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Process Automation: A Case of Analogue Signal Conditioning using Variable Frequency Drive Controller

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Abstract:

This study presents the development of a process control system using variable frequency drive (VFD) as applied to water pumping and filling system. The results of the evaluations of the study showed that the use of the VFD conforms to the Affinity Laws of using centrifugal pumps whenever there were variations of pump supply frequency corresponding to the difference between process value and process set point. These variations in frequency results in variation of energy consumption of the three phase motor thus the savings as compared to constant frequency drive.

Keywords — **Variable frequency drive, Affinity laws, Three phase motor**

I. INTRODUCTION

In the past, controlling pressures in industrial operations are done by manually manipulating valves. Today these can be done automatically by the use of controllers and computers alike. The connectivity of process elements (sensors and actuators) and their controllers made process control more accurate and fast. In the current economy situation companies try to reduce their expenses. One of the solutions is to improve the energy efficiency of the processes. It is known that the energy consumption of pumping applications range from 20 up to 50% of the energy usage in the certain industrial plants operations. Some studies have shown that 30% to 50% of energy consumed by pump systems could be saved by changing the pump or the flow control method. (Ahola et. Al, 2010)

Nowadays, centrifugal pumps are often controlled by adjusting their rotational speed, which affects the resulting flow rate and output pressure of the pumped fluid. Typically, the speed control is realized with a frequency converter that allows the control of the rotational speed of an induction motor. (Ahonen, 2011)

However, these new technologies are not readily available in most academic institutions. For students involved in process control, it is imperative for them to learn and keep pace with the evolution of these technologies to be able to have the competence required by the industry.

This study was conducted to bridge the problem of technology transfer to the academe. The main objective of the study was to design and develop a pressure control trainer using VFD controller to be used for related subjects in fluids mechanics and process automation and evaluate the study according to its safety, functionality, efficiency, and competency.

II. METHODOLOGY:

The methodology used in this project was anchored primarily on the design, prototyping and performance evaluation.

2.1 Design

The pressure control trainer is designed to operate in a close loop feedback control system (Fig. 2.1). The set-up component design (Fig. 2.2) is assembled based on the requirements of this loop.

The controller is the VFD controller (OMRON 3G3JX), the controlled system is a water service tank system, and the P/I transmitter (AZBIL PT1) is the feedback and measuring device. The set-point, error signal, and controller output signal are all coming through the controller.

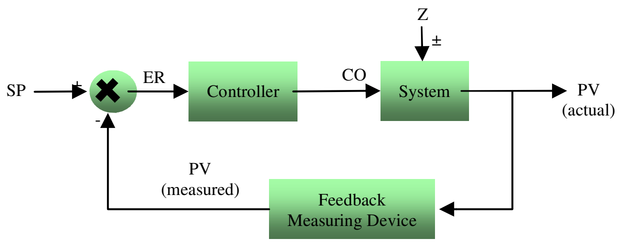


Fig. 2.1: Feedback Control loop

Legend:
SP (w)- set point (desired pressure setting)
PV (x)- process value (system pressure reading)
ER (e)- system error (SP-PV)
CO (y)- controller output to actuator(pump motor)
Z(z) – system disturbance (cause change in PV)
Controller- automate the system (PLC)
System- controlled (pressure parameter)

