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SMART PV MODULE FOR GRID-CONNECTED PV SYSTEMS

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ABSTRACT

Photovoltaic (PV) system has the main issue of efficiency when it comes to connect the PV system with the grid. The main causes are mismatching losses, partial shadows, variations in current–voltage (I–V) characteristics of PV modules due to manufacturing processes, differences in the orientations and inclinations of solar surfaces, and temperature effects. These losses can be reduced by use of suitable techniques. This paper presents the smart PV module concept, high-efficiency dc–dc converter with maximum power point tracking (MPPT) functions with low cost and power line communications (PLC). We analysis the different architecture of grid-connected PV systems: centralized, string, and modular topologies. The proposed system, i.e., the smart PV module, fits within this last group. The analysis on topology of boost dc–dc converter as well as its principles of operation is performed. By comparing the different MPPT method the best results are obtained for the incremental conductance method. PLC in every PV module used for communication and its viability for grid-connected PV plants are considered and analyzed in this paper.

Keywords: *dc–dcpower conversion, frequency-shift keying (FSK), photovoltaic(PV) power systems, pulsewidth-modulated*

I. INTRODUCTION

Photovoltaic (pv) systems in building environment

RENEWABLE energy sources (RES) are considered as a technological option for significantly contributing to the sustainable energy supply in India. PV energy generates electricity from solar radiation and, at present, represents one of the RES emerging technologies due to the continuous cost reduction and technological progress. The minimum element in the manufacturing of PV systems is the PV module. A typical panel is composed of 30–36 series-connected solar cells, with an open-circuit voltage (Voc) near 20 V and a short-circuit current (Isc) around 3–4 A. For most applications, e.g., integration in building environment and autonomous applications, the power of one PV module is not enough. As a result, it becomes necessary to group PV modules until the desired current and voltage levels are achieved.

The efficiency of commercial PV modules is about 14%–16%. However, PV systems show additional losses that are important in many cases. If not considered during the PV design phase, unreal estimations will be foreseen, and public image of PV energy could be damaged. Issues carried out by the University of Tokyo over 71 Japanese PV systems [1] have shown losses of up to 25%. Causes are varied, ranging from load mismatching (although most PV systems have maximum power point tracking (MPPT) incorporated), differences in current–voltage (I–V) characteristics, shadows and obscurances, dust, losses in PV inverter, low-radiation losses, and MPPT losses. The situation of losses becomes worst in complex configurations such as those integrated in roofs and facades. Great number of modules brings a huge complexity, in addition to the mentioned losses in PV systems. The complexity represents also an additional problem in maintenance and control operations since a failure in one PV module placed at a big facade is difficult to detect. A predictive maintenance comprises localization and definition of related faults. Localization of failures in a PV system is very important in any condition and even more in building integrated PV (BIPV) systems. Thus, a quick detection of failures would avoid energy losses due to malfunctions of PV systems.

Alternatives for grid-connected pv systems

Introduction of PV energy into the building environment is relatively novel. First, systems consisted in a great number of modules, series and parallel connected to a unique large inverter (central inverter).

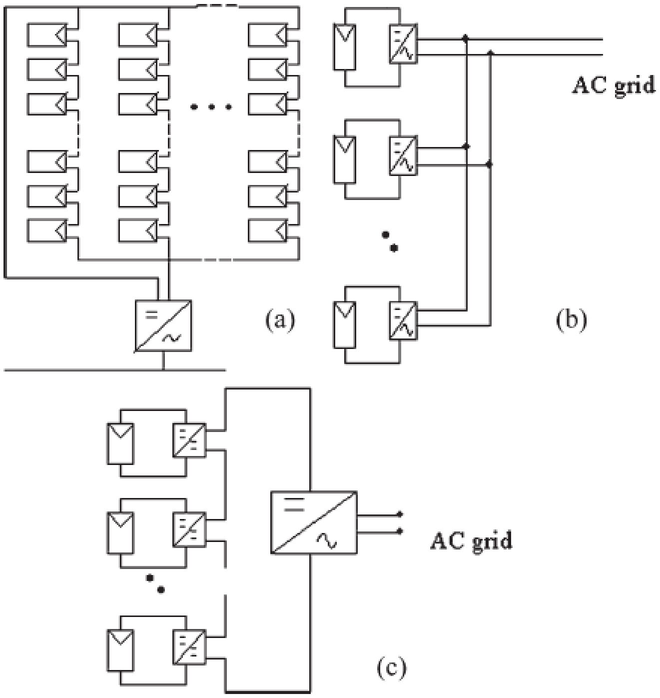

Fig:1 Configuration for BIPV systems. a) Centralized system. b) AC module. c) Modular system

