Preliminary study and experimental test of Peltier cells for a potential implementation in a renewable energy device.

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Abstract: - The present work focuses its attention about the need of implementation of a cooling system for photovoltaic cells. In fact the efficiency and technical lifetime is strongly affected by temperature of photovoltaic cell and this is a fundamental topic for every installation but above all in the cases of regions with a very hot climate or for concentrated photovoltaic plants. In a specific way it is proposed preliminary evaluations and study for a potential use of a thermoelectric cooling system for PV, based on Peltier cells. An overview of Peltier cells, treating about their functionality, properties and possible applications, is presented. It is performed an experimental phase, which is based on the creation of the setup and preliminary tests on Peltier cells for the next implementation in a cooling system for PV cells.

Key-Words: - Peltier Cell, Photovoltaic Cell, Seedback Effect, Renewable Energy.

1 Introduction

Today the topic of energy is a crucial point for the future development of the human society. Humanity needs an increasing quantity of energy in the future and the interesting estimation of Energy Outlook of Energy Information Administration EIA quantifies a boost of +55% for the worldwide consumption of energy in the next thirty years [1]. All scientific community agrees about the idea that conventional sources of energy will finish a day. It is no easy to foresee this day and besides it is a strong challenge to find new energy sources able to override the conventional ones.

In this scenario there is an increasing interest for renewable energy sources as wind and solar energy, which are candidates as future potential contribute for the reduction of consumptions of conventional energy sources or for the complete substitution of them [2].

Solar energy is one of the most widely adopted renewable energy sources, that can be implemented in various applications. For example thermal management using thermal collectors or electricity generation through special optical solar cells as Photovoltaic cells (PV).

PV cells are semiconductor systems, which convert the solar energy in electrical energy.

High capital cost and low conversion efficiency are known as the two main obstacles to globalize the use of solar power and particularly of photovoltaic panels. For this reason the international scientific community is performing any effort to improve the efficiency of conversion of these systems and to increase the final output power obtained.

The efficiency rate of the system depends by the type of semiconductor material, used for the creation of the solar cell. At the present in function of the used semiconductor material, efficiency varies from 7 and 40% under optimal operating conditions [3].

Besides the semiconductor material, adopted for the construction of the PV cells, many other issues are able to influence the performance of these elements. For example elevated temperature and dust accumulation are fundamental problems in any application but above all in desert regions with a very hot climate.

We focus on the topic of the influence performed by temperature of the cells on the efficiency.

2 Cooling of PV cells

The photovoltaic cell can absorb about 80% of the solar incident energy but only a portion is converted in electrical energy. The residual part will be dissipated as heat, which will carry to an increase in the temperature of the photovoltaic module.

A PV module can reach temperatures as high as 40 °C above ambient. This is due the fact that PV cells convert a certain wavelength of the incoming irradiation (visible spectrum plus some part of the infrared spectrum), that contributes to the direct conversion of light into electricity, while the rest is dissipated as heat [4].

This heat and the increasing temperature not only have an influence on the efficiency but also on the technical life-time of the cell. In the recent years prices of solar cells are progressively decreasing and industries are focused on ensuring the maximum energy system production (kWh/kWp) and to improve the lifetime because longer lifetime means longer energy generated by the system. In this way the cost of photovoltaic solar energy ($/kWh) can decrease [5].

In the first subsequent picture it is showed the influence on the output power of a single-crystalline silicon PV cells for different operating temperatures.

In the second image it is illustrated the temperature dependence of the maximum output power [6, 7].

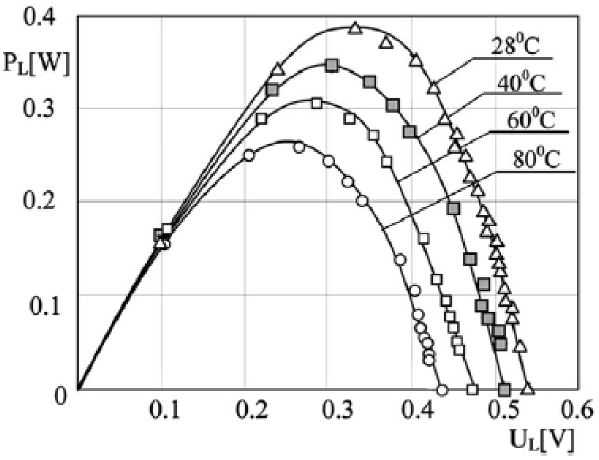

Figure 1: Output power of a single-crystalline silicon PV cells for different operating temperatures.

