Experience with Ultrasonic Transit Time Flow Meter for Hydro Power Plant Efficiency Measurements

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Abstract

During efficiency measurement of hydro turbine in a hydro power plant is critical and tedious task. In case of discharge measurement in closed conduit (penstock), Ultrasonic Transit Time Flow meters (UTTF) especially clamp on type is considered to be more popular due to ease in installation, low cost and less time required for installation. However its accuracy is some time under question as its accuracy depends on surface roughness of penstock and velocity profile at the location of measurement which are not accurately known. Under the present paper, experiences with UTTF gained during field acceptance tests conducted at several hydro power plants in different part of India for efficiency measurements are discussed. Difficulties faced in receiving the signals for different pipe diameters response obtained with UTTFs of different models for some discharge conditions are presented. Based on the experiences, it is found that estimation of differential time of flight accurately is a challenging task and high time resolution is required especially in small diameter pipes. Further the accuracy in the measurement of discharges varies with the incident angles and delay in absolute propagation time has also been experienced.

1. Introduction

In India, hydro power plants having installed capacity upto 25 MW are categorized as small hydro plants (SHP). The estimated potential of SHP projects in India is about 20,000 MW and as per the records of Ministry of New and Renewable Energy (MNRE) 2016, only 4,341 MW has been exploited so far. A review on the small hydro power development in India has been carried out by Mishra et al. (2015). Government of India (GoI) encourages and supports private SHP developers with financial incentive. Before release the incentive amount, performance evaluation of SHPs is mandatory. MNRE assigned Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee (AHEC/IITR) to carry out the performance testing for these SHPs plants. Efficiency measurement of hydraulic turbine is the main task in the performance evaluation of a SHP plant.

For evaluation of hydraulic turbine efficiency, discharge measurement is an important and tedious task. AHEC conducted efficiency test as per AHEC standard (2012) on more than 200 small hydro projects and it has been found that discharge measurement in closed conduit as well as in large discharge open channel is a challenging task. In order to measure the discharge, flow measuring devices are grouped in three main categories as (i) integrative methods viz differential pressure measurement (ii) semi integrative methods viz acoustic measurement and (iii) sampling based methods which are discrete number of velocity measurement using velocity area methods. So far AHEC has used non-intrusive UTTF at 132 hydropower stations for discharge measurement.

Non-Intrusive Ultrasonic transit time flow meter (UTTF) now a days is very popular method for measuring the discharge as it is considered a simple, less time consuming and low cost method. The main advantage to use on-intrusive UTTF as it is designed to clamp the ultrasonic sensor outside of the pipe without drilling the penstock or interrupting the flow. Sanderson et al (2002) provided the guide lines for use on non-intrusive UTTF.

1.1 Working Principle of Non – Intrusive UTTF

The difference in time is measured by UTTF when an ultrasonic signal is transmitted from the first transducer and is received by the second transducer after crossing the pipe flow. A comparison is done for upstream and downstream measurements. During the presence of flow, sound wave moves faster if traveling in the same direction and slower if moving against it. Since the ultrasonic signal is to travel the pipe section before being received by the sensors, the liquid should not contain significant amount of solids or air bubbles, which otherwise weak the signal.

The discharge is measured by using transit time difference between ultrasound wave travelling from transducer T1 to transducer T2 and from transducer T2 to transducer T1 as shown in Fig. 1. If the ultrasonic beam in the fluid is at an angle θ to the pipe axis then the volumetric discharge Q_v is related to the time difference $\Delta T = T_{12}-T_{21}$ by Eq. (1);

