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Performance Testing and Evaluation of Small Hydropower Plants

H.K. Verma[1)] and Arun Kumar[2)]

1) Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee – 247667, India
2) Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee – 247667, India

Email (of corresponding author): hkvfee@iitr.ernet.in, hkvfee@gmail.com

ABSTRACT

In recent years the necessity of carrying out performance testing and evaluation of small hydropower (SHP) plants has been felt globally and initiatives have been taken in several countries to address this need. In India, performance testing is a pre-requisite to get subsidy for new SHP stations from the Government. This is carried out by a multi-disciplinary team of the Indian Institute of Technology Roorkee (IITR), generally as per the provisions of the International Standard IEC:60041 (1991) and the guidelines of the Government of India.

This paper presents the important details of the performance testing and evaluation carried out by the IITR Team on 18 SHP stations located in 5 States of India. Special attention is given to the more difficult and intricate aspects of these exercises, namely the selection and deployment of methods and instruments for the measurement of absolute water discharge, pressure head, free water level, net head and relative discharge. The difficulties experienced and challenges involved are also brought out in the paper.

Keywords: *Discharge measurement, water level measurement, index test on turbine, performance evaluation, performance testing, pressure head measurement, relative discharge measurement, unit efficiency test.*

1 INTRODUCTION

The necessity of testing and evaluating the performance of small hydropower (SHP) plants is felt globally due to a variety of concerns, some of which are as follows:

(a) Subcontractors with no domain expertise are being involved in design, construction or installation of SHP plants.
(b) Newcomer equipment suppliers without much experience are replacing the established manufacturers.
(c) The contractual relationships between the plant owner, designer, contractor and supplier are not very transparent.
(d) There are hardly any standards and guide-lines prepared for and addressing the issues related to SHP plants specifically.

The Government of India (GoI) Ministry of New and Renewable Energy (MNRE) lays considerable emphasis on the good performance of new SHP stations and wants to ensure it by linking the financial incentive to an SHP owner with the performance of the station put up by him/her. The requirements laid down in this regard are: (a) the power station should in general perform well, (b) the weighted-average efficiency of generating units should be at least 75%, and (c) the station should have attained 80% of the projected generation for a minimum of 3 months in continuation. In addition, the GoI wants to bring about total transparency in the contracts between the owner, contractor and equipment supplier with a view to ensure a healthy competition based entirely on the quality of services and products. To meet these objectives, the GoI has made the testing and evaluation of SHP stations, aimed at verifying their performance, mandatory for release of any subsidy.

This paper defines the scope of the performance testing and evaluation of SHP stations and reports on the rich experience gained by the multi-disciplinary testing and evaluation team of the Indian Institute of Technology Roorkee (IITR). Eighteen SHP stations have been tested and evaluated during the period of December 2004 to May 2007 in 5 States of India. These power stations have different installed capacities, unit types and sizes, heads and discharges, and use different methods of head creation (canal fall, dam toe or run of river). Salient features of the stations tested, alongwith the methods and instruments deployed for various measurements for the unit efficiency and index tests in relation to the relevant International Standards, namely IEC:60041 (1991) and IEC:61116 (1992), are presented. Each site had different parameters and presented a unique situation necessitating a critical examination in advance for the purpose of selecting the methods and instruments to be deployed for various measurements. The biggest challenge for the test team of IITR was to conduct the performance tests in the absence of provisions required for such tests in majority of the plants.

2 OBJECTIVE AND SCOPE OF PERFORMANCE TESTING

2.1 Objective

In broad terms, the dual objective of the performance testing of SHP stations can be stated as under:

(i) To verify that all parts, systems and auxiliaries in the power station are performing their assigned functions correctly.

(ii) To verify that the generating units in the plant are operating at or above the prescribed efficiency value.

The objective of (i) is to check the qualitative working of the power plant, while that of (ii) is to find out whether the generating units meet the mandated efficiency requirements.

2.2 Scope

The overall scope of performance testing is listed below:

(a) Inspection of all works, parts, systems and station auxiliaries
(b) Functional checks on devices and systems
(c) Error checks on measuring instruments
(d) Secondary injection tests on protective relays
(e) Operational tests on control systems
(f) Measurement of noise and vibrations of generating units
(g) Measurement of maximum power output of generating units
(h) Evaluation of efficiency of generating units
(i) Index test on turbines

Thus, performance testing comprises inspection, functional checks, tests, measurements and analysis as necessary to meet the broad objectives laid down in the previous section. Further details in respect of the three major tests at (g), (h) and (i) are given in the following sections.

3 PERFORMANCE EVALUATION

3.1 Maximum Power Output Test

The objective of the test is to verify the capacity of the generating units to deliver continuously the rated maximum power output specified by the manufacturer. It consists in running the machine at rated head and discharge (as far as possible) for a time long enough for the temperatures of the bearings and windings of the machine to stabilize. These temperature rises should not exceed the maximum permissible values. In case the head is different from the rated head of the turbine or the discharge available is inadequate, correction in the output power is made.

