Improvement in Efficiency of Solar Thermal Power Plant by New Methodology

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Abstract— This research work is focused on the effective utilization of Solar Thermal Power Plant (STPP). The concept is to operate solar thermal plant along with the hydro power plant. It is proposed in this research work that it will lead to improvement in overall efficiency of the system. The other significant advantages are also discussed in detail. The favourable location thought of for this concept is a dam site. There are two reasons for selecting this location. The first one is that we can have advantage of existing head and the installed setup of hydro power plant. Second reason is that we can use baron land including hills and river banks to establish the solar thermal plant which will reduce the initial cost of the plant. The technical details including the parameters, dimensions, available power generation, overall efficiency of the suggested scheme etc. have been presented in detail.

Key words: Solar Thermal Power Plant, STPP

I. Introduction

The fossil energy is getting reducing and environment is polluting every day, people needs kind of green energy which can be used for forever. In this situation, solar energy is the first choice. Over a half century, many type of STPP improves day by day. Some has been Commercial application, some still in the test. The problem is the unstable steam parameter due to the change of solar radiation intensity so STPP cannot run continuously because of disappearance of solar radiation. This research work is oriented to put forward a solution to these problems.

II. Construction

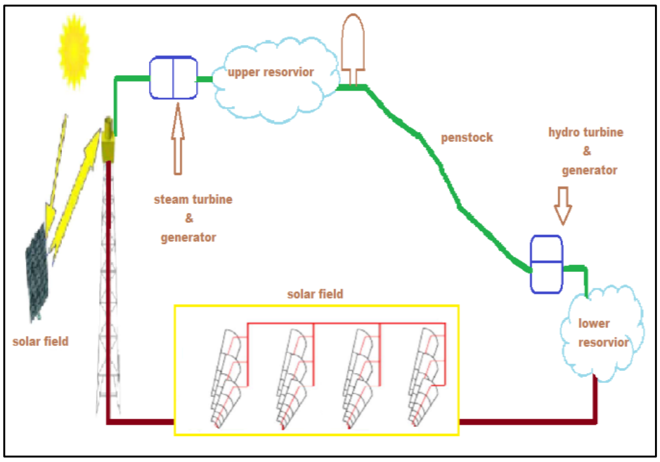

Fig. 1: Block diagram of novel solar thermal power plant

The combined scheme of power plant is shown in figure 1. The main feature of this plant is it operates in combination of two plants. Upper reservoirs is located at hilly area as we knows that most of the hydro power plants are located at such geographic location where high head is available also this gives benefits to locate solar panel for thermal power plant so extra cost for constructing tower can be eliminated. The lower reservoir stores the water came through tail race of hydro plant. Parabolic trough solar collectors are shown in fig 1 which used to heat water to convert it into steam. Additional solar field (if needed) can be used to boost up the steam temperature and pressure.

III. Operation

The stored water in main reservoir is passing through the penstock and drive the hydro turbine. The water came through the tail race will stored in lower reservoir this water will used to generate steam by solar thermal power plant now according to law of thermodynamics this generated steam will automatically goes upper side through the pipes. Due to elevation of steam from lower to upper side this steam will lose their heat and pressure in some amount this can be further heated by solar collector located at the top side now this super-heated steam is used to drive steam turbine. The steam came from turbine is at low pressure and temperature this steam is again converted into water by condenser and this water is stored in upper reservoir. By using such scheme we can get advantage of pumped storage hydro power plant along with the solar thermal power plant.

IV. Advantages

- By using such combination of plant we can use this plant as base load plant as well as for peak load plant. It also helps in increasing plant load factor.
- As we know that stand alone operation of solar thermal power plant is less efficient, with the help of this combination, we can increase the overall efficiency of plant.
- The plant utilization factor of the combination is more as compared to stand alone operation of any one of these two plants.
- Continuous operation of this plant is possible because at night solar irradiations are not available thus we cannot operate solar thermal plant at night or cloudy weather condition but by this operation we can get major advantage. In such situations only hydro plant will operate alone from stored water of upper reservoir. Downstream (lower reservoir) water is fed back to upper reservoir during day time when full solar irradiation is available.
- Cost of purchasing land for solar thermal power plant is eliminated because hydro power plants are located in such geographical area where large unused land area is available including hills and river banks.

V. ACTUAL PARAMETERS OF NOVEL MODEL

A. Solar Field and Heliostat Field Collector Parameters

A 17 MW solar thermal power plant with heliostats field technology consisting 2750 heliostat field collectors and the total area occupied by the plant is 1500000 m2.

Technology	**Tower System**
Installed capacity	17 MW
Direct normal irradiation	1997 kW h/m^2 yr
Number of heliostats	2750
Aperture	264,825 m^2
Full load hours	3650
Technical lifetime	25 years
Plant load factor	41.66%
Energy generated per year	62050 MWh
Energy generated in the Lifetime	1551 GWh
Area occupied	1500000 m^2
Annual average solar field Efficiency	45.6%
Thermal efficiency of the Cycle	39.09%
Net efficiency	16.7%

Table 1: Characteristics of the studied solar thermal power plant [2]

Steam temperature	600 ºC
Steam pressure	3045.69 psig or 210 barG
Specific enthalpy of superheated steam	3529.32 kJ/kg
Specific heat of superheated steam	2.82085 kJ/kg·K or 0.6738 kcal/kg°C
Specific volume of superheated steam	0.017129 m^3/kg
Viscosity of superheated steam	0.0340385 mPaS

Table 2: Steam Calculations [3]

B. Steam Velocity

$$\text{Steam velocity (v)} = \frac{m_s \times V}{3600 \times \pi \times \left(\frac{d}{2}\right)^2}$$

Steam velocity should be chosen between 40 to 60 m/s. we have chosen 50 m/s [3].

