International Journal of Research
Available at
https://edupediapublications.org/journals
p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 08
July 2017

A Novel Approach for Power Quality Improvement in Distributed Generation.

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ABSTRACT

Harmonic reduction in inverters fed from a standalone PV system is currently becoming important in medium power applications. This paper focuses on the design and analysis of various passive filters for power quality improvement in standalone PV systems. Different passive filters are designed and analysed to reduce the total harmonic distortion of the proposed system. The passive filters include LC, LCL and LLCC filter topologies. A comparison study of the total harmonic distortion reduction with the above filters is done. Further, the paper attempts to show that the use of LLCC filter with a standalone PV system can highly improve the power quality of the system. Results are verified using simulations in MATLAB-SIMULINK environment. This paper focuses on the analysis and design of various passive filter designs for a single phase standalone PV system for medium power applications. The passive filter design is carried out with LC, LCL and LLCC filter topologies. The work evaluates the total harmonic distortion (THD) using each passive filter and a comparison is done with respect to power quality improvement. This paper is organised as follows: Section II discusses in brief the modelling of the standalone PV system. Section III describes the various passive filter designs for the standalone PV system. Section IV analyses the simulation results and Section V concludes the work.

I. INTRODUCTION

Among the renewable energy sources, a noticeable growth of small photovoltaic (PV) power plants connected to low-voltage distribution networks is expected in the future [1], [2]. As a consequence, research has been focusing on the integration of extra functionalities such as active power filtering into the PV inverter operation [3], [4]. Distribution networks are less robust than transmission networks, and their reliability, because of the radial configuration, decreases as the voltage level decreases. Hence, usually, it is recommended to disconnect low-power systems when the voltage is lower than 0.85 pu or higher than 1.1 pu [5]. For this reason, PV systems connected to low-voltage grids should be designed to comply with these requirements but can also be designed to enhance the electrical system, offering “ancillary services” [6]. Hence, they can contribute to reinforce the distribution grid, maintaining proper quality of supply that avoids additional investments. However, low-voltage distribution lines have a mainly resistive nature, and when a distributed power generation system (DPGS) is connected to a low-voltage grid, the grid frequency and grid voltage cannot be controlled by independently adjusting the active and reactive powers [7]–[9]. This problem, together with the need of limiting the cost and size of DPGS, which should remain economically competitive even when ancillary services are added, makes the design problem particularly challenging.

This paper proposes to solve this issue using a voltage controlled converter that behaves as a shunt controller, improving the voltage quality in case of small voltage dips and in the presence of nonlinear loads. Shunt controllers can be used as a static var generator for stabilizing and improving the voltage profile in power systems and to compensate current harmonics and unbalanced load current [10]–[18].

In this paper, the PV inverter not only supplies the power produced by the PV panels but also improves the voltage profile, as already pointed out [19]. The presented topology adopts a repetitive controller

[20]–[27] that is able to compensate the selected harmonics. Among the most recent Maximum Power Point Tracking (MPPT) algorithms [28]–[31], an algorithm based on the incremental conductance method has been chosen [32]–[35]. It has been modified in order to take into account power oscillations on the PV side, and it controls the phase of the PV inverter voltage. This paper is organized as follows. Section II discusses the possible voltage and frequency support provided by a DPGS converter connected to the grid. Section III discusses the use of shunt controllers for voltage dip compensation. The PV system improved with shunt controller functionality is proposed in Section IV. Section V presents the simulation results, and Section VI shows the experimental results. Finally, Section VII presents the conclusions.

MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Additional power harvested from the modules is then made available as increased battery charge current. MPPT can be used in conjunction with a mechanical tracking system, but the two systems are completely different.The problem considered by MPPT methods is to automatically find the voltage VMPP or current IMPP at which a PV array delivers maximum power under a given temperature and irradiance. In this section, commonly used MPPT methods are introduced in an arbitrary order.A. Fractional Open-Circuit Voltage The method is based on the observation that, the ratio between array voltage at maximum power VMPP to its open circuit voltage VOC is nearly constant.

