Study and experimental test of Peltier cells for an energy recovery system in a renewable energy device

MASSIMO VISCARDI[1], ROMEO DI LEO[1]
[1]Department of Industrial Engineering
[1]University Federico II of Naples
[1]Via Claudio 21, 80125, Naples
[1]ITALY
maviscar@unina.it

Abstract: - The present work focuses its attention about the need of implementation of an energy recovery system for a renewable energy device as photovoltaic cells. In a specific way the present paper is addressed to the evaluation of a potential use of Peltier cells to recover waste heat of PV, using the Seedback effect. An overview of Peltier cells, mainly focused on their functionality, properties and possible applications, is initially presented. The results of an extensive experimental test campaign is then presented; these tests have mainly been dedicated to the evaluation of Peltier cells properties in the electrical conversion of heating energy produced and/or not dissipated during the photovoltaic phenomena in siliceous PV cells. The last part of the work presents the results of a parallel test campaign where Peltier cells have been used as thermoelectric cooling devices, in the aim to improve the PV cell performance. In fact the efficiency and technical lifetime of these latter elements, is strongly affected by temperature of photovoltaic cell. This point and the dissipated heat are fundamental topics for every installation but above all in the cases of regions with a very hot climate or for concentrated photovoltaic plants.

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].

Besides they represent a potential contribute to the reduction of greenhouses gas CO_2, which is one on the most important cause of the global warming of the planet. In this frame after the Kyoto meeting on the environment the European Community announced the “2020 targets”. These targets define for the climate change and energy sustainability a greenhouse gas emissions 20 lower than 1990, 20% of energy from renewables and 20% increase in energy efficiency [3]

Solar energy is one of the most widely adopted renewable energy sources, which 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 on the type of semiconductor material, used for the production of the solar cell. At the present in function of the used semiconductor material, efficiency varies from 7 and 40% under optimal operating conditions [4].

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 increasing the final output power obtained and on the influence performed by temperature of the cells on the efficiency.

2 Dissipated heat of PV cells and cooling systems

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.

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 [5].

This dissipated 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 also to improve the lifetime because longer lifetime means more energy, generated by the system. In this way the cost of photovoltaic solar energy ($/kWh) can decrease [6].

Figure 1 shows the influence on the output power of a single-crystalline silicon PV cells for different operating temperatures.

Figure 2 illustrates the temperature dependence of the maximum output power [7, 8].

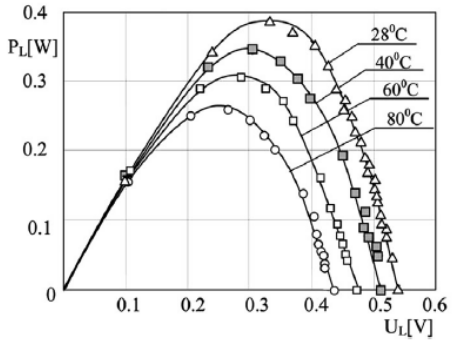


Figure 1: Output power of a single-crystalline silicon PV cells for different operating temperatures.

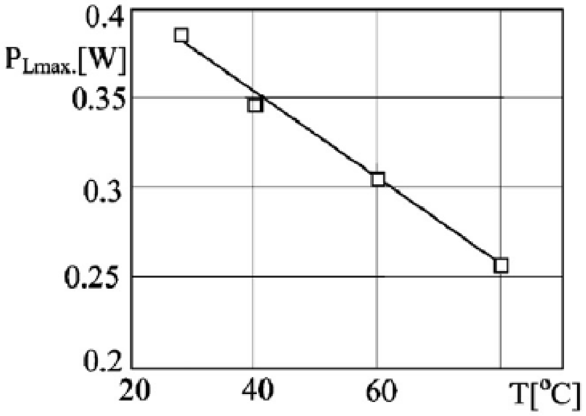


Figure 2: Temperature dependence of the maximum output power for a single-crystalline silicon PV cells.

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 [9]. In this case the amount of dissipated heat is extremely high.

This great amount of dissipated energy can be converted in electrical energy to improve the total amount electrical energy produced by PV panels and to decrease the temperature of PV modules.

For this reason in all applications and especially in concentrated PV designs it can be evaluated the convenience of integrating a solar cell energy recovery system. Besides it can be useful to integrate also a solar cell cooling system to extract the heat not converted in electricity. The aim is to increase the production of electrical energy and to prevent excessive cell heating and the consequence of deteriorated performance and lifetime.

