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A study on Solar Thermal Conversion

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Abstract— As an alternative of the fossil fuel based energy generation or conventional power generation Solar Power or Solar Energy is one of the most convenient ways as Non Conventional Energy. Solar energy is the most reliable source of energy as it is unlimited and available to extract as our demand.There are two types of solar Energy conversion: Solar Photovoltaic and Solar Thermal. This research paper emphasizes on the detail process of Solar Thermal Conversion.

Index Terms— Minimum 7 keywords are mandatory, Keywords should closely reflect the topic and should optimally characterize the paper. Use about four key words or phrases in alphabetical order, separated by commas.

1 Introduction

THE radiative solar energy reaching the earth during each month is approximately equivalent to the entire world supply of fossil fuels. Thus, from a purely thermodynamic point of view, the global potential of solar energy is many times larger than the current energy use. However, many technical and economic problems must be solved before large-scale use of solar energy can occur. The future of solar power deployment depends on how we deal with these constraints, which include scientific and technological problems, marketing and financial limitations, and political and legislative actions including equitable taxation of renewable energy sources.

Approximately 30 percent of the solar energy impinging on the earth is reflected back into space. The remaining 70 percent, approximately 120,000 terawatts [terawatt is equal to 1012 watts], is absorbed by the earth and its atmosphere. Solar radiation reaching the earth consists of the beam radiation that casts a shadow and can be concentrated and the diffuse radiation that has been scattered along its path in space from sun to earth. The solar radiation reaching the earth degrades in several ways. Some of the radiation is directly absorbed as heat by the atmosphere, the ocean, and the ground. Another component produces atmospheric and oceanic circulation. A third component evaporates, circulates, and precipitates water in the hydrologic cycle. Finally, a very small fraction is captured by green plants and drives the photosynthetic process [1].

2 Solar Thermal Energy

It is important to understand that solar thermal technology is not the same as solar panel, or photovoltaic, technology. Solar thermal electric energy generation concentrates the light from the sun to create heat, and that heat is used to run a heat engine, which turns a generator to make electricity. The working fluid that is heated by the concentrated sunlight can be a liquid or a gas.

Different working fluids include water, oil, salts, air, nitrogen, helium, etc. Different engine types include steam engines, gas turbines, Sterling engines, etc. All of these engines can be quite efficient, often between 30% and 40%, and are capable of producing 10's to 100's of megawatts of power. Photovoltaic, or PV energy conversion, on the other hand, directly converts the sun's light into electricity.

This means that solar panels are only effective during daylight hours because storing electricity is not a particularly efficient process. Heat storage is a far easier and efficient method, which is what makes solar thermal so attractive for large-scale energy production. Heat can be stored during the day and then converted into electricity at night. Solar thermal plants that have storage capacities can drastically improve both the economics and the dispatch ability of solar electricity [2].

2.1 Solar Radiation Collection & Concentration

Solar energy is collected as high-temperature heat, generally by means of mirrors or lenses that track the motion of the sun and direct a concentrated solar flux onto a receiver. Temperatures up to 1000 K can be generated by this means, high enough to produce the high-pressure steam used in modern steam turbines to generate electricity.

The temperature to which a surface is heated by a certain flux of incident solar energy is determined by the balance of incident radiation and loss by conduction, convection and radiation. The use of selective surfaces that absorb visible sunlight but do not lose energy by infrared radiation will achieve high temperatures. The temperature obtained can be increased by boosting the flux of incident sunlight by use of concentrating mirrors or lenses. A fairly low concentration ratio, obtainable with simple optics, can be combined with a selective surface to efficiently produce temperatures high enough for electrical power generation.

Three basic collection geometries of sunlight for solar thermal conversion: non-concentrating, concentrating to a line, and concentrating to a point [3].

2.2 Solar Energy Collector

There are three kind of solar energy collection or solar radiation collection. They are:

(1) Non Concentrating Collectors

(2)Concentrating to a Line

(3)Point Focusing

The collector and receiver systems come in three general configurations. In the first, heliostats completely surround the receiver tower, and the receiver, which cylindrical, has an exterior heat transfer surface. In the second, the heliostats are located north of the receiver tower (in the Northern Hemisphere), and the receiver has an enclosed heat transfer surface. In the third, the heliostats are located north of the receiver tower, and the receiver, which is a vertical plane, has a northfacing heat transfer surface.

2.4 Thermal Analysis of Flat Plate Collectors

Here the thermal analysis of the collectors is presented. The two major types of collectors flat plate and concentrating are examined separately. The basic parameter to consider is the collector thermal efficiency. This is defined as the ratio of the useful energy delivered to the energy incident on the collector aperture. The incident solar flux consists of direct and diffuse radiation. While flat-plate collectors can collect both, concentrating collectors can utilize direct radiation only if the concentration ratio is greater than 10 (Prapasetal, 1987).

