International Journal of Engineering Works
Kambohwell Publisher Enterprises
ISSN: 2409-2770
Vol. 4, Issue 5, PP. 101-107, May 2017
www.kwpublisher.com

Hybrid System for Electricity Generation using Waste Heat & Wind from Exhaust Duct of Generator

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***Abstract*—**The objective of this paper is to utilize wasted heat and hot pressurized air from the exhaust duct of the generator in generating station to produce electricity. This heat and exhaust air is produced due to two types of losses i.e, core losses and copper losses inside generator and its temperature gradient with respect to the external environment. To accomplish this task a hybrid system consisting of Thermoelectric Cells and Wind Turbine assembly is designed in which Thermoelectric Cells produces electricity using the wasted heat based upon the Seebeck effect while the wind turbine generates electricity due to high speed wind striking its specially designed blades according to the modern Aero-Dynamical designs. This hybrid system will work in parallel with the main Generator acting as auxiliary electricity generating source. This system will provide improved results at higher temperature differences and high pressure of wind.

***Keywords*—** Hybrid Generation, Peltier cells, Seebeck Effect, Thermo-Electric Generators, Wind turbine.

I. INTRODUCTION

In electrical power station, electricity is generated by different means. Most power stations contain one or more generators, a rotating machine that converts mechanical energy into electrical energy. At generating stations, most of the useful energy is wasted in the form of heat. It is estimated that about 65% of the energy is lost due to copper losses, eddy current losses and hysteresis losses. In order to utilize this wasted heat energy, Engineers and Technologists around the world have spent decades seeking means to harness this wasted energy. Most such efforts have focused on thermoelectric devices to produce electricity from a temperature gradient, but their efficiency was limited.

The aim of this research paper is to work on such a hybrid system (combining both heat and wind energy) which can convert this wasted heat and wind from the exhaust duct of generators into useful energy with enhanced efficiency. The idea presented here is basically an energy recycling process which is environment friendly i.e; it can provide the clean and pollution-free energy. This hybrid system will be designed using thermoelectric generator (TEG) and wind turbine assembly both of which will work in parallel to satisfy the purpose.

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa using a thermoelectric device. The term "thermoelectric effect" comprises three different effects: the Seebeck effect, Peltier effect, and Thomson effect. The Seebeck effect, named after the German physicist Thomas Johann Seebeck, who in 1821 discovered it, is the direct conversion of heat into electricity at the junction of two dissimilar metals [1]. The Peltier effect is the presence of heating or cooling at an electrified junction of two different conductors and is named after French physicist Jean Charles Athanase Peltier, who discovered it in 1834 [2]. Thomson effect which describes the heating or cooling of a current-carrying conductor with a temperature gradient was predicted by William Thomson in 1851 [3]. Thermoelectric effect has multiple applications including power generation and energy recycling (TEG), refrigeration, temperature measurements (Thermocouples & Thermopile) and Thermal cycles for polymerase chain reactions [4].

The major design goal of hybrid system (TEG & Wind Turbine assembly) is to harness waste heat and wind at the generating stations and industrial facilities.

II. THE CONSTRUCTION MATERIALS

This Hybrid system consists of power generation from two sources i.e. from wind turbine and thermoelectric cells. Thermoelectric cell TEC-12706 being used here is made up of bismuth telluride with physical dimensions of 40 mm x 40 mm x 3.5 mm. More recent devices use highly doped semiconductors made from bismuth telluride (Bi2Te3), lead telluride (PbTe), calcium manganese oxide (Ca2Mn3O8) or combinations thereof, depending on temperature. [5] It is attached to the frame with the help of thermal paste. Whereas, Wind turbine is made of a bicycle dynamo, and steel blades are designed according to the aero dynamical designs.Wind energy is converted to other form of energy by the blades of wind turbines. The blades of the wind turbines are designed in two different ways, the drag type and lift type [6].