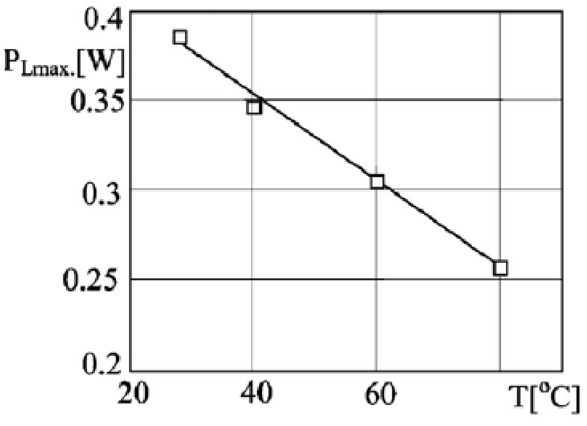

Figure 2: Temperature dependence of the maximum output power for a single-crystalline silicon PV cells.

The function of the efficiency and lifetime of photovoltaic cells with temperature is a potential problem of every application (especially in very hot climate) but above it is strongly adverted in the case of Concentrated Photovoltaic (CPV) .

For this application the use of mirrors permits to obtain illumination fluxes 500-2000 times higher than natural light [8]. In this case the amount of dissipated heat is extremely high.

In all applications and especially in concentrated PV designs it can be useful to integrate a solar cell cooling system to extract the heat not converted in electricity. The aim is to prevent excessive cell heating and the consequence of deteriorated performance and lifetime.

Various methods can be employed to achieve cooling of PV systems. However, the optimum cooling solution is critically dependent on several factors such as, PV technology employed, types of concentrators' geometries, and weather conditions at which the system is installed. Challenges are mainly present in hot and humid climate regions where cells may experience both short and long term degradation due to excessive temperatures.

Methods of cooling PV panels fall mainly into two categories, namely passive and active cooling [7].

Passive cooling mechanisms refer to technologies used to cool the PV panel without additional power consumption. The mechanism implies transporting heat from where it is generated and dissipating it to the environment [7].

There are many possible passive cooling systems as for example the application of bodies constructed with high conductivity materials (for example aluminum, cooper,….) or the application of fins or protruding surfaces to enhance the heat exchange with environment.

Other passive cooling systems are based on the implementation of phase change materials, circuits for the natural circulation or heat pipes.

An example of this typology is a photovoltaic panel for the roof of an house with heat-sinks, installed on the back sheet of the panel. For this system the heat is dissipated in the environment by surfaces of heat-sinks through natural air convection and radiation. Both mechanisms present a low order of magnitude for this reason an active system is required particularly in applications as installations in hot climate places.

Active systems consume power to improve the extraction of heat for example using fans to force air or pump water [9].

Clearly an active system is implemented in the situations where the added efficiency permits to produce an increment of energy greater than the amount consumed to feed the cooling equipment. These systems can also be used in the situations in which additional advantages can be produced as for example waste heat recovery for domestic water heating.

All technologies used for cooling a PV cell are summarized in the next picture.

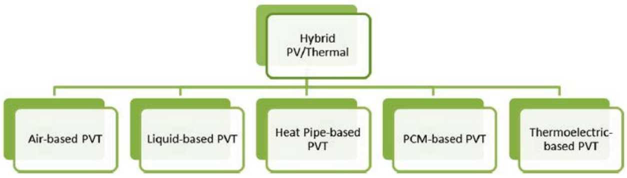

Figure 3: Different heat extraction mechanism.

The present work has the final aim of studying a new cooling system, which falls in the thermoelectric family, depicted in Fig. 3. The system will be based on the technology of Peltier cells.

In the developments of the present activity the commercial Peltier cells will be used in two phases in two different ways.

In the first step of the activity the Peltier cell will be used as a refrigerator system to control the temperature of PV cell. In this situation the aim will be to maintain the system in a wanted operating condition, characterized by a higher efficiency of conversion.

