THERMAL ENERGY STORAGE SYSTEM FOR GRID APPLICATION

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Abstract - *The world is aiming for carbon neutral by 2030 which results in shutting down all the coal power plants which results in un-employment of thousands which results in economic unsustainability. The current scenario is going behind Li-ion battery storage system for grid energy storage which is not adequate and sustainable. This article deals with the problem of energy storage for grid application and sustainable development. The proposed energy storage system is based on thermal energy storage. Electricity is stored thermally during off peak hours and retrieved back to electric energy on peak hours. The energy is stored in a cubical structure. The results are optimized for a course of 24 hours and the results are promising the consistency of the proposed system*.

***Key Words*: Thermal Energy Storage System, Li-ion Battery Alternative, Grid Storage System.**

1.INTRODUCTION

The green concept is emerging and getting engaged exponentially from last decade. By the start of last decade, industry got a kickstart for the electric era by transforming transportation and logistics systems to electric system. The demand for the energy is increasing day by day. This concept results in zero carbon emission strategy which cause un employment of thousands. The grid storage system which are operational these days is also not adequate. Industry standard Li-ion batteries have much serious problems like they are prone to fire catching, lower charging cycle, and the Li-ion battery made from much expensive and rare earth metals are not sustainable. The ideology of thermal energy storage system which has emerged a long time ago come in to play now in grid level energy storage application. A new technique has been proposed which can hold the energy for over a time of 24 hours with decreased losses and will be a source of income for thousands who will lose their job due to green concept and also give life to the dying coal power plant.

In this research, the discussed areas are the fatal flaws of Li-ion batteries, Economic unsustainability created by the green initiative and utilization of resources. There are many alternatives to the Li-ion battery storage system which are not promising in future so far now. This paper deals with the application of conventional energy storage system with new technology. This paper proposes the ideology of thermal energy storage system with the application of binary cycle, electromagnetism and also thermodynamics. The proposed system could be made into reality with ease.

1.1 Characteristics

The proposed system will promote the term of sustainability by the concepts of reduce, reuse and recycle. The use of recycled steel will promote the sustainability as well as reduce the cost and increase the efficiency. The proposed system will help the stalling coal power plants to get back in operation in a different way so that the large capital and land can be utilised for productivity without a considerable modification. The coal power plant will promote the employment opportunities to an extent. The proposed system will ensure the storage of electric power in large volume with no dust and fumes.

2.LITERATURE SURVEY

The number of studies in the application of thermal energy storage in the grid application are quite low. The recent studies on the Li-ion batteries are shown, how vulnerable they for both environment and for economy of the world. Some studies in the binary cycle have shown its promising future for the application of this system. From the study Fernandes, Nereus. (2018). "Induction Heating - Theory and Applications", The concepts of induction heating is obtained. [1]. From the work done by O. Lucía, P. Maussion, et. al "Induction Heating Technology and Its Applications: Past Developments, Current Technology, and Future Challenges," (2014), The design and development concepts of induction coil for heating purposes [2]. From the insight of Fokin, L.R., Popov et. al (2011) "Equation of state and thermodynamic properties of saturated and superheated mercury vapors up to 1650 K and 125 MPa", The characteristics of mercury under higher temperature [3]. From the review done by Sarbu, et. al, "A Review on heat transfer analysis in thermal energy storage using latent heat storage systems and phase change materials" The properties and mechanisms of heat transfer [4]. From the study conducted by Ketul M Patel et.al (2019) "An Overview of Applications of Induction Heating" design parameters of induction heating are obtained [5]. From the work conducted by Hengyun Zhang (2020) "Thermal modeling, analysis, and design", the working of thermal power plant is [6]. From the work conducted by Bavane, Vikas et. al (2017) "Energy Analysis of Thermal Power Plant", analysis of thermal power plant is done [7]. Akhmetov et.al (2016). "Thermal energy storage systems", the concepts of thermal energy storage system [8]. From the work conducted by Al-Taha, Wadhah et. al. (20180 "Performance Analysis of a Steam Power Plant" the parameters affecting performance of a thermal power plant [9]. From the research work conducted by Gang Li et. al, "Thermal energy storage system integration forms for a sustainable future" (2016), the concepts of future energy storage systems. [10]. From the work done by Alessandro Franco et. al, "Optimal design of binary cycle power plants for water-dominated, medium-temperature geothermal fields", the design of binary cycle for discharging system [11]. From the study by Hasanuzzaman, M, et. al (2017), "Global electricity demand, generation, grid system, and renewable energy polices", the data denoting global energy demand collected. From the insight of Albers, et. al (2008) "High-Temperature Properties of Nuclear Graphite", the characteristics of graphite under elevated temperatures is noted [13]. From the work by Yu Zhiwu, et.al (2005) "Experimental research on the mechanical properties of steel after high temperature", The properties of steel under elevated temperature is noted [14].

