Simulation of central receiver solar thermal power plant with inclusion of storage tank.

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Abstract— **Mathematical modeling is done for the external central receiver solar thermal power plant. Code is developed for the same and simulation for performance of plant is done by using Visual Basic. In this plant configuration, external receiver receives the incident solar radiation reflected by heliostats. Thermal losses are determined in the receiver and net thermal power from receiver is stored in storage tank. This stored thermal energy is further used to run the turbine. Here effect of inclusion of storage tank on electrical power generation is studied by simulation. Three days namely, cloudy day, winter day and summer day are studied for variation in thermal energy storage. Simulation is also done for the annual power generation with zero hours, eight hours and twelve hours of storage. Comparison is made between effect of increase of concentration ratio and utilization of thermal energy in power plant.**

Keywords— simulation of power plant, thermal energy storage, molten salt, concentration ratio Introduction

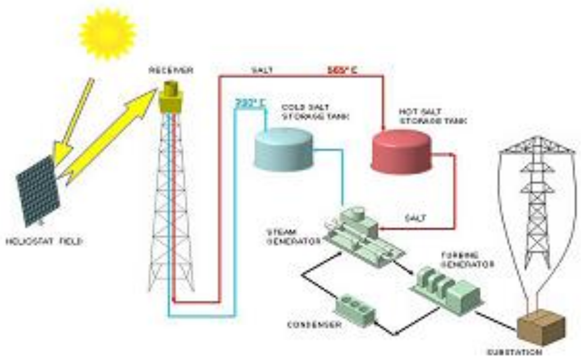

Fig. No.1 Central receiver solar thermal power plant with two tank storage

I. INTRODUCTION

A central receiver solar thermal power plant must satisfy the energy demand like any other power plant. The electrical output of a central receiver solar thermal power plant is affected by the variation in weather. It is unavailable in night and every time a shadow is cast on collection area, the power output is either reduced or plant stops operating. In order to cope with these fluctuations and to utilize the maximum solar radiation, system of thermal energy storage is required for smooth functioning of plant [5]. A thermal energy storage system can collect energy in order to shift its delivery to a later time or to smooth out the plant output during intermittently cloudy weather conditions. Hence, the operation of a solar thermal power plant can be extended beyond periods of no solar radiation without the need to burn fossil fuel. Times of mismatch between energy supply by the sun and energy demand can be reduced. All thermal power generated from the receiver is delivered to the thermal storage tank, provided the thermal storage tank can accept it (i.e. until the storage tank is full). The turbine operates, after a minimum amount of thermal power required to run the turbine is accumulated in the storage tank. The extra thermal energy remains in the storage tank. This process continues till the availability of sunshine hours. The stored thermal energy is used to run the plant after the sunshine hours. It is also used when the intermittently cloudy weather conditions occur during the daytime [7]

II. THERMAL ENERGY STORAGE

Two tank storage system namely one hot tank and one cold tank is used for storage of thermal energy. The storage fluid in the cold tank goes to the receiver, gets heated up to high temperatures and is stored in the hot tank as shown in Fig.1. Each tank is considered large enough to hold the entire charge of storage fluid [4]. The tanks are thermally insulated, therefore very less thermal energy loss takes place. Solar Two power plant had thermal energy loss of 180 kW for storage tank of 3 hours. Therefore, based on these results, it is expected that annual storage efficiency of the thermal storage tank is about 99% . Due to ideal thermal energy storage in two tank storage system, it is preferred for central receiver solar thermal power plants [8]. The use of thermal storage system depends on the daily and yearly variation of radiation and on the electricity demand profile. The storage systems used in solar thermal

Fig. 2 Storage tank for Solar Two power plant

power plants are relatively cheaper than other renewable energy sources such as photovoltaic and wind energy sources [1]. Fig 2 shows two storage used for Solar Two power plant.

The storage material used for thermal energy requires the following properties

- High energy density (per unit mass or per unit volume) is required in the storage material
- Good heat transfer between heat transfer fluid and the storage medium.
- Chemical compatibility between heat transfer fluid and storage medium.
- Chemical stability at high temperatures.

