Innovative Approach for Non Conventional Electrical Power Generation Utilizing Solar Heat and Wind Kinetic Energy

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ABSTRACT
This paper presents an integrated approach of electricity generation by combining the kinetic energy of wind and solar thermal energy by using specifically designed wind tunnels and solar thermal energy storage system in a solar chimney power plant. The tunnels are designed to control wind velocity in the vicinity of the solar chimney whereas thermal energy storage system enhances the rate of energy generation. This paper describes the design and working of a prototype. The parameters for the prototype were derived by using simple flow equations. The design incorporates a coaxial turbine installed inside the solar chimney and wind flows through specifically designed static tunnels from all the directions. This Design enables to overcome the drop in power generation capacity of solar energy based power station when cloudy and rainy conditions persist. It was observed that due to tunnels the wind velocity increases and can be controlled, While thermal energy and chimney effect adds to wind velocity. Therefore electricity generation appreciably increases for larger time, besides the ease in maintenance and protection from storm.

Keywords: Solar chimney; solar heat power generation; Renewable energy; Wind energy; up draft tower

I INTRODUCTION

Earth receives energy from Sun as light and heat. This energy is mainly responsible for life on Earth. Most of the solar energy thus received from sun is reflected back to atmosphere and some of its part is absorbed on Earth. Solar thermal energy plays significant role in increasing the kinetic energy of the wind. At present, commercially clean power is generated by using photovoltaic cells or by using wind turbines.

Wind turbines due to large inertia and long blades cannot rotate if wind velocity is below 5 m/s and needs to shut down when wind velocity is in excess of 25 m/s. This restricts the electricity generation by wind turbines only when wind velocity is in the range of 8 m/s to 20 m/s. This further complicates the task of selecting a suitable site for erecting a wind turbine. Very few places are suitable on earth, where these turbines can be installed. Since horizontal wind turbines are to be mounted on a tower of about 40 m height along with generator which makes its maintenance a difficult task.

Earth receives more heat from Sun as compared to light. This fact led to many authors to use heat for generation. The idea of converting heat to electricity is quite old [1]. In 1983 a prototype plant was constructed and tested. It worked for 8 years successfully. Presently, two commercial plants one in China and other in Australia are under construction with a capacity of around 200 MW, using turbines and synchronous generator [2]. These power plants require a very high chimney (around 200m height) and large land area (around 10 hectare per MW) for heat storage. These power plants work for 20 hours a day. If special techniques are used for heat storage such as water or black granules or molten salt, .these power plants can work 24x7 supplying base loads in tropical countries and deserts. The need of large land area and height of solar chimney has restricted the wide spread use of the solar chimney based power plants [3] [4].

To overcome this limitation with same capacity of generation a new concept of integrating solar heat and wind energy was given by Nigam et al [5]. However the paper does not describe the heat storage techniques on land. They have used less efficient vertical axis turbine, giving low energy recovery.

An integrated approach can be used to generate power, utilizing wind and solar thermal energy simultaneously, with reduced thermal storage area and chimney height. The proposed power plant should use more efficient coaxial turbine .This approach will reduce the size and cost of the solar chimney power station for the same amount of power generated.

II THE PROPOSED POWER PLANT MODEL

(a) Design outline

The integrated approach described utilizes kinetic energy of wind and solar thermal energy simultaneously to generate clean and green electricity. The power plant based on this integrated approach is termed as Solar Heat and Wind Power Plant (SHWPP). Fig.1 shows a schematic diagram of SHWPP. Its design consists of a hexagonal base with suitably designed wind tunnels in all its six arms. Area of input duct is gradually reduced so that input area of wind tunnel is five times larger than the area of outlet. However it is not

 ISBN: 2278-4187

necessary to keep ratio of input to output cross sectional area fixed at five and can be altered suitably as per requirement. The wind velocity is therefore increased five times from inlet to outlet of the tunnel due to this reduction. [5].

Bottom of the tunnels are made of aluminium or steel and rest on black granules and sand which are filled below them as shown in fig(1). Top and side walls of the tunnels are made of glass. These glass panels transmit heat received from sun to bottom metallic plates and then to sand and granules for storage.

All these six tunnels arms are arranged in hexagonal form and thus provide 360^0 access for wind to enter the chimney from any direction. These tunnels bend upwards and open inside the hexagonal metallic chimney. The use of low friction surface enables to achieve smooth air flow. The chimney is covered all around its periphery by glass panels up to 80% of its height. The air between chimney and glass panels stores the heat which is coming inside through glass panels.

A coaxial wind turbine is preferably mounted at half the height of the chimney. The other end of the shaft is connected to generator located in a control room to generate power as shown in Fig 1.

