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# The Study and Exploration of Geothermal Energy in Different Regions of the United Arab Emirates with a Suitable Design and Development of an Innovative Low-Cost Steam Control System

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**Abstract:** ***This paper is concerned with designing and implementing a low-cost working model of the geothermal power plant. Hot spring steam at high pressure and temperature is fed into a 3D printed steam turbine designed on Solid works software, which converts the thermal energy of steam into mechanical energy. While the turbine then converts the mechanical energy into electrical energy via the generator. In this paper, a closed-loop steam control system is designed to control the solenoid valve to feed the steam into the turbine if the temperature and pressure from the hot spring reach a predefined minimum value. The UAE's clean energy strategy includes producing 75% of electricity from clean energy sources by 2050. Underground geothermal heat, which is the heat generated by high temperature hot springs, is the first choice for power generation. Researchers evaluated the potential for power generation at geothermal locations in Al Ain, Ras Al Khaimah, and other sites of the UAE. They concluded the possibility for 1, 000 megawatts of electricity using geothermal energies from these areas.***

**Keywords:** Geothermal Power Plant, 3D printed, Steam Turbine, Solid Works, Closed-loop, Control System, UAE

## 1. Introduction

Researchers found that the water temperature reaches as hot as 120 degrees (Celsius) beneath the surface of about 3 kilometers deep. According to Dr. Hakim Saibi, associate professor of geophysics at UAEU and one of the researchers, the findings pointed to the possibility of tapping geothermal energy in the UAE. "The potential for using geothermal energy is good. Based on our results and the data gathered at the sites, we can produce around 1, 000 megawatts of electricity using the geothermal points from these areas.

The United Arab Emirates (UAE) locates on the southern shore of the Arabian Gulf, on the north-eastern edge of the Arabian Plate. Although most of the country is covered in Quaternary sediments (Figure 1), the bedrock geology is well exposed in the Hajar Mountains, the Musandam Peninsula in the eastern UAE, and along the southern side of the Arabian Gulf west of Abu Dhabi. The Emirates' geology can be divided into nine major components:

- UAE-Oman ophiolite from the Late Cretaceous.
- In the northern UAE, a Middle Permian to Upper Cretaceous carbonate platform series has been discovered (the Hajar Supergroup).
- In the Dibba and Hatta Zones, a deformed sequence of thin limestone and related deep-water deposits, volcanic rocks, and melanges.
- A ploydeformed metamorphic rock series that can be found in the Masafi – Ismah and Bani Hamid locations.
- A newer Late Cretaceous to Palaeogene cover sequence exposed at the western edge of the Hajar Mountains in a foreland basin.
- The Hajar Mountains have a vast suite of Quaternary fluvial gravels and consolidated alluvial fans.
- In the western Emirates, a series of Late Miocene sedimentary strata has been uncovered.
- In the Arabian Gulf, several salt domes were producing islands with complicated dissolution breccias and a diverse clast suite of mostly Neoproterozoic (Ediacaran) sedimentary and volcanic rocks.
- The iconic Abu Dhabi sabkhas and extensive Quaternary to recent aeolian sand dunes, which underpin the majority of Abu Dhabi Emirate, are formed by a sequence of Holocene marine and near-shore carbonate and evaporate deposits along the southern edge of the Arabian Gulf. more than 1 km below the earth's surface in depth. The energy travels to the earth's surface by convection and conduction while it arises from the radioactive decay energy from the middle of the earth in temperature ranging up to 6650°C.

