WAIMATE WEST - AN ENERGY NEUTRAL WATER TREATMENT PLANT

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ABSTRACT

The existing Waimate West Water Treatment plant struggled to achieve compliance in accordance with Drinking Water Standards for New Zealand (DWSNZ) under typical operating conditions, and failed under high rainfall or flood conditions. And further, the assets were aging and in need of substantial refurbishment if they were to remain in service. Hence South Taranaki District Council decided to replace the existing treatment plant. The new treatment plant was commissioned spring 2014.

Low Total Cost of Ownership was a key objective for the upgraded plant, along with achieving consistent compliance. A number of measures were incorporated to reduce energy usage in the new plant. As part of the replacement project, it was initially assumed the existing raw water pump station would need to be upgraded however, a closer examination of the raw water hydraulics identified the opportunity to not only eliminate this pump station, but also incorporate a Pump As Turbine (PAT) installation that generates sufficient energy for the 18 ML/d treatment plant to be approximately energy neutral.

PAT installations utilise standard off the shelf centrifugal pumps coupled with a standard three phase induction motor, reducing both the capital and maintenance costs, including eliminating the need for specialist servicing. This simplicity makes the technology ideal for implementation on smaller scale installations, and makes implementation realistic for small scale applications. With increasing energy costs, desires for low carbon generation and the increasing acceptance of embedded generation within the power network there may be many opportunities for implementation of similar installations within raw and treated water networks.

This paper discusses the technical issues in the implementation of the PAT.

KEYWORDS

Water Treatment, Energy Efficiency, Pump As Turbine, PAT, Embedded generation

1 INTRODUCTION

The existing Waimate West Water Treatment Plant (WTP) was constructed in 1972. The plant supplies approximately 800 rural properties, 200 properties in the Kaponga urban area and 450 properties in the urban area of Manaia. A large proportion of the water is to supply the 26,380 hectares of predominantly dairy farm land, as well as significant commercial users including Shell Todd Oil Services (STOS), Balance Agri-Nutrients, Fonterra lactose factory in Kapuni and the Yarrow's bakery in Manaia. The supply serves a human population of approximately 2,000 and a cow population of approximately 75,000 to 80,000. The supply has a raw water capacity of 18,000 m^3/d.

The existing plant did not consistently meet the Drinking Water Standards for New Zealand (DWSNZ) requirements and the condition of the steel structures in the filtration plant in particular were poor and nearing the end of their useful life. South Taranaki District Council (STDC) sought to upgrade this plant to enable compliance with DWSNZ to be achieved and renewal of assets to provide reliability and a low total cost of operation.

STDC elected to replace the existing processes with a new treatment plant. The new plant was commissioned in the spring of 2014.

PAT technology is not new, with much of the technical information available dating to the 1970's. However, application of modern four-quadrant variable speed drive technology allows the variable flow control of PAT's, improving the range of applications for this technology.

2 RAW WATER HYDRAULICS

The existing plant had two raw water intakes; one from the Otakeho Stream and the other from the Mangawhero-iti Stream. The instantaneous peak plant capacity, as limited by the raw water consent, is 206L/s, with 85L/s from the Otakeho stream and 121L/s from the Mangawhero-iti stream.

The new plant was to maximize the available treated water capacity within the consented raw water take constraint. Under the consent, the Otakeho flow is to be utilized prior to the Mangawhero iti take being utilized.

The Otakeho stream intake consisted of a 3.4 km raw water main that connected into the Mangawhero-iti raw water main via a pressure reducing valve and head break chamber. This pipeline then supplied raw water to the Waimate West WTP. Up to 12,000m^3/d (139L/s) could gravitate to the WTP, but any additional flow was boosted using an axial flow pump.

During the upgrade to the existing plant, it was identified that if the Otakeho flow did not connect into the Mangawhero-iti at the head break chamber, then the head could be maintained through to the treatment plant, and the existing pipeline could convey the lower head flow from the Mangawhero iti without boost pumping.

A new Otakeho pipeline was constructed, which only ties in with the Mangawhero-iti source at the new WTP and therefore negates the need to break the pressure in the line to match the hydraulic grade line at the Mangawhere-iti intake. The excess head has been used to generate electricity at the new WTP. The second pipeline also provides operational flexibility to remove the existing pipeline from service for maintenance if required (Mangawhero-iti out of service).

