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Variable Speed Drives: Energy Saving and SCADA System

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Abstract: In this paper, implementation of variable speed drives (VSD) in a water treatment plant (WTP) and its capability in energy consumption reduction is presented. Conducted in Titi WTP, Negeri Sembilan, Malaysia, the project was run for four years, i.e. from early 2011 until the end of 2014. In the duration of four years, four VSDs are installed in the raw water pump house (RWPH) and treated water pump house (TWPH) of the plant with a power rating of 130kW and 260kW respectively. The electrical energy consumption of the plant before VSD installation was recorded as reference and a comprehensive supervisory control and data acquisition (SCADA) system was installed to remotely and automatically control the pump operation of the WTP. From The results obtained, it can be observed that, at the end of the four years, a saving of 26.64% and 24.58% for the energy consumption (kWh) and the overall cost (RM) respectively is achieved. Meanwhile, the payback period or the return on investment (ROI) period is calculated to be 3.4 years.

Keywords: Non-revenue water, Variable speed drives, Energy saving, SCADA, Telemetry System

1. Introduction

Energy consumption in the industrial sector makes up a significant energy global usage of 37% from the total global energy delivered. Operation of water treatment plant (WTP) in particular, to a large extent, is energy dependent. In WTP, in order to meet the customers' demand, water pumps are heavily utilized which usually runs for 24-hours in the pump houses. In Titi WTP, the existing water pumps utilizes soft starters to start, runs at maximum speed, for 365 days every day, until plant shutdown which occurs only once a year. Continuous use of pumps will incur high energy consumption, meanwhile running at full speed will incur high maximum demand. Therefore, to reduce the energy consumption in the plant, a more efficient approach is desirable.

One approach to overcome the excessive use of energy in a WTP is through installation of variable speed drives (VSD) for individual water pumps. VSD is an electronic device, capable in modulating the motor frequency hence varying the motor speed depending on the current requirement. Since WTP operates on current water demand which varies continuously, it seems imprudent to let the pumps run constantly without any variation of speed. Hence, through installation of VSD, the problem of energy wastage in a WTP can be overcome. However, to avoid undesirable damage of pumps or motors, the chosen VSD should be installed according to the characteristics of the pumps. Therefore, trending and analysis of the pump operation as well as study on compatible energy requirement, needs to be determined in order for the VSDs to be working harmoniously with the pumps.

To ensure that the VSDs run according to the plant demand, the level of the clear water tanks and the reservoir tanks, as well as the inlet and outlet flowrate of the WTP must be monitored. Overflown tanks will cause water wastage of the plant, high flow rate is caused by unnecessary pumping, which contributes to an increase in plant loss, energy consumed and non-revenue-water (NRW).

In a WTP, water wastage will add on to the overall operational cost. Therefore, by monitoring several parameters in the plant, both energy and water wastage can be avoided. To monitor these parameters, a supervisory control and data acquisition system (SCADA) is highly desirable. With SCADA, the VSD can be automatically controlled from a control room, which might be located a distant away from the plant. SCADA system utilizes human machine interface (HMI) that can remotely and automatically control the VSD when there is a change in the set parameters.

Water wastage in plants or non-revenue water (NRW) has become the national concern off late. NRW is

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the water lost between water distributors and customers, which is a serious yet continuous predicament confronted in a global level. NRW has become a huge problem to Malaysia since water demand increases constantly due to the growing Malaysian population as well as the uneven volume of rain water in Malaysia. Current NRW of Malaysia is 36.6% i.e. the unbilled water, or water wastage is nearly half of the water supplied. The installation of VSD in WTP is anticipated to assist the nation in reducing NRW percentage hence saving more water in preparation for the future.

Therefore, in this article, the author emphasizes on the benefit of installing VSD in a WTP, with a complete SCADA system in order to remotely monitor the plant to reduce energy and water wastage. Titi WTP, which is located in Jelebu, Negeri Sembilan will be used as the case study. Data obtained for this paper is obtained from ZEC engineering Sdn Bhd, a power and control company capable in performing the energy consumption management for a WTP.

