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FLEXIBLE AND RELIABLE OPERATION OF A PHOTOVOLTAIC SYSTEM THROUGH A BACK-TO-BACK CONVERTER

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ABSTRACT

Photovoltaic systems, despite their 40 % annual growing over the 10 last years, have yet high initial installations costs. There are oversizing problems and storage difficulties inherent of isolated systems. For interconnected systems, the islanding is still the main challenge. This work proposes the use of a "back-to-back" converter that allows the improvement of the sun's energy, especially in localities where the distribution network is intermittent. The proposed configuration enables the operation of photovoltaic systems in three different operation modes at the point of maximum power and a smooth transition between modes without the need of batteries for storage. Simulation results in PSCAD/EMTDC are presented to prove all the functionality of the proposed configuration.

INTRODUCTION

The increase of the number of renewable and intermittent energy in the energy matrix, associated with the different methods of distributed generation has required new strategies for the control and operation of the electric system to maintain reliability, performance, quality and safety of the same. Many challenges are encountered in the integration of these renewable sources against standards, procedures, laws and environmental restrictions with the proliferation of several techniques of distributed generation.

On the other hand, contrary to wind generation systems that have mechanisms that ensure the ability to operate under short duration voltage variations in grid (low-voltage ride-through), distributed power generation systems like photovoltaic systems must be completely disconnected from the network when the occurring of islanding [1].

The possibility of operation in various modes should ensure flexibility and optimal operation (operation on the maximum power point) both when the system is connected to the network, as well as the operation during islanding mode. This is accomplished by a converter "back-to-back" with the photovoltaic generation situated between the two converters.

One converter is connected to the network while the other converter supply an isolated load, considered a priority load and can operate with variable frequency and voltage [2]. The isolated load priority considered in this paper is a three phase induction motor of 1 hp, for water pumping, for human supply.

The literature presents some islanding operation scheme, but for PV systems but none of them allows operation at the MPPT during this occurrence.

The proposed configuration will be examined for three different operation modes: a grid connected operation in which the entire photovoltaic generation is delivered to the distribution network and the local loads placed on the point of common coupling (local and neighbours loads) through the converter #1 (first operation mode); standard operation in which the power of the PV generator is shared between the network and an isolated load (converter #1 and #2 operating at nominal voltage and frequency - second operation mode); and autonomous operation during an occurrence of islanding (variable frequency and voltage for the isolated load and fixed frequency and voltage for local load – third operation mode).

With this configuration, the complexity problems about load management of the distributed generation connected systems will be simplified. The problems of intermittency, oversizing and storage characteristics of isolated systems also will be eliminated.

NOMENCLATURE

GPV	[-]	*Photovoltaic generator*
Vpv	V	Voltage of PV CC link

Ipv	A	Voltage of PV CC link
Pload	W	Load Power
Pgrid	$[W/m^3]$	Power grid
TIM	[-]	Tree phase induction motor
T	[K]	Temperature
G	$[w/m^2]$	Irradiance intensity
MEN		Management device
AI		Anti-islanding

OVERVIEW OF PHOTOVOLTAICS GRID CONNECTED SYSTEMS

The possibility of interconnecting renewable energy sources to the grid for low or medium voltage through the power electronic interface is mainly responsible for the vertiginous growth of the integration of photovoltaic systems in the energy matrix.

The presence of the grid allows controllability improvement and stability of the interconnected systems. The grid voltage can provide the appropriate synchronized signals, the DC link control and other control signals such additional protection against islanding necessary for a reliable and safety operation of the system.

The grid makes also unnecessary the storage system commonly used in isolated systems. However, other problems such islanding, power quality, reliability are found.

The complete structure of a grid connected photovoltaic system without the storage system is shown in Figure 1. The system consists of a photovoltaic generator, a grid, a transformer (which among other features provides galvanic isolation between the converter and the network), an islanding protection device (AI), a management (MEN) loads (local and neighbour loads connected at the PCC [1].

