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Design of Air Motor Speed Control System for Small Scale Compressed Air Energy Storage Using Fuzzy Logic

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Abstract. Research on energy storage technology is an interesting topic, especially in Small Scale Compressed Air Energy Storage (SS-CAES) which is considered more environmentally friendly and does not have degrade over time such as other energy storage technologies. To generate the power in SS-CAES, it is by adjusting the rotation speed of the generator to get the certain speed by the user. However, existing research shows that the speed control still utilizes electric torque that counteracts the mechanical torque of the turbine rotation, so this is considered to be wasteful of power. Therefore, this paper will provide control of the generator rotation speed by utilizing the air that passes through the generator (mechanical torque only). This speed control utilizes fuzzy logic to achieve the desired speed and reach steady-state in less than 10 seconds..

Keywords; motor, speed control, small scale, energy storage, fuzzy logic.

1. Introduction

The development of research on energy storage technology is a popular topic at this time [1–4]. This topic relates to the issue of power backup at peak shaving, synchronization, environmental problems caused by the use of this technology and cheaper cost in operation [5]. One technology was chosen to solve this problem by utilizing Small Scale Compressed Air Energy Storage (SS-CAES) [6–8]. SS-CAES is an energy storage technology that utilizes compressed air energy stored in tanks to produce electrical energy. To control the power output of this system, it is the same as power generation technology in general. That is by turning the generator according to the speed that has been referenced to produce the power needed by the user [9,10].

On the topic of speed control in SS-CAES, there are several studies that have been conducted, among them is by Lemofouet [11] and Kokaew [12–14]. In that research, to be able to adjust the rotational speed of the generator, the control concept uses a mechanism between mechanical torque and electric torque [12,13]. In that concept, the mechanical torque caused by the air passing through the air motor will be reduced by an electric torque whose value of the electric torque is regulated using a buck converter. The result of the torque reduction will produce the remaining mechanical torque used to rotate the generator. The greater the torque against mechanical torque will make the generator speed lower, and vice versa. However, by looking at the concept of research, the air coming out of the tank is not regulated and only adjusts the torque of electrical to control the rotation speed of the generator. So it can be said to be wasteful on the use of wasted air pressure from the tank. Whereas in the research conducted by Maia [15], the researchers created a micro-CAES system that uses an air valve on its system. By using this concept that presented by the researchers in this paper, the problem of wasted air can be solved



by eliminating the setting of the electric torque. However, the research only discusses the results of the system when it is run and does not discuss how users can achieve the speed of the desired air motor to produce the required power.

To overcome this issue, in this paper the researchers will discuss and present a concept of speed regulation that only utilizes mechanical torque in regulating speed without requiring electric torque to increase and reduce the rotating speed of the generator. This is done by regulating the rate of air passing through the air motor by regulating the air valve to reach the desired speed. Because in the previous study [12,13] to control the speed of the air motor carried out using PI control and the control still has an issue in setting the values of K_p and K_i that require a mathematical model of the system to be controlled, so in this study researchers will use another artificial intelligence system. We looked at the use of PI control, this will certainly make the control system less universalized when applied to other systems. Because with the change of the controlled plant, it requires rearranging the system settings, especially on the value of K_p and K_i [16,17]. Therefore, in this study the intelligence system will be used is Fuzzy Logic Controller (FLC). FLC is considered to be superior to this problem because FLC does not need for exact knowledge of the mathematical model power system [18,19]. By using this control, it will certainly make the system formed more universal without the need to look for mathematical equations and can reach time quickly.

2. Control Design

2.1 System block

The block diagram of this system can be seen in figure 1. In that block, the researcher takes several data parameters to be analyzed. These parameters are voltage, current, air pressure that passes through the air motor and the rotational speed of the generator. The data will be stored in the datalogger to observe the effect of changing the angle of the air valve. In this system control, the valve used is a servo valve with a continuous model.

