Memorial University of Newfoundland
Faculty of Engineering and Applied Science

ENGI8680 Process Control & Instrumentation

Lab 6

Design and Simulation of Fuzzy Logic Controllers for a Compressed Air System

Mitchell Stride (201517901)
Noah Quilty (201616364)

Aug. 5 2020

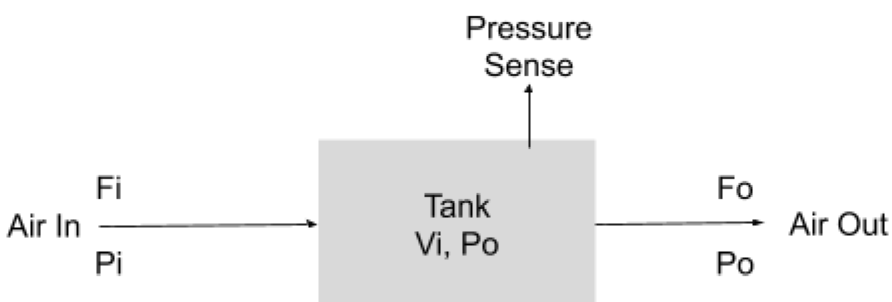
Table of Contents

1.0 Introduction

This lab serves as exposure to the instrumentation and simulation involved in a compressed air energy storage system. Compressed Air Energy Storage (CAES) works by compressing air to later generate electricity when needed. This lab will focus on the design and simulation of PID controllers for this system. Due to COVID-19 access to lab space has been prohibited thus the system typically used for this experiment were simulated using Simulink rather than actually constructing and measuring them.

2.0 Dynamic Modeling

Using the known system variables and basic equations we can generate a system model as follows.



Using mass balance equations, to find CAES model

$$Rate\ of\ air\ accumulation\ =\ Air\ in\ -\ Air\ out$$

$$\frac{dP_oV}{dt} = FiPi\ -\ FoPo$$

Then we can find stored energy. Energy in compressed air assuming ideal gas law..

$$PV\ =\ nRT$$

$$PV\ =\ \frac{m}{M}RT\ ;\ M_{air} = 28.9645\ \frac{g}{mol}$$

$$If\ Energy\ [J]\ =\ PV\ \Rightarrow Work\ =\ Change\ in\ PV\ \Rightarrow\ Power\ =\ Change\ in\ \frac{PV}{time}[J/s]$$

