# INSTRUMENT NETWORKING FOR EFFICIENCY MEASUREMENT IN SMALL HYDRO POWER STATIONS

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## ABSTRACT

Efficiency test on a turbine–generator unit in a hydro power station needs simultaneous measurement of a number of variables located in different places in the station using suitable instruments placed close to the respective variables. The measurement data from these instruments can be acquired simultaneously, centrally and reliably by networking them with a controller and/ or a computer. This paper examines the types of electrical output signals from these instruments and explains how to connect them in a network using the RS-485 serial data standard. A typical instrument network for the application in hand is described, highlighting its technical features and benefits.

## 1 INTRODUCTION

Determination of efficiency of a generating unit, comprising turbine and electric generator on a common machine shaft or coupled through a speed-changing gear box, requires measurement of hydraulic power input to the turbine and electric power output from the generator, and calculation of the ratio of the two powers. The hydraulic power input to the turbine $P_t$ is given by:

$$P_t = g\rho HQ \quad \text{watts}$$

Where g is the acceleration due to gravity in $m/s^2$,
$\rho$ is the density of water in $kg/m^3$,
H is the net water head in m, and
Q is the water discharge through the turbine in $m^3/s$.

The international standard value of g is 9.806 $m/s^2$. However, its actual value at a given location is a function of the latitude and altitude of the location and the same should be used for achieving a higher accuracy in the measurement of the unit efficiency. Values of g are given in IEC-60041.

The density of water $\rho$ is approximately 1000 $kg/m^3$ and is actually a function of the purity of water, its temperature and absolute pressure. Values of $\rho$ for pure water are available as a standard table in IEC-60041.

The electrical power output of the generator is measured by using a high-precision portable 3-phase wattmeter, power analyzer or watthour meter. Either two-wattmeter or three-wattmeter method is used depending on whether the generator output is 3-phase 3-wire or 3-phase 4-wire, respectively. Suitable pre-calibrated instrument transformers of matching class of precision are interposed for connections to the wattmeter.

The unit efficiency test based on the above concepts requires the following measurements in steady-state conditions (steady hydraulic condition and steady electric load):

(a) The electric power output at generator terminals
(b) The water head at inlet of the turbine
(c) The suction head
(d) The absolute discharge (flow)
(e) The rotational speed of the turbine

(f) The gate (or needle) opening
(g) The voltage at generator terminals
(h) The power factor of generator load
(i) The frequency of generator output

The first four measurements are used directly in the efficiency calculations, while the parameters at (e) through (h) are measured to establish the desired test conditions. If there are any differences between the actual and the desired values of these parameters, then the same can be used for making necessary corrections in the measurements taken at (a) through (d).

It is essential that all the nine measurements listed above are made simultaneously even though these parameters are located at different places in the power station. This necessitates locating the measuring instruments close to the respective measurands (i.e. the quantities measured) and networking them so as to read them all at the same time from a central location. The control room of the power station would generally be the best central location for such data acquisition through distributed measurements.

This paper looks into the various types of the electric output signals available on the participating instruments, their conversion into a common format, choice of networking protocol and selection of communication links with the goal of setting up a centrally controlled distributed measurement system for measuring unit efficiency in a small hydro power (SHP) station. The flowmeter being a vital measuring instrument in the efficiency test and there being a large variety of its output signals, special emphasis is laid here on its connectivity to the network.

## 2 ELECTRIC OUTPUT SIGNALS FROM INSTRUMENTS

The efficiency test on a generating unit of a SHP station needs typically a flowmeter for water discharge measurement, one or two pressure or level meters for head measurement, a tachometer for the measurement of speed of the turbine shaft, a position transducer for measuring gate/valve opening and 3-phase power analyzer for the measurement of power, voltage, power factor and frequency. Now a days, all higher-end measuring instruments, like flowmeters, high-precision wattmeters/power analysers/watthour meters and pressure and position transducers are designed to output one or more electric signals. These signals represent the value of the measurand and fall under one of the categories given below:

**(A) Analog Signals**

(i) <u>D.C. Voltage:</u> 0-1 V, 0-5V or 0-10 V, which varies linearly with the measurand.
(ii) <u>D.C. Current:</u> 4-20 mA or 0-20 mA, which varies linearly with the measurand.

**(B) Digital or Pulse Signal**

(i) <u>Digital or Binary Pulses:</u> TTL compatible or “open collector” output, the frequency varies linearly with the measurand (like flow rate or velocity in a flowmeter, speed of rotation in a tachometer, etc.).