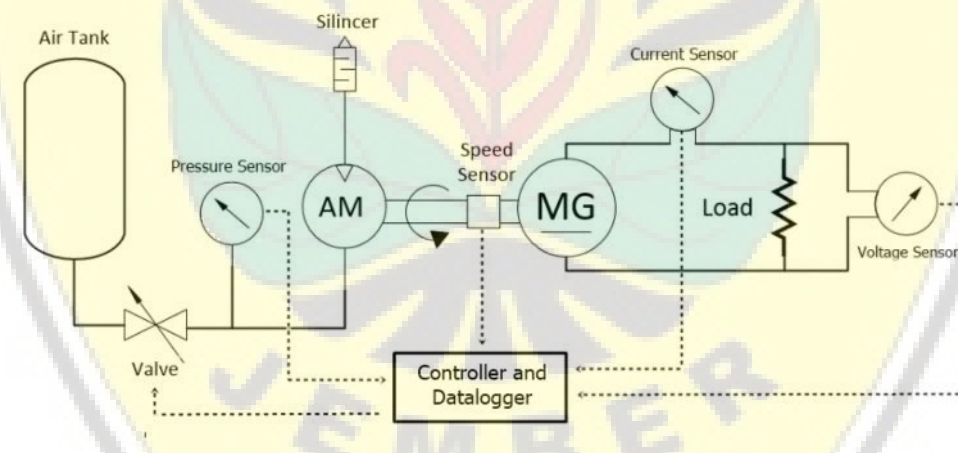


Figure 1. Block diagram of the system

2.2. Fuzzy logic controller design

In Fuzzy Logic control, the Fuzzy model used is closed loop control. For clearer blocks of control used, can be seen in Figure 2.

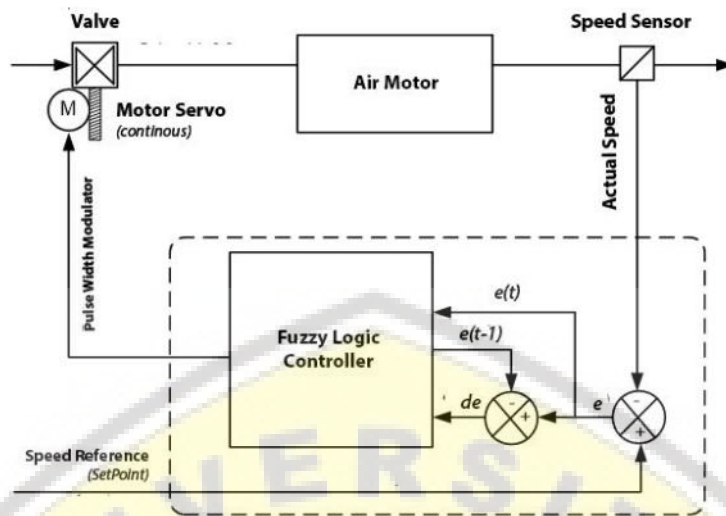


Figure 2. Controller diagram block

The input from the FLC (Fuzzy Logic Controller) system is the rotational speed of the generator which is processed with equation 1 to get the Error and equation 2 values to get the DeltaError value. The membership input function in this control is shown in Figures 3. Whereas for the output of this system is the PWM signal to control the servo. The membership output function shown in Figure 4 with the actual system output control value obtained by equation 3 and the rule used is shown in Table 1.

$$e = \text{SetPoint} - \text{ActualSpeed} \quad (1)$$

$$de = e(t) - e(t - 1) \quad (2)$$

where:

