GRID INTERCONNECTION OF RENEWABLE ENERGY SOURCES AT THE DISTRIBUTION LEVEL WITH POWER QUALITY IMPROVEMENT FEATURES

K. Mounika[1],Y.Rajesh Babu[2]

[1]P.G Scholar, [2]Assistant Professor
KKR & KSR institute of Technology and Sciences, Guntur, AP, India.

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 these grid -interfacing inverters when installed in 3-phase 4-wire 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 4-wire 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 MATLA B/Simulation.

Index Terms: *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.

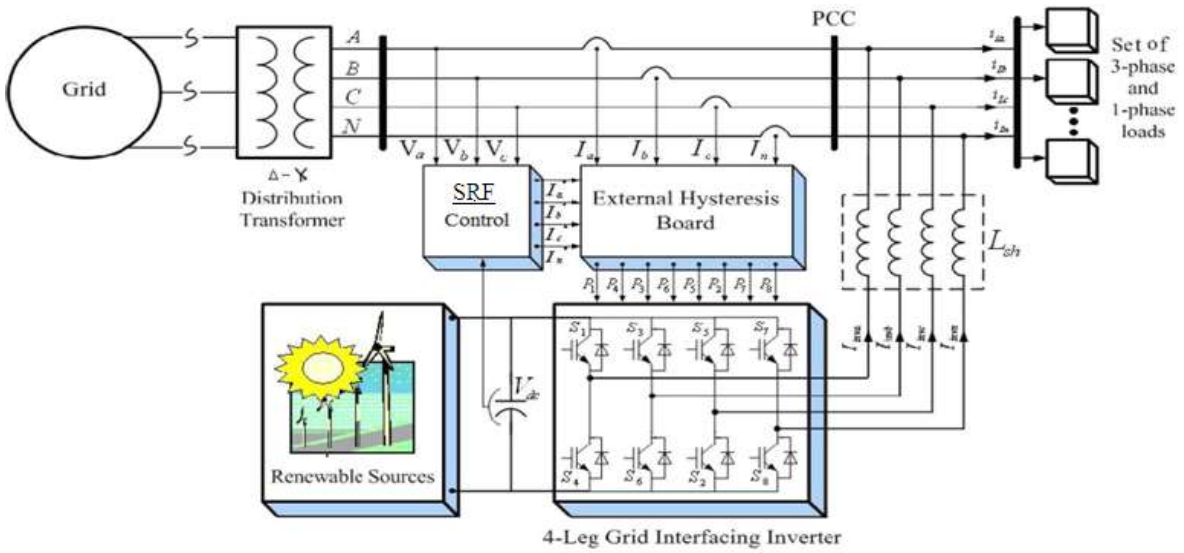

Fig. 1 Schematic of proposed renewable based distributed generation system

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

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

P_{RES} is the Power Output if Renewable Energy Sources
The current flow on the other side of dc-link can be represented as

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

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 4-wire system is shown in Fig. 1. 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.

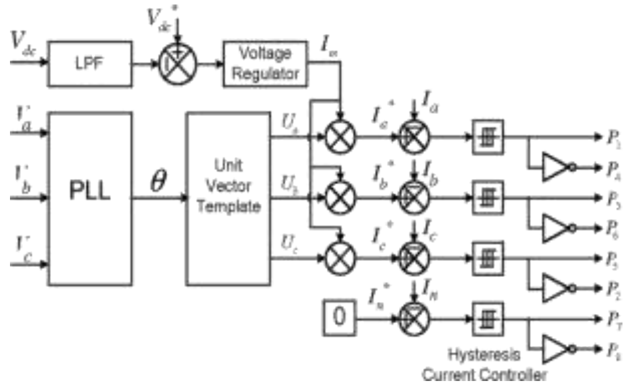

Fig.2 Block diagram representation of grid-interfacing inverter control

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

$$U_a \ = \sin \emptyset \quad \ldots\ldots\ldots\ldots\ldots\ldots.. (3)$$

$$U_b \ = \sin(\emptyset - \tfrac{2\pi}{2})\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

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

The Actual dc link voltage ($_{Vdc}$) 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.RESULTS

In order to verify the proposed control approach to achieve the objective for grid interfaced DG systems connected to a 3-phase 4-wire network, an extensive simulation study is carried out using MATLAB/Simulink. A 4-leg current controlled voltage source inverter is actively controlled to achieve balanced sinusoidal grid currents at unity power factor (UPF) despite of highly unbalanced nonlinear load at PCC under renewable generating conditions. A RES is connected on the dc-link of grid-interfacing inverter. An unbalanced 3-phase 4-wire nonlinear load, whose harmonics, need to be compensated, is connected on PCC. The waveforms of (a) Grid voltages, (b) Grid Currents (c) Unbalanced load currents, (d) Inverter Currents are observed. The corresponding active-reactive powers of grid, load and inverter are observed. Positive values of grid active-reactive powers and inverter active-reactive powers imply that these powers flow from grid side towards PCC and from inverter towards PCC, respectively. The active and reactive powers absorbed by the load are denoted by positive signs.