Various methods can be employed to achieve these two goals. For the first one the possible choice is the use of Seedback effect of Peltier cells. Instead for the cooling system, the optimum 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.

Methods of cooling PV panels fall mainly into two categories, namely passive and active cooling [8].

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 [8].

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 [10].

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 Figure 3.

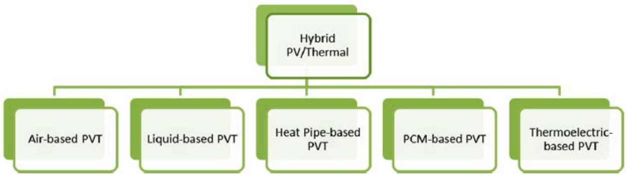


Figure 3: Different heat extraction mechanism.

The present work proposes to analyze the implementation of a Peltier cell, used for the electrical conversion of dissipated heat and also for a cooling system, which falls clearly in the thermoelectric family, depicted in Fig. 3.

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 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.

In the second 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 [11].

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

3 Seedback effect and 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 physicist 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 it is given an electric 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 occurs 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 [12].

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.

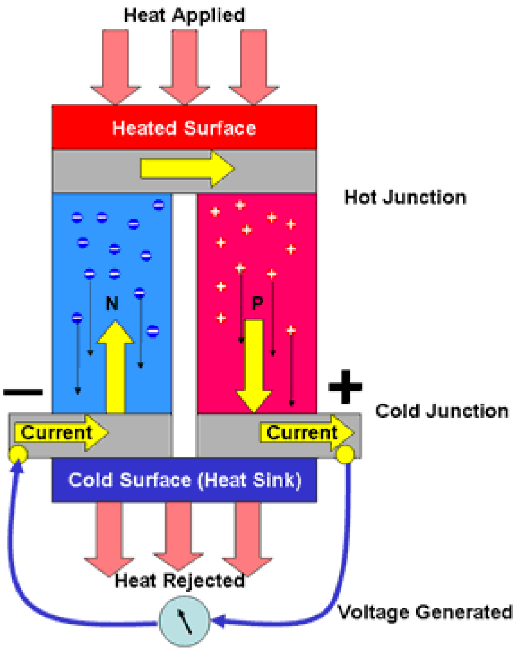


Figure 4: Semiconductor Seedback Effect.

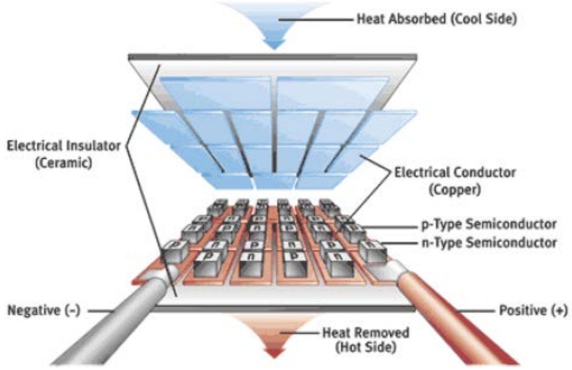


Figure 5: Basic structure of a Peltier cell.

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 [13].

Peltier modules possess salient features of being compact, lightweight, noiseless in operation, highly reliable, maintenance free and no moving or complex parts [14, 15].

Applying a difference of electrical potential to the cell, which allows a passage of a given current through it, an area cools while the other gives off heat.

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 of 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.

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 efficiency 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 as 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, 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 [16]

The next section presents an experimental analysis of a Peltier cell, which will be used in the subsequent step to improve the amount of energy obtained, generating electrical energy thanks to the use using the heat dissipated by PV module for the Seedback effect (hybrid photovoltaic-thermal system).

4 Experimental Analysis

The first experiment campaign has been conducted to evaluate the improvement of power, obtained by PV cell, through the implementation of the Peltier cell, used in a passive way to convert the dissipated thermal energy in electrical one. For this reason it has been prepared the set-up, depicted in figure 6 - 7 and described in the subsequent lines.

