PERFORMANCE TESTING OF SHP STATIONS: WHY, WHAT AND HOW?

Dr. H.K. Verma
Professor of Electrical Engg
Indian Institute of Technology Roorkee
Roorkee – 247667
hkvfee@gmail.com

1. INTRODUCTION

Different countries define small hydro-power (SHP) stations or projects with different upper limits of plant capacity. In India, a hydro-power station with an installed capacity of 25 MW or less is taken as a SHP station. Furthermore, smallest hydro-power stations with installed capacity upto 100 kW are called as 'micro' and those with a capacity between 101 kW and 2000 kW as 'mini' hydro power stations.

The total potential of SHP projects in India is estimated at about 18,000 MW. A total of 5815 potential sites with an aggregate capacity of 16,090 MW have been identified till March 2010. As of March 2009, 2430 MW had been harnessed through 674 SHP projects and a further capacity of 483 MW was being added through 188 projects under implementation.

2. Need of Performance Testing

More than 80% of the identified SHP potential still remaining untapped, the Government of India (GoI) now encourages and financially assists the power producers in taking up new SHP projects. The financial assistance from GoI in SHP sector is also available for certain other purposes. In regard to new SHP projects, the main concerns of GoI are that the generation should be as designed and projected, the generation efficiency is as guaranteed, the equipment conforms to standards and the power quality is good. To that end, the release of financial assistance by GoI is subject to the fulfillment of several conditions as follows:

(a) Project should have attained 80% of projected generation for minimum of 3 months.
(b) Weighted average efficiency of generating units should be at least 75% (with certain exceptions).
(c) Overall performance of the station should be good.
(d) Plant equipment should conform to Indian/International standards.
(e) Tender document should contain adequate penalty and guarantee clauses.
(f) Bidding process should be transparent.

The Government of India has, therefore, made performance testing and evaluation of new SHP stations mandatory for availing financial assistance. It has identified AHEC, IIT Roorkee as the testing agency for this purpose, and provided to it funds for procuring necessary test equipment.

The multi-disciplinary test team comprises not only the faculty and scientists of AHEC, but also the faculty from the Departments of Electrical Engineering, Civil Engineering and Mechanical Engineering of IIT Roorkee. During the past 7 years (Dec. 2004 to Dec. 2011), the team has tested 99 SHP stations with station capacities ranging from 1 x 150 kW to 3 x 8.25 MW, heads ranging from 1.86 m (semi-Kaplan turbine) to 530 m (Pelton turbine) and generators of synchronous and induction types. These exercises have also given the team a variety of experience in terms of the designs and technologies used in the hydro-power stations and the methods and instruments employed for conducting various performance tests.

3. OBJECTIVE AND SCOPE OF PERFORMANCE TESTING

3.1 Objective

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

(a) To check and verify that all parts, systems and auxiliaries in the power station are performing their assigned functions ***correctly***.
(b) To test and verify that the generating units are operating ***efficiently***.

The objective at (a) is to check the ***qualitative working*** of the power station, while that of (b) is to find out whether the generating units meet the efficiency requirements ***quantitatively***.

3.2 Scope

The overall scope of performance testing is listed below:

(a) Inspection of all parts, systems and station auxiliaries.
(b) Functional checks on simpler 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 the parameters critical for generation.
(g) Measurement of maximum power output of generating units.
(h) Verification of efficiency of generating units.
(i) Generating additional information through index test.

Thus, performance testing comprises inspection, functional checks, tests, measurements and analysis as necessary to meet the broad objectives laid down earlier. Further detailing in respect of the testing of each individual major component/system is given in the following sections. It should be understood that the tests named here are carried out subject to the technical feasibility. Furthermore, detailed diagnostic investigations on any faulty component/system are outside the scope of performance testing.

4. WATER CONDUCTOR SYSTEM

4.1 Overall Inspection

To begin with, the complete water conductor system is inspected to observe any apparent problems or deficiencies in its design or construction.

4.2 Measurement

The following measurements are made if instruments are already installed in station with a view to make an initial assessment.

(a) Different water levels/pressures
(b) Gross head
(c) Discharge rate

5. GENERATOR

5.1 Currents and Voltages

The following quantities are measured on each generator at different loads to verify the working of the generators:

(a) Line currents
(b) Terminal voltages
(c) Power
(d) Power factor
(c) Excitation voltage / current

5.2 Temperature Rise

Any overheating in the generators would be revealed in the following temperature rise measurements:

(a) Temperature rise of stator
(b) Temperature rise of rotor
(c) Temperature rise of cooling medium

6. TURBINE – GENERATOR UNIT

6.1 General Health

Temperature rise, sound level and vibration levels are the good indicators of the general health of any machine. To that end, the following measurements are carried out on each generating unit, subject to the accessibility of the relevant part for fixing sensor(s):

(a) Temperature rise of bearing oil
(b) Sound level
(c) Bearing vibrations
(d) Shaft vibrations

6.2 Performance Measurement

(a) Maximum Power Output

The maximum electrical power output actually available from the generating unit should match the value specified by the manufacturer. The test should be conducted at rated head and discharge as far as possible.