3. METHODOLOGY

The data that are used for optimizing the parameters and research works has been collected from various sources such as from research papers and other statistical data available from trusted websites and govt: bodies. The collected data are optimized on the Ansys software and all the simulations are done in the Ansys software.

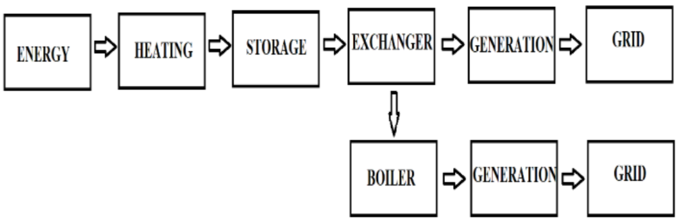

Fig -1: Block diagram of the proposed system

Figure 1 represents the block diagram of the system. During the off-peak hours, the energy is consumed from the grid, used to heat the cubical structure using an inductive heating coil and energy is stored as heat energy. Energy is retrieved back using binary cycle. The system contains 3 types of boilers at 1800, 1000, 200 degrees Celsius to increase the efficiency. The turbine will rotate the alternator and there by electricity is generated and supplied after meeting grid parameters.

The proposed system has a cubical structure with a size of 3650 milli meter. The cube is surrounded with a layer of vacuum of thickness 500 MM which is made of polyurethane and then one more layer of vacuum of thickness 500 MM. The cube is a mix of both steel and graphite. The steel sections are cylindrical in shape and having 100 MM diameter and 100 MM length. There is a gap of 50 MM between two steel sections. The gap is filled with graphite. There is a distance of 325 MM from both sides of wall of the cube. All the data are optimized for solar photovoltaics in which adequate lighting for 8 hours is available. The losses are optimized for 24 hours. The cube consists of 26392784 nodes and 70594499 elements. The simulation is done for 1000000 iterations. The simulation is done at 0.01 pascal pressure condition to satisfy the vacuum condition. The element size is given as 0.01 to get better results. The simulation is done for 24 hours.