This system acts like a mini hybrid power house consisting of wind turbine and thermoelectric cells in series-parallel combinations. It is installed on the exhaust duct of generator. The heat energy produced in the generator is due to copper loss (I^2R), core loss, frictional loss & mechanical loss. All these

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losses contribute to heat energy. This heat energy must be removed by means of the exhaust duct of the generator for the proper operation of generator.

III. Operation/Working

The operation of hybrid system starts as the hot pressurised air released from the ducts of generators is directed to pass through the assembly of thermoelectric cells. These are connected to the iron frame and it is filled with water which acts as a coolant as shown in Figure 1.

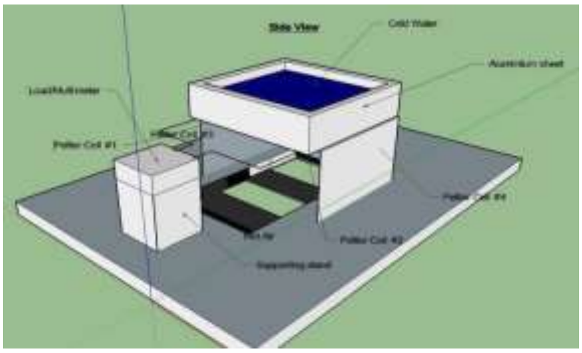


Figure 1: Hybrid System Model

The cells are connected in series in order to improve output voltage and these series connected cells further connected in parallel to improve output current so as a whole the power output is increased, refer to Figure 2.

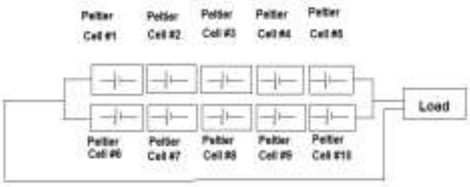


Figure 2: Connections of TEG

As the temperature difference is created on both sides i.e, by means of hot wind and cold water a potential difference is created between the two sides sensed by a voltmeter which gives the magnitude of thermoelectric voltage generated due to temperature difference[7]. The typical efficiency of TEGs is around 5–8%[8]. Shown in Figure 3, Wind turbines are also connected in series-parallel combination to generate electricity from pressurized air moving out from exhaust vents depending upon the wind speed, blade size, and air density.

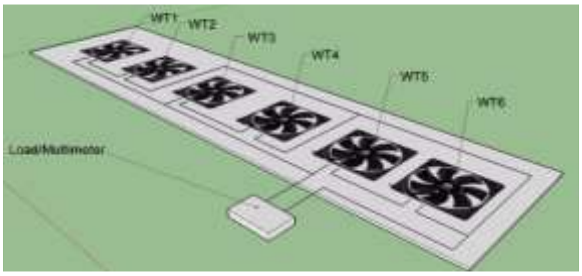


Figure 3: Model for Wind Turbine Assembly

The combined power sources connections shown in Figure 4.

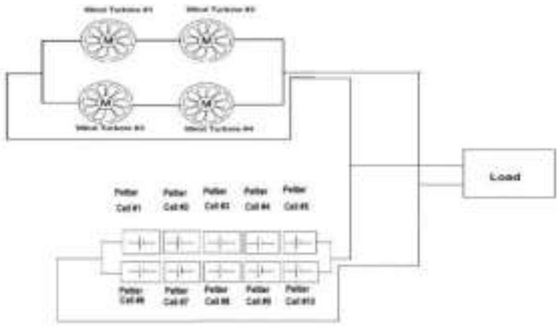


Figure 4: Combined Sources-Hybrid Model

With the passage of time, water heats up and the temperature difference reduces which leads to decrease in the voltage so water is being replaced or cooled after certain time in order to get maximum output and efficiency. Figure-5 shows a more robust and improved design for this project in which wind turbines and thermoelectric generators are installed in such a way that water has inflow & outflow paths and air circulation path is available in order to avoid losses and to make most of the air proportion useful.

