Power Quality Improvement Features Using Grid Interconnection Of Renewable Energy Sources At The Distribution Level

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Abstract - **Renewable energy resources (RES) are being increasingly connected in distribution systems utilizing power electronic converters. This paper presents a novel control strategy for achieving maximum benefits from this grid - interfacing inverters when installed in 3-phase distribution systems. The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. The inverter can thus be utilized as: 1) power converter to inject power generated from RES to the grid, and 2) shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. All of these functions may be accomplished either individually or simultaneously. With such a control, the combination of grid-interfacing inverter and the 3-phase linear/non-linear unbalanced load at point of common coupling appears as balanced linear load to the grid. This new control concept is demonstrated with extensive MATLAB/Simulation.**

keywords - **Active power filter (APF), Distributed generation (DG), distribution system, grid interconnection, power quality (PQ), renewable energy**

I. INTRODUCTION

Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). The utility is concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality (PQ) issues. Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. With the advancement in power electronics and digital control technology, the DG systems can now be actively controlled to enhance the system operation with improved PQ at PCC. However, the extensive use of power electronics based equipment and non-linear loads at PCC generate harmonic currents, which may deteriorate the quality of power.

The non-linear load current harmonics may result in voltage harmonics and can create a serious PQ problem in the power system network. Active power filters (APF) are extensively used to compensate the load current harmonics and load unbalance at distribution level. This results in an additional hardware cost.. Here, the main idea is the maximum utilization of inverter rating which is most of the time underutilized due to intermittent nature of RES. It is shown in this project that the grid-interfacing inverter can effectively be utilized to inject active power and having in load current performs following important functions: 1) transfer of active power harvested from the. Moreover, with adequate control of grid-interfacing inverter, the objectives can be accomplished either individually or simultaneously. The PQ constraints at the PCC can therefore be strictly maintained within the utility standards without additional hardware cost. In this paper inter connection of distributed generation and grid with reduced harmonics is proposed.

II. SYSTEM DESCRIPTION

The proposed system consists of RES connected to the dc-link of a grid-interfacing inverter as shown in Fig.1 the voltage source inverter is a key element of a DG system as it interfaces the renewable energy source to the grid and delivers the generated power. The RES may be a DC source or an AC source with rectifier coupled to dc-link. Usually, the fuel cell and photovoltaic energy sources generate power at variable low dc voltage, while the variable speed wind turbines generate power at variable ac voltage. Thus, the power generated from these renewable sources needs power conditioning (i.e., dc/dc or ac/dc) before connecting on dc-link. The dc-capacitor decouples the RES from grid and also allows independent control of converters on either side of dc-link.

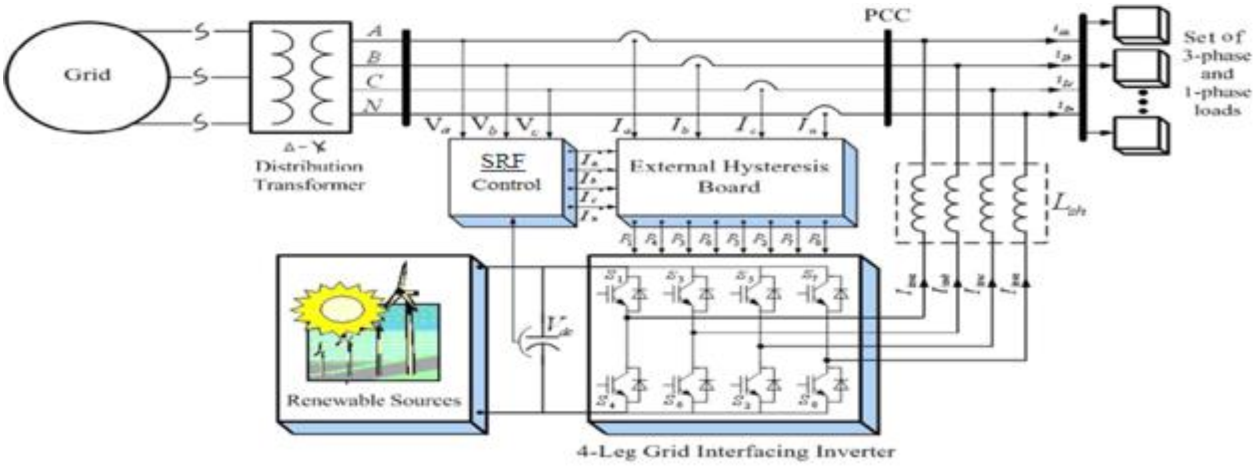


Fig. 1 Schematic of proposed renewable based distributed generation system

2.1 A DC-Link Voltage and Power Control Operation

Due to the intermittent nature of RES, the generated power is of variable nature. The dc-link plays an important role in transferring this variable power from renewable energy source to the grid. RES are represented as current sources connected to the dc-link of a grid-interfacing inverter. The current injected by renewable into dc-link at voltage level V_{dc} can be given as

$$I_{DC1} = \frac{P_{RES}}{V_{DC}} \quad \dots\dots\dots\dots\dots\dots\dots\dots \text{ (1)}$$