(b) Unit Efficiency Test

The test aims at determining the absolute (actual) efficiency of the generating unit or the turbine under specified conditions. This is the most difficult and most expensive test in the whole exercise of performance testing of a power station. It 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 each ***with high accuracy***. Efficiency can be determined alternatively from the water temperature rise due to the losses in the turbine using thermodynamic method in case water head is 500 m or more.

The standard IEC-60041 specifies the following eight methods of discharge measurement and mentions limitations and scope of each method, while also giving their application details ***(Reference 1)***:

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

Methods at (a) and (h) are more commonly suited and more often used. The choice of the method of measurement may be affected, as per IEC-60041, by the following factors:

(a) Limitations imposed by the design of the plant
(b) Cost of special equipment and its installation
(c) Limitations imposed by plant operating conditions, for example draining of the system, constant load or discharge operation, etc.

While IEC-60041 makes the unit efficiency test mandatory, IEC-61116 (that addresses SHP installations) makes the test optional in the following cases ***(Reference 2)***:

(i) The machine size is small not justifying the high cost of performing this test.
(ii) The efficiency value is not of real use as the available water flow greatly exceeds the usuable flow.
(iii) It is technically difficult to carry out the test.

The standard IEC-62006 classifies small hydraulic installations as under on the basis of measurements / tests requirements ***(Reference 3)***:

Measurement Class A: Normal Test Program
Measurement Class B: Extended Test Program
Measurement Class C: Comprehensive Test Program

IEC-62006 lays down the requirement of efficiency test for Class C only.

(c) Index Test

The test involves the measurement of relative (indexed) discharge as opposed to the absolute discharge measurement for the unit efficiency test. As per IEC-60041, the test aims at evaluating or verifying the following:

(i) The relative variation in the unit efficiency with the load.
(ii) The relative variation in the unit efficiency with the gate / valve.
(iii) Relationship between runner blade angle and guide vane opening in the case of a double regulated machine.

The relative discharge measurement required for the index test is possible by one of the following methods (IEC-60041):

(i) Measurement of pressure difference between suitably located taps on the turbine spiral case (Winter-Kennedy method).
(ii) Measurement of pressure difference between suitably located taps in tubular turbines.
(iii) Measurement of pressure difference between suitably located taps on a bend or taper section of the penstock.
(iv) Single-path ultrasonic transit-time flowmeter.
(v) Measurement by means of a single current meter
(vi) Measurement of needle stroke on pelton turbines.

IEC-61116 does not mention the index test on turbines, whereas IEC-62006 specifies it for machines of Class B and Class C only. Since the test can yield useful information and is not very expensive, it may be carried out on every machine, if technically feasible.

7. MEASURING INSTRUMENTS AND INSTRUMENT TRANSFORMERS

7.1 Error Checks

All ***electrical panel meters*** (ammeters, voltmeters, kilowatt and power factor meters, energy meters, frequency meters) and ***digital multi-function meters*** are subjected to a limited error check. The readings of these meters at the respective operating points are compared against a portable reference meter to measure their errors at the most important point(s), that is the points around which they are usually required to measure. If a meter is found to have an error beyond its accuracy class, further testing would be desirable.

A similar check may be carried out on ***speed indicator,*** if necessary. Comparison may be made against a reference frequency meter (as also recommended in IEC-308) because of the high resolution and accuracy of reference frequency meters.

7.2 Functional Checks

In view of the non-critical nature of the parameters measured/recorded and difficultly in placing transducers, error measurement on the following instruments may not be carried out. Instead, simple checks on their functioning may suffice.

(a) Gate / valve / needle position indicators
(b) Speed indicators
(c) Temperature indicators
(d) Temperature scanners

7.3 Ratio Tests

The CT and VT ratios may be verified, if in doubt, either on-line by measuring the primary and secondary currents/voltages, or off-line by measuring the transformer ratio using a digital turns ratio tester.

8. PROTECTIVE GEAR

8.1 Secondary Injection Tests on Measuring Relays

A portable secondary injection test set is used to test all the measuring relays (or various relay functions of multi-function digital relays). Normally it is considered sufficient to carry out operating value and operating time tests (the latter for time delay relays and delay elements only) at the prevailing relay settings. In case of the doubtful working of a relay, a more detailed secondary injection test may be conducted. The relays employed in a SHP station for generator protection may include some or all of the differential, over-current, earth-fault, voltage-controlled over-current, restricted earth fault, over and under voltage, negative sequence, directional power and field-failure relays. Transformer protection may include differential, over-current, earth-fault and restricted earth fault relays.

