Journal of Electrical and Electronics Engineering
Vol. 1, No. 1, June 2016, 7-10

Retrofication of Cascade Control System and Implementation of Human Machine Interface in A Water Treatment Plant

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ABSTRACT

In Indonesia urban area, due to low water distribution pressure at day, many inhabitants who live far from water distribution center get their fresh water share only at night or sometimes never. In order to ensure even distributed fresh water, there is a certain pressure that needs to be maintained. On a real technical project, an advance cascade controller will be installed in a water treatment plant to control multiple pump for maintaining distribution pressure. Furthermore, a corresponding Human Machine Interface (HMI) will be installed for easier daily monitoring and operation. Measurement data shows improved performance of the system, with only 0.02 bar of pressure error and better load distribution among the operating pumps.

Keywords: water treatment plant, cascade controller, Human Machine Interface

I. INTRODUCTION

Water is an essential element for almost all known life forms. Based on World Water Forum II, held on March 2000 in The Hague, Netherlands, Indonesia is one of the countries who will face water crisis by year 2025. This problem is caused by poor water management. Pusat Penelitian Geoteknologi LIPI ever mentioned in one of their articles that nowadays water, especially in urban area, is rare and becomes an expensive commodity. In Indonesia urban area, many of the inhabitants who live far from water distribution center get their water share only at night or sometimes never. The situation in remote areas is even more critical. Improving water distribution system could contribute in solving this problem.

Water treatment is a sequence of industrial-scale processes used to make water acceptable for a desired end-use. This processed water can be used for drinking water, industry, medical and many other uses. Water treatment process may be different with small-scale water sterilization practices. The goal of all water treatment process is to remove existing contaminants in the water, or reduce the concentration of such contaminants so the water becomes fit for its desired end-use. The processes involved in treating water for drinking purpose may be solids separation using physical processes such as settling and filtration, and chemical processes such as disinfection and coagulation [MGH82].

To make sure that the treated water is distributed evenly, a certain water pressure needs to be maintained. The pressure has to be high enough to reach the farthest area of the water distribution system but adequately low enough to prevent the pipe from breaking. The system also must be able to handle critical situation when the pressure drops fast and not too responsive in order to prevent hunting which causes unstable system. Hunting is a situation where the feedback control cannot steadily put the pressure on the set-point, but producing an oscillating cycle of pressure above and below the set-point, outside the tolerance range [KF02], [DPC82],

Several works devised to improve the operation of water distribution system are already proposed. In [[LBP12], contrains in smooth water flow while respecting the power levels defined by electricity supplier is elaborated. Electricity cost, maintenance cost, maximum power peak, and level variation in reservoir becomes the objective to be minimized [CL04].

In this project, the improvement in a water treatment plant by using a cascade controller and the corresponding Human Machine Interface (HMI) for easier system operation and data readout is presented. The successful implementation of these improvements will enable seamless pump staging and de-staging and distributed running hour of the pumps. The HMI can also interact with inverters directly through a MODBUS RTU communication protocol.

II. CASCADE CONTROLLER

Cascade control is common control system used to control multiple pumps in parallel. Cascade control offers energy saving based on affinity laws. The Danfoss Advance Cascade Control (DACC) (Fig.1.) is capable to control multiple parallelly configured pumps in such a way that makes them works like a single larger pump. The pump will be automatically staged (turned on) or de-staged (turned off) in order to satisfy the output for flow or pressure. The selection of which pump to be staged is based on the running hour of the pumps. DACC can only be applied in Danfoss VLT FC 202 Aqua series and VLT 8000 Aqua series [DS202], [D0422].

In this project, two inverters (VFD) are to be retrofitted. The new inverter is VLT FC 202 series which has MCO 102 advance cascade controller installed [DA722]. The old

Received: 25 January 2016 *Revised: 18 March 2016* *Accepted: 4 May 2016*

inverter VLT 8000, is still expected to be included in the retrofitted system. The latter will serve only as the slave and will be controlled by the earlier mentioned inverter .

The master inverter receives the feedback from the pressure sensor. Only master inverter will get the pressure feedback. The master's PID controller then calculates the required speed for each pump, via the corresponding inverter.