P_{RES} is the Power Output if Renewable Energy Sources

The current flow on the other side of dc-link can be represented as

$$I_{DC1} = \frac{P_{inv}}{V_{dc}} = \frac{P_G + P_{LOSS}}{V_{dc}} \quad \dots\dots \text{ (2)}$$

Where P_{inv} and P_G, P_{LOSS} are total power available at grid-interfacing inverter side, active power supplied to the grid and inverter losses, respectively. If inverter losses are negligible then $P_{RES} = P_G$

2.2. *Control of Grid Interfacing Inverter*

The control diagram of grid- interfacing inverter for a 3-phase system is shown in Fig. 2. The fourth leg of inverter is used to compensate the neutral current of load. The main aim of proposed approach is to regulate the power at PCC during 1) $P_{RES} = 0$ 2) $P_{RES} < total\ load\ power$ and 3) $P_{RES} > P_L$ While performing the power management operation, the inverter is actively controlled in such a way that it always draws/ supplies fundamental active power from/ to the grid.

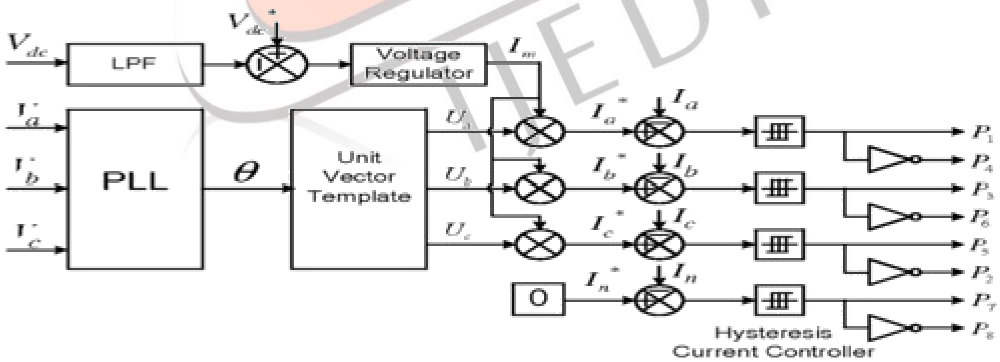


Fig.2 Block diagram representation of grid-interfacing inverter control

If the load connected to the PCC is non-linear or unbalanced or the combination of both, the given control approach also compensates the harmonics, unbalance, and neutral current. The duty ratio of inverter switches are varied in a power cycle such that the combination of load and inverter injected power appears as balanced resistive load to the grid. The regulation of dc-link voltage carries the information regarding the exchange of active power in between renewable source and grid. Thus the output of dc-link voltage regulator results in an active current (I_m) . The multiplication of active current component $(I_m)$with unity grid voltage vector templates (U_a, U_b, U_c) generates the reference grid currents(I_a^*, I_b^*, I_c^*) . The reference grid neutral current I_n^* is set to zero, being the instantaneous sum of balanced grid currents. The grid synchronizing angle θ obtained from phase locked loop (PLL) is used to generated unity vector template as

$$U_a = \sin \emptyset \quad \dots\dots\dots\dots\dots\dots\dots\dots \text{ (3)}$$

$$U_b = \sin(\emptyset - \frac{2\pi}{2}) \dots\dots\dots\dots\dots\dots \text{ (4)}$$

$$U_c = \sin(\emptyset + \frac{2\pi}{2}) \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The Actual dc link voltage (V_{dc}) is sensed and passed through a first order low pass (LPF) to eliminate the presence of switching ripples on the dc-link voltage and in the generated reference current signals. The difference of this filtered dc-link voltage and reference dc-link voltage V_{dc}^* is given to a discrete PI regulator to maintain a constant dc-link voltage under varying generation and load conditions. The dc-link voltage error $V_{dcerr\,(n)}$ at nth sampling instant is given as :

$$V_{derr} = V_{dc}^* - V_{dc(n)} \ \ldots\ldots\ (6)$$

The controller for proposed system is shown in Fig.2.