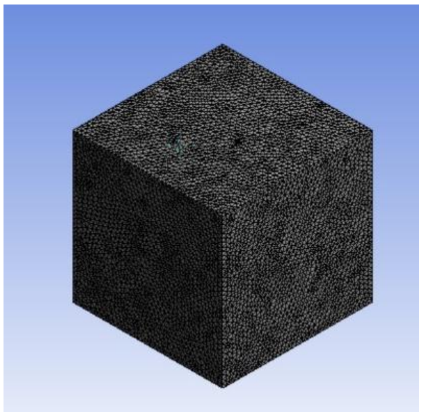

Fig -2: Geometry of thermal energy storage system

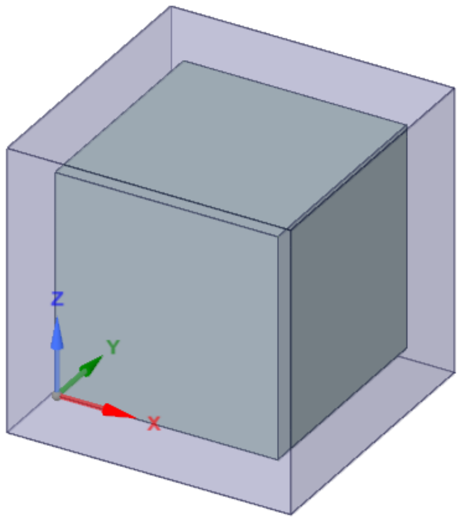

Fig -3: Enclosure of thermal energy storage system

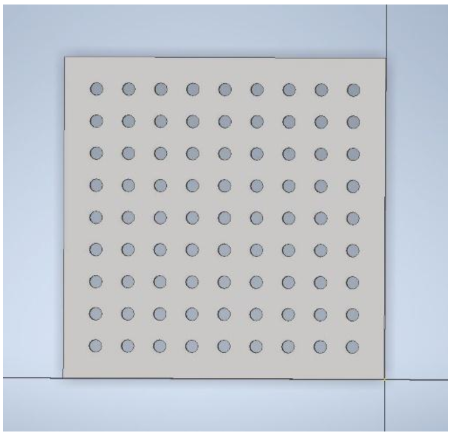

Fig -4: Cross-section of thermal energy storage system

Parameters	Values
Temperature(K)	1813
Internal emissivity	0.625
Wall thickness(mm)	500
Heat generation rate(W/m3)	140.04
External emissivity	0.75
Heat transfer coefficient(W/m2-K)	200
Free stream temperature(K)	300

3.1 Heating System

The system heated and steel sections are bringdown to its molten state for the energy storage. The steel sections can be melted down at 1538 degree Celsius. The graphite layer over the steel sections will prevent the flow of molten steel from its mold to surroundings. The heat is given through induction heating.

The depth of penetration of magnetic field can be obtained by

$$D = \sqrt{\frac{\rho}{\pi f \mu}} \quad (1)$$

The power transferred to steel sections can be obtained by the formula

$$P_w = (N \cdot 1 \cdot K_c)^2 \cdot \frac{\pi \cdot d \cdot \rho}{\delta \cdot L} \cdot Q_{rod} \text{ (Watt)} \quad (2)$$

The picture of the coil has given below

Fig -5: Cross-section of heating coil

The coil has outer diameter of 3.65 meter which is located in the 4 faces of the cubical structure.

3.2 Storage System

The energy thus stored in the form of heat need to be retained for over a course of 24 hours. A thick layer of 10 MM of vacuum is provided in between the outer wall and the cube. The vacuum will insulate the cube with the outside world resulting longer retentivity of the heat with minimum loss. The only heat loss is due to the radiation which can accounted as following.

$$Q = \varepsilon\sigma A(T1^4 - T2^4) \quad (3)$$

3.4 Discharge System

Once the structure is energized and stored via vacuum insulation, The energy will get discharged as needed to deliver the power requirement during the off-peak hours when there is no or least supply and demand is high. The discharging is done by using binary cycle. The binary cycle uses the mercury as the working fluid to retrieve the heat energy to convert the energy into electricity.

Heat Exchanger Effectiveness Equation: This equation describes the effectiveness of the heat exchanger used to transfer heat from the geothermal fluid to the working fluid. It is given by:

$$\varepsilon = (T1 - T2) / (T1 - T3) \quad (4)$$

Net Power Output Equation: This equation describes the net power output of the power plant. It is given by:

$$Wnet = (m2 * (h2 - h4)) - (m1 * (h1 - h3)) \quad (5)$$

Heat Input Equation: This equation describes the heat input from the geothermal fluid. It is given by:

$$Q_{cube} = m1 * (h1 - h3) \quad (6)$$

Thermal Efficiency Equation: This equation describes the thermal efficiency of the power plant, which is the ratio of the net power output to the heat input from the geothermal fluid. It is given by:

$$\eta th = Wnet / Qcube \qquad (7)$$

3.RESULT

All the simulations have been done in Ansys software. The system is heated towards 1538 degree Celsius. The radiation from the cubical structure over a course of 24 hours is noted. The temperature retentivity over a time period of 24 hours is noted. Pressure loss in the cabin which is made vacuum is also noted. The temperature of internal, enclosure, also the vacuum space is also noted. The obtained results are given below.