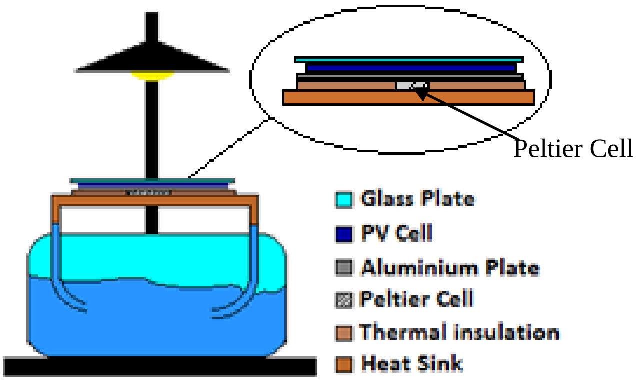


Figure 6: Schematic representation of set up.

Figure 7: Physical realization of Set-up.

The experiments have been conducted using a single photovoltaic cell (Table 1), carefully, covered by a glass plate.

The Photovoltaic cell has been laid on an aluminium plate by means of conductive paste so as to create an homogeneous and improved thermal contact between the two surfaces.

Table 1: Features of PV cell

Type	Polycrystalline cell
Size	156mm x 156 mm
Thickness	190 μm

Front (-)	silver bars for bus (1,6 mm) with anti-reflective coating in blue
Rear (+)	Bearing sealing off 3mm (Ag), rear surface (Al)

Because the Peltier cell (Table 2) covers a smaller surface than the photovoltaic cell, it has inserted an insulating sheet of cork, which surrounds the Peltier cell.

Table 2: Features of Peltier cell

Type	TEC1-12715
Size	40mm x 40 mm
Thickness	4 mm
Maximum power	231W (15,4V x 15A)
ΔT_{max}	70°
R(Ω)	1,8 – 2,5
Weigh	25 gr.

The Peltier Cell is in direct contact with the aluminium plate through its upper surface (there is only specifically inserted a thin film of conductive paste) and in direct contact with the heat exchanger through its upper surface (there is only specifically inserted a thin film of conductive paste). The heat exchanger is connected through pipes to a reservoir of water at ambient temperature.

The subsequent figure shows assembly phases of the system from the level of heat sink versus the glass plate.

Figure 8: 1) Application of lower face of Peltier Cell to the heat sink; 2) Thermal insulation and conductive paste on Peltier cell; 3) Aluminum plate and conductive paste; 4) Application of conductive paste for the electrical link between Al. plate and PV cell; 5) Application of PV cell; 6) Workbench

To monitor changes in temperatures on the two faces of the Peltier cell and on the upper surface of the PV module, it has been decided to use three thermocouples. The first one is appropriately applied on the upper surface of PV, the others, everyone on a face of the thermoelectric device.

The lighting conditions has been simulated using a 220 V lamp placed at different heights. The reason for this choice is due to the fact that our purpose is of monitoring the operation of the photovoltaic cell coupled to Peltier cell, to improve the energy production. This requires laboratory controlled conditions and at the present not the use of a variable sunlight. This step it will be eventually faced to monitor the use of the photovoltaic cell coupled to Peltier cell in the natural operative environment. Such point is crucial for the measurements performed because the comparison with the use or not of the Peltier cell takes place under the same controlled laboratory conditions.

PV module and Peltier cell are electrically linked to a variable electronic load MWL, which allows of adjusting the level of absorbed current in a range of 0-20 A, by means of a multi-turn potentiometer, that operates at voltages between 0 and 20 V. This instrument was used to detect, to the variation of the electrical load, the characteristic curve V-I or V-R and, therefore, the power supplied by the PV cell and the Peltier cell under different conditions of load.

In this first type of experiment the Peltier cell is used in a passive way. The temperature difference, which is created between the faces of the Peltier cell, due to heating of the photovoltaic cell and the cooling imparted by the heat exchanger, is used to produce additional energy which is added to that produced by the photovoltaic cell. The experiments have been conducted at different heights of the lamp in order to simulate different conditions of light and more in particular different conditions of temperature. The aim of this study is to understand how much additional energy would be produced.

The typical test is performed following the scheme below:

1. Choose an height of the lamp.
2. Turn on or off the heat exchanger pump.
3. Measure the surface temperature of the PV module through the thermocouple.
4. Turn on the lamp.
5. Acquire values for voltage and current through Megaris tester for different applied electrical loads to obtain the characteristic curve of the module (figure 9).
6. Repeat the previous point for different superficial temperatures of the PV module until the stationary condition is gained.

