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Energy Efficiency in the Water Distribution System

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Abstract: ***PDAM is one of the drinking water providers that is responsible for providing water to the community. Electricity or energy costs that must be paid by PDAM are around 30% of all operational costs, of which about 80% are for electricity or costs for treatment plants and distribution, especially for pumping cost.Energy efficiency efforts can be done by first identifying the factors that influence energy consumption and then selecting the appropriate technology according to the site conditions.Water supply system, water demand profile and leakage rate are main factor that affect the energy consumption of the drinking water distribution system. Some things that are considered in determining the energy efficiency technology to be used are the water supply network, the service area topography, the energy efficiency technology that has been used and others. Asset management can also play a role in the analysis of technology requirements for energy efficiency. The technology in this paper implies pressure regulation for energy efficiency such as pump scheduling, tank, variable speed pump, pressure reducing valve, harmonic oscillator tank and pump as turbine.***

Keywords: PDAM, distribution, energy efficiency, pressure

1. Introduction

Water is a basic human need that increases gradually. The water demand increases due to several factors, for example, population growth, increasing urbanization, environmental pollution, and climate change[1]–[3]. The government must provide the public's basic needs for water. That is by the mandate of the RPJMN 2020-2024, namely the provision of access to safe and proper drinking water and sanitation. Expanding the coverage of PDAM services is one way to achieve access to safe drinking water but is constrained by costs. The highest cost component that must be incurred by PDAM is electricity or energy costs that can reach 30% of the total operational cost[4], [5]. The high cost of electricity is caused by the use of energy that is not by the increase in the production/distribution capacity of drinking water, the age of the equipment, and the inefficient energy use[4].Water networks, an application of technology, topography, climate, operation efficiency, and city shapes/population distribution have a significant impact on energy for water supply[6]–[9].

Water distribution systems are designed to deliver safe and reliable drinking water[8]. Water distribution systems consist of one or more Hydraulic Pressure Zones (HPZs) [10]. About 80% of the total treatment anddistribution costs are for electricity or energy costs, especially for pumping costs[2], [11], [12]. In 2017, the electricity cost of one water treatment plant PDAM Ketapang 98 million rupiahs each month[4]. Energy consumption of water treatment plant PDAM TirtaKhatulistiwa Pontianak about 1.051 MWh/month [5]. The consumption of electrical energy (kWh) in the IPA Pengok PDAM Tirtamarta Yogyakarta based on the type of load is dominated by the pump load of 15.769,17 kWh or 98,8%, the lighting load of 126,18 kWh or 0,79%, and a load of electronic equipment of 55,65 kWh or 0,34%[13].The price of electricity tends to increase which caused the electricity cost burden of PDAM will automatically increase.

In the past decade, the focus on energy efficiency is so high that many studies have discussed it. Technology for energy efficiency is very diverse, such as implementing pump scheduling, installing tanks, installing valves, and a combination of pumps and tanks, etc. So the purpose of the paper is to discuss the factor that impacts energy consumption and how to reduce energy consumption in water distribution. This paper is expected to help in considering and determining the technology used for energy efficiency. In section 2 discusses factors that impact energy consumption. The next section discusses technology to reduce energy consumption. In section 4 discusses the outcome of the research. The research conclusions are described in section 5

2. Factor that impact energy consumption

a) Water Supply System

The topography is a factor that influences the selection of a water supply system. The water supply system is divided into pumping and gravity systems. The gravity system is the cheapest one. That is supported by research conducted by Lam et al (2017)[7], energy use per capita in Melbourne is smaller than in San Diego because the water supply system'sMelbourne is predominantly gravity-fed. In a water distribution system, the high operational cost is represented by the pumping system[2], [7]. Energy intensity of water distribution ranges from 0,010 to 0,341kWh per kiloliter water supplied [7]

Huang et al [12] show that specific energyconsumption and total water supply volume has significant correlation. If water supply volume increase so specific energy consumption decline. Water supply volume estimate by two factors, population and integrated domestic water consumption of the specific city.

b) Water Demand Profile

Liter water per capita is the most significant factor which influences energy use. Water demand describes customer characteristics and is the key to energy efficiency. The supporting factor in energy efficiency besides the water demand profile is the electricity tariff structure[7], [10]. In general, the water demand profile is taken in a daily time frame. For more detail, water demand can be retrieved in a weekly time frame and then divided into weekday profiles (business days) and weekend profiles[14].

c) Leakage

A pumping system is one of the high operational costs that is magnified by every liter of water lost to leaks before reaching the customer[2].Leaks can be divided into burst and background leakage.Leakage is associated with water losses, energy wastage, health, and environmental problem[15].

