Know Your Flow: Flow Data Used to Realize 3% More Generated Power

Steven Hendren, Sales Manager, Rittmeyer AG, Switzerland/USA
James Besha, Jr., President, Albany Engineering, USA

Abstract

In this case study, a flowmeter is used to determine the turbine performance curves at the Stuyvesant Falls Hydroelectric Plant. The data reveals some surprises and a new operating plan is devised to increase generated power by ≈3%. The flowmeter investment is paid off in a few months and net profits are increased substantially. Further benefits are realized in terms of CapEx planning to optimize financial resources and maximize returns. Additional benefits of a permanently installed flowmeter in terms of life cycle management and outage recovery are also explored.

Background

Stuyvesant Falls Hydroelectric Plant is a turn of the century power plant near Albany, NY built in 1899 and operated until 1994. It was purchased by Albany Engineering Corporation in 2008, modernized and placed back in to service in 2012. It has two generating units with a combined operating capacity of approximately 6 MW and generates approximately 15,000 MW-hr/yr. The plant operates run-of-the-river and is fed by a small pool approximately 0.5 miles upstream via two 7.5’ diameter, 2850’ long penstocks (Fig. 1). Each penstock is connected to a horizontal Francis turbine and operates with 95 feet of head. The penstocks were repaired when the facility was rebuilt and about 25% of the penstock was replaced.