Table 1 - Key Hydraulic Levels

Key Area	**mRL**
Mangawhero-iti pipeline at WTP boundary	336.00
Otakeho Intake	430.80
Water Treatment Plant HGL at inlet (allowing for rapid mixing losses)	332.60

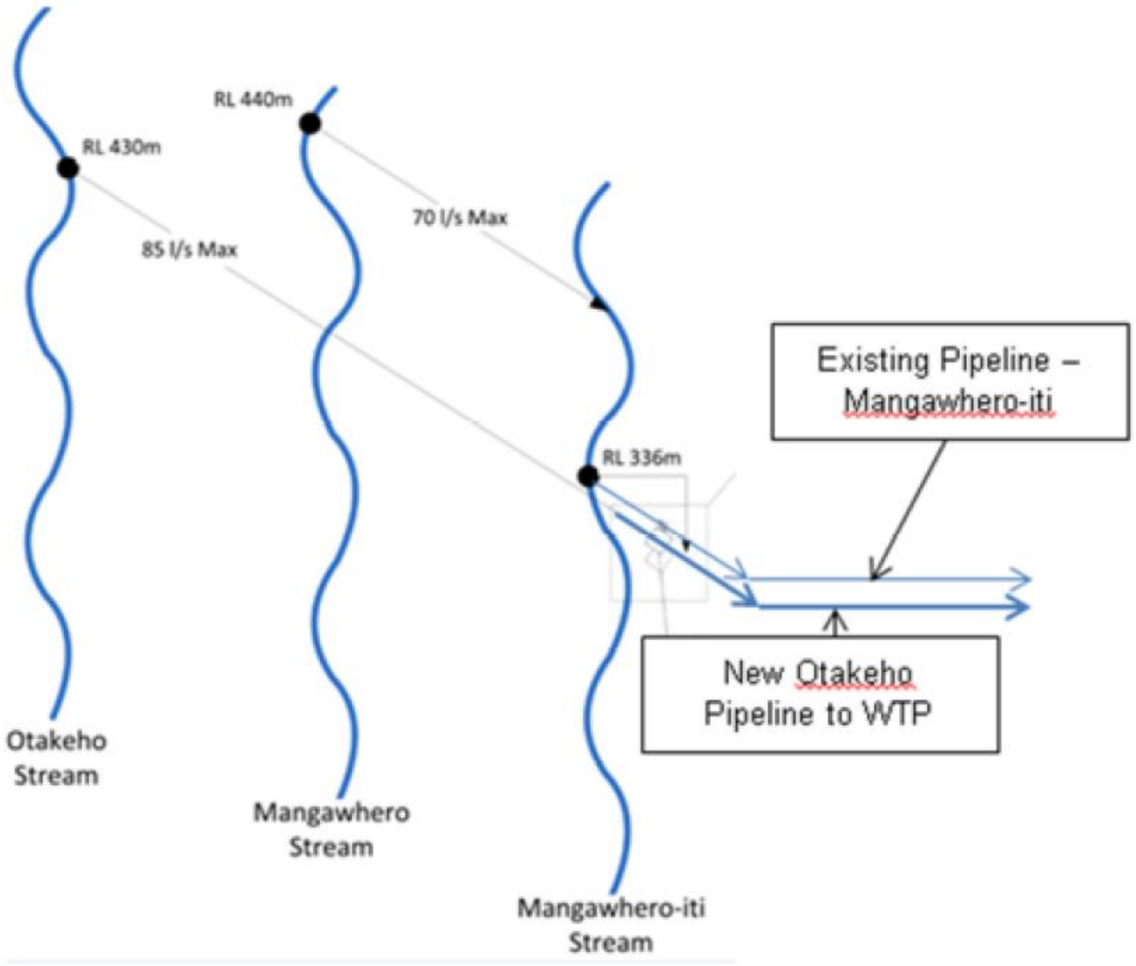


Figure 1 – Raw Water Hydraulic Schematic

3 DESIGN DEVELOPMENT

3.1 MECHANICAL

Electricity is generated from the excess head in the Otakeho line using a pump as a turbine (PAT). A conventional end suction centrifugal pump coupled with a squirrel cage motor was installed. The pump acts as the turbine and the motor as the generator. The motor operates at a fixed speed.