III. SIMULATION

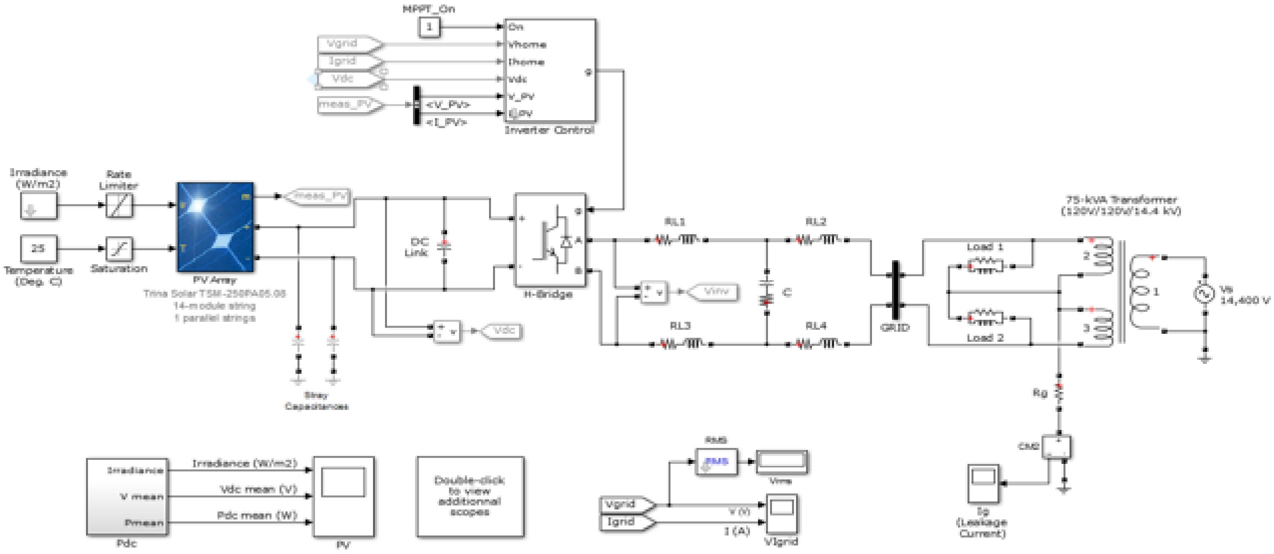


Fig 3: Simulation connected diagram

The initial input irradiance to the PV array model is 250 W/m2 and the operating temperature is 25 deg. C. When steady-state is reached (around t=0.25 sec.), we get a PV voltage (Vdc_mean) of 424.5 V and the power extracted (Pdc_mean) from the array is 856 W. At t=0.4 sec, sun irradiance is rapidly ramped up from 250 W/m^2 to 750 W/m^2. Due to the MPPT operation, the control system increases the VDC reference to 434.2 V in order to extract maximum power from the PV string (2624 W). These values correspond well to the expected values. To confirm that, use the Plot button of the PV Array menu to plot the I-V and P-V characteristics of the PV string based on the manufacturer specifications.

If you look at the leakage current (Ig scope), you will notice that there are no current flowing through the stray capacitance of the PV modules. This is due to PWM method used and the filter topology. Now, if you select the PWM unipolar modulation method (using the Inverter control menu) and repeat the simulation, you will see a significant leakage current in the system. All the simulation results are shown in below figures 5, 6, 7, 8, 9, 10, 11.