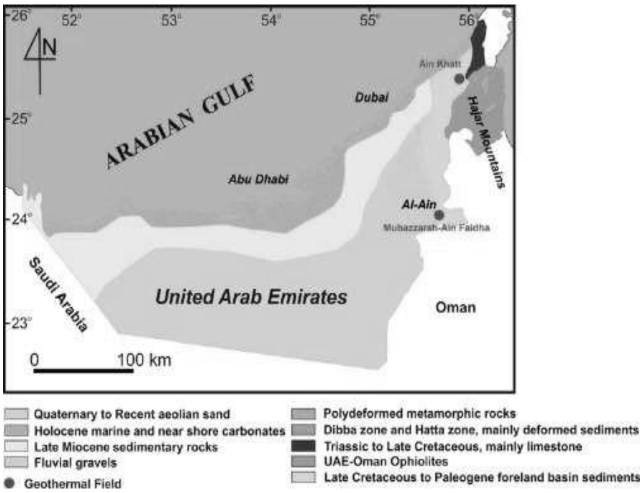

**Figure 1:** Geological Map of UAE Showing the Location of The Two Main Geothermal Fields

The initiative's primary goal is to create a cost-effective geothermal power plant control paradigm. By 2050, the UAE plans to generate 75 percent of its power from renewable sources. This project aims to build and implement an autistic spectrum model of a geothermal power plant. The project's purpose is to design and construct a low-cost geothermal power plant. Furthermore, power production is needed to address power energy supply issues and eliminate fossil fuels. The UAE has a lot of geothermal potentials. However, there is currently no implementation plant there.

## 2. Concept and Design

### 2.1 Single Stage Steam Turbine

In this geothermal plant prototype, we used a gas heater to heat the water to 130-degree C. As an effect, the design of the prototype turbine was limited to a single-stage impulsive turbine type, as shown in Fig.2. Many considerations inspired this design, mainly the pressure of the inlet steam, which is relatively low, and the low velocity of the steam. The idea behind this prototype turbine is to increase the velocity of the steam before it strikes the blades, increasing its performance while keeping the pressure constant during the energy conversion. In contrast, in a reactive turbine, the pressure drops gradually. On the other hand, this prototype is a single-stage turbine, which indicates that rotating blades are organized in a certain way. Due to the low steam jet velocity and energy losses due to friction, both would be signed utilizing the multi-stage turbine and would impact its performance.

**Figure 2:** A Single Stage Impulsive Steam Turbine

The steam turbine performance depends on the dynamic action of steam, which is represented by the change of the steam's velocity, first passing through the nozzle at an angle where it expands and attains some speed. At the same time, the pressure drops, the steam then enters a set of moving blades at an angle, it grows again dropping in force and also in velocity, the blades are made symmetrical, that means the angle on the fixed blades is equal to the angle on the moving blades, this is to avoid sudden change in the direction of the steam, which would result in energy loss.

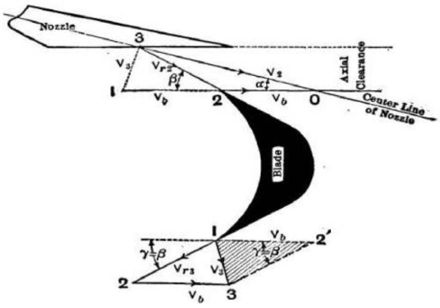

**Figure 3:** The Velocity Triangle of An Impulsive Steam Turbine

The structure of a single-stage impulsive steam turbine is shown in Fig.4; we identify the main components of this turbine: 1-the turbine casing, 2-the blades of the turbine, 3-the nozzle, 4-the exhaust pipe.

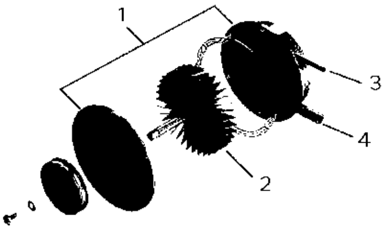

**Figure 4:** The Structure of a Single Stage Impulsive Steam Turbine

We distinguish three types of nozzles, convergent, divergent, and the mix of both. Since the steam velocity is low on this prototype, a convergent type nozzle increases the speed.

The angle of the blades, the height, and the length of the blades are all aspects to consider while designing steam turbine blades. Steam goes through the nozzle of the turbine model at a temperature of 130 degrees Celsius. The discharge angle of the rotating blades is 20 degrees, the steam passes through an area of the blade of 0.4, this requires a total area in which the steam gives equal to 0.4 / (sin 20) = 1.4, and since this is a single-stage turbine, the height of the rotor must be equal to 0.4 / (sin 20) = 1.4. Since this is a single-stage turbine, it is necessary to prevent any steam leakage and allow maximum energy conversion. The blades' height and length, roughly 1.2 cm, are designed to minimize losses via impact and friction due to the low-velocity steam input. The design of single stage impulsive turbine blades is shown in Fig.5.