7. Acquire temperatures of upper and lower faces of Peltier, using thermocouples and its characteristic curve (figure 10), using the Megaris tester.
8. Repeat the previous point for different superficial temperatures of the surfaces of Peltier cell until the stationary thermal condition is gained.

Evaluating the test data performed at different height and temperatures, it’s possible to compare, at first, the behavior of the efficiency of the PV cell when the temperature of upper surface of PV panel increases.

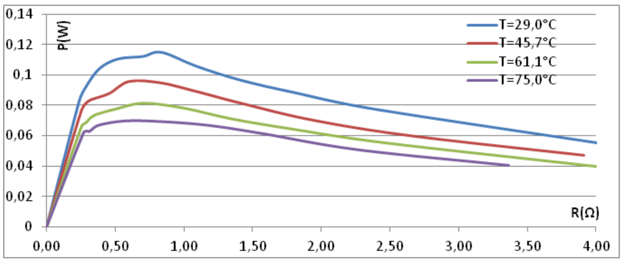


Figure 9: P-R curve of PV cell for the Test at height of lamp = 10 cm and the pump of heat exchanger off.

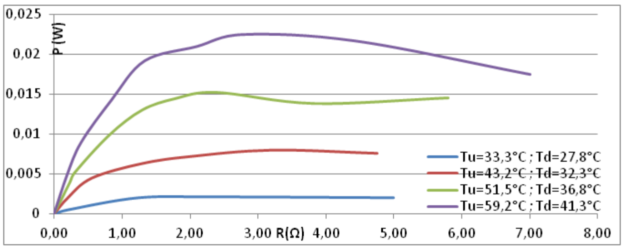


Figure 10: P-R curve of Peltier cell for the Test at height of lamp = 10 cm and the pump of heat exchanger off.

From figure 9 and other graphs about P-R curves of PV cell, referred to different heights of the lamp, it is visible that the maximum power decreases with the increment of the temperature.

Inside each test at a fixed height the luminosity is constant and then the decrease of the maximum power leads to a decrease of the efficiency of the PV cell. The decreases of maximum power in the range of temperature 39-67 °C is approximately 20% equivalent to 7,2% each 10°C. These considerations are supported by table 3:

Table 3: Experimental data.

where:
H = is the height of the lamp (distance from the lamp and the glass sheet);
ΔT= difference between the maximum temperature of upper face of PV (stationary condition) and its initial temperature in the test.

Figure 11shows in a clear way (after 36 C°) that at the same upper superficial temperature of the PV module, its performance is the same for tests with heat exchanger pump on and off (respectively named “with” and “without” exchanger). Clearly the maximum temperature in stationary condition will be higher for the pump of heat exchanger “off” than the case “on” as it also evident by values of ΔT, reported in table 3.

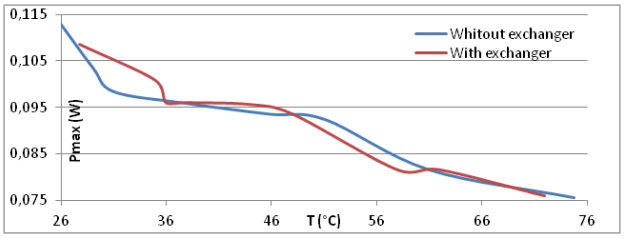


Figure 11: Maximum power of PV cell for different temperatures of its upper surface in cases of pump heat exchanger “on” and “off”.

The behavior of the Peltier cell with increasing temperature of upper PV surface is different from that seen for the PV cell. In fact, the maximum power increases with the increment of the temperature (figure 12).

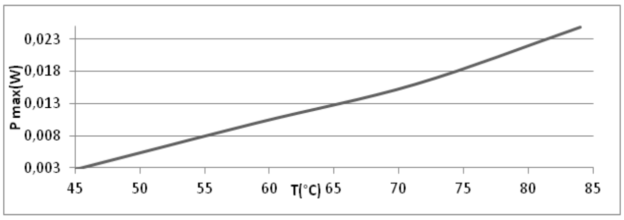


Figure 12: Maximum Power given by Peltier cell versus Superficial Temperature of PV Module

For the Peltier cell the maximum value of the power, obtainable at a temperature of 84 °C, is 89% greater than the value, initially measured at the temperature of 45 °C, corresponding to an increase of 23% every 10 °C. The limit of energy production of the Peltier cell is due to the reduced $\Delta T_{Peltier}$ between its upper and down surfaces as shown by figure 13.

