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INTER-HARMONIC MITIGATION IN A SINGLE PHASE GRID CONNECTED PV SYSTEMS WITH MAXIMUM POWER POINT TRACKING MODIFICATION

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ABSTRACT

Interharmonics are emerging power quality challenges in grid-connected Photovoltaic (PV) systems. Previous studies and field measurements have confirmed the evidence of interharmonic emission from PV inverters, where the Maximum Power Point Tracking (MPPT) is one of the main causes for interharmonics. In that regard, the MPPT parameters such as their sampling rate have a strong impact on the interharmonic characteristic of the PV system. In general, there is a trade-off between the interharmonic emission and the MPPT performance when selecting the sampling rate of the MPPT algorithm. More specifically, employing a faster MPPT sampling rate will improve the MPPT efficiency, but it will also increase the interharmonic emission level. To solve this issue, a new mitigating solution for interharmonics in PV systems is proposed in this paper. The proposed method modifies the MPPT algorithm in a way to randomly select the sampling rate between the fast and the slow value. By doing so, the interharmonics in the output current can be effectively reduced due to the distribution of the frequency spectrum. On the other hand, the MPPT performance of the proposed method can be maintained similar to the case when employing a fast MPPT sampling rate. The effectiveness of the proposed interharmonic mitigation has been validated experimentally on a single-phase grid-connected PV system.

INTRODUCTION

THE widespread use of renewable sources in the generation of electrical energy and the increased penetration of distributed generation has led to a growing interest in electrical distribution systems. On the other hand, the presence of a large number of grid-connected systems creates new problems related to safety and protection systems, the grid interface, and power quality. Among renewable sources, one can note the widespread use of single-phase grid-connected photovoltaic (PV) systems for low power level, installed near customers [1]. From the point of view of power quality, the goal is to obtain a sinusoidal current as the output of the grid-connected PV system. Unfortunately, harmonics are present in the output current because of the use of power semiconductor devices and the variable power flow of the PV panels. Furthermore, the grid usually supplies many nonlinear loads, which absorb distorted currents [2]. These currents, flowing through the impedances of the power distribution system (variable with frequency), result in a distortion of system bus voltage [3].

Moreover, interharmonic components may be present because the power-electronic devices of photovoltaic systems usually have switching frequencies not synchronized with the supply frequency. As is well known, the possible effects of interharmonics are noise in audio amplifiers, additional torques on motors and generators, additional noise in inductive coils (magnetostriction), and the blocking or unintended operation of ripple control receivers. In addition, they may affect synchronization techniques, such as phase-locked loop (PLL) or methods based on spectral analysis, used for synchronous sampling in instrument applications and for the synchronization with the power frequency in devices such as uninterruptible power supplies (UPS), active filters, and grid-connected devices [4], [5]. Therefore, interharmonics are an important class of power systems phenomena [6]. Consequently, the high level of distortion in currents and voltages has made necessary the improvement of the definitions of limits in power systems and the standardization of analysis procedures that are able to ensure an accurate monitoring of harmonic and interharmonic distortion in power networks.

Presently, the IEC 61 000-4-30 standard gives a complete view of testing and measurement techniques for power quality [7]. This standard, as well as the international standards for testing and measurement techniques for electromagnetic-compatibility (EMC) problems and power system networks, refers to IEC 61 000-4-7 [8] to define harmonics and interharmonics measurements. A revision published in August 2002 defines accuracy limits, measurement procedures and requirements for harmonic and interharmonic measurement instrumentations up to 2 kHz (or 9 kHz). Usually, voltage and current are not stationary, but it is always useful to obtain their distortion analysis. Also, in the standard IEC 61 000-4-7, a new concept is introduced: the spectral lines grouping. Furthermore, the standard defines some distortion factors: the well-known total harmonic distortion (THD), the group total harmonic distortion (THDG) and the subgroup total harmonic distortion (THDS). In order to restrict spectral leakage only to nonstationary signal and to ensure repeatable and comparable results, the limits for the synchronization of the sampling frequency set by the standard are very tight. It can be observed that International and European standards on grid-connected PV systems refer currently only to the THD factor to evaluate the amount of harmonic distortion. Moreover,instruments currently available on the market are often not updated to the above-mentioned new standard and calculate only the THD factor. Finally, it is useful to study which of the currently defined distortion factors is best suited to detect harmonic and interharmonic pollution. The aim of this paper is to present a theoretical and experimental comparison of the various THD factors in order to show how the new definitions allow one to achieve a better understanding of the harmonic and interharmonic pollution of a gridconnected PV system. First, a review of international and European standards on grid-connected PV systems is presented. Second, the new approach of the line grouping and the different THD factors are introduced. Third, in the paper, the performances of the harmonic distortion factors are analyzed by means of a PC-based instrument proposed by the authors in agreement to IEC 61 000-4-7, a commercial power analyzer and a power calibrator. The last part deals with experimental tests carried out on a single-phase grid-connected PV system, installed on a roof footbridge at the Faculty of Engineering—University of Palermo, by comparing the measurement results obtained by the PC-based instrument with a commercial power analyzer.