**(C) Serial Data Ports**

(i) <u>RS-232 Serial Port:</u> Single-ended pulse voltage conforming to RS-232 serial data standard of EIA (Electronic Industries Association) for point-to-point communication. Allows connection of a single instrument to a controller (or personal computer) for transfer of data from the instrument to the controller and change of settings of the instrument from the controller under the control of software.
(ii) <u>RS-485 Serial Port:</u> Differential pulse voltage conforming to RS-485 serial data standard of EIA for multi-drop or network communication. Allows connection of upto 32 instruments to a controller (or personal computer) in networking mode. The

controller can acquire data from any or all instruments and read/change their settings under the control of software. The language (message structure) should conform to a standard protocol like MODBUS. Other protocols used by instrument manufacturers are the JBUS, CANBUS, FIELDBUS, LON, etc.

Each instrument has two sections: The first section is an appropriate sensor that uses a physical phenomenon to covert the physical input quantity (the measurand) into an electrical quantity. The second section is the electronics, which converts the electrical quantity into an analog or pulse signal (see figure 1).

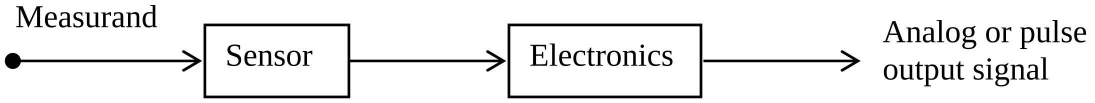


**Fig. 1** Architecture of category A and B instruments

However, the instruments belonging to the category C incorporate a counter or analog-to-digital converter (ADC) alongwith a microprocessor (μP) to convert the instrument output into a serial data. The μP also handles communication on serial port and can perform additional functions, like data processing, calculations, linearization, compensation, auto-ranging and auto-calibration. A semiconductor memory is also included for storing data and settings as well as software instructions (see figure 2).

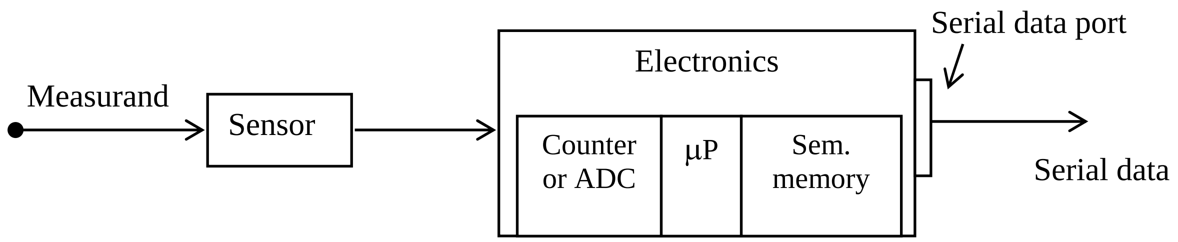


**Fig. 2** Architecture of category C instruments

## 3 INSTRUMENT NETWORKING

The need to place various measuring instruments close to the locations of respective measurands in a SHP station for the unit efficiency test and linking them all to a controller or personal computer in a central location by setting up a network stands explained. RS-485 communication network can be a good choice for setting up such a distributed measurement system. Low-cost modules, called as remote data acquisition modules or RDAMs, are available from a number of electronics manufacturers to support RS-485 based networking. These modules can interface the instruments/devices not equipped with RS-485 serial port to RS-485 network, can acquire data directly using simple sensors like thermocouples & strain gauges and output the same on RS-485 port, can `repeat' (or restrengthen) the RS-485 signals if they get attenuated because of the use of long wires, can provide wireless communication link in a RS-485 network if laying of wires in difficult or impossible, and can perform central control and data acquisition functions. Figure 3 illustrates how, for example, a flowmeter with any electrical output can be connected to RS-485 network using such RDAMs. The technique can be used for networking any and all types of instruments / transducers.

