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Impact of Grid Connected Photovoltaic System on Total Harmonics Distortion (THD)

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ABSTRACT

Integrating renewable energy resources, especially photovoltaic systems with microgrids have become an unavoidable choice for most countries and India has achieved its NDC target with a total non-fossil-based installed energy capacity of 157.32 GW which is 40.1% of the total installed electricity capacity. As per Foreign Direct Investment (FDI) data cell, DPIIT, the Indian 'Non-Conventional Energy' sector received an FDI of US$ 797.21 million during 2020-21. On 28.04.2021, the Government introduced, Production Linked Incentive Scheme "National Programmed on High-Efficiency Solar PV Modules" with an outlay of Rs. 4,500 crores to support and promote the manufacturing of high-efficiency solar PV modules. Which in turn bring some challenge to the electrical utility operator. The results are demonstrated by determining the THD versus the photovoltaic load flow to the connected grid. Moreover, two solutions for power quality improvement are suggested. The first is based on switching at very low current flow conditions and the second is based on adding filters to the system. Finally, the two proposed approaches are implemented using MATLAB Simulink simulation and are compared for their efficiency and applicability.

KEYWORDS: *Solar energy; Photovoltaic (PV); power quality; Total Harmonic Distortion (THD)*

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1. INTRODUCTION

Renewable energy has recently been considered an efficient source of power that can provide sustainable and clean energy. In India, the government has this vision to extend the installation of solar plants all over the country to decrease the dependency on fossil fuel resources. But this trend put us in a challenge to overcome the technical impacts of these resources on the electrical grid. Solar stations can be categorized, according to their connection to the main grid, into two types, off-grid, and on-grid plants. Off-grid solar plants provide electric power for loads that cannot be connected to the main power grid, yet it remains isolated from the main grid and has no impact on its performance[1]. While on-grid stations are used in distributed to provide energy for specific loads, usually installed and operated by individuals, and are directly connected to the main grid through meters to exchange power with the utility grids, especially in distributed generation systems, where individuals are encouraged to invest in solar plants to meet their load consumption and get financial benefits from energy exchange[2].

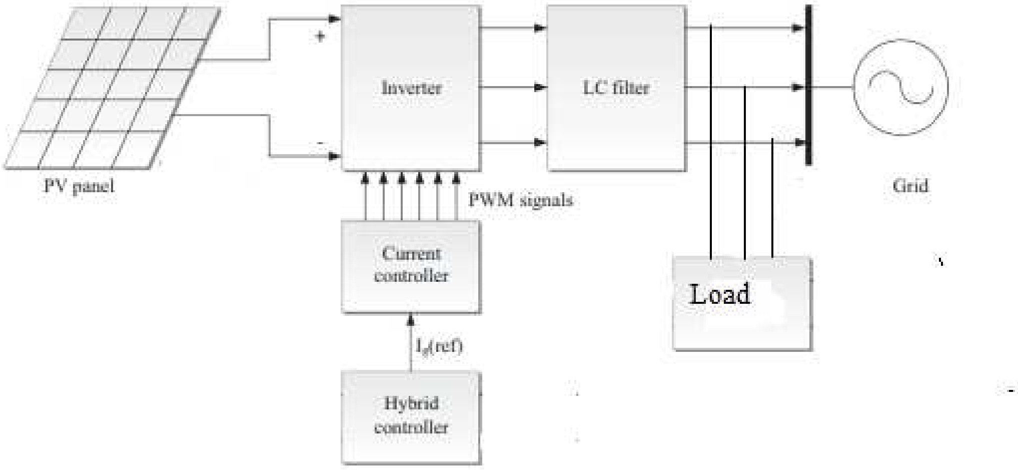

Fig-1 Block diagram of proposed model

The total harmonic distortion (THD) is needed for quality evaluation of electrical quantities, e. g. an output voltage or current. Transmitted signals can be obtained e. g. from sinusoidal ones to other ones, e. g. to the square waveform of the fundamental period. THD is defined as the sum of all harmonic components of the voltage or the current waveform compared to the fundamental component of the voltage or the current wave. Investigation of THD in this paper is done using Fourier series and from them derived numerical infinite series.

