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Power Quality Improvement of Grid Connected Solar PV System

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Abstract: *In this dissertation, the design, modeling and analysis of a single phase grid connected photovoltaic (PV) system feeding nonlinear load is carried out. Normally, the phase-locked loop (PLL) circuits are used for synchronization purposes and generation of in-phase and quadrature templates. However, this paper presents an interesting application of FLLs for achieving load compensation for power quality improvement as well as estimation of phase and frequency components. Design and modeling of controllers using these FLLs for achieving power quality improvement is presented in the paper. A second order generalized integrator based frequency locked loop (SOGI-FLL) for control of a 5 kW PV interfaced single-phase compensator for power quality improvement is presented. The purposed control with voltage source converter (VSC) provides harmonic reduction, synchronization, fast dynamic response and enhance the overall power quality of the proposed system. The proposed system is designed in MATLAB/Simulink and results are analyzed under change in solar irradiance and nonlinear unbalanced load. The Total Harmonic Distortion of source voltage and source current is less than 5%, which follows the IEEE-519 standard.*

Keywords: VSC, second order generalized integrator, PV array

I. INTRODUCTION

Low-frequency oscillations have been observed in a real-world solar photovoltaic (PV) farm. The goal of this research is to build a simplified analytical model in the synchronous frame for large-signal simulation and small-signal analysis. The second model assumes that PV's dc side is represented by a constant dc voltage behind impedance. The simplified models are compared with an electromagnetic transient (EMT) test bed with full details on time-domain simulation results, admittance frequency-domain responses, and eigen value-based stability analysis results are discussed [1]. The implementation of a control approach for an active power transfer between solar photovoltaic (PV) array and the grid/ load along-with power quality (PQ) improvement by eliminating harmonics and compensating reactive power required by the load in the distribution network. The prominence of the control algorithm lies in the efficient switching of voltage source converter (VSC), by generating reference grid currents, which are obtained through indirect current control technique is discussed [2]. In recent years, grid connected photovoltaic system has emerged with its simplicity, reliability and endurability. The ranges of grid tie inverters (GTI) are classified as small scale as several tens of kilowatts and large scale as hundreds of megawatts. Accordingly, the standard of interconnecting to the grid is made higher extent in improving its power system reliability, efficiency and cost. Moreover, the working of grid connected inverter primarily depends on robustness in control strategy, even working in abnormal grid conditions such as deviation of voltage and frequency.. The structure of the phase locked loop (PLL) with grid synchronization techniques for single phase and three phase is discussed in brief [3]. the performance of a grid connected photovoltaic (PV) system used as an active filter is presented. The system can also operate as a standalone active filter. The system was connected to a 1 kW PV array and tested with the loads typically found in households: small motors, personal computers and electronic ballasts. The results show that the system can correct the power factor to values close to unity for all the cases tested, thereby improving the efficiency of the electric energy supply is described [4]. This article presents a dynamic voltage support (DVS) scheme for achieving low-voltage ride-through (LVRT) with a grid-connected photovoltaic (PV) inverter during the voltage sag fault. The DVS scheme is achieved by formulating an additional reactive active current control mode which is developed from a conventional reactive current control approach. This provides