Non-revenue water (NRW) is the difference between water produced and water that can be the bill. The leakage is one of the components. NRW contributes to about 25% of the average energy consumption of water[7].

Energy consumption is related to the headloss in the urban water distribution network [6]. The hydraulic gradient represents the head loss per meter of pipe length. Ghorbanian et al [8]show that the reduction of energy in a system with a high leakage rate is more than in low leaks system.

Based on Huang et al [12]the energy consumption per unit of water declines when the leakage rate increase. There are two reasons for this condition. Seen from the hydrodynamic aspect, the head loss is lower when the flow leaks along the course than when is no leakage because lower flowrate means lower resistance of pipe, thus leading to lower energy consumption. The other reason is specific energy consumption counted based on total of water supplied from water treatment plant instead of that received by the end users.

Experiments conducted by Bolognesi et al [16]explain the effect of leakage on energy consumed and energy efficiency, by showing the conclusion that reducing leakage saves energy can improve energy efficiency.

d) Technology to reduce energy consumption

Energy efficiency can be applied by minimizing actual energy consumption and improvising ways to spend energy properly[16].The optimal solution for energy management in an integrated water system has a different alternative. That is given based on water system characteristics, especially the availability and quality of the resources, the network topology (supply network), the topography of the served area, and processes in the treatment plants (technology)[2], [6], [8].Before selecting and applying technology for energy efficiency, some data is required, such as a water demand profile, a map of the existing distribution network (including the location of pumps, tanks, and valves), and the electricity tariff structure.

Bolognesi et al [16] introduce a new reference for energy efficiency evaluation that called Unavoidable Minimum Energy (UME). UME establishes a more realistic baseline taking into account the layout and length of the network as well as pipe sizes and node heights. Optimization of the existing distribution network can be achieved by varying the diameter, pump, or both.

Based on SNI 7509:2011[17],the minimum pressure in the water distribution system is 7.5 m at the customer connection. When the minimum pressure requirement is exceeded it will result in energy loss [18]. Pressure management is one solution that can help regulate pressure on the system. Many studies have implemented pressure management using several options, such as using reservoir tank, variable speed pump (VSP), pump scheduling, and others.

Pums are used to raise the pressure of water flow, so the pressure high enough to offset the resistance of pipeline and elevation fluctuation [12]. Optimal pump operation in water distribution systems has economic benefit[7] by shifting the pumping times from higher electricity costs to cheaper ones [10], [14].The shift of operation to the cheapest period reduces electricity cost by 16.4% compared to the baseline and reduces pumping cycles by 57% which contributes to reducing equipment aging[14]. Pump scheduling can decrease energy or electrical bill by considering water demand profiles, characteristic pump, and electricity tariff structure. A factor that needs to be considered when using a pump, namely the pumps aging due to the number of pumping cycles[14]which can affect pump efficiency.

Experiments conducted by Luna et al [19] use a hybrid algorithm to optimize the pump scheduling system in order to reduce energy consumption and costs.Optimization of the pump scheduling system depends on water availability, water demand, and water storage risks. The water demand profile is used to determine the optimal pump status for a certain period of time, minimizing operating costs, as well as energy consumption. Optimized pump scheduling can increase energy efficiency by an average of 15% -25% compared to actual operation, however this value can decrease if more water is stored in the tank.