$$Q_v = \frac{k.\pi.D.c_1^2.\,\Delta T}{16.cot\theta} \qquad (1)$$

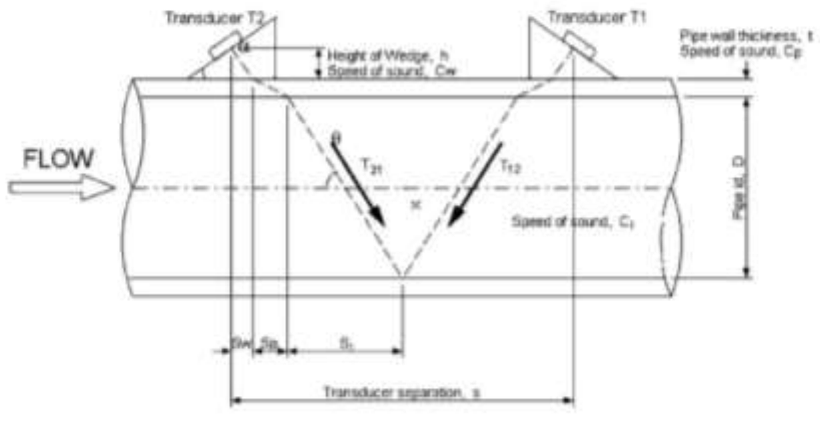

Figure 1: Schematic diagram of a clamp-on transit time flowmeter [Sanderson and Yeung (2002)]

where c_1 is the speed of sound in the liquid, D is the internal diameter of the pipe and k is the correction factor as given in Eq.2;

$$k = \frac{\overline{v}_{pipe}}{\overline{v}_{beam}} \qquad (2)$$

Where, $\overline{v}_{pipe}$ is the actual velocity in the pipe, and $\overline{v}_{beam}$is the average velocity measured along the beam.

For Speed of sound in pipe material (c_w) with an angle α to the pipe axis, it can be represented by Eq. 3;

$$Q_v = \frac{k.\pi.c_1.c_w.D.\sqrt{1-\left(\frac{c_1.sin\alpha}{c_w}\right)^2}.\Delta T}{16.sin\alpha} \qquad (3)$$

For better accuracy in the measurements, it is necessary to obtain an accurate distance between the transducer T1 and T2.

The spacing between transducer can be determined by using Eq.4;

$$s = 2s_w + 2s_p + 2s_1 \qquad (4)$$

where, s_w is the separation through the wedge, s_p is the separation through the pipe and, s_1 is the separation through the liquid

Measurement in UTTF highly depends on velocity profile in both fully developed and distributed flow conditions. The average velocity along the beam is established by UTTF .Thus value of k in Eq. 1 is not unity and depends on

Reynold number and pipe surface roughness. Lynworth1979 presented the variation of k with Reynold numbers for smooth pipe as shown in Fig.2 .

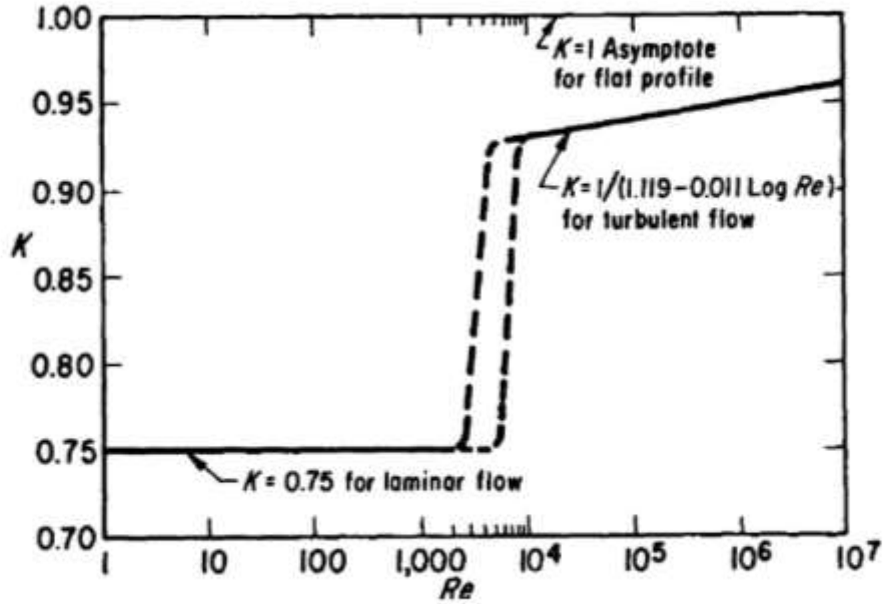

Figure 2: k factor against Reynold number against fully developed flow in smooth pipe [6].