The IEEE standard 929-2000 "Recommended practice for utility interface of photovoltaic systems" contains guidance regarding the equipment and functions necessary to ensure the compatible operation of PV systems that are connected in parallel with the electric utility (personnel safety, equipment protection, power quality, and utility system operation). With respect to the power quality of the PV system output, the IEEE standard 519-1992 "Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems" sets limits of harmonic voltage and current at the point of common coupling (PCC). This standard establishes limits equal to 5% for the current and voltage THD factors that the producer should deliver to the customer. This standard also gives individual harmonic limits as the percentage of the fundamental frequency component at full system output. The IEC standard 61727 (European standard EN 61727) "Photovoltaic (PV) systems—Characteristics of the utility interface" addresses the interface requirements between PV systems and the utility, and provides technical recommendations. With regards to power quality and, in particular, to harmonics, the standard says that low levels of current and voltage harmonics are desirable. When harmonic limits are defined, the THD factor is always taken into consideration. In particular, different limits are given for the current, 5% for total current harmonic distortion (THDI), and the voltage, and 2% for total voltage harmonic distortion (THDV) with a 1% maximum for individual voltage harmonics. The European standard EN50160 "Voltage characteristics of electricity supplied by public distribution systems" provides a limit for the total voltage harmonic distortion equal to 8%, including up to the 40th harmonic. Moreover, limits for individual voltage harmonics are specified.

As an example, in Italy, too, harmonic limits are given by considering only the THD factor. The Italian technical standard CEI 11-20 (Italian Electrotechnical Committee) "Electrical energy production system and uninterruptible power systems connected to I and II class network" provides the criteria that can be applicable to all electrical energy production systems and also to PV plants including grid interface and protection devices and systems. Moreover, in Italy, in connecting the PV plants to the public electrical grid, the document DK 5950 "PV plants connection criteria to low voltage electrical distribution systems" edited by ENEL (Italian electrical utility) must be considered.

The new distortion factors according to IEC 61 000-4-7 are based on the concept of spectral line grouping. Therefore, in the following paragraph, a brief review of this concept is presented. As is well known, the calculated spectrum is equal to the real one, only if the analyzed signal segment is stationary and if it is an integer multiple of its period, which means using a sampling frequency multiple of the fundamental signal frequency [9]. Otherwise, a spread of signal spectral components (i.e., leakage) over closed bins is obtained. The synchronization of sampling reduces, but does not eliminate, the leakage error (i.e., the spreading out of the energy of harmonic components to adjacent spectral bins), due to the fluctuation of voltage and current signals in power systems. In order to improve accuracy and obtain comparable results, the standard [8] introduces the concept of grouping (i.e., the root mean square (rms) of different closed spectral lines and three different aggregation intervals). This procedure allows one to reduce the errors due to the presence of fluctuating harmonic and interharmonic components, which cause "sidebands" close to the harmonics [8], [10]. The standards [7], [8] define a signal observation window equal to 10–12 fundamental periods (50–60-Hz power systems) and, thus, the spectral resolution obtained is 5 Hz (Fig. 1). These lines are grouped by evaluating the rms in different configurations, groups, or subgroups, depending on what kind of measurement is to be performed (harmonics or interharmonics or both).