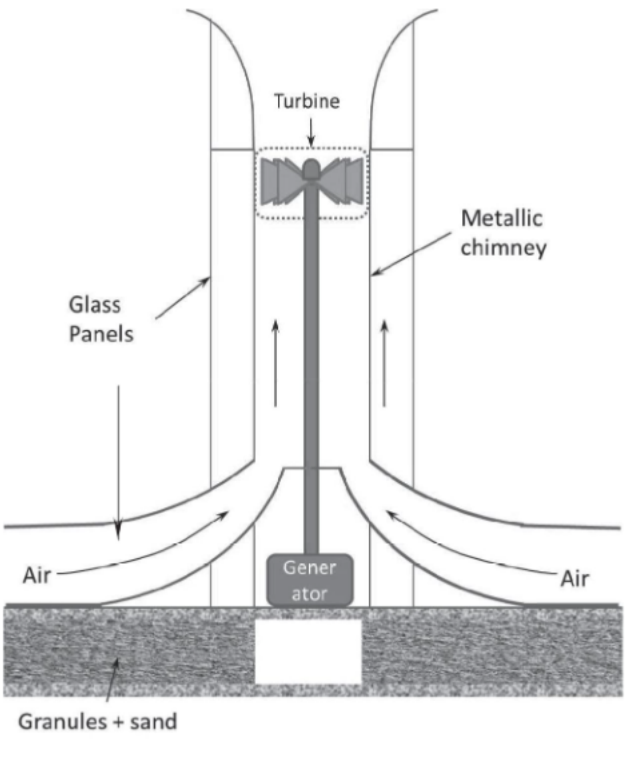

Fig. 1. Schematic Diagram of the Integrated Solar Heat and Wind Power Plant (SHWPP)

(b) Working Principle

Six tunnels are spread around the chimney. The top surface of the tunnels carries solar glass panels owing to which solar heat gets transferred to bottom metallic plate of chimney from where it passes (Through conduction) to sand and granules stored below it. The heat is absorbed by air in the tunnels and by sand and granules on the ground, raising their temperature. Glass panels are provided around chimney up to 80% of its height. The air between glass and chimney stores heat, from where it is conducted to the air flowing through it, thus increasing the draft.

Winds blowing in the area from any direction may enter from one or two tunnels. Since tunnels are opening inside the chimney, air will be sucked due to chimney effect .Since, the inlet area A_i is kept 5 times the outlet area A_o. Therefore, the air moving through tunnels will accelerate and final velocity at the outlet of the tunnels will be five times the inlet velocity (see table). The incoming air gets heated while moving through the tunnels (i) due to solar rays falling on it and (ii) via conduction from sand and granules stored at the bottom of the chimney.

 ISBN: 2278-4187

The ratio of input to output cross sectional area of the tunnels can be varied to regulate the velocity of the air in the chimney. If required, input cross sectional area may be kept smaller than outlet cross-sectional area to reduce the wind velocity. Thus the velocity of air can be kept within desired limit through chimney for smooth functioning of the turbine. Amount of air intake can also be controlled during low and high velocity winds.

The air moving through chimney will further accelerate and gain kinetic energy due to the heat absorbed from solar panels outside chimney and chimney effect. Thus the total kinetic energy of air moving through chimney will be due to combined effects of natural wind velocity, thermal energy received from Sun and chimney effect. Velocity of air inside chimney can be controlled by placing deflectors in tunnels.

The coaxial turbine can be mounted near about 50% of the height of the chimney with one shaft towards ground end connected with the generator. Speed of the generator can be changed by controlling air velocity through tunnels thus enabling stable operation.

III DATA ANALYSIS

(a) Effect of tunnel area reduction

Let Cross-sectional area at input of tunnel = A_i

Cross-sectional area at output of tunnel = A_o

Ratio of Input to output cross-sectional area AR = A_i/A_o

Incoming air velocity at the tunnel = V_i

Outgoing air velocity from the tunnel = V_o

Neglecting friction losses and local currents, energy continuity and mass flow equations have been used to calculate the velocity and other parameters at the end of the tunnel.

Energy continuity equation

$$\frac{V_i^2}{2gJ} + C_pT_i = C_pT_o + \frac{V_o^2}{2gJ} \qquad \text{............ (1)}$$

Mass flow equation

$$A_iV_id_i = A_oV_od_o \qquad \text{............ (2)}$$

Assuming adiabatic process

$$\frac{T_i}{T_o} = \left(\frac{d_i}{d_o}\right)^{\gamma-1} \qquad \text{............ (3)}$$

$$\frac{P_i}{P_o} = \left(\frac{T_i}{T_o}\right)^{\frac{\gamma}{\gamma-1}} \qquad \text{............ (4)}$$

P_i, T_i, d_i are the pressure, temperature and density of incoming air at the tunnel and P_o, T_o, d_o are quantities at the outgoing air at the tunnel.

Let the values of the variables at the entry of the tunnel are

$P_i = 1.033$ kg/m^2, $T_i = 300$ °K and $d_i = 1.17$ kg/m^2 and

γ =1.4, $C_p = 0.238$, J = 427 and g =9.81 m/s.

