Accumulating thermal energy and conversion into electrical energy

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***Abstract*—The rapidly change of climate is a problem we need to solve as fast as we can. Small step can to be installing Photovoltaics and Wind Power Plants (PVPP/WPP) into electricity power generation mix, they are cheap, easy to install, low cost for maintenance and with around 150 kg CO_2/MWh [x] combined with adequate Energy Storage (ES) with low or none carbon emissions can be gamechanger with war against CO_2 and climate change. The biggest challenge with PVPP and WPP Plants implementation to electricity mix is variability of generation output witch depends from the primary source (especially wind, solar and water) when they are unavailable back-up power is required to fast respond to the grid needs (active and reactive power, frequency response etc.). The renewable energy recourse had unpredictable and fluctuating power output and the overall effectiveness of the system depends from their adequate energy storage otherwise the PP must be curtailed. Even more, the PVPP and WPP will never achieve their full potential and be able to replace the convectional power plants**

Keywords* — *(Thermal energy, Accumulating electrical energy)

I. INTRODUCTION OF THERMAL ENERGY STORAGE

Thermal energy storage is single form of energy storage that is used and developed from centuries. There are many different applications and study cases that researchers work to develop this type of energy storage to be more and more attractive nowadays and the main reason is long duration energy storage is needed. Some countries are in advanced stage and even install pilot projects which used for hot water for domestic or public usage [5]. Some heat storage materials are with low or even non carbon emissions and help energy transition to be sustainable, affordable and with inclusive low cost. Even more, TES can help to balance energy load demand and supply on a daily, weekly or even seasonal basis, presented in thermal storage systems. TES can also reduce load profiles peak demand, energy consumption and costs and overall efficiency of renewable power plants [Dinçer, 2011]. In this case the Thermal Energy Storage System (TESS) will be targeting the weekly-monthly generating load profiles basis, with peak shaving curve characteristics or fixed output can be some of the scenarios that can be used with large capacity energy storage system.

Accumulate the energy in storage can be many different materials depending of the specific of the project. We can see different materials and their classification [7] by the status of the energy storage material. According to the way heat is stored in thermal energy the classification is as following:

- Sensible heat – solids and liquids
- Latent heat – solid-liquid, liquid-gas, solid-gas
- Chemical heat – liquid-gas, gas-gas, solid-gas

Water from liquids is with very good thermal properties and better from solids with surface contact and heat transfer. But the low temperature make water good for low temperature projects. In this case we need as high as can heat for higher thermal energy storage capacity per kg. The water cannot meet this requirement because start to boil and change condition from liquid to gas.

The different state determinate the classifications on their main three states of the heat storage material. As simple as possible solution is the target and to achieve this Sensible heat storage materials are suitable for main the reason, no change of state or phase of the material, this can help to install in almost everywhere and with combination of low cost accumulating material can help for the fast energy transition.

From solids the sand is with good thermal properties and large amount of the global resources on the Earth. Sand is perspective of large The working temperature can be used in wide application of TESS, for heating, cooling or energy generation and the its temperature is far higher the An the water working temperature. But the other equipment still need to meet the specific temperature requirements because high sand temperature can melt it. For this reason in this case the working temperature is reduced from the melting point of the solid agent, sand to avoid phase and/or phase.

The main ingredient of the Thermal Storage Unit is foresees to be sand. The sand is composed granular of finely divided minerals particles with good thermal properties and relatively low specific heat of 830 J/kg ºC [4], and thermal conductivity 0.25 W/(m.K) [6] and the melting point is about 1573ºC [x]. The working temperature can depends from the specific needs for the project. The heat capacity can be stored for moth in Thermal Storage Unit with 2% heat loss for 30 days period according study [7].

II. CONEPT OVERVIEW

The TESS concept is to store energy into heat and discharge it to demand with heat transfer from storage material to the energy carrier fluid. In this case the storage material is sand and heat is transferred from high temperature unit that converting water into steam. Steam tube and pipes are connected in steam turbine, the turbine shaft is connected to electrical generator rotor which convert the mechanical rotating force to electrical energy. From turbine the low pressure low temperature steam is trapped in condenser to change phase of the material in to liquid. This is usually made to remove the steam from the liquid (higher efficiency) to boost pressure with high pressure water pump and repeat the cycle. In this purpose can be approaches with high pressure Rankine vapor cycle for producing useful work.

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In this chapter the basic concept principles and equations will be considered for basic purposes for the case study to theoretically analysis overall effectiveness of the system.

III. THERMAL CAPACITY

. For With the following (1), express the basic equation of Sensible heat storage materials is:

$$Q = \int_{T_1}^{T_2} m \cdot c_p \cdot \Delta T \quad (1)$$

Where Q is work in Joules/s, ΔT is the temperature difference form lower to higher value at charging phase, m is the mass of the material, $C_p$is the specific heat capacity of the material, work per kg for degree. With (1), we can calculate the total energy stored in the material. If the temperature is negligibly low, we can use the following expression:

$$Q = m \cdot C_p' \cdot \Delta T = m \cdot c_p' \cdot (T_2 - T_1) \quad (2)$$

The $C_p{}'$ is function of the temperature and we can use (2), to calculate the total average thermal energy stored. Where C_p' is the specific heat capacity of the material of average value, T_2 and T_1 is the higher and lower index of temperature.