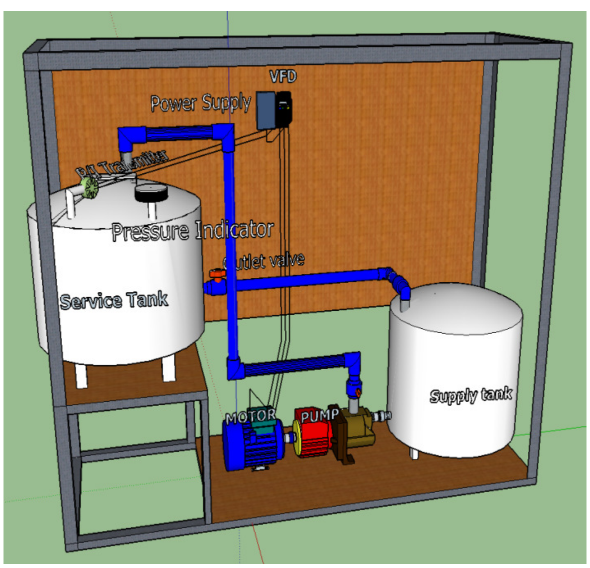
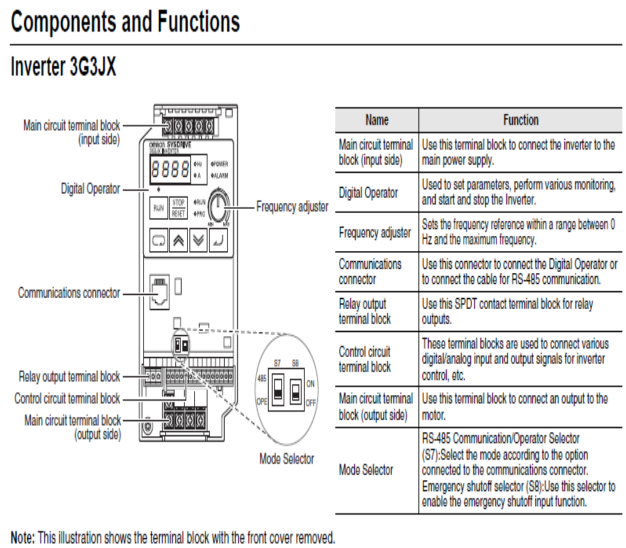


Fig. 2.2: Set-up Design Drawing

The system utilizes a variable frequency drive (VFD) controller, OMRON Sysdrive 3G3JX (Fig. 2.3), to control the motor speed of the centrifugal pump.



Name	Function
Main circuit terminal block (input side)	Use this terminal block to connect the inverter to the main power supply.
Digital Operator	Used to set parameters, perform various monitoring, and start and stop the Inverter.
Frequency adjuster	Sets the frequency reference within a range between 0 Hz and the maximum frequency.
Communications connector	Use this connector to connect the Digital Operator or to connect the cable for RS-485 communication.
Relay output terminal block	Use this SPDT contact terminal block for relay outputs.
Control circuit terminal block	These terminal blocks are used to connect various digital/analog input and output signals for inverter control, etc.
Main circuit terminal block (output side)	Use this terminal block to connect an output to the motor.
Mode Selector	RS-485 Communication/Operator Selector (S7):Select the mode according to the option connected to the communications connector. Emergency shutoff selector (S8):Use this selector to enable the emergency shutoff input function.

Note: This illustration shows the terminal block with the front cover removed.

Fig. 2.3: Variable Frequency Drive (OMRON 3G3JX)

The feedback to the controller is from the pressure to current (P/I) transmitter, Azbil PT1 (Fig. 2.4).

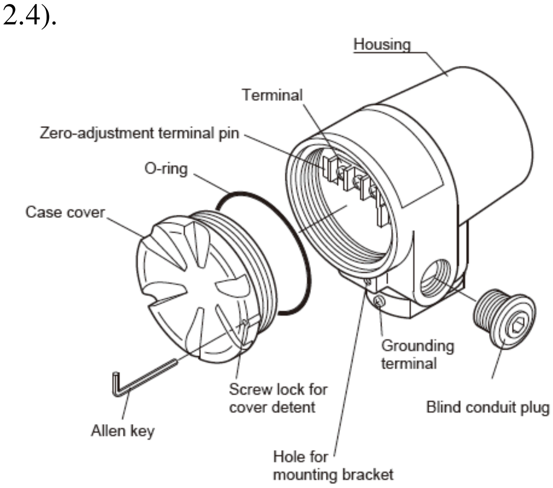


Fig. 2.4: P/I Transmitter (AzbilPT1)

The pressure changes whenever there is a disturbance (opening and closing of manual outlet valve) to the system and changes to the process value is transmitted to the controller and the controller will transmit corresponding controller output signal to the output element (actuator) which the three phase centrifugal water pump.

2.2 Development

With all the considerations of electro-mechanical safety, the assembly of components proceeded with the aid of operation manuals which are as primary literature in the development process. The VFD electrical wiring connection (Fig.2.5) is mainly anchored on the specifications required by the VFD controller.