The total harmonic distortion (THD) is needed for quality evaluation of electrical quantities, e. g. an output voltage or current of a power inverter (cf. [3]). Transmitted or generated signals can be obtained e. g. from sinusoidal ones to other ones, e. g. to the square waveform of the fundamental period. THD is defined as the sum of all harmonic components of the voltage or the current waveform compared to the fundamental component of the voltage or the current wave. Knowing properties of non-harmonic function representing an electrical quantity (voltage, current), it is possible to determine the total harmonic distortion of the investigated quantity. Investigation of THD in this paper will be done using Fourier series and from them derived numerical infinite series. Denoting the fundamental component of a voltage by U1, all harmonic components of a voltage by

U2, U3, …, Un ,… (n =1,2,3,...), the root mean square (RMS) value of U1, U2, …, Un ,… by

$$U=\sqrt{U_1^2+U_2^2+U_3^3+\cdots\dots\dots.+U_n^2} \quad (1)$$

and by u(t) the output voltage of an inverter, we can write the formula for THD of u(t) as follows

$$THD\,[u\,(t)]=\frac{\sqrt{U_2^2+U_3^2+\cdots\dots\dots+U_n^2+\cdots}}{U_1} \quad (2)$$

PV systems incorporating a powerful electronics connector that produces harmonics [5] can cause current and voltage disturbances. The sum of the different components of a high sinusoidal frequency is the harmonic of the current waveform or voltage which is an important multiplier of the basic frequency. These harmonics have a significant impact on the efficiency and reliability of energy systems, loads and protective transmission [4]. Due to the rapid growth of PV systems, attention has been paid to the harmonic distortions introduced to the grid by photovoltaic inverters.

2. Current harmonic caused by DC-link voltage ripple

In this section, we have analyzed current harmonics caused by the ripple voltage of the central region. The model is designed to take into account the voltage ripple that doubles the frequency of the pipes. A closed current harmonics solution is provided[6].

Figure 2 shows the inverter model, taking into account the voltage ripple of the central region. The Ginv and Gina inverter transmission functions shown in Figure 3 have been replaced by a shaded triangle, which is the VripVrip sinusoidal signal that doubles the line frequency of the DC VDCVDC segment. The transmission function at this stage cannot be detected because the voltage ripple changes over time. However, numerical solutions can be tested using this model for specific operating conditions [1].

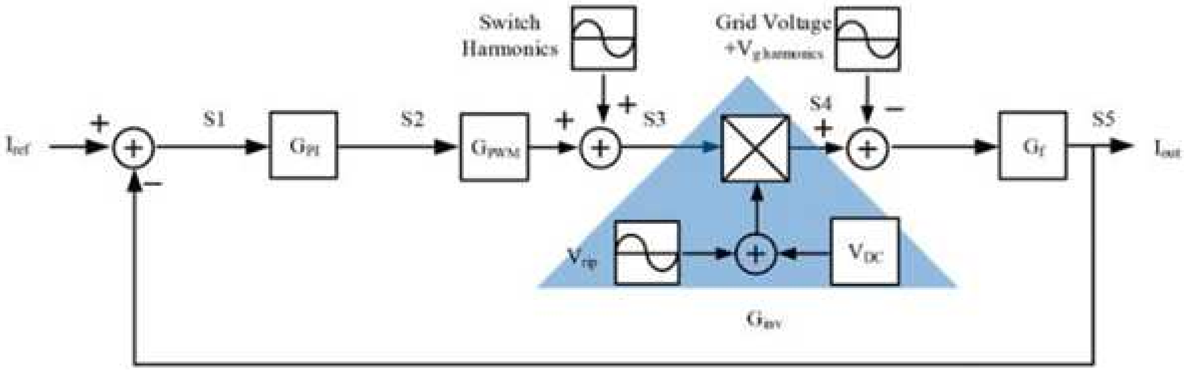

Fig-2 Model of inverter with the DC-link voltage ripple Where GPIGPI, GPWMGPWM, Ginv, Ginv, and GfGf are the transfer functions of the PI controller, PWM, inverter, and filter, respectively. Only the basic waveform is considered in this model, and harmonic knowledge is required to analyze the harmonic distortion.