e = Error

de = DeltaError

$e(t)$ = Error in t time

$e(t-1)$ = Error in t-1 time

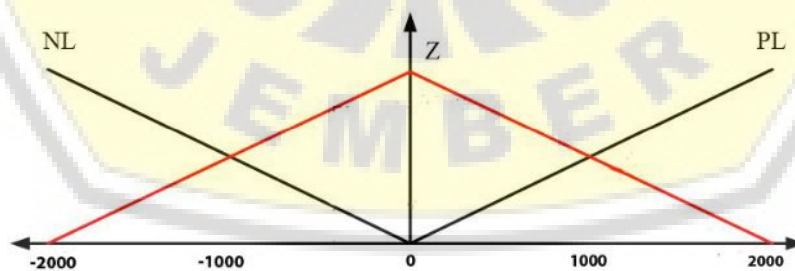


Figure 3. Error and DeltaError membership input function

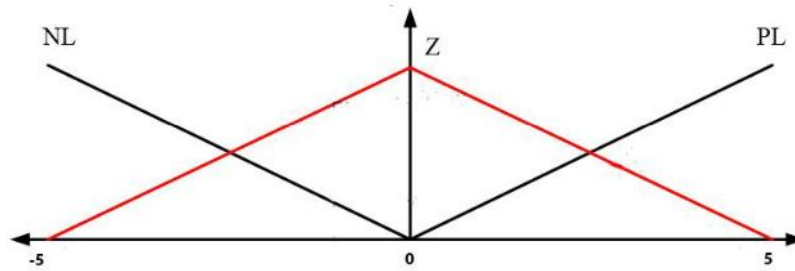


Figure 4. Membership output function

Table 1. Rule of fuzzy logic controller

de	e			
		NL	Z	PL
PL		Z	PL	PL
Z		NL	Z	PL
NL		NL	NL	Z

$$PWM = PWM + PWM (Fuzzy) \tag{3}$$

where:

PWM = PWM actual output

PWM (fuzzy) = PWM from the fuzzification process

3. Scenario Testing

To determine the success of the control system applied to SS-CAES, researchers will conduct two test scenarios with the load used is a resistive load.

3.1. Scenario 1

The first by setting the system to reach a certain speed with a fixed load. The first test objective is to find out the response time until the system goes to a steady state condition. In this test, the system will change its speed from 1200 rpm to 1800 rpm (scenario 1a) and from 2000 rpm to 1250 rpm scenario (1b). The reason researchers choose the two speeds (scenarios 1a and 1b) was to see the response when the setpoint of the system was raised and lowered.

3.2. Scenario 2

The second is to set the system to steady at a certain speed with different load changes. The purpose of this test is to determine the durability of the system until it returns to steady state conditions. In this test, the system will be set with a reference speed of 1500 rpm with the first load 10 Ω resistor. After a few seconds, a 2 Ω resistor load will be added at $t = 39$ seconds and then released at t after a few seconds the system reaches steady state.

4. Results and Discussion

By running two test scenarios that have been mentioned by the researcher in the previous section, the results of the following scenario testing are obtained:

4.1. Scenario 1

The first test is a scenario to increase the setpoint of the speed of the air motor rotation which was initially set at 1200 RPM setpoint to 1800 RPM. The results of this test can be seen in figure 5. From the results that can be seen in figure 5 shows that in this scenario, to achieve the desired speed of 1800 RPM, the system takes about 8 seconds to reach steady state. But in Figure 5, it can also be seen that the system oscillates before reaching steady state with the highest oscillation point at 2000 RPM.