stable operation of the system and achieves higher effectiveness due to the lower X/R ratio at the point of common coupling in low-voltage networks. Further, the performance of the proposed controller is assessed by simulating a 4 kW system for voltage sag faults [5]. A three phase grid tied solar photovoltaic (PV) system with power quality compensation features is presented in this paper. This system is operated to transfer power generated from solar PV array to feed linear and nonlinear loads along with compensation of several power quality (PQ) issues such as harmonics, redundant reactive power and load unbalancing. The generated DC power from PV array is converted into AC by implementing a three phase voltage source converter (VSC). In order to transfer active power and mitigate PQ problems, an efficient control technique is required for grid tied solar PV system. This work presents the use of adaptive generalized maximum Versoria criterion (AGMVC) controller for VSC used in solar PV energy conversion system. Efficient utilization of solar PV array is accomplished by using Perturb and Observe based maximum power point tracking (MPPT) algorithm. This control technique is compared with different conventional controllers such as synchronous reference frame theory (SRFT) and instantaneous reactive power theory (IRPT) along with recently developed weight based controllers viz. least mean square (LMS), least mean mixed norm (LMMN) and normalized kernel least mean fourth-neural network (NKLMF-NN) [6]. An enhanced third-order generalized integrator (TOGI) method has been proposed for the estimation of grid frequency and the synchronizing signals. The proposed method precisely estimates grid frequency and synchronizing signals in the presence of high harmonic content, phase change, frequency change, noise, and DC-offset in the grid voltage. A robust frequency estimator based on three consecutive sampling method has been integrated with TOGI algorithm for accurate frequency estimation. The proposed technique gives zero steady-state error in case of frequency estimation under different grid voltage conditions [7]. Most issues carried out about building integrated photovoltaic (PV) system performance show average losses of about 20%-25% in electricity production. The causes are varied, e.g., 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. This paper presents the intelligent PV module concept, a low-cost high-efficiency dc-dc converter with maximum power point tracking (MPPT) functions, control, and power line communications (PLC) [8]. When the insolation is weak or the PV modules are inoperative at night, the RPC feature of PV system can still be used to improve the utilization factor of the system is presented [9]. The maximum useful weights of the octocopter, hexacopter and quad copter, were 77%, 55% and 32% that of the decacopter. The controls for each of the configurations are identified and for the configurations with control redundancy, the power optimal controls are presented [10]. This paper discusses the design, modeling and analysis of a single-phase grid-tied photovoltaic (PV) system feeding a variety of loads. Normally, the phase-locked loop (PLL) circuits are used for synchronization purposes and generation of in-phase and quadrature templates. However, this paper presents an interesting application of PLLs for achieving load compensation for power quality improvement as well as estimation of phase and frequency. Three PLL algorithms are considered which include the conventional Delay PLL, Enhanced PLL and Second-Order Generalized Integrator Frequency-Locked Loop (SOGI-FLL). Design and modeling of controllers using these PLLs for achieving power quality improvement is also presented in the paper. Suitable comparisons are drawn to investigate the performance of different PLLs for two purposes viz. grid synchronization and achieving compensation in a single-phase grid-tied PV system [11]. A SOGI-FLL for control of a 5 kW PV interfaced single-phase compensator for power quality improvement is presented. The total harmonic distortion of the proposed system is satisfying the IEEE -519 standard.