3.2 Unit Efficiency Test

The test aims at determining the actual efficiency of the generating unit(s) under specified conditions. This is the most difficult and time-consuming test in the whole exercise of performance testing of a power station. The efficiency of a turbine-generator unit is given by the ratio of the electrical power output of the generator to the hydroelectric power input to the turbine. The latter is equal to the product of the net water head availed by the turbine, the discharge rate through it, the density of water and the acceleration due to gravity of earth at the location of the plant. Therefore, the unit efficiency test involves measurement of absolute value of the discharge through the turbine, the net water head available at the turbine and the electrical power output of the machine, all under specified operating conditions and with high accuracy.

If the water head is high, the turbine efficiency can be determined alternatively from the water temperature rise due to the losses in the turbine using thermodynamic method and the generator efficiency can be taken from the factory or prototype tests conducted on it. However, this method has not so far been attempted by the IITR Team.

While IEC:60041 (1991) makes the unit efficiency test mandatory, IEC:61116 (1992), which applies to small hydraulic installations, makes the test optional in the following cases:

- (i) Where the machine size is small, not justifying the high cost of this test,
- (ii) Where the efficiency value is not of real use as the available water flow greatly exceeds the usable flow, or
- (iii) Where it is technically difficult to carry out the test.

Because of the requirements of release of subsidy from GoI, efficiency test is conducted on all SHP plants irrespective of these conditions.

3.3 Index Test

The index test aims, as per IEC:60041 (1991), at evaluating or verifying the following:

- (a) ***Relative variation*** in the unit efficiency with the load or the valve / gate opening, or
- (b) ***Relationship*** between the runner-blade angle and the guide-vane opening in the case of a double-regulated turbine.

The test therefore involves measurement of relative (indexed) discharge as opposed to the absolute-discharge measurement required for the unit efficiency test. It is worth noting that IEC: 61116 (1992) does not specify the index test. However, since the test can yield very useful information to the plant operators / owners for future evaluation / comparison and yet it is not expensive or cumbersome, it is carried out as far as possible.

4 SHP STATIONS TESTED BY IITR TEAM

Some salient particulars of the SHP stations tested by the IITR Team are given in Table 1 to facilitate discussion of the methods and instruments deployed for testing. Of the 18 SHP stations, 8 are based on canal-fall, 8 are run-of-river type and two are dam-toe based. The rated water head for 8 canal-fall based stations and the two dam-toe based stations is either 'low' or 'ultra low', the range being 10 m to 2.4 m. The actual net head in most of these cases was found to be even lower. Only one power station of canal-fall type, the rated head being 72 m, falls in the 'medium' range. Five of the 8 run-of-river power projects have either 'medium' or 'high' head (38 m to 290.4 m), the remaining three have only 'low' head (5.7 m to 17.5 m). The rated discharge per turbine ranges from 0.27 m^3/s (steel conduit) to 56 m^3/s (open channel). The installed capacities vary from a meager 150 kW to 24.75 MW, while the machine sizes vary from 150 kW to 8.25 MW. All types of turbines, including syphon-intake Kaplan, have been tested during these exercises. Excepting one SHP station in Punjab state, that uses an induction generator, all of them use synchronous generators.

Table 1: Particulars of the SHP Stations on which performance testing has been conducted

S. No.	Name of SHP Station, State	Type of project	Type of turbine/shaft	Rated capacity (MW)	Rated head (m)	Rated discharge of turbine (m^3/s)
1.	Madhavaram, AP	Canal-fall based	Kaplan/vertical	2x2	6.88	34
2.	Babbanpur, Punjab	Canal-fall based	Semi-Kaplan/ vertical	2x0.5	2.4	26
3.	Chakbhai, Punjab	Canal-fall based	Kaplan/ vertical	2 x 1	4.37	26.797
4.	Ching, HP	Run of river	Pelton/horizontal	2x0.5	145	0.43
5.	Manal, HP	Run of river	Pelton/horizontal	2x1.5	201.35	0.88
6.	Sahyadri, Karnataka	Canal-fall based	Semi-Kaplan/ vertical	1x0.3	5.5	5.68
7.	Someshwara, Karnataka	Run of river	Kaplan/ vertical	3x8.25	17.5	56
8.	Aleo Manali, HP	Run of river	Pelton/horizontal	2x1.5	290.4	0.63
9.	TB Dam, Karnataka	Dam-toe based	Kaplan/horizontal	3x2.65	10	31.2
10.	Sugur, Karnataka	Run of river	Kaplan/ vertical	3x1.5	5.7	32.2
11.	Mandegere, Karnataka	Canal-fall based	Kaplan/horizontal	2x1.75	6.8	30.86
12.	Chunchi Doddi, Karnataka	Run of river	Francis/horizontal	3x3.5	96	4.1
13.	Varahi Tail Race, Karnataka	Run of river	Kaplan/ vertical	3 x 7.5	38	23.61
14.	Killa, Punjab	Canal-fall based	Kaplan/ vertical	2 x 0.875	4.49	22.986
15.	Lohgarh, Punjab	Canal-fall based	Syphon- intake Kaplan/vertical	2 x 1	3.63	30.2
16.	Salag, HP	Run of river	Francis/horizontal	1 x 0.15	72	0.27
17.	Sahoke, Punjab	Canal-fall based	Kaplan/vertical	1 x 1	5.17	22.732
18.	RAB Sagar, MP	Dam-toe based	S-type Kaplan / horizontal	2 x 5	5.6	43.17