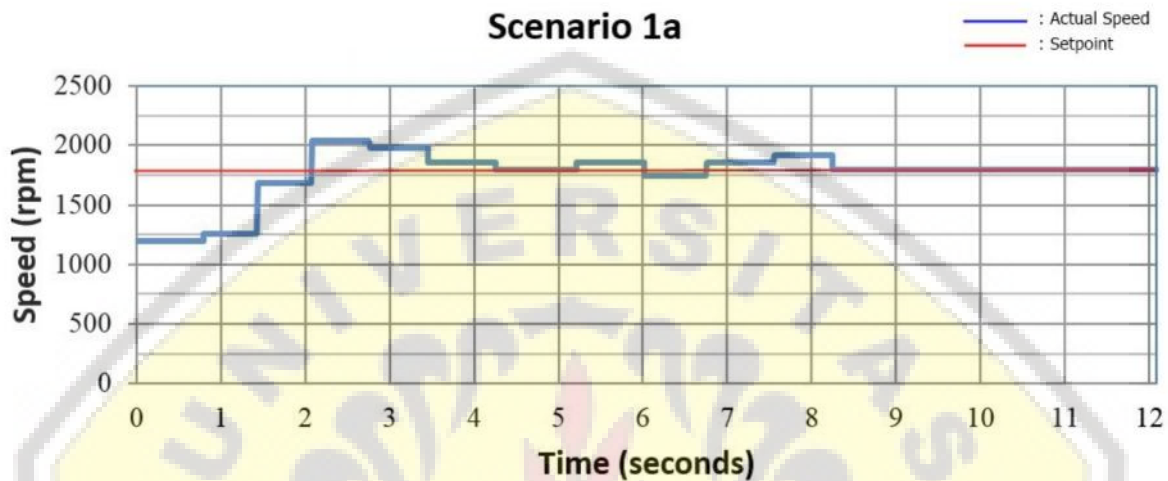


Figure 5. Speed testing results by raising the setpoint from 1200 RPM to 1800 RPM.

Whereas for the next test, the second test is a scenario to reduce the setpoint on the air motor rotation speed which was initially set at 2000 RPM setpoint to 1200 RPM. The results of this test can be seen in figure 6. The results obtained show that in this scenario the system only takes about 7 seconds to get to steady state. But same as the previous scenario, in this test the system also has oscillations with a minimum value of 1200.

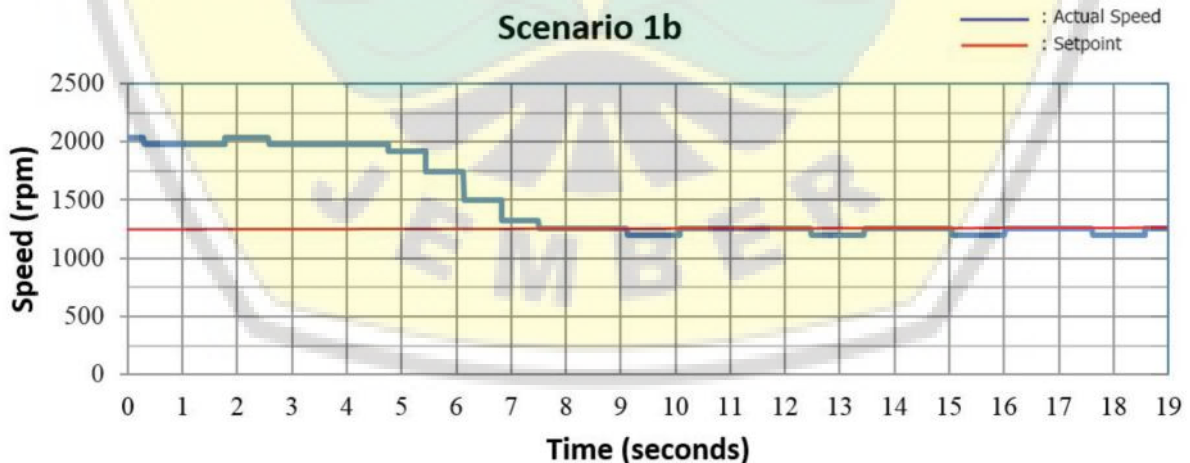


Figure 6. Speed testing results by lowering the setpoint from 2000 RPM to 1250 RPM.

4.2. Scenario 2

The next scenario is scenario 2. In this test, the system will be tested in dynamic conditions or in running conditions. When the speed is stable, the load installed on the system will be added and reduced to change the electric torque on the system. So that changing the electric torque will cause a change in the rotating speed of the generator motor due to the power that opposes the mechanical torque in the system changes. The results of this test can be seen in figure 7.

From figure 7 it can be seen that, when the system starts first, the speed of the system is 1500 RPM. Then at 39 seconds, the load from the system is added in series so that the electric torque that opposes mechanical torque becomes smaller than before. The effect that occurs is the increase in speed. So that at 39 seconds the system oscillates with a maximum value of 1860 RPM for 3 seconds to achieve steady-state conditions. At 49 seconds, the load previously installed in the series circuit is released. The effect of the electric torque becomes increased because the electric current gets bigger and makes the air motor speed decrease. So at that time the system oscillates down with a minimum oscillation value at a speed of 1260 RPM for 5 seconds and returns to steady-state.