Ioss et al (2002) carried out experiments regarding the uncertainty of UTTF due to flow profile and turbulence as UTTF provides a flow velocity averaged along the particular acoustic path [5]. Uncertainty in UTTF measurement is comparatively found to be more than the other methods of discharge measurement. Moore et al (2000) carried out the work on UTTF with theoretical velocity profile and concluded that the weightage of individual path velocities can be chosen to control errors especially for extremely non-uniform or asymmetric flow profiles [10]. Distance between the transducers is also an important factor for accuracy of measurement. Mahadev et al (2008) discussed the effect of separation distance between the transducer on the flowmeter output signal and developed a ray tracing method to model the ultrasonic wave propagation [8]. This allows the contribution of each wave path, including internal wall reflections.

UTTF of different makes models such as Siemens, GE, RR and Ultra flux have been used for discharge measurement at various hydro power plants in different parts of India by AHEC. Based on experience of using UTTF for discharge measurements of SHP plants in the field, various aspects related to UTTF application are discussed in this paper. Comparison of readings taken by different models of UTTF taken at the same location has also been made. The locations of the power plants are shown in Fig.3 where discharge was measured with UTTF. Features and parameters of power plants are given in Table 1. During discharge measurement UTTFs were installed on common penstock and distance between two pairs of transducer was kept 4D-5D, (where D is the diameter of pipe).

