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DESIGN AND DEVELOPMENT OF HYBRID THERMAL ENERGY STORAGE SYSTEM USING FIRE BRICKS

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Abstract: This paper presents the design and development of a hybrid thermal energy storage (TES) system using high-alumina fire bricks as a sensible heat storage medium. The increasing penetration of renewable energy sources like solar and wind introduces intermittency issues, creating a need for reliable energy storage solutions. The proposed system utilizes a dual charging mechanism combining solar energy and electrical resistive heating to ensure continuous operation. The storage core consists of fire bricks arranged to maximize heat transfer and retention. Experimental observations show that the system can achieve temperatures up to 350℃ and deliver usable heat above 150℃ for industrial applications. The system demonstrates low heat loss, cost-effectiveness, and long operational life, making it a promising solution for industrial heating and renewable energy integration.

Index Terms **- Thermal Energy Storage, Fire Bricks, Renewable Energy, Sensible Heat Storage, Hybrid Energy System, Industrial Heating.**

I. INTRODUCTION

Thermal Energy Storage (TES) is an important technology used to store excess energy in the form of heat and utilize it when required. With the rapid growth of renewable energy sources such as solar and wind, maintaining a balance between energy generation and demand has become a major challenge. These sources are intermittent in nature, which leads to instability in the power system.

To address this issue, a hybrid TES system using fire bricks is proposed. Fire bricks are capable of storing large amounts of heat due to their high thermal capacity and ability to withstand high temperatures. The system stores energy during off-peak hours or when renewable energy is available and releases it during demand periods.

NEED OF THE STUDY.

The rapid transition from conventional fossil-fuel-based energy systems to renewable energy sources such as solar and wind has created new challenges in power generation and utilization. Although renewable energy is environmentally friendly and sustainable, it suffers from a major limitation—intermittency. Solar energy is only available during daylight hours, and wind energy depends on unpredictable atmospheric conditions. This mismatch between energy generation and demand leads to inefficient utilization of available resources and sometimes results in energy curtailment.

Another critical issue associated with high penetration of renewable energy is grid instability due to low inertia. Traditional power systems rely on rotating machines like turbines, which provide mechanical inertia and help maintain system frequency. However, renewable energy systems are mostly inverter-based and lack this inherent inertia, making the grid more vulnerable to sudden disturbances and frequency fluctuations.

In addition to power system challenges, there is a significant and continuous demand for industrial process heat, particularly in the temperature range of 150℃ to 300℃. Industries such as food processing, textiles, and chemical manufacturing depend heavily on fossil fuels like coal and natural gas to meet this heat requirement. This not only increases operational costs but also contributes to high carbon emissions and environmental pollution, including greenhouse gases and particulate matter.

To address these challenges, there is a strong need for an efficient, cost-effective, and sustainable energy storage solution. The proposed firebrick-based Thermal Energy Storage (TES) system provides a practical approach to overcome these issues. It enables the storage of excess electrical energy in the form of heat during periods of low demand or when renewable energy is available. This stored energy can then be utilized later, ensuring a continuous and reliable heat supply.

Furthermore, the system allows industries to perform heating operations without relying on coal or other fossil fuels, thereby reducing carbon emissions and supporting clean energy goals. Another major advantage is the ability to utilize off-peak electricity, which is available at lower tariffs. By storing energy during off-peak hours and using it during peak demand periods, industries can significantly reduce their overall energy costs.

II. RESEARCH METHODOLOGY

The proposed system is designed as a **hybrid thermal energy storage (TES) unit**, capable of storing heat energy and delivering it in a controlled manner for industrial applications. The main idea behind the design is to combine **two energy sources (solar + electrical)** into a single storage medium so that the system can operate continuously, even when solar energy is not available.

At the centre of the system, a **fire brick storage chamber** is used, which acts like a thermal battery. These bricks absorb heat during charging and release it during discharge. To maintain the stored heat for a longer duration, the chamber is surrounded by a **multi-layer insulation system**. The inner layer is made of ceramic fiber, which can withstand very high temperatures, while the outer layer consists of glass wool to reduce heat loss to the surroundings. This arrangement ensures that the outer surface remains near ambient temperature even when the internal temperature exceeds 300–350°C.

