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Development and Implementation of a Solar Powered Steam Turbine Model

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ABSTRACT

A solar powered steam turbine model is presented in this paper. It is a power generating system that is designed to use renewable energy as fuel for generating electricity. The energy radiation from the sun is received by the solar collector (copper pipes) in stripes fitted in an insulated box painted black. The solar powered steam turbine act as a renewable energy resource in regions where there is abundant and consistent sunlight. High energy efficiency of concentrating solar thermal power plants can be ensured only if matching Rankine cycle components like steam turbine, condenser, feed water heaters, are also of high energy efficiency. The steam generated from the solar energy drives a turbine that is coupled to an alternator which generates electricity.

Keywords: thermosiphon, heat, solar energy, solar collector, steam, design and construction

INTRODUCTION

Solar energy is the energy from the sun, which has a high rate of replenishment within a relatively short time compared to the rate at which the energy is being utilized. Solar thermal plant is a fast growing technology, where thermal energy is generated by concentrating the direct solar radiation on a flat plate solar collector (Sambeet Mishra, 2012). The growth and change in the energy utilization sector with its related impact on environmental awareness have led to the utilization of renewable energies cooling techniques in the last years with a focus on solar energy (Fareed, Auatf, Yaseen, & Mohamad, 2012). With the advancement in technology and the consumption of energy resources, the need to use renewable resources increases. For this reason, it is desired to improve the management and utilization of renewable resources in order to reduce the environmental impact and emissions of greenhouse gases responsible for climate change. Solar energy as fuel source for generating electricity has its advantage over conventional fossil fuel as it is inexhaustible and pollution free. Solar energy can be transformed into thermal or electrical energy by the use of solar collectors or photovoltaic panels. Solar collector, the device used to convert the suns radiation to heat usually consist of a surface that efficiently absorbs radiation and convert this incident flux to heat which then increases the temperature of the absorbing material (Salas, Aguilar, Milón, & Braga, 2012) . This study will be focusing on using solar power design to power the steam turbine system (Derick Chiosaabuofu, 2015). The objective of this paper is to explore the importance and advantage of renewable energy development and implementing a power plant system using solar energy which is environmental friendly.

Brief Literature Review

(Alejandro, Charbel, & Victor, (2014)) Proposed a system that will convert thermal energy into mechanical energy by means of the Rankine cycle. The Rankine cycle is responsible for generating 85% of the electricity in the world either by biomass, coal, solar and nuclear power plants. Not only did this project not pollute the environment, it also helped by

showing people that there are better, cleaner and more efficient ways to generate power. The main components which will require the most attention will be the solar reflector, and the actual steam engine. (Derick, 2015) Presents a review of solar steam engine generator technology and how it can be applied to concentrated solar power plant as almost all the power plant station in the world today uses turbine steam engine to run and turn generator to produce electricity while most power stations use to generate electricity through fossil fuels, which emit carbon dioxide and other pollution. (Ugwuishiwu, Owoh, & Udom, 2016) This research gave an exposure on the various ways solar energy can be harnessed for numerous waste treatment processes. Almost all forms of waste treatment require

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energy which is scarcely available considering the global energy crisis. The objective of the research was to enumerate the solar energy applications in waste treatment as a way of global environmental protection and energy management. (Thiyagarajan, GokulKumar, Karthickeyan, Naveen, & Nikilaesh, 2017) Worked on a project to design and fabricate Tesla-turbine powered solar refrigerator, with steam as the working fluid. Looking into the potential of the TELSA turbine as a more efficient turbine which will be used in the energy conversion process, and thus provide refrigeration to inaccessible areas of the country not connected to the national grid. All these researches are either talking about using waste or other technologies, but our paper is looking at harnessing the energy of the sun to generate electric power.

Materials and Method

The system consists of an insulated box painted with black from inside. Inside the box, copper pipes are fitted in stripes and covered with glass. Cold water from the reservoir enters the solar collector (copper pipes) and the end of the copper pipes are connected to the storage tank. The solar radiation passes through the glass in front of the solar collector and strikes the box with the solar collector present inside and the solar energy is absorbed as heat as shown in Figure 1.

Figure 1: Solar collector

This causes the water inside the solar collector to become very hot, and so the water contained in the copper pipes gets heated up and become lighter. The lighter water (steam) flows into the storage tank in Figure 2 through thermosiphon principle.

Figure 2. System frame and storage tank.

Selection of Materials

In the selection of material for construction, two factors were considered namely: cost and properties of the materials.

Solar Collector: Some of the materials that could be use include copper, galvanized iron and mild steel. Among these alternatives, copper is the best due to its high thermal conductivity. For this reason, copper was used.

Glassing: Glassing is needed as part of the solar collector to help aid heating. For this paper, a convex glass was used.

Steam Tank: The steam tank is made up of rolled galvanized steel with the inside properly lagged to prevent heat loss.

Frame/Stand: Mild steel was also used for the frame and stand because of its good weld-ability property.

Fundamental Block Diagram

Figure 3 shows the block diagram of the system which includes blocks of components used in making the circuit functional, the various components involved in the circuit are included in the block diagram.