2. Variable Speed Drives

Variable speed drives (VSD), as the name suggest, is an electronic device capable in controlling the rotational speed of an electric motor. This is achieved by controlling the frequency of the electrical power supplied to the motor. Unlike in the conventional case, the input power supply is connected to the input of the VSD. The power supply is then run from the output of the VSD to the electric motor. The VSD is able to invert the supplied frequency to the desired frequency per requirement of the electric motor. The utilization of VSD increases the efficiency of the electric motor since the motor runs at a rate proportional to the AC current supplied to it.

From literature, significant energy saving in the electric energy consumption when VSD is installed can be seen in [1-6]. Since VSD is capable in controlling the motor's speed, torque and mechanical power output, its application in the industry can provide significant saving in the electricity usage, simultaneously the electricity bills incurred, as discussed in [4] and [5]. In [5] in particular, a significant amount of energy is saved, simply by changing the motor load using VSD. Similar results were obtained when VSD is implemented on motors of pumps and fan application in buildings [4] and hospitals [1]. Meanwhile, in [6], the marketing manager of ABB Helsinki itself states that the application of VSD in motor application can have a reduction of energy usage of up to 40%. On top of it all, the payback period for VSD application i.e. the return of investment (ROI) is reasonable, i.e. between 1 to 3 years as was stated in [5] and [4].

In this article, the installation of four VSDs in the raw and treated water pump houses of Titi WTP in Malaysia is presented. From the application, the reduction in electrical energy usage is apparent even in the first year of installation. Elaboration on Titi WTP and the energy saved through installation of four VSDs is presented in the subsequent section.

2.1 Supervisory, Control and Data Acquisition System

Supervisory Control and Data Acquisition (SCADA) system provides remote monitoring and control system and currently has becoming a backbone of many process industries. The implementation of SCADA in WTP and Wastewater Treatment Plant (WWTP) can be seen in [7, 8]. In these plants, SCADA is used to provide real-time application management environment by providing tools for implementation and testing of sophisticated control system and data quality analysis. Guides on implementing SCADA properly can be found in [9], whereby the case study of a WWTP is used.

Meanwhile, the implementation of SCADA in power plants and refinery is elaborated in [10-12] where major infrastructures and processes can be remotely monitored and control from a central control room. In the literature, the advantages of SCADA system can be clearly seen and the importance of the implementation is highly desirable in process automation industries for an efficient and cost effective plant operation.

Some important features of the supervisory control and data acquisition (SCADA) system in waste or wastewater treatment plant are control, monitoring, alarm system, data logging and diagnostic [7]. Meanwhile in the control features, maintaining specific levels in tanks and retaining prescribed flow rates, can be easily achieved in SCADA system by consecutive standard control algorithm such as P, PI, and PID. By implementing Boolean Logic, controlling the application scheduling such as automating starting and stopping pumps, opening and closing valves and others can also be done in SCADA system.

Providing an effective visual interface between the process and an operator is the key function of monitoring features. SCADA structures generally consists of an advanced set of tools to display individual process values, including animated graphic illustrations of the procedure. SCADA offers the means of taking real time data and provides the trending of the data to identify subtle process changes occurs.

Another coveted feature of SCADA system is data logging. When data are conveyed into a system, the SCADA will document selected data into an electronic records that may be recollected and reviewed at a later time. By utilizing the historical data, further analysis or reports can be prepared. Through historian function, such as record on the track energy charges and consumption, bill validation and report on cost avoidance can be trailed. In addition to that, data logged from SCADA can be conveniently used for analysis to further improve the plant operation, as an aid for decisional support mechanism [13].

Incorporated into the data or record and graphical displays are alarm roles that can raise and display alarms as they arise which is alarm features tasks. On some system, they may be secured by Auto-Paging or Auto-Phone–dialling features which will automatically inform operating employees when a problem occurs. In diagnostic feature, few SCADA systems have integrated statistical packages that may be used for online evaluation of process data to notice unusual behaviour of the process. This can lead to secure calibration of instrument or forthcoming failures of control components.

In this paper, to provide remote monitoring of the whole plant process, a SCADA system is implemented in Titi WTP to automatically control the installed VSD in the raw and treated water pump houses.

