SOLAR THERMAL ENERGY STORAGE SYSTEM: ITS NEED AND CHALLENGES

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Abstract - The progression of energy supply always faces some difficulties as the demand for energy always remains higher than production. Energy from conventional sources leads to global warming, whereas energy from non-conventional sources is occasional. Solar energy is the prime source of renewable energy and it requires use of storage medium. The storage medium stores energy when it is available in full excess and delivers stored energy when supply is inadequate or when direct sunlight is not available. Thermal energy storage system plays an important role to achieve high efficiency and uninterrupted operation. The paper deals with scope of thermal energy storage system and different techniques of storing solar thermal energy. This article is expected to explore current trends, opportunities, needs and challenges in solar thermal energy storage systems.

Keywords - Concentrated solar power (CSP), thermal energy storage (TES), sensible heat storage, phase change storage (PCM), thermo-chemical storage, Heat transfer fluid (HTF)

Nomenclature

\( A_m \) fraction melted
\( A_r \) fraction reacted
\( C_p \) specific heat (J/Kg K)
\( C_{lp} \) average specific heat between \( T_m \) and \( T_f \) (J/kg K) dt
\( m \) mass of heat storage medium (kg)
\( Q \) quantity of heat stored (J)
\( T_f \) final temperature (°C)
\( T_i \) initial temperature (°C)
\( T_m \) melting temperature (°C)
\( \Delta h_m \) heat of fusion per unit mass (J/kg)
\( \Delta h_r \) endothermic heat of reaction

I. INTRODUCTION

The \( CO_2 \) emissions are considered responsible of the climate changes of the earth. As the emissions are produced also by burning the fossil fuels to produce electrical energy, many countries in the world are transforming their national electrical production systems from fossil fuels to renewable energy sources. Solar energy is the prime source of renewable energy. Solar power systems can be divided into two major types: direct and indirect solar power. The direct solar power converts solar radiation directly to electricity using a photovoltaic (PV) cell. The indirect solar power converts the solar energy first to heat and then to electrical energy, as in the case of concentrated solar power (CSP). CSP technology can be further divided into two categories: solar collectors concentrate the sun rays along a focal line or on a single focal point. Focal line systems is the single-axis tracking system eg. parabolic trough and linear Fresnel plants. Solar dish & solar tower plant are point focus systems and both having two-axis tracking system to concentrate the power of sun as shown in fig 1.
II. THERMAL ENERGY STORAGE IN CSP PLANT

Concentrating Solar Power (CSP) technology is now acquiring an increasing interest, especially if built with thermal energy storage (TES). TES system is a subsystem of solar power plant to store and convert the concentrated energy into electricity generation. TES technologies are generally divided into two types: direct thermal storage and indirect thermal storage. In direct method, the heat transfer fluid is the storage medium, while in indirect method a storage medium is different than the transferring fluid. The difference between direct and indirect storage system is determined according to the location of the thermal storage tank according to the medium and transfer material. Fig. 2 shows types of TES techniques for CSP plant. They are divided into three main categories: a) sensible b) latent c) thermo chemical storage.

2.1 Sensible Energy Storage

Specific heat capacity of the material is utilized to store the thermal energy in sensible heat storage system. Sensible heat storage occurs both in solid and liquid state, where the material does not go under any phase transformation in charging or discharging cycles and the temperature of material is not remaining constant. The amount of energy stored using sensible heat is given by:

$$Q = \int_{t_i}^{t_f} m c_p \, dt = m c_p (T_f - T_i)$$

From the above expression it is clear that the amount of thermal energy stored depends upon amount of the storage material, specific heat of the medium and difference between the changes in
temperature from initial to final stage. The effectiveness of TES system depends on the thermophysical properties of the storage material like its melting and freezing points, conductivity, enthalpies of fusion or reaction, density, viscosity. Storage material used can be molten salt, concrete thermocline or packed bed thermocline. Molten salt is a mixture of NaNO₃ and KNO₃. This fluid remains in liquid state during both charging and discharging states. Drawback of molten salt is relatively low stored energy density; due to this it requires large insulated storage vessels.

2.2 Latent heat storage (Phase change materials)

PCMs have both latent and sensible enthalpies which contribute to the stored energy density. It is the most compatible storage system for CSP technology because the thermal energy delivered is isothermal. The method by which energy has been stored is based on the latent heat of fusion of the material (material may be organic or inorganic). In this storage medium undergoes a phase transformation. During this transformation temperature remains constant and the energy stored in latent heat storage medium is given by:

\[ Q = \int_{t_i}^{t_f} mC_p \, dt + \int_{T_m}^{T_f} mC_p \, dt + ma_m \Delta h_m \]

\[ = m[C_{sp}(T_m-T_i) + a_m \Delta h_m + c_p(T_f-T_m)] \]

Disadvantage of this storage system is these phase change materials suffer during the discharge process due to low thermal conductivity of the solid phase. This results in lower power density for PCM systems.

