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Integrated Solar PV and Thermoelectric Energy System: A Review

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Abstract: *The market of solar thermal and photovoltaic electricity generation is growing rapidly. New ideas on hybrid solar technology evolve for a wide range of applications, such as in buildings, processing plants, and agriculture. In the building sector in particular, the limited building space for the accommodation of solar devices has driven a demand on the use of hybrid solar technology for the multigenerational of active power and/or passive solar devices. The importance is escalating with the worldwide trend on the development of low-carbon/zero-energy buildings. Hybrid photovoltaic/thermal (PVT) collector systems had been studied theoretically, numerically, and experimentally in depth in the past decades. Together with alternative means, a range of innovative products and systems has been put forward. Final success of the integrative technologies relies on the coexistence of robust product design/construction and reliable system operation/maintenance in the long run to satisfy the user needs. This paper gives a broad review on the published academic works, with an emphasis placed on the research and development activities in the last decade.*

Keywords: *solar; Photovoltaic; thermoelectric; power generation; water heating*

I. Introduction

In Recent years, the fast development and the growing demand of comfort have increased the energy consumption, and surging oil and gas consumption and increasing environmental awareness have prompted more and more sustainable development [1]; originally born as a problem of ethics and morality, the development of alternative energy sources has become a pressing requirement since the global pollution problem has become relevant. Over the last decade, photovoltaic (PV) technology has attracted strong interest of the industry and of many researchers [2]. Research on solar cell has been carried out since 1960, and different technologies have been proposed to reduce the material and to increase the production capacity.Currently, silicon modules represent the leading PV technology because of both their capability to provide high efficiency and the great availability of silicon material on the earth. In particular, mono crystalline solar cells offer the highest efficiency of more than 20% [3]. Two alternative typologies developed to reduce the cost in PV modules production are: 1) the polycrystalline silicon that provides worse performance in terms of efficiency (13%–16%) and 2) the amorphous silicon that offers low efficiency (6%–9%), but is less affected by high temperatures and shading.With respect to the PV cells based on crystalline silicon, thin-film technology is less expensive since it uses few materials and less manufacturing process. Depending on the technology, thin-film module prototypes have reached efficiencies between 7% and 13% [4-5].

Despite PV is considered a commercially mature technology, the efficiency of the PV plants is still quite low; therefore, in the best of cases, about 80% of the potential energy available would be wasted. On the other hand, this technology continuously reduces its cost and requires technical advance and new research for efficiency increment [6-7]. Therefore, many researchers have focused on the reduction of the losses that affect solar panels such as losses caused by the sunlight, the conditioning circuit required, the energy storage system, the Joule effect, and so on [8-9].

The rest of research paper is design as follows. The overall previous work is described in Section II. Section III describes problem formulation. Performance parameter describe in section IV. Finally, Section V describes the conclusion of paper.

II. Literature Review

This section will provide the brief description and highlights the contribution, remarks and factors of the work done by the researchers. Many attempts have been made in the past to achieve the maximum accuracy while segmented the images

A. Makki et al (2016) demonstrated photovoltaic cells in which generate electricity can be used as on flat panel roof application, such on houses, buildings and in solar farms. While solar thermal technology can be harnessed for two distinctive applications; electricity is generated by steam mechanical engines, which usually used in large power plants, or providing hot water, which generally demonstrate in domestic application [1].

M. Li et.al (2015) demonstrated solar collectors are special type of heat exchangers, which transform solar radiation energy into thermal energy. It is a key element of a solar thermal system, where the incoming solar radiation is absorbed and transformed into useful heat. The useful heat is convey from the absorber to circulating fluid, where the hot water can be generated [2].

Z.M. Yang et.al (2015) studied about hot water can be used either straightaway or to be stored in storage tank, where it can be used at night and/or cloudy days. The solar collectors and thermal energy storage are the two essential parts in a solar thermal system. The solar collectors should have excellent optical performance; that is, absorbing as much as possible and release the heat at the needed speed [3].