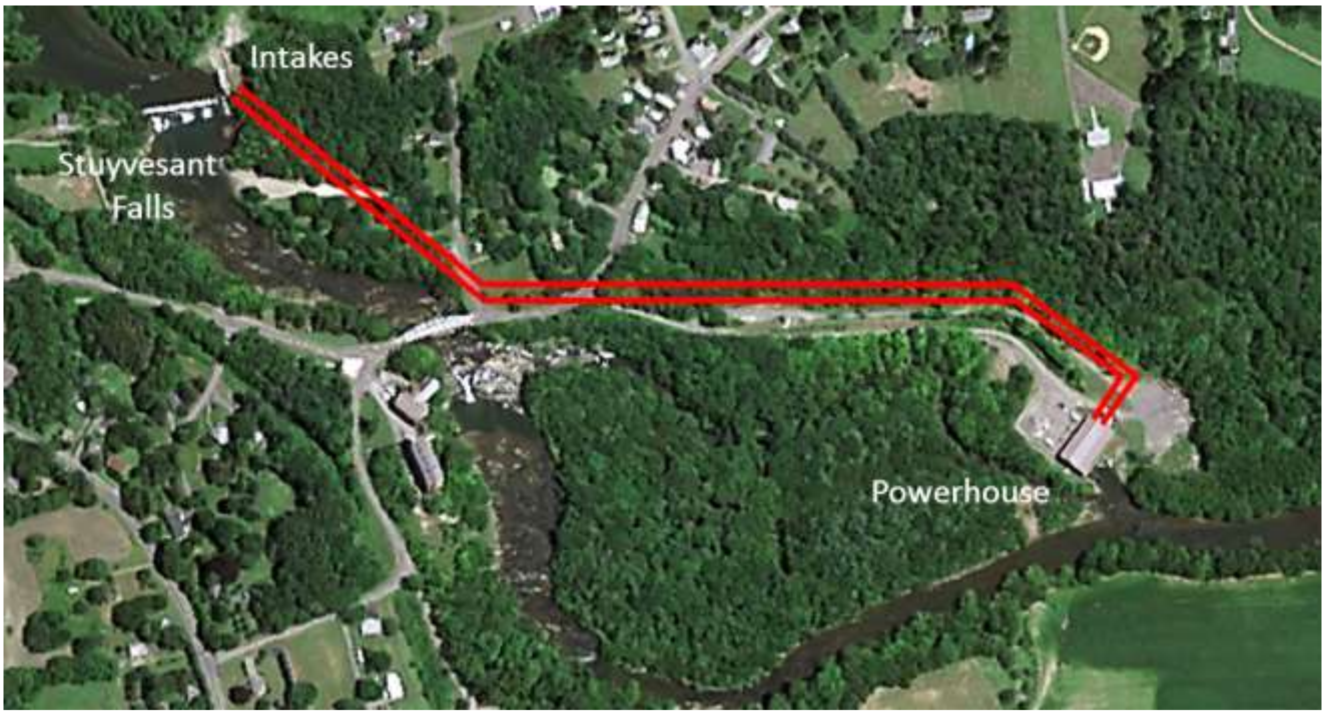

Fig. 1: Stuyvesant Falls Hydroelectric Plant

Flowmeter Considerations

This site is considered to be a near-ideal site for a transit time flowmeter. There is a long straight run of penstock on the order of 20 pipe diameters entering the powerhouse. There is a minor disturbance at the turbine shut-off valve, several pipe diameters into the powerhouse. Then there are several more pipe diameters of straight run before an ≈45 degree bend in to the turbines. These downstream disturbances were deemed insignificant for these tests. Since this is an operating efficiency test, as opposed to a turbine performance test, relative flow uncertainties are the most critical both over the flow range and penstock-to-penstock. Absolute flow uncertainties of 1-2% can easily be accepted. Therefore, a Rittmeyer RISONIC modular transit time flowmeter with a pair of clamp-on transducers in a 1E1P single path arrangement was selected for this installation.

While this site is near-ideal, it's possible to measure flow in much shorter penstocks. A straight run of at least 5-7 diameters is preferred. However, research at Oak Ridge National Laboratory is demonstrating that transit time flowmeters can even be deployed in short converging intakes as found in many low head dams. Further, a Winter-Kennedy flowmeter, such as the RIPRESS smart W-K solution, can be permanently installed. While not as accurate and subject to turbine coefficient changes over the complete life cycle, many of the benefits below can be realized.

Flow Data Leads to a New Turbine Strategy

Turbine performance curves were determined using the Rittmeyer RISONIC modular transit time flowmeter in April 2016. The results are presented in Fig. 2. This is the first turbine performance data taken at this site. The turbines were originally presumed to have reasonable efficiency at low flow. That, along with other operational considerations, led to the development of a sequential unit deployment strategy. It called for one unit to be run as needed up to the peak efficiency point. If more water was available, then the first unit was left at peak and the second unit was brought on as water allowed. The new flow data showed that this strategy was not optimum. Due to the much lower efficiency at low flows, more power could be generated with a balanced unit approach. This new strategy calls for immediately backing the first unit down as the second unit is deployed so that both are running at equal output.

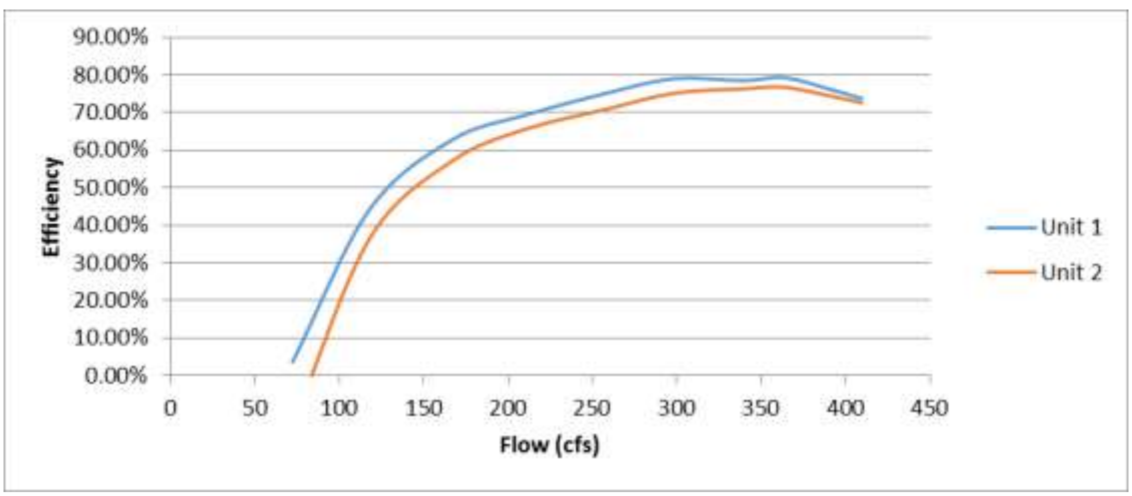

Fig. 2: New Turbine Efficiency Curves

Data from the previous 12 months of operation, which represent a fairly typical year, were used to analyze potential benefits of the new operating strategy. The results showed that an additional 1.3% of power could have been generated if the new unit deployment strategy had been employed.

Flow Data Reveals Differences in Turbine Efficiency

For various reasons, Unit 2 has always been used as the primary unit, making it the first to come up and the last to shut down. The new turbine data revealed a significant difference in turbine efficiency with Unit 1 having 2.3% greater efficiency, on average.