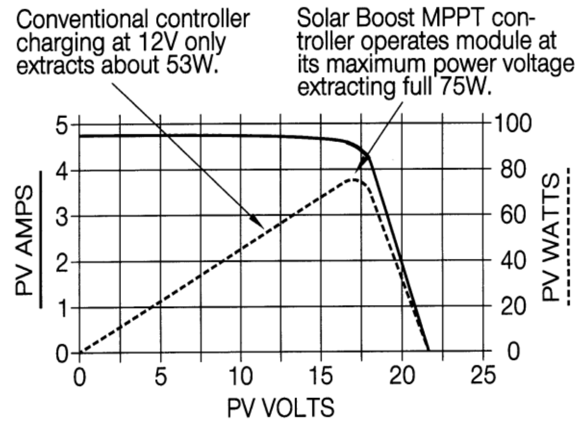
$V_{MPP} \approx k_1 V_{OC}$ This factor k1 has been reported to be between 0.71 and 0.78. Once the constant k1 is known, VMPP is computed by measuring VOC periodically. Although the implementation of this method is simple and cheap, its tracking efficiency is relatively low due to the utilization of inaccurate values of the constant k1 in the computation of VMMP.

B. Fractional Short-Circuit Current The method results from the fact that, the current at maximum power point IMPP is approximately linearly related to the short circuit current ISC of the PV array.

$I_{MPP} \approx k_2 I_{SC}$ Like in the fractional voltage method, k2 is not constant. It is found to be between 0.78 and 0.92. The accuracy of the method and tracking efficiency depends on the accuracy of K2 and periodic measurement of short circuit current. C. Perturb and Observe in P&O method, the MPPT algorithm is based on the calculation of the PV output power and the power change by sampling both the PV current and voltage. The tracker operates by periodically incrementing or decrementing the solar array voltage. If a given perturbation leads to an increase (decrease) in the output power of the PV, then the subsequent perturbation is generated in the same (opposite) direction. So, the duty cycle of the dc chopper is changed and the process is repeated until the maximum power point has been reached. Actually, the system oscillates about the MPP. Reducing the perturbation step size can minimize the oscillation. However, small step size slows down the MPPT. To solve this problem, a variable perturbation size that gets smaller towards the MPP.However, the P&O method can fail under rapidly changing atmospheric conditions. Several research activities have been carried out to improve the traditional Hill-climbing and P&O methods. A three-point weight comparison P&O method that compares the actual power point to the two preceding points before a decision is made about the perturbation sign. Reference proposes a two stage algorithm that offers faster tracking in the first stage and finer tracking in the second stage. D. Incremental Conductance The method is based on the principle that the slope of the PV array power curve is zero at the maximum power point.(dP/dV) = 0. Since (P = VI), it yields:

$$\Delta I/\Delta V = -I/V \text{, at MPP}$$
$$\Delta I/\Delta V > -I/V \text{, left of MPP}$$
$$\Delta I/\Delta V < -I/V \text{, right of MPP}$$

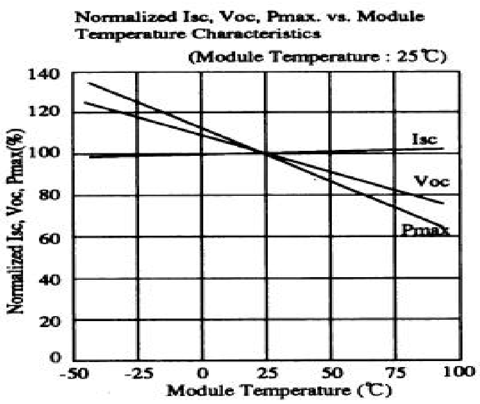
The MPP can be tracked by comparing the instantaneous conductance (I/V) to the incremental conductance (ΔI/ΔV). The algorithm increments or decrement the array reference voltage until the condition of equation (4.a) is satisfied. Once the Maximum power is reached, the operation of the PV array is maintained at this point. This method requires high sampling rates and fast calculations of the power slope To understand how MPPT works, let's first consider the operation of a conventional (non-MPPT) charge controller. When a conventional controller is charging a discharged battery, it simply connects the modules directly to the battery. This forces the modules to operate at battery voltage, typically not the ideal operating voltage at which the modules are able to produce their maximum available power. The PV Module Power/Voltage/Current graph shows the traditional Current/Voltage curve for a typical 75W module at standard test conditions of 25°C cell temperature and 1000W/m2 of insulation. This graph also shows PV module power delivered vs. module voltage. For the example shown, the conventional controller simply connects the module to the battery and therefore forces the module to operate at 12V. By forcing the 75W module to operate at 12V the conventional controller artificially limits power production to »53W.



