Available online at www.elixirpublishers.com (Elixir International Journal)

Renewable Energy

Elixir Renewable Energy 119 (2018) 51122-51125

ISSN: 2229-712X

Heat Accumulation System for Solar Power Station with Parabolic Trough Solar Collector

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ARTICLE INFO

Article history:

Received: 16 May 2018;

Received in revised form: 16 June 2018;

Accepted: 26 June 2018;

Keywords

Thermal storage system

Solar radiation

Parabolic trough solar collector

Heat transfer fluid

Thermal losses

Absorber.

ABSTRACT

The current work presents a theoretical study of the solar power plant with parabolic trough solar collector, the power generated from the solar power plant was calculated with using the thermal storage system without using such a system then comparison between the two cases. The calculations of the thermal storage system in terms of the size of the thermal tank and the temperature of the heat transfer fluid inside the thermal tank as well as its mass are implemented. The theoretical study are completed at Baghdad city (Long. of 44.25° East and Latit. of 33.19° North). The results were obtained by simulating the solar power station with parabolic troughs for both cases by using the thermal storage system and without it. During this work, some hypotheses were created to facilitate the solution of the system of equations for such plants. It was assumed that the specific heat of the heat transfer fluid in the tank of heat accumulation system was constant, It was calculated at the outlet temperature solar field for the heat transfer fluid, which was up to 390 °C, in addition to other hypotheses will be identified during the study steps. As a key to solving the issue was initially calculated direct solar radiation for Baghdad city and the result indicates that the frequency distribution of direct solar radiation was not more than 14% of the radiation values which less than 500 W/m^2. Thus, the results leads us to the inference that during the months of low temperature in a city such as Baghdad, don't need a large increase in the size of the solar field or keep the solar field as it is and use thermal storage system, be in our case with a small size which is therefore reflected that be a reasonable cost. The power generated from the solar power plant was also calculated for both cases without the use of thermal storage systems and with it, where the capacity of the solar power plant under study with a value of 50 MW, It is noted that the maximum value of the net power was achieved during some months of the year, especially in June, July and August. As for thermal storage, it is clear that the station is work for more than 20 hours during the day in June, July and August. Therefore, the results obtained in this study were compared with the results obtained from the Solar Advisor Model, which was implemented by the National Renewable Energy Laboratory in the United States of America. There was a reasonable consensus in the results, but it does not match exactly because the working conditions of both cases, the geographical position and the situation is completely different weather but remains the general behavior of the two stations is similar.

Introduction

Heat-storage devices are installed on solar power plants, which are characterized by some of the positive benefits of the most prominent: [1]:

1. Concentrated solar power plant using parabolic trough collectors, which include a thermal storage system, can be operated at times when heat collection from the sun ceases due to the absence of direct solar radiation because of clouds or at night time by using thermal energy previously stored in accumulation system of heat through the hours of daylight when direct solar radiation is obtainable, thus the collection of solar energy, as well as the supply of thermal energy, will not be simultaneous.
2. The potential disorders in the output can be independent and ineffective by isolating them from the input area of fluid of heat transfer to the collector of the solar field. Because the heat accumulation system acts like a good heat pillow and prevents feedback of perturbations affecting the output temperature of the working medium.

The second feature has special significance because it improves the performance of the solar field in the days when invisibility occurs in direct solar radiation due to the recurrence of the clouds.

Regardless of how effectively the solar field is controlled, the outlet heat transfer fluid temperature of the collector depends on the cloud transients, and thus its oscillations are possible [2, 3]. These fluctuations directly affect the working heat transfer fluid inlet temperature, if there is no heat storage system between them. Accumulation system of hot water to be applied for solar collectors with low temperature like as collectors type of flat plate is in appropriate for the systems that are used parabolic trough, the fact that the requirement to withstand the thermal tank for high pressure lead to a significant rise in prices [4, 5].

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For this cause, an oil heat transfer is used for collectors with parabolic troughs.

Depending on the operating environment in which the heat is stored, can be used one of two forms of accumulation systems [6, 7] with one or two type of heat transfer fluid. Obviously, the lowest temperature in heat storage should always be above the salt melting point (about 250 ° C) [8, 9, 10].

The heat energy is transferred by heat exchangers from industrial oil, which is the heat transfer fluid in the solar field to molten salt, which represents the storage medium in the thermal storage system. Figure 1 shows a simplified diagram of a solar power with parabolic troughs and a thermal energy accumulation system that is used the molten salt.