The system also includes an **electronic control unit** based on Arduino Uno, which continuously monitors the temperature using K-type thermocouples placed at different locations inside the brick matrix. Based on these readings, the controller operates heaters and blower using relay modules. A hysteresis-based control logic is used to maintain the temperature within a safe range (approximately 290°C to 350°C).

For heat extraction, a **centrifugal blower** is used. When activated, it forces air through the hot brick channels, and the heated air is then supplied through an outlet for industrial use.

Heat Storage Principle

The thermal energy stored in the system can be estimated using the basic heat transfer equation:

$$Q = mc\Delta T$$

where
Q= heat stored (J)
m= mass of fire bricks (kg)
c= specific heat capacity (J/kg·°C)
ΔT= rise in temperature

As the temperature of the bricks increases from ambient (~25°C) to around **350°C**, a significant amount of heat is stored in the system. This stored energy is later extracted during the discharge process.

Thermal Charging Characteristics

During the charging phase, heat is supplied using a hybrid input (solar + electric heaters). The experimental results show that the temperature increases rapidly in the beginning and then gradually slows down as it approaches the maximum value.

The observed temperature variation is given below:

Table 1 Temperature Rise with Time

Heat Retention (Storage Performance)

After reaching the maximum temperature, the system was isolated to study heat retention capability. Due to effective insulation, the temperature drop is slow.

Table 2 Observation Table Heat retention

Time (min)	Normal Env (∘C)	Isolated Chamber (∘C)
0	350.0	350.0
30	178.4	265.8
60	97.4	203.4
120	41.2	122.9
180	28.6	78.7

Heating and Cooling Characteristics

The thermal performance of the proposed TES system is analyzed using the temperature vs time graphs shown in Fig.1. The graph consists of two parts: the heating phase and the cooling (heat retention) phase, comparing the normal environment with the insulated chamber.

