PV self-consumption in cities: Solarfighter Experience

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***Abstract*—Small grid-tied PV systems for self-consumption and/or net-metering applications can intensively contribute to spread distributed renewable energy generation and the penetration of smart grids. Also they offer environmental benefits and savings for consumers. Unlike medium-large scale PV facilities, the integration of these small PV systems in city environments faces some specific challenges. Solarfighter is an all-in-one micro PV tracking system developed for this kind of applications. We explain here our experience, analyzing the specific needs of these applications and how they are solved in Solarfighter.**

Keywords—micro-inverter; grid-tied photovoltaics; self-consumption; net-metering; smart-grids.

I. INTRODUCTION

Cities consume huge amounts of electricity and typically their consumption profiles match very well with PV generation times. Electrically cities are environments starving of generation and with lots of consumers, in this sense they are ideal environments for spreading grid-tied PV generation in net-metering or self-consumption modalities. PV integration in cities presents not only benefits for users and the environment, but they can contribute for smart-grids spreading, reinforcing the typically saturated grids and making them more monitored and controllable. However integration of PV systems in cities still presents some challenges. On one hand physical limitations related to the building environment and on the other hand electrical and control requirements which ensure that the generated electricity complies with the normative and also contribute to improve the quality of the typically over-saturated electricity networks.

This paper resumes these limitations and requirements for small PV systems in cities and presents how the Solarfighter project has tried to solve them. This is an all-in-one micro-PV tracking system which includes a PV module integrated in a single-axis tracking system, grid-tied micro-inverter and monitoring system.

II. PV SELF-CONSUMPTION IN CITIES: KEY ISSUES

A. Architectonical environment

The first step for sizing a PV facility is the study of the location. Unlike PV farms or PV facilities at rural locations, the city environment for PV system is characterized by:

- Limited area and volume for the installation. Not only for PV modules, but also for inverter cabinets, control rooms or batteries banks (in case of PV systems with storage capacity).
- According to the latitude and longitude of the site exists an optimum orientation and tilt angles for maximizing the annual energy yield of a PV facility. However, in general, the city environments lack available surfaces and many available are not at the optimal orientation or inclination [1].
- Esthetic or practical restrictions for structures, cable or modules. At the same time PV modules very close to the building surfaces will decrease their efficiency[2], as the recommended ventilation is not assured.
- Partial shadowing in many moments, due to the proximity of buildings, chimneys or other typical obstacles.

B. Electrical & Smart-grid environment

Most of the countries have a technical normative to regulate the connection of PV systems to the main grid [3]. Until now PV generation connected to low-voltage distribution network was a passive actor, only safety limitations and a minimum quality of the signal were required. Basically:

- Stop generation because over/under voltage or frequency limits and in case of island condition.
- Quality thresholds for THD, power factor and injected DC current.

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However, the present regulatory tendency is to require active capabilities to the PV generation, in order to contribute to a better control and quality of the main-grid. For instance, the latest German normative [4] demands:

- Active power derating at overfrequency. It will help the network operator to balance the demand-generation curve.
- Reactive power control according to a set point provided by the network operator. Since some inverters are able to inject reactive (capacitive or inductive) power, this capability helps the network operator to control the power factor and reduces losses.

In a Smart-grid, the generation devices are expected to be active and fully monitored, contributing to a better control, safety and efficiency of the grid [5]. This will be a requirement but also a potentiality for PV systems integration in cities, typically with better access to communications than rural environments.

Fig. 1. Tracker facing east (morning)

Fig. 2. Tracker in flat position (noon)

Fig. 3. Tracker facing west (afternoon)

C. *User's Role*

In the most of the cases, due to the limited space, PV installations in cities will be less of 1kWp per house. Therefore the cost of installations will be a determinant factor for the users. In this sense, DIY (Do It Yourself) approaches are very attractive since mounting cost is highly reduced, however the installation steps must be simplified.

As said before, city environments have very good communication access, so users will be able to monitor and control their PV installation using accessible media, e.g. through smart-phone or web application.

III. SOLARFIGHTER EXPERIENCE

Solarfighter is an all-in-one micro-PV tracking system which includes:

A. *High quality Si photovoltaic panel*

The standard PV module size makes Solarfighter easily transportable and mono-crystalline silicon technology allows to have 250-300W_p (peak power depends on the model) in 1.6m^2.

B. *Micro-tracking system and integrated structure*

The Solarfighter micro tracker is a single axis tracker that can be used on a horizontal or tilted surface. It is insanely compact and has one of the lowest weight to power ratios of any tracker. Fig. 1, 2 and 3 show the tracking positions for a south-oriented surface. By following the sun the Solarfighter can produce more than 30% of the energy generated using the same PV panel as a standard fixed installation[6]. This difference between fixed and tracking system can be even more dramatic for not optimal orientated surfaces. The tracking controller detects the tilt and orientation of the supporting surface and optimizes the tracking position in order to obtain the highest power at any moment.

Regarding esthetic needs, the integrated structure reduces the visual impact, all components are kept under the module and at horizontal position all the system has a height of 70 mm over the roof surface. The color of the module frame and the structure components have been chosen black to keep an esthetic uniformity. Hence, the installation is reduced to fix the base component to the supporting surface by four screws.

Fig. 4. View of the backside of a Solarfighter

C. *Micro-inverter and tracking-controller*

Both are kept in the same box under the PV module (Fig. 4). The tracking controller is an open loop solar tracker with astronomical algorithm and wireless communications which has the following main features:

- Constantly monitors the system and communicates it with a Gateway controller;
- Makes sure that the Solarfighter is always pointing in the direction that will give the highest yield;
- Makes sure that a Solarfighter is not shading other Solarfighters, using its backtracking algorithm.