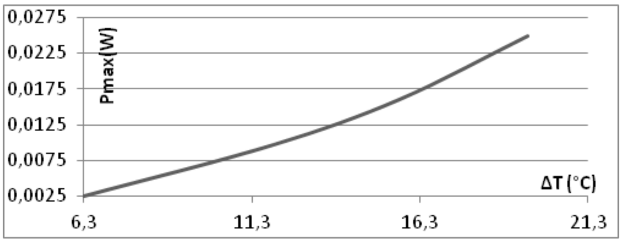


Figure 13: Maximum Power given by Peltier cell versus reduced $\Delta T_{Peltier}$ between its upper and down surfaces.

To increase the electrical power converted by Peltier it is necessary an higher $\Delta T_{Peltier}$. This can be gained by a better system of heat exchanger with the environment and a better isolation system between the back face of the PV panel and the lower face of Peltier. In support of this, figure 14 shows the difference between the output powers from the Peltier cell in the presence and in the absence of the heat exchanger at the same superficial temperatures of PV module (T=75°C).

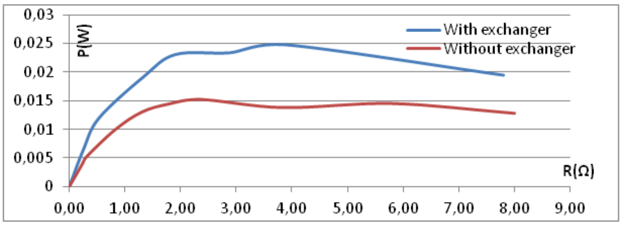


Figure 14: output powers from the Peltier cell for the same superficial temperature with heat exchanger “on” and “off”.

Clearly an increase of $\Delta T_{Peltier}$ is obtained also changing the operative conditions of the test. Clearly they are conditioned by real operative condition of PV modules and by trade-off evaluation between performance and cost of the heat exchanger system.

The maximum $\Delta T_{Peltier,}$ obtained in the Peltier cell, is equal to 23 °C with a power output of 25 mW, corresponding to the 33% of the maximum power produced by the PV module alone in the same operative conditions. The percentage increase of power produced by the system, composed with PV and Peltier Cell together is about 22%.

In the second and last experimental phase, the Peltier cell has been used in an active mode, to study whether it was possible to increase the efficiency of the PV cell, cooling it. For this reason it has been used the electrical power supply RXS SHP283C. The Peltier cell has been fed to cool its upper face and to heat the lower one The tests have been performed always with the heat exchanger switched on. In the course of the description it has been used the term "ignition" which indicates the phase of feeding of the Peltier cell.

The scheme of tests is analogous to the first experimental phase with only a new final step. When the thermal stationary condition is gained then the Peltier cell is fed by power supply to cool the PV module.

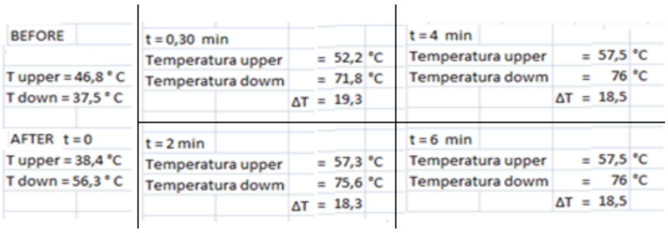
Tests are performed to different height of the lamp.

About the cooling function of Peltier cell, it has been observed that the Peltier cell quickly cools the PV cell but only for few seconds after the moment in which the feeding power is turned on. In the minutes following, the PV cell had even heated.

In fact after the “switching on” of the power supply (t=0) the upper face of Peltier has a change of temperature from 68,8 °C to 38,4 °C and lower face from 37,5 °C to 56,3 °C but it is not true after 30s.

In the subsequent table is reported the thermal history of upper and lower face of Peltier in the time after its feeding with an electrical power supply.

Table 4: Thermal behavior of upper and lower face in the time after the ignition (t=0).