$$W_{PA-PB} = nRT\int_{PA}^{PB}\frac{dp}{p} = nRT\cdot ln(\frac{PB}{PA})$$

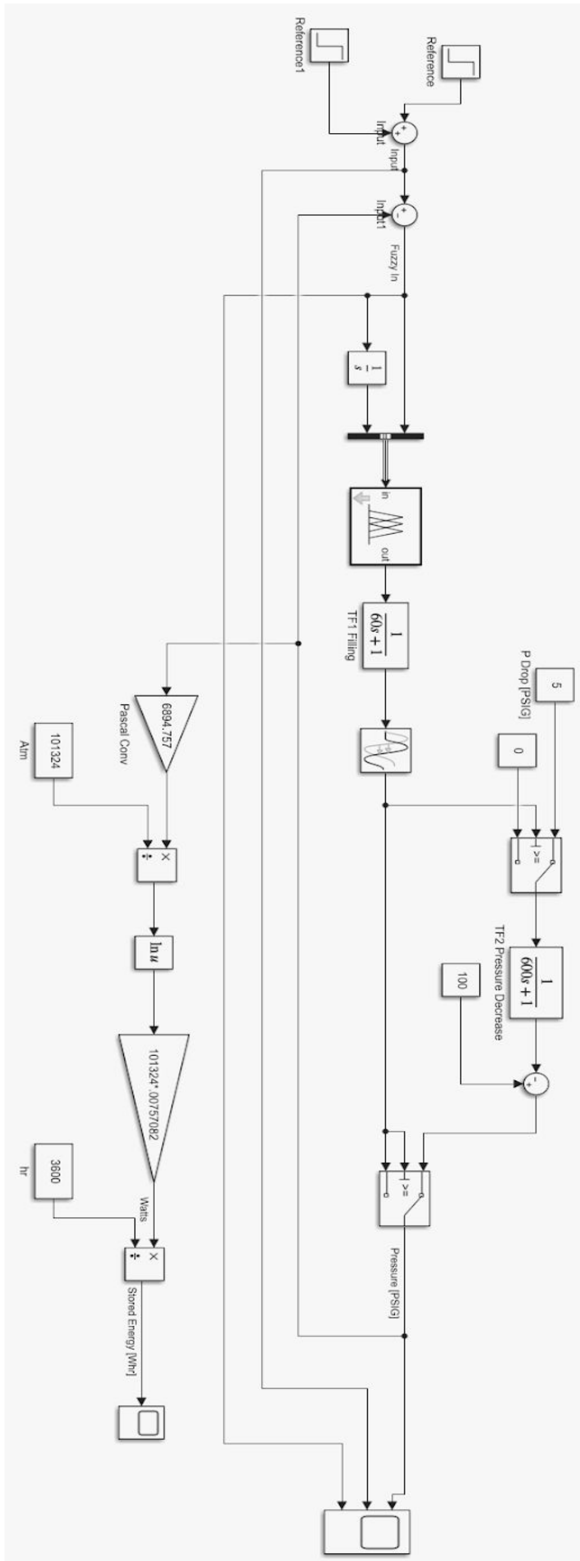
$$Initially,\ P_AV = nRT\ \ therefore$$

$$W_{PA-PB} =\ P_AV\ \cdot ln(\frac{PB}{PA})$$

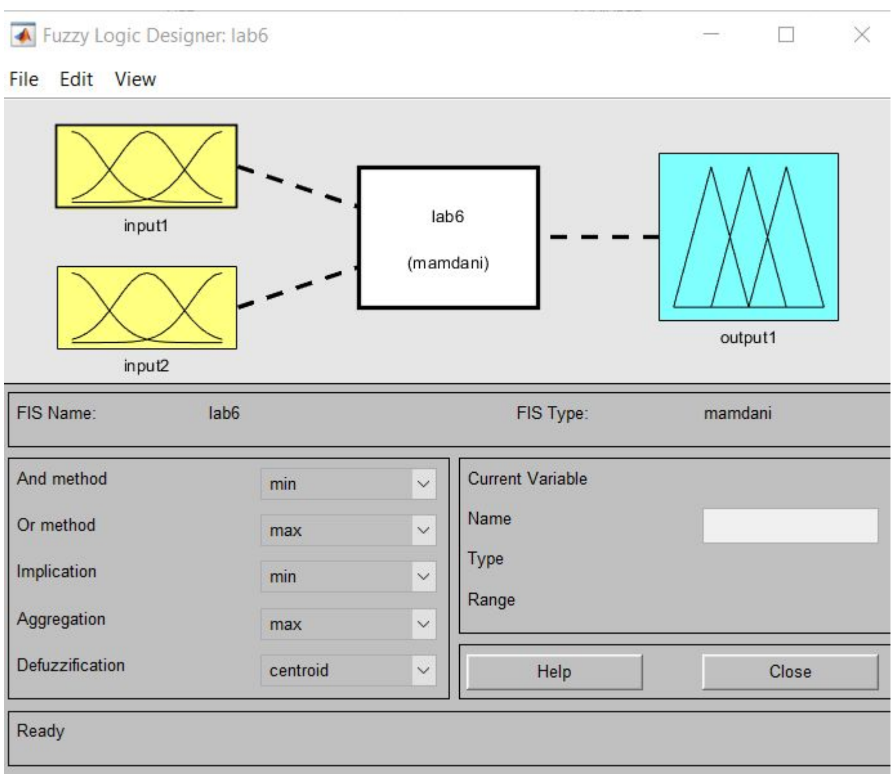
The final step is to convert this the system output pressure to Whr units.