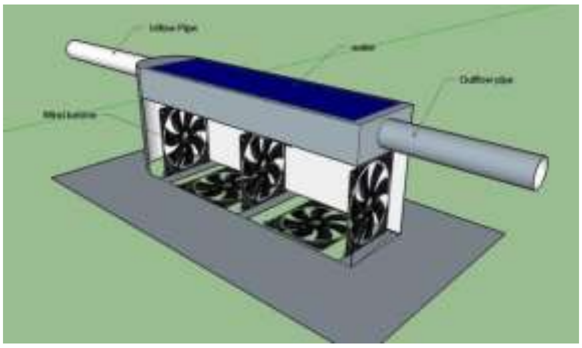


Figure 5: Hybrid System- improved design

IV. Experimental Results

Since the power output from this project is the combination of electrical power from the two independent sources i.e,

1. Thermoelectric Generator.

2.. Wind Turbine.

The formulas for calculation of power are given as:

A) From Thermoelectric Generator:

The power output of thermoelectric generator is given by Equation (1)

$$P_{TEG} = \eta VI \qquad (1)$$

Where η is calculated by using formula:

$$\eta_{ideal} = \left(\frac{T_H - T_C}{T_C}\right)\left[\frac{M-1}{M+\frac{T_C}{T_H}}\right] \qquad (2)$$

In Eq. (2), T_H and T_C are the temperatures of hot and cold sides respectively, M is the conversion unit and is calculated by the formula given in Eq. (3)

$$M = \left[1 + \frac{Z}{2}(T_H + T_C\right]^{\frac{1}{2}} \qquad (3)$$

In Eq. (3), Z is the efficiency of the material from which Thermoelectric generator is manufactured. [9] Where, Z is calculated as

$$Z = \left[\frac{S_H - S_C}{\sqrt{\sqrt{\rho_H K_H} + \sqrt{\rho_H \rho_C}}}\right]^2 \qquad (4)$$

In Eq. (4), S_C and S_H are the seebeck coefficients of cold and hot material, ρC and ρH are the electrical conductivities of cold and hot material and K_C and K_H are the thermal conductivities of cold and hot material respectively.

Case Study: Power Output from Warsak Power Station

This experimental data was obtained from the exhaust vents of generator at Warsak Hydal Power Station, Peshawar.

Experimental Readings of Thermoelectric Generator

Air Cooling:

Hot side temperature, T_H = 43.7°C

Cold Side temperature, T_C = 30°C

Voltage, V = 0.017 V

Current, I = 0.14 A

Actual Experimental Power = 0.00238 watt

Power Output for 5% Efficiency = 0.002 watt

Water Cooling:

- **A single cell:**

Hot side temperature, T_H = 43.7°C

Cold Side temperature, T_C = 18°C

Voltage, V = 0.166 V

Current, I = 0.16 A

Actual Experimental Power = 0.02656 watt

Power Output for 5% Efficiency = 0.004 watt

- **Two cells connected in series:-**

Hot side temperature, T_H = 43.7°C

Cold Side temperature, T_C = 18°C

Voltage, V = 0.356 V

Current, I = 0.16 A

Actual Experimental Power = 0.05696 watt

Power Output for 5% Efficiency = 0.008 watt

This is the output of one Peltier Cell on one exhaust duct of generator but on average 406 Peltier Cells can be connected on one exhaust vent.

Extrapolation:

There are 8 ducts of generator so total 3248 peltier cells can be connected on these ducts which can enhance the power output. The output power obtained is different in different seasons as the temperature gradient changes per season.

Power Output per Season:

a) In Winter:

- **Air Cooling:**

Experimental power output of 1 cell with air cooling/natural cooling = 0.00238 watt

Power output for 5% Efficiency with air cooling/natural cooling = 0.002 watt

Power output of 3248 cells with air cooling will be,

$\mathbf{P_{3248\ Cells}}$ = 7.73024 watt

Power Output of 3248 cells for 5 % efficiency will be;