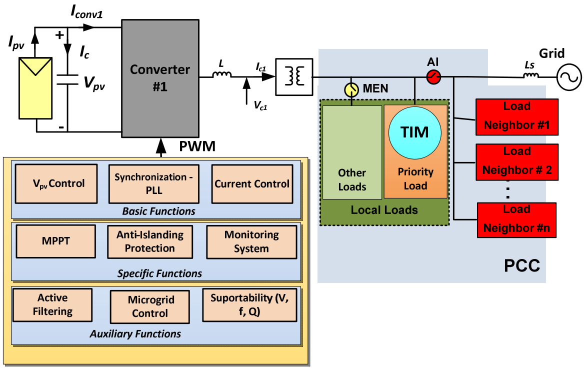

Figure 1: Standard PV system grid connected

In addition of the basic functions (Control of DC link voltage, synchronous system composite of a PLL (Phase Locked Loop) and injected current control to the grid), the control system may also involve specific functions such as ensuring maximum power transfer between the PV system and the grid by MPPT (Maximum Power Point Tracking) algorithm, anti-islanding protection and monitoring system depending on the considerate pattern (IEEE, IEC, VDE-DIN) and the dimension of the photovoltaic system. Additionally, the control may also involve auxiliary functions such as a need for active filtering, microgrid control and reactive power supplying.

This configuration enables the supply of local charges by the photovoltaic system. The excessing solar generation is injected in the grid. In the same, the grid also will compensate the deficit of PV generation to supply the loads of the producer consumer (the consumer responsible for the photovoltaic system).

In occurrence of islanding, the anti-islanding protection system (AI) will act disconnecting the PV generation to the grid. In this case, the operation of the system is similar to a stand-alone photovoltaic system supplying only local loads.

Depending on the capacity of the photovoltaic generation, an additional device protection for management load (MEN) can be used to ensure only the supplying of local priority loads, disconnecting other local charges, as shown in Figure 2. A possible alternative to the management device loads is the use of storage systems.

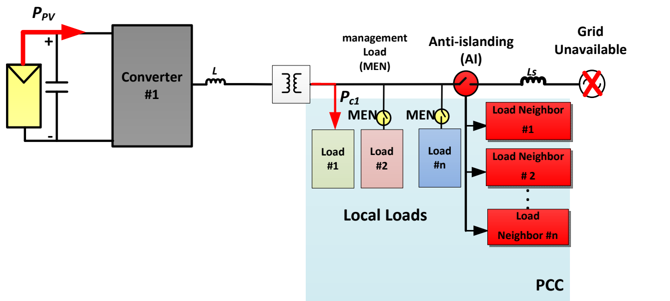

Figure 2: Management System under islanding operation

However, the storage systems used in most PV systems are lead batteries. The use of batteries increases the initial costs installations and the need for periodic maintenance of the system. Additionally, many case of environmental and public health problems are related, especially in developing countries where there are practically no political separations of toxic waste [4, 5].

This configuration is often used in distributed photovoltaic systems and has shown satisfactory results under normal operating condition. Isolated operation is also possible for some cases, but inefficient. In the occurrence of islanding, the system is controlled by fixed voltage reference and frequency. In this case, the amplitude of the alternating voltage (CA) is controlled through the modulation index (ratio of amplitude of the reference sine and triangular carrier in pulse width modulation - PWM).

However, with this topology, there is no guarantee with respect to the operation at the point of maximum power during islanding operation. There may be a large difference between the power produced by the photovoltaic system and the effective power transferred to local loads [7].

THE PROPOSED SYSTEM

The costs of PV systems are still high despite of the drastic declines in prices in recent years. The proposed configuration aims to ensure maximum power transfer between the system and the loads for both interconnected as islanded operation, while minimizing installation costs and maintenance.

The applicability of the proposed configuration was considered for sparsely populated remote rural area, characterized by a system similar to a weak power supply network: many interruptions and poor quality of supply. This fact makes the solar PV one of the bets of the energy future of the rural world, especially [7, 8] against isolation.

The proposed configuration considers two different types of loads:

i) A set of small loads supplied with fixed voltage and frequency, but which are not highly sensitive to possible interruptions. Among these loads, lighting systems, laptops for schools, chargers for cell phones or some equipment for health post (refrigerator for vaccines or sterilizer, etc.) may be cited; and [4],

ii) A three-phase motor for pumping water supply (for human consumption, irrigation, agriculture, etc.) [9] [10] [11] that can be driven with variable speed and consequently with voltage (V) and frequency (f) also variable, while maintaining the ratio V/f constant (scalar control) [2].

The proposed configuration is shown in Figure 3. The system is a "back-to-back" converter with the photovoltaic generation situated between the two converters, without the need for a storage system.