Rather than simply connecting the module to the battery, the patented MPPT system in a Solar Boost charge controller calculates the voltage at which the module is able to produce maximum power. In this example the maximum power voltage of the module (VMP) is 17V. The MPPT system then operates the modules at 17V to extract the full 75W, regardless of present battery voltage. A high efficiency DC-to-DC power converter converts the 17V module voltage at the controller input to battery voltage at the output. If the whole system wiring and all was 100% efficient, battery charge current in this example would be VMODULE ¸ VBATTERY x IMODULE, or 17V ¸ 12V x 4.45A = 6.30A. A charge current increase of 1.85A or 42% would be achieved by harvesting module power that would have been left behind by a conventional controller and turning it into useable charge current. But, nothing is 100% efficient and actual charge current increase will be somewhat lower as some power is lost in wiring, fuses, circuit breakers, and in the Solar Boost charge controller. Actual charge current increase varies with operating conditions. As shown above, the greater the difference between PV module maximum power voltage VMP and battery voltage, the greater the charge current increase will be. Cooler PV module cell temperatures tend to produce higher VMP and therefore greater charge current increase. This is because VMP and available power increase as module cell temperature decreases as shown in the PV Module Temperature Performance graph. Modules with a 25°C VMP rating higher than 17V will also tend to produce more charge current increase because the difference between actual VMP

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 08
July 2017

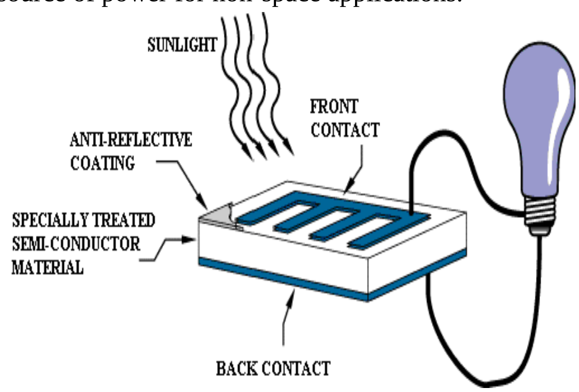
and battery voltage will be greater. A highly discharged battery will also increase charge current since battery voltage is lower, and output to the battery during MPPT could be thought of as being "constant power".



SHUNT CONTROLLER: The Shunt Controller allows two circuits to be temporally isolated from an active security system. The unit has two alarm inputs and each one is monitored by a 2K2 resistor. If this input is either open circuit or closed circuit the input is considered to be in alarm. Similarly the set inputisalso monitored by a 2K2 resistor. The set input controls the isolation of the other two inputs. Four relays are provided for alarm annunciation and control. In addition a buzzer is provided for local feedback to users. There are two modes of operation of the unit, timed and non timed, which are selected by using the on board switches. In both modes isolation of the two alarm inputs is initiated by applying the 2K2 resistor to the set input. In the non timed mode the isolation will remain until the set condition is removed (by either an open or closed circuit on the set input). In the timed mode the isolation will remain until the selected time matures or, optionally, until the set condition is removed as in the none timed mode. While the isolation is active the buzzer sounds continuously until the last 15 seconds of the timed period (timed mode only) when the buzzer sounds intermittently. If an attempt is made

PHOTOVOLTAIC INVERTER

Photovoltaic's is the field of technology and research related to the devices which directly convert sunlight into electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic effect involves the creation of voltage in a material upon exposure to electro magnetic radiation. The photovoltaic effect was first noted by a French physicist, Edmund Bequerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.



SOLAR CELL

The photovoltaic e_ect was _rst reported by Edmund Bequerel in 1839 when he observed that the action of light on a silver coated platinum electrode immersed in electrolyte produced an electric current. Forty years later the _rst solid state photovoltaic devices were constructed by workers investigating the recently discovered photoconductivity of selenium. In 1876 William Adams and Richard Day found that a photocurrent could be produced in a sample of selenium when contacted by two heated platinum contacts. The photovoltaic action of the selenium