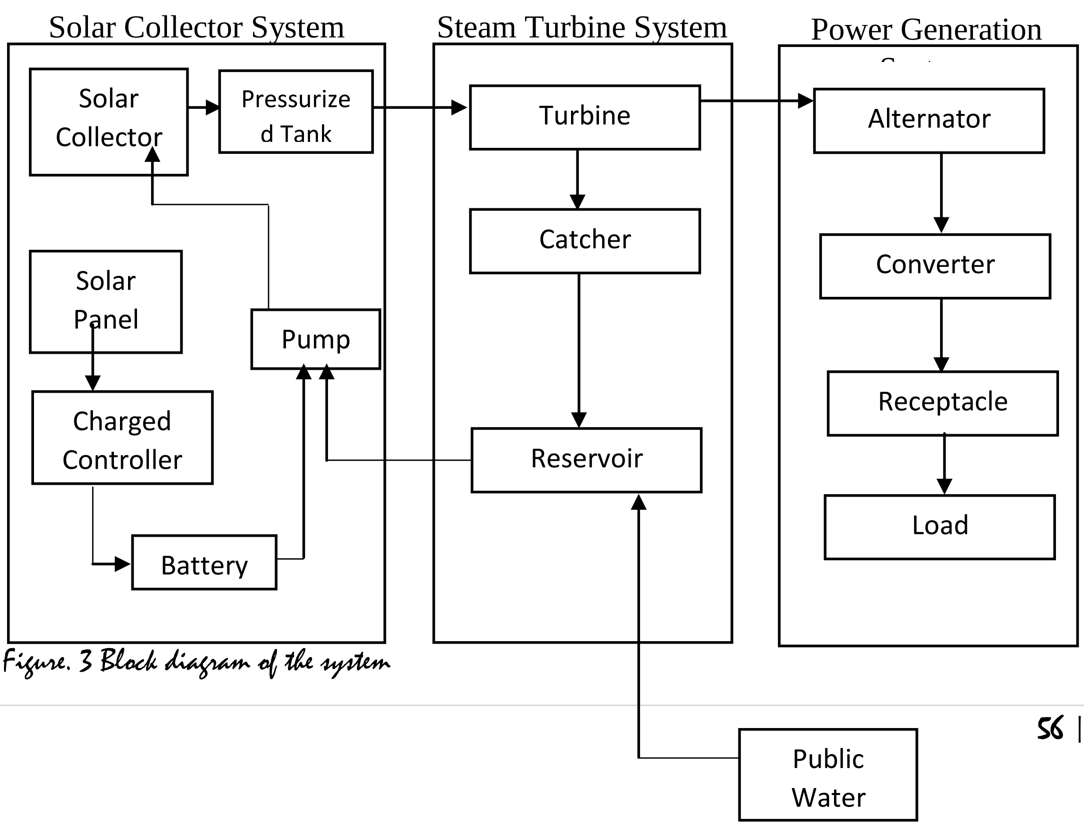

Figure. 3 Block diagram of the system

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Design Analysis

The design analysis was carried out using the layout of the block diagram of Figure 3 which comprises of three basic blocks which includes the solar collector system, steam turbine components and the power generation unit.

Solar Collector System: A solar collector is a device that collects and/or concentrates solar radiation from the Sun. These devices are primarily used for active solar heating and allow for the heating of water for personal use. The use of these solar collectors provides an alternative for traditional domestic water heating and using a water heater potentially reduces energy costs over time. A large number of these collectors can be combined in an array and used to generate electricity in solar thermal power plants. (Jordan, Kailyn, Brodie, & Jason, 2018)

Solar Collector Design Calculations: The following parameters are used for the calculation of the efficiency of the solar collector.

Parameters:

A_c = Collector Area (m^2)

F_s = Collector Heat Removal Factor

I = Intensity of Solar Radiation (W/m^2)

T_c = Collector Average Temperature (°c)

T_i = Inlet Fluid Temperature (°c)

T_0 = Outlet Fluid Temperature (°c)

U_L = Collector Overall Heat Loss Coefficient (W/m^2)

Q_i = Collector Heat Input (W)

Q_u = Useful Energy Gain (W)

Q_0 = Heat Loss (W)

η = Collector Efficiency

τ = Transmission Coefficient of Glazing

α = Absorption Coefficient of Plate

m = Mass Flow Rate of Fluid into the Collector (Kg/s)

If I is the intensity of solar radiation (W/m^2), incident on a solar collector having a collector surface area of A (m^2), then the amount of solar radiation received by the collector is:

$Q_i = IA_c$ .... (1)

There is a loss in solar radiation due to reflection and absorption of some component of the solar radiation on the collector surface. Therefore, a rate of transmission of the collector cover and the absorption rate is added to equation (1).