In such system, a fraction of the generated power by the PV cell is fed to the Peltier module to provide the necessary cooling effect for the cell. The cooling effect of a Peltier module is characterized by the amount of power supplied, meaning the more electricity is fed into the TEC module the greater the cooling effect for the PV cell. However, there is a trade-off between the net generated power by the system and the power consumed by the Peltier module, in which substantial amount of power is required to achieve significant amount of cooling, which can exceed the generated power by PV cells. Therefore, the ideal situation would be to find the optimal value of the supplied electrical current for the TEC module, which leads to the maximum net generated power [10].

In the second step the Peltier module will be used, in an inverse way, utilizing Seedback effect, to produce an electric energy from the thermal gradient on its two faces, produced by the heat dissipated by the PV cell. In this situation the system will be classified as an hybrid photovoltaic-thermal system (PVT) because heat, that is generated by electrical production of PV cells, isn't simply dissipated in the environment but it is used by the system.

In this way waste heat is used to produce an adding share of electricity.

The subsequent section presents an overview on Peltier cells, focusing on their functionality, properties and possible applications.

3 Peltier Cells

Peltier cells are thermoelectric modules, which present the ability of a direct conversion of thermal energy into electrical one. This is possible thanks to the Seedback effect, discovered by the phisic Thomas Johann Seebeck in 1821. It is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances.

The voltages produced are generally small, usually few microvolts per kelvin of temperature difference at the junction. If the temperature difference is large enough, some Seebeck-effect elements can produce few millivolts but numerous elements can be connected in series to increase the output voltage or in parallel to increase the maximum deliverable current.

The Seebeck effect is responsible for the behavior of thermocouples, which are used to measure temperature differences or to actuate electronic switches that can turn large systems on and off status.

The Seebeck effect is a reversible phenomenon; so if is given a current to the structure, which is composed by a joint between two different metals, it is possible to observe that a temperature difference occurs between two different connected metals. This reverse phenomenon is called Peltier effect, in homage to Jean Charles Peltier, who discovered it in 1834.

It's been demonstrated that the Peltier effect occur not only for the joints between metals but also for those made with semiconductor elements, both natural (silicon, germanium) or artificial.

A common element, which is the basis of a commercial Peltier device, is formed by two dissimilar semiconductor p- and n-.type junctions. These are connected electrically in series and thermally in parallel [11].

Usually to improve the cooling power of cells available on market the common choice is a connection serial-parallel: there are strips made up of individual cells P / N / P (or P / N / N), connected in cascade, in which the area P of the former is electrically connected to the N of the next, and the heads of the individual strips are connected together in parallel.

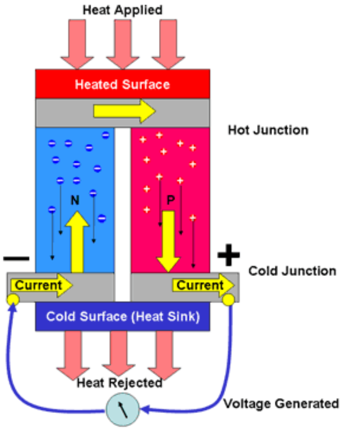

Figure 4: Semiconductor Seedback Effect.

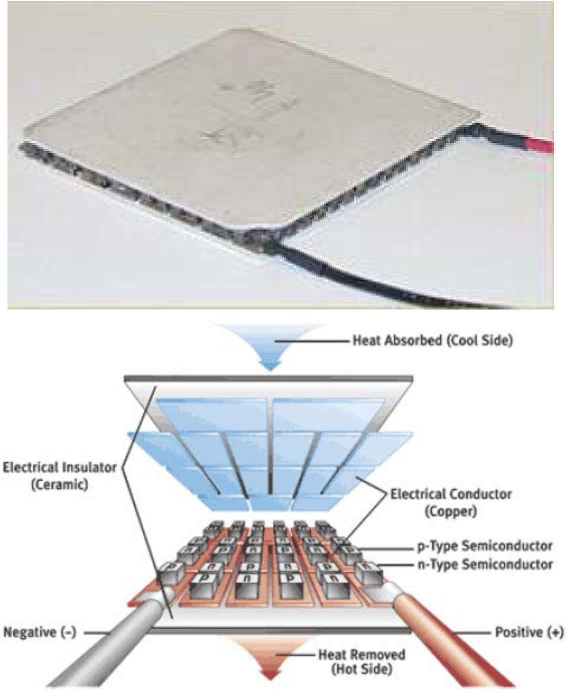

Figure 5: Basic structure of a Peltier cell.