International Journal of Research
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p-ISSN: 2348-6848
e-ISSN: 2348-795X
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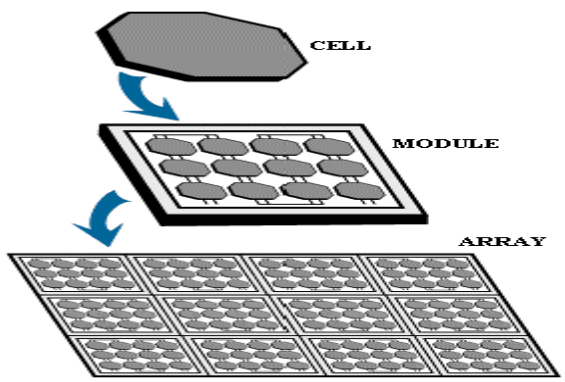
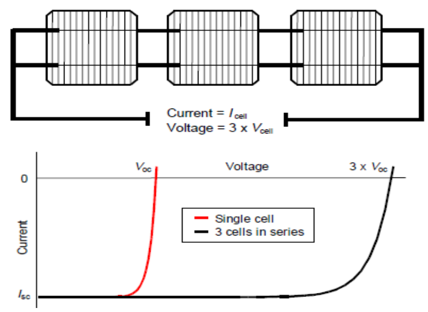
di_ered from its photoconductive action in that a current was produced spontaneously by the action of light. No external power supply was needed. In this early photovoltaic device, a rectifying junction had been formed between the semiconductor and the metal contact. In 1894, Charles Fritts prepared what was probably the _rst large area solar cell by pressing a layer of selenium between gold and another metal. In the following years photovoltaic e_ects were observed in copper{copper oxide thin _lm structures, in lead sulphide and thallium sulphide. These early cells were thin _lm Schottky barrier devices, where a semitransparent layer of metal deposited on top of the semiconductor provided both the asymmetric electronic junction, which is necessary for photovoltaic action, and access to the junction for the incident light. The photovoltaic e_ect of structures like this was related to the existence of a barrier to current ow at one of the semiconductor{metal interfaces (i.e., rectifying action) by Goldman and Brodsky in 1914. Later, during the 1930s, the theory of metal {semiconductor barrier layers was developed by Walter Schottky, Neville Mott and others



ELECTRICAL CONNECTION OF THE CELLS

The electrical output of a single cell is dependent on the design of the device and the Semi-conductor material(s) chosen, but is usually insufficient for most applications. In order to provide the appropriate quantity of electrical power, a number of cells must be electrically connected. There are two basic connection methods: series connection, in which the top contact of each cell is connected to the back contact of the next cell in the sequence, and parallel connection, in which all the top contacts are connected together, as are all the bottom contacts. In both cases, this results in just two electrical connection points for the group of cells. Series connection: Figure shows the series connection of three individual cells as an example and the resultant group of connected cells is commonly referred to as a series string. The current output of the string is equivalent to the current of a single cell, but the voltage output is increased, being an addition of the voltages from all the cells in the string (i.e. in this case, the voltage output is equal to 3Vcell)



It is important to have well matched cells in the series string, particularly with respect to current. If one cell produces a significantly lower current than the other cells (under the same illumination conditions), then the string will operate at that lower current level and the remaining cells will not be operating at their maximum power points. Parallel connection Figure shows the parallel connection of three individual cells as an example. In this case, the current from the cell group is equivalent to the addition of the current from each cell (in this case, 3 Icell), but the voltage remains equivalent to that of a single cell. As before, it is important to have the cells well matched in order to gain maximum output, but this time the voltage is the important parameter since all cells must be at the same operating voltage. If the voltage at the maximum power point is substantially different for one of the cells, then this will force all the cells to operate off their maximum power point, with the poorer cell being pushed towards its open-circuit voltage value and the better cells to voltages below the maximum power point voltage. In all cases, the power level will be reduced below the optimum.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 08
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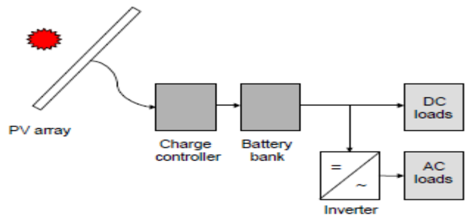