3.1 MPPT ALGORITHM:

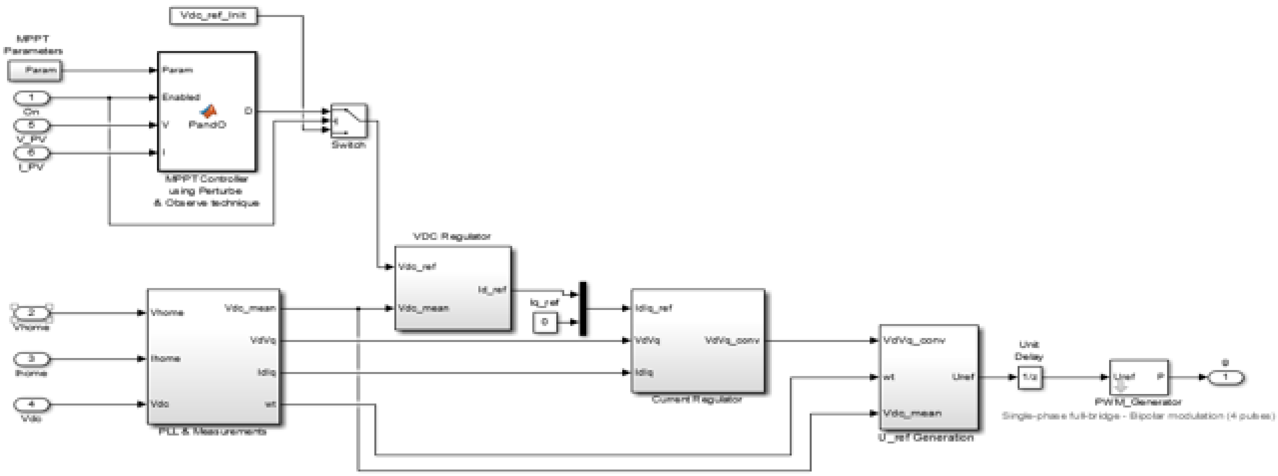


fig 4: P&O And MPPT Algorithm

3.2 Simulation Results:

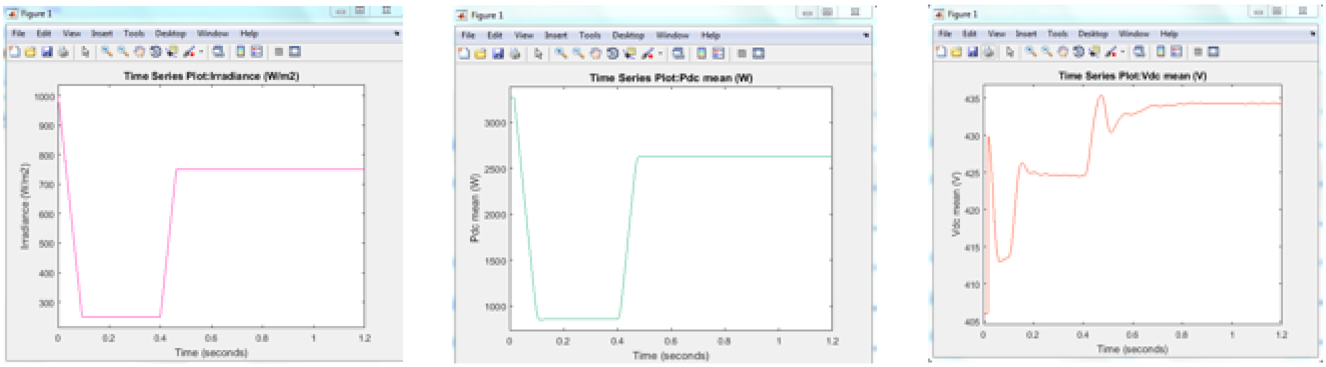


Fig.5(a),5(b), 5(c) : Result of PV cell Irradiance, Pdc mean, Vdc mean

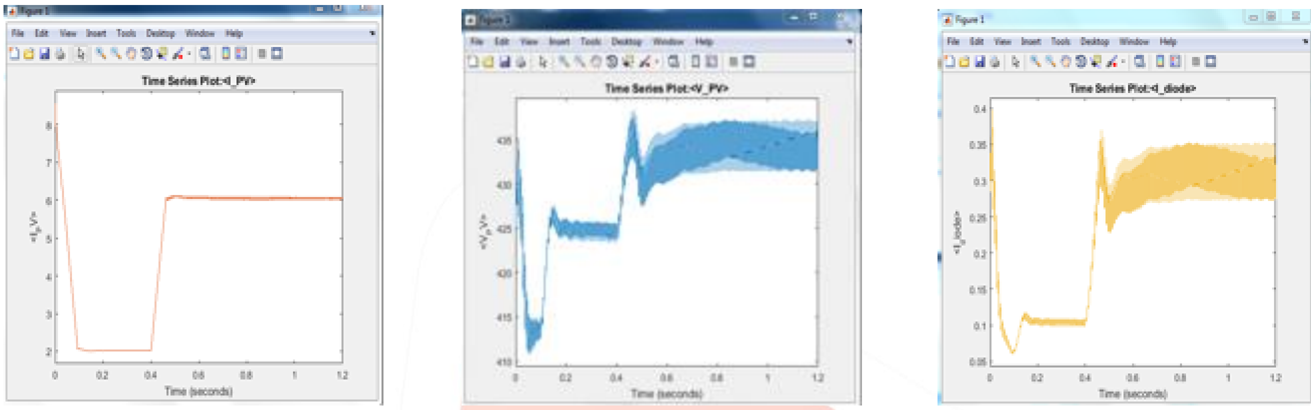


Fig.6(a), 6(b), 6(c): Results of I-PV, V-PV, I-diode

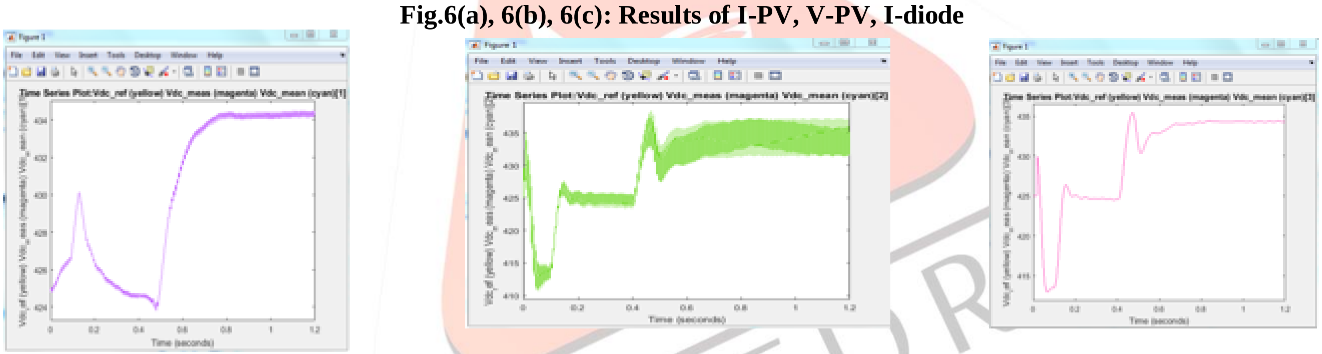


Fig.7(a), 7(b), 7(c):ResultsofVdc_ref, Vdc_meas, Vdc_mean

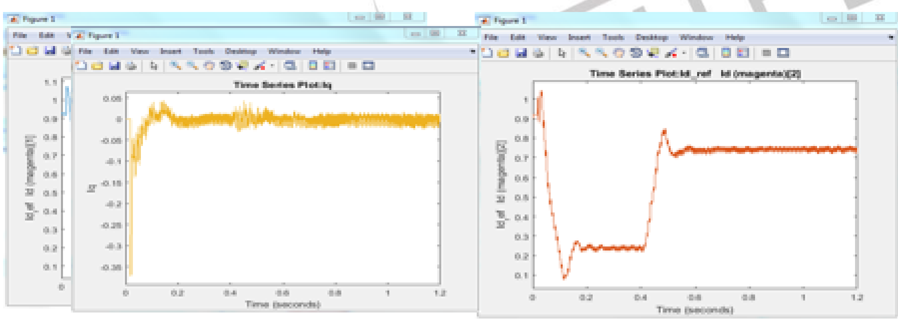


Fig.8(a), 8(b), 8(c): Results of Id_ref, Id, Iq

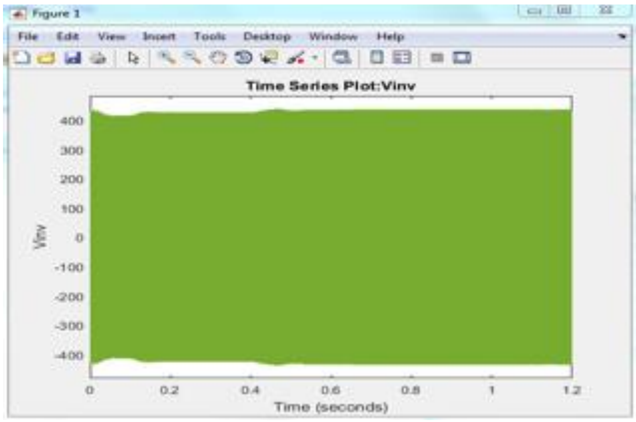


Fig.9: Result of Vinv

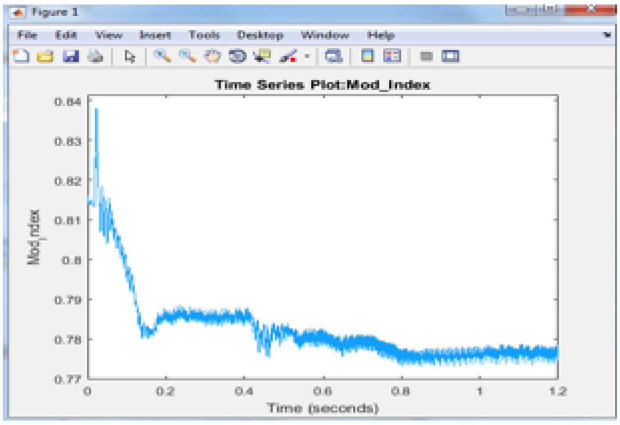


Fig.10: Results of modulation index