SCADA installed in Titi WTP can aid the plant in the following manners:

1. Managing retrieved data from end objects
2. Prevents human error through automated remote monitoring
3. Remotely control and monitor the plant operation automatically
4. Able to manage human resources
5. Capable in managing assets i.e. pumps, VSDs, actuator valves in extending their life cycle
6. Able to simplify plant management
7. Interface equipment from end to end (pumps interlocks, remote control and configuration.

2.2 Communication Network in SCADA System

SCADA system operation is commonly used in water or wastewater treatment plant. SCADA system is utilized to monitor and control the plant from a central monitoring station or control station. It involves real time data exchange from the remote area and essential action is generated for any peculiar condition. SCADA system is composed of three key elements which are human machine interface (HMI), remote telemetry units (RTU) and communications.

The purpose of HMI is to connect human operator to the system in order to display the statistics received through the browsing interface and to archive all the data received. Generally, a high end computer system is necessary to display high quality graphics, running advanced and sophisticated software system. Meanwhile, an RTU has an important role of accumulating onsite information to be sent to a central location/control room with the support of a communication network. If the system desires to send information back to the RTU, then this communication network takes it back to the desired location [10]. The RTUs are similar to Programmable Logic Controller (PLCs). Commonly, PLCs are utilized in local area which includes factory floor and are connected together usually by a local area network while RTUs are utilized in remote locations and connected by a Wide Area Network, hence covering a wider range of areas.

The communication method between the RTUs or PLCs to a SCADA system servers and terminals as well as in local or remote area, is established either hardwired or through a wireless connection. Hardwired communication method include data or Ethernet cable, phone lines, fibre optic, coaxial cable etc. Meanwhile, a wireless communication method include satellite, radio, cellular and Wi-Fi connection. A SCADA system rely on the communication system which provides a medium of data transmission between the supervisory control in the control room to the RTUs or PLCs and the end devices in a system. A preferred communication standard for local area network is using Ethernet connection. An Ethernet system connects numerous computer system to form a local area network (LAN) with matching protocols and communication parameter to control the passing of information. The choice of protocol and communication parameter is based on the function of the operational requirement, industry preference vendor and the design of the system.

The MODBUS protocol is one of the most common communication protocol for RTUs and PLC and it was designed by MODICON Corporation. During communication on a Modbus network, the protocol determines how each controller will recognize the device address, identify a message addressed to it, determine the action to be taken and extract any information or data attached to it [14]. These Modbus command set are packed as a single bit, or 16-bit word packets. There are numerous types of MODBUS and the most common one is MODBUS RTU and MODBUS ASCII (American Standard Code for Information Interchange). MODBUS RTU is an open serial communication, typically using RS232 and RS485. MODBUS RTU is a widely used protocol due to its ease of use and reliability. The protocol is widely used in building management system (BMS) and industrial automation system (IAS), such as the WTP. Meanwhile, MODBUS ASCII allows time intervals of up to one second to occur between characters without causing errors. However, the protocol is not popular in respect to a SCADA system since messages are sent using ASCII character through a communication channel. In this research, the SCADA system uses a MODBUS RTU protocol in executing its operation.

3.0 Titi Water Treatment Plant

Titi WTP is located in Jelebu Negeri Sembilan. The general operation of the Titi WTP is given in Figure 1.

