 + 1.5^2 + 1.5^2}$$
$$= \pm 2.345\ \%$$

4. PRE-RENOVATION EFFICIENCY TEST ON GENERATING UNITS

The efficiency test was conducted before renovation on all the generating units at the rated load of 15 MW. The methods and instruments used for measuring the relevant quantities, namely, discharge rate through the turbine, net water head availed by the turbine and electrical power output of the generator, are briefly described below.

4.1 Discharge Measurement

For the reasons stated earlier, a portable ultrasonic transit-time flow-meter (UTTF) with clamp-on transducers (GE-Sensing System-PT878) was used in reflection mode. A pair of transducers was fixed (clamped) on the individual penstock upstream of the power house. Readings of the UTTF averaged over 60-second periods by the instrument itself were taken every minute during the 20-minute duration of the efficiency test. Average flow over this 20-minute duration was used in calculating the unit efficiency of the generating unit.

4.2 Pressure Head Measurement

A high-precision high-resolution gauge pressure transmitter (SMAR LD-301, 0.075% basic accuracy, 0-5 MPa range) was installed at the intake to the turbine for the pressure head measurement. Readings were taken every minute during the period of the efficiency test and their average value was used in efficiency calculation.

4.3 Electrical Power Measurement

The electrical power output of the generating unit was measured by connecting a precision–class 3–phase digital wattmeter (Yokogawa WT-230) as shown in Figure 6. It was connected in parallel to the digital multi–function meter installed on the Generator Relay and Metering Panel, as shown in Figure 6. Power output was measured by using the digital wattmeter in integration mode so that any fluctuations in the power about the set-point of the governor are averaged out. The ratios of the current transformer (CT) and voltage transformer (VT) of the generator are 200A/1A and 11kV/110V, respectively. The multiplying factor for the wattmeter reading is the product of CT ratio and VT ratio, which comes out as 20,000 in this case. Therefore, the average electrical power output of the generator over the test duration, P_e, in watts is given by,

$$P_e = \frac{\text{Integrated energy in Wh}}{\text{Integration time in hours}} \times 20000$$

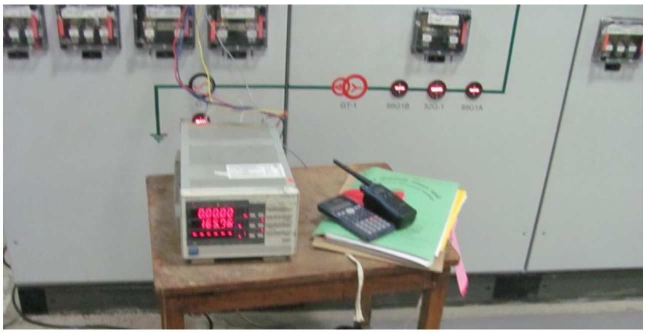

Figure 6 – Precision digital Wattmeter connected for measurement of electrical power output

4.4 Efficiency Calculation

The hydraulic power input to the turbine, P_h, in watts is calculated from the equation

$$P_h = \rho g HQ$$

where

ρ = actual density of water in kg/m^3 at actual temperature and pressure

g = actual acceleration due to gravity in m/s^2 at the project site

Q= discharge of water through the turbine is m^3/s

H = net head of water in m

$$= h_p + Z + \frac{V^2}{2g}$$

h_p = pressure head in m

Z = mean elevation of gauge pressure transmitter above the point of contact of all jets (centre line of the main inlet valve) at the Pelton wheel in m

V = average velocity of water flow at the inlet (measuring section) in m/s (Discharge Q/ area of cross-section of measuring section)

Finally, the efficiency of the turbine-generator unit in percentage is given by the following equation

$$\eta = \frac{\text{Electrical power output of genertor } (P_e)}{\text{Hydraulic power input to turbine } (P_h)} \text{ X } 100$$

4.5 Results of Unit Efficiency Test

The measured values of major parameters and the calculated values of efficiency of the four generating units before renovation are summarized in Table 1.

Table 1 – Summary of measurement results for efficiency test on generating units before renovation

Generating Unit	Net head (m)	Average discharge (m^3/s)	Power output (kW)	Unit efficiency (%)
1	338.787	6.010	14431.8	**72.41**
2	341.007	6.044	15598.2	**77.31**
3	339.238	6.112	14368.2	**70.74**
4	336.683	5.523	14568.0	**79.98**

5 POST-RENOVATION UNIT EFFICIENCY TEST

After renovation, the efficiency test was carried out in March 2013 using the same methodology and instruments as used earlier. But the test was conducted only on one of the four generating units at 100%, 80% and 60% of the rated load, which is 16.5 MW for the renovated machines.