$\mathbf{P_{3248\ Cells}}$ = 6.496 watt

- **Water Cooling:**

Experimental Power output of 1 cell with water cooling= 0.026565 watt

Power output for 5% Efficiency with water cooling = 0.004 watt

ISSN: 2409-2770

Power output of 3248 cells with water cooling will be,

$\mathbf{P_{3248\ Cells}}$ = 86.28312 watt

Power output of 3248 cells for 5% efficiency will be,

$\mathbf{P_{3248\ Cells}}$ = 12.992 watt

Hence, total power output for both air and water cooling in winter is,

$\mathbf{P_{3248\ Cells}}$ = 94.01336 watt

(b) In Summer:

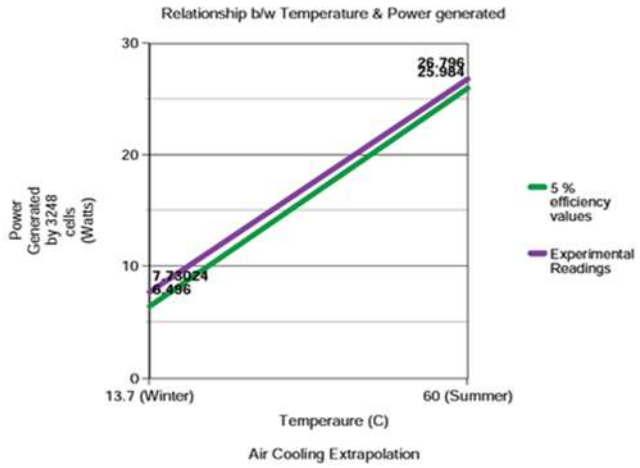
In summer season Power output from the Thermoelectric generator may exceed up to 224 watt (both air and water cooling) due to an increase in temperature difference.

$\mathbf{P_{3248\ Cells}}$ = 224 watt

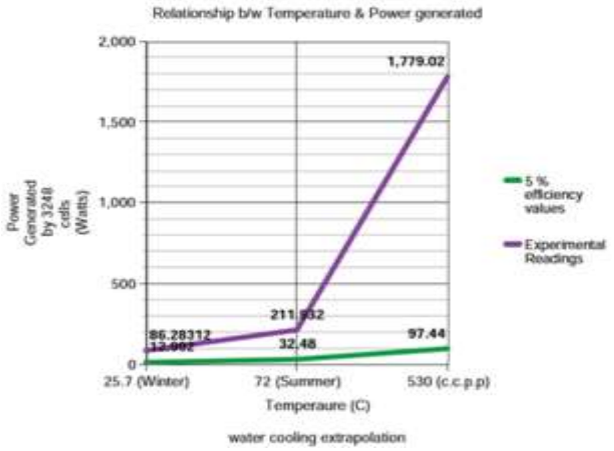
So, total power output of TEG (annually) is

P = 318.01336 watt

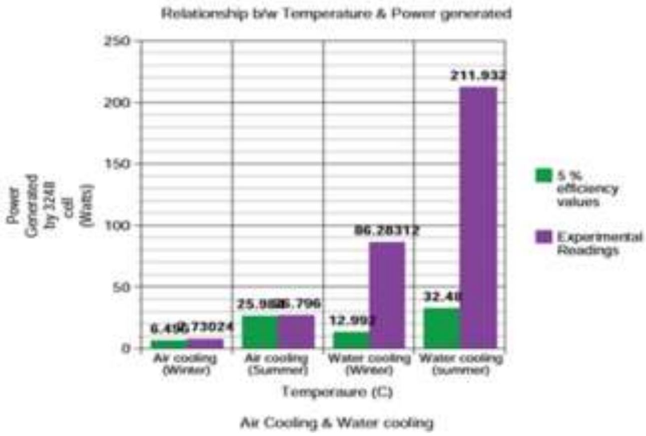
The obtained data is presented in graphical form for different seasons with air cooling and water cooling as shown in graph 1 up to graph 3.