Conventional type measuring instruments and protective relays are used in very small-capacity SHP stations because of their low cost and simplicity. In relatively larger SHP stations digital instruments and relays are employed, while the largest amongst them use numerical and management relays alongwith SCADA equipment. The degree of automation (auto-synchronization, PLC-based unit control and remote on-load tap changer etc.) is also found to vary in a similar fashion.

5 SELECTION OF METHODS AND INSTRUMENTS

As highlighted above, the nature and complexity of the metering, protection and control equipment employed vary from one power station to another. Accordingly, the test-procedure and test-equipment deployed for testing them had to vary. But the selection of methods and instruments for carrying out various measurements required in connection with the unit-efficiency and index tests presents the real challenge for several reasons. Firstly, each power station is different from others. Secondly and more importantly, hardly any provisions are made for carrying out such measurements on the plant equipment during manufacturing and on the water conductor system during construction. The other problems are the need to minimize shut down duration and cost of testing, non-availability of adequate water discharge and / or head during testing and lack of qualified and experienced engineers at site. The following paragraph give an insight into the test methods and instruments recommended by the International Standards, those selected by IITR Team, the basis of such selection and the deployment details.

5.1 Discharge Measurement

IEC:60041 (1991) specifies the following methods of discharge measurement and gives some application guidance for each method:

- (a) Current-meter method
- (b) Pitot-tube method
- (c) Pressure-time method
- (d) Tracer method
- (e) Weirs
- (f) Differential pressure devices
- (g) Volumetric gauging method
- (h) Ultrasonic transit-time flowmeter (UTTF)

The choice of the method of measurement may be affected, as per the above Standard, by the following factors:

1. Limitations imposed by the design of the plant
2. Cost of special test equipment and its installation
3. Limitations imposed by plant operating conditions, for example draining of the system, constant-load or constant-discharge operation, etc.

The Standard also recommends that provisions should be made in the plant by its owner for discharge measurement by at least two methods. Moreover, in case of penstock, a straight horizontal length without bonds alongwith some exposed portion and in case of open headrace or tailrace channel a straight section of uniform cross-section should be available to facilitate discharge measurement with current meters or UTTF. This rarely happens in reality because of lack of awareness and appreciation of these requirements, making the job of the test team very difficult. Very often compromise becomes necessary in the selection of method or instrument and / or deployment technique, leading to a larger uncertainty in measurement.

The IITR Team used a horizontal array of propeller current meters in the open power channel of several SHP stations. In each case, the current meters were fitted on steel-pipe mounting frame, which was moved vertically with a crane or chain-pulley block; see Gandhi & Verma, [2007] for details. The straight section of the channel was too short in each case and, therefore, uncertainty of measurement was high. In a few SHP stations, the array of current meters was installed at the intake/draft-tube gate and the mounting structure attached below the gate was moved vertically with the help of a motorised hoist or chain-and-pulley block. In one power station, only a single current meter could be fixed to the intake gate because of a serious space constraint, and this resulted in even higher uncertainty of discharge measurement. In one dam-toe based station, a matrix of 15 current meters was fixed on a hydraulically stream-lined steel frame through welding inside the steel duct downstream of the intake gate [Gandhi & Verma, 2007].

In the remaining 4 SHP stations, all in Himachal Pradesh, circular steel pipes are used as penstock. Clamp on type UTTF was installed on the penstock for discharge measurement in these stations (see figure 1). Because of high heads, drilling of the penstock for inserting wet-type UTTF transducers was not acceptable to the plant owners. Clamp-on transducers lead to a larger uncertainty of measurement as compared to wet-transducers.