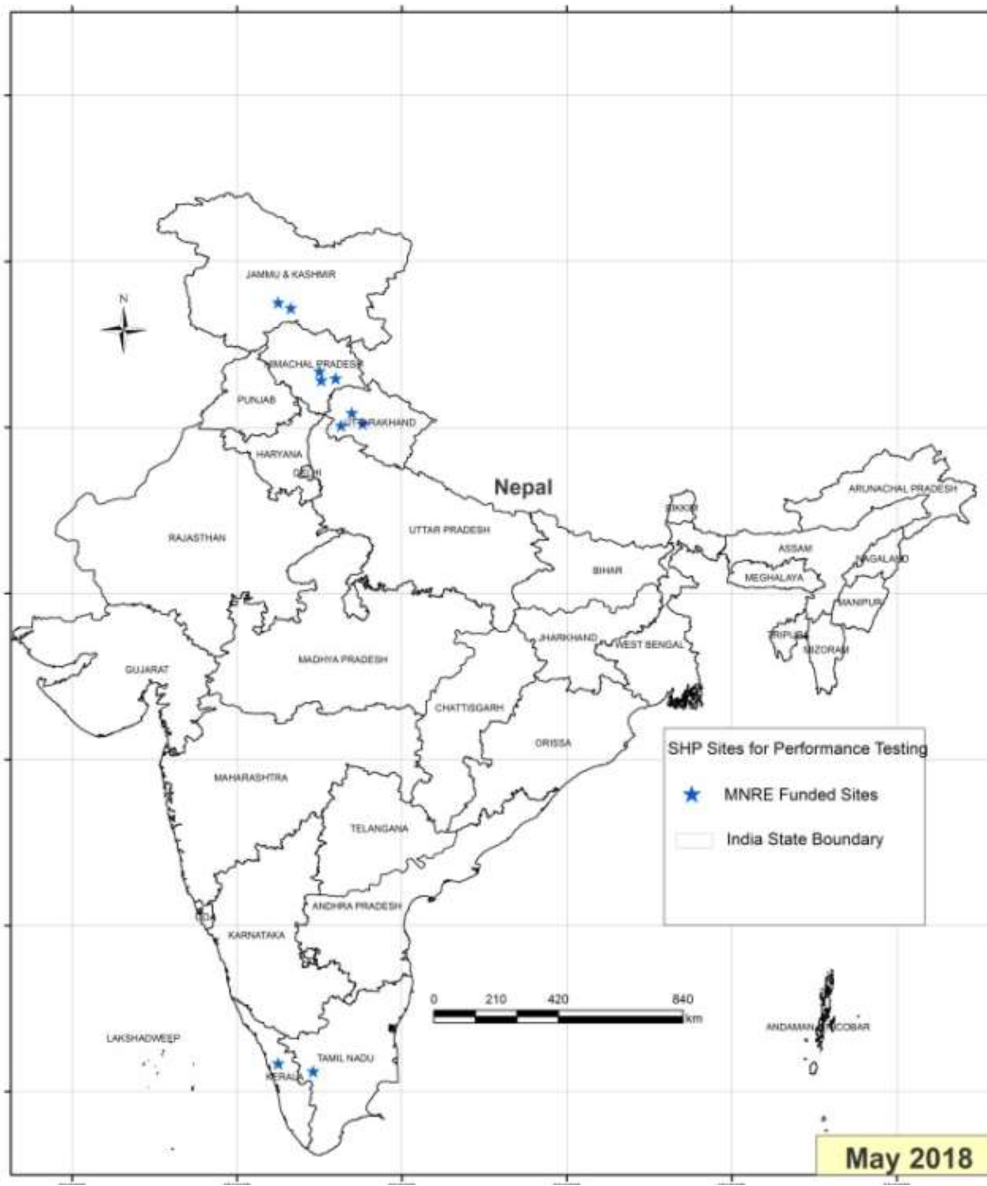

Figure 3: Location of the power stations where performance evaluation were carried out

Table 1: Features and Parameters of Hydro Plant where UTTF was used for discharge measurement.

S. No.	Hydro Power Projects	No. of Units x Capacity(MW)	Unit Rated Discharge (m^3/s)	Penstock diameter (m)	Thickness (mm)	Inclination of Penstock
1	PeriyarHEP	4 × 42	13.12	2	18	45^0
2	Nanti	2 × 7	8.3	1.5	16	10^0
3	Bhilangana	3 × 8	4.33	2.3	24	30^0
4	Motighat	2 × 2.5	4.795	1.8	14	10^0
5	Gangani	2 X 4	6.643	2.7	16	10^0
6	Jogini II	2 x 2.5	2.3	1.7	16	30^0
7	Ghanvi II	2 X 5	3.5	1.4	18	45^0
8	Phoozhithode	3 X 1.6	2.56	1	10	60^0
9	Ranhjha Ala dunadi	2 X 7.5	5.81	2.24	20	70^0
10	USHP II	3 X 35	17	3.5	16	10^0

2. Measurements

For Evaluation of the turbine unit efficiency, measurement of three parameters are required to be measured namely the discharge through turbine, the net head available to the turbine and the electrical power output of the generator. Table 1 gives the summary of features and parameter of SHP plants where efficiency tests were conducted. The best possible location was selected at the common penstock. Two UTTFs of different makes were installed for discharge measurement at each power station and the pair of transducers of flow meter was fixed in reflection mode as shown in Fig.4. Readings of UTTFs were averaged over 120/60 second periods by the respective instruments at full and partial loads condition of machines.