The micro-inverter is a 250W nominal power grid-tied inverter. The micro-inverter injects the generated PV electricity in AC form directly to the main-grid, without any extra converter or component, it is actually a plug and play ready system. It has a 2 steps power conversion topology (DC/DC + DC/AC) which makes it quite different from other micro-inverters and has the following main features:

- Search the absolute Maximum Power Point (MPPT) of the PV module at each moment. It is specially needed in cities environment, where partial shadows on one or two strings of the panel can lead to P-V curves with two, or even three maximum points (Fig. 5). The two stages topology allows the possibility of doing a periodic and very fast sweep of the PV curve to discover where the absolute maximum power point is. The sweep is only done at low power levels. So, the power production in daylight hours when shadows affect the PV array is improved and power without shadows is not affected. Due to, the two stage topology output current quality is not affected during the fast input voltage variation.
- Low power quality is usual in residential and commercial buildings where a huge number of non lineal loads are connected. So, a synchronous reference frame PLL is used to synchronize the inverter with the grid, even in the case when the grid voltage is distorted.
- Control of the injected reactive power as response to a set point provided by the gateway controller (Fig. 6). Again, the two stage topology allows an easy control of active and reactive power.
- Active power derating because over-frequency condition or as response to a set point provided by the gateway controller. This last option is used for the Zero-Export option, explained below.

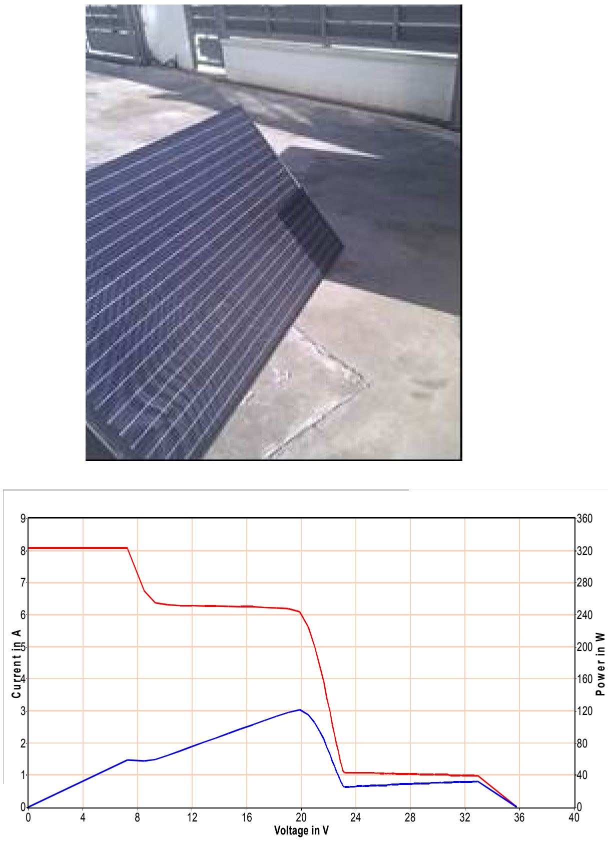

Fig. 5. Partial shading module (top) and its respective I-V and P-V curves (bottom, red and blue lines respectively). Partial shadows or stains can leads to P-V curve with various maximums. In this case, keeping the working point at a relative maximum implies 30W when the absolute maximum is at 120W.

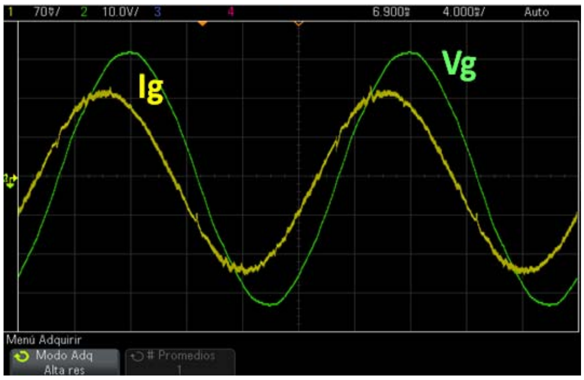

Fig. 6. Oscilloscope capture: injection of 100VAr of reactive power (grid voltage in green, and injected current in yellow).

D. *Monitoring and control system*

Users typically appreciate monitoring its generation but also its consumption, therefore we developed PowerMonitor, a device which is able to monitor: energy, active, reactive and apparent power at the coupling point with the public network. It communicates instantaneously this information to the Gateway controller.

Finally any Solarfighter-based PV installation is completed with a Gateway controller (Fig.7) which is in charge of coordinate all the Solarfighters and PowerMonitors, sends status updates over the internet and is able to implement global control actions for the complete PV facility. Radio communications have been chosen as the media between the Gateway controller and the rest of devices since it is stronger than other wireless options.

Zero-Export is an example of global control option. Thanks to the capability of power derating, if the user needs it, the PV facility can avoid to export any Wh to the public network, adjusting instantly the PV generation to the local consumption.

Fig. 7. Gateway controller

IV. CONCLUSIONS

City environment presents particular architectonic, electrical and user conditions for PV facilities. These needs and restrictions for the small PV systems integration in cities have been exposed. We have presented Solafighter experience, an all-in-one micro Solar tracking system, designed for meeting these needs and overcoming the restrictions. The experience shows that city environments are able to host PV generation but demand esthetic integration, compactness and fully controllable and monitored smart devices

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