INFLUENCE OF THE SIZING FACTOR OF THE INVERTER
ON THE CORRELATION BETWEEN ELECTRIC POWER AND SOLAR IRRADIANCE
IN A GRID-CONNECTED PHOTOVOLTAIC PLANT

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ABSTRACT: This work presents an analysis of the influence of the sizing factor of the inverter (SFI) on the delivered power of a 4800 Wp grid-connected photovoltaic system located at UFRGS Solar Energy Laboratory, Porto Alegre RS, Brazil. The installation is divided in three identical subsystems, each one constituted by two strings of 100 Wp / 24 V modules. For experimental purposes, the number of modules in each string can be varied from six up to eight. The arrays feed three 1100 W single phase string inverters. Three different cloudless days were analyzed. The experimental results indicated that the correlation between array power and irradiance was closely linear for systems with high values of SFI. For the subsystems with lower SFIs, the correlation presented nonlinearities at high irradiances due to the actuation of the power limit and/or the overheating protection of the inverters. It was observed also that the measured output power in cloudless days, for equivalent solar irradiances, is slightly higher during the morning than in the afternoon, as a consequence of the operating temperature of the modules to be higher in the afternoon.

Keywords: Small Grid-connected PV Systems, Monitoring, Simulation.

1 INTRODUCTION

Solar energy can be converted into electricity through photovoltaic modules. In order to reach proper values of current and voltage, the modules are associated in arrays. Since this electricity is generated in DC, devices called inverters are used in grid-connected systems to perform the DC to AC conversion. The output of the inverters must be compatible with the grid waveform in terms of voltage, frequency, phase and harmonic contents.

Grid-connected systems are usually designed considering the nominal output power of the inverter to be smaller than the peak power of the array. This undersizing of the inverter results in an optimization of the system overall performance in terms of costs, specially in regions in which irradiance does not reach high values for long periods and the inverter is working, most of the time, below its power limit [1], [2], [3], [4]. Inverter efficiency and harmonic distortion of the injected current do vary with the load. The efficiency usually goes worse as the level of loading decreases. Nevertheless, modern inverters can reach high values of efficiency even at 10 % or 20 % of their nominal power.

2 FUNDAMENTALS

The power delivered by a photovoltaic array to an inverter depends on which point of the I-V curve the array is operating. Ideally, the inverter should be always working at the maximum power point curve of the array. The actual maximum power point depends on ambient conditions such as irradiance, air temperature and wind speed. Most of commercial inverters have an integrated maximum power point tracker (MPPT) in order to maximize the energy conversion.

The efficiency of the maximum power point tracker can be defined as the ratio between the energy, for a certain period of time, at the inverter input with the MPPT and the energy that would be transferred to the inverter if the array were operating at the maximum power point, for the same period, as shown in Eq. 1 [5]:

$$\eta_{MPPT} = \frac{\int P_{DC} \, dt}{\int P_{MPP} \, dt}$$ \hspace{1cm} \text{Eq. 1}

where $P_{DC}$ is the power at the inverter input and $P_{MPP}$ is the power at the maximum power point.

The correlation between photovoltaic power and irradiance depends on a number of factors, such as the relation between the power of the array and the inverter, the operating temperature of the modules and the actuation of the maximum power point tracker. Some peculiarities of the inverter, such as power and temperature built-in protections can limit the delivered power.

The sizing factor of the inverter (SFI) can be defined as the ratio between the inverter nominal output power and the array power under standard conditions (1000 W/m² and cell temperature of 25 °C):

$$SFI = \frac{P_{DCnom}}{P_{STD}}$$ \hspace{1cm} \text{Eq. 2}

where $P_{DCnom}$ is the inverter nominal output power and $P_{STD}$ is the array power under standard conditions.

Martin [6] proposed SFI values of 0.65 to 0.8, 0.75 to 0.9 and 0.85 to 1 for, respectively, the North, center and South of Europe. Experimental studies for Portugal and Netherlands [2] indicate that the inverter can be undersized to, respectively, 67 % and 65 % of the nominal power of the array without significant energy losses. The optimization of grid-connected photovoltaic systems in Brazil can be obtained with SFI values smaller than 0.8 [7], [8].
The temperature of the modules depends on the irradiance, ambient temperature, wind speed, geometry of the installation, etc. For ambient temperatures between 5 °C and 35 °C, winds with velocities up to 1.75 m/s may affect the modules temperature in no more than 5 °C [9], resulting in a weak dependence between modules temperatures and wind speed in that range of wind velocities. For this specific installation, Dias [8] found a correlation taking into account only the irradiance and the air temperature. This correlation was used for the simulations in this work.

In order to avoid damages to its internal components caused by overheating, the inverter is provided with a protection feature that, when a certain temperature is reached, moves the operating point of the array away from the MPP to a new point with higher voltage and lower current. Thus the delivered power is reduced and so the dissipated heat. This state is called derate mode.

3 INSTALLATION

A grid-connected photovoltaic system was set up in 2004 at UFRGS Solar Energy Laboratory, Porto Alegre RS, Brazil (30°S 51°W). This system is constituted by 48 Isofoton I-100 (100 Wp / 24 V) modules, divided in three identical subsystems of 16 modules (two paralleled strings of eight modules) feeding three SMA Sunny Boy SWR 1100E string inverters (nominal and maximum output power of 1000 W and 1100 W respectively).

An experimental study of the optimal SFI for this specific installation was done by Dias [8], when three different SFI indexes were tested (0.86, 0.73 and 0.65), corresponding to arrays with 12, 14 and 16 modules respectively. The present analysis was performed based on the measured data from a subsystem configured with a SFI of 0.65.

More specific details about this installation are described in another work [10] presented in this Conference.