2.3 Thermo chemical Storage

This type of storage system offers highest volumetric stored energy density compared to any other thermal energy storage system. In thermo chemical storage systems, solar energy is absorbed by a forward reaction, A→B, where B is the reaction product which preheats the reactant A, and is stored at ambient temperature. The thermal energy is recovered by the reverse reaction. Thus A & B can be stored at ambient temperature and these approaches to long term storage. But the reverse

Fig 3. Schematic of parabolic trough power plant with 2-tank, molten salt thermal storage [8]
reaction should occur approximately at the same temperature as to the temperature of forward reaction. Also the losses due to pumping, compressing reactants and products need to be minimized.

![Fig.4 Schematic of generalized thermo-chemical storage cycle for CSP technologies][1]

This storage offers greatest benefit due to large quantity of heat energy can be stored which is available due to chemical reaction. But the practical implementation of this system is limited by loss of system performance due to many char/discharge cycles. Also system performance depends upon physical and chemical properties of the chemical components and of any solid-phase materials used over many cycles. Some cycles may require the handling of gas-phase reactants. As the time passes, degradation of these material properties results reducing system heat transfer rate and storage capacity.

### III. NEEDS & CHALLENGES OF THE ENERGY STORAGE SYSTEM

Several needs were identified relating to systems and components for the heat-transfer fluid. Eliminating the heat exchanger between either the HTF and storage fluid or HTF and working fluid reduces capital cost and energy losses. The air-Baryon power cycle, means for efficient heat transfer between the air and storage medium need to be modeled and developed. New alloys need to be developed that are inexpensive, strong at high temperatures, and compatible with potential heat-transfer fluids. These also include need for integrated system to define costs, requirement and need of various fluids and components within an operating power plant. Laboratories to be developed for high temperature materials and characterized methods for high temperature fluids.

For phase-change storage, it is particularly important to develop new materials with high thermal conductivity to improve heat-transfer rates upon discharging (freezing) of the PCM. Fully integrated system modeling is essential to determine the specifications and performance for PCM storage because its behavior is more complex than that of sensiblestorage systems. Of specific interest is the need to develop better model for heat transfer between the heat transfer fluid and PCM in complex geometries. New approaches must be found to overcome the losses due to build up of solid phase at heat-exchange surfaces. Encapsulation of phase-change media at scales from nano to macro must be developed to improve heat transfer and construction of a cascade of PCMs that cover the operating range of the power cycle. High-temperature materials characterization is also essential for PCM.

Thermo chemical cycles in the temperature range of 600°C -1000°C is a challenge to integrate into CSP technologies where power plant operation is subjected to frequent start up and shut down. Further due to thermo chemicals reactions in CSP systems receivers that required are quite different than current receivers which have HTF flowing through them. Thermo chemical cycle that need to be unaffected by the variable energy input and should meet requirement for both generating electricity and high efficient storage system.
IV. CONCLUSION

In this article, an overview of solar thermal energy storage techniques, its needs & challenges has been outlined. The present study concludes that, in CSP technologies thermal energy storage will be an important component of next-generation power plants because these plants will need to deliver reliable, consistent power during daylight hours and into the evening. Meeting the cost target will require significant performance improvements and cost reductions for all components and subsystems that make up a CSP plant. With respect to TES, major challenges are to design heat exchangers with sufficient heat energy flow from the storage system. New heat-transfer fluids and storage materials required that are stable at high temperature and have high stored energy density due to high heat capacities and/or multiple phase changes. Study in this direction will help the researchers to explore new design concepts & methodologies of solar thermal energy storage techniques.

V. RESEARCH AREAS IN THERMAL ENERGY STORAGE

Thermal energy storage technique has tremendous scope for further research to have better efficiency of concentrated solar power plants.

5.1 Heat-transfer fluids
- Use of particles that absorb direct solar radiation. Such particles can be used for TES.
- Develop a fluid which has improved radiative properties (single heat-transfer). This includes fluid type like liquid metals (Na, Al/Sn), nitrogen gases, high-temperature non-nitrate salts, ionic liquids, etc. From these liquid Na has been studied for nuclear power plant, so that may be applicable to CSP also.
- Characteristics of nano fluids are important to study to add nano particles into heat transfer fluids.
- Hydrogen permeation can be prevented by developing barrier coatings to evaluate variations of the HTF for Brayton systems which includes air, liquid, helium or particles.