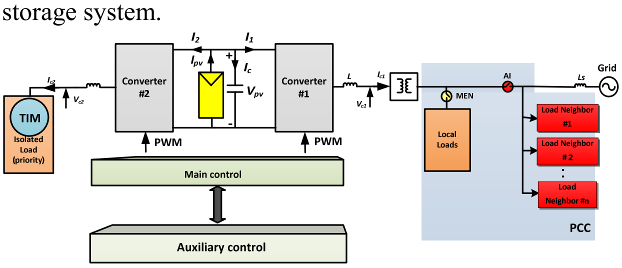

Figure 3: Configuration of the proposed system

The system consists of the two mentioned types of loads and two converters. The converter #1 operates with a fixed frequency and the converter #2 can operate with variable voltage and frequency depending of the mode of operation. The anti-islanding protection (AI) system must act disconnecting consumer producer loads to the network and neighboring loads at the PCC. The load management device (MEN) allows the disconnection and reconnection of local non-priority loads according to the capacity of the photovoltaic generation during the islanding occurrence, as is the case in the conventional configuration. The system also has a galvanic isolation transformer, switching inductors and the control system (consisting of a main control and auxiliary control that should work depending on the operating mode) that ensures balanced and flexible operation of the system.

OPERATIONS MODE

Connected Operation Mode (1st operation mode)

In this mode of operation, the motor is turned off (converter # 2 disabled). This may be due for several reasons (water-filled box, operational problems or malfunction of the motor, etc.). All the power demanded by local loads (P_{load}) is provided by the photovoltaic generator. The surplus power, if any, is delivered to the grid (P_{grid}) through the converter # 1 (Figure 4 - a). Also the grid will ensure the continuity of the supply of local loads if there is deficiency in solar generation (Figure 4 - b). The control scheme is similar to that described in standard operation.

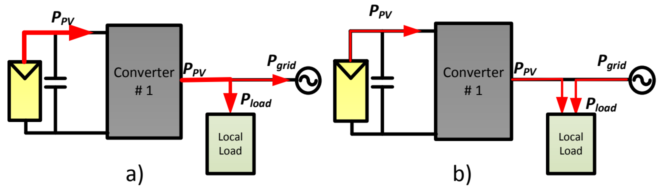

Figure 4: Interconnected operation mode: $P_{PV} > P_{load}$; b) $P_{PV} < P_{load}$

Standard operation (2nd operation mode)

This is the desired mode of operation. In standard operation, the converter # 1 is synchronized by means of a PLL whose frequency is provided by the network, like the actual photovoltaic systems.

The converter #2 operates with nominal values of voltage motor frequency (220 V and 60 Hz respectively).

The Entire power demanded by local loads and the motor is supplied by the photovoltaic system. The excessing power is delivered to the grid, as illustrated in the schematic of Figure 5 – a. In this configuration, the network will provide the difference of power required to operate the motor at nominal condition, if necessary (Figure 5 – b).

The converter # 1 works with PWM reference to current injection and forcing the PV operating in MPPT, while converter # 2 drives the motor that pumps water at rated power (rated speed ω). The converter # 2 is therefore acting in steady state operation with nominal voltage and frequency (V e f control fixed at nominal value).

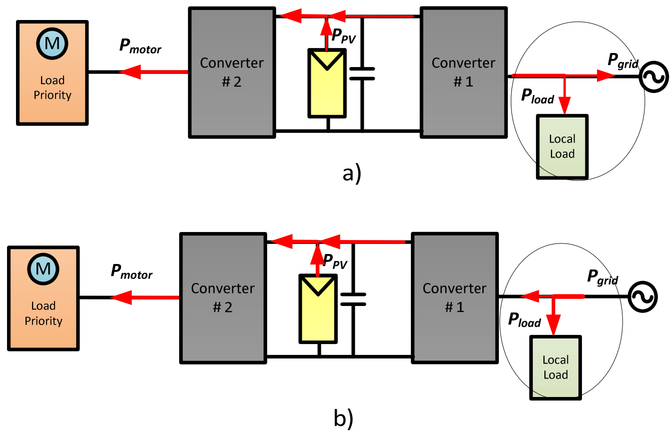

Figure 4: Standard operation scheme: a) $P_{PV} > P_{load} + P_{motor}$, b) $P_{PV} < P_{load} + P_{motor}$

Autonomous Operation Mode (3rd operation mode)

To improve the reliability and quality of supply (reducing the duration and frequency of interruptions), both converters PV system should be able to continue operating autonomously when the network is disconnected. In this case, the auxiliary control must act as same:

The converter #1 works with PWM control fixed voltage and frequency (corresponding to their nominal values, 127 V and 60 Hz, respectively).