The initial hypothesis for the difference in efficiency points to the penstock layout (Fig. 3). Unit 2 has an ≈45 degree bend close to the inlet while Unit 1 has a longer run between the bend and the inlet. Best unit performance is realized when the flow has had a chance to settle. If that's the root cause then not much can be done about it. However, this large of a difference warrants further investigation to determine if there are other factors that can be addressed to narrow the difference. Further, it demonstrates the value of making additional investments to optimize Unit 1 and make it the primary unit.

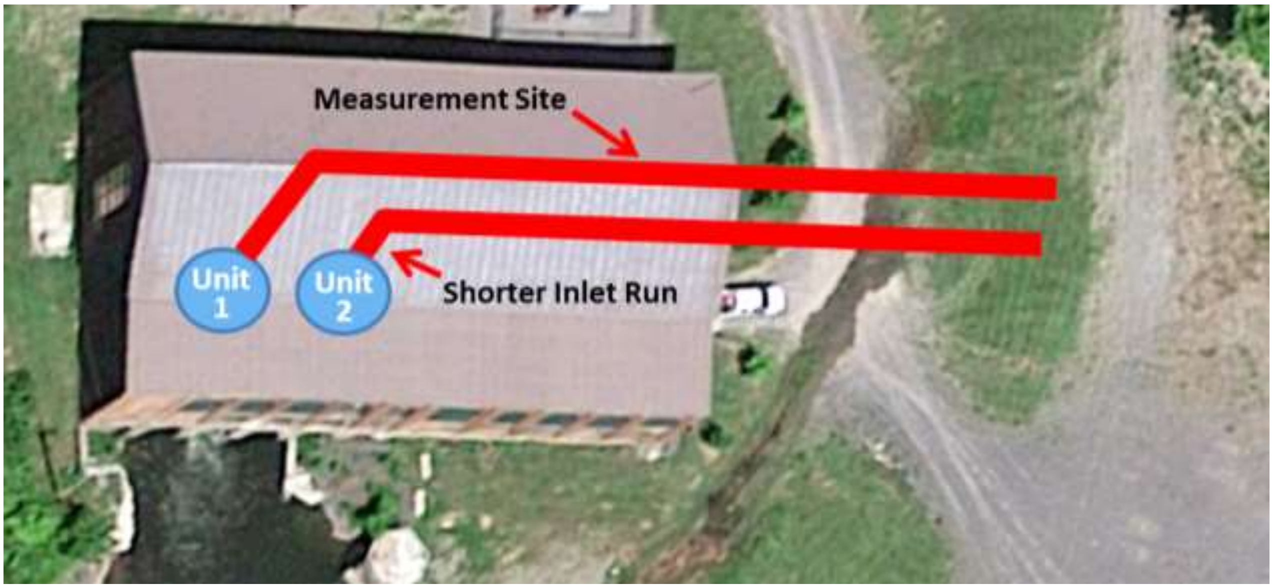

Fig. 3: Turbine Inlet Layout

Total Generation Improvements

Stuyvesant Falls operates run-of-the river so can only generate when water is available. In a normal year, the plant operates at less than 50% capacity most of the time. Using this data and the analyses above, an estimated 2.7% more energy can be generated in a typical year by utilizing the new unit deployment strategy and making Unit 1 the primary. That number could be > 3.4% in a good water year.

Financial Results of the Flow Tests

The financial information for the Stuyvesant Falls Hydroelectric Plant is proprietary so the simplified analysis in Table 1 is presented to highlight the financial results. In this case, it's clear that the flowmeter and testing investments can be paid off in a matter of months. Since efficiency improvement transfer almost directly to the bottom line, that can translate in to net profit improvement many times higher than the 2.7% additional revenue, depending on the net profit margins. In addition, simple internal rate of return (IRR) and net present value (NPV) results are shown. These were calculated over a 5-year period with a 7% base interest rate. It's clear that the flowmeter investment is extremely profitable for this site.

Net Generation	15,000 MW-hr
Par Energy Rate (w/credits)	$60/MW-hr
Eff. Improvement	2.7%
Annual Revenue Increase	≈ $ 24,300
Flowmeter Cost	$10,000
Payback period	4.9 months
IRR (5 yrs)	≈ 250%
NPV (7%, 5 yrs.)	≈ $100,000

Table 1: Financial Results

Further Analysis

The next step will be to analyze the penstocks. Now that flow rates are known with much more certainty the actual penstock losses can be determined. These will be compared to ideal penstocks to calculate the lost revenue due to penstock losses. The penstock sections vary from new to roughly patched. The cost of replacing the next worst sections of penstock can be compared to the economic benefit and a CapEx plan can be crafted accordingly. (Note: This work is already underway.)