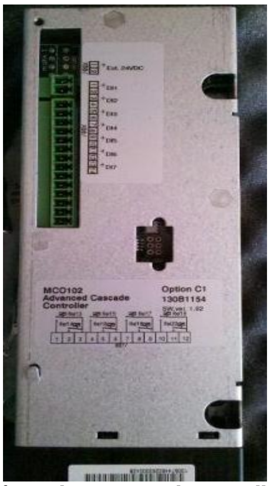

Fig. 1. Danfoss Advance Cascade Controller (DACC)

The speed set-point for all running inverter will be the same. Fig. 2 provides an overview of the system with inverter C as the master inverter. The letter F denotes the pressure sensor; while A, D, and E are the older inverters, acting as slave.

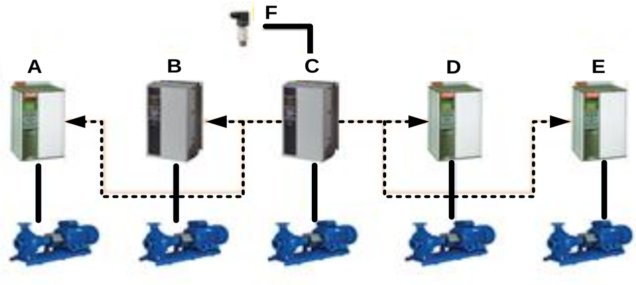

Fig. 2. System overview with inverter C as master inverter

In the proposed system, if the master switch button is pressed, the master inverter will change from C to B. Inverter C will directly change to slave and will only receive the start/stop command and also speed reference from the master's PID controller. The feedback line is also redirected from C to B. The overview of the system with current master inverter B can be seen in Fig. 3.

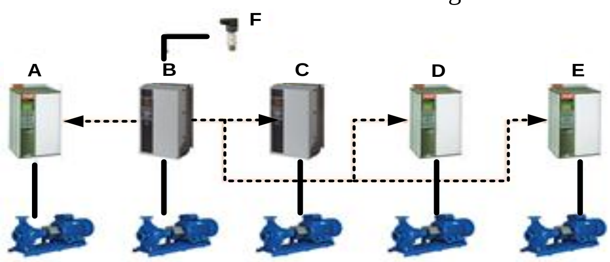

Fig. 3. System overview with inverter B as master inverter

III. Human Machine Interface (HMI)

Human Machine Interface (HMI) is also referred to as user interface, operator panel, or terminal. It provides means of controlling, monitoring, managing, and visualizing device processes. An HMI is typically resides in an office-based Windows computer that communicates with a specialized industrial computer in the plant such as Programmable Logic Controller (PLC), Programmable Automation Controller (PAC), or Distributed Control System (DCS). The HMI uses computer-based software to program the function of HMI. The software is issued by the HMI manufacturer.

Fig. 4. Brainchild HMI

In this project, the author used Brainchild HMI, as shown in Fig. 4 [BC12]. The main reasons to choose this device is the cost and the functions that it offers. The function really needed in this project is the capability to export the data log to PC via USB drive. The exported data can later be used for documentation and further analysis.

The developed program for the HMI, as shown in Fig. 5, displays the status of all inverters (the current master, speed, and also power consumption), data trending of pressure and flow, set-point, and feedback adjuster.

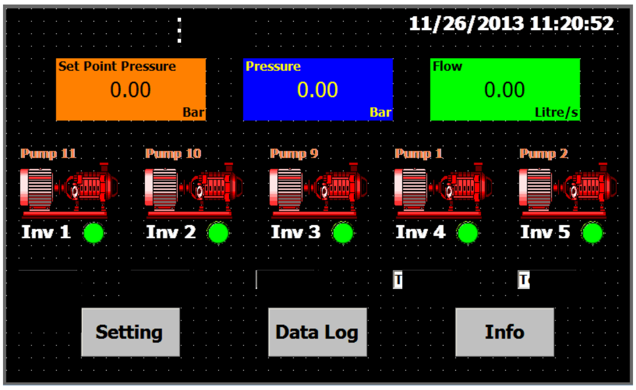

Fig. 5. HMI program before uploaded to HMI

IV. Data Acquisition

There are two data sources in this project. The first source is the inverter that sends the running hour of the pumps. The second data source is the HMI, which delivers the water pressure and water flow data.