To hold together the various parts there is a wafer structure which is made by placing side by side all the metal plates that connect the semiconductor with a plate of alumina; they are locked to each other with adhesives designed to withstand temperatures of several tens of degrees Celsius without deformation or softening, such as epoxy resin. Connections in series-parallel of industrial Peltier cells permit the construction of devices operating at differences of potential from 5 to 20 volts, which can be easily obtained by energy suppliers [12].

Peltier modules possess salient features of being compact, lightweight, noiseless in operation, highly reliable, maintenance free and no moving or complex parts [13, 14].

Subjecting the cell to a potential difference which allows a passage of a given current through it, an area cools while the other gives off heat. The cold can serve to make small air conditioners, to create portable fridges, to cool chemical solutions, to lower abruptly the temperature of various products or biological compounds, to cool electronic components such as CPU.

In all the application one of the most important parameters to be monitored is the thermal rise that is the temperature difference reached between the hot side and cold side. This temperature difference is specified by the constructor and depends on the current consumption and could be theoretically unlimited: in reality the semiconductor’s thicknesses are very thin and so the heat also diffuses to the cold side. For this reason it is necessary to use a system of heat dissipation to achieve the desired amount of cold and to maintain the temperature below a certain level, thus avoiding damage to the device.

Heat sink is addressed to facilitate the passage of heat from the hot side to the external environment, besides it is useful to isolate as much as possible the environment that faces the cold side from that in which the heat sink radiates heat.

Besides in some applications, characterized by the cooling of elements with very small extension, as for example the cooling of an electronic CPU, can be used a coldplate too.

A coldplate is a small thickness of metal, which is interposed between two surfaces of different sizes to optimize the transfer of heat. In fact without the use a coldplate, a large part of the radiant element (heat sink, the water block or Peltier element) would remain idle as not in contact with the hot part to be cooled.

Figure 6: Coldplate to cool a CPU with Peltier.

After an overview on the Peltier cells, on their functionality, properties and possible applications, it is necessary to summarize also their limits, which penalize the use.

The efficency of the Peltier cell is quite low because the electric energy input is much greater than the thermal energy taken from the cold side and in the reverse use (Seeback effect) only a small fraction of the thermal energy that passes into the cell is effectively converted into electrical energy.

The efficiency η is defined as the ratio between the cooling power Pf and the power PD (I_{max}*V_{max}) for feeding the cell and is about equal to 0,6.

This feature limits the use of the Peltier cell to applications whose power is much reduced.

Besides ad already said in the previous lines, since the cell is crossed by a flow of heat between the two sides, to maximize the difference in temperature compared to the environment of the cold side and to prevent the hot side reaches temperatures harmful to the cell itself (usually around 75 ° C), it is necessary to remove the heat generated by heat sinks, radiators or heat pipes. These lasts typically have dimensions and weights over several orders of magnitude compared to the cells themselves. This implies that the size of a thermal system based on Peltier cells depends mainly by the cooling system of the same.

In the next section it is presented an experimental analysis of two Peltier cells, which will be used in the subsequent step for the cooling of PV cell to improve its efficiency and the amount of energy obtained or to generate electrical energy, using the heat dissipated by PV module for the Seedback effect (hybrid photovoltaic-thermal system).

4 Experimental Analysis

In the effected tests two different Peltier cell models have been used. A greater cell TEC1-28822 and a smaller one TEC1-12715, whose specific characteristics are:

- Number of element:127
- Maximum voltage (Vmax):15.4V
- Maximum current (I max):15 A
- Maximun power:231 W
- ΔT max(Celsius degree):70°
- Qmax(Dt=0):137 W
- Ohm(Ω):1.8-2.4
- Size: 40x40x3.3 mm
- Weight:25 gr

Instrumentation used for tests is composed by a voltmeter, current clamp, multimeters. thermocouples, voltage generator.

The experimental setup is composed by the Peltier cell to be tested, which is connected to a heat sink through thermal conductivity grease.

The heat sink is composed by a computer fan with a pack of metallic fins for the first two tests and by a water heat exchanger for the last one, which is fed by a pump so as to maintain a temperature difference between the two surfaces of the cell. This difference of temperature ΔT was measured with thermocouples.