B. Huang et.al (2014) demonstrated the stationary collectors can heat the water up to 100°C, concentrator collectors usually used to heat water to above than 100°C. The stationary collector has the same area for intercepting and absorbing solar radiation. It has a simple structure and does not need a

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tracking device. However the energy density of stationary collector is relatively low and will not be able to reach very high temperatures [4].

T.T. Chow et.al (2014) elaborated the concentrating solar collector usually has concave reflecting surfaces to capture and directs the solar beam radiation onto a smaller receiving area, thus increasing the radiation flux It can have relatively high energy density and reach much high temperature. However, the concentrating solar collector involves complicated structure and need accurate tracking system. a number of solar thermal collectors available in the market [5].

T.T. Chow et.al (2014) studied about generate electricity from thermal energy (steam). The CSP market has been growing rapidly over the past a few year with the total global capacity of thermal power of 269.3 GWth, and 2,550 MW of electric power,while only 139 GW of electricity globally generated by Solar PV (European Photovoltaic Industry Association–EPIA, 2014.). The capacity of CSP installed in Spain in 2012 doubled relative to 2011, shows that the total world solar thermal capacity in 2014 increased by around 80% compared to 2007 [6].

G. Peiet.al (2013) studied applications of concentrator solar thermal energy is to generate electricity by the technology referred to as concentrator solar power (CSP) technology. The principle of power generation is that the steam is generated through solar radiation, and that the steam generated is used to operate turbines that rotate electricity generators so as to generate electricity. The sun light is captured by a variety of solar collectors which provide heat that is then used for several applications, including heating water for domestic uses. Water is heated to between 50° and 60°C; nonetheless, for applications that need higher temperatures, such as higher than 100°C, a special type of solar collectors, concentrator collectors are used [7].

D. Yang et. al (2013) elaborated the photovoltaic solar cells, solar concentrator converting the energy from sunlight to electricity by concentrating sunlight by collector (usually use mirrors) and reflect the light energy into receivers that convert it into heat, circulated fluid in the receiver catch the heat and become steam to rotate engine, rather than the photovoltaic which effect that directly transfers photon energy into electricity energy [8].

E.A. Chavez-Urbiola et. al (2012) indicated that concentrator solar system generate steam which be able to produce electricity by rotating various types of turbines, including steam gas turbines or Stirling engines. Concentrator collectors collect light from a large area and concentrate it in a small area; hence, because of this concentration higher temperatures, from some hundreds up to 1000°C, are attained [9].

Y. Vorobiev et al. [2011] reported an experimental realization of a combined dye sensitized solar cell (DSSC) PV and TEG system. The reported efficiency of the PV alone in the combined PV + TEG system is 9.39 % whereas the total efficiency of the PV + TEG is 13.8 %, although the temperature span of the TEG was reported to be just 6.2 ^{0}C [10].

Marlow Industries [2014] meaned that the efficiency of the TEG is at least 4.87 %, when all excess heat passes through the TEG. This is the same value of efficiency as the reported efficiency of commercial TEG modules at a temperature span of 200 ^{0}C, for which the efficiency is 5 % [11].

The commercial module used in ***H. Hashim et al. [2012],*** a Micropelt MPG-D602, has approximately a maximum power produced of 0.25 mW at a temperature span of 5 K and correspondingly a total heat flux of 0.35 W thus resulting in an efficiency of approximately 0.07 % based on the official documentation , a number drastically different than the 5% reported. Furthermore, the Carnot efficiency, hCarnot = DT Thot for a room-temperature TEG with a temperature span of 6.2 ^{0}C is 2.1 % and so the reported results clearly appear unphysical [12]Similar results were obtained by ***Hsueh et al. [2015],*** who studied an experimental realization of a coupled thin film CIGS solar cell with a TEG. Here the efficiency of the PV alone in the combined PV + TEG system was 16.5 % whereas the total efficiency of the PV + TEG was 22.02 %, although the temperature span of the TEG was reported to be just 11.6_C. This suggests a minimum efficiency of the TEG of 6.61 %, at a very small temperature span [13]

Y.-Y. Wu et al. [2015] constructed a PV + TEG system and observed an increase in efficiency from 12.5 % to 16.3 % , corresponding to an increase in power output by 30%, although the temperature gradient across the TE device was 15 ^{0}C. Given the application of 127 legs with a cross sectional area of 6:4 10 × 3 cm^2 and m length of 0.05 cm [14]

III. Problem Formulation& Challenges

Table 1 summarizes main challenges for grid-connected hybrid solar PV and wind systems with possible solutions or mitigations. Similarly, main challenges and solutions/ mitigations for stand-alone systems are summarized in Table 2.