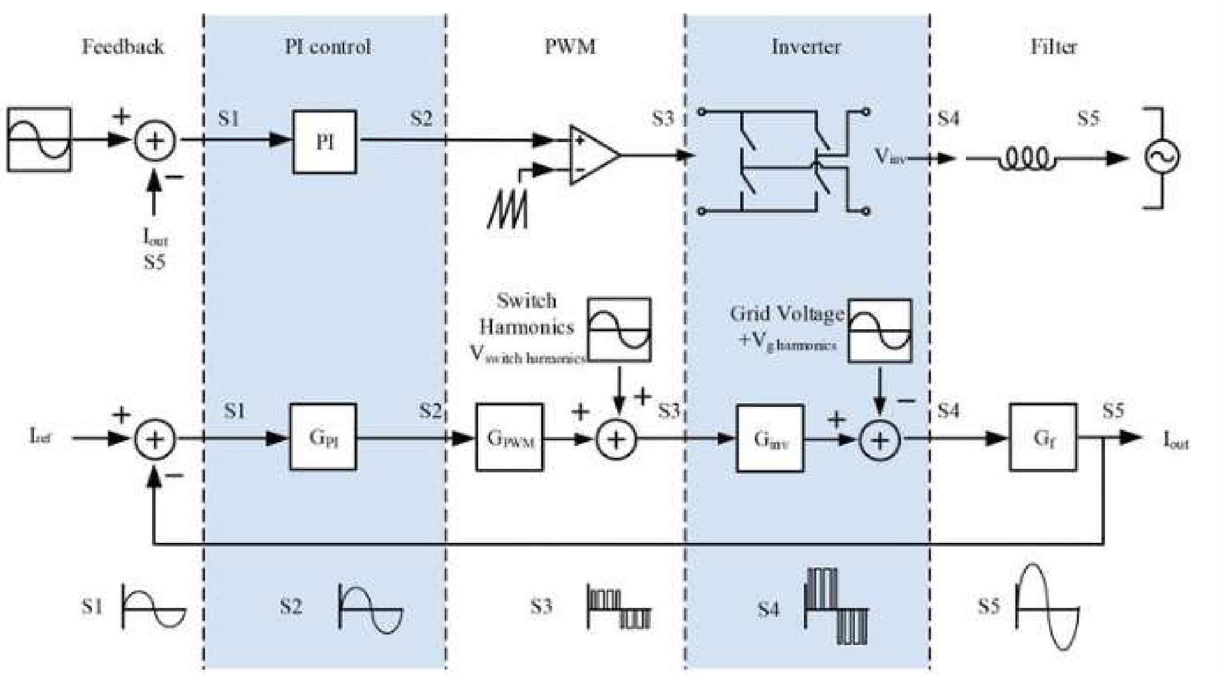

Fig- 3 Model of current-controlled PWM inverter with harmonic information

3. Modeling of the PV inverter for harmonic analysis:

At this stage, the PWM inverter framework with the control of the current single-phase PV inverter is the most commonly used bridge-to-commodity product, standard models of current inputs for this type of inverter, and the proposed standard inverters. Presented in the harmonic analysis of the model.

Table-1 Variation of THD with Load

Load (kW)	THD in power supply with solar array	THD in power supply without solar array
10	0.823	$1.48*10^{-8}$
100	0.79	$1.499*10^{-8}$
500	1	$1.86*10^{-8}$

4. Simulation and experimental results:

In this section, the simulation and experiment results are reported. By using Matlab/Simulink. The switching model simulation provides the most detailed results including the switch information and all the potential harmonic distortions.

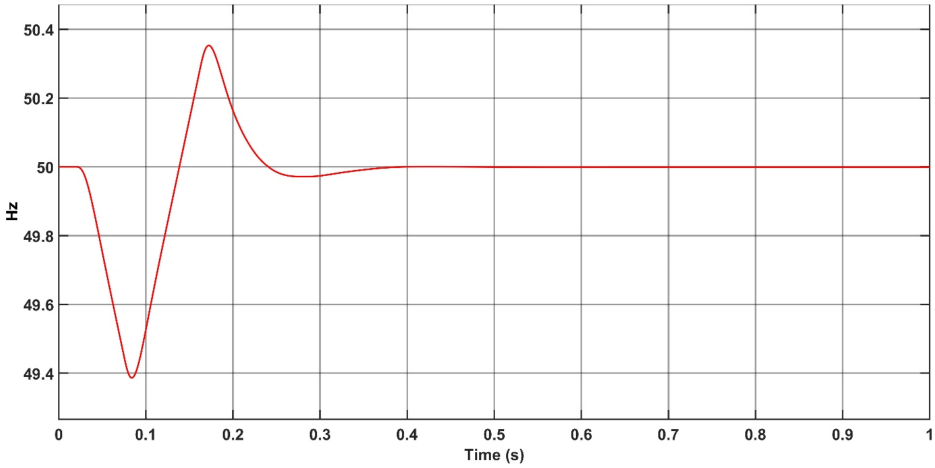

Fig-4 Grid frequency (without solar array)