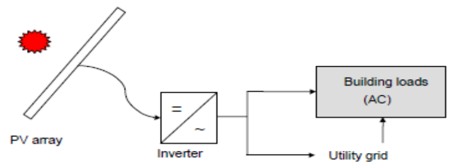

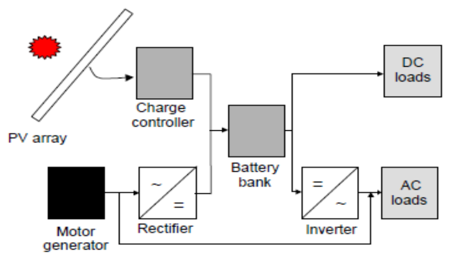

PHOTOVOLTAIC INVERTER

The inverter is the heart of the PV system and is the focus of all utility-interconnection codes and standards. A Solar inverter or PV inverter is a type of electrical inverter that is made to change the direct current (DC) electricity from a photovoltaic array into alternating current (AC) for use with home appliances and possibly a utility grid. Since the PV array is a dc source, an inverter is required to convert the dc power to normal ac power that is used in our homes and offices. To save energy they run only when the sun is up and should be located in cool locations away from direct sunlight. The PCU is a general term for all the equipment involved including the inverter and the interface with the PV (and battery system if used) and the utility grid. It is very important to point out that inverters are by design much safer than rotating generators. Of particular concern to utility engineers is how much current a generator can deliver during a fault on their system. Inverters generally produce less than 20% of the fault current as a synchronous generator of the same nameplate capacity. This is a very significant difference.

INVERTER CLASSIFICATION: Solar inverters may be classified into three broad types: Stand-alone inverters, used in isolated systems where the inverter draws its DC energy from batteries charged by photovoltaic arrays and/or other sources, such as wind turbines, hydro turbines, or engine generators. Many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source, when available. Normally these do not interface in any way with the utility grid, and as such, are not required to have protection. Grid, which match phase with a utility-supplied sine wave. Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages.Battery backup inverters. These are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection. Normally, grid-tied inverters will shut off if they do not detect the presence of the utility grid. If, however, there are load circuits in the electrical system that happen to resonate at the frequency of the utility grid, the inverter may be fooled into thinking that the grid is still active even after it had been shut down. This is called islanding.Islanding refers to the condition of a distributed generation (DG) generator continuing to power a location even though power from the electric utility is no longer present. Consider for example a building that has solar panels that feed power back to the electrical grid; in case of a power blackout, if the solar panels continue to power the building, the building becomes an "island" with power surrounded by a "sea" of unpowered buildings.

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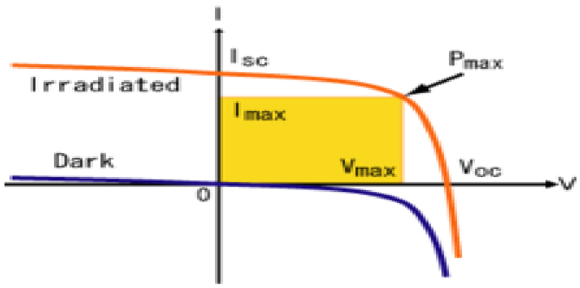
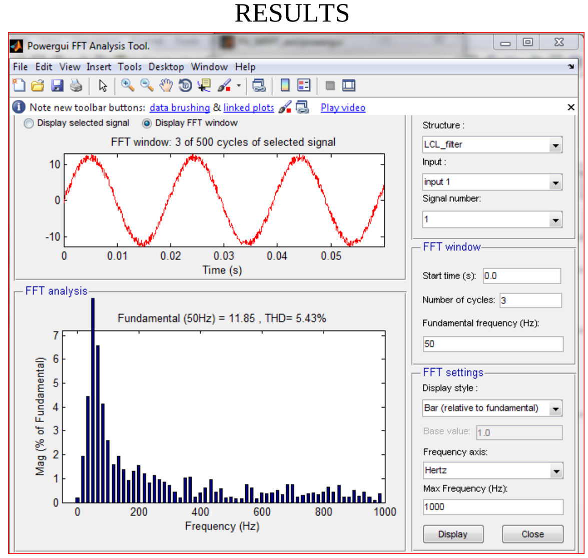