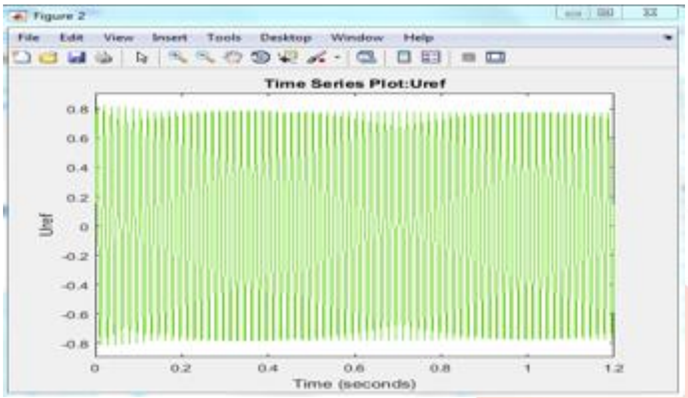


Fig 11: Results of Uref

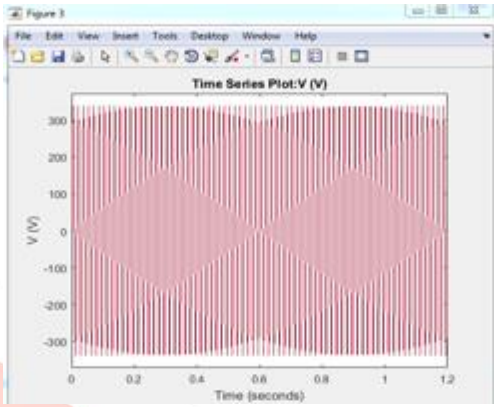


Fig 12: Time series plot of Voltage

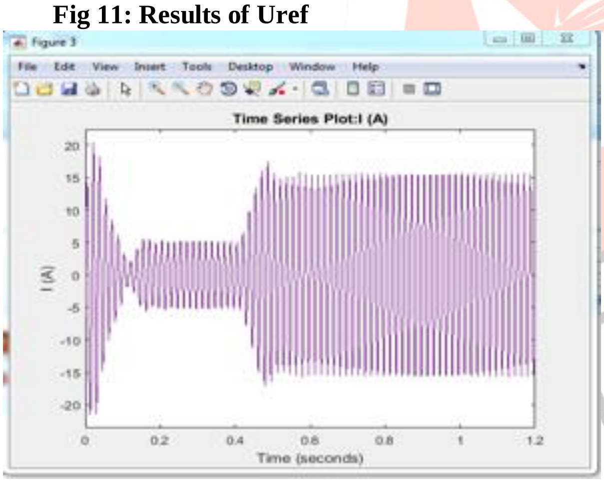


Fig 13: Time series plot of current

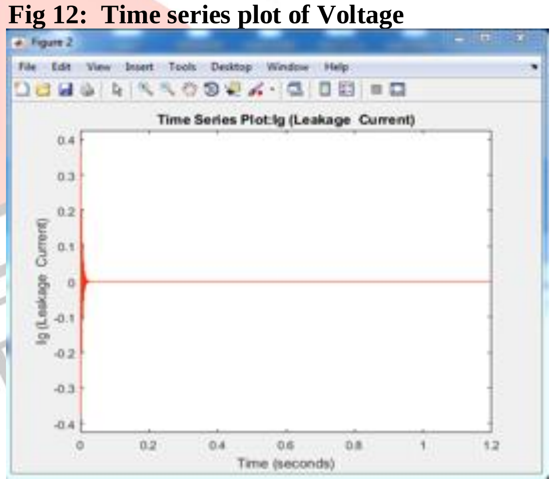


Fig 14: I-lekage

3.3 Grid interconnected PV system with SAPF:

The Matlab/Simulink simulation tool was used to develop a model that allowed the simulation and testing of the p-q theory calculation, which were implemented in the controller of shunt active power filter for three phase, three wire systems.

The controller used is PQ theory it consists in the algebraic transformation of the current and voltage of the system from the