Graph 1: Power Output of 3248 cells with air cooling



Graph 2: Power Output of 3248 cells with water cooling



Graph 3: Power Output of TEG with air & water cooling

B) From Wind Turbine:

The output power of the wind energy is calculated as

$$P_{wind}=\frac{1}{2}\rho A v^3 C_p \qquad (5)$$

In Eq. (5), A is the swept area (πr^2), r is the length of the blade, ρ is the air density (1.23 kg/m3), v is the speed of the wind (which varies season to season) [10] and C_p is the Betz Limit Constant. [11] C_p is calculated as

$$Cp = PT/Pw \qquad (6)$$

In Eq. (6), P_T is the turbine output power and is same as P i.e. (P_T =P) and P_W is the power in wind resource and is calculated as

$$P_W = ½\rho A v^3 \qquad (7)$$

Case Study: Wind Power Generation using exhaust air from ducts of generators at Warsak Power Station

The hot air emitted from the ducts of generator is a source of wind which can be utilized. The power output of a wind

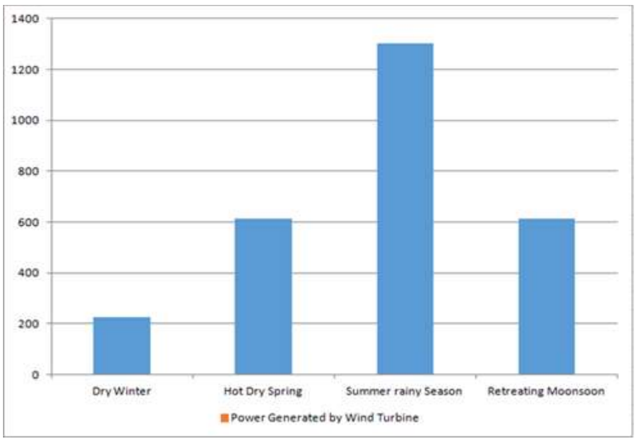
ISSN: 2409-2770

turbine having 30% efficiency and operating during whole year with different wind speeds is shown in table 1.

Table 1: Output power per season by wind energy

S.No	Wind Speed (m/s)	Power output (W)	Season
1	6.69	225.12	Dry Winter
2	9.345	614.32	Hot dry spring
3	12	1301.44	Rainy summer
4	9.345	614.32	Retreating monsoon

Power generated by wind turbine is shown in graph 4.



Graph 4: Power generated by wind turbine

Combination of Sources

When both the sources (thermoelectric generator and wind turbine) operate simultaneously their combine output per season is shown by the pie charts as given in Figure 6(a) and Figure 6(b).

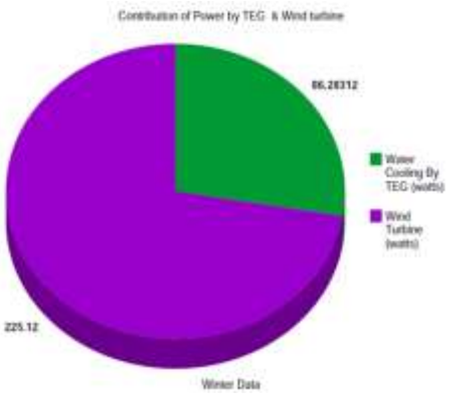


Figure 6 (a): Combined power for winter season

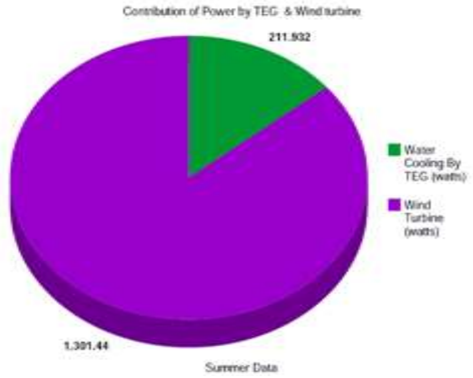


Figure 6 (b): Combined power of summer season

The total output power from these two generating sources is the sum of individual generation i.e