II. System Description

In this proposed work, the design, modeling and analysis of a single phase grid connected photovoltaic (PV) system feeding nonlinear load is carried out. Normally, the phase-locked loop (PLL) circuits are used for synchronization purposes and generation of in-phase and quadrature templates. However, this paper presents an interesting application of FLLs for achieving load compensation for power quality improvement as well as estimation of phase and frequency components. Design and modeling of controllers using these FLLs for achieving power quality improvement is presented in the paper. A second order generalized integrator based frequency locked loop (SOGI-FLL) for control of a 5 kW PV interfaced single-phase compensator for power quality improvement is presented. The purposed control with

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voltage source converter (VSC) provides harmonic reduction, synchronization, fast dynamic response and enhance the overall power quality of the proposed system.

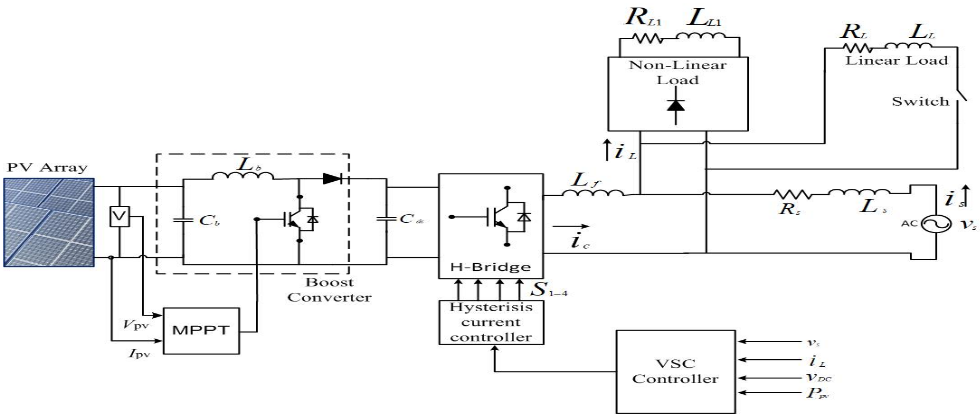


Fig. 1 Structure of 1-phase grid connected PV system

III. RESEARCH METHODOLOGY

The research methodology of the proposed system is as follows:

3.1 Synchronization Technique

The SOGI-FLL is implemented in the stationary $\alpha - \beta$ frame and used for the frequency-adaptive filtering.

The transfer functions of SOGI, which is given as equation (1):

$$SOGI(s) = \frac{v_s}{\alpha e_v}(s) = \frac{\omega' s}{s^2+\omega'^2} \quad (1)$$

whereω' is the resonant frequency of SOGI. The closed-loop transfer function of the in-phase and quadrature phase signal is given as in equations (2-3):

$$D(s) = \frac{v_\alpha}{v_s}(s) = \frac{\alpha\omega' s}{s^2+\alpha\omega' s+\omega'^2} \quad (2)$$

$$Q(s) = \frac{v_\beta}{v_s}(s) = \frac{\alpha\omega'^2}{s^2+\alpha\omega' s+\omega'^2} \quad (3)$$

The transfer-function of the error e_v is given as in equation (4):

$$E(s) = \frac{e_v}{v_s}(s) = \frac{s^2+\omega'^2}{s^2+\alpha\omega' s+\omega'^2} \quad (4)$$

$$\theta = \tan^{-1}\left(\frac{v_\beta}{v_\alpha}\right) \quad (5)$$

SOGI-FLL synchronization technique can quickly and exactly track the frequency and phase information of the grid.

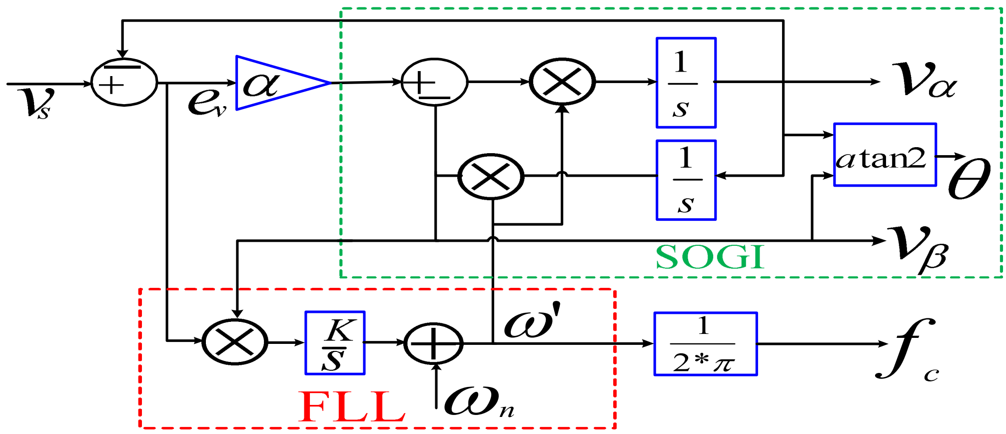


Fig. 2 Structure of SOGI-FLL for synchronization

3.2 Design of SOGI-FLL for Load Compensation

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \sin\omega t & -\cos\omega t \\ \cos\omega t & \sin\omega t \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (6)$$

So, the extracted fundamental component of the load current is givenas equation (7):

$$i_{fl} = i_d = i_\alpha \sin\omega t - i_\beta \cos\omega t \quad (7)$$

where i_{fl} denotes the extracted fundamental component of load current.