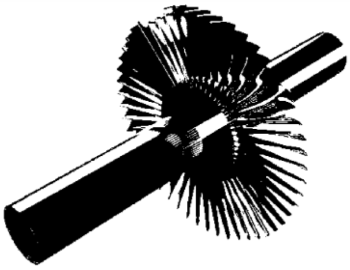

**Figure 5:** Single Stage Impulsive Turbine Blades

### 2.2 Controlling Using Arduino Uno

The Arduino Uno controls the prototype. Students used the Tinker cad software to simulate the prototype in the simulation and results. This system work when the switch is on and achieves four conditions, temperature, pressure, water level, and pump state. To control the water level, students construct three switches in the circuit for controlling water level (low, medium, and high); whenever the three switches are LOW, the water level will appear as HIGH on the LCD screen; if the two switches are LOW and the third switch is HIGH, the water level status will appear as MED in the LCD screen, the last condition when the two switches are HIGH, and the third switch is LOW, the water level status will appear as HIGH in the LCD screen.

To control the pump state, whenever the water level goes to the MED state, the pump automatically opens, which will change the state of the pump state and display it as ON to allow the water to flow from the external tank to the boiler, which will change the state of the water level from MED to HIGH in the LCD screen. Otherwise, the LCD screen will display the pump as OFF mode.

Furthermore, the temperature sensor takes the readings from the sensor based on the input by defining the value of the current temperature. Moreover, the temperature sensor includes three pins first pin is grounded, the second one is connected to an analog pin (A1) through Arduino, and the last is to 5v. Thus, Arduino converts it from analog to digital form (ADC) while it can accept up to 5V maximum and 1024 analog pins, which is 10 bits. Eventually, it displays it through an LCD screen by a Celsius unit.

In addition, the pressure sensor takes the readings from the sensor based on the input by defining the value of the current pressure. In addition, the pressure sensor consists of two pins; the first is connected to an analog pin (A2) through Arduino, while the second is grounded. Therefore, Arduino converts it from analog pin to digital form (ADC) while it can accept up to 5V maximum and 1024 analog pin, which is 10 bits. Eventually, it displays through an LCD screen by a psi unit.

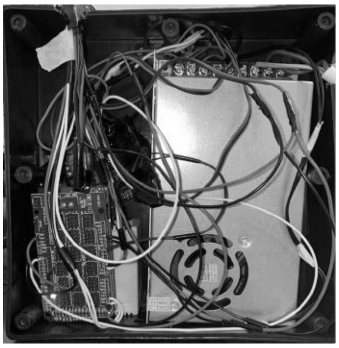

**Figure 6:** Arduino Connection

The proposed design looks as the structure shown blow

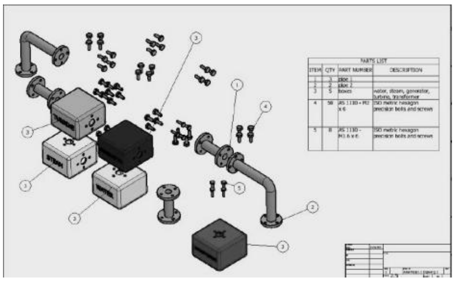

**Figure 7:** Proposed model drawing

### 2.3 Block Diagram & Flow Chart

The geothermal plant is a closed-loop system in which water is pumped using a water feed pump, and a steam valve is utilized to ensure a one-way flow between the water pump and the steam generation assembly. Water is transformed into steam in a steam generation assembly using geothermal heat. Water level, temperature and pressure sensors are used to conduct continuous monitoring. Pressure sensors are also used to control the steam valve, which allows or prevents steam from entering the turbine casing with the help of a steam valve controller. A turbine turns pressured steam energy into kinetic energy, subsequently used by a linked generator to generate electricity.