The converter #2 controls the power balance between load and generation varying the rotation of the motor that drives the pump. Scalar control allows the variation of the frequency rotation to perform the MPPT and determine the new operating point of the CC link (V_{mppt} reference).

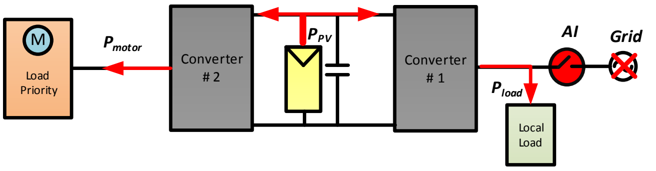

Figure 6: Autonomous operation scheme

This operation mode also provides the shutdown of the converter # 1 (local loads) depending on the demand of the isolated load (configured as a load priority). When the photovoltaic generation drops to more than 50% of nominal motor power (about 370 W), the # 1 converter should be disconnected. The operation of the system in this case is shown in Figure 2.10.

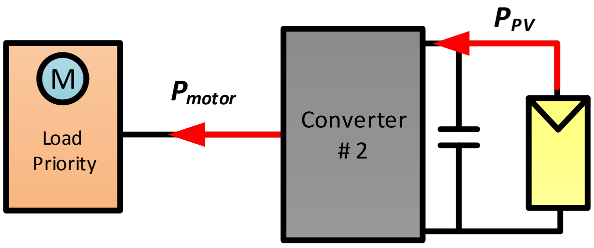

Figure 7: Equivalence of autonomous operation scheme with management load control

SIMULATION RESULTS

A photovoltaic generator studied is composite of 9 solar modules KC 130 from Kyocera (P_{mpp} = 1,100 kW - V_{mpp} = 158 V - Impp = 7,39 A), a 1 hp induction tree phases motor (220 V 60 Hz), local load (200 VA, PF 0,96) and 2 neighbours loads (200 VA, PF 0,96) for each.

Figure 8 shows the waveforms of the injected currents (Figure 8 - a) in the grid for the three phases considering the first operation mode. It also highlighted the voltage and current of phase A (Figure 8 - b). The zero angle lag proves that only active power is transferred between the PV system and the network, indicating that all the reactive power needed is provided by the network. However, in some standards like IEC, the PV generator converter should also provide the reactive power demanded by the load.

Figure 9 – a shows the DC and AC powers (this latest obtained at the output of the converter # 1). Figure 9 – b shows the total active power consumed by the loads (local and neighbours), the active power transferred to the grid (this negative power corresponds to the surplus of power supplied by the GPV.

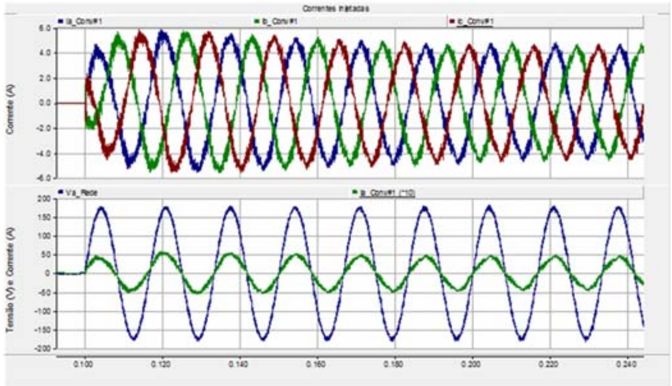

Figure 8: a) Current injected to the grid and b) Voltage and current of phase A.

One can be observed that during the first 100 milliseconds (period in which the two generation systems - the network and the GPV - were disconnected), all the power demanded by the neighbor loads came network (300 W). Later, when the interconnection occurred (100 ms), the GPV became supplying all loads (local and neighbours), and inject the power surplus in the grid (430 W). This occurrence is highlighted in Figure 9 is justified by the negative sign of the power injected to the network.