abc system to 0αβ system using the Clarke transformation. After filtering the harmonic content again the 0αβ system is transformed to abc reverse Clarke transformation

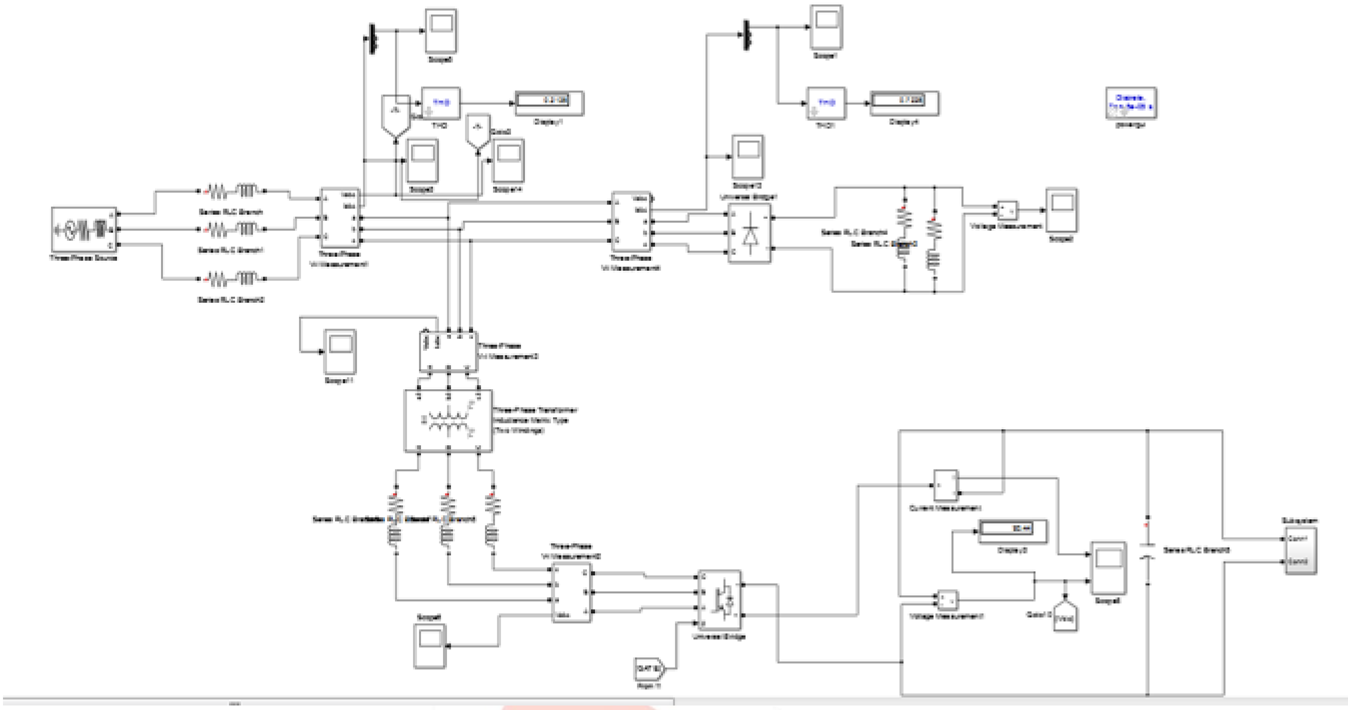


Fig. 15 Simulation model of distribution network with shunt active filter with PV system

The controller used in this project is DQ theory it consists of the algebraic transformation of the current and voltage of the system from the abc system to 0dq system using the Park transformation. After filtering the harmonic content again the 0dq system is transformed into abc inverse park transformation. The MATLAB modelling blocks of this transformation are given in fig. 16.