When EPLL is used for fundamental component extraction of the load current (i_{fl}) then EPLL structure is realized and it is computed as expressed in equation (8):

$$i_{fl} = [\int K e_v \sin\theta \, d\theta] * \sin\theta \quad (8)$$

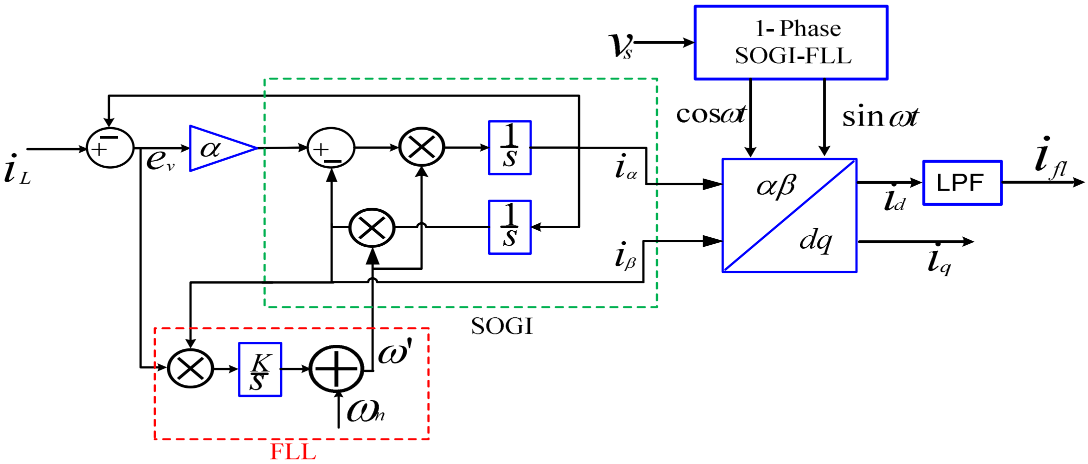


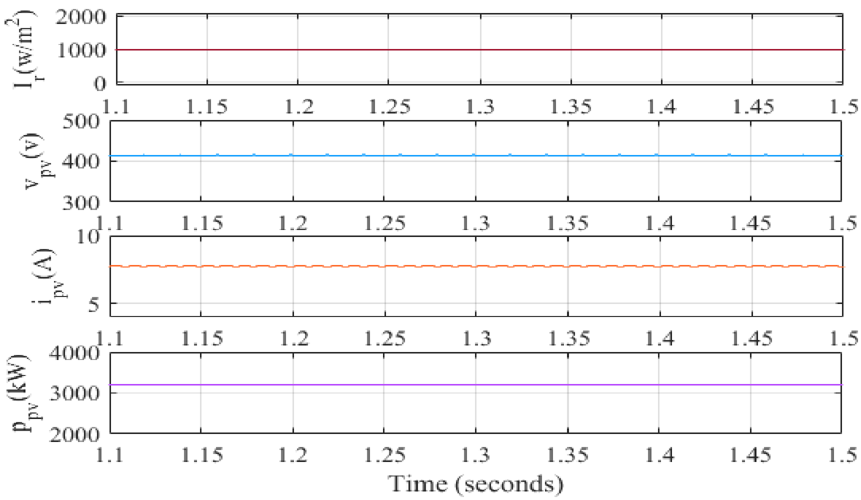
Fig. 3 SOGI-FLL control algorithm

Fig.3 shows how the SOGI-FLL is realized with i_L first decomposed into $i_{L\alpha}$ and $i_{L\beta}$ and then converted to equivalent d-q counterparts. The component i_d is filtered further using a low pass filter and this component represents the fundamental load current, i_{fl}.