Typical sets of discharge reading taken during unit efficiency measurement for turbines at Periyar Hydro station are given in Table 2. The deviation observed in the discharge reading taken by two different UTTFs is also shown in Fig. 5. Inclination of the penstock was about 45^0. Under such conditions, where penstock was inclined, UTTFs were installed in reflection mode. Measurement has been conducted on full load and partials loads for particular time duration and it was observed that with increase in load, variation in discharge value measured by UTTFs of different models has been found to be more. With increase in load, Reynold number increased which results in the high turbulence in flow. With more turbulence more variation in discharge has been found. Variations in UTTFs were found between the ranges 3.3 % to 5.3%. Same methods of discharge measurement have been deployed in hydro power station listed in Table 1 because of similar site condition and it has been observed that with increase in inclination of penstock, variation in discharge reading is found to be more. Variations in UTTFs at these sites are mention in Table (2-12) and deviation in reading is shown in Fig. (5-14). Also proper clamping (using strap) of transducer is required where inclination is more than 45^0 because propagation of acoustic signal at inclined pipe is interrupted. Other observation has been made during measurement is moisture on the surface of penstock which also affected the signal transmission cause delay in transmission. At some site vibration in penstock was also noted which resulted in increase in the variation of discharge values.

UTTF installed at Jogini II SHP

UTTF installed at Gangani Plant

UTTF installed at Ganvi II SHP

UTTF installed at USHP II SHP

UTTF installed at USHP II SHP

UTTF installed at Lower Nanti SHP

UTTF installed at Phoozhithode SHP

UTTF installed at Ranjha Ala Dunadi SHP

UTTF installed at Periyar IV HEP

Figure 4: Mounting of UTTF sensors at different SHP stations under difficult conditions

Table 2: Discharge readings taken by two different UTTFs at Periyar IV Hydro Electric Project

Load (%)	Discharge (UTTF-1) m^3/s	Discharge (UTTF-2) m^3/s
100	13.684	12.950
90	12.072	11.530
80	10.611	10.173
70	9.396	9.035
60	8.198	7.915
50	7.015	6.781

Table 3: Discharge readings taken by two different UTTFs at Lower Nanti Small Hydro Project

Load (%)	Discharge (UTTF-1) m^3/s	Discharge (UTTF-2) m^3/s
100	3.847	3.740
90	3.414	3.331
80	3.026	2.922
60	2.338	2.284

Table 4: Discharge readings taken by two different UTTFs at Bhilangana Hydro Electric Project

Load (%)	Discharge (UTTF-1) m^3/s	Discharge (UTTF-2) m^3/s
100	4.546	4.391
80	3.773	3.631
60	3.001	2.879
110	4.953	4.770

Table 5: Discharge readings taken by two different UTTFs at Motighat Hydro Electric Project

Load (%)	Discharge (UTTF-1) m^3/s	Discharge (UTTF-2) m^3/s
125	4.9623	4.778
100	4.4791	4.345
80	3.6699	3.558
60	2.9090	2.815

Table 6: Discharge readings taken by two different UTTFs at Gangani Hydro Electric Project

Load (%)	Discharge (UTTF-1) m^3/s	Discharge (UTTF-2) m^3/s
120	7.904	7.644
100	6.463	6.179
80	5.265	5.034
60	4.020	3.997

Table 7: Discharge readings taken by two different UTTFs at Jogini II Hydro Project

Load (%)	Discharge (UTTF-1) m^3/s	Discharge (UTTF-2) m^3/s
125	2.619	2.736
100	2.126	2.237
80	1.791	1.877
60	1.425	1.493

Table 8: Discharge readings taken by two different UTTFs at Ganvi II Hydro Electric Project

Load (%)	Discharge (UTTF-1) m^3/s	Discharge (UTTF-2) m^3/s
110	3.780	3.589
100	3.390	3.248
80	2.788	2.661
60	2.189	2.083

Table 9: Discharge readings taken by two different UTTFs at Phoozhithode Hydro Electric Project

Load (%)	Discharge (UTTF-1) m^3/s	Discharge (UTTF-2) m^3/s
110	2.946	2.735
100	2.645	2.462
80	2.113	1.983
70	1.872	1.768
60	1.654	1.530

Table 10: Discharge readings taken by two different UTTFs at Ranjha Ala Dunadi Hydro Electric Project

Load (%)	Discharge (UTTF-1) m^3/s	Discharge (UTTF-2) m^3/s
110	5.826	5.435
100	5.743	5.196
80	5.352	4.637
60	3.850	3.561