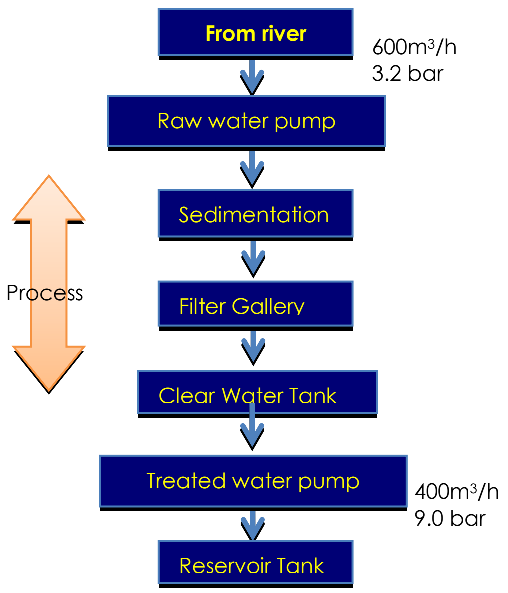

Figure 1 General operation of Titi WTP

From Figure 1, the water flow starts from the raw water at the river and pumped to the aerator in the raw water pump house with a pressure of 3.2 bar and a flow rate of 600m3/hr. The reservoir tank has a capacity of 500,000 gallon with 9 bar pressure head. The flow rate of the treated water to the reservoir tank, which is 10km from the plant, is 400m3/hr.

Titi WTP is designed for a demand of 3.2MGD of water i.e. the plant is able to distribute water to a total of 16,000 consumers. The plant is installed with two 130kW raw water pumps and two 260kW treated water pumps in the raw and treated water pump houses respectively. In Titi WTP, the reservoir tank is located 10km away from the plant hence a high motor rating of 260kW is required. However, the distance from the raw water pump house to the clear water tank is 500m away, hence a lower motor rating of 130kW is required. All motors are initially electrical driven by soft starters (SS).

The energy monthly consumption of Titi WTP in 2010 with motor soft starter, extracted from the Tenaga National Berhad (TNB) bill, and the cost incurred is given in Table 1.

Table 1 Monthly Energy Consumption in Titi WTP

No	Month 2010	Operating Hours	kWh	Tariff (RM)	Value (RM)
1	January	13.32	130,698	0.397	51,887.11
2	February	14.88	145,973	0.397	57,951.28
3	March	18.32	179,694	0.397	71,338.52
4	April	15.40	151,017	0.397	59,953.75
5	May	17.54	172,057	0.397	68,306.63
6	June	16.01	157,004	0.397	62,330.59
7	July	15.82	155,175	0.348	54,000.90
8	August	18.87	185,049	0.348	64,397.05
9	September	16.61	162,875	0.348	56,680.50
10	October	26.36	258,577	0.348	89,984.80
11	November	21.28	208,749	0.348	72,644.65
12	December	17.77	174,297	0.348	60,655.36
	Total	212.18	2,081,165		770,131.1
	Average	17.68	173,430	0373	64,1777.6

From Table 1, the highest energy consumption can be seen in October, followed by November. This may due to the high level of turbidity in the water since its rainy season. When turbidity is high, the sedimentation tank in the plant will need to be cleaned to get rid of the extra accumulated sludge, hence additional pumping is required to compensate the loss of treated water going into the filtered gallery.

Meanwhile, the average energy consumption in Titi WTP for both raw and treated water pumps, which runs for 24 hours everyday, as obtained from the soft starter panel is given in Table 2.

From the current demand analysis for Titi WTP in 2010, it is observed that the real output is 1.6MGD i.e. half of the amount produced. Hence, the required water flow rate for the raw water intake is 300m3/hr where 50% of the water is discharged through the bypass pipe to the river. For the flow rate of 300m3/hr a total of 1111.11GPM (Gallon per minute) is produced.

Table 2 2010 SS Energy Consumption

No	Pumps	*Motor Rating* kW	*Current Rating* Amp	*Running current* Amp	*Running kW* kW	*Flow rate* m^3/hr
1	Raw water	130	230	196	126	600
2	Treated water	260	420	310	200	400

From this observation, a calculation for the real total pump capacity is determined for both the raw and treated water in Table 3.

Table 3 Raw and treated water pump capacity

No	Pump criteria	Raw water pump	Treated water pump
1	Head Pressure	3.18 bar	9.13 bar
		47.73 psi	136.95 psi
2	Pump horse power (HP)	65.87 hp	65.87 hp
3	Pump energy (kW)	49.14 kW	127.44 kW
4	Pump motor rating (kW)	130kW	260kW
5	% Total pump capacity	38%	49%

From Table 3, the amount of energy used from calculation for the pumps to meet current demand is only 38% and 49% of the total pump capacity for raw and treated water pumps. Hence, in Table 4, the motor frequency of the raw water pump VSD is tuned to achieve the required energy, which is 49.14kW. In order to achieve the calculated energy, the VSD installed for the raw water pump is tuned, and the frequency and flow rate required is determined, as shown in Table 4. Hence, a saving of energy of the plant is imminent.