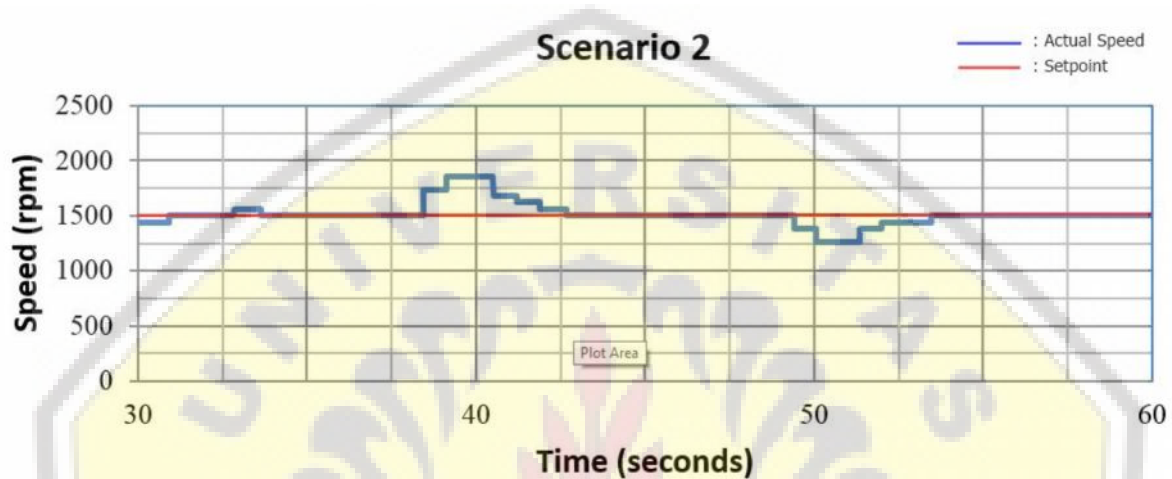


Figure 7. Speed testing results by dynamic test at the setpoint of 1500 RPM.

From the results of the two scenarios that have been obtained indicate that this system has an oscillation value in the event of a change in setpoint or change in load. The main cause of this oscillation is because the system used is a closed loop system model. If viewed with a mathematical relationship, it can be seen in equation 3 where the PWM value used to regulate the servo valve is the sum of the previous PWM with the PWM output (fuzzification) system. With the difference in error and delta error generated due to changes in speed before and after being controlled, it will produce a different fuzzy output. The effects caused by this system can be seen in scenario 1b where the system at steady state condition has a speed that is not constant, ie switching from 1250 RPM to 1200 RPM repeatedly. This is because the speed sensor also has an oscillation value at that speed and affects changes in the fuzzification value or system output because the error and delta error values also change.

5. Conclusion

In this study, we have presented the results of research on the speed control of SS-CAES to reach the desired speed of the user. The basic idea of the reason for speed regulation is because in power generation, the parameters used are the rotational speed of the air motor and the generator connected to one connection.

In this paper, we have removed the previous control model and presented a new control concept. In the previous control, to control the speed is used an electric torque setting to raise and lower the generator speed. But in this study, the control is used with mechanical torque regulation, that is by regulating the rate of air passing through the air motor as premove from the SS-CAES system. In addition, the researcher also added an artificial intelligence system in the form of fuzzy logic to simplify and universalize the system in application to other systems without the need to search for mathematical equations from the system first such as previous research.

To find out the success of the system in this study, two experimental scenarios were carried out. The first scenario relates to the setpoint speed change with mode: raising the setpoint and decreasing the setpoint. Whereas the second scenario is to replace the load installed on the system, then the system will be ordered to maintain steady state conditions at a certain setpoint.

From the results that have been obtained indicate that the system has been able to achieve the desired speed by the user in less than 10 seconds. In the first scenario, the system has reached a maximum time of 8 seconds. Whereas in the second scenario, that is when the system experiences a load change, the system is able to maintain speed and return to steady state conditions in a maximum time of 5 seconds. With the results of the research contained in this paper, we believe that this system will greatly assist other researchers in the control process of SS-CAES. This system has been formed with Fuzzy Logic, so that if user want to apply it to another plant, it no longer requires mathematical equations. Users only need to make modifications to the membership input and membership output of the system that adapts to the plant.

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