The pump duty was designed for 80 l/s at an inlet head of 30 m and outlet head of 5m. In reality the operating conditions differed from this design capacity for the following two reasons:

- The actual head can vary significantly, and this is believed to be due to issues with the intake design that results in a loss of flow during high river flow or flood conditions, and the raw water pipeline draining down. Following refilling it can take several days to restore the pipeline capacity as air works its way out of the pipeline.
- An existing off take at the upper end of the raw water pipeline requires backpressure, and operating the pipeline at the full capacity results in a loss of flow to this connection. This connection is in the process of being moved to the treated water system, and hence this constraint will be removed soon.

A tachometer is used to monitor shaft speed with a 4-20mA analogue output. The motor breaker is closed when the shaft speed is close to 1500 RPM, to avoid the motor drawing power.

A downstream flow control valve was included to provide the flexibility to operate over a range of flow. As discussed in the electrical section, the installation was originally proposed to utilize a VSD capable of operating the pump over a range of shaft speeds and hence flow. However during detailed design it was found suitable VSD's were only available as custom built units in the required size, and as this was not consistent with the desire for a simple installation a fixed speed design was implemented, and hence the need for the flow control valve. This does limit the power output obtained at flows different from the design operating point.

In addition a bypass valve is included if flows in excess of the design flow is required. The bypass also operates if the PAT trips, including when the plant is operating off generator rather than mains supply.

3.1 ELECTRICAL

The upgrade of the Waimate West Water Treatment included the replacement of the site power distribution system and the design included;

1) A standby diesel generator that could operate in synchronism with the electrical system for the purpose of avoiding a restart of the treatment plant on return of grid power, and also use the electrical system as a load for load testing of the generator to avoid the use of temporary resistive load banks.
2) A pump driven induction generator (or induction motor driven by a prime mover) that, when driven above synchronous speed, would generate power to the system.

The concept design allowed for the use of a four-quadrant variable speed drive. The fundamental advantage of a four-quadrant variable speed drive is that by virtue of the electronics, it is capable of regenerating power back to the system when driven by a source of power. Since the minimum rating of available four-quadrant variable speed drives is 75kW, which exceeded the rating of the 22kW of the induction generator, the use of the variable speed drive option was discarded, and the concept of using a direct-on-line connection to the power system was followed.

The advantage of induction generators are that they automatically synchronize with the power system and as such depend on the power system for frequency and voltage control, further, they are self-excited in that no DC field voltage is required as compared to synchronous generators i.e. The system provides the excitation (magnetizing current) and consumes reactive power (kVAR), and the induction generator supplies real power (kW).

Prior to implementing the system, approval was required from the line company to ensure that the design was in accordance with their embedded generation policy. The primary requirements being the implementation of an electrical protection system to ensure that;

- The diesel generator or induction generator, when operating in synchronism with the network, did not contribute to faults external to the plant in that the protection system was required to determine the difference between power being generated by the diesel generator and induction generator to that of the power system.
- The diesel generator and induction generator would not connect to the mains supply in the event that the line company's feeder end was open circuit, or if being worked on by maintenance personnel (short circuit due to earthing procedures).
- The induction generator would be disabled when the diesel generator was in operation. It was simpler to disable the induction generator as the marginal benefit of operating the induction generator in parallel with the diesel generator did not warrant the additional control and protection requirements.

The overall principle of determining the difference between generated power versus system power was achieved through a voltage transformer that was connected to a NVD (neutral voltage displacement relay) located upstream of the main incoming site transformer to detect ground faults. The output of the NVD, system voltage and current transformers was monitored by the diesel generator controller (InteliGen) that included ROCOF (Rate of change of frequency) protection.

The diesel generator protection and control system included an InteliPro (Protection Relay for Parallel Applications) and an Inteli New Technology Modular Gen-set Controller.

The induction generator Siemens protection relay monitored the incoming low voltage and used the principle of ROCOF for detecting an upstream power failure that would open the contactor of the motor-starter due to a change of frequency that would occur in the event of an electrical fault.

The induction generator motor-starter included a control input from a tachometer that enabled/disabled the operation of the motor-starter within defined parameters of the synchronous speed. The direct-on-line motor starter included a protection relay that, besides the normal motor protection features, included an input from the voltage transformer.

The system has been in operation since October 2014 and has contributed to the reduction of energy costs.