From Table 4, the motor frequency is varied from 38Hz to 50Hz to analyse the parameters obtained. It is observed that, at a flow rate of 300m3/hr, the head pressure and the pump energy obtained are similar to the values calculated in Table 3. To ensure the investment yield profitable outcome, the return on investment (ROI) will be elaborated in the section 4.2.

4.0 Methodology

To achieve significant savings in the Titi WTP, eight VSDs along with a SCADA pack are installed in Titi WTP beginning June 2011 for the RWPH and TWPH. The general operation and the system architecture of Titi WTP after the VSD and SCADA installation is given in figure 2 and figure 3 respectively.

From figure 2 and 3, there are four remote terminal units (RTU) utilized for the raw water pump house, treated water pump house as well as the reservoir tank. The RTU are responsible to obtain data from the electronic devices (flow meter, VSD and level sensor) to be sent to the control room. The RTUs act as an interface between the end object and the SCADA system by transmitting telemetry data. These data are used by the control room to control or monitor the end device hence appropriate control action can be executed. The telemetry system for Titi WTP can be seen in Figure 4.

Ladder diagram is used to program the RTUs in order for the pump to operate according to current demand. Current plant demand is relative to the water level of the reservoir tank. If the water level falls between a certain limit, the VSD motor frequency will vary accordingly. Upon installation, the energy consumption of Titi WTP is monitored and controlled for three years. The monthly power consumption as well as the cost incurred for Titi WTP are logged and analyzed from June 2011 until June 2014. Data are retrieved from TNB bill as well as from the logged data from the SCADA pack installed. In Table 6, the average energy consumption, as well as the costs incurred is presented.

5.0 Results and Discussion

5.1 Payback Period

A simple payback period for Titi WTP can be calculated using a simple formula (1).

$$\frac{\text{Cost of Energy Efficiency product}}{\text{Annual } electricity \text{ savings}} \tag{1}$$

For Titi WTP, the VSD costs for 130kW and 260kW motor are RM34,000 and RM40,000 respectively. The maintenance cost comes up to RM5,000 monthly whereby a visit from the system integrator is done twice a year. Including the engineering and cabling work as well installation work of the VSD, the total cost is RM750,000. Hence, this is the cost of energy efficiency product. To calculate the annual electricity savings, data from Table 6 is utilized. The annual savings for 2011 until 2014 after VSD installation is tabulated below with the 12 months equivalent amount for comparison purposes. Amount of electricity bill and energy used in 2010 before VSD installation are RM 770,131.13 and 2,081,165.00 kWh respectively.

To calculate the payback, annual savings for the years 2012 and 2013 will be used since these are the only years that the VSD runs fully in Titi WTP without any significant increase in the electricity tariffs. The following simple calculation is used to obtain the plant payback through VSD installation (2) and (3).

$$\frac{\text{Cost of Energy Efficiency product}}{\text{Annual } electricity \text{ savings}} \tag{2}$$

Payback from calculation for 2013

$$\frac{750{,}000}{226{,}018.88} = 3.3 years \tag{3}$$

Therefore, for Titi WTP, the average payback period is 3.4 years, i.e. within the appropriate payback period of a process plant.

5.2 Return on Investment

From Table 5, the average energy consumption of the soft starter control panel for 15 months i.e. before VSD installation is 174,750.40 kWh @RM 63,872.19. Meanwhile, the average energy consumption for the motor for 39 months after VSD installation is 128,198.28 kWh @ RM 48,169.47. From a simple return on investment calculation given below,

$$\frac{\text{Gain from Investment - Cost of investment}}{\text{Cost of investment}} \tag{4}$$

The percentage electrical energy saving for Titi WTP from 2010 until 2014 is given below:

$$\frac{128{,}198.28kWh - 174{,}750.40kWh}{174{,}750.40kWh} \times 100\% = -26.64\% \tag{5}$$