In this paper, the authors have presented a theoretical and experimental comparison between the different THD indexes, defined by IEC 61 000-4-7, in order to show their performances and their limitations in the evaluation of the harmonic and interharmonic pollution of a grid-connected PV system. The experimental comparison was carried out by means of a PC-based instrument developed by the authors and a commercial power analyzer. Test signals generated by a power calibrator have allowed one to show how both the THD and the THDS are unable to detect the presence of interharmonic components. On the contrary, the THDG is well suited to detect the presence of interharmonics components, because of the approach of the spectral lines grouping. The evaluation of the three distortion indexes carried out in a PV plant agrees with the expected results.

LITARATURE SURVEY:

1)Theoretical and experimental comparison of total harmonic distortion factors for the evaluation of harmonic and interharmonic pollution of grid-connected photovoltaic systems

Grid-connected photovoltaic systems are increasingly used in electrical distribution systems. However, they inject distorted currents. Therefore, special attention must be paid to harmonic and interharmonic measurements. The new edition of IEC 61000-4-7 introduces the concept of harmonic and interharmonic groups, which implies new expressions for total harmonic distortion (THD) factors. In this paper, a theoretical and experimental comparison is made between the different THD factors in order to show which of the currently defined distortion factors is best suited to detect harmonic and interharmonic pollution. Experimental tests were carried out first by means of a calibrator and subsequently in a single-phase grid-connected photovoltaic system. In both cases, measurements were carried out with a PC-based instrument developed by the authors and able to calculate the distortion factors according to IEC 61000-4-7.

2)Time and frequency domain evidence on power quality issues caused by grid-connected three-phase photovoltaic inverters

The amount of grid-connected inverters has been growing steadily over the past decade due to increase in renewable power generation. These inverters have been reported to degrade power quality in the grid in areas where the amount renewable power generation is large. However, the reasons behind the power quality issues are not yet extensively reported in the literature. The output impedance of single and three-phase PV inverters has been reported to resemble a negative resistance over a frequency range which depends on the selected control scheme and control parameters. Negative resistance can cause impedance-based interactions which may lead to instability, especially, when the inverter is connected to a weak grid which has large inductance. The main contribution of this paper is the experimental results which clearly show that the inverter has a significant role on the reported power quality issues. The inverter is shown to generate harmonic, interharmonic or even sub harmonic currents depending on the processed power, component sizing, control parameters and the grid impedance. The paper also demonstrates that these phenomena can be accurately predicted by applying the well-known Nyquiststability criterion.

3)Experimental-based evaluation of PV inverter harmonic and interharmonic distortion due to different operating conditions

This paper presents the results of comprehensive testing and subsequent detailed analysis of the obtained test results, evaluating harmonic and interharmonic performances of photovoltaic inverters (PV Inviters) for a range of different operating conditions. The presented results indicate significant power-dependent changes in harmonic and interharmonic emissions of tested PVI for different supply voltage conditions (presence of voltage waveform distortions and various source impedance values). To correctly quantify and describe these changes in PVI performance, this paper discusses and applies measurement procedures and metrics for evaluating harmonic and interharmonic emission recommended in existing standards, as well as some additional metrics and indicators. For some operating conditions, tested PVI significantly increase both harmonic and interharmonic emissions, and this paper also discusses the impact of PVI control (e.g., maximum power point tracking control) as a possible origin of the interharmonic distortion.

PROPOSED SYSTEM CONFIGURATION

The experimental test in this paper is conducted based on the single-stage single-phase PV inverter shown in Fig.6.1, where the system parameters are given in Table I. In this configuration, the PV inverter is employed to control the power extraction from the PV arrays and convert it to the ac power delivered to the grid [10]. In order to maximize the PV energy yield, the operating voltage of the PV arrays (i.e., corresponding to the dc-link voltage vdc) is determined by the MPPT algorithm during the operation. The dc-link voltage vdc is regulated through the control of the output current ig by a current controller, where the phase angle of the output current sin(θg) is obtained using a Phase-Locked Loop (PLL).