Theoretically, the phase change material has a phase change point when the phase transition happens, but in practice this happens in curtain temperature range instead of one exact point. The specific heat capacity C_p is function of enthalpy and the temperature:

$$c_p(T) = \frac{dh(T)}{dT} \quad (4)$$

From (1), and (2), we can calculate the total power that can be stored in thermal storage unit material per kg.

IV. HEATER AMPACITY

The heaters are needed to charge the thermal storage material from curtain value to another. Depending of the process this can be implement in many different ways. In this case requirements for the heaters must be as following:

- High thermal resistance and durability
- Low cost
- Easy for operate process

Graphizied heater rods used in electric-arc furnace are with high thermal resistance, low cost and easy for implement in many different thermal processes. For this study purposes we can calculate the diameter of the heating electrode:

$$d = \sqrt[3]{\frac{0.406 \, . I^2 . \delta}{K}} \quad (4)$$

Where I is the linear current in Amperes, δ is electrode resistivity and K is specific load per surface. Current can be found from following (5):

$$I = \frac{Prod}{Vmax \, . \, \sqrt{3}} \quad (5)$$

Where $Prod$ is the active power of the heater, $Vmax$ is maximum voltage. The diameter of the resistive heater electrodes can be find also by the allowable current density (A/cm²). From (4) and (5), we can found the total active area of the heaters required and electrical power required.

V. DISCHARGING CAPACITY

Steam tubes have to transfer the heat flow from the storage material to fluid trough metal tube wall. The cycle is with constant pressure and the power flow will be regulated with expansion valves. This expansion valves must be designed for high pressure temperature purposes and with emergency stop of the TESU to prevent extreme high pressure in the tube systems. This can be calculated from Fourier's law of conduction in (6):

$$Q = k \, . A \, . \frac{\Delta T}{l} \quad (6)$$

Where k is thermal conductivity of the material, A is the heat transfer area, ΔT is the temperature difference across the material, l is thickness of the material. For the cross section the (6), can be transformed to have the following form:

$$A = k \, . \frac{\Delta T}{l.Q} \quad (7)$$

The cross section of the tubes can be take into account with sizing of the TESS sand tank. We know the cross section of the fluid tube and we can find the total energy that can be transferred if we know the speed of the fluid mass. Also must to be taken into account change in potential energy and change in kinetic energy for the output power plus the turbine heat loss from surroundings. The (8), will have the following form:

$$\Phi \, . P_{\mathrm{t}} = \frac{\Delta H}{s} \, . \frac{\Delta K\varepsilon}{s} \, . \frac{\Delta P_{\mathrm{t}}\varepsilon}{s} \quad (8)$$

Where Φ is turbine loss heat loss from surroundings, $\Delta K\varepsilon$ is the change of kinetic energy, ΔH is the change of enthalpy, $\Delta P_{\mathrm{t}}\varepsilon$ is change of potential energy, P_{t} is the thermal energy input.
Important here and must be taken into account is the change of kinetic and potential energy which also will be reflected to enthalpy and overall TESS performance. In the simulations models of thermal reactor must be considered and take account for the design stage. The simplified of (8), is (9) and we can use it when change of energy is negligible:

$$\Phi \, . P_{\mathrm{t}} = m \, . (h_{\mathrm{out}} - h_{\mathrm{in}}) \quad (9)$$

Equation (9), showing the total useful power to the output of the steam turbine, rotor can be connected to the shaft and can use the rotating energy to produce electricity with stable output while discharging from TESS and the delivered discharging energy can be stored from low cost energy (PVPP and WPP).

In this scenario with predominant renewable energy and long duration energy storage

The overall of the system efficiency of the system can be found from following (10):

$$\eta = \frac{P_e}{P_t} \tag{10}$$

From (10), can be find the total theoretically efficiency of the concept system. Subsequent publications will expand the different chapters for detailed check of the reliability of the following method.

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

REFERENCES

[1] S. Giullano, R. Buck, on "Analysis of Solar-Thermal Power Plants With Thermal Energy Storage and Solar-Hybrid Operation Strategy," article in Journal of Solar Energy Engineering, September 2010.

[2] Europian commision, decision at meeting in 2018.

[3] M. Filonchyk, M. Peterson on An integrated analysis of air pollution from US coal-fired power plants,

[4] G. Mellom M. Ferreira, M. Robaina, "Wind farms life cycle assessment review: CO2 emissions and climate change," in esearch Unit on Governance, Competitiveness and Public Policies (GOVCOPP), 14 November 2020.

[5] M. Diago, A. Iniesta, T. Delclosm T. Shamim, N. Calvet on "Characterization of desert sand for its feasible use as thermal energy", nstitute Center for Energy (iEnergy), Department of Mechanical and Materials Engineering, 2015.

[6] C. Surez, F.J. Pino, F. Rosa, J Guerra on "Heat loss from thermal energy storage ventilated tank foundations," AICIA, niversity of Seville, Avda, 2015.

[7] D. Snleckus "*https://www.rechargenews.com/energy-transition/logical-step-toward-combustion-free-heat-finns-launch-worlds-first-sand-based-energy-storage/2-1-1253027*".

[8] L. Applied Mathematics and Mechanics Vol. 55, Issue IV, 2012 The Technical Writer's Handbook. Mill Valley, Universitatea Tehnica Cluj-Napoca, 2012.