The initial energy saving by Titi water treatment plant can be represented in figure 4. From the sudden drop of operating cost per hour in April 2011, signifies that a significant amount of electrical energy usage has dropped prior to the installation of the four VSDs in April 2011. Throughout the installation of VSD in Titi WTP has seen a consistent drop of energy consumption as well as the cost incurred as seen in Table 6

6.0 Conclusion

In this paper, eight VDSs are installed in Titi WTP for the four raw pumps (130kW) and four treated water pumps (260kW) for a duration of four years (2011 until 2014). It was observed that the VSDs installed are able to vary the motor speed of the pumps according to current demand automatically, hence reducing the energy consumed significantly. Through SCADA system installed, these pumps can be remotely monitored and controlled hence optimizing Titi WTP operation. The energy consumption of Titi WTP has been reduced to as much as 26.6% and 24.6% for the electrical energy used (kWh) and TNB cost respectively. Therefore, it can be indisputably concluded that the installation of VSD has caused a significant reduction in the energy consumption in Titi WTP, hence the electricity bills incurred On top of that, since the plant is run automatically, the operator assigned has less responsibility, hence deployment of workers to other skill operation is a possibility.

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References

[1] J. Tolvanen, "Saving energy with variable speed drives," *World pumps,* vol. 2008, pp. 32-33, 2008.

[2] E. Abdelaziz, R. Saidur, and S. Mekhilef, "A review on energy saving strategies in industrial sector," *Renewable and sustainable energy reviews,* vol. 15, pp. 150-168, 2011.

[3] R. Saidur, "Energy consumption, energy savings, and emission analysis in Malaysian office buildings," *Energy Policy,* vol. 37, pp. 4104-4113, 2009.

[4] E. Ozdemir, "Energy conservation opportunities with a variable speed controller in a boiler house," *Applied Thermal Engineering,* vol. 24, pp. 981-993, 2004.

[5] R. Saidur, N. Rahim, H. Ping, M. Jahirul, S. Mekhilef, and H. Masjuki, "Energy and emission analysis for industrial motors in Malaysia," *Energy Policy,* vol. 37, pp. 3650-3658, 2009.

[6] B. Mecrow and A. Jack, "Efficiency trends in electric machines and drives," *Energy Policy,* vol. 36, pp. 4336-4341, 2008.

[7] B. Humoreanu and I. Nascu, "Wastewater treatment plant SCADA application," in *Automation Quality and Testing Robotics (AQTR), 2012 IEEE International Conference on*, 2012, pp. 575-580.

[8] A. Archana and B. Yadav, "PLC & SCADA based automation of filter house, a section of Water Treatment Plant," in *Emerging Technology Trends in Electronics, Communication and Networking (ET2ECN), 2012 1st International Conference on*, 2012, pp. 1-6.

[9] A. Korodi and I. Silea, "Specifying and tendering of automation and SCADA systems: Case study for waste water treatment plants," in *Control Applications (CCA), 2014 IEEE Conference on*, 2014, pp. 1503-1508.

[10] M. N. Lakhoua, "SCADA application of a water steam cycle of a thermal power plant," in *Modeling, Simulation and Applied Optimization (ICMSAO), 2013 5th International Conference on*, 2013, pp. 1-5.

[11] A. Firoozshahi and L. Mengyang, "Water treatment plant intelligent monitoring in large gas refinery," in *Computational Technologies in Electrical and Electronics Engineering (SIBIRCON), 2010 IEEE Region 8 International Conference on*, 2010, pp. 785-789.

[12] A. Firoozshahi and S. Kim, "Intelligent and innovative monitoring of water treatment plant in large Gas Refinery," in *Control Applications (CCA), 2010 IEEE International Conference on*, 2010, pp. 269-273.

[13] I. Stoian, D. Capatina, S. Ignat, and O. Ghiran, "SCADA and modeling in water management," in *Automation, Quality and Testing, Robotics, 2014 IEEE International Conference on*, 2014, pp. 1-6.

[14] P. P. L.A Sunil "SCADA a tool to increase efficiency of water treatment plant," *In Asian Journal of Engineering and Technology Innovation,* vol. 04, p. 7, 2014.