Initially, the grid-interfacing inverter is not connected to the network (i.e., the load power demand is totally supplied by the grid alone). Therefore, before time t=0.72 s, the grid current profile is identical to the load current profile. At t=0.72 s, the grid-interfacing inverter is connected to the network. At this instant the inverter starts injecting the current in such a way that the profile of grid current starts changing from non linear to sinusoidal current.

The three phase load current waveform is shown in Fig.3 Due to the Non linear loads the current waveform is distorted and contains harmonics.

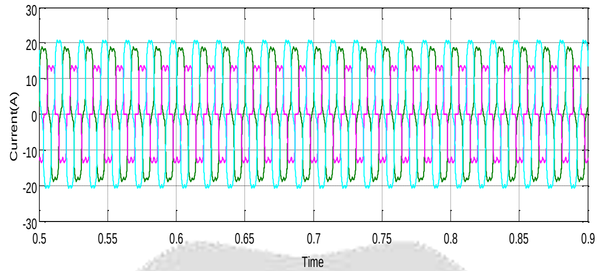

Fig.3 Three Phase Load current

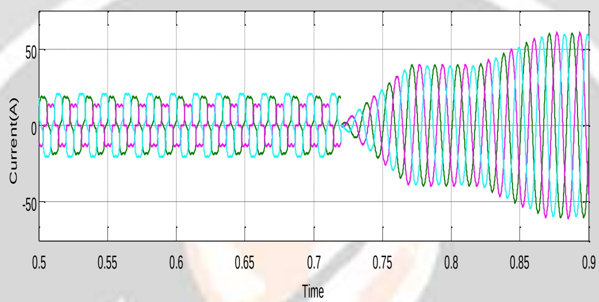

Fig. 4 Three Phase Grid current

The three phase grid current waveforms are shown in Fig.4. Due to the Non linear loads, the current waveform is distorted and contains harmonics. At time 0.72 the Shunt Active power filter is switched on hence the load current is compensated and became harmonic free.

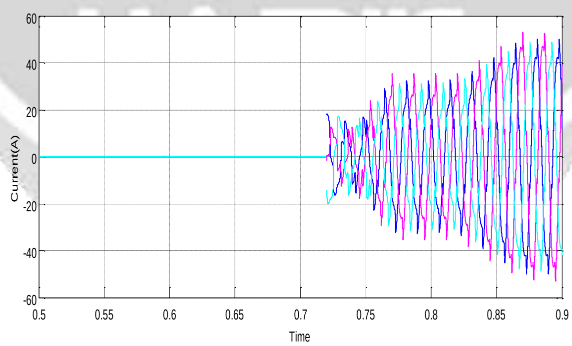

Fig. 5 Three Phase injected current

The three phase injected current waveform is shown in Fig.5 At time 0.72 the Shunt Active power filter is switched on hence the load current is compensated by injecting the compensating current. Hence in the wave form up to 0.72 sec zero current is injected.

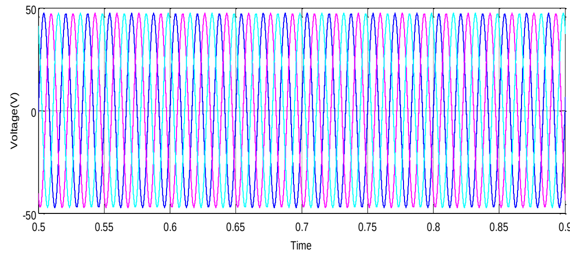

Fig.6 Three phase Grid Voltage

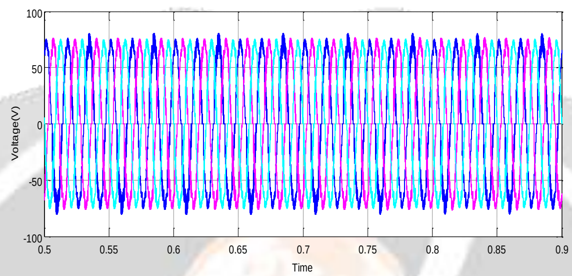

Fig. 7 Three phase Load Voltage

The three phase grid and load waveforms are shown in Fig. 6 and Fig 7 respectively. Due to the Non linear loads, the load voltage waveform is distorted but due to Shunt active power filter the Grid voltage waveform is compensated. Three phase Grid voltage and Current are shown in Fig.8.