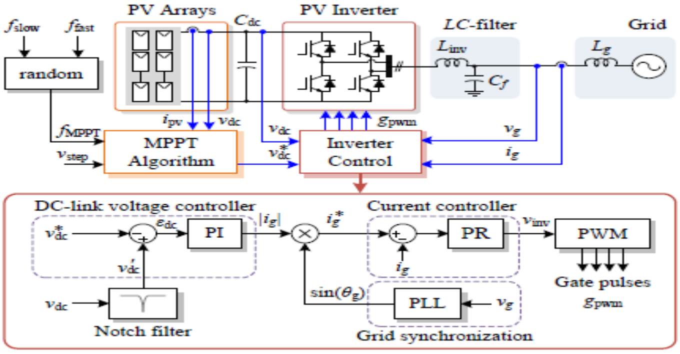

Fig 1:System diagram and control structure of single-stage single-phase PV inverter (PI - Proportional Integral, PR - Proportional Resonant, PWM - Pulse Width Modulation, PLL - Phase-Locked Loop).

TABLE I
PARAMETERS OF THE SINGLE-PHASE GRID-CONNECTED PV SYSTEM.

PV rated power	3 kW
DC-link capacitor	$C_{dc} = 1100\ \mu F$
LC-filter	$L_{inv} = 4.8$ mH, $C_f = 4.3\ \mu F$
Grid-side inductance	$L_g = 2$ mH
Switching frequency	$f_{inv} = 8$ kHz
Controller sampling frequency	$f_s = 20$ kHz
Grid nominal voltage (RMS)	$V_g = 230$ V
Grid nominal frequency	$f_g = 50$ Hz

The MPPT algorithm is essential for the PV system in order to maintain the operating point of the PV arrays close to the MPP and thus maximize the energy yield during the operation. In this paper, the Perturb and Observe (P&O) MPPT algorithm is employed [9], where the perturbation step-size vstep and the MPPT sampling rate fMPPT are the MPPT parameters. One important characteristic of the P&O MPPT algorithm (and also other hill-climbing MPPT methods) is the power oscillation during the steady-state operation [9]. This behavior is shown in Fig. 6.2, where the PV inverter operates underconstant solar irradiance condition. Two MPPT sampling rates of 2.5 Hz and 5 Hz are employed to demonstrate the performance of the PV system with different MPPT sampling rates. Comparing the operating condition with two times difference in the sampling rate can clearly demonstrate their impact on the interharmonic characteristics. It can be seen that the PV arrays voltage oscillates within three operating points, which correspond to the "top of the hill" in the powervoltage characteristic of the PV arrays. This is achieved when the sampling rate is properly selected below the PV-power settling time as discussed in [11]. Notably, the frequency ofthe oscillation is proportional to the MPPT sampling rate.the oscillation is proportional to the MPPT sampling rate.

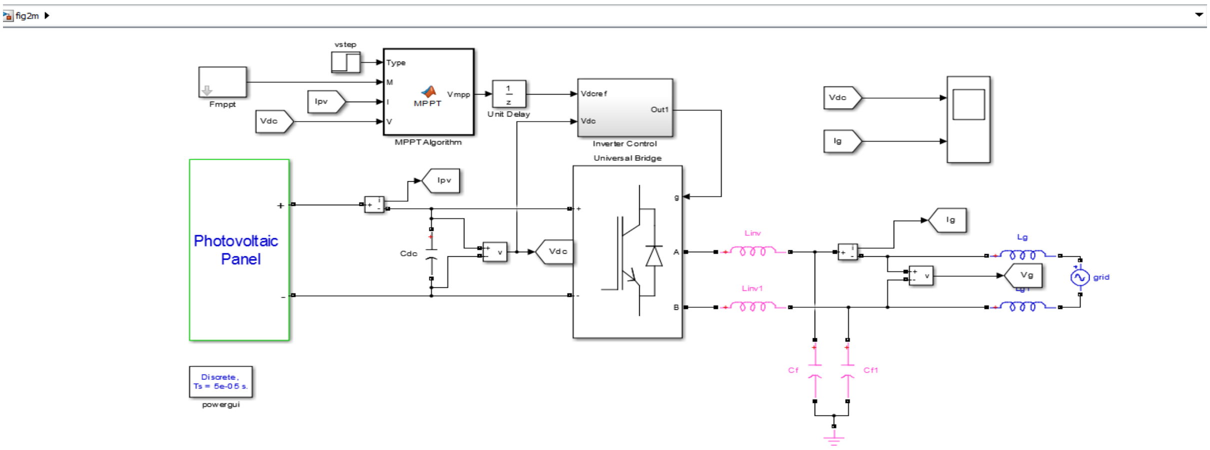

FIG 2 SIMULATING CIRCUIT DIAGRAM WITH PV SYSTEM WITH MPPT .

