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Technical-economic study of cooled crystalline solar modules

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ABSTRACT

Methods of cooling monocrystalline and polycrystalline solar modules with water vaporizing are analysed in the paper regarding the effects of temperature on performance and its economic relations. Since water usage may present a significant cost the aim of the research was to create a cooling system that operates without loss of flowing water. Results are evaluated from technical and economic points of view in relation to several countries based on systems with 5 kW capacity. Ideal setting of spray heads at 2 bar pressure was achieved with a distance of 0.26 m between the spray heads. In our experiment, a temperature following procedure was tested manually. Due to this procedure, the surface of the module can be cooled with an average temperature value that is calculated after cooling, depending on the temperature of the control solar module. Analysing the daily data of monthly production the number of "ideal days" in a given month were estimated. Comparing the temperature decrease as a result of vaporization measured in summer and in autumn showed no significant difference. The results achieved confirm the connection between temperature change and efficiency change of monocrystalline and polycrystalline solar modules (0.5%/1 °C), discussed in previous scientific literature. Effective application of solar module cooling systems is around 10–15% more expensive than the cost of systems without cooling. In general, under current economic conditions the operation of cooled solar modules is viable mainly in South European countries.

1. Introduction

Since the energy demand of mankind increases continuously, utilization of renewable energy resources is increasingly important besides reducing environmental effects. Solar energy is a clean and sustainable energy resource available in huge volume with greatest potential for all humans (Sahu, 2015; Hosenuzzaman et al., 2015). Around $8 \cdot 10^8$ TW h energy arrives to the surface of the Earth from the Sun each year equalling a potential around 8000 times greater than the energy demand of the world (Roth, 2005).

In recent years the distribution of solar modules developed rapidly mainly due to decreasing production costs, fast technological development and state support introduced in several countries. Nowadays the production costs of the photovoltaic (PV) systems and therefore their price is decreasing as well so the installation of the PV systems has shorter return time of investment. According to the data of Renewables, 2015 GSR the total installed performance of solar PV systems was 23 GW in 2009. This capacity increased to 117 GW by 2014 (REN21, 2015; IEA, 2014).

Spreading of solar PV systems has been intensified since the turn of the millennium due to the decreasing investment costs and the development of the technology. In recent decades certain examples show an increase of 40–90% of the total installed performance of installed systems with 40% decrease of investment costs in a year (REN21, 2015; Jäger-Waldau et al., 2011; Jäger-Waldau, 2013, 2011). Further reduction of investment costs can be achieved only by significant development of the production technology or by finding new processes or basic material.

Silicium based crystalline solar modules are the most widespread worldwide. These types react most sensitively to temperature rise influencing negatively electric energy production. As a result, one of the most effective methods of enhancing performance is to cool down the solar modules. In aim of this research was to study the effects of cooling with water as water is capable of releasing significant amount of heat. For this reason a vaporizing cooling system was created.

Several factors can influence the efficiency of utilizing solar energy arriving onto the Earth (Garcia and Balenzategui, 2004).

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One of the important factors in the case of solar modules is temperature undulation caused by the changing of daily temperature and global irradiation (Skoplaki and Palyvos, 2009; Alami, 2014). During hot days in Hungarian climatic conditions the temperature of solar modules may reach 60–70 °C. Due to its high temperature, the energy production of solar modules decreases, however, this could be solved by various cooling technologies (Chandrasekar et al., 2015). According to Bahaidarah et al. (2013, 2016), Zaoui et al. (2015), the performance of photovoltaic modules depends strongly on the temperature of operation.

Efficiencies in electricity production of 25.6% ± 0.5% and 20.8% ± 0.6% can be found in the case of monocrystalline and polycrystalline solar modules available in the market and their share of the market is around 85–90% due to their reliability (IEA, 2014; Green et al., 2015; Cosme et al., 2015; P.Corporation, 2014; Verlinden et al., 2014). The produced heat is not only lost but it also reduces the amount of producible electric energy. High module temperature limits the current energy production in the short-term and accelerates the ageing of solar modules in the long-term (Ndiaye et al., 2014; Kahoul et al., 2014). Reduction of efficiency may vary according to the type of the solar module. In the case of silicium based crystalline models, efficiency decreases by 0.5% with 1 °C of temperature increase (Skoplaki and Palyvos, 2009; Chandrasekar et al., 2015; Radziemska and Klugmann, 2002).

Simultaneous with the universal application of solar modules and the increasing number of installations research and development activities focusing on avoiding and solving the short-term and long-term efficiency decrease mentioned above become more of an issue. For this various active and passive cooling procedures can be applied with which the operation temperature of solar modules can be controlled (Elnozahy et al., 2015; Du et al., 2012). According to Chandrasekar et al. (2015), four groups of cooling techniques can be identified, namely air based, water based, heat exchanger/coolant based (Ji et al., 2008) and heat based categories.

