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EXPERIMENTAL CHARACTERIZATION OF THE PV PANEL - CONVERTER INTERFACE

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Abstract — *The PV panel-to-DC/DC converter interface was studied experimentally. Following some simulation result a confirmation was searched for the existence an AC component of the input voltage of the DC/DC converter which, in the same time, is the output voltage of the PV panel. Conditions were discovered that confirmed the existence of AC signals at the interface. Corresponding spectral analysis was performed and consequences were discussed.*

1. INTRODUCTION

At the end of 2009 the world was running 23 GW of photovoltaic electricity, the equivalent of 15 coal fired power plants. At the end of 2010, this number should have reached more than 35 GW [1]. We are aware of the fact that just a portion of the energy hitting the Earth's surface from the Sun every day could power all our cities several times over.

The European Photovoltaic Industry Association (EPIA) and Greenpeace International made a model showing that, under one scenario which follows the expansion pattern of the industry to date and includes moderate political support, photovoltaics could provide 345 GW by 2020, i.e. around 4% of the world's electricity needs in 2020.

The benefits of solar electricity usage include clean and sustainable electricity to the world and the carbon footprint of PV systems is decreasing every year. PV systems can provide clean power for small or large applications. They are already installed and generating energy around the world on individual homes, housing developments, offices and public buildings.

Historically the first applications of photovoltaics were stand-alone systems especially in remote (rural) areas where it was not feasible to connect to the main utility grid. Stand-alone systems vary widely in size and application from wristwatches or calculators to remote buildings or spacecraft. Second type of PV systems is a grid-connected system which is connected to a large independent grid (typically the public electricity grid) and feeds power into the grid.

Grid connected systems vary in size from residential (2-10kWp) to solar power stations (up to 10s of GWp). Nowadays, installations of grid-connected PV systems are increasing due to several advantages compared to stand-alone PV systems. Their implementation, however, is enabled by extensive implementation of power electronic subsystems and appropriate software. Thus the optimal design of modern PV oriented power systems as part of the SmartGrid concept may be accomplished by proper modeling and simulation of entire PV-electronic power system.

Trying to establish some influence to the PV system design chain, in our recent proceedings [2] we proved by simulation that the interface of the photovoltaic (PV) panel and the DC to DC converter is by no means a place with simple signals. Namely, due to the commutations within the converter, the current, or better to say, energy taken from the PV panel has a pulse shaped waveform. As a consequence, the current, voltage, and power waveforms at the PV panel's output have a significant AC component that is to be identified and consequences studied. Usually that interface is equipped by an electrolytic capacitor of a large capacitance that is supposed to short-circuit the AC component of the interface voltage. Its AC current sinking capacities, however, were shown to be limited and the AC component was not eliminated. Furthermore, real capacitors exhibit series resistance and inductance that influence the resulting voltage at the basic and harmonic frequencies of the main switches. Needless to say that all, the capacitance, inductance, and resistance of the electrolytic capacitor are strongly temperature dependent and subject of aging. All together, it was shown that because of the alternating component of the PV-panel-output-voltage that comes from the converter the PV-panel's working point is taken out of the maximum power point very frequently and with amplitude that can reduce the output power significantly.

Here we try to verify the results obtained by simulation on an experimental setup. Three types of measurements will be performed the two of them using good insolation while the third under lower insolation. The properties of the whole system were established first. That include the output current, voltage, power and converter efficiency were measured under good insolation. Then the properties of the PV panel and the PV panel-to-converter interface were established by measurements under good insolation. Finally, the interface was characterized under lower insolation.

The paper is organized as follows. First the characterization of the system under consideration will be discussed. Measurement and corresponding extracted data will be given in the second paragraph. In the third paragraph characterization of the interface will be given for both good and low illumination. Finally, discussion of the results and some conclusion will be given.

2. DC CHARACTERIZATION OF THE PV SYSTEM

In these proceedings we consider a real system built of a solar panel, DC/DC converter and a resistive linear load. The system is schematically represented on Fig. 1.

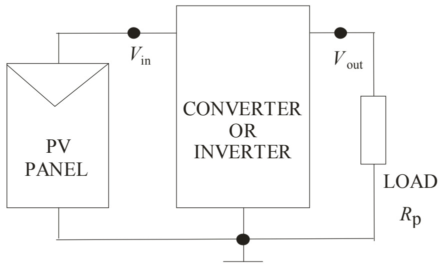

Figure 1. *Representation of the PV system to load connection*

A function of a PV cell is simple: it absorbs photons from sunlight and releases electrons, so when there is a load connected to the cell, electric current will flow. PV cells are based on a variety of light-absorbing materials, including mono-crystalline silicon, polycrystalline silicon, amorphous silicon, thin films such as cadmium telluride (CdTe) and copper indium gallium selenide (CIGS) materials, and organic/polymer-based materials.