Table 11: Discharge readings taken by two different UTTFs at Upper Sindh Hydro Electric Project-II (USHP II)

Load (%)	Discharge (UTTF-1) m^3/s	Discharge (UTTF-2) m^3/s
95	20.294	19.151
90	18.619	17.526
85	17.451	16.568
80	17.037	15.787

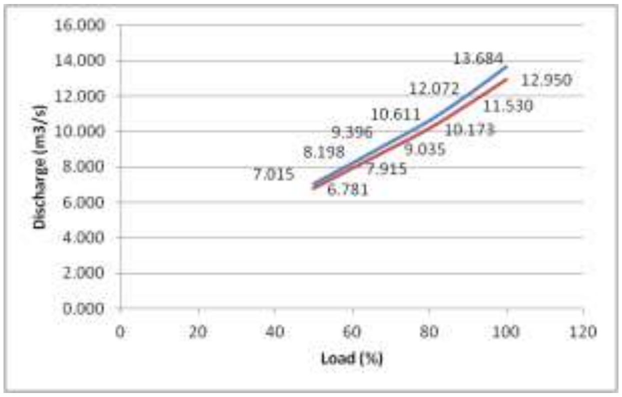

Figure 5: Deviation in the discharge readings taken by two different UTTFs

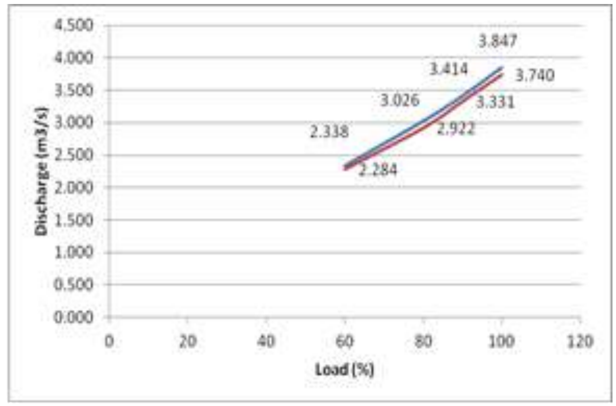

Figure 6: Deviation in the discharge readings taken by two different UTTFs

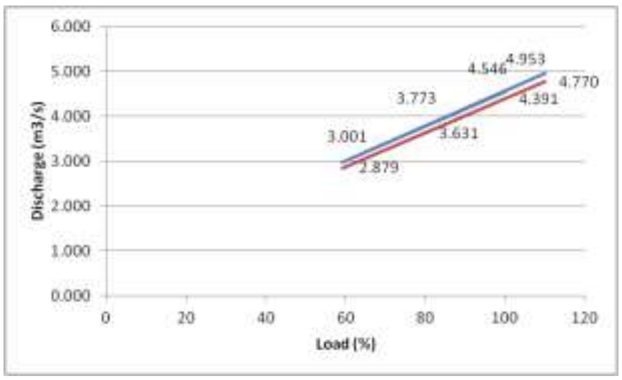

Figure7: Deviation in the discharge readings taken by two different UTTFs

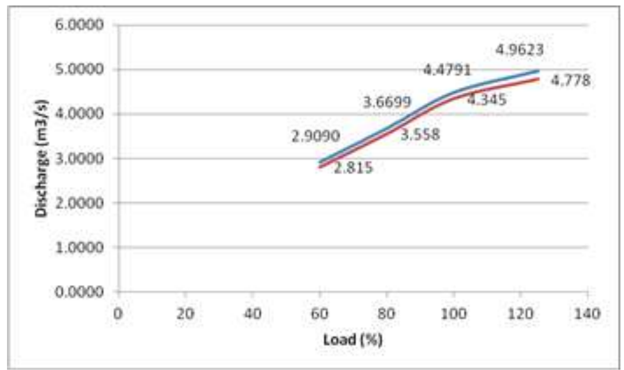

Figure 8: Deviation in the discharge readings taken by two different UTTFs

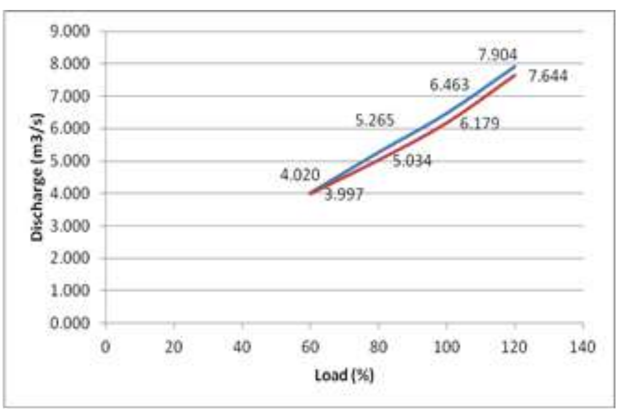

Figure 9: Deviation in the discharge readings taken by two different UTTFs

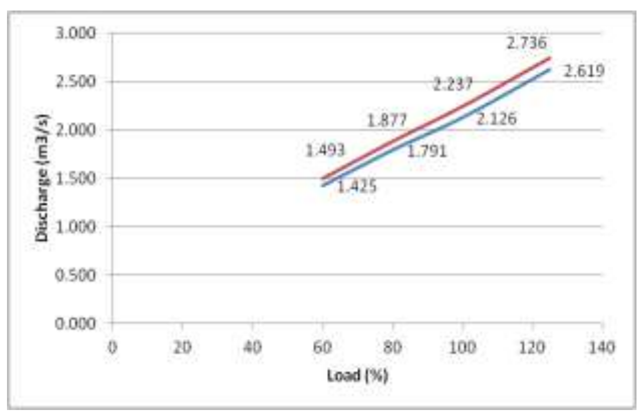

Figure 10: Deviation in the discharge readings taken by two different UTTFs

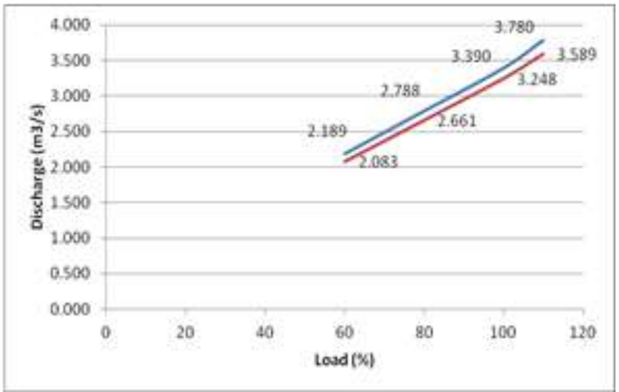

Figure 11: Deviation in the discharge readings taken by two different UTTFs

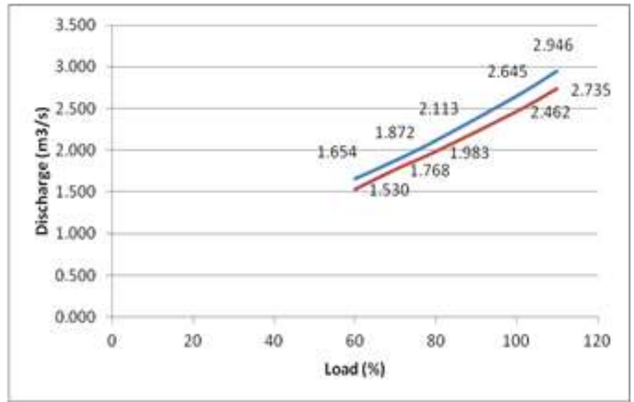

Figure 12: Deviation in the discharge readings taken by two different UTTFs

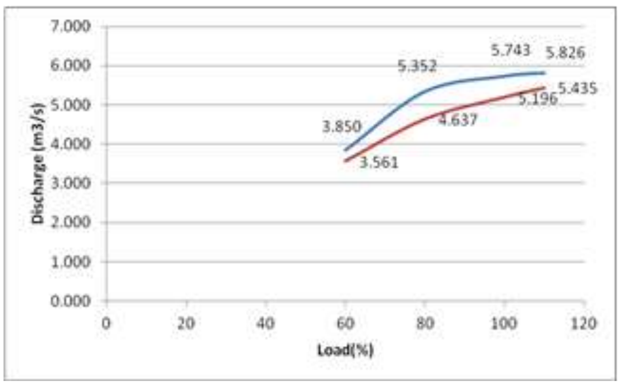

Figure 13: Deviation in the discharge readings taken by two different UTTFs