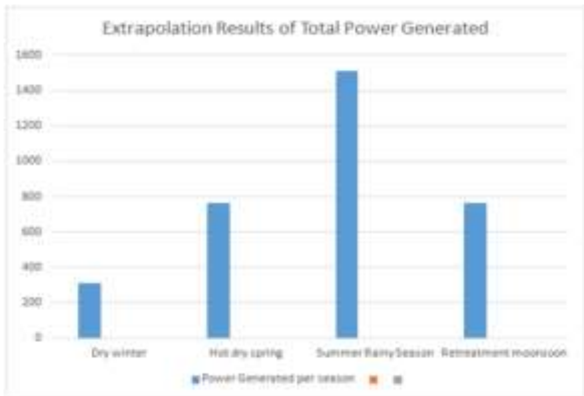
$$P_{Total} = P_{TEG} + P_{Wind} \quad (8)$$

Table 2 shows the combine data for wind turbine and thermoelectric generator

Table 2: Combine output of wind turbine and TEG

Season	Wind Turbine Power Output (W)	Thermoelectric Generator Power Output (W)	Total Power Generation (W)
Dry winter	225.12	86.28	311.403
Hot dry spring	614.32	149.105	763.425
Summer Rainy Season	1301.44	211.932	1513.372
Retreating monsoon	614.32	149.105	763.425

The Combine extrapolated power output of the wind turbine and thermoelectric generator is shown in graph 5.



Graph 5: Combine Power output per season

V. CONCLUSION

This paper puts forward the idea of energy recycling into practice and proposes a design strategy for a hybrid system of power generation by using the peltier cells (complete assembly is thermoelectric generator) and wind turbines. Thermoelectric generator operates on the waste heat being released from generator exhaust duct and converts this heat or temperature difference into useful energy (DC Voltage). Similarly, the waste hot wind from generator's ducts is used to operate the wind turbine thus transforming it into electrical energy. The output of this hybrid system is directly related to the temperature difference and speed of wind. So increasing these variables we can enhance the power output of the system. The output of this system is in the form of DC voltage which can be converted to AC by means of inverters or it may also be used as it is for DC operated systems. The beauty of this hybrid system is that it is much environment friendly as there are no harmful gas emissions during its operation. Moreover, its installation cost is comparatively low and maintenance as well as operational (running or fuel) cost is almost zero. It's not only a way to recycle energy but is also a sufficient source of electrical power which can cope with the energy requirements of the generating stations at hand (auxiliary source of energy). Extending this idea to other big industries using heavy machinery may lead it to yield the enough power to overcome the present energy crisis in the country.

VI. FUTURE RECOMMENDATIONS

This hybrid system of power generation is a sort of initiative in the field of Renewable Energy Resources having almost negligible running cost. This paper just presents the core idea about the conversion of waste heat and exhaust wind energies into useful electrical energy. Still much work can be done in this field to generate a clean and environmental friendly source of energy. Some key recommendations are as under:

1. The Thermoelectric Generators could be installed at combined cycle power plants (CCPP) and steam or Thermal Power plants where the temperature is in hundreds of degree Celsius. Thus the power output may be increased up to an appreciable amount.

2. The efficiency of wind turbine can be modified by improved designing & manufacturing of blades. Best arrangement of this complete assembly at proper location in the generators can also increase electrical power generation.

3. By adding more cells and turbines to the system as per requirement the power output can be increased and this idea may be extended to satisfy the needs of multiple users.

4. The peltier module or thermoelectric generator can also be used as a mini air-conditioner.

5. The use of this system at generating stations will reduce their reliance on the auxiliary sources for their operation by which a considerable amount of money will be saved and a good amount of profit will be obtained annually.

ACKNOWLEDGMENT

Thanks to Almighty Allah, by the grace of whom we succeeded in accomplishing this research. Then, we would like to thank Engr. Faheem Ali for his constant support and valuable suggestions and encouragement during the research process. Thanks to our parents too for their support and precious prayers. We then forward our sincere apologies to all those whom we might not succeed to mention.

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She possesses good programming competency mainly in MATLAB and c language and has been working on many relevant tasks. Her additional interests and skills include informal sketching and drawing.

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