The PV cells are connected together into columns (cell connected in series) and rows (columns connected in parallel) in order to get appropriate values of output voltage and current, respectively. The structure obtained is mounted on panels hence the name. Fig. 2 depicts a typical DC characteristic of a small panel. Here the output current and power of the panel are shown as functions of the panel output voltage.

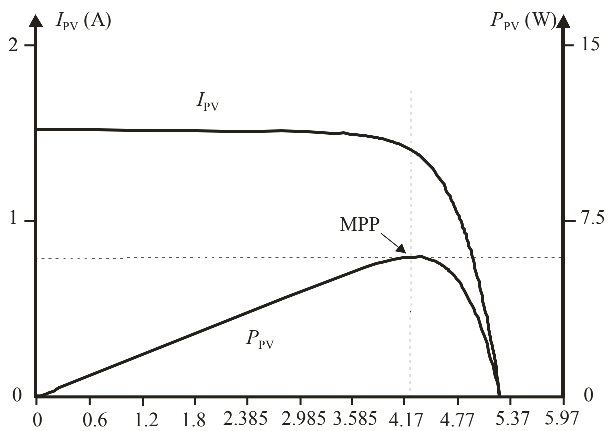

Figure 2. *Measured output current and output power as a function of the output voltage of a PV panel (not the one measured here). MPP stands for Maximum Power Point.*

The characterization of the system depicted in Fig. 1 was performed using a PV panel consisting of 18 cells connected in two equal columns. The Mean Well NSD15 -S converter was used. Resistor denoted by R_p was used as a variable load. Its lowest resistance values were limited by the modest driving capabilities of the DC/DC converter.

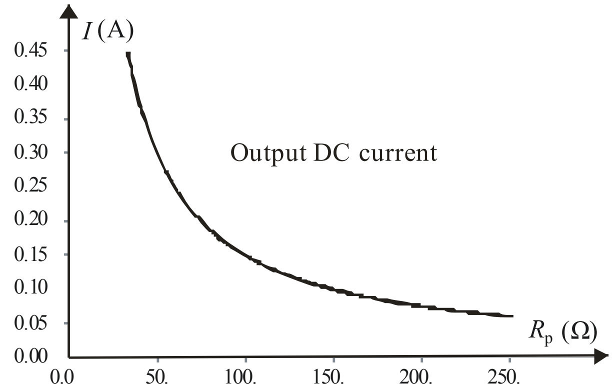

Figure 3. *The output DC current of the system*

For characterization of the system the following dependences were measured as a function of the load resistance: the output DC current, the output DC voltage, the output DC power, the input DC power. That enabled the converters efficiency to be computed.

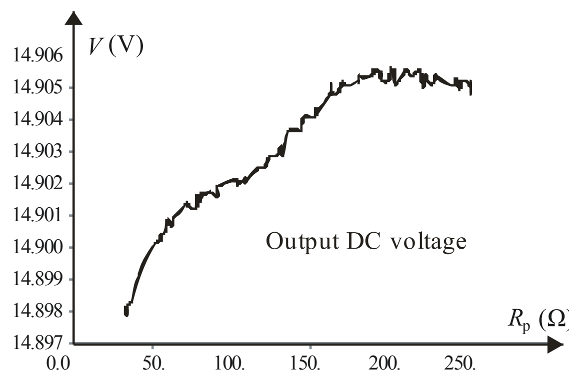

Figure 4. *The output DC voltage of the system*

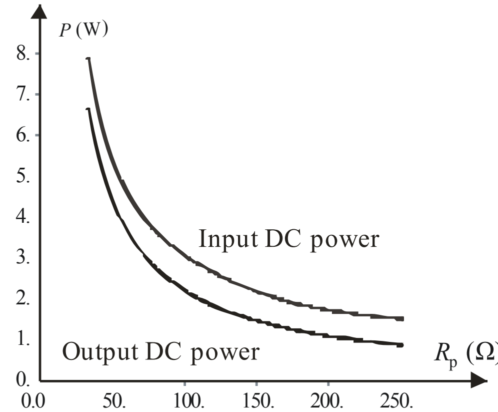

Figure 5. *Input and output DC power of the converter*

All these dependences are depicted in Figures 3.-5. The measurements were undertaken at noon of the (sunny) April 20, 2012. The panel was positioned for best incident angle of the incoming light. As can be seen from the diagrams the output voltage is practically independent of the load which is very good while the power, both at the input and the output, is decreased when the load resistance is raised. That, in a smaller scale, stands for the efficiency of the converter.