5.1 Results of Efficiency Test

The average values of discharge, pressure head and electrical power output, measured as per earlier description, are used for calculating the unit efficiency at each load. Subsequently, the efficiency of the turbine is also calculated by dividing the unit efficiency with the generator efficiency, which had been evaluated earlier based on factory tests on the generator and is taken here as a given data. The results are summarized in Table 2.

Table 2 – Summary of measurement results for efficiency test on one generating unit after renovation

Quantity	**Load on unit**		
	100%	**80%**	**60%**
Averaged discharge (m^3/s)	5.634	4.504	3.380
Net head (m)	341.470	343.146	344.509
Electrical power output (kW)	16560.3	13302.9	9986.7
Unit Efficiency (%)	**87.77**	**87.76**	**87.46**
Generator efficiency as evaluated earlier (%)	98.43	98.28	97.96
Turbine Efficiency (%)	**89.17**	**89.30**	**89.28**

5.2 Assessment of Uncertainty of Unit Efficiency Measurement

5.2.1 Uncertainty of Discharge Measurement: Uncertainty of average velocity measurement by UTTF

under the prevailing conditions = ±2.0 %

Uncertainty of cross-sectional area and geometry of pipe = ± 1.5 %

Therefore, total uncertainty of discharge measurement is

$$f_q = \sqrt{2.0^2 + 1.5^2}$$

$$= \pm 2.5\ \%$$

5.2.2 Uncertainty of Head Measurement:

Uncertainty of gauge pressure transmitter	= ± 0.075 % of 500 m
	= ± 375 mm
Uncertainty of measurement of elevation of pressure transmitter	= ± 10 mm
Uncertainty of velocity head measurement	= ± 10 mm

Therefore, total uncertainty of net head measurement is

$$f_h = \sqrt{375^2 + 10^2 + 10^2}$$

= ± 375.267 mm in 340 m

= ± 0.110 %

5.2.3 Uncertainty of Electrical Power Measurement:

Uncertainty of wattmeter	= ± 0.2 %
Uncertainty of CT	= ± 0.2 %
Uncertainty of VT	= ± 0.2 %

Therefore, total uncertainty of electrical power measurement is

$$f_e = \sqrt{0.2^2 + 0.2^2 + 0.2^2}$$

= **± 0.346 %**

5.2.4 Overall Uncertainty of Unit Efficiency Measurement: Finally, the overall uncertainty of unit

$$f\eta = \sqrt{2.5^2 + 0.110^2 + 0.346^2}$$

efficiency measurement is

= ±2.526 %

6. CONCLUDING REMARKS

The result of measurement of discharge in the open channel revealed that the water conductor system was able to carry more water (24.193m^3/s) than the tail-race discharge of Shanan Hydro Power Station, viz. 20 m^3/s.

During the efficiency test on the four generating units before renovation, attempt was made to conduct the test on each unit at the same head and discharge. However the head varied from 336.6 to 339.0 m and discharge varied from 5.5 to 6.1m^3/s for different units. It is seen that unit efficiency of the four units before renovation was in the range of 70-80%. The minimum efficiency was observed as 70.74% for unit-3 and the maximum efficiency was observed as 79.98% for unit-4, which was the youngest unit (commissioned in 1981).

The results of post-renovation testing show that the unit efficiency has substantially improved and is 87.77% at rated load. Assuming that after renovation all the generating units have this efficiency value, the average gain in unit efficiency is 12.66%, with the minimum and maximum improvements being 7.79% (unit-4) and 17.03% (unit-3), respectively. The renovation has resulted in generation of more than 66 MW from the 4 units (now rated as 16.5 MW each) as compared to a power output of less than 60 MW before renovation, because even with full availability of discharge, some units could not generate the pre-renovation rated output of 15 MW. The plant load factor, which had fallen because of frequent maintenance, has now substantially improved due to all-time availability of the machines and running of the machines at full capacity due to modernization of controls.

ACKNOWLEDGEMENT

The authors acknowledge the financial support provided by Ministry of New and Renewable Energy, Govt. of India for field testing equipment at IIT Roorkee, HPSEB for sponsoring testing before renovation and M/s Andriz Hydro for testing after renovation. The support of Technical staff of AHEC is also duly acknowledged.

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