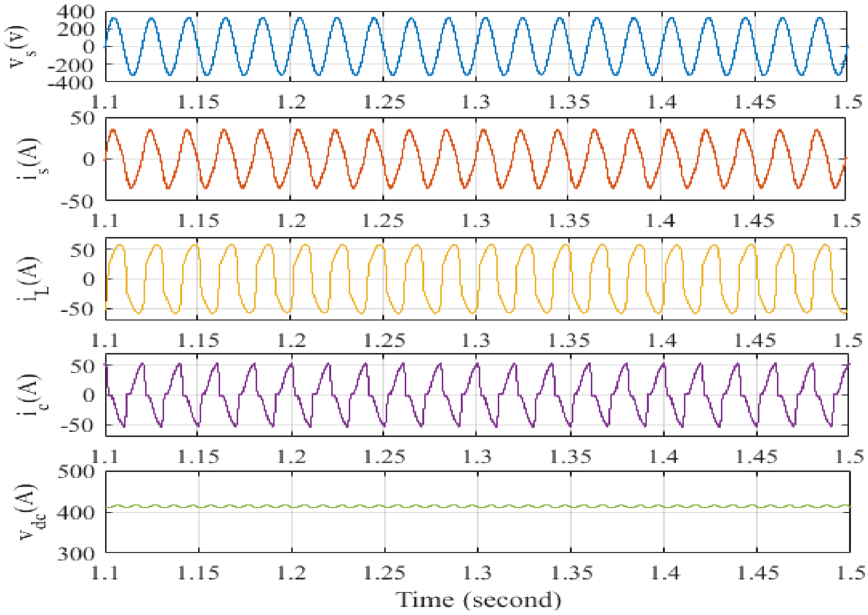
IV. Results and Discussion

In this section, the dynamic response of the proposed system is examined and results are taken under different operating condition.

4.1 Steady State Response of the Proposed System under Fixed Solar Irradiance and Load



(a)

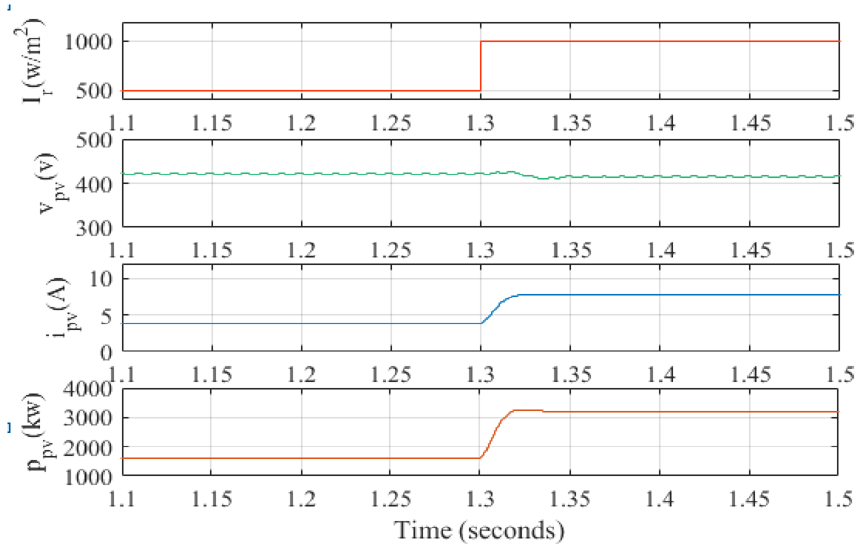


(b)

Fig. 4(a) and (b) Steady state response of the proposed system under fixed solar irradiance feeding balanced nonlinear load