VSP is a pump with a variable speed drive (VSD) whose task is to regulate the rotational speed of the pump's electric motor by changing the frequency of the input power. When the speed of the electric motor changes, the hydraulic performance of the pump changes.VSD provides a means to control the delay during the charging and discharging processes[15]. The study by Monsef et al[18]presented that control with VSP for management pressure can reduce energy cost by 28%. They reduce excess pressure when water demand is low. Finding the optimal set point of VSP at maximum and minimum demand time is the key to management pressure.Combining the tank and pump can have a greater impact than using a direct pumping system[8].

PRV (pressure reducing valve) is used to regulate the pressure at the entrance of the network[15].PRV is installed at the DMA inlet then the water pressure in the zone network can be adjusted by operating the PRV[20].PRV is not a partially closed in-line valve with a fixed value of the degree of opening, but a self-adjusting PRV opening[21]. There are several type of PRV, namely fixed outlet, time-based and flow-based PRV. The most commond use in water distribution system is fixed outlet PRV.Moslehi et al [22] change fixed outlet (FO-PRV) to time-based (TM-PRV) by installing time-controller and flow-based (FM-PRV) at inlet of DMAby implementing a flow meter and electronic controller. The most benefical scheme use FM-PRV that can reduce 13% AZP and 12% daily leakage.

Storage tank provides more reliable water supply and reduces the energy cost of pumped water by shifting pumping times between different electricity tariffs[10].The tank fills during the low electric tariff period and then empties during the peak period can give the cheapest cost[8], [10]. However, that case is assumed to use a fixed speed pump[10].Control the pressure in the system, can reduce energy consumption. The reduced delivery pressure is achieved by changing the elevation tank[8].The tank placed downstream can minimize the pipe sizes, provides reliability, and minimizes the water age in the network[3].

The popular automation system in past decades is Supervisory Control and Data Acquisition (SCADA) that is used to monitor and control the water distribution system. The advantage of using SCADA can decrease the installation and maintenence cost of water distribution systems[10]. SCADA allows monitoring of several variables, for example, water level, flow rate, electric power supply and etc[14]. Control logic in PLC is usually used to control schemes that have been arranged according to design and needs. Simple control is installed in pumping stations or water tanks. Local control by PLC used in water utilities is not suitable to run real-time pump scheduling programs. The impact of that, the potential of achieving efficient energy and cost savings are not fully utilized[10].

Latchoomun et al [15]use the hydropneumatic tank as a harmonic oscillator tank for leakage and energy reduction in the water distribution system. A harmonic oscillator tank (HOT) applies a combination of water level and air pressure for optimal distribution. HOT uses the concept of energy storage before consumption. They use three scenarios to test leakage and energy reduction: a) Direct Pumping into Network with a fixed PRV setting, b) Pumping with a VSD, c) Harmonic oscillator tank scheme. This scenario applies in two conditions, low and high leakage. The HOT scheme is the most efficient energy-wise among the three scenarios with 95.40% at low leakage and 86.45% at high leakage. Problems that sometimes arise when using the HOT system. When the water level in the tank is low, the pump has to work more to fight the large volume of air and hammer effect from dissolved air.

Tahani et al [23]and Kramer et al [24]uses PAT (Pump As Turbine) as power generation and pressure regulation in water distribution systems. PAT reduce pressure when the direction of flow inverse and high pressure flow enters the PAT and then pump oparate as turbine. Main factor of PAT's performance is rotational speed variation (centrifugal variable speed pump).PAT speed will increase until the maximum steady-state condition is reached due to sudden load loss on the generator.BEP (Bestefficiency point) of PAT should be know because PAT effiency drops when it operates away from the best efficiency point. The idle point is the operating limit of the turbine and is represented as the runaway characteristic on the hill chart of the hydraulic machine.

Supported by research Lydon et al [25], PAT has the potential to reduce energy costs but its performance is difficult to predict. Usually the PAT performance is predicted from the pump characteristics (Q-H curve). However, ideally the selection of PAT requires one year of siteflow and head analysis. Analysis of site conditions will determine the feasibility of using PAT in the distribution system and the design point.Field conditions so that PAT is efficient and cost-effective is that the water distribution network only operates with gravity and does not need to place a booster[26].

