EEE342 Lab 3 Preliminary Report

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1. Introduction

The aim of this preliminary work is to improve our ability in identifying and formulating real life engineering problems and to propose possible solutions for them.

This preliminary work consisted of three parts. In the first part, we propose a possible geographical location of a gas storage tank on Nabucco line based on economic, political, social and environmental issues. In the second part we discuss and identify possible technical and non-technical problems which may be encountered during the gas storage/distribution process. In the final part, we develop a mathematical model for the gas storage tank system and propose a controller to control the gas flow to Turkey and abroad.

2. Laboratory Content

The city I've chosen for the gas storage location is Nevşehir which is located in the heart of Central Anatolia, known for its natural beauty and strategic inland position. Nevşehir is close enough to the Nabucco pipeline's path, making it a practical midpoint storage and distribution hub. My choice is based on economic, political, social and environmental factors. Nevşehir and the pipeline's route is given in the following picture.

Fig. 1: The Nabucco Pipeline and Nevşehir

The main reasoning in the choice I made comes from a research about choquet integrals. Five decision maker experts from Turkish Petroleum were asked to pick four most suitable spots for natural gas storage in Turkey in an MDCM (Multi-Criteria Decision Making) study [1] which analyzed the best location to store natural gas between the 4 cities for the given criteria using choquet integrals. Mersin, Antalya, Batman and Nevşehir were the four cities these experts chose for the researchers to analyze. Given these four cities, only Nevşehir is at the supposed route of the Nabucco Gas Pipeline project.

There are certain key economic factors that contribute to Nevşehir as my choice. Nevşehir's central location makes it ideal for distributing gas to both western industrial regions and eastern transit zones. An energy infrastructure project in Nevşehir would provide a major boost to the local economy, encouraging investment and supporting small businesses and employment.

Politically speaking, as part of the government's long-term goal to make Turkey an energy hub, establishing a central node in Nevşehir supports this decentralization and reduces over-dependence on coastal regions. Also, Nevşehir is close to Ankara, enabling better coordination with government institutions.

Socio-geographically, Nevşehir is located in one of Turkey's safest and most politically stable regions, away from border tensions or ethnic conflict zones. Nevşehir is not densely urbanized and investing in Nevşehir may support regional equity and social inclusion. Also, Nevşehir is not in earthquake risk zone, where nearly 80% of the country is endangered by earthquakes.

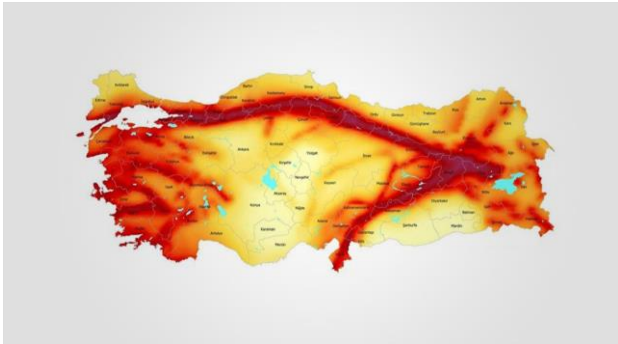

Fig. 2: Earthquake Risk Map of Turkey

Environmentally, there are large plains outside protected areas in Nevşehir where the facility can be placed with minimal ecological damage and extremely reduced costs. Also, unlike coastal or mountainous areas, Nevşehir is not prone to flooding or landslides, reducing environmental risks for sensitive gas infrastructure.

There are many problems that may be encountered during the gas storage/distribution process. Some of these problems can be technical.

Natural gas (NG) can be stored as a liquid or as a gas. To store it as liquid requires cooling below -160°C until it condenses and keeps it cold. Storing it as a gas requires much more volume but requires less energy for storage. Thus storage as a gas in large underground caverns is the most economical method [2]. Regardless of which method is chosen to store the gas, to keep the temperature of the gas stable is very crucial to not have any pressure-related issues. Fluctuating external temperatures may lead to very unwanted outcomes. To overcome this temperature issue, advanced automated control systems for real-time temperature monitoring can be installed. Also, insulated cryogenic storage tanks with pressure-relief systems can be used as well as redundant cooling systems to be used when necessary.