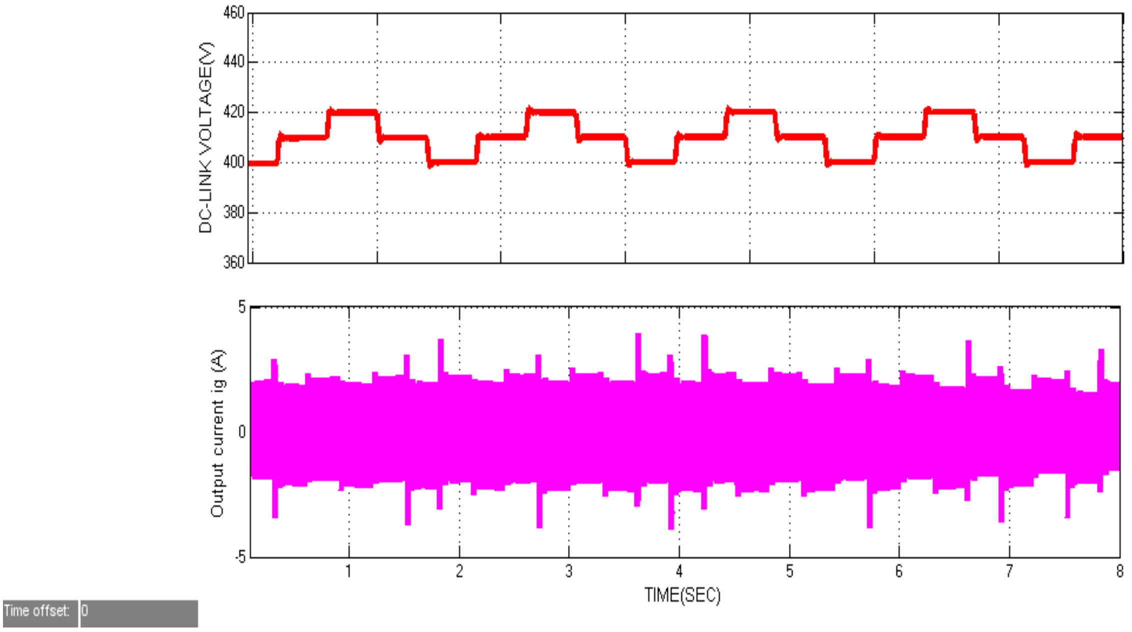

Fig 3 Load voltage with output current anf Dc-link at fmppt_2.5Hz.

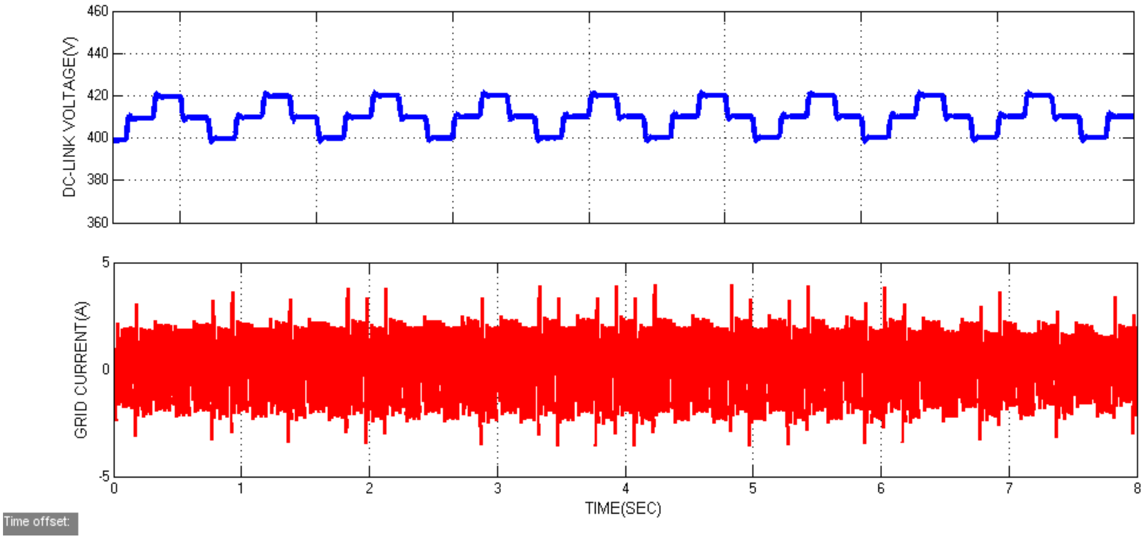

Fig 4 Load voltagewith grid curreng and dc link at fmppt-5MHz.