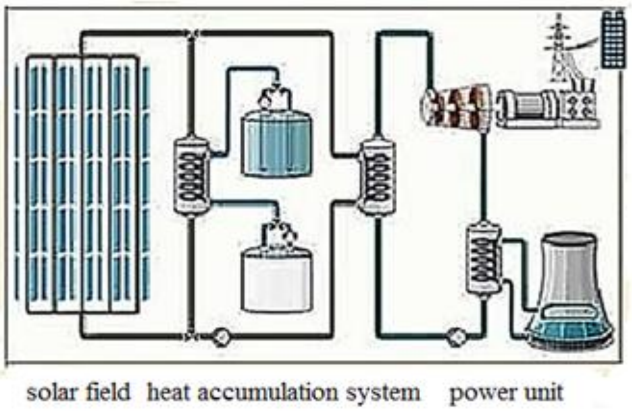

Figure 1. The scheme of a parabolic solar thermal power station.

Theoretical Study and mathematical model

Accumulation system of thermal energy, which contains two thermal reservoirs and used molten salt from more thermal storage systems appropriate and effective for solar power plants, which are used to produce electrical energy in a wide range. They are called commercial stations, which contain a solar field that extends over large tracts of land. The basic equation for calculating the accumulation system is as follows:

$$M_{res}C_{res}\frac{dT}{dt} = \dot{m}_{HTF}\, c_{HTF}\left(T_{in} - T_{out}\right) + UA_{loss}\left(T_{amb} - T_{in}\right) \qquad (1)$$

M_{res} - mass fluid for heat transfer in the reservoir, kg

C_{res} - Specific heat of working fluid in the reservoir, kJ/(kg K),

C_{HTF} - Specific heat of working fluid solar field, kJ / (kg K)

UA_{loss} - heat losses coefficient of the tank, kW/K

T_{in} - temperature of working fluid at the reservoir inlet, °C;

T_{out} - temperature of working fluid at the reservoir outlet, °C;

T_{amb} - ambient temperature, surrounding the tank, °C;

dT/dt - the variation of the average accumulation reservoir temperature with the time, °C/h.;

$\dot{m}_{HTF}$ - the rate of mass flow working fluid of solar field, kg/h.

It is assumed that the mass of fluid in the reservoir is immutable. The storage reservoir is sized to store the mass of heat transfer fluid which are equivalent to those in the solar field and the expansion tank. The mass of fluid in the tank is determined by the volume of the receiving heat collection tubes elements and the expansion tank, multiplied by the density at an initial temperature of working fluid at the solar field outlet.

Transforming the equation (1), we obtain:

$$M_{res} = \frac{\pi\left(D_{tub}\right)^2}{4} L_{loop} N_{loop} \rho\left(T_{out,init}\right) + V_{res}\rho\left(T_{out,init}\right) \qquad (2)$$

Where D_{tub} - the diameter of the tubes of the solar field, is assumed to be 70 mm;

L_{loop} - the length of the loop of one assembly of the solar collector, m;

N_{loop} - number of loops in the solar field;

ρ - the density of heat transfer fluid (VP-1 terminol), kg/m^3;

$T_{out,init}$ - the output temperature of the solar field in the initial state, T_{out} = 390 ° C;

V_{res} - volume of the expansion tank, V_{res} = 283m^3.

Results and Discussion

The mass of the working fluid in the tank is calculated by the formula (2) and is equal to 313000 kg. Note that equation (2) does not include the mass of the working fluid in the whole system, since it does not take into account the amount fluid of heat transfer in the heat exchangers, in the pipelines of the lines leading to the field and from the field. The specific heat of the fluid in the tank is assumed constant. Specific heat of fluid for heat transfer is estimated at the outlet temperature of the solar field in the initial state (390 ° C). Since heat losses in the fluid of heat transfer are taken into consideration heat losses in the solar field, the loss coefficient for the accumulation tank assumed to be zero (0 kW / K) [11, 12, 13]. As can be seen from Fig. 2, the frequency distribution for the direct solar radiation for the city of Baghdad (Iraq) shows that, its direct solar radiation below 500 W / m2 is approximately 13.7% of the entire time of year. This means that in order to increase the efficiency of the annual output of the solar field does not require a significant increase in the size of the field to compensate for the heat production in the months when the solar radiation is weak. In Baghdad, in comparison with other regions, throughout the year the radiation is longer (hence, a smaller size of the solar field is required). This is confirmed by Fig. 3 and 4, which shows a uniform average monthly net output power, for two cases (without the accumulation of heat and with it).