Bonthuys et al [27] explained that asset management can be used to identify energy recovery and leak reduction potentials. The development of a city distribution system hydraulic model uses data from asset registers and customer profiles in the city asset management plan. The pressure profile of the hydraulic model analysis is compared with the minimum operating pressure of the system so that areas of overpressure can be identified. the excess pressure can then be exploited for energy recovery

3. Discussions

Energy efficiency efforts can be done by first identifying the factors that influence energy consumption and then selecting the appropriate technology according to the site conditions. There are three main factors that affect the energy consumption of the drinking water distribution system. First, the water supply system used in distribution systems, gravity systems tend to be cheaper than pumping systems. second, the water demand profile that describes the water consumption characteristics of the customer. third, the leakage rate in the system, reducing the leakage rate can improve system energy efficiency.

Technology selection for energy efficiency needs to pay attention to several things such as the water supply network, service area topography, existing technologies that have been used and others. The data needed to plan energy efficiency technology are water demand profiles, maps of existing distribution networks and electricity tariff structures.Asset management can also play a role in the analysis of technology requirements for energy efficiency. Some alternative energy efficiency technologies can be seen in Table 1

Table 1: Technology for Energy Efficiency

Technology	*Description*
A combination of pump scheduling and elevated tank	• The pumping time is done when the electricity tariff is cheap or LWBP • The pump used is a fixed speed pump • Reservoirs fill when electricity rates are low and when electricity rates are high it stops filling • To make it easier, you can use an algorithm in setting the pump on / off time • The reservoir height is determined based on the remaining pressure to be achieved at the farthest customer
Direct pumping using a variable	• VSD can control rotation speed by changing the input power frequency • Variable Speed Pump (VSP) can reduce excess pressure when water demand is low

Technology	*Description*
speed drive (VSD)	• The main key in using VSP is to determine the optimum point when the water demand is maximum and minimum
Pressure Reducing Valve (PRV)	• PRV functions to regulate the pressure that enters the network • PRV is installed at the DMA inlet • There are 3 types of PRV in the market, namely fixed outlet (FO-PRV), time based (TM-PRV), and flow based (FM-PRV). which is often used is FO-PRV while the one that has the highest advantage is FM-PRV
Harmonic Oscillator Tank (HOT)	• Hydropneumatic tanks are used as harmonic oscillators which can increase pressure • HOT uses a combination of water level and air pressure for optimal distribution. The pump fills the tank until the pneumatic pressure point is reached then it is discharged through the distribution network • This technology needs to be added with a pneumatic circuit consisting of a compressor with a storage vessel, an electro-valve and a pneumatic regulator which functions as an air regulator to provide pressure in the tank.
Pump As Turbine (PAT)	• PAT can be used as a power plant and pressure regulator in distribution networks • PAT can reduce the pressure when the flow direction is reversed and has a high pressure then the pump operates as a turbine • The main key for PAT to operate optimally is to determine the BEP (best efficiency point) of PAT because the efficiency of PAT will decrease significantly when operating not at BEP. • PAT performance is difficult to predict, usually PAT performance is predicted through the characteristics of the pump used • Planning using PAT requires analysis of the annual flow and head • Efficient and cost-effective when the water distribution network operates only by gravity and does not need to place boosters

4. Conclusions

Water supply sytems, water demand profile and leakage rate are main factor that affect the energy consumption of the drinking water distribution system. Some things that are considered in determining the energy efficiency technology to be used are the water supply network, the service area topography, the energy efficiency technology that has been used and others.The technology in this paper implies pressure regulation for energy efficiency. A combination of pump scheduling and elevated tank, Direct pumping using a variable speed drive (VSD), Pressure Reducing Valve (PRV), and Harmonic Oscillator Tank (HOT) utilizing pressure settings so that there is no over or under pressure to the furthest customer, besides that, it can reduce energy consumption on the distribution network. Pump As Turbine (PAT) can also reduce energy consumption by utilizing high pressure to become a power generator. To make it easier, you can use an algorithm in setting the automatic system.

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