To analyze the field of temperature of the Peltier cell is used an infrared thermo-camera by Flir.

For all tests the environment temperature is 25 °C.

Figure 7: Instrumentation and experimental set-up with Peltier cell, linked to the water heat exchanger.

In the first test it has been controlled actual operation of first cell (TEC1-28822): connecting it to the voltage generator terminals and, due to its internal resistance, a flow of current is generated, which produces the heating of one face and the cooling of the other. Measures of voltage, current and Δt have been made within 30 seconds of each other. Also measures with thermo-camera have been performed.

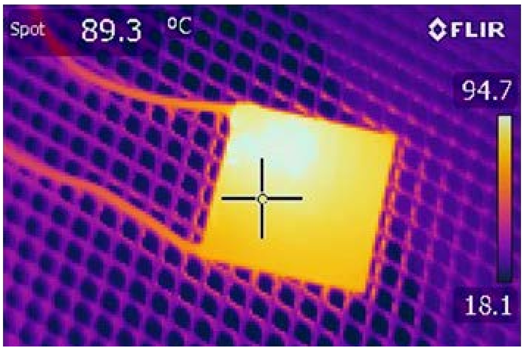

Figure 8: Infrared image of Peltier cell.

Not considering the transitory condition of the first point of measure, in the upper picture of Fig. 9 it is evident the increase for the difference of temperature ΔT, which confirms the efficacy of the system of cooling, adopted for with hot face of the Peltier cell.

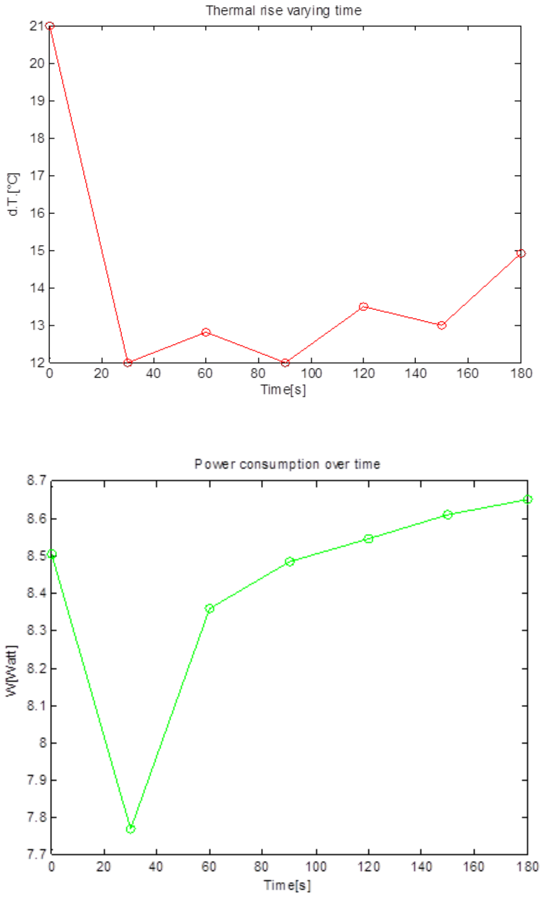

Figure 9: Measures of thermal difference ΔT and power of feeding of Peltier cell in the time (measures performed every 30 s).

The same test is repeated but to highlight the effectiveness of the cooling system, it is turned off at t=90s (fourth point of measure). Besides to accomplish this aim the power to feed the Peltier cell is specifically held constant in the time as it is shown in Fig.10 (where the y-scale is enlarged but power values are in the interval 9-9,07 W).

In this case as it is shown from figure 10, there is an increase of ΔT till t=100s (cooling system on) and a strong decrease after this time due to the off condition of the cooling system. In this phase the heat, produced by the Peltier cell, fed by the voltage generator, is transmitted by the hot face to the cold face without a sufficient dissipation in the environment and the consequent reduction of ΔT.

It is possible to note that in both tests performed, when the cooling system is active, giving similar value of electrical power to the Peltier cell (respectively 8,5 and 9W), the system gains similar values of ΔT (respectively 14 and 15 °C) in similar temporal intervals.

This is the mark of a strong reproducibility of the experimental results.