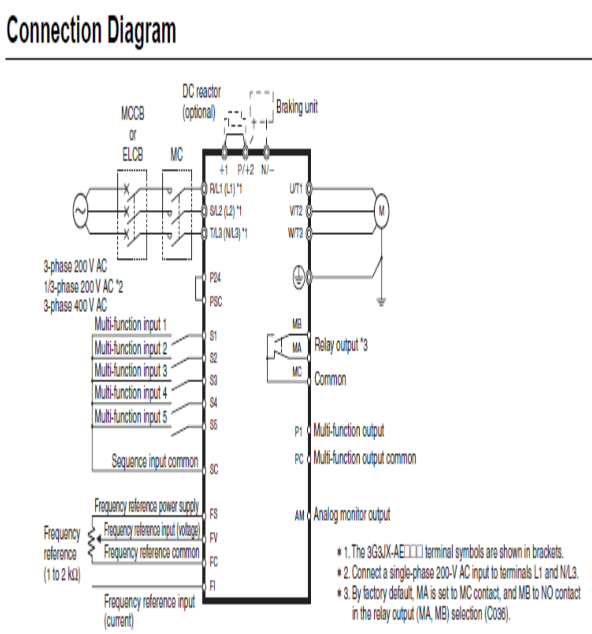


Fig. 2.5: VFD Connection Diagram

The pressure transmitter is connected to VFD controller based on the connection diagram (Fig.2.6) of the VFD controller. The transmitter has specific wiring requirements to ensure proper operation and reliability of measurement.

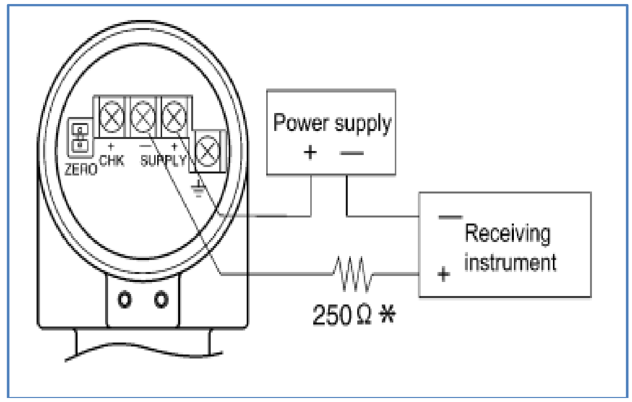


Fig. 2.6: P/I Transmitter wiring diagram

2.3 Testing

In testing the control system components, several protocols are followed before the trials are conducted to the control system. The vertical and horizontal aligned of the set-up are checked using standard tools such as level gauges. The calibration of multi-tester are assured with that use of standard testing equipment with refutable record.

Fig. 2.5: Process Control Test Set-up

The use of branded control components is essential in the assurance of reliable and accurate performance. The test set-up above was tested for alignment and leakage before it was commissioned for use.

III. RESULTS AND DISCUSSION

There are several tests conducted in the study to check the performance of the pressure control system: These tests are done to check the response of the control system to different system disturbances and settings. The main objective of the control system is to achieve the system set value or set point at quickest possible settling time.

3.1 Process Control Test Data

The pressure transmitter is a P/I transmitter, pressure to current transmitter. The pressure in the tank measured is converted in its equivalent standard mA signal in the range of 4mA – 20 mA. The mA signal is taken from the multimeter connected to the CHECK + and negative supply (-) terminal of the pressure transmitter. The disturbance valve (manual globe valve) is estimated to be partially open at 25% for this test data (Table I) and all other VFD configuration settings are set to company default values.

TABLE I
PROCESS CONTROL TEST DATA

Set point (Hz) (F001)	Pressure (kPa)	Feedback (mA)	Motor (V) (D013)	Motor (A) (D002)	Motor Hz (D001)
60	82	16.54	182	0.8	56.1
55	76	15.74	173	0.7	52.4
50	71	14.93	165	0.7	49.8
45	65.5	14.15	158	0.6	47.1
40	60.5	13.32	150	0.5	44.8
35	55.5	12.44	142	0'5	41.8
30	51	11.66	135	0.4	39.2
25	45	10.82	126	0.4	36.9
20	40	9.99	118	0.3	34.4
15	35	9.11	110	0.3	30.7
10	29.5	8.22	100	.0.2	28.0
5	24	7.50	91	0.2	24.5

Fig. 3.1: Gathering Test Data using Multi-tester and VFD Display

In Fig. 3.1 shows that the test data are gathered using the multitester(feedback, mA), pressure indicator (kPa), and VFD controller display using parameter numbers F001 (setpoint), D001(motor frequency), D002 (motor current), D013(motor voltage).