At present, technology has evolved toward architectures consisting of a group of series-connected panels and a PV inverter (string technology). The number of modules is around 20–30 per inverter, and there will be as many inverters as the application needs (< 5 kW per inverter). This architecture improves PV system performance in the presence of irregular situations, in comparison with central inverter architecture. Mismatching and shadowing losses are reduced since the number of PV modules that work under a single MPPT converter is lower. However, there are other technologies, such as those that incorporate modules with a PV inverter—a dc–ac converter—for each (ac modules) [3], and their numbers are increasing. They are called modular systems, and at present, they show a great number of advantages and a few disadvantages against string architecture. Within the field of modular systems, research activities are focused on the dc–dc converters but applied to the PV module [4]. Our research group is developing an intelligent PV module that incorporates a dc–dc converter with integrated MPPT function. Its most suitable application will be the integration in the built environment—mainly roofs and facades—as they seem the most complex PV systems. Fig. 1 shows the three different technologies that are considered to be most suitable for BIPV applications. Up to now, performed analysis shows that modular systems have less cabling losses, although those systems are more expensive. However, comparison between both technologies cannot be made only in terms of economic reasons. There are also improvements in the performance of PV modular systems against partial shadows or modules mismatching.

Smart PV modules

Principles of Operation the PV array analyzed in this document consists of 20 PV modules connected in series for a residential rooftop application. Unfortunately, avoidance of partial shading in this environment is not always feasible. Trees, buildings, television aerials, and other roof structures result in a substantial reduction in system performance.