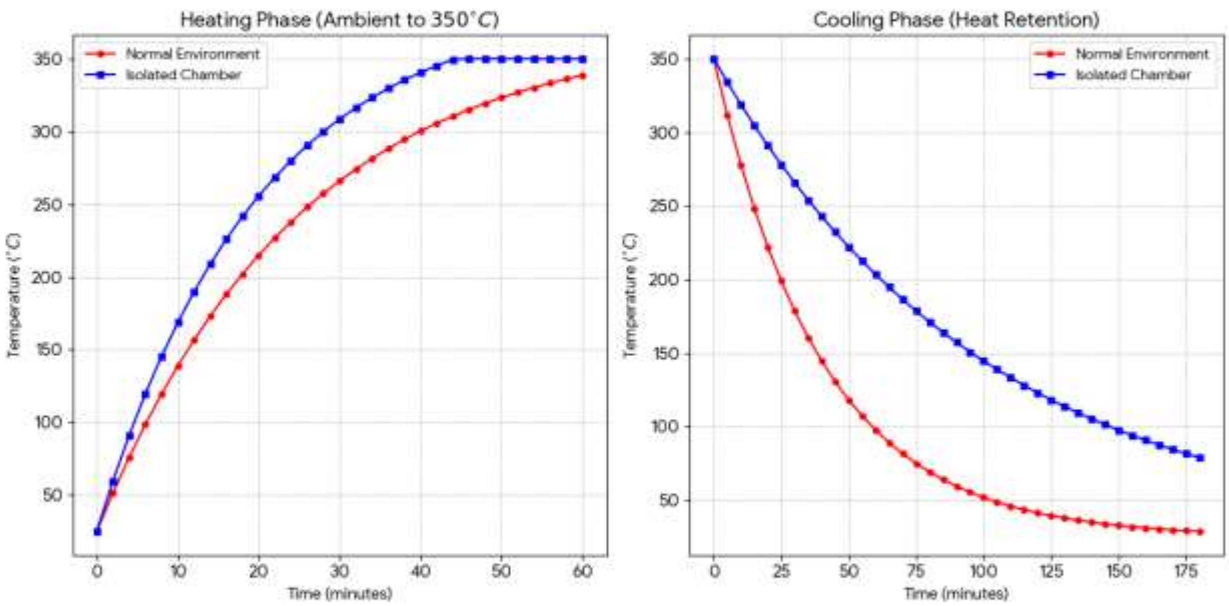

Fig.1 Heating and Cooling Characteristics

Heating Phase (Ambient to 350°C)

From the left graph, it can be observed that the temperature of the system increases continuously with time for both cases. However, the isolated chamber shows a significantly faster rise in temperature compared to the normal environment.

At the initial stage (0–10 minutes), the temperature rise is very steep due to a large temperature difference between the heater and surroundings. As time progresses, the rate of increase gradually reduces, and the curve starts flattening as it approaches the maximum temperature. This behavior indicates a transition from linear heating to a saturation region, which is typical in thermal systems.

The isolated chamber reaches the set temperature of 350°C in about 60 minutes, whereas the normal environment remains slightly lower (around 330–340°C). This clearly shows that insulation reduces heat loss and improves heating efficiency.

Cooling Phase (Heat Retention)

The right-side graph represents the cooling or heat retention characteristics of the system. After the heating phase, the system is allowed to cool naturally, and the temperature drop is recorded over time.

It can be clearly seen that the isolated chamber retains heat much more effectively than the normal environment. In the normal case, the temperature drops rapidly, especially in the initial period, due to direct exposure to ambient conditions.

In contrast, the insulated chamber shows a gradual and controlled decrease in temperature, indicating reduced heat loss. Even after a long duration, the temperature remains significantly higher compared to the normal environment.

Experimental setup of control circuit for Thermal Energy Storage system using Arduino, relay module, and temperature sensing unit

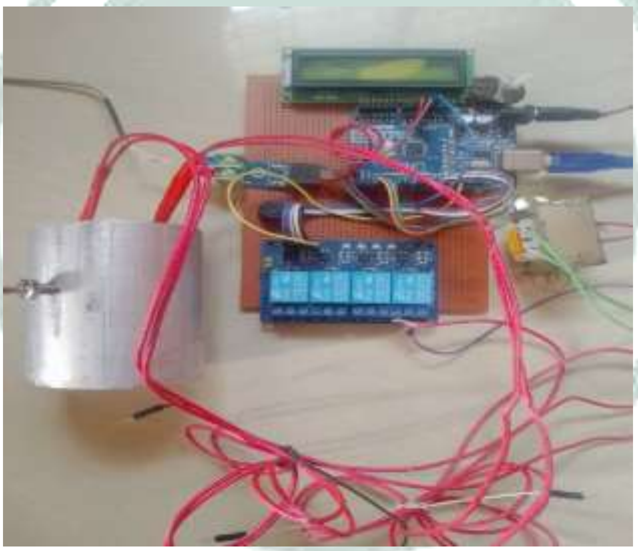

Fig.2 Experimental Setup

The fig. 2 shows the experimental control and monitoring setup of the thermal energy storage (TES) system. It is built on a PCB and includes an Arduino Uno, relay module, LCD display, thermocouple sensor, and power supply. The Arduino acts as the main controller, processing temperature data and controlling heating and discharge operations. Temperature is measured using a thermocouple and displayed on a 16×2 LCD. A 4-channel relay module controls the heater and blower based on set limits, ensuring safe operation. A transformer provides power, and a buzzer gives safety alerts. The setup demonstrates reliable and automated system control.

CONCLUSION

The developed fire brick-based TES system is a cost-effective and sustainable solution for energy storage. It successfully stores excess energy and delivers high-temperature heat for industrial applications. Compared to batteries, it offers longer life, lower cost, and environmental benefits. The system also supports renewable energy integration and helps in reducing carbon emissions

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