BEFORE	t = 0,30 min		t = 4 min	
T upper = 46,8 °C	Temperatura upper	= 52,2 °C	Temperatura upper	= 57,5 °C
T down = 37,5 °C	Temperatura dowm	= 71,8 °C	Temperatura dowm	= 76 °C
	ΔT	= 19,3	ΔT	= 18,5
AFTER t = 0	t = 2 min		t = 6 min	
T upper = 38,4 °C	Temperatura upper	= 57,3 °C	Temperatura upper	= 57,5 °C
T down = 56,3 °C	Temperatura dowm	= 75,6 °C	Temperatura dowm	= 76 °C
	ΔT	= 18,3	ΔT	= 18,5

It’s possible to see that the cooling phenomenon of PV cell has a very short duration in the time and it affects only the part of the PV cell attached to the Peltier cell. In any case, this drawback could be reduced by the use of a conductive layer connecting the Peltier cell and the PV cell.

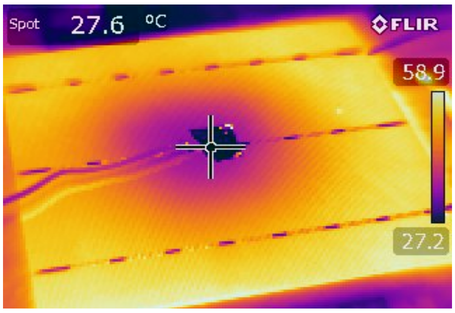


Figure 15: Cooling of the central zone of the PV cell. Thermal Image acquired with IR Thermo camera Flir E40bx.

It has been possible to see that over time the superficial temperature of the cell increased. The reason of this effect is probably due to a bad insulation between the faces of the Peltier cell.

Conclusion

This work has been addressed to two focal points. The first concerns the problem of recovering the dissipated heat from the lower face of the PV cell when it is stricken by a light. The second one is linked to the variation of efficiency with the temperature of the PV module. In the present work it is investigated potentialities of the Peltier cell technology to face these topics.

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

For the first abovementioned focal point the present work shows that it is possible to use the Peltier cell in a passive mode to recovery thermal energy, converting it in electrical one. In this way it is possible to increase energy production of a system composed by PV module together Peltier cell respect to the PV module alone. An increase in the difference of temperature $\Delta T_{Peltier}$ between upper and lower face of Peltier cell carries an increase to the electrical energy converted by the heat, dissipated from the photovoltaic cell. In the experimental campaign of the present work it is possible to observe that the power, produced by Peltier cell, varies with the temperature in the range from 2% to 33% of the maximum power produced by the PV module.

This experiment was conducted using a single Peltier cell, and so it is possible to think that by using, a greater number of Peltier elements, distributed along the all surface of the photovoltaic cell, it is possible to increase the performance of energetic recovery of the system. The found data of this work can be used as a comparison for future developments of the this study on the use together of PV module and Peltier cell.

Clearly the very high percentage value of 33% for the electrical power produced by Peltier, respect to the power generated by PV module, obtained from tests, is a very optimistic result. In fact it is necessary to highlight that this result is achieved for an high superficial temperature (73,9 °C) where its efficiency decreases. For this reason it will be required a trade-off analysis and an investigation about operative conditions of the panel in very hot climate region as desert or in applications with sunlight concentration approach. Besides considering the better performance about electrical power generated by the other PV modules, implemented in the real applications on the field, we must wait lower percentage values of improvement. These topics will be investigated in a future development of the activity.

The present work has also more briefly 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.

In a specific way it is performed preliminary experimental test for a potential use of a thermoelectric cooling system for PV, based on Peltier cells.

The experimental campaign shows that in the realized conditions, the Peltier cell doesn’t give a good global performance about because the cooling capacity of the surface of PV module is restricted to only few seconds after the feeding power for Peltier is turned on.

At the present, this not satisfactory behavior leads to require a more deep study with a theoretical and experimental approaches to evaluate other thermal insulation systems between upper and lower faces of Peltier, other heat exchange systems, other Peltier devices, with the final aim of a more detailed study and dimensioning of the entire set-up.

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, Preliminary Theoretical Study about a "Piezoelectric Shingle" for a Piezoelectric Energy Harvesting System in Presence of Rain, *Mathematical and Computational methods in Electrical Engineering “Proceedings of the 2th International Conference on Power and Energy, System, POES’15, Malta, August 2015.*

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

[4] Website of European Commision, http://ec.europa.eu/europe2020/europe-2020-in-a-nutshell/targets/index_en.htm

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

[6] 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.

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

[8] 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.

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

[10] 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.

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

[12] 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 performance, *Renewable Sustainable Energy* Rev. 2014, 30, pp. 337–355.

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

[14] 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.

[15] 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.