For the running hour data acquisition, the author used USB cable. The running hour data are collected from each master inverter. The author used software developed by Danfoss to program the Danfoss inverters from PC.

For the pressure and flow data, the author used USB drive. The author has created a button in the HMI program to trigger dump data that has been logged in the HMI to a USB drive. To view the data, Historical Viewer software developed by Brainchild can be used.

The data acquisition period is 1 month. During the 1 month data acquisition, the flow meter has not been installed. The data is collected for analysis in each week. The total number of data sets that are acquired is 8 (4 data sets of running hour and 4 data sets of pressure).

V. Results and Discussions

A. Pressure data

The data of the pressure is presented in graphical form. The data are shown in weekly basis and then given analysis.

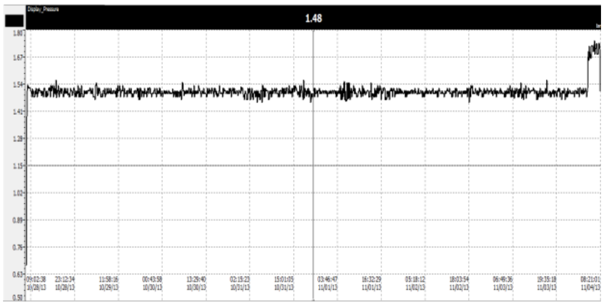

Fig. 6. Running hour data 28 October 2013 – 4 November 2013

As we can see in Fig. 6, there is a slight increase in the pressure at the end of the record period. This is not because of the system failure. The operator changed the set-point from 1.50 to 1.70 bar. The reason is because there are some leaking pipe sections. The set-point was increased because the piping division want to identify the location of the leaking pipe sections. After the location were found, the set-point was set to normal again.

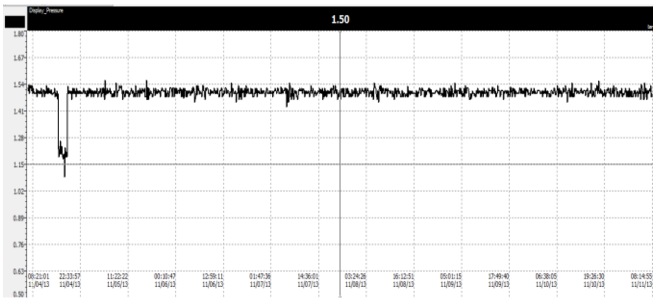

Fig. 7. Running hour data 4 November 2013 – 11 November 2013

In Fig. 7, we can see there is a pressure drop in the beginning of the graph. The reason for this is because the operator decreased the set-point for the pipe repairing measure. Afterwards, the operator returned the set-point to 1.50 bar again. In Fig.8 and Fig.9**Error! Reference source not found.**, we can see that the graphics seem to be steady. It proved that without the presence of major operation problems, such as pipe repairing or power shut down, the proposed system is able to maintain the pressure in the set-point value with tolerance of 0.02 bar.

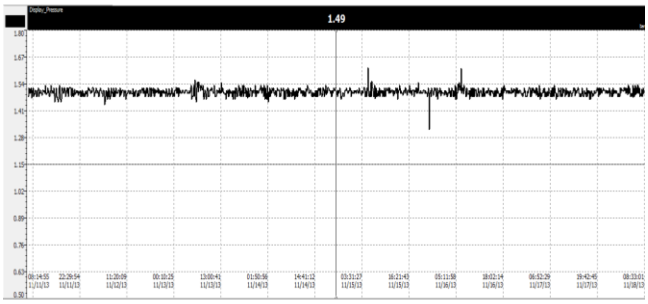

Fig. 8. Running hour data 11 November 2013 – 18 November 2013

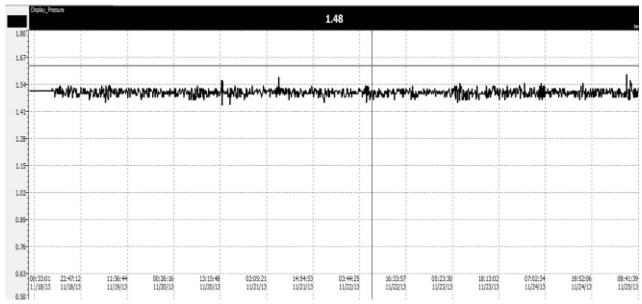

Fig. 9. Running hour data 18 November 2013 – 25 November 2013

From 1 month pressure data, the author concluded that the DACC has successfully maintained the water pressure to match the set-point value of 1.50 with tolerance 0.02 bar.