To improve the cooling system, fan for CPU and metallic fins have been substituted with the water heat exchanger fed by a pump in the experimental setup.

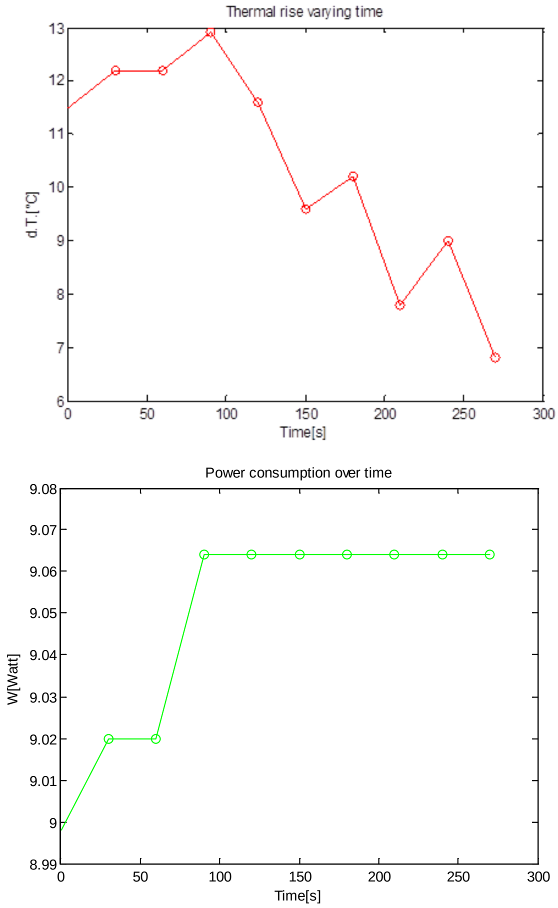

Figure 10: Measures of thermal difference ΔT and power of feeding of Peltier cell in the time in the case of a computer fan on the hot side (measures performed every 30 s).

In the last test the setup configuration with heat exchanger has been used and in this case two Peltier cells have been used. The first one TEC1-28822 is connected to voltage generator to have the thermal rise. This cell is used like an heat source for the second one TEC1-28822. The heat produced from the first device is transmitted to the second one and measures of voltage and current are performed to evaluate the energy conversion produced by the Seebeck effect for the second cell.

Not considering the first measure, Fig. 11 shows clearly the increase of electrical power generated by the Peltier cell TEC1-28822 to the increase of temperature difference ΔT between its hot and cold face.

These measures and evaluation represent the preliminary step for the subsequent experimental phase in which a photovoltaic panel is subjected to a light energy in laboratory controlled condition (using an artificial lamp) and on its back face is applied the Peltier cell TEC1-28822.

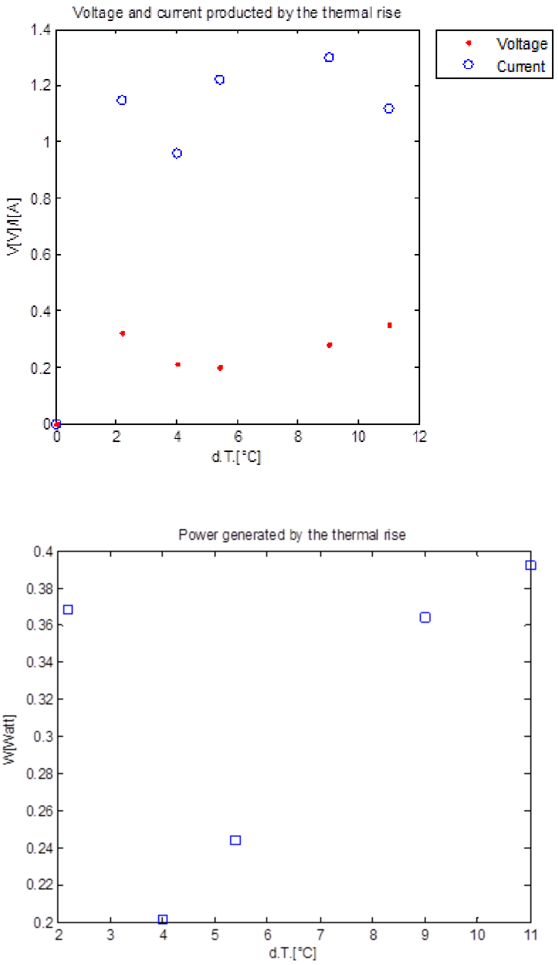

Figure 11: Voltage, intensity of current (upper picture) and power produced by thermal rise in the Peltier cell TEC1-28822.