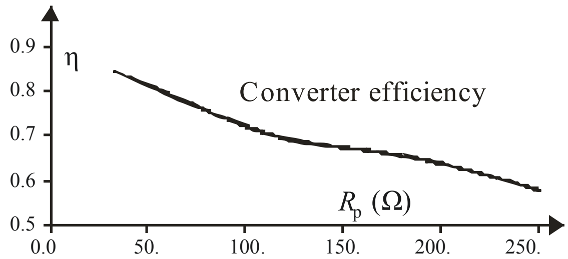

Figure 6. *The converter efficiency*

The converter efficiency is computed as $\eta = P_{DCout}/P_{DCin}$. Fig. 6. shows that if some kind of cooling system was implemented for the output of the converter one would probably produce a higher value of the efficiency since lover values of the load resistance would be allowed.

3. DESCRIPTION AND AC CHARACTERIZATION OF THE PV PANEL

Besides the characteristics depicted in Fig. 2, for DC characterization the dependence of the electrical quantities of the panel as a function of the load resistance are of interest. These are shown in Fig. 7. and Fig. 8.

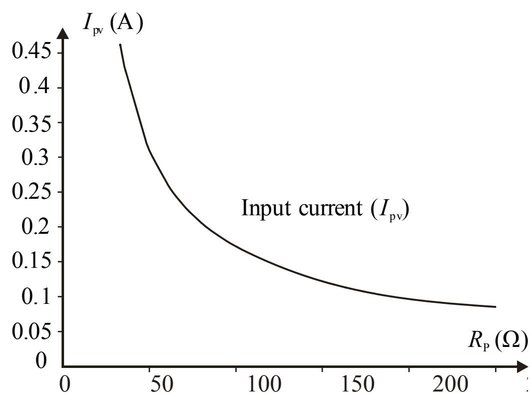

Figure 7. *The DC component of the PV panel's current as a function of the load to the system under full insolation*

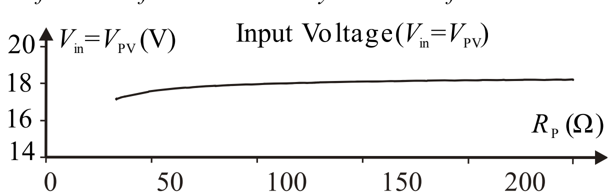

Figure 8. *The DC component of the PV panel's current as a function of the load to the system under full insolation*

It is important to note that the working conditions of the PV panel were out of the maximum power point which is depicted in Fig. 2. That can be recognized by inspection of Fig. 5. where the power delivered by the panel is denoted as "input DC power". It can be seen that the power is monotonically decreasing with the rise of the resistance of the load. The reason for that were the low driving capabilities of the convertor available to the authors. Otherwise lower values of R_P would be used.

For this proceedings of crucial importance is the fact that when measurements with high insolations were done no alternating component of the panel's current and voltages was observed. That was in contrast to the expectations based on the results obtained by simulation.

New measurements were performed, however, in a cloudy day. Completely different results were produced by the absolutely same measurement setup. Namely, both the PV panel's current and voltage got a significant AC component due to the decrease of the photovoltaic current and the relative rise of its component that is driving the internal diode of every PV cell in the panel. In that way the output resistance of the PV panel is raised and the converters currents produces a voltage drop that is time dependent.

All this may be recognized from Fig. 9. and Fig. 10. where the measurement results are depicted.

Fig. 9. represents the current that is leaving the PV panel and entering the converter as a function of time. As can be seen a considerable AC component reach of harmonics may be observed with the main constituent at the converters switching frequency.

Similarly, Fig. 10 represents the PV panel's output and the inverter's input voltage as a function of time for measurement under cloudy weather. Here again, significant AC component is observed. To quantify, Fig. 11 depicts the spectrum of the signal from Fig. 10. As can be seen the DC component is only 12 dB larger than the first harmonic, while the rest of the harmonics are not easily negligible.