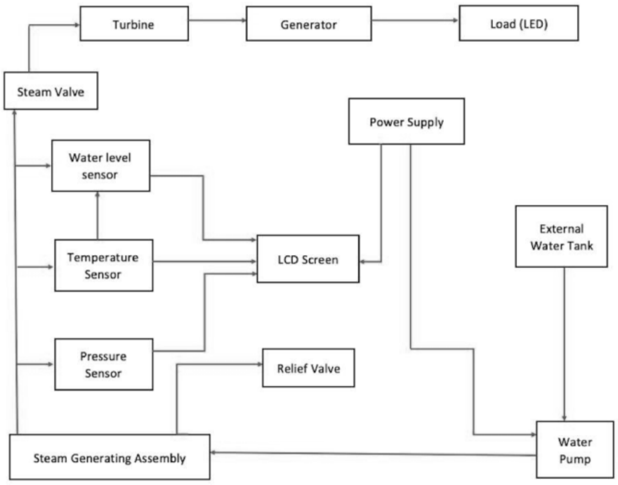

**Figure 8:** Block diagram of proposed model

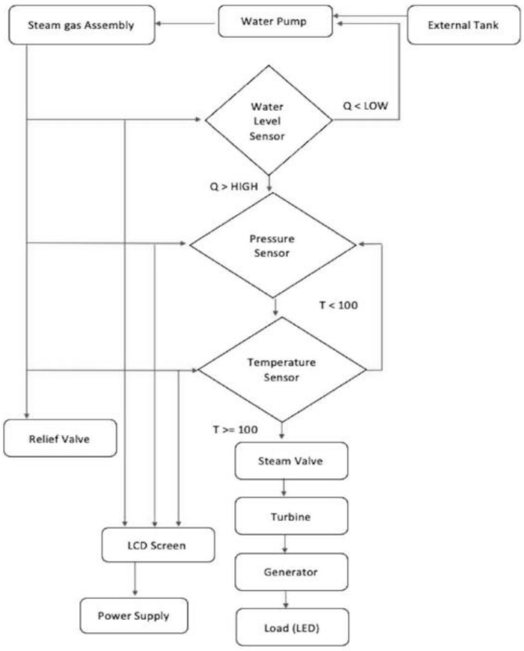

**Figure 9:** Flow chart of proposed model

## 3. Experiment and Result

In the simulation results, we have used the Auto Cad software to design a 3D model of a single-stage impulse turbine to show the assembled design of the turbine, as shown in Fig.10. In addition, we demonstrate the individual components of the turbine using Auto Cad software and printed out through 3D printer.

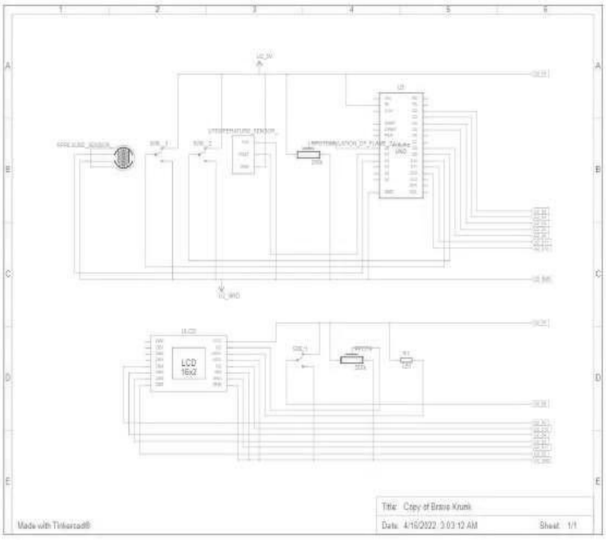

**Figure 10:** Circuit Diagram of the Sensors

These sensors are meant to be put inside the boiler to measure the pressure, water level, and temperature inside the boiler. After successfully running the circuit, connections were made on Arduino to sense and measure all the physical variables as shown below.