The solar central receiver power plants operate at high temperatures, therefore behavior of storage material at operating temperature becomes very important. Salts are being used in central receiver power plant because of their high mass and volumetric heat storage capabilities, their abudance in nature and their low cost per unit storage capability [6] Most of the salts have freezing point in the range of 250^{0}C to 265^{0}C and they remain liquid upto 450^{0}C to 565^{0}C. These are given as minimum and maximum temperature in Table No.1. These salts have low vapour pressure at high temperature and do not react with water/steam, therefore are not hazardous.

III. MODELLING AND SIMULATION

Mathematical modeling is done for the external central receiver solar thermal power plant. Code is developed for the same and simulation for performance of plant is done by using Visual Basic. In this plant configuration, external receiver receives the incident solar radiation reflected by heliostats. Thermal losses are determined in the receiver and net thermal power from receiver is stored in storage tank. This stored thermal energy is further used to run the turbine [2]. Here effect of inclusion of storage tank on electrical power generation is studied by simulation.

According to the India Meteorological Department (IMD), in India, solar radiation levels show the highest annual radiation received in Rajasthan. Latest year, for which the data is available is 2007. Therefore, hourly weather data for one of the cities of Rajasthan, Jaipur for the year 2007 obtained from the National Renewable Energy Laboratory (NREL, USA) is used for study [9]. Hourly weather data of solar radiation, ambient temperature and wind speed are taken as input for simulation. The plant capacity is taken as 10 MWe Receiver diameter as 9m and height 14m. Heat transfer fluid in receiver and in storage tank is Hitec. Here, the number of hours of storage is not specified as maximum possible storage is determined for the given plant configuration.

IV. THERMAL ENERGY STORAGE WITH VARIATION IN SOLAR INCIDENT FLUX

For this simulation, it is assumed that the storage tank is capable of absorbing all the incident energy. This assumption is made to find the maximum possible number of hours of plant run after sunshine hours. To study the effect of variation of incident solar radiation on storage, three random days of the year are selected for the simulation. One day is selected receiving an average amount of solar radiation as 767 W/m2 i.e. on 22/2/2007(summer day). The other day receiving the average amount of solar radiation (winter day) i.e. 21/11/2007 receiving 398 W/m2 is selected. The cloudy day of 25/7/2007 is also studied for intermittent clouds.

A. CLOUDY DAY

Weather data of jaipur obtained from NREL website shows that on 25th July 2007 the incident solar radiation increases after sunrise but at 11.00 a.m. it starts decreasing due to intermittent clouds till 1.00 p.m. and then again it starts increasing. Therefore this day is studied for intermittent clouds. In Fig.3, line shown by Pthreqd shows the minimum thermal energy required to run the turbine. The clouds appear between 12.00 noon to 2.00 p.m. During the period of clouds, solar radiation is not enough to produce the minimum required thermal energy and hence the plant cannot operate during clouds as shown in Fig 3. But if the same plant is equipped with a storage tank, excess thermal energy produced from 10.00 a.m. till 12.00 noon is stored and when the clouds affect the plant performance, the stored energy can be used to operate the plant from 12.00 noon to 2.00 p.m.

Thus it helps to operate the plant continuously. Further it is also seen that the plant stops operating after sunshine hours i.e. at 5.00 p.m. if there is no storage. But with the inclusion of storage, it stores the excess thermal energy from 2.00 p.m. till 5.00 p.m. and utilizes it to operate the plant after sunshine hours i.e. till 9.00 p.m. Therefore in total, in a day, storage helps to operate the plant for an extra 6 hours, 2 hours during clouds and 4 hours after sunshine.

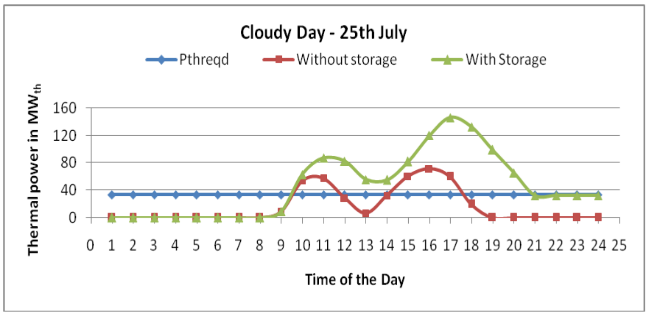

Fig.3 Thermal power produced by receiver over 24 hrs on a cloudy day – 25th July 2007