Gas leakage due to material fatigue, valve failure, or pipeline corrosion during storage and distribution can be very harmful as well. Just as in the temperature case, gas leakages cause pressure-related issues and can be extremely dangerous. Smart sensors -IoT-based pressure, flow, and gas detectors- should be used during the distribution and storage phases. Also, advanced corrosion-resistant coatings and high-quality welding should be used.

Nevertheless, not all problems are technical and can be solved with engineering practices. We, as engineers, should also take these non-technical problems into account when designing a system.

For instance, resistance from locals due to land usage, safety concerns, or environmental fears can be a bottleneck for the project. This is a social and legal issue rather than a technical one. The legal base for the land that the storage will be built upon should be well-established. Also, the good sides of the storage system should be propagandized to the locals, such as the advantages on local labor, national status of Turkey in the world stage when involving in a big project should be emphasized if and before any resistance occurs.

Another non-technical problem we might face is diplomatic problems. Gas-flow interruptions to Turkey due to wars and conflicts (i.e. Azerbaijan-Armenia) might bottleneck the gas supply. Or any political disagreements and possible embargoes on Turkey by European countries may bring the project to an end. In this world, we can't "**engineer**" peace or diplomatic alignments.

Then, we moved onto the mathematical relations within our systems.

$$R_{out}(t) \ = \ R_{out,1}(t) \ + \ R_{out,2}(t)$$
$$R_{out}(t) \ = a \cdot \sqrt{2g \cdot h(t)} + a \cdot \sqrt{2g \cdot (h(t) - h_0)}$$

Using the conservation of mass, we derived the following equation:

$$\frac{d}{dt}\big(\rho \cdot A \cdot h(t)\big) = R_{in}(t) \ - \ R_{out}(t) = f(h, R) =$$
$$= R_{in}(t) \ - \ a \cdot \sqrt{2g \cdot h(t)} - \ a \cdot \sqrt{2g \cdot (h(t) - h_0)}$$
$$\frac{d}{dt}\big(h(t)\big) = \frac{\big(R_{in}(t) \ - R_{out}(t)\big)}{A \cdot \rho}$$

We need to linearize, hence:

$$f(h, R) \ = \ \frac{1}{\rho \cdot A} \cdot \Big(R_{in} - a\sqrt{2g}\big(\sqrt{h} - \sqrt{h - h_0}\big)\Big)$$

The operating point is as follows:

$$R_{in,x} = a\sqrt{2g \cdot h_x} + a\sqrt{2g \cdot (h_x - h_0)}$$

The initial height of the unit is 9m, and the gas level is always greater than 5m. I chose my steady state gas level to be 7m. My Bilkent ID is 22201689. Now we have the following:

$$a \ = \ 3.75; \ A = 900; \ h_x = 7m$$

$$g = \frac{9.81m}{s^2}; \ \rho = 0.68 \ \frac{kg}{m^3}$$

The equation then becomes:

$$R_{in,x}(t) \ = \ 67.43$$

The relation between Rin and h(t) is non-linear. We need to approximate using taylor series. Hence,

$$\frac{dh}{dt} \approx \frac{\partial f\big(h_x, R_{in,x}\big)}{\partial h}\Delta h \ + \ \frac{\partial f\big(h_x, R_{in,x}\big)}{\partial R}\Delta R$$

Where:

$$\frac{\partial f\big(h_x, R_{in,x}\big)}{\partial h}\Delta h \ = \ \frac{1}{\rho A} \cdot - \left(\frac{a\sqrt{2g}}{2\sqrt{h_x}} + \frac{a\sqrt{2g}}{2\sqrt{h_x - h_0}}\right)$$

And, where:

$$\frac{\partial f\big(h_x, R_{in,x}\big)}{\partial R}\Delta R \ = \ \frac{1}{\rho \cdot A}$$

If we substitute, we get:

$$\frac{dh}{dt} \ \approx \ - 0.0147 \cdot \Delta h \ + \ 0.0016 \cdot \Delta R$$

Then take the laplace transform:

$$s \cdot H(s) - h(0) = -0.0147 \cdot H(s) + 0.0016 \cdot R(s)$$

Then we obtain the transfer function as

$$G_p(s) = \frac{H(s)}{R(s)} = \frac{0.0016}{s + 0.0147}$$

Now, we are asked to design a controller in the form:

$$G_c(s) = K \cdot \frac{(s + a)}{s \cdot (s + b)}$$

The characteristic polynomial for the new system becomes:

$$1 + G_c(s) \cdot G_p(s) \ = \ 0 \ \Rightarrow$$

$$s \cdot (s + b)(s + 0.0147) + 0.0016 \cdot K \cdot (s + a) = 0$$

$$s^3 + (b + 0.0147)s^2 + (0.0147 \cdot b + 0.0016 \cdot K)s + 0.0016 \cdot K \cdot a$$

We then implemented a Routh Table to check for conditions of stability.