IV. Objectives of Hybrid Solar PV and Thermo Electrical System

From the literature review, it can be seen that the thermal efficiency of the SHPTE hybrid is comparable with and not much lower than that obtained with the present application of the ETHPSC for solar water heating. However, its electrical efficiency is low, about less than a few percent. At the present moment, because thermo electrical modules are quite expensive, the hybrid system does not seem to be commercially attractive although solar energy is free. Future research studies are encouraged to develop new TE materials in order to reduce the cost of TE modules. Studies are also required to determine the performance of employing stacked TE modules. In line with this, system design involving incorporating

TE and heat sinks needs to be developed further to improve the total conversion efficiency. Very little work has been carried out to determine the system performance based on actual weather condition. More works need to be carried out based on actual operating weather conditions.

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Table 1: main challenges and possible solutions for grid-connected system

Sr. No	**Challenges**	**Solutions**
1	Voltage fluctuation due to variations in wind speed and irregular solar radiation	Series and shunt active power filters. Power compensators such as fixe/switched capacitor or static compensator. Less sensitive customer's equipment to power disturbance/voltage distortions and utilities line conditioning systems
2	Frequency fluctuation for sudden changes in active power by loads	PWM inverter controller for regulating three- phase local AC bus voltage and frequency in a micro grid.
3	Harmonics by power electronic devices and non-linear appliances.	PWM switching converter and appropriate filters.
4	Intermittent a energy's impacts on network security	Accurate statistical forecasting and scheduling systems. Regression analysis approaches and algorithms for forecasting weather pattern, solar radiation and wind speed. Increase or decrease dispatchable generation by system operator to deal with any deficit/surplus in renewable power generation. Advanced fast response control facilities such as Automatic Generation Control and Flexible ACA Transmission System.
5	Synchronization	The most popular grid synchronization technique is based on phase-locked loop. Other techniques for synchronization include detecting the zero crossing of the grid voltages or using combinations of filters coupled with a non-liner transformation.

Table 2: Main challenges and possible solutions for stand-alone system

Sr. No.	**Challenges**	**Solutions**
1	High storage cost	Combining both PV solar and wind powers will minimize the storage requirements and ultimately the overall cost of the system.
2	Less usable energy during the year.	Integration of renewable energy generation with battery storage and diesel generator back-up systems.
3	Intermittent energy / power quality	Integration of renewable energy generation with battery storage or fuel cell and in some cases with diesel generator back-up systems.
4	Protection	Suitable protection devices need to be installed for safety reasons including up gradation of existing protection schemes in particular when distributed generators are introduced.
5	Storage runs out	Integrate PV and wind energy sources with fuel cells.
6	Environmental and safety concerns of batteries and hydrogen tanks.	Integrating PV and wind energy sources with fuel cells instead of large lead-acid batteries or super storage capacitors, leads to a non-polluting reliable energy source and reduces the total maintenances costs.

V. Conclusion

This paper has provided a review of challenges and opportunities on integrating solar PV and wind energy sources for electricity generation. The main challenge for grid-connected system as well as the stand-alone system is the intermittent nature of solar PV and wind sources. By integrating the two resources into an optimum combination, the impact of the variable nature of solar and wind resources can be partially resolved and the overall system becomes more reliable and economical to run. This definitely has bigger impact on the stand-alone generation. Integration of renewable energy generation with battery storage and diesel generator back-up systems is becoming a cost-effective solution for stand-alone type. The wind-battery-diesel hybrid configuration can meet the system load including peak times.

Energy management strategies should ensure high system efficiency along with high reliability and least cost. Good planning with accurate forecasting of weather pattern, solar radiation and wind speed can help in reducing the impact of intermittent energy.

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