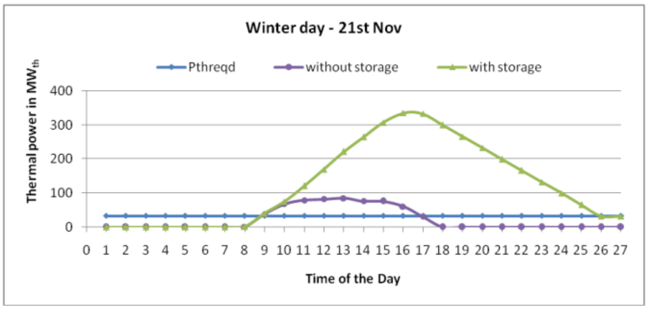

Fig. 4 Thermal power produced by receiver over 24 hrs on a winter day – 21st Nov 2007

B. WINTER DAY

A random day of winter season 21st Nov 2007 is selected for the study. Fig. 4 shows that the plant receives enough solar radiation to operate the plant for 8 hours i.e. from 9.00 a.m. till 5.00 p.m. without the storage tank. With the inclusion of storage of thermal energy, plant can operate for 9 hours after 5.00 p.m., thus in total, in a day for (8+9=) 17 hours

C. SUMMER DAY

A random day of summer season receiving abundant amount of solar radiation, 22nd February 2007 is selected for study. Fig. 5 shows that, without storage, the plant receives enough solar radiation to operate the plant for 9 hours i.e. from 9.00 a.m. till 6.00 p.m. With inclusion of storage of thermal energy, plant can operate for 16 hours after 6.00 p.m., thus in total, for (9+16=) 25 hours. It is observed that at the end of the day i.e at 12.00 in the night, thermal energy in the storage tank is 376.86 MWth. This thermal energy can be utilized to operate the plant for 10 hours of next day as shown in Fig 5.

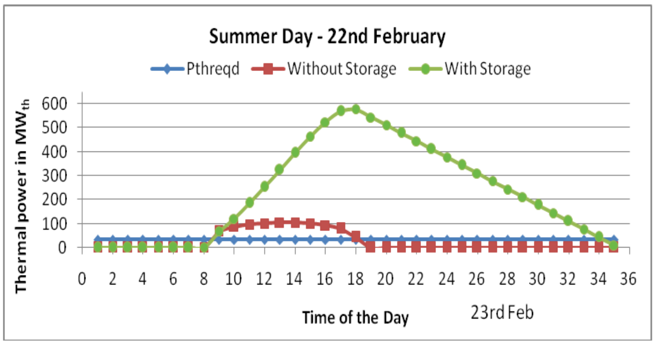

Fig. 5 Thermal power produced by receiver over 24 hrs on a summer day – 22nd Feb 2007

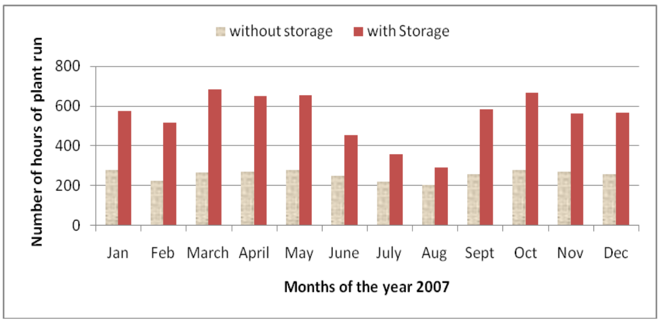

Fig. 6 Number of hours of plant run without and with storage in all months of 2007

V. EIGHT HOURS OF THERMAL ENERGY STORAGE

A storage hour is defined as the storage capacity necessary to run the power plant at rated output power for one hour. The amount of thermal energy required to run the plant is determined and excess thermal energy is stored in storage tank. For studying, the benefit of thermal energy storage, a storage tank with capacity of 8 hrs is considered. The amount of thermal energy required to run the plant for 8 hours is calculated. This amount is the maximum amount of thermal energy that can be stored in the storage tank. During the simulation, excess thermal energy is determined and is sent to the storage tank. When the storage tank is full, rest of the thermal energy produced is lost and wasted. These calculations are done for every given time interval i.e. every hour of the day. Depending upon the amount of thermal energy stored, number of hours for which the plant can run are determined and added together to find the total number of hours of plant run in a day. Fig.7 shows the total number of hours of plant run for every month. Similarly storage tank of capacity 10 hrs and 12 hrs are also considered separately and the values represented graphically in Fig.7.