3	1	$0.0016 \cdot K + 0.014 \cdot b$
2	$0.0147 + b$	$0.0016 \cdot K \cdot a$
1	$0.0016 \cdot K - 0.0147 \cdot b - \dfrac{0.0016 \cdot K \cdot a}{0.0147 + b}$	0
0	$0.0016 \cdot K \cdot a$	0

We must have the following properties for the table to be stable:

$$K \cdot a > 0; \;\; b > (-0.0147)$$

$$K - 9.1875 \cdot b > \frac{K \cdot a}{b + 0.0147}$$

The following configuration of variables satisfies the above conditions:

$$K = 1; \; a = 0.01; \; b = 0.02$$

$$G_c(s) = \frac{(s + 0.01)}{s \cdot (s + 0.02)}$$

Then, we plotted the bode plot of $G(s) = G_p(s) \cdot G_c(s)$using Matlab:

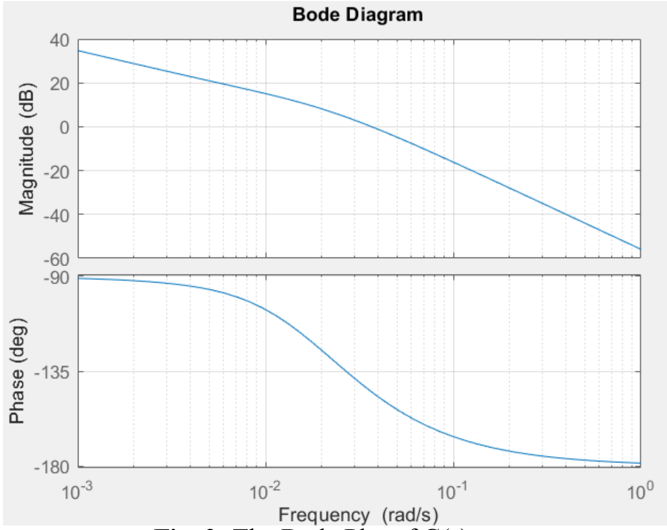

Fig. 3: The Bode Plot of G(s)

Also, using Matlab, we calculated the gain margin, phase margin and delay margin of the system.

```
M =

  struct with fields:

     GainMargin: Inf
    GMFrequency: Inf
    PhaseMargin: 35.1133
    PMFrequency: 0.0368
    DelayMargin: 16.6636
    DMFrequency: 0.0368
         Stable: 1
```

Fig. 4: The Margins of G(s)

The gain margin of the system is infinite. The phase margin is 35.11 and the delay margin is 16.66. Matlab also checks the stability of the system and returns “0” or “1”. We obtained “1”, therefore, the system is stable.

3. Conclusion

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The lab was a total success. We successfully proposed a sensible choice for the storage location and successfully developed a mathematical model for the tank. The controller system we designed also worked well. We were able to create a stable system within the given criteria.

4. Appendices

Matlab Code:

```
Gp = tf(0.0016,[1,0.0147]);
K = 1;
a = 0.01;
b = 0.02;
Gc = tf([K,K*a],[1,b,0]);
G = Gp * Gc;
bode(G);
grid on;
M = allmargin(G)
```

REFERENCES

1. [1] N. Çetin Demirel, T. Demirel, M. Deveci, and G. Vardar, "Location selection for underground natural gas storage using Choquet integral," Journal of Natural Gas Science and Engineering, vol. 45, pp. 368–379, Sep. 2017, doi: https://doi.org/10.1016/j.jngse.2017.05.013.
2. EIA, "The Basics of Underground Natural Gas Storage - U.S. Energy Information Administration," Eia.gov, 2016. https://www.eia.gov/naturalgas/storage/basics/