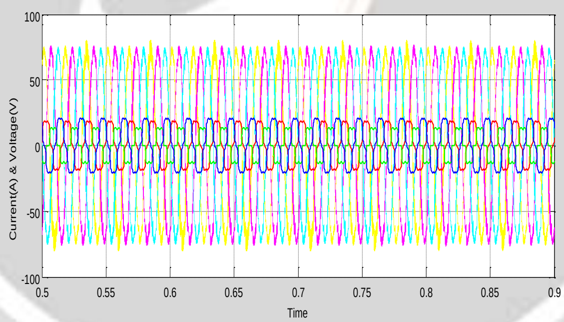

Fig.8 Three phase Grid Voltage and Current

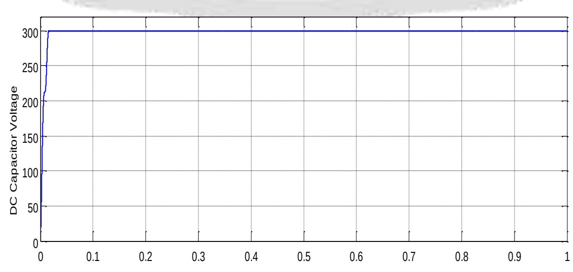

Fig.9 DC Capacitor Voltage

The DC Capacitor Voltage waveform is shown in Fig 9. Here The DC side capacitor maintains a DC voltage with small ripple in steady state, acts as an energy storage element to supply real power difference between load and source during the transient period.

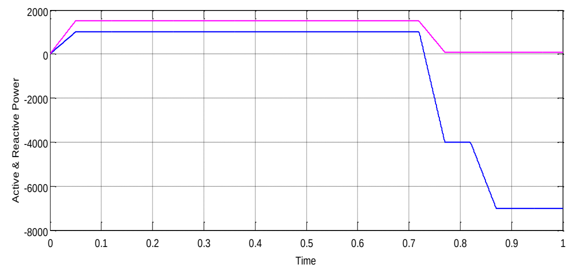

Fig. 10 Active and Reactive Power at the Grid

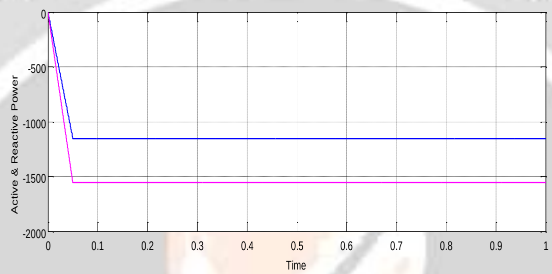

Fig 11 Active and Reactive Power at the Load

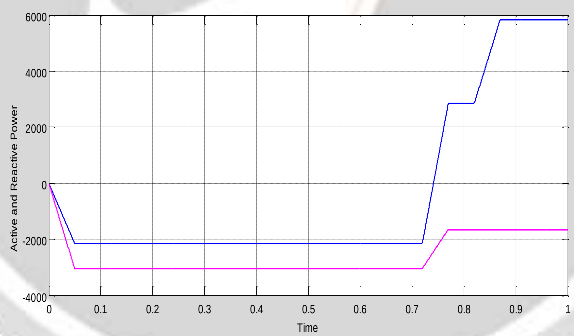

Fig.12 Active and Reactive Power at the Inverter

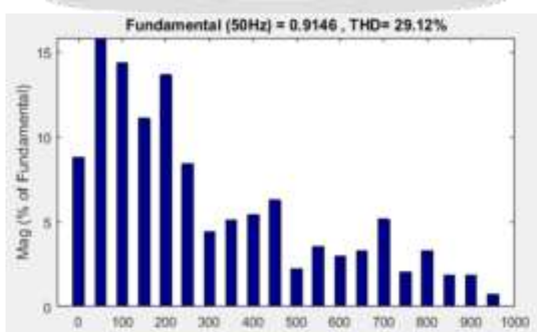

Fig.13 THD of grid Current before SAPF turned ON

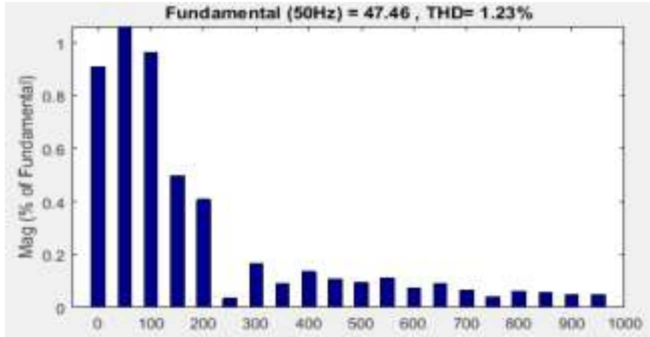

Fig.14 THD of grid Current after SAPF turned ON

The Total Harmonic distortion of Grid current waveform before SAPF turned ON is shown in Fig 13.The THD value is 29.12%. The Total Harmonic distortion of Grid current waveform after SAPF turned ON is shown in Fig 14. The THD value is 1.23%.Hence the Harmonics in Grid Current are compensated.

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-wireDGsystem. 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 18.18%. The Total Harmonic distortion of Grid current waveform after SAPF turned ON is 2.79%. Hence current harmonics in Grid currents are compensated.

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