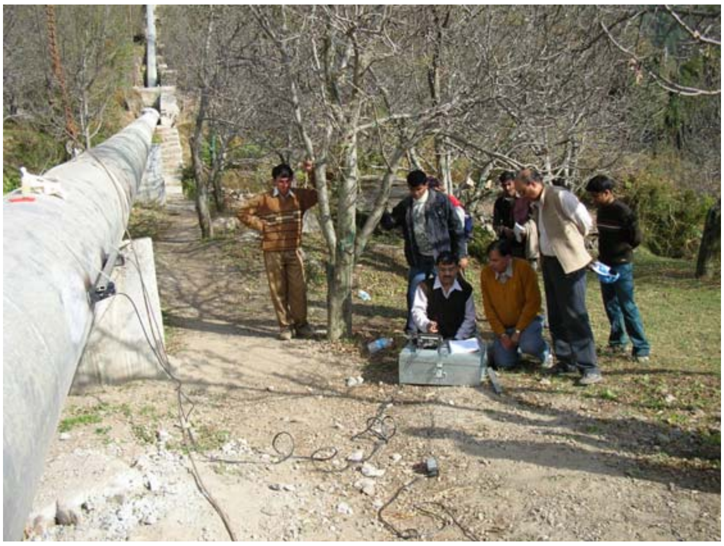

Figure 1: Discharge measurement with UTTF transducers clamped on penstock

5.2 Head / Level Measurement

Measurement of net water head available at the turbine is obtained from the difference of the total water heads at the inlet and outlet of the turbine. In many situations, the conditions are not conducive to measuring the water head or free water level at the inlet of the turbine or at the outlet of the draft tube. In such a case, the values measured need to be corrected for the head losses taking place between the measurement point and the intake or between the draft tube outlet and the measurement point, respectively. Evaluation of the total head at the turbine-inlet and draft-tube-outlet requires: (a) marking of reference levels at or near these points using a high-precision electronic total-survey station, (b) measurement of either the pressure head or the free water level at / near these points, (c) calculation of velocity heads at these points from the discharge rate already measured, (d) calculation of gross head by taking the difference of total heads so evaluated, and finally (e) assessing the head losses, if any, and subtracting from the gross head to obtain the net head.

The methods recommended in IEC:60041 (1991) for measuring pressure head are liquid-column and dead-weight manometers, spring pressure gauges and electronic transducers. IITR Team uses the last method, wherein a high-precision pressure transducer with digital readout is deployed. Figure 2 shows this type of instrument connected to a box-type pressure equalizer which joins the pipes coming from four pressure taps on the draft tube. In most of the power stations where this method was used, such pressure taps and pressure equalizer had to be arranged at the time of testing in conformity with the said Standard.

Figure 2: Digital pressure transducer installed for head measurement at draft tube

The methods recommended for free water level measurements in the Standard are bubbler with compressed air, immersible pressure gauges and ultrasonic level sensors. The IITR Team deployed high-precision immersible pressure transducers with either local or remote digital display (as per the requirement) in the few situations where the channel bed was not covered by silt and proper measuring well had already been constructed as laid down in the above Standard. In other cases of free-water level measurement in open channels, a digital ultrasonic level sensor was installed at either abutment (see figure 3). For this purpose, location with minimum surface turbulence is selected. Average of the levels measured by the two sensors installed on opposite abutments is used in head calculation.

Figure 3: Ultrasonic level sensor installed on left side abutment of headrace channel for free water level measurement

5.3 Power Measurement

For measurement of the power output of a generator, a portable digital reference wattmeter (of accuracy class 0.2) is connected in parallel to the panel wattmeter of the generator. Where a test terminal block or sliding-links in the CT terminals are provided in the metering panel of the generator, the reference wattmeter can be connected in the circuit for the test conveniently, that is, without shutting down the machine or opening its circuit breaker after removing the load. Even such a simple and inexpensive provision was not available in some SHP stations, possibly out of ignorance.

5.4 Relative Discharge Measurement

The relative discharge measurement required for the index test can be carried out by one of the following or similar methods [IEC:60041(1991)]:

(i) Winter-Kennedy method can be used to access the relative discharge by measuring the differential pressure between two suitably located pressure taps on the turbine case. Figure 4 shows how a digital differential pressure transducer is deployed for this measurement.

Figure 4: Differential pressure transducer installed for relative discharge measurement for the index test

(ii) As an alternative to (i) above, pressure taps can be provided near the two ends on a taper piece in the penstock or on two sides of a bend in the penstock.
(iii) Average-velocity measurement with a single-path ultrasonic transit-time flowmeter.
(iv) Point-velocity measurement by means of a single current meter. For better results, IITR Team used average-velocity measurement by locating a row of (multiple) current meters at a depth of 0.6 times the total water depth.

In many power stations tested by the IITR Team, none of above provisions was available / possible. In four of them, the head being high, the discharge was small and it was possible to temporarily install an uncalibrated thin-sheet rectangular weir and measure the water head over the weir using an ultrasonic level sensor (see figure 5).