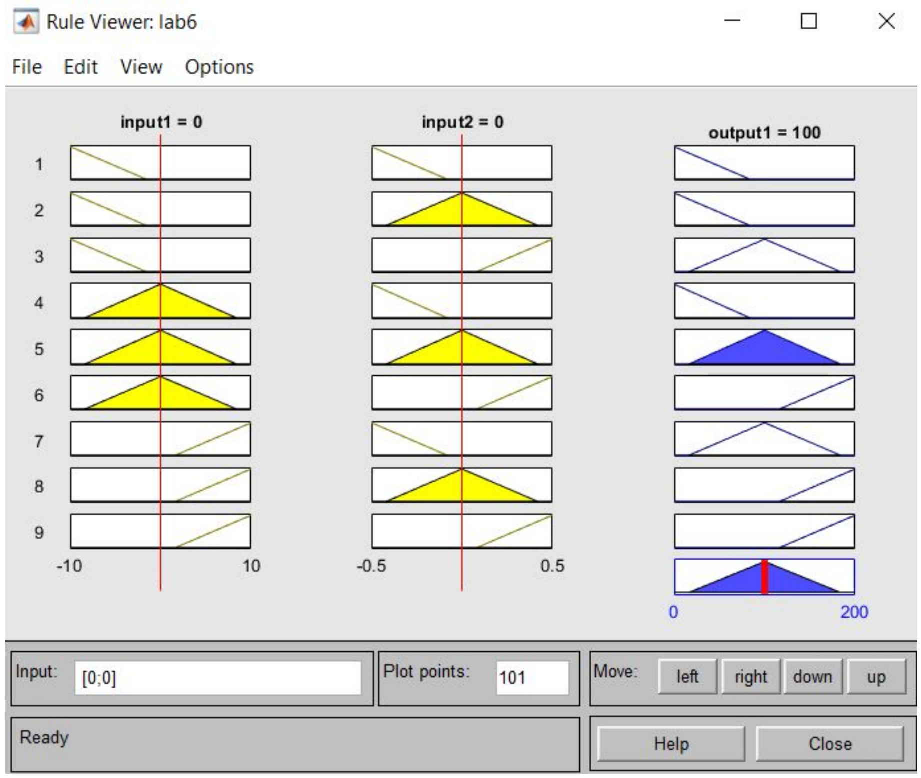
3.0 Simulation

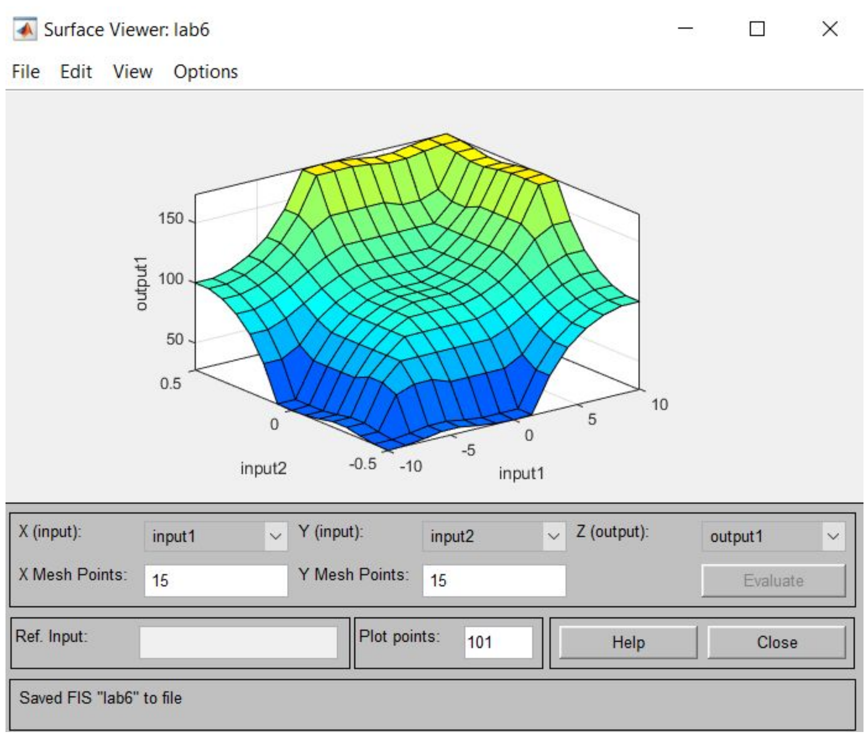
3.1 Fuzzy Logic Controller



The system model is used to represent the compressed air tank when it is both accumulating air and also discharging. The compressor is represented by the series combination of the step input, transfer function block, and the delay block. The switch blocks are used to simulate the accumulating and discharging behaviour of the tank.
The condition on the leftmost switch block is to pass the first input (5) unless the second input (accumulating pressure) is less than 95. If that condition is not satisfied the third input (0) is passed. The rightmost switch block is used to display the correct pressure behaviour of filling or discharging the tank.
This lab focused on adding fuzzy logic control instead of relay ON/OFF or PID control. The step input is now the mixing of two pressure setpoint that equal a 100 and the fuzzy logic controller responds when accumulating pressure (Below the setpoint for discharging). This could be implemented by variable pressure pumping achieved through pump power control via duty cycle, power control, SCR. The system was then tuned for the optimal response. Low overshoot, low settling time, and quick response was achieved.
Captures of the system tuning process can be seen below.