5.2 Sensible energy storage
- Develop some additives into molten salt that lower down its freezing point near to ambient temperature.
- Develop protective coatings for potentially corrosive storage fluids with lower-cost wall materials.
- Develop new materials for storage application at high temperature. These includes inter-metallic materials, nano fluids, high temperature materials derived from natural sources like cement, rocks, sand, lava, etc.

5.3 Latent heat storage (Phase change materials)
- Investigation of metal alloy PCMs is needed to develop materials or composites with higher thermal conductivity in solid state.
- Methods to develop micro or nano sized phase change materials which is needed to reduce heat-transfer losses occur during charging & discharging of the storage material.

5.4 Thermo chemical Storage
- Identification and development of new cycles for solar thermal storage which required general capability that 1) consider kinetics, thermodynamics heat recovery, byproducts, etc. 2) models software for high level chemical process in chemical storage cycles.

REFERENCES

I. G. Glatzmaier May 20, 2011," New Concepts and Materials for Thermal Energy Storage and Heat-Transfer Fluids", Summary Report for Concentrating Solar Power Thermal Storage Workshop
II. Chu, Y., & Meisen, P. (2011),"Review and comparison of different solar energy technologies", Global Energy Network Institute (GENI), San Diego, CA.
III. Sharma A., Tyagi V.V., Chen C.R. and Buddhi D (2009),” Review on thermal energy storage with phase change materials and applications”. Renewable and Sustainable Energy Reviews 13, 318–345.
IV. Wang, Ucilia, "The Rise of Concentrating Solar Thermal Power", Renewable Energy World, July 6, 2011.

V. TransWorld News “Concentrating Solar Power Systems: Market Shares, Strategies, and forecasts, Worldwide, 2011 to 2017,” September, 2011.

VI. S. Kurtz, Technical Report, “Opportunities and Challenges for Development of a Mature Concentrating Photovoltaic Power Industry”, NREL/TP-520-43208 Revised November 2009.

VII. Luigi Cirocco , Martin Belusko , Frank Bruno , John Boland , Peter Pudney “Optimization of Storage for Concentrated Solar Power Plants” mdpi, Challenges Jornal, Vol. 5, pp. 473-503, 2014.

VIII. Menendez, R.P.; Martinez, J.A. A Novel Modeling of Molten-Salt Heat Storage Systems in Thermal Solar Power Plants. Energies 2014, 7, pp.6721-6740.

IX. L. F. Cabeza, C. Sole, A. Castell, E. Oro and A. Gil, "Review of Solar Thermal Storage Techniques and Associated Heat Transfer Technologies," in Proceedings of the IEEE, vol. 100, no. 2, pp. 525-538, Feb. 2012.

X. R. Sioshansi and P. Denholm, “The Value of Concentrating Solar Power and Thermal Energy Storage," in IEEE Transactions on Sustainable Energy, vol. 1, no. 3, pp. 173-183, Oct. 2010.

XI. F. Wei et al., "A Novel Thermal Energy Storage System in Smart Building Based on Phase Change Material," in IEEE Transactions on Smart Grid, vol. 10, no. 3, pp. 2846-2857, May 2019.

XII. C. C. Sorrell, T. C. Palmer, L. J. Bowen and A. Nakaruk, "Solar-thermal energy conversion and storage: Conductive heat transfer using bulk graphite," 2009 International Conference on Applied Superconductivity and Electromagnetic Devices, Chengdu, 2009, pp. 197-200.

XIII. F. Bruno, W.Y. Saman, M. Liu, “Concentrated solar power generation and high temperature energy storage. In Creating Sustainable Communities in a Changing World” Roetman, P.E.J.; Daniels, C.B., Eds.; Crawford House Publishing: Belair, Australia; Book 18, pp. 159–170, 2011.

XIV. Zohreh Ravaghi-Ardebili, Flavio Manenti, Nadson M. N. Lima, and Lamia Zuniga Linan “Study of Direct Thermal Energy Storage Technologies for Effectiveness of Concentrating Solar Power Plants” AIDIC, Chemical Engineering Transactions, Vol. 32, pp. 1219-1224, 2013.

XVI. Purohit, I., & Purohit, P. (2010). Techno-economic evaluation of concentrating solar power generation in India. Energy policy, 38(6), 3015-3029.