Maximum power point tracking is a technique that solar inverters use to get the most possible power from the PV array. Any given PV module or string of modules will have a maximum power point: essentially, this defines current that the inverter should draw from the PV in order to get the most possible power (power is equal to voltage times current maximum power point tracker (or MPPT) is a high efficiency DC to DC converter that presents an optimal electrical load to a solar panel or array and produces a voltage suitable for the load.PV cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to V/I as specified by Ohm's Law. A PV cell has an exponential relationship between current and voltage, and the maximum power point (MPP) occurs at the knee of the curve, where the resistance is equal to the negative of the differential resistance (V/I = -dV/dI). Maximum power point trackers utilize some type of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell. Traditional solar inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows though all panels in the string. But because different panels have different IV curves, i.e. different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some panels will be performing below their MPP, resulting in the loss of energy.[1]Some companies (see power optimizer) are now placing peak power point converters into individual panels, allowing each to operate at peak efficiency despite uneven shading, soiling or electrical mismatch. At night, an off-grid PV power system uses batteries to supply its loads. Although the battery pack voltage when fully charged may be close to the PV array's peak power point, this is unlikely to be true at sunrise when the battery is partially discharged. Charging may begin at a voltage considerably below the array peak power point, and a MPPT can resolve this mismatch. When the batteries in an off-grid system are full and PV production exceeds local loads, a MPPT can no longer operate the array at its peak power point as the excess power has nowhere to go. The MPPT must then shift the array operating point away from the peak power point until production exactly matches demand. (An alternative approach commonly used in spacecraft is to divert surplus PV power into a resistive load,

DESIGN PARAMETERS FOR THE PV MODULE AND BOOST CONVERTER

Parameter	Value
Output Voltage of the PV Module	60 V
Output Voltage of the Boost Converter	325 V
Switching Frequency of the Boost Converter	25 kHz
Inductor, L value in the boost converter circuit	12.5 mH
Capacitor, C value in the boost converter circuit	160 µF

RESULTS



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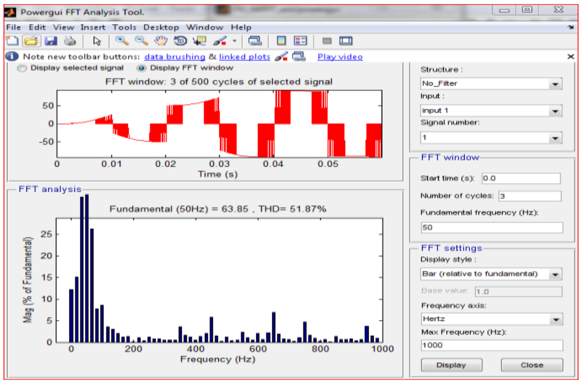

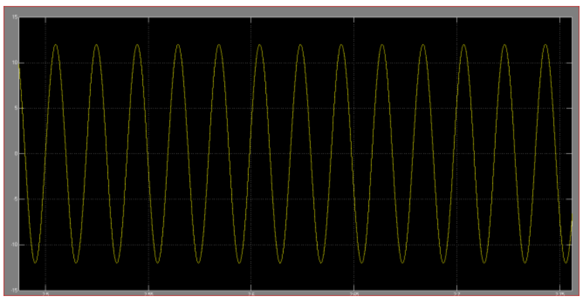

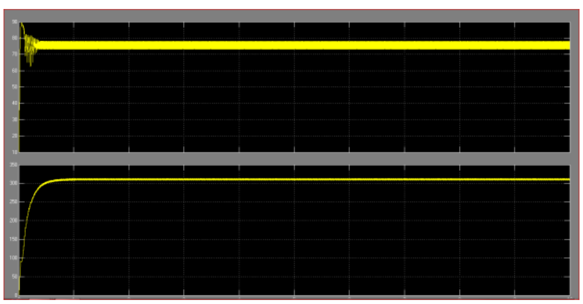

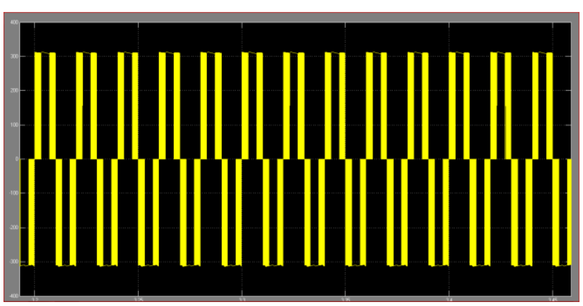

CONCLUSION

In this paper, a single-phase PV system with shunt controller functionality has been presented. The PV converter is voltage controlled with a repetitive algorithm. An MPPT algorithm has specifically been designed for the proposed voltage-controlled converter. It is based on the incremental conductance method, and it has been modified to change the phase displacement between the grid voltage and the converter voltage maximizing the power extraction from the PV panels. The designed PV system provides grid voltage support at fundamental frequency and compensation of harmonic distortion at the point of common coupling. An inductance is added on the grid side in order to make the grid mainly inductive (it may represent the main drawback of the proposed system). Experimental results confirm the validity of the proposed solution in case of voltage dips and nonlinear loads.

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