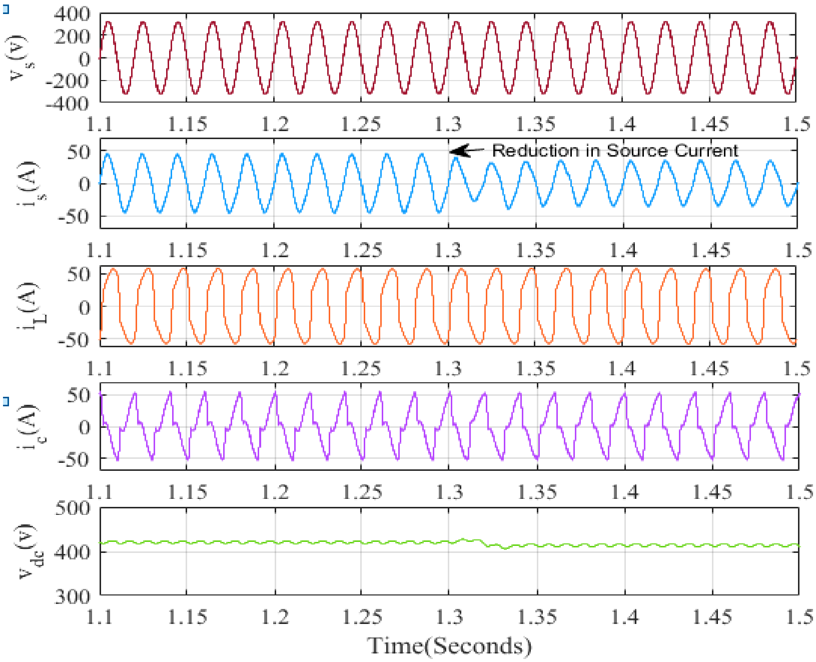
Fig. 4(a) and (b) shows steady state response of single-phase grid connected PV system under fixed solar irradiance feeding balanced nonlinear load. Fig. 4(a) shows the solar irradiance is fixed at 1000 w/m^2. During fixed solar irradiance the PV voltage, PV current and PV power are 400V, 7.02A and 3.1kW respectively. The steady state response of source voltage, source current, load current, compensator current and dc voltage is analyzed. The proposed control successfully extracts the fundamental load current component under different operating conditions. Moreover, The proposed control with VSC enhances the overall power quality and provides power support, load balancing and harmonic suppression during nonlinear load condition.

4.2 Dynamic Response of Proposed System under Change in Solar Irradiance



(a)

Fig. 5(a) and (b) represents dynamic response of single phase grid interfaced system under change in solar irradiance feeding balanced load. Fig. 5(a) shows the change in solar irradiance from 500 w/m^2 to 1000 w/m^2 at t=1.3s. During the change in solar irradiance level, the PV current and PV power is increased. Fig. 5(b) shows the dynamic response of source voltage, source current, load current, compensator current and dc link voltage. During the variation in solar level at t=1.3s, the source of the proposed system is decreased. The controller maintains all the parameters stable during transient condition.



(b)

Fig. 5(a) and (b) represents dynamic response of single phase grid interfaced system under change in solar irradiance feeding balanced load

4.3 Dynamic Response of Proposed System under Fixed Solar Irradiance Feeding Unbalanced Load

Fig. 6 shows the dynamic response of single phase grid interfaced solar PV system under fixed solar irradiance level feeding unbalanced nonlinear load. The load of proposed system is removed t=1.2s and load is connected at t=1.4s. The source current, load current and compensator are reduced during load removal. The controller maintains the source voltage and the dc link voltage is increased during the load removal duration.