B. Running hour data

The acquired data is then summarized and presented in Table 1. The mean running hour in a certain week is denoted by μ, while Δ_{avg} is the average of absolute difference between an inverter running hour to the value of μ. The quotient Δ_{avg}/μ shows how well the implemented controller distributes the task, *i.e.* the running hour, among the operating pumps. The lower the value of Δ_{avg}/μ, the better the task distribution.

In Table I, we can see that Δ_{avg} of the first week is 15.25 hours from the mean running hour of 109.25 hours. It means that the range of well-distributed running hour should be between 94 hours and 124.5 hours. There are 3 inverters, (Inverter A, Inverter C and Inverter D) whose running hours are outside this range. Δ_{avrg}/μ (%) of the first week running hour is 13.96 %. It means that the running hour distribution deviate 13.96 % from the mean value. For the second week, the situation is much improved, with the value of Δ_{avg}/μ (%) equals 1.96 %. This is the best result compared to other weekly data.

Table 1. Running hour for 4 inverters in 1 month.

	1st Week	2nd	3rd Week	4th Week
Inverter A	126 hours	221 hours	346 hours	474 hours
Inverter B	123 hours	221 hours	339 hours	471 hours
Inverter C	86 hours	209 hours	351 hours	458 hours
Inverter D	102 hours	216 hours	295 hours	410 hours
μ	109.25	216.75	332.75	453.25
Δ_{avg}	15.25	4.25	18.88	21.63
Δ_{avg}/μ **(%)**	13.96	1.96	5.67	4.77

We will now relate the running hour with the pressure data. On the second week occured an incident of pipe leaking. This situation gave the DACC more opportunity to balance the running hour among the inverters and the respective pumps. For the third week, the Δ_{avg}/μ (%) is 5.67 %. If we relate with pressure data in Figure 8, we can see that the graph fluctuates less. This stable pressure condition gave the controller less opportunity to balance the running hour. Thus the value of Δ_{avg}/μ (%) increased slightly. For the last week, the Δ_{avg}/μ (%) is 4.77 %. The last week graphic behavior is similar with that of the third week and the Δ_{avg}/μ (%) is approximately the same. The overall Δ_{avg}/μ (%) in one month is 6.59 %. This result can be interpreted as that the running hour of all pumps are so close to each other, that the average absolute difference between a certain running hour and the average running hour is only 6.59 %. The DACC is successful in distributing the running hour equally with the Δ_{avg}/μ (%) less than 10 %.

VI. CONCLUSION

Based on the data collected from the project of Retrofication of Cascade Control System and Implementation of Human Machine Interface (HMI) in a water treatment plant, there are several conclusions that can be taken.

The project is conducted with the objective to distribute the running hours among the pumpus. The project was designed and implemented successfully. The proposed system can maintain the pressure in the desired set-point and also distribute the running hour of all pumps evenly within an acceptable tolerance of 10% of the average running hours.

Furthermore, the implementation of Human Machine Interface (HMI) is designed and designated to ease the communication with all inverters through MODBUS RTU as communication protocol. The HMI can display all the necessary information for easy daily monitoring. The pressure data of the system can be imported from HMI to a flash disk. The data later can be viewed graphically via Historical Viewer software in PC for documentation and further analysis. Finally, the running hour data of the inverters can be imported to PC via USB cable. The data later can be viewed via MCT10 software in PC for documentation and further analysis.

As additional conclusion, it can be stated that the performance of Retrofication of Cascade Control System proposed by the author is sufficient and satisfactory. The system could maintain the pressure with tolerance ± 1.3%, or 0.02 bar of the set point 1.50 bar. The result exceeds the initial expectation of 5%. The performance of Implementation of Human Machine Interface (HMI) proposed by the author can be considered sufficient and satisfactory. The HMI is programmed informatively, reliably, and user friendly.

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Received: 13 January 2016 *Revised: 8 April 2016* *Accepted: 19 May 2016*