3.2 Affinity Laws Comparison

The change in flow, head (pressure) and power are related to the Affinity Laws in using centrifugal pumps as discussed earlier in Chapter 1.

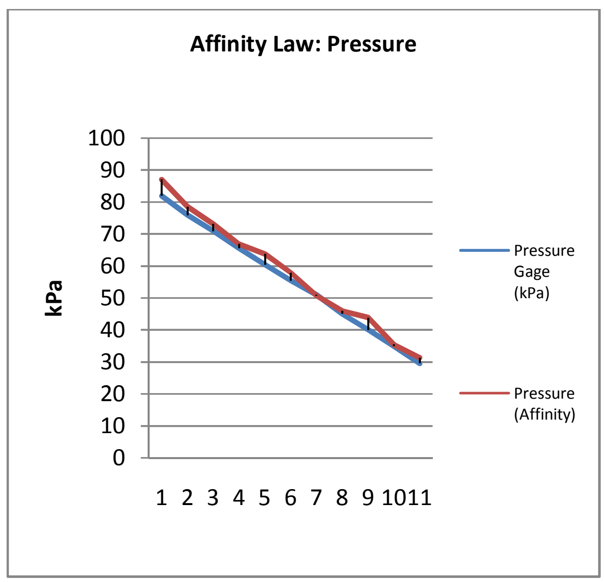


Fig. 3.2: Affinity Law for Pressure

Figure 3.2 shows that the pressure transmitter values are consistent with the trend of the pressure values as computed and plotted using the affinity laws of hydraulics. This test could easily confirm the validity of the affinity law.

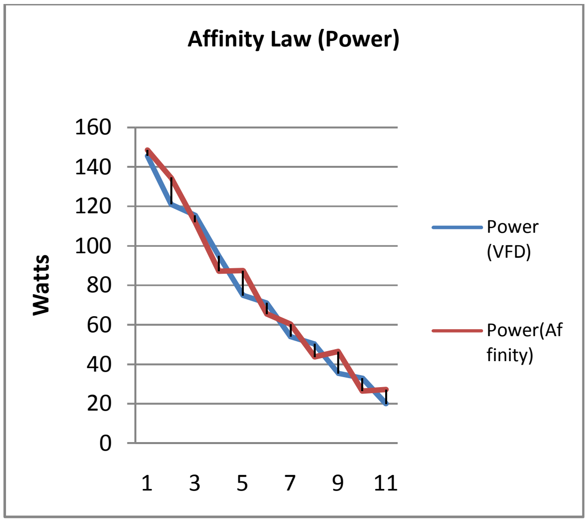


Fig. 3.3: Affinity Law for Power

Fig. 3.3 shows also that the electrical values gathered from the setup which are used to compute the pump power are consistent with the trend of the power values as computed and plotted using the affinity laws of the centrifugal pump. This test could again easily confirm the validity of the affinity law even in the complex nature of VFD controlled process. The variation of power in relation to pressure variation clearly affirms the lowering of operation cost when using the VFD. Energy efficiency is one key element in the use of VFD controllers.

3.3 Analog Signal Conversion

If the sensor measures physical quantity (level, pressure, flow, temperature) and converts it to a standard analog signal equivalent in the range of 4mA to 20 mA, the sensor is generally called a transmitter. The study uses a P/I transmitter wherein the pressure is read from the tank and equivalent analog signal is sent to the VFD controller.