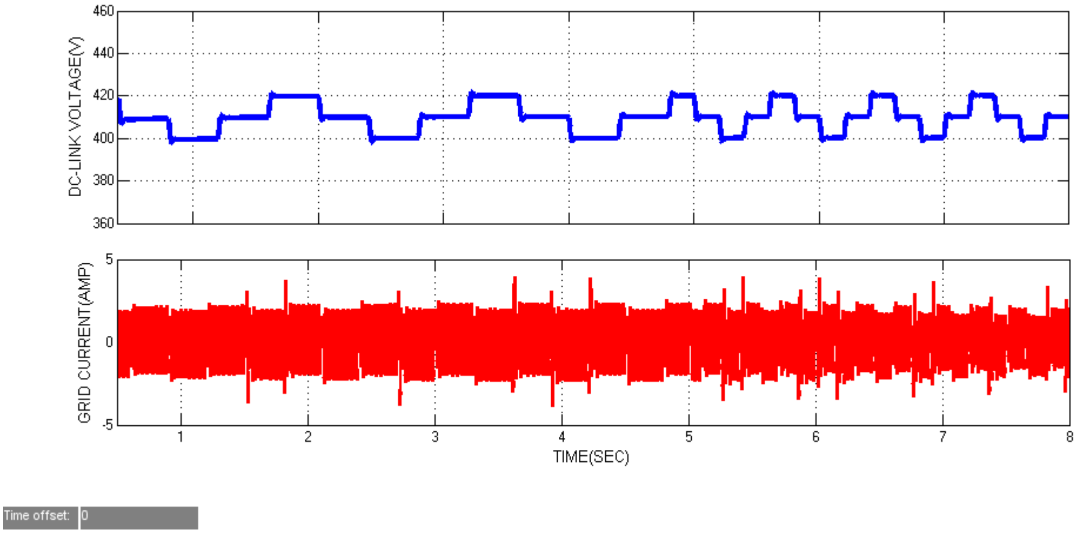

Fig 5 Load voltage with load and time at fmppt random.

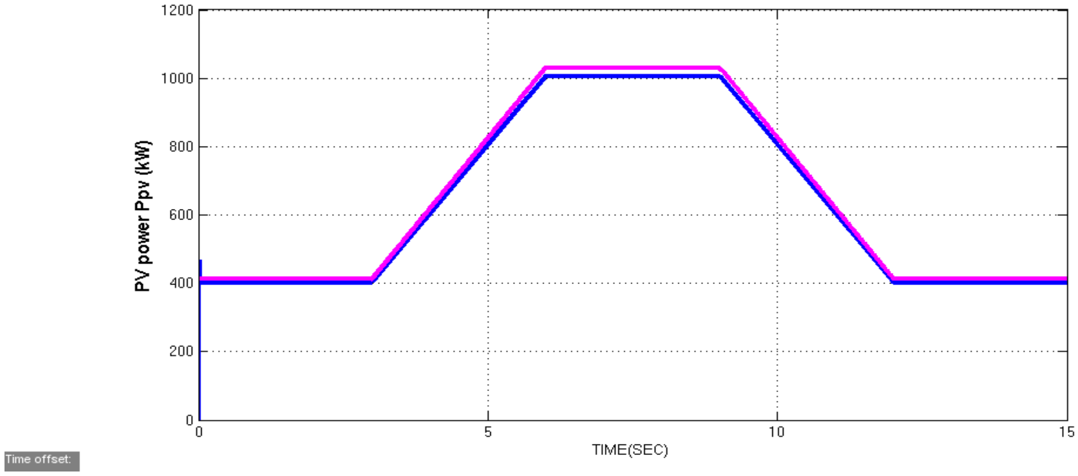

Fig 6 Experimental waveforms at Fmppt-2.5Hz.