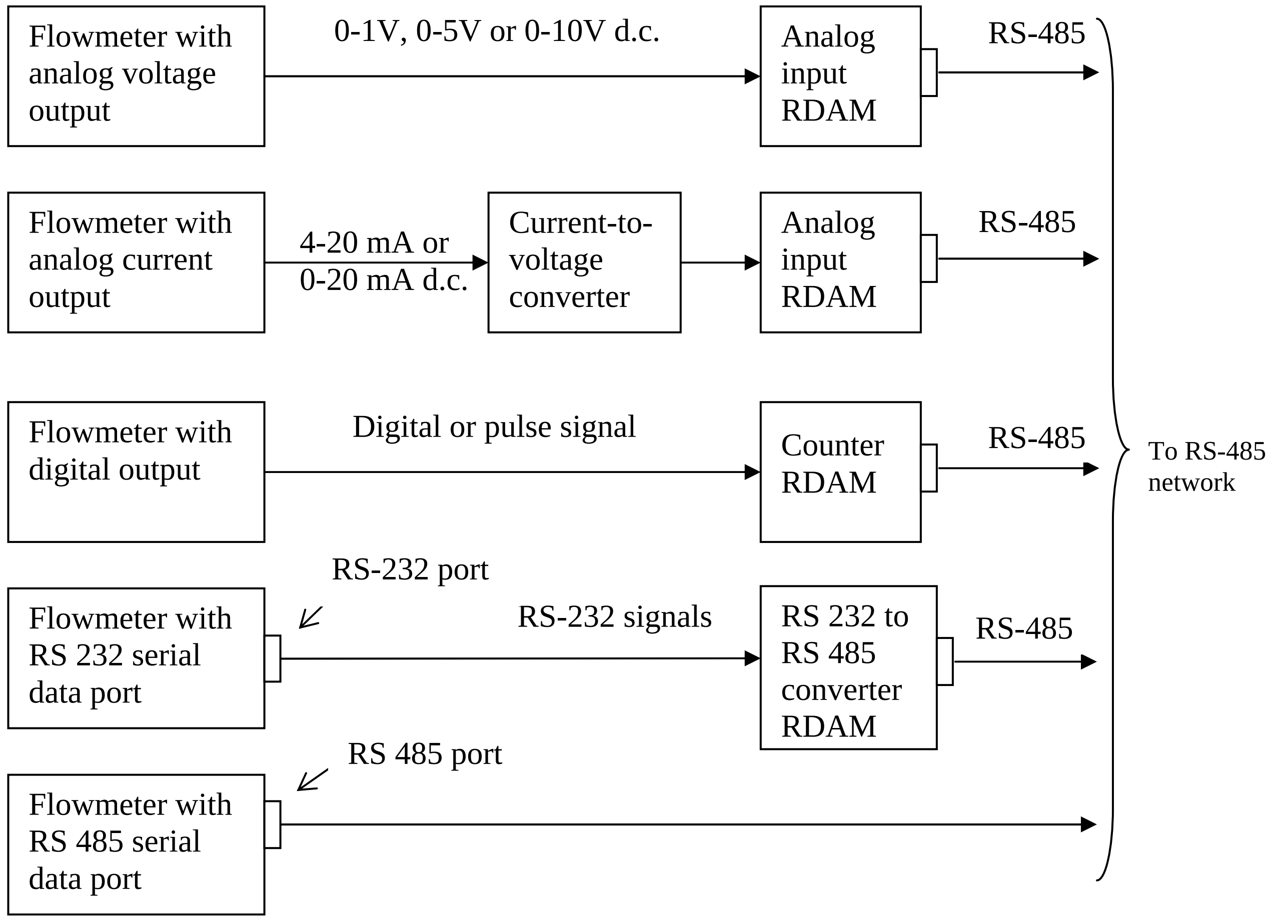


**Fig. 3:** Connecting a flowmeter with any type of output to RS-485 network

## 4 INSTRUMENT NETWORK FOR UNIT EFFICIENCY TEST

A typical instrument network for carrying out unit efficiency test in a SHP station, designed on the basis of the foregoing concepts and techniques, is given in figure 4. It can, as it is, take care of the inter-instrument distances in the range of a few hundred metres. Longer distances encountered in large hydro power stations would need RS-485 repeater modules. The network also includes wireless links as the laying of wires between certain locations may be cumbersome or impossible.

The controller unit, laptop computer and power analyzer are placed in the control room of the power station, while the flowmeter is placed in the forebay/approach channel or on the penstock. One pressure transducer is installed at the inlet of the turbine and another one in the draft tube or tail race. A position transducer is used for measuring the opening of the gate/needle. A tachometer with opto-electronic sensor is located close to the turbine shaft. Two pairs of wireless communication (modem) modules with bundled antennas of 300-metre range are interposed in the RS-485 network for transmission of data between the control room and the forebay and between the control room and the tail-race.

In the present example, the flowmeter and pressure transducers give analog outputs, the tachometer gives digital (pulse) output and the power analyzer has RS-232 data port. Appropriate converters and interface modules (RDAMs) are used to network these instruments to the controller unit. The controller can not only acquire data from all the instruments but also read and change the settings of the RDAMs as well as the instruments equipped with RS-232 or RS-485 data port. The controller has a limited memory for data and program storage and can support only a numeric display unit. Therefore, a laptop computer is connected to the controller through its USB port and a

USB-to-RS232 converter, as shown in figure 4. The computer can process and analyse the data using custom or standard software and provide interactive numerical, textual and graphical display of results on its monitor.