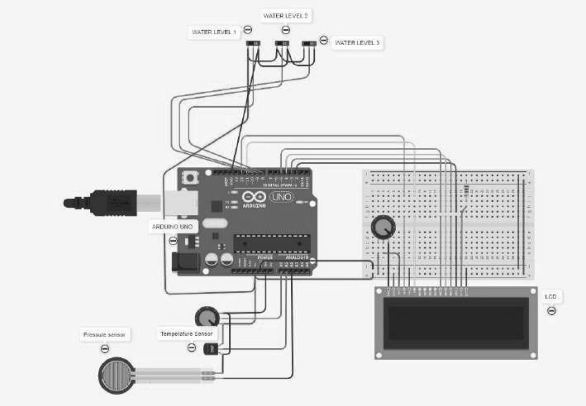

**Figure 11:** Sensors Connections on Arduino

A pump was used to pump the water into the boiler, and water level sensors were used to measure the volume of water in the boiler. The water in the boiler was heated and converted into steam by using a gas burner. The boiler position on the burner was set by using two supporting stands. The pressure in the boiler is kept in a safe working range. In case pressure goes high at a value of 188 psi; the pressure relief valve will open to release the pressure and keep it less than 188 psi. The pressure and temperature inside the boiler are measured using pressure and temperature sensors installed inside the boiler. The pipes are used to direct this pressurized steam toward turbine blades.

The rotating speed of the turbine is 300 rpm maximum. The pressure of steam can also be increased manually by using a manual booster valve. This produced steam from the boiler then rotates the blades of the steam turbine, which is connected to the generator through a shaft. The generator produces electricity which is confirmed by lighting up a LED or bulb. The produced voltage lies in the range of 0-6 volts depending upon the rpm of the turbine and steam pressure. The connections of various prototype parts have been shown below.

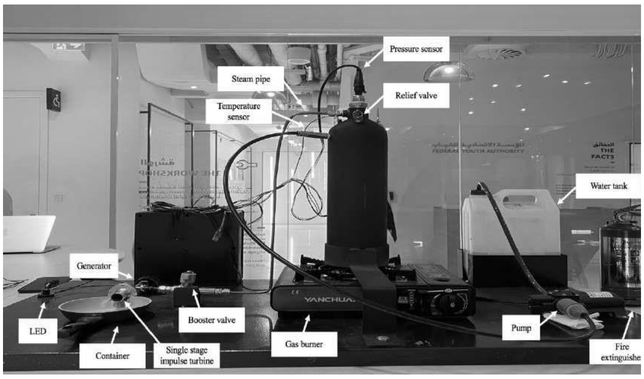

**Figure 12:** Connections of Different Components of Prototype (1)

**Figure 13:** Connections of Different Components of Prototype (2)

**Table 1:** Experiment Result

| Type of pressure | Pressure (psi) | Temperature (C degree) | Speed (rpm) | Voltage (V) | Current (mA) |
|---|---|---|---|---|---|
| Low | 170 | 120 | 100 | 1.445 | 13.5 |
| Medium | 175 | 125 | 145 | 2.01 | 33.4 |
| High | 185 | 150 C | 250 | 4.31 | 62.8 |

Table 1 As shown in the results table, when pressure is low, the turbine rpm is also low, resulting in the generator producing only 19.507 mW of electricity. When the pressure was kept in a medium range of 175 psi, the rpm increased to 145; thus, the power increased up to 67.134 mW. When the pressure was held at a high range of 185 psi, the rpm was 250, and produced power was 270.66 mW. Therefore, from these results, it can be deduced that increasing pressure results in higher rpm and consequently high-power production from the prototype, as shown in the following graphs.