4 EXPERIMENTAL ANALYSIS

The installation has been monitored for more than one year with a data acquisition system constituted by a Agilent 34970A unit interfaced to a computer. The registered data included the voltages and currents of the three subsystems, the individual voltages of the modules of one subsystem, the irradiance, the ambient temperature and the temperature of the inverters, measured at their heatsinks. Three distinct situations were observed. For the analysis of the correlation between photovoltaic power and irradiance, three clear sky days were chosen to represent each situation. The influence of some factors the on the system performance, such as the SFI, the ambient temperature and the operating temperature of the modules and inverters, was analyzed.

The first case, depicted in Figs. 1 and 2, is represented by a day in which there was no overloading or overheating of the inverter. During this day the ambient temperature was below 30 °C and the maximum temperature of the modules and the inverter was about 50 °C and 55 °C respectively. The maximum irradiance was about 800 W/m², while the maximum power achieved by the subsystem was around 1000 W. Under such conditions the correlation between the power of the array and the irradiance is linear from 200 W/m² and up. The nonlinearities below this level are due, mostly, to partial shadings at dawn and sunset caused by trees and other obstacles in the surroundings. They are also due to fluctuations on the array voltage produced while the inverter is settling on. Nevertheless, the energy lost at these moments is not significant.

The second case, shown in Figs. 3 and 4, is represented by a day in which the output power limit of the inverter was surpassed. The maximum ambient and modules temperatures were 20 °C and 45 °C, respectively. The maximum temperature of the inverter was about 58 °C, just below the thermal protection threshold, while the peak irradiance reached almost 1000 W/m². The overloading protection of the inverter actuated between 10 AM and 2 PM and the array power was limited to about 1200 W over that period.

Under these conditions the correlation between the power of the array and the irradiance is linear from 200 W/m² to 800 W/m². From this level up, the DC power remains limited in about 1200 W, as a consequence of the limitation at the output power. This condition persisted for about two hours and resulted, of
Figure 3: Behavior of irradiance, DC power, ambient temperature, temperature of the modules and temperature of the inverters along a clear sky day, with actuation of the overloading protection.

Figure 4: Correlation between DC power and irradiance for the same day presented in Fig. 3.

Figure 5: Behavior of irradiance, DC power, ambient temperature, temperature of the modules and temperature of the inverters along a clear sky day, with actuation of the inverter overloading and thermal protections.

Figure 6: Correlation between DC power and irradiance for the same day presented in Fig. 5.

actuated, the inverter was automatically drawn to the derate mode. The inverter kept in derate mode from noon until 4 PM. In this case the energy loss (about 15% in this day) was significantly increased when compared to the previous case.

Figure 6 shows that, under these conditions, the correlation between the power of the array and the irradiance is again linear from 200 W/m² to 800 W/m². The power limiting is represented by the plateau around 1200 W. When the inverter is drawn to derate mode, the delivered DC power lowers significantly. This behavior can be observed as the “loop” in the graphic, closed when the inverter gets back to its normal operational condition.

The installation was monitored along several months with each of the three subsystems configured with SFI of 0.86, 0.73 and 0.65. An analysis of the measured data indicated that in mid-season and summer cloudless days (when the protections would be more prone to actuate) the subsystem with SFI 0.86 always behave as in Figs. 1 and 2. The subsystem with SFI 0.73 had a tendency to present a behavior as shown in Figs. 3 and 4 and the subsystem with SFI 0.65 as in Figs. 5 and 6.

It can be observed also that, in all analyzed cases, the delivered power for equivalent solar irradiances is slightly higher during the morning than in the afternoon.

5 COMPUTATIONAL ANALYSIS

The analysis of the measured data shows that, for equivalent levels of irradiance, the current of the array does not vary appreciably between the periods of the morning and the afternoon. Nevertheless, the array voltage (and thus the delivered power) is significantly lower in the afternoon.

Table I presents experimental data showing the influence of the operating temperature of the modules on the output power of the array for irradiances ranging from 200 W/m² to 800 W/m².

CREARRAY [11], a simulation software developed at UFRGS Solar Energy Laboratory, was used for the computational analysis. This software is capable to analyze the behavior of a photovoltaic array considering the effects of temperature, irradiance and possible differences between the modules of the array. The program calculates the array I-V curve from modules manufacturer data or from measured modules I-V curves.

All the modules were characterized at the Laboratory
in which there was no overloading or overheating of the installation, associated to different SFIs. In the first case, one representing different operating conditions of the inverter, the correlation was linear throughout. In the second case the inverter exceeded the power limit around noon, but did not reach the thermal protection threshold. The correlation was linear up to about 800 W/m² and then a plateau, defined by the power limitation, was reached. In the last analyzed case both overloading and thermal protection actuated. The correlation was again linear to irradiances up to about 800 W/m², remained on the power limit plateau for a while and then decreased as the inverter entered the derate mode.

In all three cases the delivered DC power for equivalent solar irradiances, while in the linear region of the correlation, was slightly higher in the morning than in the afternoon. The simulations confirmed that this difference was due to the higher operating temperature of the modules in the afternoon, as a consequence of the higher ambient temperature.

It must be stressed that the present results and conclusions are valid only for systems employing the same kind of inverter and cannot be extended to other models or brands of inverters without previous analysis of their behavior.

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REFERENCES


6 CONCLUSIONS

This work presented an analysis of the influence of the sizing factor of the inverter on the correlation between irradiance and DC power of a 4800 Wp grid-connected photovoltaic system at UFRGS Solar Energy Laboratory. Three clear sky days were analyzed, each one representing different operating conditions of the installation, associated to different SFIs. In the first case, in which there was no overloading or overheating of the