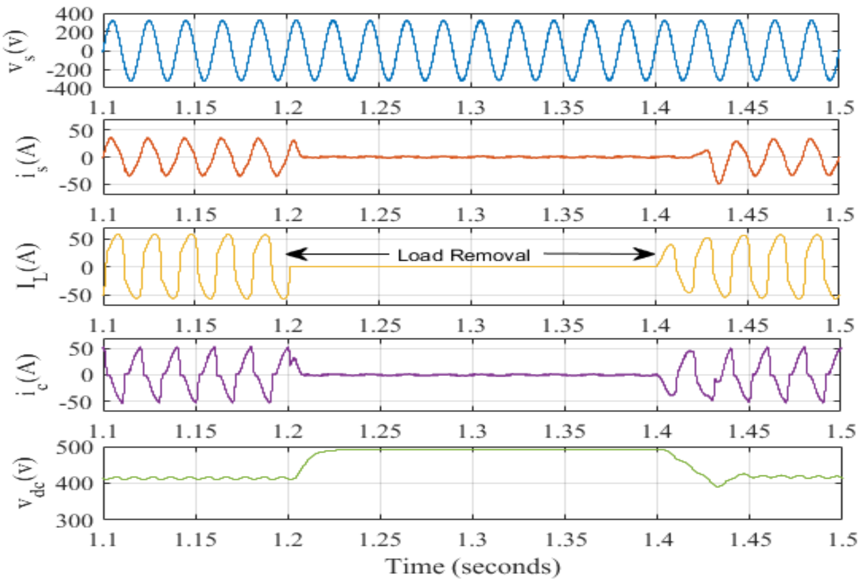
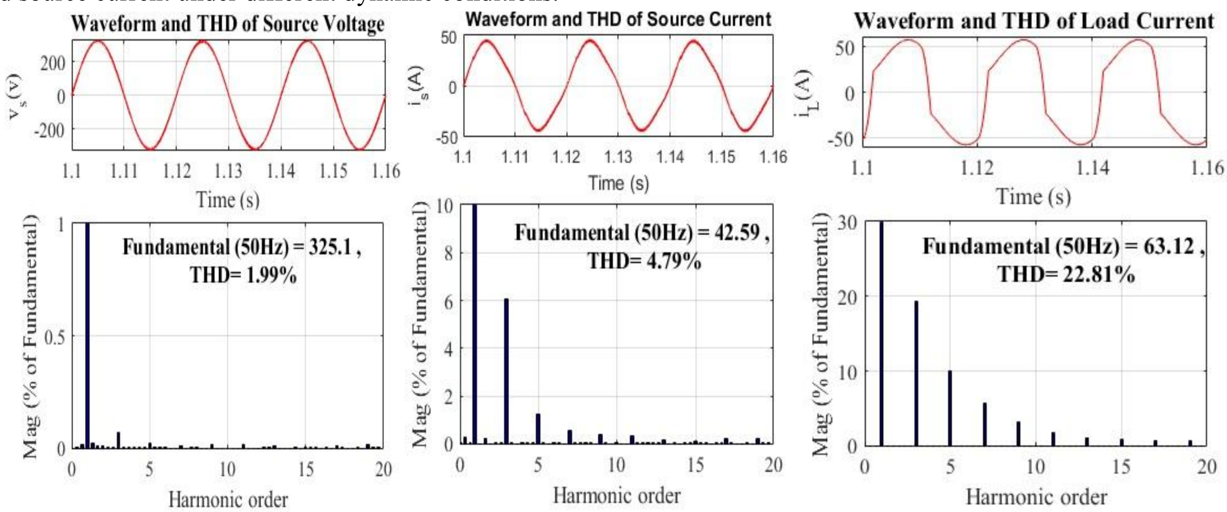


Fig. 6 Dynamic response of single phase grid interfaced solar PV system under fixed solar irradiance level feeding unbalanced nonlinear load.

4.4 Harmonic Analysis of Grid Interfaced PV System

Fig. 7(a)-(c) shows the harmonic analysis of grid interfaced PV system. The THD of source voltage, source current and load current are 1.99%, 4.79% and 22.81% respectively. The proposed control effectively maintains the source voltage and source current under different dynamic conditions.



(a) (b) (c)

Fig. 7(a)-(c) Harmonic analysis of source voltage, source current and load current

V. Conclusions and Future Scope

This paper has discussed the design, modeling and simulation of single phase grid interfaced solar PV system. The SOGI based FLL is successfully extract the fundamental load current component under worst load condition. Hence, the use of SOGI-FLL for both these purposes has been demonstrated for a 5 kW grid-interfaced PV system. The results have shown that the algorithm provides multiple power quality improvement features and has the potential to correct power factor on the supply side, reduce harmonics and respond well under dynamic load variations. The THD of source voltage and source current is satisfying the IEEE-519 standard.

In the coming years, technology improvements will ensure that solar becomes even cheaper. It could well be that by 2030, solar will have become the most important source of energy for electricity production in a large part of the world. This will also have a positive impact on the environment and climate change. Moreover, the proposed system with suitable controller can be used to minimize power quality problems.

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