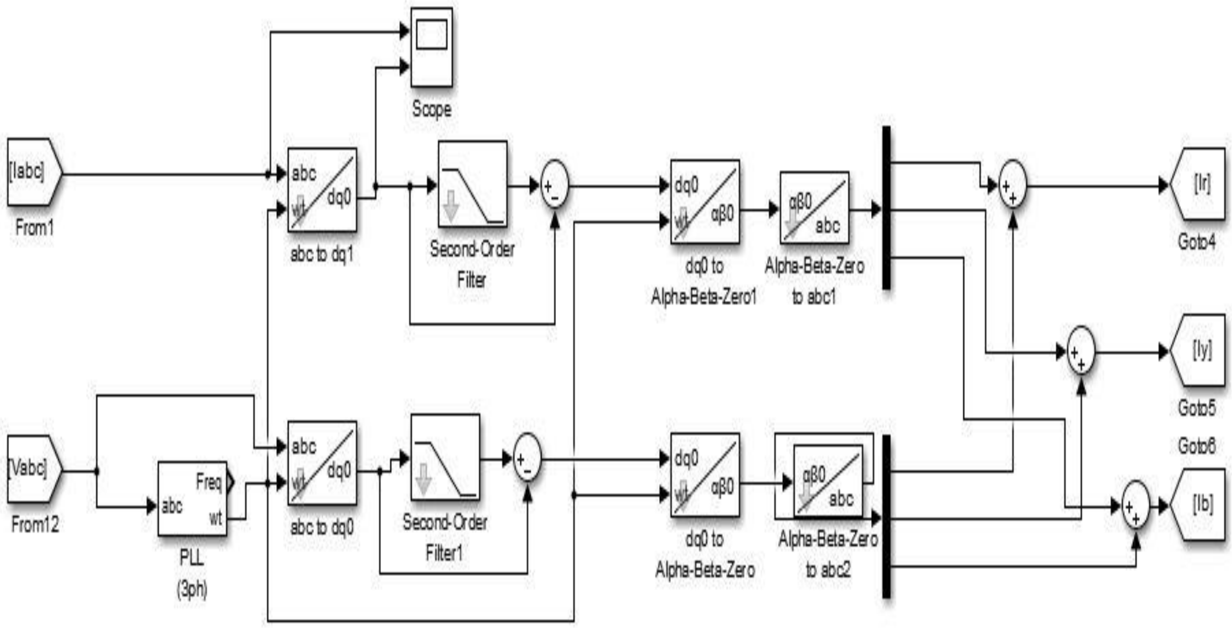


Fig. 16 DQ theory

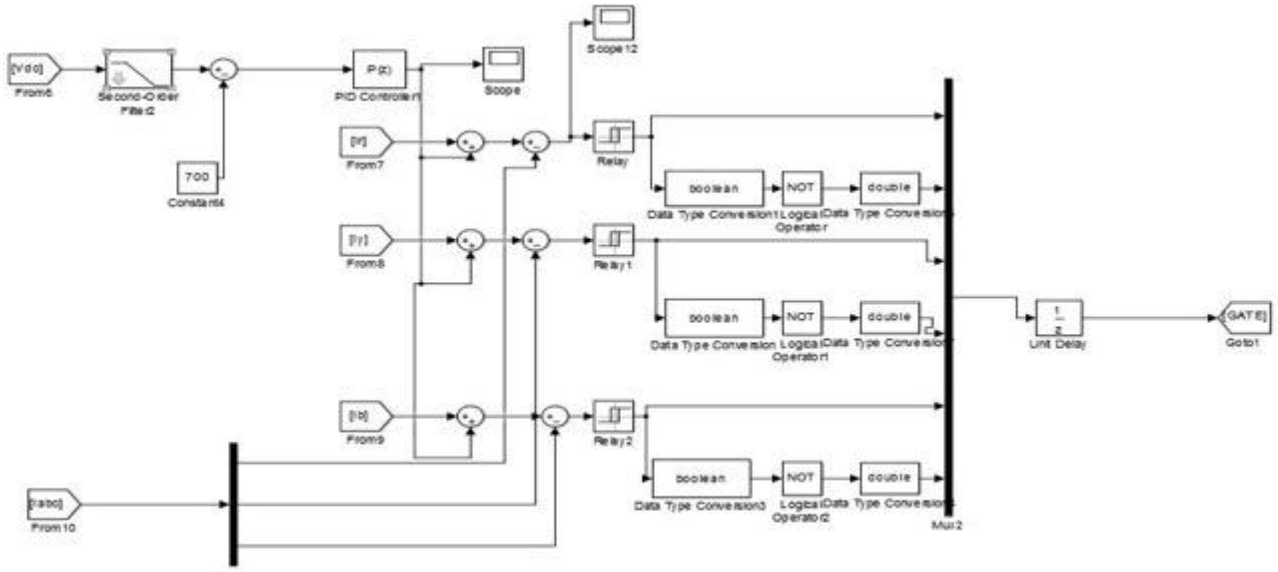
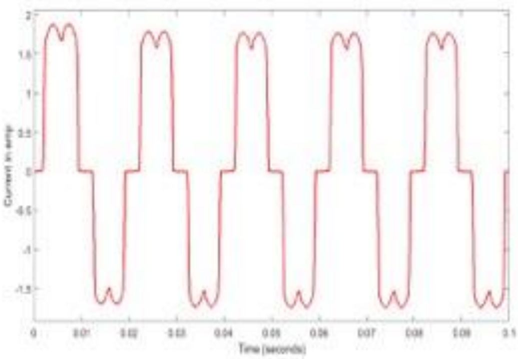


Fig. 17 Pulse generator using Hysteresis control

The hysteresis current controller was developed to generate the switching pulses to control VSI switches by comparing the real current to the reference current. The control scheme gives the switching pattern of active filter switches in order to maintain the real injected current within desired hysteresis band (HB) as illustrated in fig 17.