4 PAT CONTROL

The hierarchy of flow is:

1) The Otakeho will be utilised up to its maximum flow setpoint, with the hydro bypass valve closed.
2) Mangawhero-iti flow is utilised up to its maximum consented capacity.
3) Otakeho hydro bypass valve is opened (hydro goes off line), if Otakeho flow <95% of its maximum setpoint

The induction generator motor-starter is to close once the motor speed is greater than 1475 RPM, and open if either the Otakeho flow is less than 200 m^3/h or the diesel generator is in operation.

The operation of the induction generator motor-starter is interlocked with the power system in that in the event of a power outage the induction generator motor-starter is to open. The motor-starter will close after the mains power has been restored and after the diesel generator has shut down.

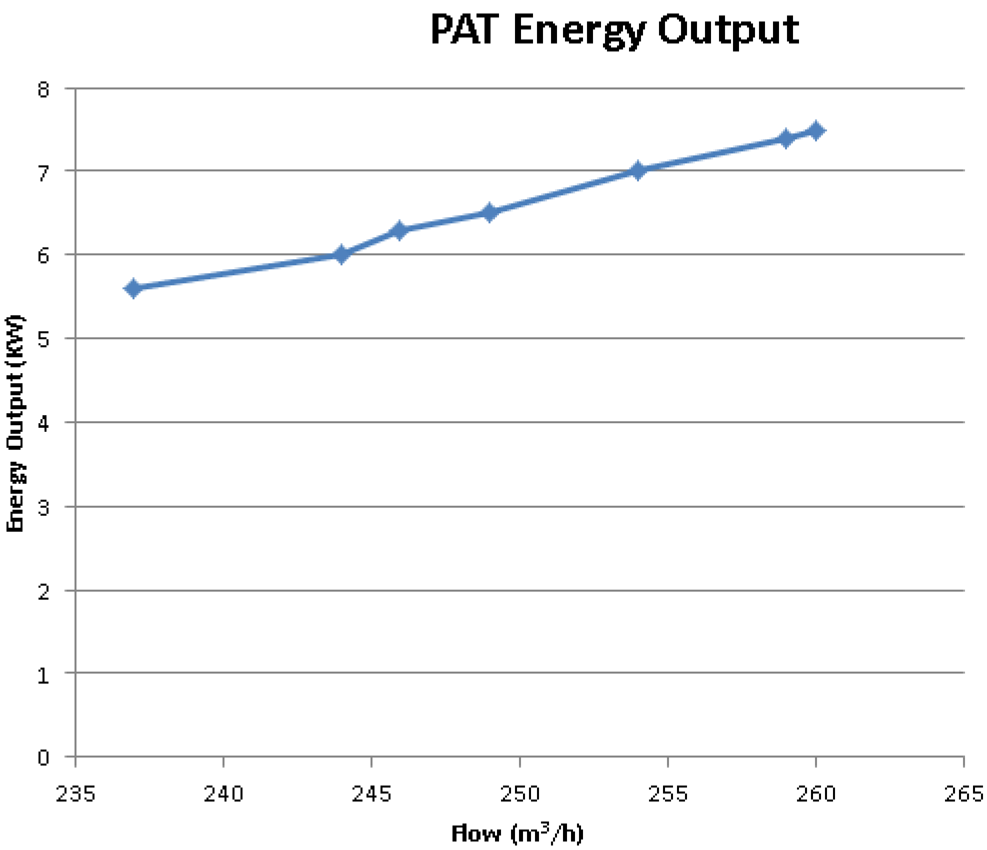
Alarms are generated by the motor protection relay if the speed exceeds the range of 1375 to 1575 rpm.

5 PERFORMANCE

The Waimate West Water Treatment Plant was commissioned in July 2014 and hydro in October 2014. The Otakeho supply and PAT has been operating at reduced flow of typically 230 m3/h, until a raw water supply off the pipeline is transferred to the treated water supply. This means the maximum generation capacity of the PAT is not utilized, limiting the energy output to around 5 KW, compared to the approximately 7.5-8 kW at maximum output.

The following graph provides the measured energy output versus flow. As noted above, use of a regenerative VSD would have enabled full utilization of the available hydraulic energy over a broader range of flow, but at additional cost and complexity.