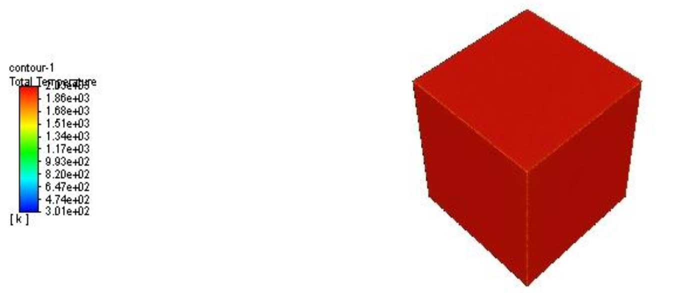

Fig -5: Temperature contour of the inner cube, the temperature thus simulated is 1800 Kelvin.

Figure 5 shows the simulated result shows the state of the cube after the heating process is done. The cube is heated up to the melting point of the steel ie: 1811 K.

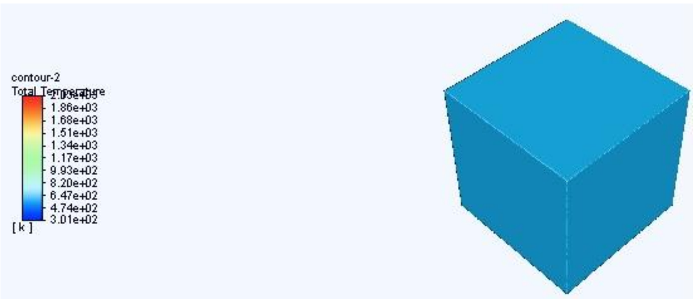

Fig -6: Temperature contour of the outside cubical structure, the simulated temperature is 573 Kelvin.

Figure 6 shows the simulated result shows the temperature outside the temperature the structure after the two-stage insulation of vacuum and poly urethane.

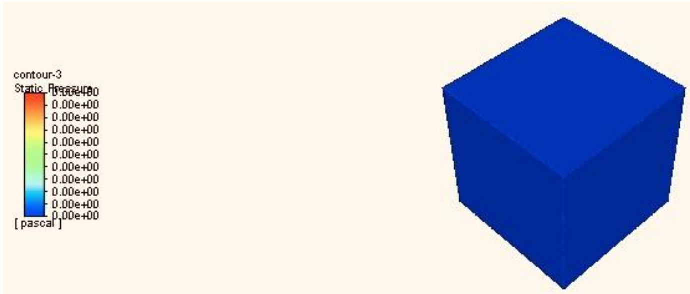

Fig -7: The contour mapping of pressure over the vacuum space.

Figure 7 shows the simulated result shows, The pressure consistency of the structure under operation, as the structure is able to maintain the initial condition given.

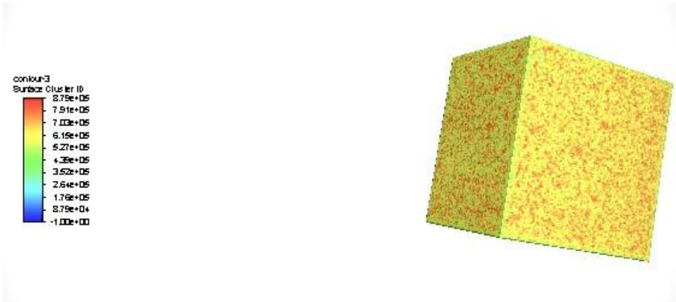

Fig -8: Contour mapping of radiation coming out from the surface of the cube.

Figure 8 shows the radiation coming out from the cubical structure after the heating is done. The radiation coming out is not uniform and it resembles the iron pellets placed in it.