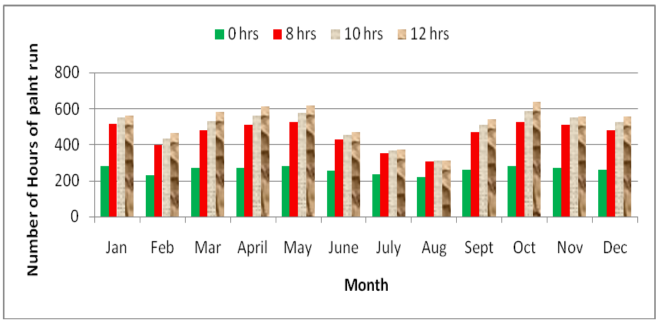

Fig.7 Monthwise number of hours of plant run with different storage hours.

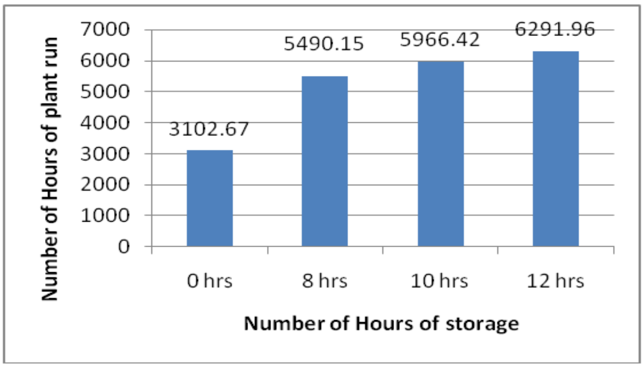

Fig.8 Yearly number of hours plant can run with different no. of storage hours

Fig 8 shows the number of yearly hours the plant can run with different number of hours of thermal storage. Number of hours of plant run increase by 76.94% for 8 hrs of storage, whereas for 10 hrs of storage, it increases by 92.29% and for 12 hrs of storage, it increases by 102.79%.

Besides increasing the generation of power by using storage tanks, generation of power can also be increased by increasing the area of heliostats and hence the absorber area of incident solar radiation, i.e. concentration ratio [3]. Fig.No.9 shows the number of hours of plant run with 8 hours of storage with concentration ratio of 400 and without storage for concentration ratio of both 400 and 600.

It can be seen from Fig.9 that increasing the concentration ratio from 400 to 600 has only increased number of hours of plant run by 73 hrs in the entire year whereas if 8 hrs of storage of thermal energy is done, for concentration ratio of 400 itself, the number of hours of plant run increases by 2388 hrs, i.e. it increases by 76.98%. Therefore it reduces the cost of electricity production. Thus it is seen that increasing storage of thermal energy is more beneficial as against increasing concentration ratio.

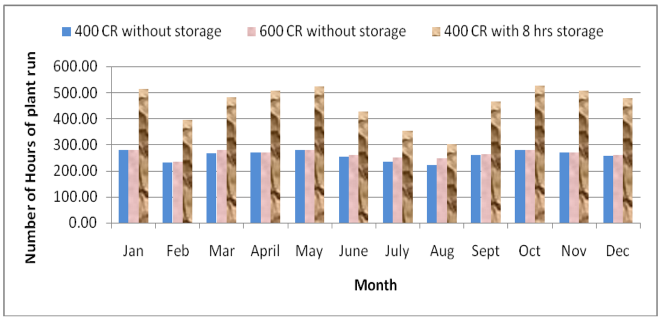

Fig.9 Monthwise number of hours of plant run with different CR and storage hrs

VI. CONCLUSION

Inclusion of thermal storage tank in power plant helps the power plant to run continuously in cloudy weather. It also helps the plant to run after sunshine hours. The numbers of hours of plant operation with inclusion of storage tank is more than double of plant operation without storage. Only in three months, i.e., June, July and August, the number of hours of plant run is increased by less than double as they are rainy months and less solar radiation is received in these months. Increasing storage of thermal energy is more beneficial as against increasing concentration ratio

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