3.4 OUTPUT SIMULATION WAVEFORMS

Shunt active filters injects the compensating current into the line hence corrects the source current into sinusoidal. The following waveform shows the source current and load current before injecting shunt active filter compensating current. In this method we use non-linear load, hence load is distorted with harmonics.



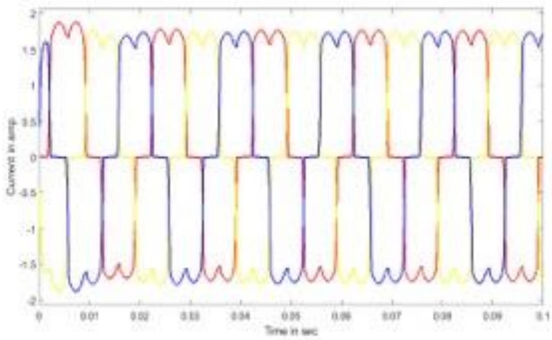


Fig. 18 Single phase load current waveform without SAP filter

Fig. 19 Three phase load current waveform with SAP filter

The fig 20 shows the three phase source current and single phase source current waveforms after connecting shunt active filter.

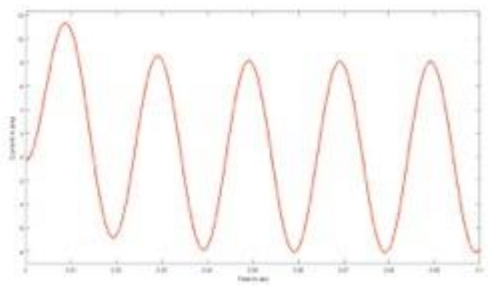


Fig. 20 Single phase source current waveform with SAP filter

Fig. 21 Three phase source current waveform with SAP filter

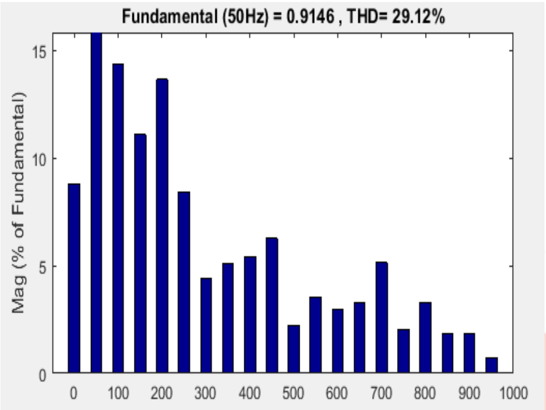


Fig. 22 THD analysis for Source Current without SAPF

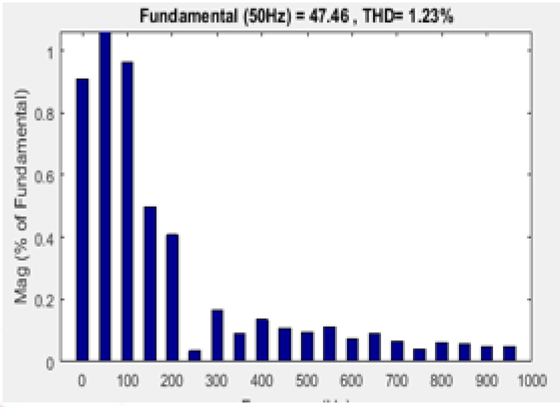


Fig. 23 THD analysis for Source Current with SAPF

In the fig 22 it is observed that the source current THD is 29.12% before the shunt active filter get activated. In the fig 23 the source current THD is 1.23% after the injection of compensating current into the power system. Hence the power quality is improved.

IV CONCLUSION:

This paper has presented a novel control of an existing grid interfacing inverter to improve the quality of power at PCC for a 3-phase 4-wire DGsystem. It has been shown that the grid-interfacing inverter can be effectively utilized for power conditioning without affecting its normal operation of real power transfer. The grid-interfacing inverter with the proposed approach can be utilized to inject real power generated from RES to the grid, and operate as a shunt Active Power Filter (APF). Extensive MATLAB/Simulink simulation results have validated the proposed approach and have shown that the grid-interfacing inverter can be utilized as a multi-function device. The current harmonics and non-linear load connected to the PCC, are compensated effectively such that the grid side currents are always maintained as balanced and sinusoidal at unity power factor. The Total Harmonic distortion of Grid current waveform before SAPF turned ON is 29.12%. The Total Harmonic distortion of Grid current waveform after SAPF turned ON is 1.23%. Hence current harmonics in Grid current are compensated.

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