The Peltier cell will be cooling thorough the water heat exchanger and this setup will be used for two main tests.

First one will be the analysis of improvement for efficiency of the PV cell, controlling the temperature through the feeding of Peltier cell. The final aim is to improve the net electrical energy produced by PV module.

The second one utilizes the Peltier cell to produce electrical current, through the heat dissipated by the PV module and the Seedback effect of the Peltier cell.

Figure 12: New setup with PV element.

Conclusion

The present work has focused its attention about the need of implementation of a cooling system for photovoltaic cells. In fact the efficiency and technical lifetime is strongly affected by temperature of photovoltaic cell and this is a fundamental topic for every installation but above all in the cases of regions with a very hot climate or for concentrated photovoltaic plants.

In a specific way it is proposed preliminary evaluations and study for a potential use of a thermoelectric cooling system for PV, based on Peltier cells.

In the previous pages is reported an overview of Peltier cells, treating about their functionality, properties and possible applications.

Finally, it is presented an experimental phase, which is based on the creation of the setup and preliminary tests on Peltier cells.

Three tests have been conducted, using one or two Peltier cells and two different cooling systems for the cooling of the same Peltier module.

The results obtained will be useful for the next step of the activity, which is the creation and testing of the cooling system for PV cells, based on Peltier devices. These devices will be used not only for the cooling system to control temperature of PV module and to maximize the production of electrical energy but also to convert the heat dissipated by PV in electrical energy, using the Seedback effect.

References:

[1] AA.VV., Energy Outlook 2013 dell'EIA, *EIA Energy Information Administration,* 2013

[2] Di Leo R., Viscardi M., Ferrini G. and. Lecce L, ……………………………………………… ………………………………………………

[3] Kurtz S., Opportunities and challenges for development of matureconcentrating photovoltaic power industry, *National Renewable Energy Laboratory*, 2011, 5200–43208 (NREL/TP).

[4] Luque A, Hegedus S., Handbook of photovoltaic science and engineering. 2nd ed., 2011, West Sussex, John Wiley & Sons.

[5] Chatterjee S. ,TamizhMani G., BAPV arrays: side-by-side comparison with and without fan cooling., in IEEE photovoltaic specialists conference (PVSC), 2011, vol 7, pp537–542.

[6] Radziemska E., The effect of temperature on the power drop in crystalline silicon solar cells. *RenewableEnergy*, 2003, 28, pp.1–12.

[7] Makki A., Omer S., Sabir H., Advancements in hybrid photovoltaic systems for enhanced solar cells performance, *Renewable and sustainable energy reviews*, 41, 2005, pp. 658-684.

[8] Teo H. G., Lee P.S., Hawlader M.N.A., An active cooling system for photovoltaic modules, *Applied Energy*, 90, 2012, pp. 309-315.

[9] Royne A., Dey C.J., Mills D.R., Cooling of photovoltaic cells under concentrated illumination: a critical review. *J. Solar Energy Solar Cell*, 2005, 86, pp. 451–483.

[10] Najafi H, Woodbury K.A., Optimization of a cooling system based on Peltier effect for photovoltaic cells, *Sol Energy*, 2013, 91, pp.152–60.

[11] Elsheikh H.M., Shnawah D.A., SabriM.F.M., Said S.B.M., Hassan H.M., Bashir A.M.B. et al., A review on thermoelectric renewable energy: principle parameters that affect thei rperformance, *Renewable Sustainable Energy* Rev. 2014, 30, pp. 337–355.

[12] Cimmino G., Pedicino P., A Peltier application for thermal and electrical production, thesis of master degree (first evel), *University of Naples Federico II, 2014.*

[13] Omer S.A., Infield D.G.,.Design optimization of thermoelectric devices for solar power generation, *Sol Energy Mater Sol. Cells*, 1998, 53, pp.67–82.

[14] Ahiska R,, Dislitas S., Omer G., A new method and computer-controlled system for measuring the time constant of real thermoelectric modules, *Energy Convers Manage*, 2012, 53(1), pp.314–321.