Thus,

$Q_i = \mathrm{IA}(\tau\alpha)\mathrm{A}$ . . . . (2)

As the collector absorbs heat, its temperature becomes higher than the ambient temperature and heat is also lost to the atmosphere due to convection and radiation. The rate of heat loss depends on the overall heat transfer coefficient (U_L) and the collector temperature

$Q_O = \mathrm{U_L A}(\mathrm{T_c} - \mathrm{T}_a)$ . . . . (3)

Therefore, useful energy extracted by the collector is

$Q_U = Q_i - Q_o = IA(\tau\alpha) - U_L A(T_c - T_a)$ .... (4)

It is also known that the rate of extraction of heat from the collector may be measured by means of the amount of heat carried away in the fluid passed through it, that is

$Q_U = mC_p(T_o - T_i)$ .... (5)

Due to the difficulty in defining the collector average temperature (T_c), It is convenient to define a quantity that relates the actual useful energy gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature. This quantity is called collector heat removal factor (F_R)

$F_R = \frac{mC_p(T_o - T_i)}{A[I(\tau\alpha) - U_L(T_i - T_a)]}$ .... (6)

The actual useful energy gain (Qu), is found by multiplying the collector heat removal factor (FR) by the maximum possible useful energy gain. Therefore,

$Q_U = F_R A[I\tau\alpha - U_L(T_i - T_a)]$ .... (7)

Equation 7 is generally known as HOTTEL WHILLER BLISS equation

A measure of a flat plate collector performance is the collector efficiency (η) defined as the ratio of the useful energy gain (Qu) to the incident solar energy over a particular time period:

$\eta = \frac{\int Q_U\, dt}{A \int I\, dt}$ .... (8)

The instantaneous thermal efficiency of the collector is:

$\eta = \frac{Q_U}{AI}$ .... (9)

$\eta = \frac{F_R A[I\tau\alpha - U_L(T_i - T_a)]}{AI}$ .... (10)

$\eta = F_R\tau\alpha - F_R U_L\left(\frac{T_i - T_a}{I}\right)$ .... (11)

Steam Turbine System: In general, a steam turbine is rotary heat engines that convert thermal energy contained in the steam to mechanical energy or to electrical energy. In its simplest form, a steam turbine consists of a steam generator, turbine, condenser, feed pump, and a variety of auxiliary devices. The basic operation of the steam turbine is similar to the gas turbine except that the working fluid is water and steam instead of air or gas (Steam Turbine, 2019). Turbine is a rotary engine that converts the energy of a moving stream of water, steam or gas into mechanical energy (Mini-Hydro Turbine: Solution to Power Challenges in an Emerging Society with Abundance of Water, 2017, pp. Emannuel Ighodalo Okhueleigbe, Ofualagba Godswil, 2017). Steam turbine converts a part of energy of the steam at high temperature and pressure into mechanical power, which may subsequently be converted into electrical power.

Turbine Blade Design Calculations: The requirement is obtained from research and is necessary because the turbine blade has to be light in weight and to be rotated by a velocity of the incoming steam. It also has to withstand the high temperature. Since moisture is involved, the material is supposed to be corrosion resistant. The material used for the turbine blade is steel and turbine casing is aluminum. These were chosen to reduce the overall weight, withstand high steam temperature and pressure.

Number of revolutions, N =750rpm

Turbine Wheel Diameter, D = 0.112m

Inlet Velocity, v = 8.366m/s

Chosen Inlet Blade Angle, α =12°

DC Generator: A dc generator is an electrical device used for generating electrical energy. The main function of this device is to change mechanical energy into electrical energy. There are sources of mechanical energy available such as hand cranks, internal combustion engines, water turbines, gas and steam turbine etc. (Dc Generator, 2019)

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DC Generator component

a) **The Stator:** The stator is an essential part of the DC generator and the main function is to provide the magnetic fields where the coils spin. This includes stable magnets, where two of them are reverse poles facing. These magnets are located to fit in the region of the rotor.

b) **The Rotor:** This is an essential part of the DC generator and it includes slotted iron laminations with slots that are stacked to shape a cylindrical armature core. Generally, these laminations are offered to decrease the eddy current loss.

DC Generator Specification

Voltage	12v
Current	2A
Power	24w
Phase	Single Phase
Power Factor	0.8
Torque	3143Nm
Speed	500rpm

Figure. 4. Solar Powered Steam Turbine Design Diagram

Figure. 4. Solar Powered Steam Turbine Design Diagram

Figure 4 shows the solar powered steam turbine design diagram. The principal behind the system is based on thermosiphon effect via capillary action. A metal sheet is exposed to solar radiation, the temperature rises until the rate at which energy is received is equal to the rate at which heat is lost from the plate of the solar collector; this temperature is termed as the 'equilibrium' temperature. The back of the plate is protected by wood and the exposed surface of the plate is painted black and is coved by a convex glass sheet, then the water in the copper pipes gets heated up and becomes lighter. The lighter water (steam) then moves to the storage tank for release to fire the turbine and then generate electricity via the alternator coupled to the turbine.

CONCLUSION

There is continuous rise in energy demand in the world and conventional fossil fuel alone can no longer be depended on to meet this demand. Hence the need to harness renewable resources (in our case, solar energy) to develop solar thermal power plants which are technically possible options to supply a significant fraction of the world energy demand. From the design analysis and implementation presented in this paper, we were able to use

The energy from the sun to generate electricity and this technology could be applied to rural communities not connected to the national grid. The system is affordable and environmentally friendly.

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