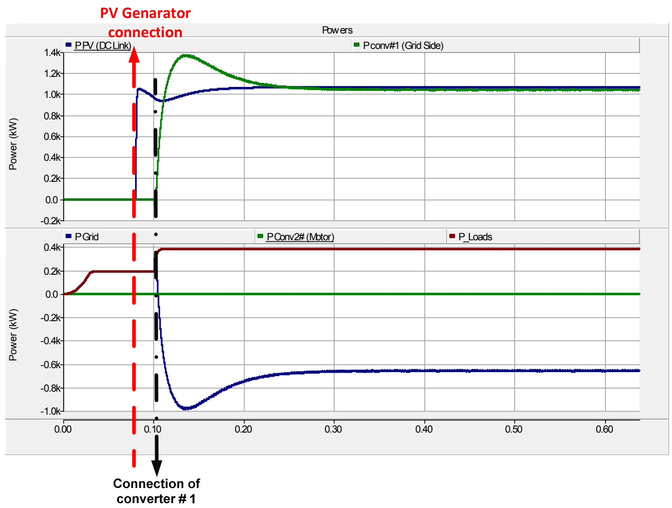

Figure 9 a) Power of DC side and Converter #1, b) Grid, load and motor power in the 1st operation mode

The standard operation assumes that the grid, the PV generator and the loads are connected (both converters operating). When the GPV is operating at nominal conditions, the power delivered by it is able to supply both the motor as well as local and neighbours loads, and eventually inject surplus power in the grid as occurred in the configuration described in the previous section. In this scenario, the motor was connected to the system through the converter # 2 after 0.7 seconds when the system was still operating in condition presented above (1st operation mode).

Figure 10 shows the waveforms of the currents injected to the network (Figure 10 - a) and the voltage and current of phase A (Figure 10 - b).

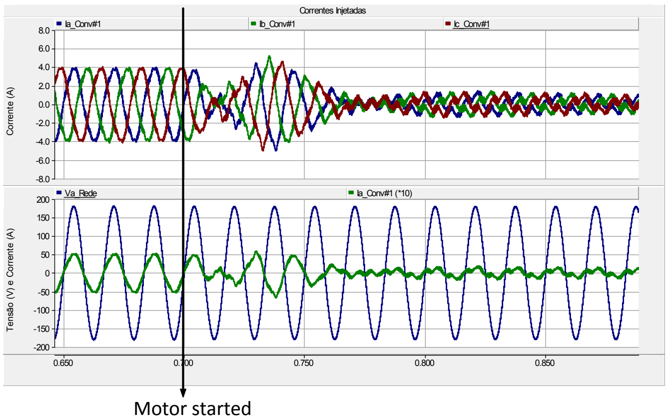

Figure 10: a) Currents injected to the network after the engine starting, b) Voltage and current in phase A

Figure 11 – a shows the DC and converter #1 powers. Figure 11 – b shows the local and neighbours powers, the grid and converter #2 powers at nominal operating conditions. Note the negative value of the power drawn by the converter #1 (about 1.3 kW) during motor starting. After the starting of the motor, the power injected in the network, which before was 1,060 kW, was reduced to about 150 W.

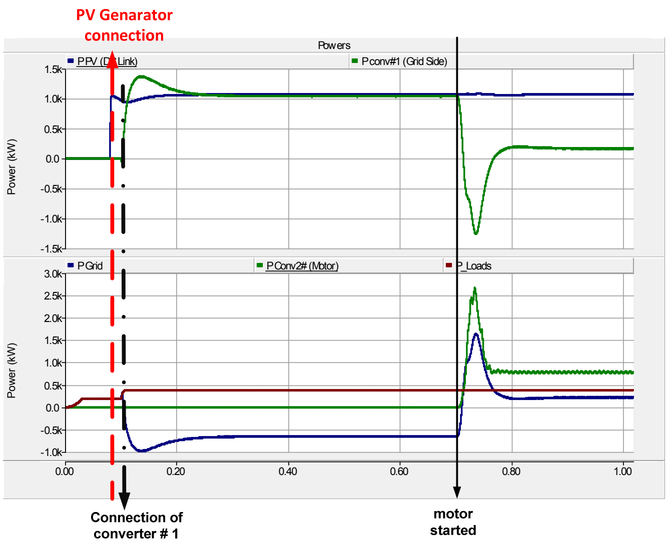

Figure 11 a) Power of DC side and Converter #1, b) Grid, load and motor power in the 2nd operation mode

One can observe a decrease of the power injected in the grid through the converter #1 after connecting the pump motor. In this case, the power provided by the photovoltaic generator is shared by the two converters. The control structure adopted establishes the converter # 2 as priority in power supply. And if a deficiency occurs in photovoltaic generation, the network should provide the motor power demand through the back-to-back converter.

