Research Proposal

**School of Civil Environmental and Mining Engineering**

**Real time control of pump operation for use in water distribution systems**

**Matthew Sergi**

# 1**. Project Summary**

This aligns with a current movement within the water resources research community towards the development of methods and techniques for the *smarter management* or development of *intelligent systems* for water resources infrastructure. Given the rise of low-cost and rugged sensors, water utilities are able to increasingly monitor the hydraulic states of their infrastructure. The availability of these large data sets has driven industry interest in academic research on the development of analytic methods and tools for the purposes of better and more efficient management of the infrastructure. This project will look at the development and analysis of a framework for the real-time control of variable speed pumps within water distribution systems.

In typical water distribution systems, pumps are used to transport water from a water source to a storage facility and are controlled using scheduling. This method has two major disadvantages, firstly the system requires the pumps to deliver more than the required demand and secondly large areas of land are required for water storage. However by replacing scheduling with real time control, the pumps are only required to provide the demand at any given time and reducing the reliance on storage. In turn, this would correspond to a reduction in operation and land costings as well as minimise environmental impacts. There are a number of factors currently limiting the implementation of such control to pumps and the nature of the control interface requires further research.

# 2. Project Details

## 2.1 Introductory Background

Water can be described as a fundamental requirement for human survival. In addition to consumption, water also provides other benefits such as; sanitation, transport, industry, food processing and agriculture (Riyanto and Chuei, 2009). Water is provided to consumers through a series of interconnecting pipe lines and this network is referred to as water distribution system (WDS). Early water distribution systems (WDSs) utilise gravity to mobilise the water and required the source to be above the system. However with technological advancements, pumps can now be utilised to transport water to areas which previously would have been deemed unsuitable to settle.

The added benefits in which pumps provide come at the disadvantage of electrical energy consumption. When designing a project, costing is one of the most important factors. For a WDS, operational costs of pumping tends to be one of largest expense over the project design life and it is in the clients best interest to minimise these cost especially with the increasing prices of electricity. In addition to the financial costs, the production of electricity causes significant damage to the environment due Greenhouse Gas (GHG) Emissions. As a result the reduction of energy usage is paramount (Wu et al, 2010) due to the economic and financial losses.

A further benefit of real time control is the removal of water storage reservoirs and tanks. The amount of water stored for a typical city can be in the magnitude of tens of thousands of mega litres and consumes large quantities of land. This is land usage can come at a significant cost both financially and environmentally. It is in our best interests to minimise costing and this can be achieved through utilising the real time control of pumps

In order to implement the real time control of pumps two key components are required, firstly the addition of a sensor to relay system information and secondly a controller to adjust pump speed accordingly. The sensors are readily avail be and currently used in WDSs to collect data about usage and other system parameters. Additionally, there are a number of controllers available for the control of plant with the proportional-integral-differential (PID) and proportional-integral (PI) controllers being the most common controller type found in industry for the real time control of pumps (Visioli, 2006). However, directly applying real time control of pumps within a WDS is currently unavailable (van der Vaart, 2007).

One of the main issues which are limiting such implementation is the presences of transients found in pipelines and WDS. The transients are caused by sudden changes in pressures or flow within a WDS which then oscillates throughout the pipeline. This is detrimental to system performance as the controller would attempt to adjust the pressure accordingly causing other pressure changes which would interact with the initial transient (Anil Naik et al, 2012).

Another hindrance faced is the delay in signal response between the sensor and the controller. Due to pipelines generally spaning over large distanced there is a delay between the sensor detecting a change, the pump to make the required adjustment and then this adjustment to be transferred back to the sensor. Having large delays may cause the controller to act blindly and resulting in the making larger than necessary changes (Hang et al, 2004). Similarly, the large change by the pump can cause oscillations in the system and greatly affect the system’s ability to ensure the required pressures and flow are met.

## 2.2 Research Questions

The reliable provision of adequately pressurised potable water to consumers within a distribution system whilst minimising energy requirements is a complex task. The development of a framework for a real-time control strategy will involve addressing the following questions

1. Distribution systems are not static in nature but contain highly dynamic hydraulic behaviour. Dealing with this dynamic behaviour is a crucial part of the framework to be developed within this research. The dynamics within a pipe network system take the form of propagating pressure waves, that undergo a time-delay and attenuation in their propagation. This research will investigate and develop approaches for dealing with this phenomena to ensure that the developed control strategies do not exacerbate this problem, but can work effectively with the system dynamics.
2. How do typical water distribution system parameters such as pipe properties, system demand and size affect controller performance?
3. Talk about pump stations with multiple pumps (i.e. the situation is made more difficult/interesting with systems of pumps, not just single pumps)
4. Another system complexity is that we have highly time varying demands – talk about consumers and how they induce random loads on the system (i.e. we have to deal with real system demands like taps turning on and off, toilets flushing etc, not the idealised smooth diurnal demands), and so this will impact our control strategy and we will need to investigate this influence
5. What controller or algorithm is best suited for the real time control of variable speed pumps?