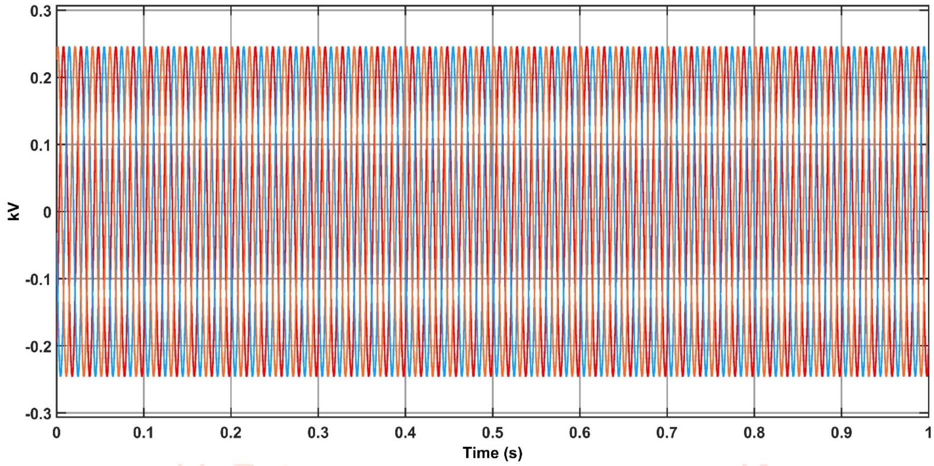

Fig –5 Grid Voltage without (solar array)

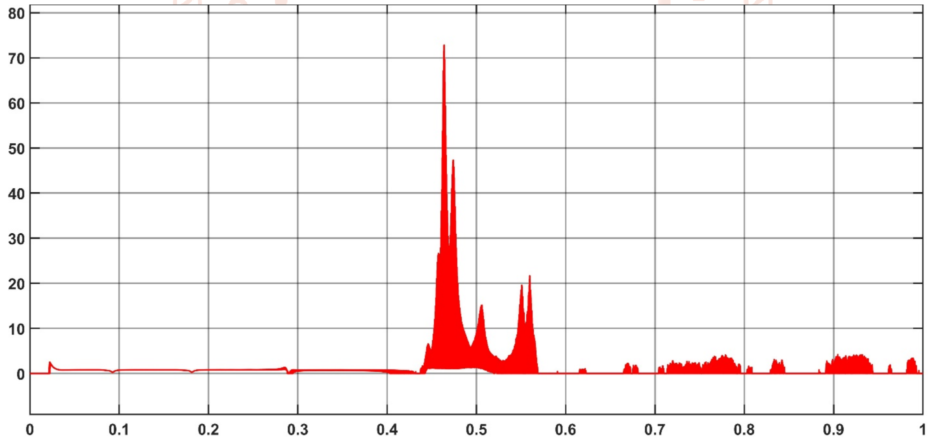

Fig –6 THD of power supply (without solar array)

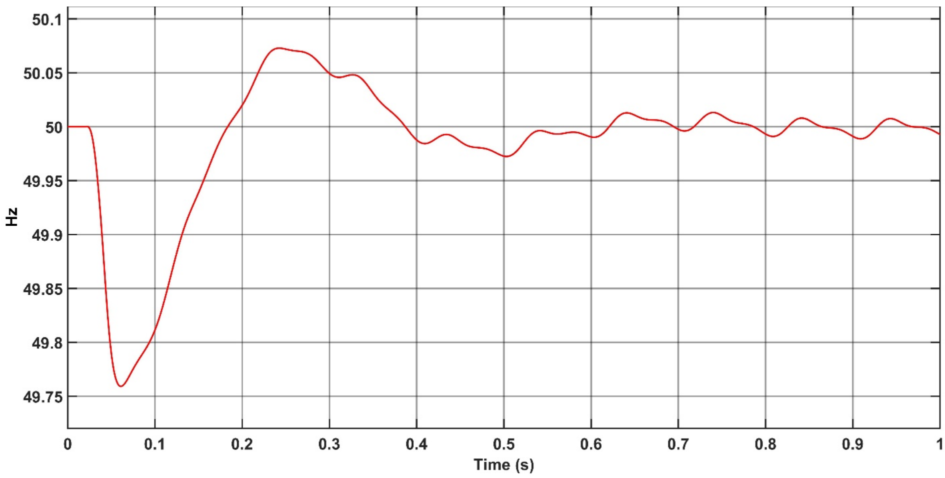

Fig- 7 Grid frequency (with solar array)