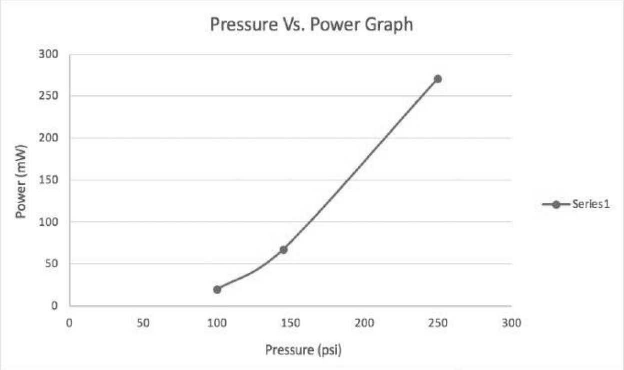

**Figure 14:** Pressure Vs. Power Graph

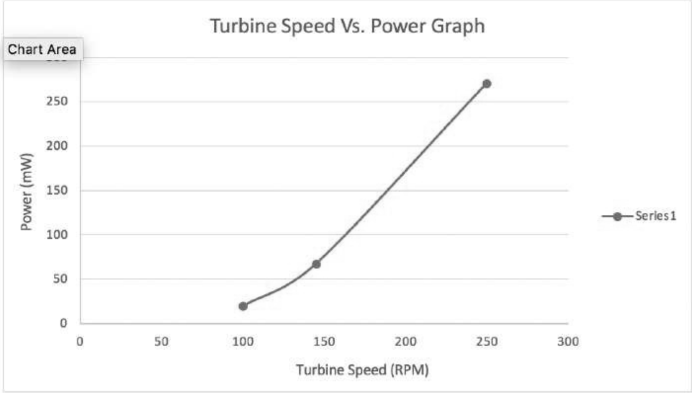

**Figure 15:** Turbine Speed Vs. Power Graph

The power produced can be calculated by using following formula:
P = IV
Where P is the power produced at turbine shaft in milli Watts
I is the current flow in milli Amperes
V is the voltage in Volts
Plow = (13.5) (1.445) = 19.507 mW
Pmed = (33.4) (4.0) = 67.134 mW
Phigh = (62.8) (4.31) = 270.66 mW

## 4. Recommendation & Future Works

To enhance the electrical output of the power plant, it is mandatory to improve the efficiency of the turbine by making some modifications in its design. Also, plant life is a critical factor that can be enhanced by using such materials in turbine manufacturing that may resist corrosion and work upon dry steam and saturated steam. By reducing the stresses induced on the surface of the rotor disc, blade root, and transition fillet, the fatigue life of the turbine can be enhanced, which will help improve the financial viability of the geothermal power plant. Turbine life is primarily affected by cracks due to stresses that may be overcome by applying compressive stresses. The significant losses in the turbine are due to the inefficient profile of the nozzle. These losses can be avoided by designing an optimized shape of the turbine nozzle.

Moreover, some key factors are related to site selection for the installation of the geothermal power plant. The seismic survey of the geothermal site is of crucial importance as it will help to know about the energy prediction of that site. The source characterization is substantial, which can be done by using geochemical and geophysical technologies. Those sites must be selected that have low risk and may put the slightest danger for workers. The place should be safe for drilling and must be cost-effective. Those sites where drilling and extraction of geothermal energy are not cost-effective must not be chosen. Sites chosen must be near to grid and transmission life. Otherwise, transmission losses will cause a financial setback. As the significant role of geothermal energy is to be a green energy source, proper handling of brine and effluent must be done to avoid negative environmental impacts. Otherwise, geothermal energy will be no more a green energy source

## 5. Conclusion

This study aimed to accomplish a cost-effective geothermal power generation plant model and its implementation to reduce the electricity cost from geothermal sources and mitigate GHG emissions. High pressure and high-temperature steam were fed to a steam turbine designed using solid works software and 3D printed. The purpose of this turbine was to convert the energy in steam into mechanical energy, which was further converted into electricity by using a generator. A closed-loop steam control introduced in this prototype was capable of maintaining the temperature and pressure of fed steam within the desired limit with the help of a solenoid valve. UAE's future energy goal defined by Clean Energy Strategy includes at least a 75% energy mix from renewable energy technologies. In the visible region of solar and wind energy's intermittency, geothermal energy appears to be a competent and reliable future energy source for the UAE's power generation sector. Different studies have explored Al Ain, Al Khaimah, and many other potential sites that can be used for power generation at economic viability and carry a technical potential of 1000 MW from these sites.

Geothermal energy, like any other renewable energy source, has the advantage of being a clean, renewable, and widely used energy source. The potential of geothermal energy in the United Arab Emirates has been widely discussed in articles showing that developing geothermal power plants in the UAE can overcome climate change problems and reduce reliance on fossil fuels. Increase. This project has proposed a prototype, keeping in mind the positive aspects of geothermal energy sources. A turbine design has been explained, best suited for extracting energy from steam produced from geothermal wells. The suggested turbine is single stage impulse turbine, which is capable of operating in different working conditions. Geothermal energy may be effectively turned into electrical energy by using this turbine.

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