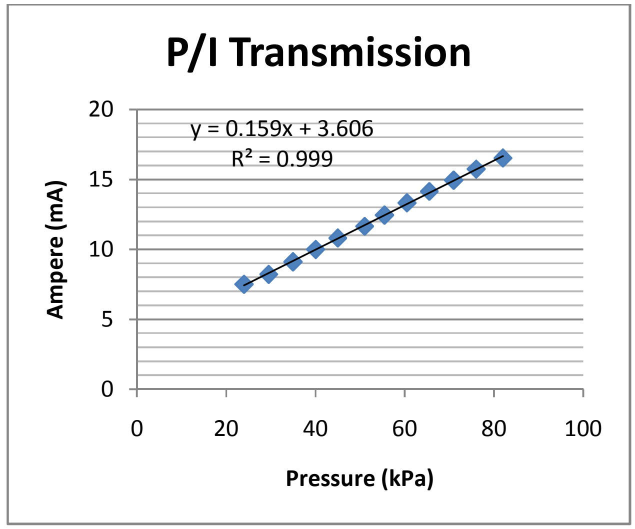


Fig. 3.4: Pressure to Current Transmission

The Fig. 3.4 above shows the relationship between the pressure and corresponding equivalent standard current transmission signal in the range 4mA to 20 mA. The resulting equation suggests that the value 3.6 is near the expected initial value of 4 mA although slightly lower. These offset can be rectified by recalibrating the transmitter using standard calibrating equipment. The coefficient of determination R2 is 0.9994 which means the data points are very close to the trend.

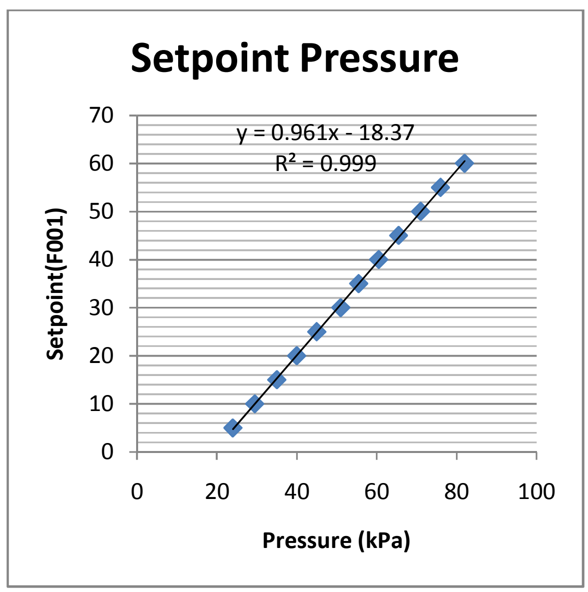


Fig. 3.5: Set point (F001) and Actual pressure

The Fig. 3.5 above shows the relationship the set point setting in VFD (Code F001) and the corresponding actual pressure. The equation suggests that the pressure transmitter was initially calibrated to a minimum pressure setting estimated to be around 20 kPa and a maximum setting at around 100 kPa. This relationship between the two values is very important to establish especially if the lower range and upper range values are unknown in cases when the SFC (Smart Field Communicator) is not available at the moment. You can still use the pressure transmitter provided your set pressure is within the measuring range as determined through testing; however it is still necessary to have a SFC on hand. The set pressure is then achieved by configuring accordingly F001 of VFD controller.

IV. CONCLUSION & RECOMMENDATION

4.1 Conclusion

Based on the test data gathered, it is clear that the study has achieved it main purpose which is to control pressure and maintain pressure at a desired set value. For a particular set pressure (set value) the control system responds accordingly to achieve the set point. The control system also responds to disturbances, opening and closing the outlet valve, by actuating the pump motor accordingly. It should be noted again that the control action (response) is limited only on the PID default values as suggested by operation manual.

Comparison of controller values and calculated theoretical values affirms the validity of the Affinity laws. The control of pump speed using VFD controller is the key to controlling pressure as describe by the Affinity laws.

The use of VFD controller shows the reduction of power requirement of the pump motor whenever set pressure is reduced. This automatic adjustment of power translates to power savings when using VFD as compared to the traditional full load operation of pumps running without VFD speed controller.

The respondents of the technical evaluation find the trainer useful in improving competency in process automation, fluid mechanics, and industrial motor control. Conversely, they have found the trainer safe, functional and accurate, this observation can be expected towards an advance device just like VFD controller which has built-in features that can ensure safety, automation and accuracy.

4.2 Recommendations

1. Since the pump was only retrofitted with a separate three phase motor, it is recommended to use a pump unit with built-in three phase motor to ensure the hydraulic efficiency and accuracy.
2. Although technically we can still use the P/I transmitter within its existing range, it is recommended that a SFC (Smart Field Communicator) should be purchased and made available for recalibration and checkup.
3. Since the study was conducted on 25% opening of the outlet valve due to constraints of the retrofitted pump unit, it further recommended that studies will conducted up to 100% open after improving the piping.
4. The study was conducted using default PID values, it recommended for further study using different parameter values of the PID controller function of the VFD.

V. ACKNOWLEDGEMENT

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