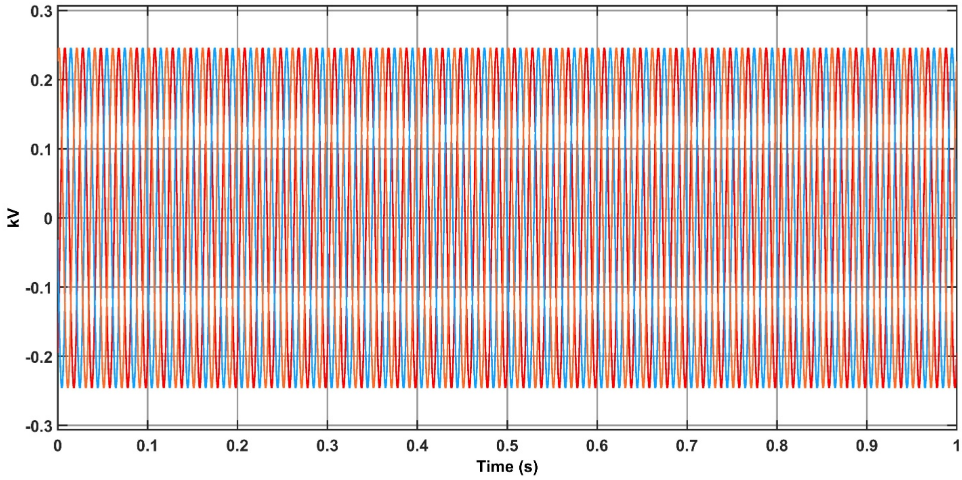

Fig – 8 Grid Voltage with (solar array)

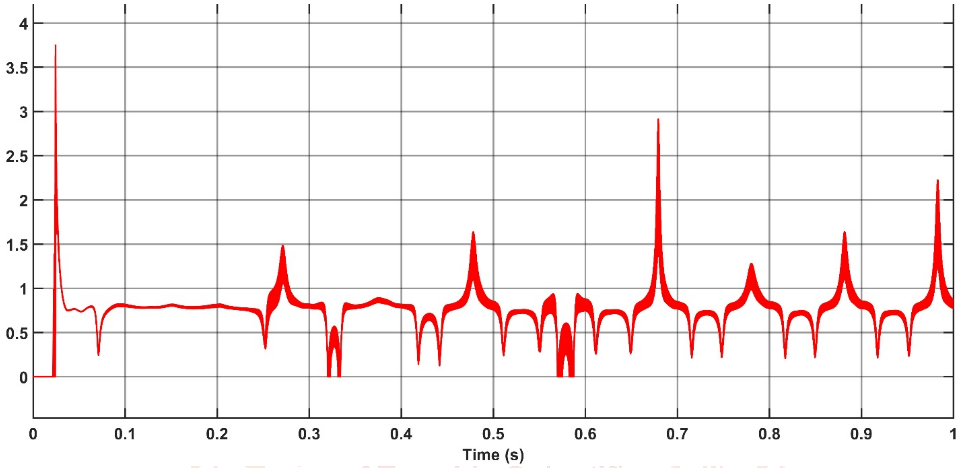

Fig –9 THD of power supply (with solar array)

Table -1 shows the variation of THD with load in both cases (with a solar array and without a solar array). In conclusion, the design with a solar array shows high THD, and as the load increases, THD decrees slowly. The corresponding figure of THD is shown in fig 9 and 6 whereas grid frequency with a solar array and without solar array has been presented in fig 4 and 7.

5. Conclusion:

In this work, a standard model modified from a diagram of a common control structure is introduced to analyze the harmonic production process caused by a PV inverter. The cause of the harmonics has been identified. A series of unusual harmonics in the current output of a DC link capacitor is produced by a voltage ripple that doubles the line frequency. The relationship between harmonic amplitude and intermediate circuit voltage ripple is shown. The proposed solution is confirmed by the results of testing and imitation. This is a tool for diagnosing power quality problems in grid-connected inverter systems. Designers can also use this to consider the trade-off between DC link capacitor size and the output harmonics of the current output.

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