Additional Benefits of Knowing Flow

Optimizing Complex Turbines: Knowing flow rates can be used to optimize operations and increase efficiencies. The above example is for a multi-unit Francis turbine plant. There's even more opportunity for optimization with Kaplan and Pelton turbines. These have additional variables that can be optimized such as blade pitch and nozzle settings. This can lead to significant efficiency improvements even in small single unit plants.

Turbine Interaction: Even if exact turbine curves are known, they're usually measured or simulated in isolation. That is, the adjacent turbines are usually at zero flow. In operation, the adjacent turbines can be at various operating points leading to interaction between them as shown in Fig. 4. Directly measuring flow can reveal these interactions and allow for efficiency optimization.

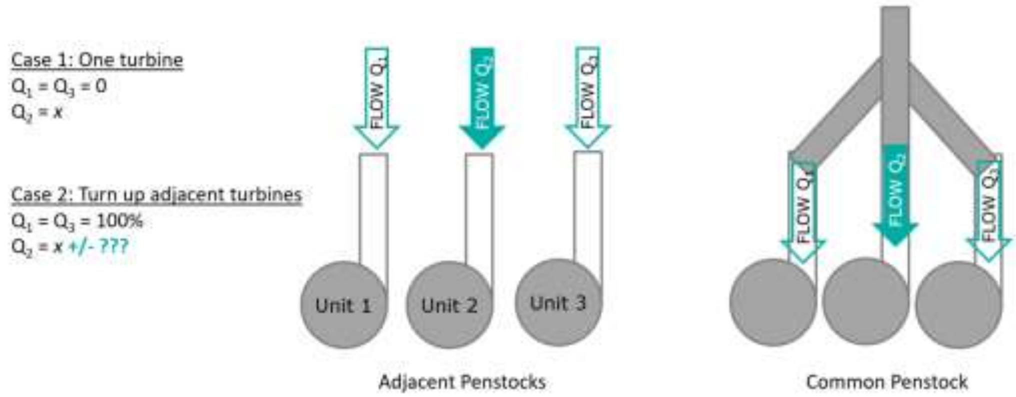

Fig. 4: Turbine Interaction

Long-Term Maintenance/Optimization: As seen in this case study, knowing actual flow can help optimize maintenance plans. Unit performance can degrade over time with the component wear. These may not be apparent if using the turbine curves to infer flow since the curves can shift with these changes. Just one optimized maintenance decision, such as with Unit 1 and 2 in this case study, can easily pay for the cost of the flowmeter and pay dividends to come.

Life Cycle Management: Similarly, aging turbines can have shifting turbine curves so inferring flow may not be accurate. Therefore, actual turbine performance changes can be masked. Directly measuring the flow can lead to optimized life-cycle management decisions. Turbines that are operating with lower efficiencies than expected may warrant replacement earlier than planned. Conversely, turbines operating with higher efficiencies may be able to run longer. Finally, the order of replacement on multi-unit plants can be optimized.

Outages: Many operators are comfortable inferring flow from the turbine curves when everything is running well. However, as the saying goes, "there's no such thing as too much information when things go sideways". Knowing the true flow can help reduce troubleshooting intervals. This is especially true in more complex turbines such as Pelton and Kaplan designs where several problems could have similar symptoms. If a true flow measurement can save hours of downtime over the life of the flowmeter then the investment will more than pay for itself.

Conclusion

The Stuyvesant Falls case showed tremendous advantages to knowing the true flow, even in a small hydro station. These may not be the typical results as sometimes the assumed turbine curves will be proven right and no benefit will be realized. However, in a fleet of hydro stations it's likely that plant operations can be optimized overall and efficiency gains realized. Even an average of 1% improvement can lead to a rapid repayment of the investment and significant long term increases in net profits. Additional benefits can be realized in maintenance and long-term CapEx management, and in potentially restoring generation more quickly during an outage.

***Steven Hendren** is currently the Sales Manager Rittmeyer AG covering the Eastern USA and Canada. In addition to sales, his responsibilities include technical support and project management support. Prior his move in to sales, Steven was an Electrical Design Engineer in such areas as power supplies and communications. Steve holds a Bachelor of Science degree from Missouri S&T and an MBA from Capital University.*

***James A. Besha, Jr., P.E.** is an electrical engineer and President of Albany Engineering Corp. (AEC) in Albany, NY. AEC plans, develops, designs, builds, rehabilitates, operates and maintains numerous hydroelectric and water resource projects primarily in New York State. In addition to work for clients, AEC owns and operates three hydroelectric facilities with several others under development.*