All the contour mappings are given above. The following graph will give the behavior of the proposed system over time.

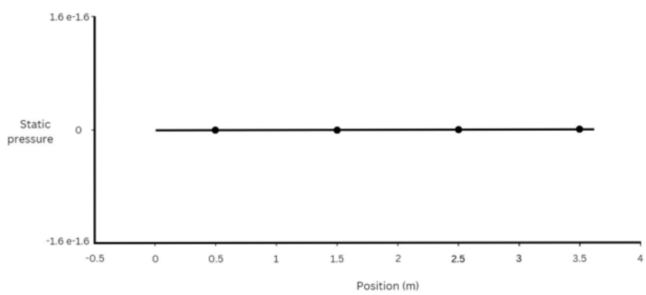

Chart -1: Pressure vs Position.

From the chart 1, the obtained result is there is no increase in pressure over the positions. The pressure is uniform everywhere which ensures the complete vacuum over the intermediate system which ensures the minimal loss of heat due to radiation and also no heat transfer rather than radiation.

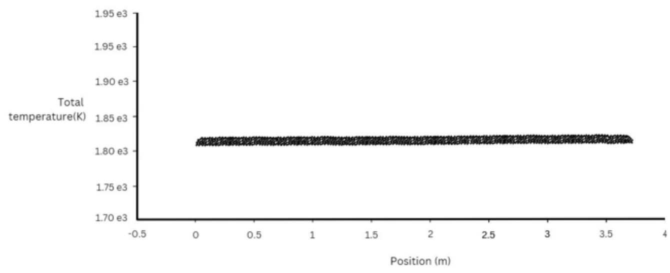

Chart -2: Temperature vs Position

From the chart 2, temperature vs position will give how the cube is getting energized with the inductive coil. The heat is distributed uniformly all over the cube over the dimension of 3650 milli meter.

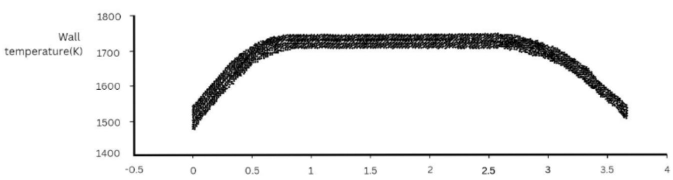

Chart -3: Wall Temperature vs Position

From the chart 3, wall temperature vs position which gives the result of temperature retentivity over a course of 24 hour. There is a drop in temperature in the corners due to radiative losses. The radiative losses are more prone to corner or the sharp edges.

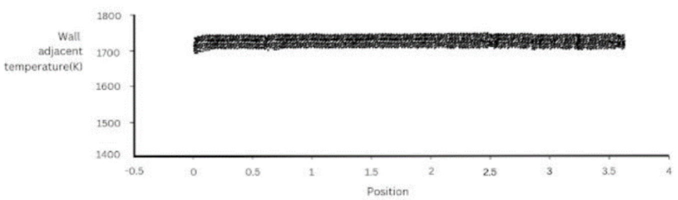

Chart -4: Wall adjacent temperature vs Position

From the chart 4, the outside wall temperature which is almost constant after 24 hours which ensures the energy retentivity of the system which ensures the efficiency of the system.

The results obtained after the simulations are very satisfying. The proposed thermal energy storage system is holding the energy without much losses under laboratory condition as given in simulation.

CONCLUSION

The proposed system can be an alternative for the energy storage in the grid application as an alternative to the Li-ion batteries which are in the market as of current standard. The proposed system could hold the temperature and heat energy stored for over 24 hours without much losses and could deliver maximum output or the heat from the cube to the binary cycle system and then to the steam cycle system where which the energy is extracted. As the system proposed to practice in a coal power plant with in built setups such as boiler, cooling tower, turbine, generator and connection to the grid, the proposed system will give an employment to the people who are working in this field and for people who are losing their job in this field due to the green concept.

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