8.2 Functional Checks

Functional checks on the following would be normally enough:

(a) Circuit breakers
(b) Tripping / master relays
(c) Auxiliary relays
(d) Fault annunciators

9. CONTROL PANELS AND SYSTEMS

9.1 Control Panels

Before testing control systems, an inspection and functional checks on various parts/accessories of the control panels and desks, as listed below, are carried out to identify the defective parts or accessories, if any:

(a) Indicating lamps
(b) Push buttons
(c) Selector & control switches
(d) Panel light
(e) Panel light switch
(f) Space heater
(g) Thermostat for space heater
(h) Buzzers / bells / hooters
(i) MCBs / MCCBs / Contactors
(j) Other functionally important devices

9.2 Regulation / Control Systems

The following regulation and control systems are tested to verify their overall functioning. Quantitative tests on them are generally not required:

(a) Flow regulation
(b) Level regulation
(c) Field regulation
(d) Manual synchronization
(e) Automatic synchronization
(f) Manual and automatic start / stop sequences
(g) Emergency stop sequence
(h) Tap-changer control
(i) Tap-changer AVR relay
(j) Governor
(k) AVR

10. Power and Station Transformers

10.1 Temperature Rise

Of all the major power equipment in a power station, transformer is least troublesome. Unless a problem has been experienced with a transformer, its general condition can be verified by measuring the temperature rise of the main and conservator tanks.

10.2 Ratio Test

If there is a reason to doubt the transformer ratio (possibly due to shorted turns), transformer ratio test can be carried out. A portable digital turns ratio tester can measure this ratio with an accuracy of 0.1 percent. However, the test requires a shutdown and complete isolation of the power transformer from the system.

11. STATION AUXILIARIES

Satisfactory working of all auxiliary systems, or station auxiliaries as they are generally called, is essential for the successful operation of the power plant. However, some of them are extremely critical (e.g. station d.c. supply), and others are not so critical (e.g. drainage system or dewatering system). A thorough inspection of all the station auxiliaries present should be carried out to verify that all of them are functioning normally. They may include the following:

(a) Station AC supply
(b) Station DC supply
(c) Emergency power supply
(d) Oil pumping units
(e) Cooling system
(f) Vacuum pumps
(g) Air compressors
(h) Drainage system
(i) Dewatering system
(j) Earthing system(s)
(k) Equipment handling crane and hoists
(l) Other auxiliaries, if any

12. STEPS IN PERFORMANCE TESTING AND EVALUATION

The performance testing of SHP station is carried out in five steps as follows:

12.1 Power Station and Generation Data Collection

All important data and drawings of the SHP station, relevant for the survey, inspection, checking and testing of the power station, are obtained from its owner. The owner would obtain a large part of this data from the design consultant, contractor and equipment manufactures concerned. In addition, the generation data for the period starting with commissioning date and the projected generation as per DPR are obtained from the owner.

12.2 Planning

Based on the data and drawings obtained, the test agency then plans inspection, checks and tests that need to be carried out, and prepare a complete schedule of checks/tests. Constraints like non-availability of provisions for certain difficult tests, like index test and turbine efficiency test, and inadequacy of water etc. need to be considered at this stage.

Due to general lack of awareness on the part of power station designers, generally the provisions necessary for measuring discharge rate, water levels and water head are not made in power stations. An advance visit, where necessary, can be made to recommend installing of certain facilities, like the following ones.

(a) Drilling holes and fixing pressure taps at the inlet to the turbine, on its casing, or on a taper piece in, the penstock depending upon the situation.

(b) Installing a manifold for pressure equalization between pressure taps.

(c) Installing a thin plate weir in the tail race.
(d) Exposing a portion of the penstock, or making access to an already exposed portion, for fixing an ultrasonic transit-time flowmeter.

(e) Fabricating a frame for mounting propeller current meters for discharge rate measurement.

12.3 Instrument Checking / Recalibration

The necessity of rechecking or recalibrating the test instruments should be examined and necessary actions should be taken so that the instruments are fit for conducting tests at site.

12.4 Site Tests

Inspection, functional checks and tests in the power station are then conducted as per the schedule. As a good practice, each ***vital parameter*** should be measured by two independent methods as far as possible, one of which is used in the preparation of test report and the second one is for cross checking of the results of the first method.

12.5 Reporting

Finally, a test report is prepared. For each major test or measurement, the report mentions the method and instrument used alongwith the test results. For critical measurements, an assessment of the uncertainties of measurement is made. Remarks and conclusions on the test results are given for the benefit of the end users of the report. The remarks are normally expected in the form of `satisfactory' or `not satisfactory' for each inspection /check/test.

The actual and projected generation data are analyzed. The weighting factors for different loads are obtained from the flow-duration curve. These weighting factors alongwith the values of the unit efficiency at different loads are used to calculate the weighted average efficiency.

The report, at the end, may give conclusions with respect to the following:

(a) General design and quality of construction of the power station.
(b) General performance of each major part, system and auxiliary in the power station.
(c) Actual generation vis-à-vis projected generation.
(d) Weighted average efficiency of generating units.
(e) Conformity of the plant equipment to Indian/International standards.

References

1. IEC Standard 60041, “Field Acceptance Tests to Determine the Hydraulic Performance of Turbines, Storage Pumps and Pump Turbines”, 1991.

2. IEC Standard 61116, “Electromechanical Equipment Guide for Small Hydroelectric Installations”, 1992.

3. IEC Standard 62006, “Hydraulic Machines - Acceptance Tests of Small Hydroelectric Installations”, 2010.