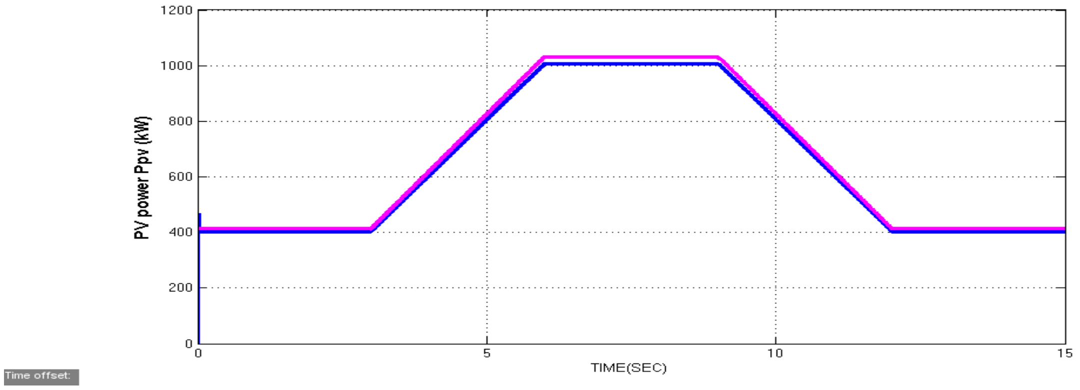

Fig 7

Experimental waveform at Fmppt-5Hz.

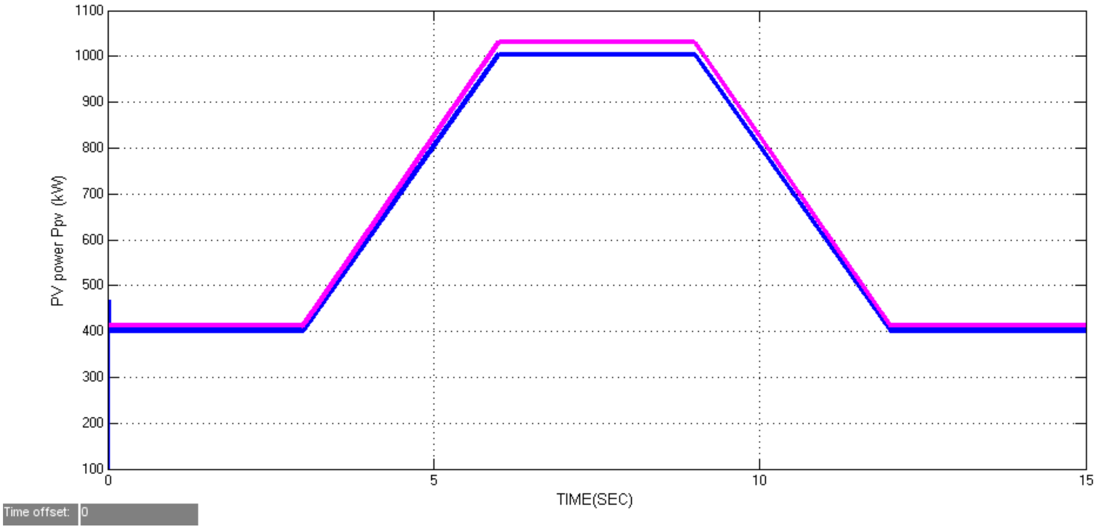

Fig 8 Experimental waveforms at Fmppt-random.

CONCLUSION

With the conventional MPPT implementation, there is a trade-off between the interharmonic emission and the MPPT efficiency when selecting the sampling rate of the MPPT algorithm. To solve this issue, a new mitigating solution for the interharmonics in PV systems has been proposed in this paper. The proposed method modifies the MPPT algorithm by randomly selecting the sampling rate of the MPPT algorithm during the operation. By doing so, the frequency spectrum of the output current can be smoothen and the amplitude of the dominant interharmonics can be significantly reduced. Moreover, the MPPT performance of the proposed mitigating solution can be maintained close to the conventional MPPT operation with a fast MPPT sampling rate, where similar tracking efficiency during a dynamic operating condition can be achieved. The performance of the proposed method has been validated experimentally under both steady-state (e.g., interharmonics) and dynamic operations (e.g., MPPT efficiency).

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