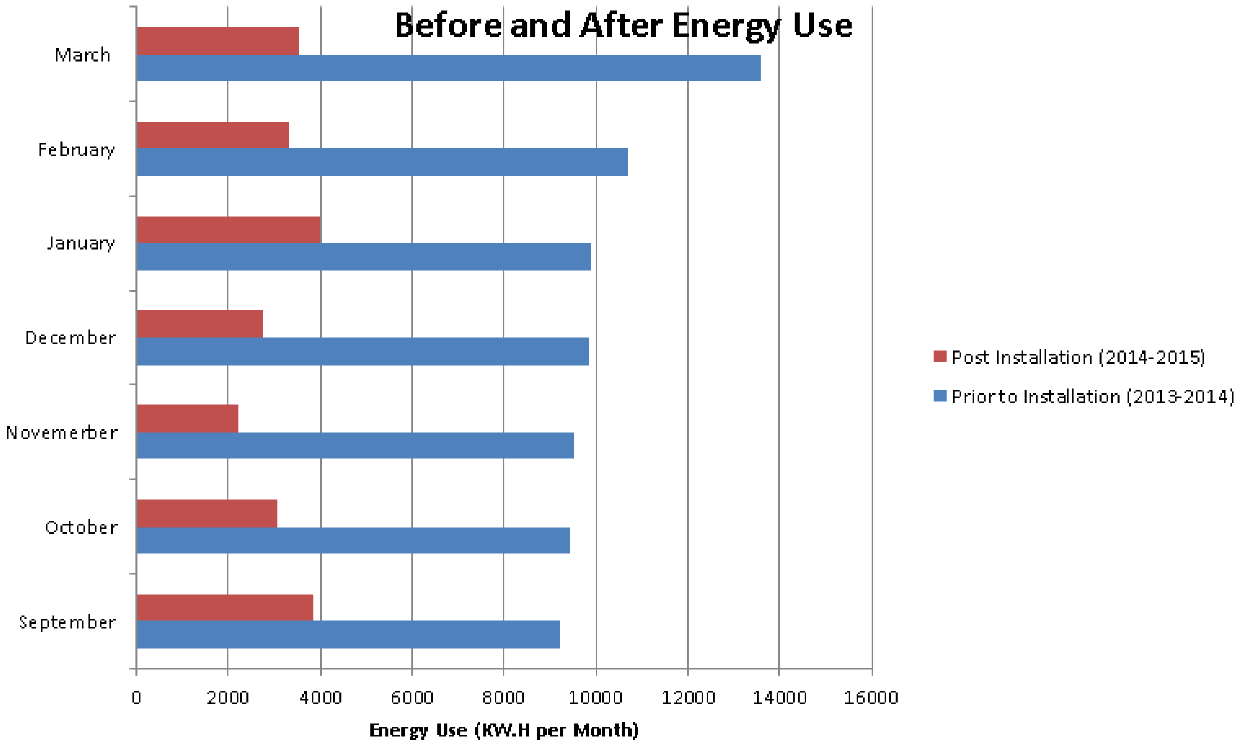
Figure 2 – Energy Output



The graph below provides a summary of actual plant energy use.

Typically under base load the plant returns a small amount of energy to the grid, and under backwashing energy is imported from the grid. The data below shows the plant has been a net consumer of energy. The balance is expected to improve signifncantly when the constraint on the raw water pipeline operation is removed shortly and the plant should be close to energy neutral. In addition, a fault with an overload breaker caused the hydro to be regularly off line until resolved in March 2015, reducing the avaialablity and energy output. In adition, the new WTP operates at higher output than prior to the upgrade.

Figure 3 – Treatment Plant Energy Use



6 CONCLUSIONS

Installation of an end suction centrifugal pump has been successfully implemented as a PAT installation. The installation uses simple technology and hence is applicable at small scale. The installation provides a useful energy output. By reconfiguring the raw water collection system not only has a raw water boost pump station been eliminated, but the energy has been recovered.

A fixed speed installation was implemented which suited the installation with a typically fixed flow outout, and maintained the simplicity.

Use of available regenerative VSD technology would enable use of the PAT over a wider range of flows while fully utilizing the available

Another side benefit of the use of a PAT in comparison to a flow control valve is the substantial reduction in noise.

ACKNOWLEDGEMENTS

We would like to acknowledge South Taranaki District Council for having the willingness to try new innovative ideas and implement this technology. It is only by organizations and individuals taking the leadership and adopting such technology that use will become more widespread and assist in achieving a more sustainable energy future.