During the islanding operation mode, initially one considers the system operating in normal condition, with the nominal values of insolation and temperature. However, islanding was detected after 1.2 seconds. The standalone process operation mode will be initiated by the activation of the auxiliary control.

Figure 12 - a) shows the balance of power between the photovoltaic generator, the network, the converter # 1 and the converter # 2 (Figure: 12 – b).

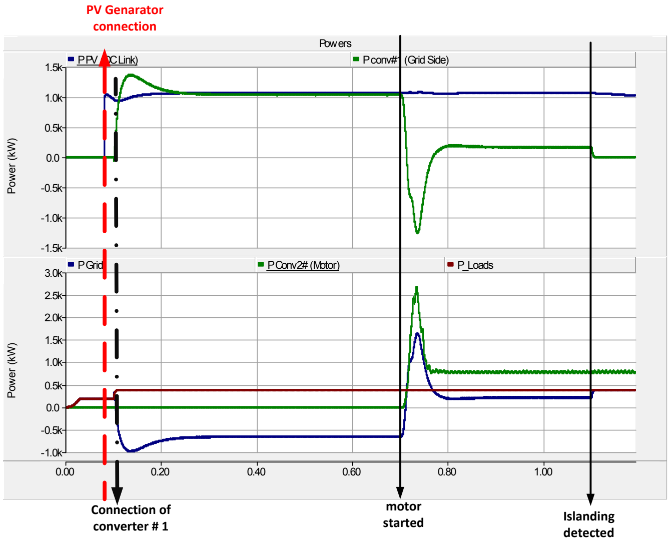

Figure 12 a) Power of DC side and Converter #1, b) Grid, load and motor power in the 3rd operation mode

One observes that in this particular case, the engine continued to operate at its nominal conditions established as seen in Figure 13. It (Figure 13 - a) can be proven that the pumping speed of the engine suffered no disturbance during islanding. With this scenario, the PV system, even when operating as standalone system has the capacity to supply the motor in steady state and inject surplus power (100 W) in the local loads through the converter # 1. In this case, the MPPT control is ensured by the converter # 2 by scalar control [40] (V/F constant). A smooth transition between these modes of operation is an additional reliability to integrate this configuration on the photovoltaic pumping

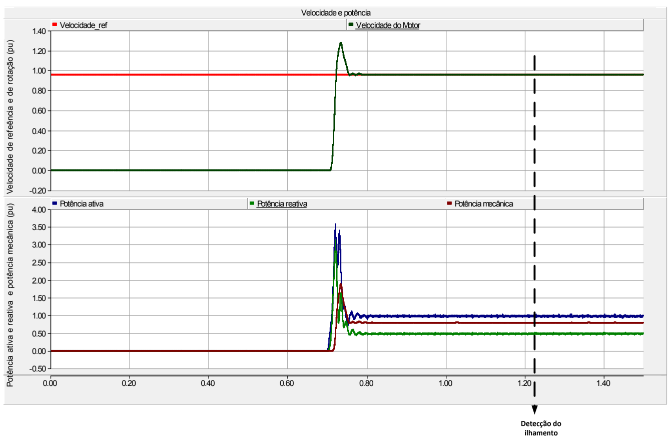

Figure 13: Speed, electrical and mechanical powers the engine during islanded and interconnected operations

CONCLUSION

The operating capacity of this configuration in three distinct ways, beyond the simplicity of establishing load management (disabling the converter # 1) system will certainly contribute to a better use of solar photovoltaic. Furthermore, the transition between modes of operation represents a contribution in terms of reliability in the application of the "back-to-back" converter in photovoltaic systems.

The results obtained with the three phase induction motor shown that PV systems can be a viable and efficient alternative to the field of irrigation, especially in isolated areas, where the power grid is intermittent. The proposal configuration, when implemented with scalar control, ensures the supply of water during islanding. And in this case, there is no need for oversizing the PV system, or the use of batteries for storage to supply the motor (single load). The motor still operating and pumping rate will depend only on weather conditions (intensity of solar radiation and temperature).

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