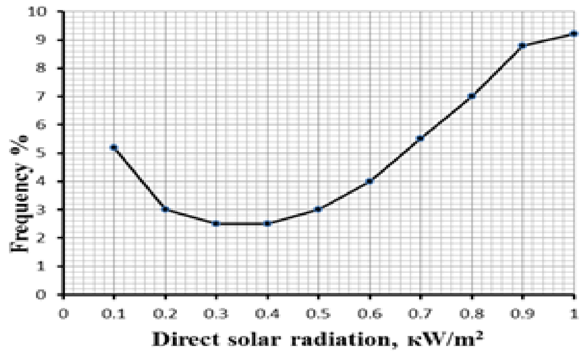

Figure 2. Frequency of direct solar radiation throughout the year.

To evaluate the results obtained in this paper, they were compared with the Solar Advisor Model, which is abbreviated by letters (SAM), this model progressed at the US National Renewable Energy Laboratory (NREL) [14, 15, 16].

In Fig. 5 shows the comparative results of calculations of two variants of power plants: the solar power station proposed by the author with heat accumulation and SAM USA. At the same time, values were determined: the cost of electricity, which was estimated for the real discount rate, and the annual useful power.The comparison results show that the characteristics of the proposed model correspond to the characteristics of the SAM, but there are some deviations. These deviations are due to the fact that in these cases, different assumptions were made in the simulation.

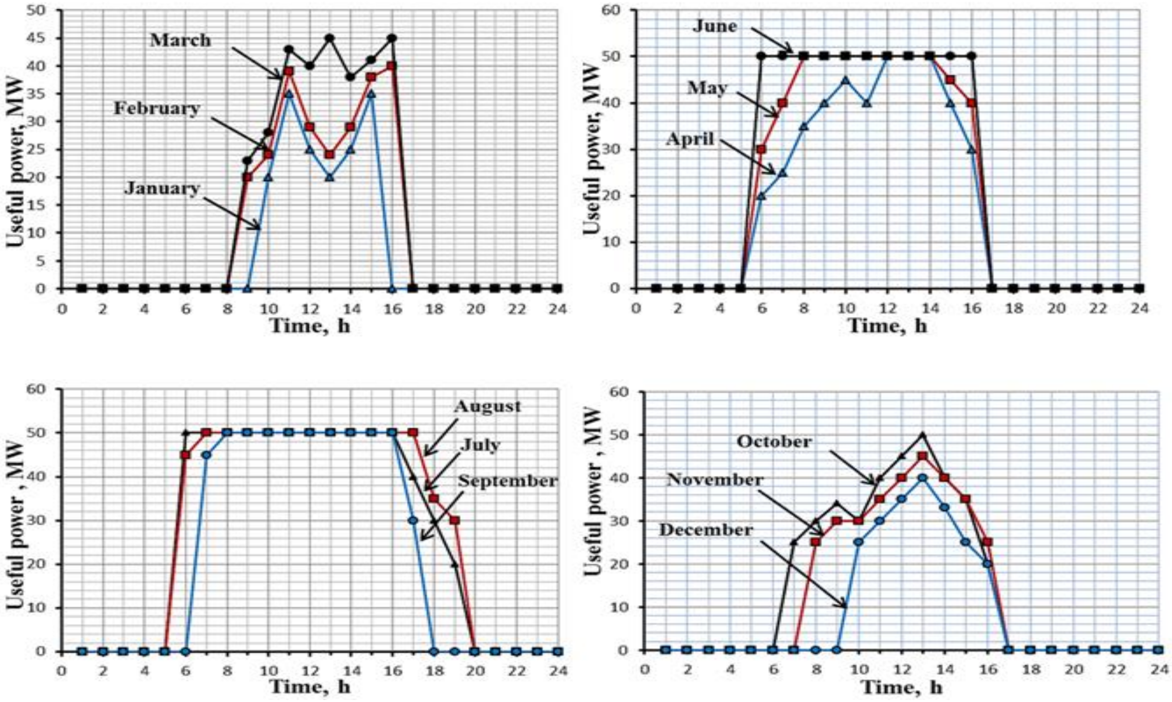

Figure 3. Monthly average distribution of useful power, calculated at the minimum cost of electricity, without accumulation of heat.