## 2.3 Project Objectives

The primary objective of this project is the development and analysis of a framework for the real-time control of variable speed pumps within water distribution systems.Based on the previous research conducted, a number of key objectives are required to be overcome to insure that the research achieves its final outcome. This aims of the proposed research are to:

* Investigate the relationship between torque and turbine losses in water pumps to accurately model a typical pump used in a water distribution system.
* Construct a computer based model which can accurately model demands found in typical water distribution systems.
* Examine how system parameters and sensor location can affect controller performance
* Implement various controller systems to a simulated model to determine the most suitable controller to utilise for the real time control of variable speed pumps.
* Develop a systematic framework for the implementation of real time control in water distribution systems.

## 2.4 Significance

Using real time control techniques for pump and plant operation have been widely used amongst the electrical and mechanical fields, particularly within the last decade. An example of such implementation is documented by Wang and Ma (2009) where by PI controllers were used in conjunction with variable speed pumps and heat exchanges to maintain a high rise building temperature. This method was tested against the typical scheduling method and found to provide power savings between 12.7% and 32.4% depending on season conditions. Other examples of real time control is with wind generators (Deraz, 2013) and hydroelectric plans (Rajagopal, 2010) and where it was used to minimise large changes and maintaining desired outputs while maximising efficiency.

Real time control has provided many advantages to other industries, the translation into water engineering has become an important area of interest. Due to the nature of application to the water engineering field, only limited research has been conducted over the last few years. A case where real time control has been implemented for pumps in a WDS is presented by van de Vaart (2007) where three controllers with different input values were designed in a cascade formation to vary pump output. In addition to this controller setup being complex, the system is still susceptible to instabilities and may take up to several minutes to stabilise during a transient event.

A further example of this is simulations conducted by Ding and Cao (2010) which required a pump to ensure constant pressure was maintained in the simulated water distribution system. The controllers used were able to provide a constant pressure in the system however no correlations between the system and controller types were defined. This work also outlined a number of issues which the controller had to overcome and include; the presence of transients, non-linearity, delays, controller tuning, pump starting frequencies and oscillations.

As seen in the literature presented, the real time control of pumps is a significant improvement over the scheduling method commonly implemented. Such control strategies are able to ensure demands are met while also provided large energy and cost savings to other fields. Due to these improvements, research into applying such method to water distribution systems have received increasing attention. However, a number of gaps are still present in the literature and include:

* Currently no defined controller or controller tuning to maximise performance of pumps in the event of transient conditions.
* There is no correlation between controller parameters and system parameters of a water disturbing system.
* There is no defined method of prevention for transients caused by the pumping in reaction to an original transients
* There is no defined method for improving system performance of such systems.

## 2.5 Theoretical framework and methods

As I have been conducting research on such project over the course of my Honours Research project, some initial concepts and a simplified model has been developed. Additionally, a number of controllers and relationships have been made but require further advancements to the model and additional testing. With the base model in place the following methods need to be completed:

1. Implement a functional pump model which accounts for inertial forces and losses.
2. Compare how the system performance varies when using the pump model which utilises torque as the control parameter.
3. Create a simulated water distribution system which can accurately represent a typical water distribution system found in most cities.
4. Conduct a sensitivity analysis for various system sizes, properties and sensor locations.
5. Investigate a range of pre-existing control strategies and controllers typically used in real time control.
6. Develop a controller algorithm and sensor combination which is best suited for a pump when applied in a water distribution system.

# 3. Research Plan

The research would span over a duration of three years and aims to follow the timeline outlined in the chart below.



# 4. References

Anil Naik,K, Srikanth.P, Pankaj Negi, 2012. IMC Tuned PID Governor Controller for Hydro Power Plant with Water Hammer Effect. *Procedia Technology*, 4, 845- 853.

Deraz. S.A, Abdel Kader. F.E 2013. *A new control strategy for a stand-alone self-excited induction*

*generator driven by a variable speed wind turbine*. Renewable Energy, Vol.51, 263 - 273.

Ding C, Cao L 2010. Self-adaptive Fuzzy PID Controller for Water Supply System. *In International*

*Conference on Measuring Technology and Mechatronics Automation*. China, 2010. China: IEEE Computer Society. 311 - 314.

Hang, C.C, 2004. Smith Predictor and its Modifications. *Smith Predictor and its Modifications*, Vol. 2, 1-5.

Rajagopal. V, Singh.B, Kasal.G.K 2010. *Electronic load controller with power quality improvement of isolated induction generator for small hydro power generation*, *IET Renew. Power Generation*, Vol. 5, Issue. 2, 202-213

Riyanto, E. Chuei, TC. 2009, *A heuristic revamp strategy to improve operational flexibility of water*

*networks based on active constraints,* Chemical Engineering science, Vol 65, Issue 9, 2758-2770

Van der Vaart, E. *Control System Analysis for The Pump Stations of the Perth Integrated Water Supply Scheme*. W.A.: Water Corporation, 2007.

Visioli, A, 2006. *Practical PID Control (Advances in Industrial Control)*. 2006 Edition. Springer.

Wang.S, Ma.Z, 2010. Control Strategies for Variable Speed Pumps in Super High-Rise Building. *American*

*Society of Heating, Refrigerating and Air-Conditioning Engineers*, 1, 36 - 43.

Wu Z, Todoni, M & Walski T, 2009, Modelling Variable speed pump operations for target hydraulic

characteristics, *Journal of the American Water Works Association* No. 101 pp 54-64