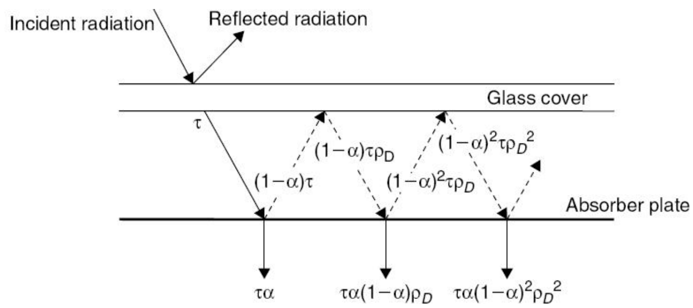

Figure: Incident radiation and Reflected Radiation

Most of the absorbed solar radiation by solar cells is not converted to electricity and increases their temperature, reducing their electrical efficiency. The PV temperature can be lowered by heat extraction with a proper natural or forced fluid circulation. An interesting alternative to plain PV modules is to use hybrid PV/T systems, which consist of PV modules coupled to heat extraction devices, providing electricity and heat simultaneously. PV cooling has been applied to concentrating PV systems and recently to PV building installations. The total energy output (electrical plus thermal) of the hybrid PV/T systems depends on the solar energy input, the ambient temperature, the wind speed, the operating temperature of the system parts and the heat extraction mode. The electrical output is of priority and the operating conditions of the system thermal unit must be adapted accordingly. Several theoretical and experimental studies of hybrid PV/T systems exist. Among the first, Kern and Russell, 1978, give the main concepts of these systems with results, by the use of water or air as heat removal fluid. Hendrie, 1979, presents a theoretical model on PV/T systems using conventional thermal collector techniques, Bhargava et al 1991 and Prakash 1994, present results regarding the effect of air mass flow rate, air channel depth, length and fraction of absorber plate area covered by solar cells (packing factor, PF) on single pass, Sopian et al on double pass, 1995 and on single pass and double pass hybrid PV/T system performance, 1996. In the above works the calculated thermal efficiencies of liquid type PV/T systems are in the range of 45% to 65%, the higher values derived for systems that include thermal losses suppression by using air gap with glazing. Regarding air type PV/T systems, the thermal efficiency depends strongly on air flow rate, air duct depth and collector length. For higher values of air flow rate, small air duct depth and long PV/T systems, thermal efficiencies up to about 55% are given by the theoretical models. The packing factor is an important parameter in most of the above papers. 2 Bergene and Lovvik, 1995, give detailed analysis on energy transfer between the different components of a liquid type hybrid PV/T system with results for their electrical and thermal efficiencies. A parametric study of a PV cladding for building roof and façade is presented by Brinkworth et al, 1997, steady state simulation results regarding PV/T air heating systems with single and double glass are included in the work of Garg and Adhikari, 1997 and a commercial PV/T system for domestic applications has been presented by Elazari, 1998. Several practical concepts are included in all the above, aiming to thermal efficiencies up to about 70% for liquid and 60% for air cooled PV modules. Recent publications on PV/T systems present new investigations, as systems that are based on latent heat storage, developed for installation on building facades and providing warm water, by Hauser and Rogash, 2000. Recently, the combined PV/T module with hot water storage tank was suggested by Huang et al, 2001 and alternative PV/T system designs were included in the works of Zondag et al, 2002 and 2003. The electrical and thermal output of hybrid PV/T systems can be increased by using concentrators of solar radiation of low concentrating ratio as proposed by Al-Baali, 1986. Theoretical models predicting thermal and electrical performance of hybrid PV/T systems with flat booster reflectors are given by Garg et. Al, 1991, or with CPC reflectors by Garg and Adhikari, 1999. The systems are based on air heat extraction and the authors suggest to replace a number of higher cost cells by lower cost reflectors. Recently the work of Brogren et al, 2000, gives interest results from a water cooled PV/T system with 4X CPC reflectors that presents yearly electric output increase by 20%. By concentrating PV/T systems a cost reduction in the PV part is achieved, but continuous orientation is needed, rendering them complex for usual building applications. Stationary booster specular reflectors could be a low cost alternative in achieving higher solar input, but they are not suitable for use with PV modules, because the variation of the reflected solar radiation results to a non uniform density of illumination on the PV surface, reducing the electrical efficiency of the system. The increase of the total energy output of the hybrid PV/T systems can be achieved by using diffuse reflectors of aluminium sheet, as boosters, which give an almost uniform distribution of the reflected solar radiation on PV surface. The booster diffuse reflector applied to hybrid PV/T systems with additional glazing, can balance the negative effect of the reduction of the incident solar radiation on PV surface from the additional glazing, with the positive effect of the increased solar radiation input from the diffuse reflector. Regarding the cost of the hybrid PV/T systems, the thermal unit for the system with the pc-Si PV module and heat extraction by water circulation increases the system cost by about 8 %, considering the cost of the plain pc-Si PV module as base. If we include the cost of external pipes and other components for water circulation we have a total cost increase of about 10 %. In hybrid systems with heat extraction by air circulation, the cost increase is about 5 %, only for the thermal unit of the system used with the pc-Si PV module, and about 8 % if the system includes a