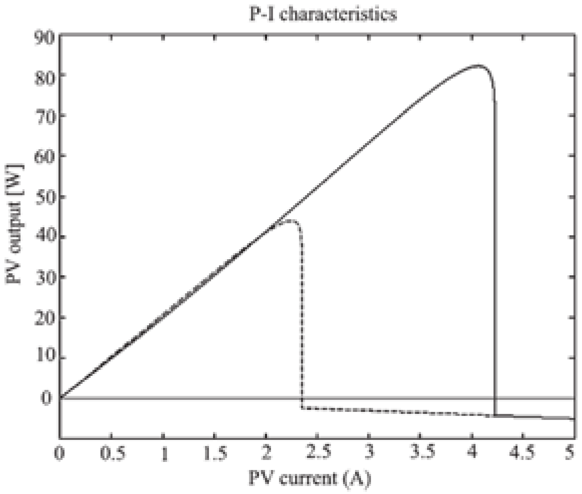

Fig.2 P-I characteristics of PV module in shaded and unshaded condition

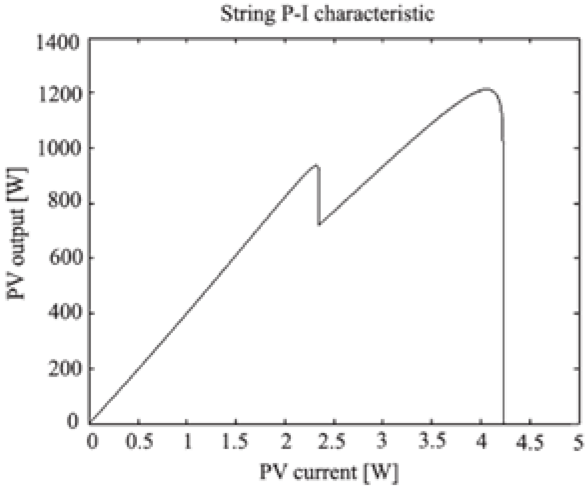

Fig. 3 PV series string P-I characteristics

In the proposed case, part of the array is installed near a chimney that causes significant shading over five of the 20 PV modules. Fig. 2 shows a Matlab simulation plot of output power for an 80-W PV module (BP 580F) under two different sunlight conditions. The solid curve which represents the output of an unshaded module (900 W/m2), presents a power maxima of 82 W. However, a shaded module (500 W/m2), which corresponds to the dashed curve, limits its maximum output power to 44 W. additionally, note that the optimal power and current are different from each other. Negative values of power in the right part of the curves show the conduction of the associated bypass diodes when the passing current is greater than the short-circuit current of the PV module. In this case, the PV module operates as a load for the system, instead of as a generator, resulting in a loss of power and energy. Considering the aforementioned possibilities, this paper discusses the performance of two different topologies, namely 1) the centralized topology, in which all PV modules are connected in series to a single inverter with a centralized MPPT, and 2) the modular architecture, in which the PV array is arranged in a series string of intelligent PV modules with its own MPPT. With the centralized MPPT, all PV modules connected in series are forced to drive the same current. If they cannot drive this current, then their associated bypass diodes conduct. Although diodes protect PV modules from "hot-spot" effects, they introduce multiple maxima on the array power–current P–I curve, as shown in Fig. 3, resulting in problems with MPPT. Even if the MPPT reaches the greatest power maxima, i.e., 1213 W at 4 A, the shaded PV modules would be acting as passive loads, significantly reducing the efficiency of the whole PV system. With the smart PV modules, there is no interconnection between PV modules, but there is interconnection between the associated dc–dc converters. Therefore, each PV module can operate at its own optimal power and current, and all the available energy in the PV array can be delivered. Losses from shading of a single PV module are limited to that module; any unshaded modules nearby are unaffected. In the example, whereas unshaded modules generates 82 W operating at 4 A, shaded modules outputs 44 W at 2.25 A. Hence, PV array supplies 1450 W, which is almost 20% more than that with the centralized MPPT. Apart from shading, any other reason of mismatching between PV modules causes very minor losses and these turn out to be more proportional to the degree of mismatching in a modular system than for an equivalent central inverter system.

Converter Topology and MPPT Strategy

As stated, the proposed intelligent PV module is basically a standard PV panel incorporating a dc–dc converter with MPPT controller. With respect to the dc–dc converter topology, the boost converter, which is also known as the step-up converter, is considered the most advantageous in this application because of its simplicity, low cost, and high efficiency. The conversion ratio between input and output voltages of the ideal boost converter varies with the duty ratio D of the switch, according to the following equation:

$$V_{out} = V_{in} / (1 - D)$$

Since $D \in [0, 1]$, the boost converter always provides a higher output voltage than its input. This characteristic is especially convenient to achieve the bus voltage required by the inverter from the output voltage of fewer PV modules and also to work with lower string output currents and, consequently, to reduce cabling losses. At worst, when a significantly shaded or failed module is unable to generate the string output current, this will be short circuited, and the remaining modules will be able to reach the required string voltage. Anyway, this situation only occurs for significant mismatches in power outputs if a suitable voltage boost is being used [4]. Finally, the small necessary size of its components, i.e., capacitors and inductor, to manage power of up to 100 W makes boost converter suitable to be mounted behind the PV panel most likely in its junction box. MPPT controllers find and maintain operation at the maximum power point (MPP) using an MPPT algorithm. Many such algorithms have been proposed in the literature [5], [6]. However, it is difficult to find standardized comparisons or appropriate methods for determining MPPT performance apart from [7], where methods to measure the accuracy, error, and efficiency of MPPT algorithms are presented. Using these guidelines, a wide variety of available MPPT techniques and possible modifications and improvements were discussed. The scope of the study was limited to those algorithms thought to be applicable to low-cost implementations with microprocessor control. Despite their simplicity, analog methods, which use the voltage and the current from the PV module directly to control the operating point, were discarded in the study due to their excessive dependence of environmental influences. Many other algorithms, like short-current pulse-based method [8] or two stage methods [9], were not simulated either because of their uncertain efficiency or clear complexity. After this first analysis, only two hill-climbing methods were seriously considered, namely: 1) the perturb and observe (P&O) method and 2) the incremental conductance method. Whereas the former continues to be by far the most widely used method in commercial PV MPPT, the latter usually appears in the literature as a progress in efficiency. In fact, the incremental conductance method was developed to avoid the drawbacks of the P&O method. With the aim to realize a comparison between them, these two optimized algorithms were simulated bearing in mind the available hardware and its limitations, such as the resolution of measurements or the precision in the control of the signal pulse width modulation (PWM). MATLAB simulation results show a bit better performance obtained with the incremental conductance method under random variations of isolation, temperature, and charge.