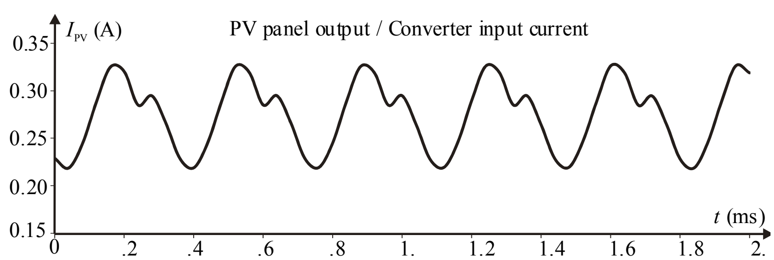

Figure 9. *The PV panel's output and the inverter's input current as a function of time for measurement under cloudy weather,* R_P=100 Ω

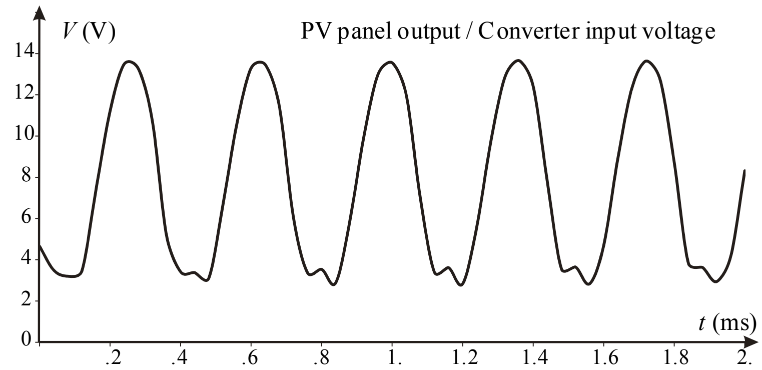

Figure 10. *The PV panel's output and the inverter's input voltage as a function of time for measurement under cloudy weather,* R_P=100 Ω

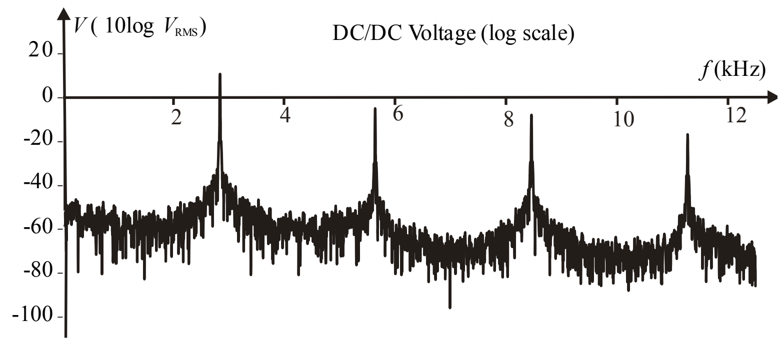

Figure 11. *Spectrum of the PV panel's output and the inverter's input voltage as a function of frequency for measurement under cloudy weather,* R_P=100 Ω

4. CONCLUSION

In this proceeding, we investigated the properties of a photovoltaic system under two external conditions: sunny and cloudy weather. Currents and voltages were measured while power, efficiency, and spectrum were calculated. Two parameters were used as variable: the time and the load resistance.

It was shown by measurement that if sunny conditions are present there is no AC component at the PV panel's output, neither in the current nor in the voltage waveform. We understand that at these conditions the photocurrent of every diode is large enough to keep the internal diode in the high current region where the dynamic resistance of the diode is very small. In that way the switching within the converter does not influences the working conditions in the PV panel and in the diodes that constitute the panel. If, however, the weather is cloudy or from any other reason the insulation is reduced, the above mentioned photovoltaic current gets reduced so rising the values of the internal resistances of the diodes and rising the overall output resistance of the PV panel. That, now, gives rise to time dependent components in the PV panel's current and voltage coming from the converter.

In conclusion we may say now that the electrical and power delivery properties of a PV panel are strongly related to the insolation. That stands not only when output power is considered but also when working conditions of the PV cells are observed. The AC component, as it is obvious, develops a heating of all PV cells so reducing the efficiency in an indirect manner. In addition, it pushes the MPP out of its optimal position with a frequency high above the capabilities of the MPP control circuit. In that way additional power is lost with no chances to be restored.

All these considerations suggest that precautions are to be taken during design of a PV system to reduce the AC component fed back to the PV panel. In that the switching frequency is to be considered as one of the most important design parameters what will be investigated in our near future work.

ACKNOWLEDGEMENT

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