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complete forced air 3 circulation system. The corresponding cost increase for the PV/T systems with the additional glazing is about 10% and for the additional diffuse reflector is about 5%. The cost increase of hybrid systems with a-Si PV modules is relatively higher (about double) compared to that with pc-Si PV modules, with equal aperture area for both PV module types. This is explained as the thermal unit is of the same cost, but the a-Si PV modules are of lower cost (almost half) compared to pc-Si PV modules. In all hybrid PV/T system applications the additional cost of the complete thermal part (heat extraction from PV modules, working fluid and flow mode, circulation pipes, pumps, system thermal energy storage, etc) must be compared to the cost of the plain PV installation, calculating the electrical output gain by the PV cooling procedure, in order to optimize the system and make it cost effective. The added thermal unit must be durable, as PV cooling may give to solar cells longer time of acceptable operation than that corresponding to plain PV applications. The cost of the added thermal system can be the same for all PV types used in hybrid systems, for the same heat extraction mode and equal aperture area of PV installation, but the thermal efficiency differs with the PV type, with higher values for a-Si PV modules, because of their lower electrical efficiency and lower optical losses. Details about new concepts and results on PV/T systems one can find in the works of Tripanagnostopoulos et al 1996; 1998; 2000; 2001; 2002.

2.5 Solar Thermal Power Plant

Southern California is chosen for the study as representative of a high solar insulation site. The Power Plant Cycle The solar thermal system, figure: 2, consists of a collector-storage loop (low temperature storage tank to solar collector to high temperature storage tank to boiler and back to the low temperature storage tank) and a simple Rankine cycle loop (Boiler to turbine-generator to condenser to feed pump and back to the boiler).

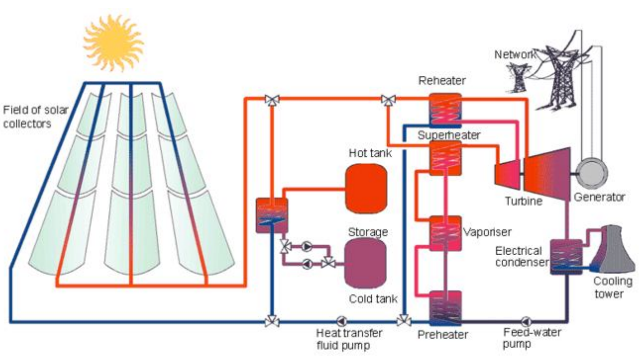

Figure: Solar Thermal Power Plant Cycle

In the collector-storage loop, a heat transfer fluid is pumped through the solar collectors, heated to a high temperature, and then stored in an insulated high temperature storage tank, which is also equipped with an auxiliary natural gas burner for temperature control of the tank. The auxiliary gas burner makes up the difference between the collected solar energy and the heat input needed for the refrigerant loop Rankine cycle to produce 50 kWe. Heat transfer fluid discharged from the boiler is collected in the low temperature storage tank to be pumped through the solar collector again. Refrigerant in the Rankine cycle is evaporated in the boiler, expanded through the turbine, condensed, and then pumped back to the boiler.

Working fluid selection - The Rankine cycle working fluid selection criteria are flammability, toxicity, Ozone epletion Potential (ODP), Global Warming Potential (GWP), consideration of cycle temperatures and pressures, and the 1sl and 2nd law efficiencies. R123 is chosen over all other candidates considered because it is a good thermodynamic match to the operating cycle temperatures, poses not ammability or toxicity hazard, and has acceptable ODP and GWP potentials.

Mineral oil is selected for effective heat transfer of solar radiation from the collector to the cycle boiler. This oil is well below its boiling point at the designed 160°C solar collector output temperature, which allows the collector to operate at atmospheric pressure. This simplifies collector design and enhances safety.

System Components - Table 1 presents the three major categories of solar collectors that are widely used. Note the estimated temperature ranges and combined collector and Rankine cycle efficiencies.

2.6 Land Requirement

An important challenge for solar thermal is the amount of space or land required for efficient production of energy. Not only space, but space that gets a consistent amount of direct beams of sunlight. Solar thermal power plants usually require 1/4 to 1 square mile or more of land or space. One silver lining of global climate change and human impact on the land is that more and more farmland is becoming unsuitable for agricultural production. This land, presumably originally chosen for its sun exposure, begs to be used for solar thermal energy production. Utilization of desertification can prove to be a boon for solar thermal real estate procurement and growth.