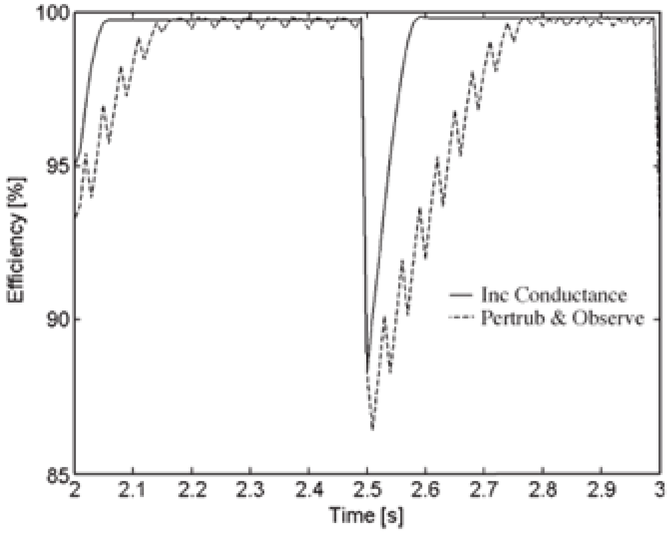

Fig: 4 Efficiency of MPPT algorithms: Incremental conductance method and P&O method.

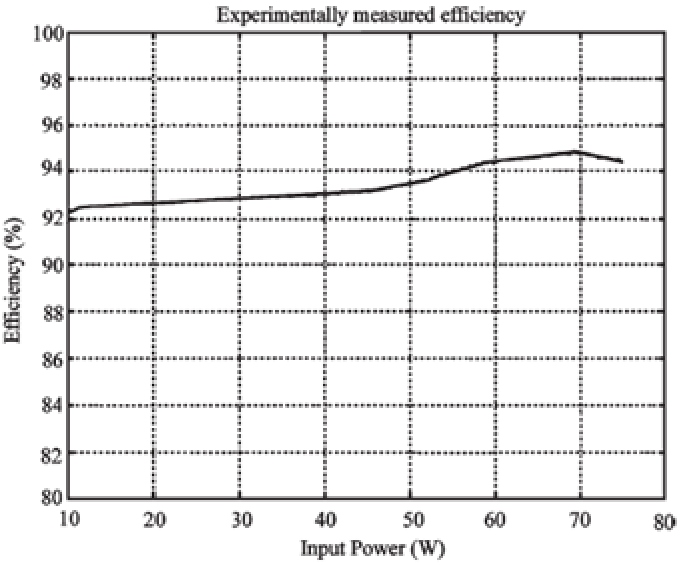

Fig: 5 Experimentally measured efficiency of smart PV module

Future Research Strategies

The next step in the research of Smart PV modules is the monitoring of modular PV plants. Data obtained from the main parameters of each PV module will be stored in databases frothier later analysis and processing. The implementation of an intelligent failure detection system will allow users to enhance PV plants maintenance operations in the base of provided data. These novel detection strategies will be applicable in great PV plants, such as BIPV, in which the number of modules makes it almost impossible to detect exactly the failure situation. Once an abnormal situation is detected, the control and monitoring system is intended to act in consequence. One interesting Application could be the remote power control of smart PV modules. If the control system detects an excess of power above the maximum input power in the PV inverter, a command will be sent to the whole PV modules in the sense of reducing the amount of delivered power and fixing it to a percentage of their maximum output power (e.g., 80%–90%).Finally, a survey on the performance of modular PV systems has to be carried out regarding PV inverter and possible modifications of power architecture that arises from the use of intelligent PV modules. Several tests have established that two consecutive MPPT algorithms (PV inverter and dc–dc converter) can lead to work in local MPP if a good sizing is not addressed.

II. CONCLUSION

This paper has described an innovative concept of PV module: the smart PV module solution. It is based on the design and development of a PV module-integrated micro system. The developed electronics consists of a dc–dc converter with MPPT control and other general functions, such as power conditioning, module protection, and PLC. In the cases of undesired PV system performance (partial shadows, mismatching), electrical losses are reduced and system efficiency is enhanced, as the dc–dc converter allows each PV module to work in its MPP independently from the rest of the PV panels. Several MPPT algorithms and configurations for dc–dc converters have been considered and simulated, which show the best results for the incremental conductance MPPT method and boost configuration for the dc–dc converter topology. Experimental results have shown a maximum efficiency of 95%.
At present, smart PV module is a more efficient and cheaper global term solution for BIPV systems, and it provides a great level of independence from an architectonic point of view. In this sense, it should be economically feasible.

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