Assuming area reduction ratio AR = 5 and input velocity $V_i = 5$ m/s

Substituting above values in equations 1 to 4

$$d_o = \frac{(A_iV_id_i)}{(A_oV_0)} = \frac{29.25}{V_o}$$

Hence

$$T_o = 300\left(\frac{29.25}{V_o}\right)^{0.4}$$

Substituting the value of T_o and other constants in the equation 1, the polynomial in V_o comes out to be

$$V_o^{2.4} - 5.982 \times 10^5 V_o^{0.4} + 2.168 \times 10^6 = 0 \qquad \text{............ (5)}$$

On resolving equation (5) we get

$V_o = 25.06 \sim 25.00$

Other parameters calculated from above equations at the outlet of tunnel are as follows:

T_o=300°K, d_o = 1.17 kg/m^2, and P_o =1.033 kg/m^2

This indicates no change in the conditions when ratio of cross-sectional area reduction and velocity is low. However these parameters changes significantly at larger air velocity and high ratio of cross sectional area reduction. The values calculated at various conditions are shown in the table below.

Table 1

Values of various parameters for different ratio of cross-sectional areas of the tunnel

Area ratio (AR)	3			5			8		
V_i m/s	5	10	20	5	10	20	5	10	20
V_o m/s	15	30	60	25	50	104	40	82	185
d_o	1.17	1.17	1.15	1.17	1.17	1.125	1.17	1.14	1.01
T_o	300	300	300	300	300	295	300	297	283
P_o	1.033	1.033	1.033	1.033	1.033	0.970	1.033	0.997	0.842

As Given in Table-1 the lower wind velocity can be increased by suitably choosing the area reduction ratio. If the natural wind velocity is higher, the area reduction ratio can be small or even reversed to suit the system. Thus stable turbine operation is possible in the power plant. These are approximate calculations neglecting friction and local currents hence may not be valid at higher wind velocities, but it signifies the underlying principle. Since wind velocity can be controlled, so this design is suitable for lower wind velocities. Because of heat storage and wider wind velocity operation the system can generate energy for longer time with stable operation.

(b) Chimney effect

The velocity of air at the bottom of the chimney is given by

$$V = [2gHa']^{1/2}$$

Where Ha' is the actual height of the column of the hot gas in meter which would produce the pressure P kg/cm2

If H is the height of the chimney and T2 and T1 are the temperatures at bottom and top of it,

$$Ha' = 0.8H \left[\frac{T2}{T1} - 1\right]$$

Velocity will be somewhat less if friction is also considered.

Therefore velocity of the air at the bottom of the chimney will depend on the physical height of the chimney and ability of the chimney to absorb the heat from outside hot air trapped between solar panels and chimney. Total area of solar panels and ability of chimney to absorb heat are major factors for efficient operation.

IV DISCUSSIONS

Energy of air at the top of the chimney is due to initial energy of air at the entrance of tunnels plus solar thermal energy acquired during transit through tunnels and chimney, fig. 1. As the air passes through tunnels the velocity increases in proportion to input/output area ratio, as shown in table-1. Thus the air velocity at the top of chimney is added effect of initial wind velocity, solar heat, tunnel area ratio and chimney effect, as shown in table-1. Air velocity increases with increase in tunnel area ratio. Very little effect is observed in density and temperature, only at higher velocity. Drop in these parameters will reduce or even may reverse due to solar heat as it is not taken into consideration during calculation. Therefore velocity will increase without drop in density. A coaxial turbine is installed inside the chimney at a height of 80% giving good energy recovery. This power plant will harness both wind and solar heat simultaneously in one power plant as disered.

The integrated approach of utilizing solar thermal energy (stored on the ground and around chimney), kinetic energy of wind and chimney effect in one single power plant has the potential of producing power 24x7 even during cloudy and rainy season. Its design is simple, easy to operate and maintain. The only moving parts are turbine and generator rotors. The complete power plant may be designed to work in semi or full automatic mode. If made to run commercially it will incur very little running cost. Its other benefits are:

(a) Unlike the solar chimney power plant (using solar chimney and storing heat only at ground, without wind kinetic energy) heat is stored around both the chimney and ground thus reducing the requirement for large land area.

(b) SHWPP generates more energy as it also simultaneously utilizes wind energy as compared to solar chimney power plant of same size.

(c) Stable operating conditions are possible to achieve as quantity of incoming air and its velocity can be monitored and controlled in the proposed design.

(d) 24x7 generation of electricity due to the area under the tunnels and around chimney is effectively used for heat storage. This is unlike other standalone windmills, where generation is totally dependent on the available wind velocity.

V CONCLUSION

This paper describes the simultaneous usage of solar and winds kinetic energy to produce electricity. The outer surface of the chimney used for heat storage enables the user to reduce the land area requirement. It is possible to control the velocity of wind in the chimney by changing the area reduction ratio of the tunnels. Approximate analysis presented in the paper describes operational feasibility of the proposed SHWPP. Detailed analysis of the system should be done including friction and heat flow.It will also need to find better position of turbine.

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