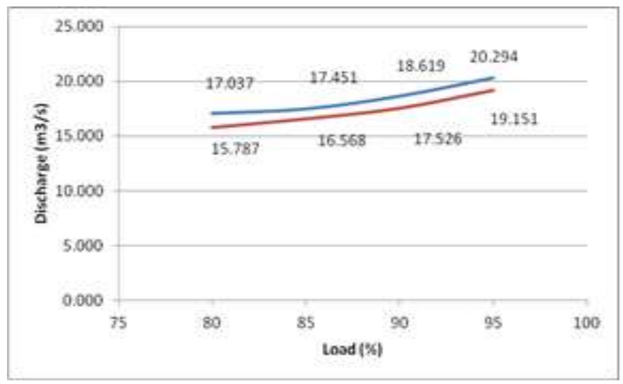

Figure 14: Deviation in the discharge readings taken by two different UTTFs

3. Analyzation

As discussed earlier, UTTFs were used over a wide range of pipe sizes, wall thicknesses, and lining materials. A significant difference in discharge values was observed for UTTFs of different makes. Variations in discharge in percentage are given in Table 12

Table 12: Variation in discharge in percentage by UTTFs of different makes.

SHPs		1	2	3	4	5	6	7	8	9	10
		Periyar	Nanti	Bhilangana	Motighat	Gangani	Jogini II	Ganvi SHP	Phooz-hithode	Ranjha Ala Dunadi	USHP II
Inclination of penstock		45^0	10^0	30^0	10^0	10^0	30^0	45^0	60^0	70^0	10^0
		Difference in discharge measured by UTTFs of different make (%)									
Load(%)	100	5.36	2.77	3.41	3.72	4.4	5.26	4.35	6.926	10.52	5.97
	80	4.13	3.44	3.78	3.06	4.38	4.77	4.77	6.131	15.41	7.91
	60	3.45	2.3	4.05	3.22	0.57	4.79	5.08	7.553	8.09	--

It has been observed that inclination of penstock also affect the uncertainty in discharge readings of UTTFs. At Phoozhithode SHP and Ranjha Ala Dunadi SHPs, where variation has been found more than others SHPs as inclination of penstock at these station was 60^o and 70^o respectively. Fluctuation in load of hydro generator may also affect the velocity profile in penstock. This has been observed at USHP-II. SHP plant where grid stability was not good at this project. There has been lot of variation in frequency, thus fluctuation in power output was high due to this a large variation in counts of UTTFs installed at USHP-II has been observed.

4. Conclusion

In small hydro plants discharge measurement is a challenging task as these power plants observed frequent discharge varying condition due to availability of discharge in the streams. Also plant owners may not be able to provide the required provisions for discharge measurement and after commissioning of station, it would be very difficult to deploy other methods of measurement. Under such conditions UTTF was a good choice for discharge measurement because of its easy installation and low cost. However some factors related to its installation should be considered before installation of UTTFs. The installations in pipe should not be more than 45^0 and proper grid stability is required. Some conclusion based on observation. It has been observed that the UTTF can be used for inclined penstock. The error will be large for penstock inclination more than 45^0.

5. Acknowledgement

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