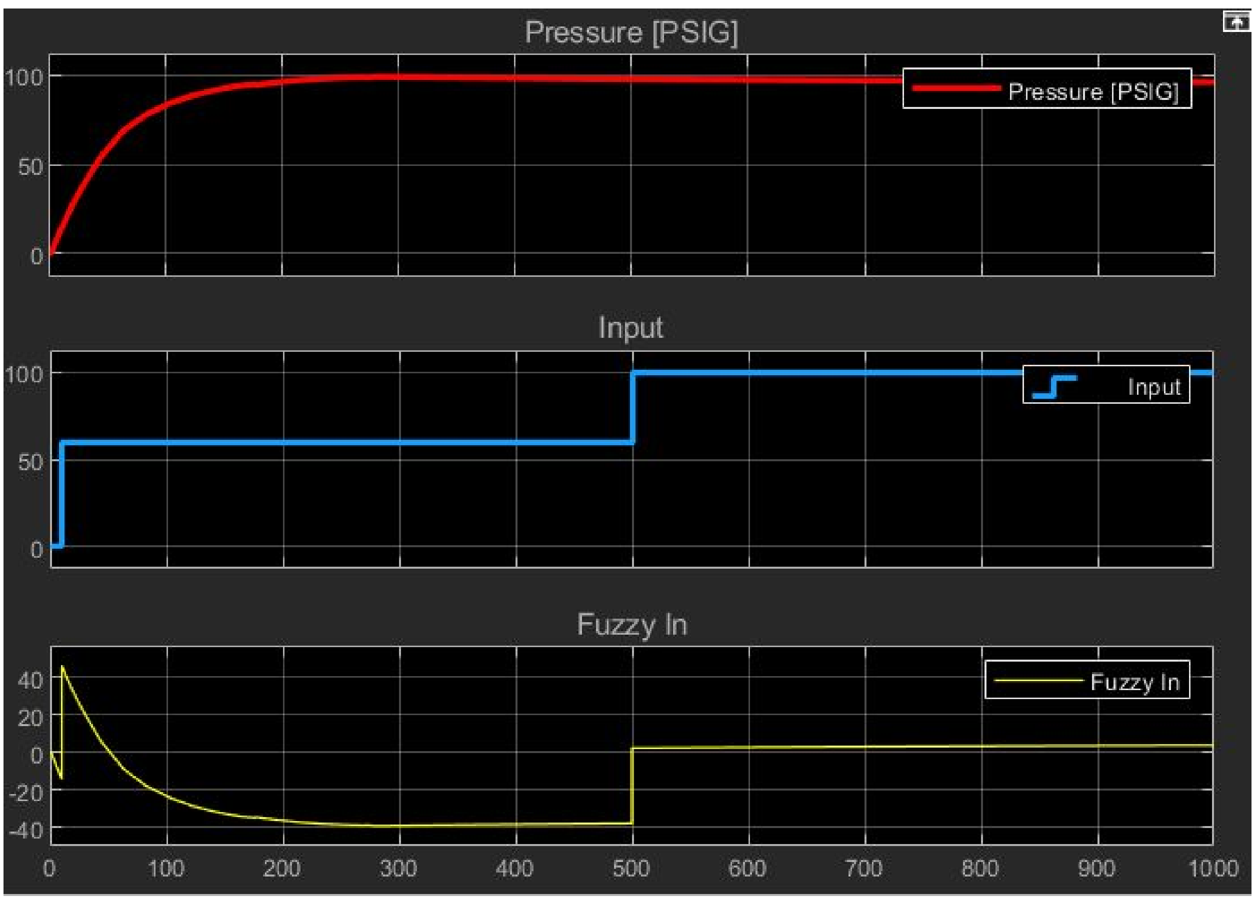






The above tuning process involves setting up two inputs and their range. Then the corresponding membership functions that go with each input and output. In the case of the CAES system the input to the fuzzy logic is the error and change in error integrator. Next step is to set the mamdani fuzzy control set. The odd number of rules seen in the second block rule viewer displays the appropriate output based on different membership functions of the inputs. From the rules implemented we can see the surface view is similar to the example given in lecture 27.

Below is the system output. The 'Input' is the setpoint while the 'Fuzzy In' signal includes the system feedback. The system was then tuned for the optimal response. Low overshoot, low settling time, and quick response was achieved. Captures of the system I/O can be seen on the following page. The simulation indicates that a physical realisation of the system with the same parameters would be controlled quite accurately. There is very little overshoot from the response of the system and consequently settling time is also very low. However, a small yet abrupt change in pressure (and consequently stored energy) can be seen at T=500 when the set point is increased. The system response is very smooth and the appropriate response to minimize pump motor starting / stopping in a real implementation.



4.0 Conclusion

Mitchell individually contributed to the lab by starting the report and deriving the dynamic model. After doing the first simulation, Noah took over to finish the simulations and complete the report with results.

From this lab the group became familiar with CAES systems and learned how to derive the equations for a basic model. The lab also served to further our Simulink experience and knowledge by learning how to implement fuzzy logic control to existing systems.