The wire networking needs simply one pair of twisted wires running between RDAM modules. All the modules work on 24 V d.c. power supply, which is obtained either from a.c. mains through a power adapter or a small battery, as available.

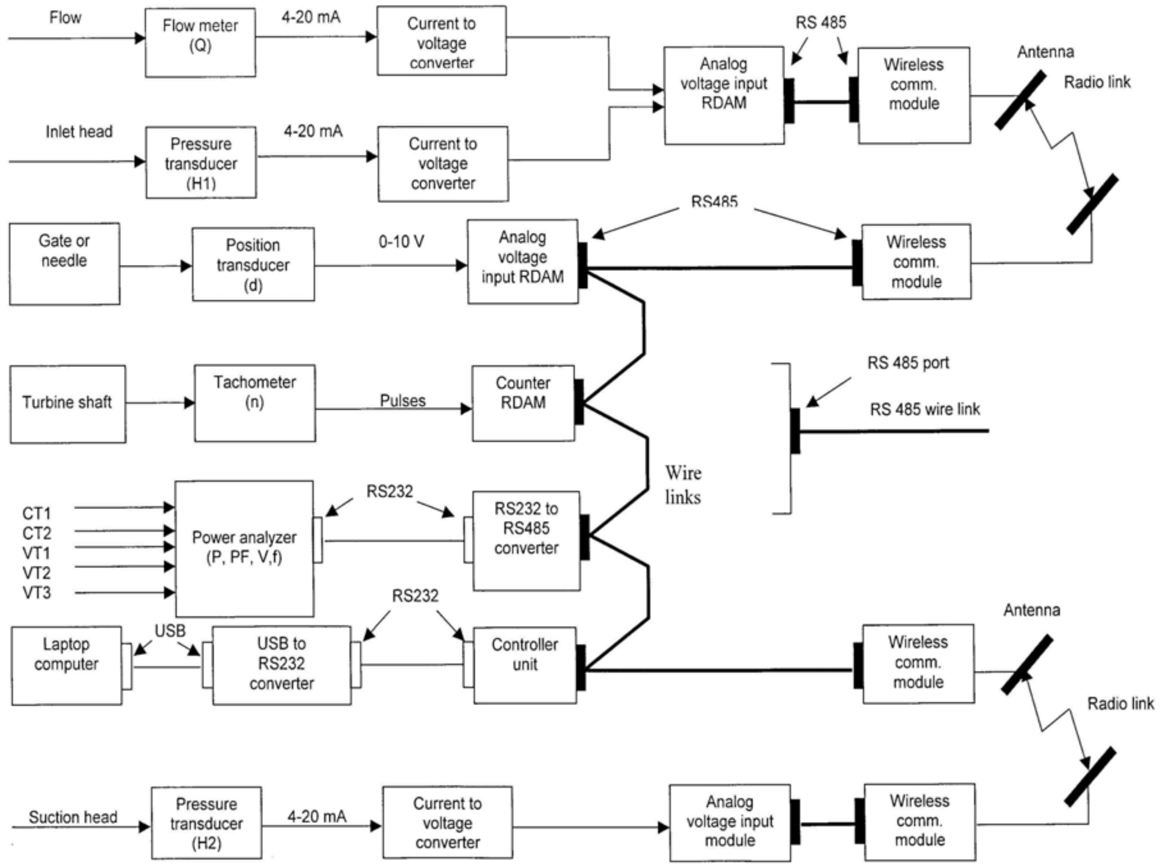


**Fig. 4** Distributed measurement system with RS485 instrument network for unit efficiency test

## 5 CONCLUSION

As the size of the hydroelectric power station increases, necessity rather than convenience becomes the reason for creating a network of instruments. In such a situation, this is the only practical method of acquiring all the measurement data simultaneously, centrally, reliably and interactively. As the data is collected in a computer, it can be processed and analysed then and there, needing no transportation of data.

The techniques described here allow networking of all types of measuring instruments with any type of electrical signal output. Old and low-cost instruments invariably lack a networking port, but the use of interface modules enable their connection to a network conveniently and seamlessly. While this approach saves such instruments from obsolescence, the cost of networking is also low. The element of wireless communication within the network makes every location in a power station easily accessible.

## REFERENCE


IEC-60041 (1991): Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump turbines.