This paper focuses on water based procedures (water vaporizing). In the case of vaporizing with water evaporation decreases the operation temperature of solar modules compared to modules operating in similar conditions without cooling (Abdolzadeh and Ameri, 2009). Change in temperature-efficiency thus temperature-performance is linear (Skoplaki and Palyvos, 2009). Performance of solar modules in shade free, ideal conditions is influenced dominantly by two factors, global irradiation and temperature (Skoplaki and Palyvos, 2009).

According to Skoplaki and Palyvos (2009), 1 °C increase of module temperature results in 0.3–0.5% of efficiency loss in general, however, according to Chandrasekar et al. (2015), this efficiency loss is 0.5% in the case of crystalline solar modules. On a typical summer day with 58 °C of module temperature (Odeh and Behnia, 2009) detected efficiency rise of 4–10% when the module surface temperature reached 26 °C. Similar water vaporizing experiments of Abdolzadeh and Ameri (2009) showed that 23 °C temperature decrease resulted in 17% efficiency increase.

The quantity of energy which can be produced by a solar PV module mainly depends on its type and composition, the joint effects of the location and the current environmental factors. Modules were tested and certified under laboratory conditions where their nominal performances were established (STC - Standard Test Conditions, AM = 1.5 air mass, 1000 W/m^2 solar radiation, and 25 °C module temperature). However, these conditions were not given during operation, so PV modules typically do not reach their nominal performance (T.S.A.Inc., 2015).

Fluctuating energy production is a severe disadvantage of photovoltaic modules as it shows a great difference depending on the period of use in terms of both the given part of the day and the actual season. Off grid systems can surmount this disadvantage only to a limited extent and they call for especially costly electric current storage equipment. In many countries it is possible for even residential customers with household-sized power plants to feed the energy produced by PV modules into the national grid.

In the analysed countries it is possible for residential customers to input energy produced by solar modules into the national electricity network in the framework of Household Size Small Power Plant System (HSSPPS). In the system delivery price of the produced energy is not guaranteed. Instead the electric energy produced by solar modules is bought by the service provider at actual price for electric energy (gross 0.112 EUR/kW h) if electric energy consumption of the consumer is less than the energy it produces and it does not exceed the nominal performance of 50 kW (Pintér et al., 2015; E_ON, 2015a). Above this value, between 50 kW and 20 MW and between 20 MW and 50 MW delivery prices are 0.10 EUR/W h and net 0.09 EUR/kW h respectively (E_ON, 2015b). Differences between prices indicate well that it does not worth for residential consumers to produce electric energy exceeding the consumption of the consumer.

In Croatia residential consumers receive step-like pricing for electric energy supplied into the electricity network according to the following:

- in the case of a system below 10 kW: 0.344 EUR/kW h,
- between 10 and 30 kW: 0.291 EUR/kW h,
- above 30 kW: 0.215 EUR/kW h.

A contract is made between the energetic market operator in Croatia (HROTE) and the producer for 14 years (Z.Energija, 2015; U.Nation, 2012).

Delivery of residential produced electric energy in Spain is composed of two gears giving pricing of 0.283 EUR/kW h and 0.15675 EUR/kW h until 20 kW of system capacity and above 20 kW respectively. Contracts cover 30 years (P.Magazine, 2015a).

In Australia residential consumers can also input energy produced using solar modules into the national electricity network. Most solar PV systems have a performance of 1.5–10 kW. Delivery price does not depend on capacity (Synergy, 2015; Martin, 2013).

In the USA the price of energy supplied into the national network from solar modules is also independent of PV system size. In the case of San Diego (California) the time frame of the contract is 10, 15 or 20 years while in the case of Miami (Florida) it is 20 years (O.U.C. (OUC), 2015; P.Magazine, 2015b; C.P.U. Commission, 2015).

2. Methods and details of the technical and economic assessment

The aim of the current research was to create a vaporizing cooling system that on the one hand would operate without loss of flowing water and on the other hand focuses only on the cooling effect resulting from the heat of the evaporation of water and on the achieved efficiency increase and performance maximum. Technical and economic evaluation of the results was compared to solar modules without cooling. Justified application of vaporizing cooling systems is determined in the case of Hungary and of other countries with more favourable climatic conditions and a reliable regulation of green energy delivery. Another important factor for the application of the vaporizing technology was the access to water nearby for water supply.

Countries and locations analysed were the following:

- Hungary (Keszthely and Siófok)
- Croatia (Šibenik)
- Spain (Murcia)