With solar thermal technologies being developed and advanced by companies such as eSolar, Brightsource, Abengoa, Acciona, Ausra and Schott Solar, the world has a new alternative. The benefits of eliminating coal from our energy diet are many. By not burning fossil fuels, countries can be truly energy independent. Also, by limiting, and hopefully eliminating, carbon emissions, a nation's pollution will not be windswept into another nation's territories, further cementing the concept of independence. Solar thermal plants are being built around the world, and many new planned plants are in the works. Solar thermal is the current solar electricity cost champion, but more improvements are needed to beat the cost of the lowest-cost fossil fuels in a legislative climate without subsidies or carbon taxes.

2.7 Performance Analysis of a Double Pass Thermoelectric Solar Air Collector

"Over the last few years, different PV/T systems, based on air and water as heat carrying fluid, have been studied, developed and reported in literature. For example, Kalogirou has studied experimentally an unglazed hybrid PV/T system under the force mode of operation for climatic condition of Cyprus. He observed an increase in the mean annual efficiency of a PV solar system from 2.8% to 7.7% with a thermal efficiency of 49%. Hagazy and Sopian et al. investigated a glazed PV/T air system for a single and double-pass air heater for space heating and drying purposes. They have also developed a thermal model of each system. Thermal energy for the glazed PV/T system is increased with lower electrical efficiency due to high operating temperature. However, there is another technology for combined electrical and thermal energies namely: thermoelectric (TE) technology. The term TE refers to solar thermal collectors that use TE devices as an integral part of the absorber plate. The system generates both thermal and electrical energy simultaneously. A TE device for power generation consists of n and p semiconductors connected electrically in series and thermally in parallel. Heat is supplied at one end of the TE, while the other end is maintained at a lower temperature with a heat sink . As a result of the temperature difference, a current flows through an external load resistance. TE has the advantage that it can operate from a low grade heat source such as waste heat energy. It is also attractive as a means of converting solar energy into electricity. A number of simulations as well as experimental studies have been reported on solar-driven TE power generators. Chen derived a thermodynamic analysis of solar-driven TE power generator based on a well-insulated flat plate collector. A thermodynamic model including four irreversibilities is used to investigate the optimum performance of a solar-driven TE generator. The example discussed by Chen is based on an extremely well-insulated flat plate collector, which, in practice, may be difficult to achieve. Gunter et al. constructed a prototype of a solar thermoelectric water heater. The hot side of TE module was heated by solar hot water. Meanwhile, the heat was released at the cold side of TE module via a heat sink. Three vacuum tubes with heat pipes, each with a 0.1m2 absorber area and with water as the heat pipe medium, were connected via a specially designed heat exchanger to a fluid circuit acting as a heat sink. Test result showed that the electrical efficiency reached a maximum value of 1.1% of the incoming solar radiation, which is around 2.8% of the transferred heat. Scherrer et al. presented a series of mathematical models based on the optimal control theory to assess the electric performance of a skutterudites-based solar TE generator as a function of sun-spacecraft distance, and optimized its design parameters (such as dimensions, weight and so on) when operating at a distance of 0.45 a.u. from the sun, for 400Welectrical output power and for a required load voltage of 30 VCD. The simulation results indicated that the skutterudites-based solar TE generator offered attractive performance features as primary or auxiliary power source for spacecraft in near-Sun missions. Maneewan et al studied a thermoelectric roof solar collector (TE-RSC) to reduce roof heat gain and improve indoor thermal comfort. Maneewan's TE-RSC combined the advantages of a roof solar collector and TE to act as a power generator. The electric current produced by the TE modules was used to run a fan for cooling the modules and improve the indoor thermal conditions. The subsequent simulation results, using a real house configuration, showed that a TERSC unit with a 0.0525m2 surface area could generate about 1.2W under solar radiation intensity of about 800W/m2 and at ambient temperatures varying between 30 and 35 1C. The induced air change rate varied between 20 and 45 ACH (number of air changes per hour) and the corresponding ceiling heat transfer rate reduction was about 3–5W/m2. The electrical conversion efficiency of the proposed TE-RSC system is 1–4%.

This paper is about the testing and development of TE solar air heater to determine its performance in Thailand. The theoretical model and testing were within experimental error of each other. The results showed that with an air flow-rate of .123 kg/s the overall efficiency was 80.3% with the electrical efficiency of around 5.7%.

TE uses the same idea of thermocouples, ie. The higher the difference in temperature, the higher the voltage. So by cooling one side of the TE and collecting that warmer air, the thermal and electrical efficiency goes up.

4 Conclusion

Finally it can be said that a solar thermal power conversion process should follow all the procedures coorectly.

Acknowledgment

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