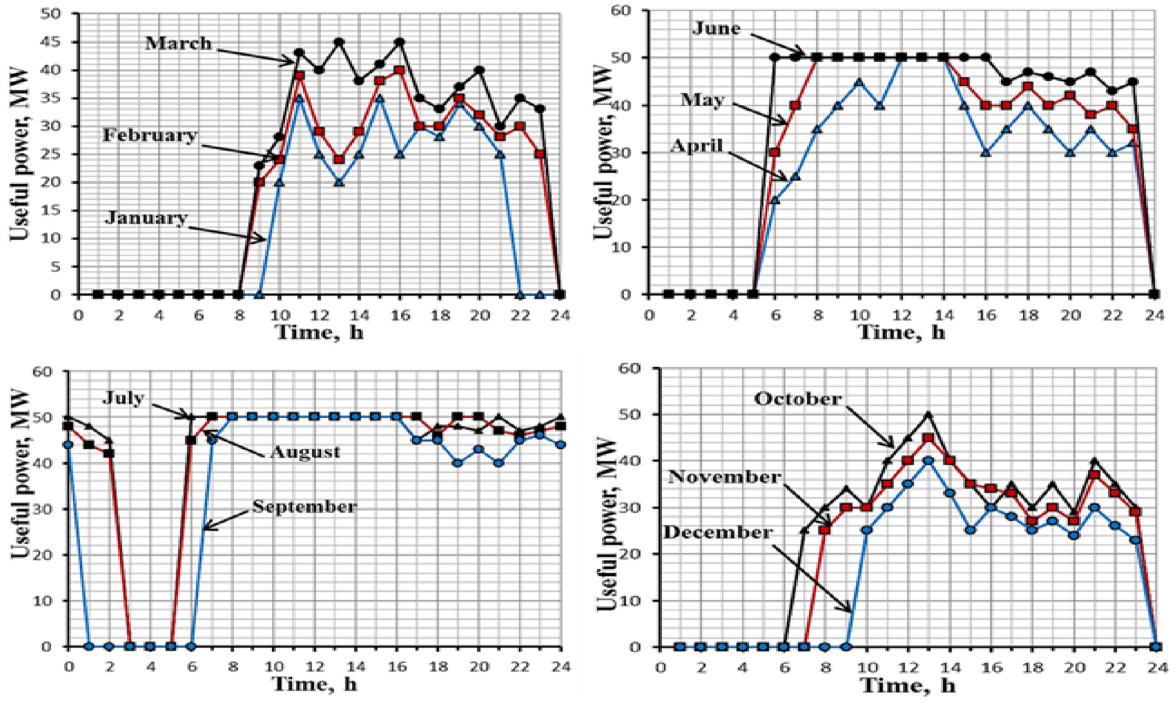

Figure 4. Monthly average distribution of useful power, calculated at the minimum cost of electricity, with the accumulation of heat.

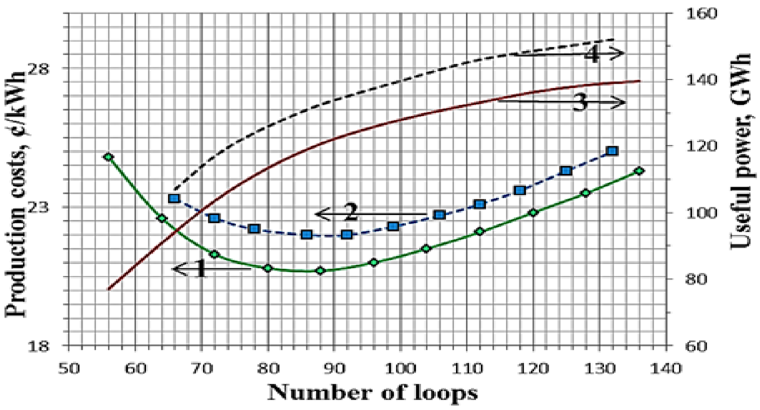

Figure 5. Comparison of production costs and annual useful power for the proposed model of the power plant and the System Advisor Model (SAM) [15]: 1 and 3 - for the proposed model; 2 and 4 - for the SAM model.

Conclusion

The proposed model is more conservative than the models developed by SAM, USA (NREL), this explains the fact that the received power in our version is less than the values obtained in the SAM variant. The real discount rate calculated by the proposed model is also lower than the values obtained in the SAM because of the difference in the annual cost of electricity, which is proportional to the useful annual capacity.

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