C. Pipe Size and Steam Flow Rate

- Pipe grade DIN 2448
- Pipe size DN 2700 mm

Steam Flow (kg/hr) = $3600 \times \pi \times \left(\frac{v}{V}\right)\left(\frac{d}{2}\right)^2$

Steam flow rate = 60166937.36 kg/hr [4].

D. Pressure Loss through Piping

- Pipe length 130 m

$$\text{Pressure loss } (\Delta P) = \frac{0.6753 \times 10^6 \times q^6 \times l\,(1+\frac{91.4}{d})}{\rho \times d^5}$$

Pressure loss (ΔP) = 2290 Pa or 0.023 bar [4].

E. Size of Lower Reservoir

For 10 hour of operation per day we can obtain size of reservoir at lower side and requirement of water [8].

- Water required = 60166937.36×10 = 601669373.6 kg
- Cubic meter water = 601669.37 m^3
- Water required in litre = 601631550.5 litre [5].

F. Size of Upper Reservoir

The losses occur in condenser and other accessories are nearly approximately equals to 15% hence we can get amount of water that flow through hydro plant.

- Water required = 601669373.6 ×.85 = 511418967 kg
- Cubic meter water = 511418.967 m3
- Cubic feet water = 18060589.97 ft^3 [5].

G. Losses to Elevate Steam

1) Heat Loss throughout Pipe

The radiation and convection losses are negligible so it's neglected. A 1-inch pipe will lose 10 watts per foot with no thermal insulation, but will only lose about 1.5 watts per foot with 1 inch of fiberglass thermal insulation. This 1 inch of insulation will also produce a 40°F temperature difference, which could provide freeze protection in a very low maximum ambient.

The basic formula for heat loss is:

$$Q = UA\,(T_1\text{-}T_2)$$

From above formula losses with 1 inch of fiberglass thermal insulation for 130 meter pipe is 177.84 KW.

2) Losses Due to Friction and Gravity

$$\text{Reynolds number (Re)} = \frac{\rho v D}{\mu}$$

Where,
ρ = density of steam (kg/m)
v = velocity of steam (m/sec)
D = diameter of pipe (m)
µ = viscosity of steam (mPas)
From above Reynolds number is 18.35×10^8.
Roughness for steel pipes is 0.000045.
Relative roughness of pipe = K_s/D
From above equation value is 0.000016.

- By using value of Reynolds number and relative roughness in moody's chart which is to be used for finding friction factor (f) we can get friction factor.
- The friction factor is 0.008.
- The moody chart used by USA is taken for our reference. There are two type of moody chart one is used by European countries and another is used by USA/AUS.
- D'Arcy equation for energy loss or head loss due to friction and gravity

$$H_f = \frac{fLv^2}{2gD}$$

Where,
H_f = head loss to friction (m)
f = friction factor
L = length of pipe (m)
v = velocity (m/sec)
g = gravitational constant (9.81 m/s^2)
D = diameter of pipe (m)
The value of H_f is 0.166 meters.

H. Power generated in hydro plant for closed loop operation

Power from hydro power plant =

$$\frac{head\ in\ feet \times water\ cubic\ feet\ per\ second \times efficiency}{11.8}$$

Where,

11.8 = converts units of feet and second into kilowatt
Efficiency of hydro plant is around 80 to 90%. With 80% efficiency and head of 130 meter output power of hydro plant is
From above,

- Cubic feet per second water is 501.68 ft^3/sec
- Head in feet = 425.96 feet

$$\text{Power (P)} = \frac{425.96 \times 501.68 \times 0.8}{11.8} = 14487.98 \text{ KW}$$

The losses to elevate steam are 177.84 KW by subtracting this losses from power output we can get the net output power of hydro plant is 14310.15 KW. For 10 hour of operation per day in closed loop operation energy generated is 143.10 MWh [6].

I. Comparison of Efficiency

Efficiency of Standalone operation of STPP can be obtained from solar irradiations input to plant [2].

- Solar irradiations = 382 W/m^2
- Area of single collector module = 96.3 m^2
- Total number of collectors are used = 2750
- Total input to STPP plant = 101.16 MW
- Output of plant = 17 MW

$$\text{Efficiency} = \frac{17}{101.16} \times 100 = 16.7\%$$

Efficiency of combine operation

- Total output of plant = 31.31 MW
- $\text{Efficiency} = \frac{31.31}{101.16} \times 100 = 30.95\ \%$

The improvement in efficiency by comparison is 14.25 %.

VI. CONCLUSIONS

In this work, the new concept of solar thermal power plant system considered in which efficiency of this novel model is obtained which quite greater than stand-alone operation of solar thermal power plant. The efficiency of STPP in standalone operation (solar to electrical efficiency) is 16.7%. By combination of this two plant (novel model) we can get efficiency is 30.95%. Thus the improvement in efficiency is 14.25%. The other advantage we can get is continues operation of plant could be possible without any other technologies (pumped storage) are used. Also large unused land area is used for power generation by STPP this increases capacity of plant.

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