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Power Quality Improvement for Renewable Energy Sources with 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 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 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. The grid interfacing inverter is connected to a 3-phase 4-wire system and hysteresis current control method is used to generate gate pulses. Here renewable energy resource (RES) is represented as a dc source. This new control concept is demonstrated with extensive MATLAB/Simulink simulation studies.

KEYWORDS: Active Power Filter (APF), Distributed Generation (DG), Distribution System, Grid Interconnection, Power Quality (PQ), Renewable Energy.

I.INTRODUCTION

Electric utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Seventy five percent of total global energy demand is supplied by the burning of fossil fuels. But increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards renewable sources as a future energy solution. Since the past decade, there has been an enormous interest in many countries on renewable energy for power generation. The market liberalization and government's incentives have further accelerated the renewable energy sector growth. RES integrated at distribution level is termed as 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 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 nonlinear loads at PCC generate harmonic currents, which may deteriorate the quality of power . Generally, current controlled voltage source inverters are used to interface the intermittent RES in distributed system. Recently, a few control strategies for grid connected inverters incorporating PQ solution have been proposed. In an inverter operates as active inductor at a certain frequency to absorb the harmonic current. But the exact calculation of network inductance in real-time is difficult and may deteriorate the control performance. A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in. In a control strategy for renewable interfacing inverter based on– theory is proposed. In this strategy both load and inverter current sensing is required to compensate the load current harmonics. 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. However, in this paper authors have incorporated the features of APF in the, conventional inverter interfacing renewable with the grid, without any 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 paper that the grid-interfacing inverter can effectively be utilized to perform following important functions:1) transfer of active power harvested from the renewable resources (wind, solar, etc.); 2) load reactive power demand support; 3) current harmonics compensation at PCC; and 4) current unbalance and neutral current compensation in case of 3-phase 4-wire system. Moreover, with adequate control of grid-interfacing inverter, all the four 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.

The paper is arranged as follows: Section II describes the system Description. Hysteresis Current Control in Section III .Extensive experimental results are discussed in Section IV and, finally, Section V concludes the paper.

Literature Survey

In [1], 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 power converter to inject power generated from RES to the grid and shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current.

In [2], it have been presented the performance comparison of Shunt Active Power Filter (SAPF) and Hybrid Active Power Filter (HAPF) with three different non linear loads Two different PI controllers based on average load active power and synchronous reference frame theory are employed in this simulation study.

In [3], presents a comprehensive review of active filter (AF) Configurations , control strategies, selection of components, other related economic and technical considerations, and their selection for specific applications.

In [4], he has been studied analytically and tested using computer simulations and experiments. In the experiments, it has been verified that the filter keeps the line current almost sinusoidal and in phase with the line voltage supply. It also responds very fast under sudden changes in the load conditions, reaching its steady state in about two cycles of the fundamental.

II. SYSTEM DESCRIPTION

A. Topology

Active power filters are power electronic devices that cancel out unwanted harmonic currents by injecting a compensation current which cancels harmonics in the line current. Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. Generally, four-wire APFs have been conceived using four leg converters. This topology has proved better controllability than the classical three-leg four-wire.

B. Voltage Source Converter (VSC)

A Voltage Source Converter (VSC) is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. It also converts the DC voltage across storage devices into a set of three phase AC output voltages. It is also capable to generate or absorbs reactive power .As in the Fig.1 the system consist of an RES connected to the dc-link of a grid-interfacing inverter. The voltage source inverter interfaces the renewable energy source to the grid. The RES may be a DC source or an AC source with rectifier coupled to dc- link. The fuel cell and photovoltaic energy sources generate power at variable low dc voltage, but the production of power in variable speed wind turbine is variable ac voltage. So before connecting on to a dc-link, the power generated from these renewable sources needs to be power conditioned (i.e., dc/dc or ac/dc). Usually the fuel cell integration is provided by using a unidirectional DC/DC converter (to obtain regulated high voltage DC), an inverter and a filter in order to accommodate the DC voltage to the required AC voltage (single phase or three phases).

A. DC-Link Voltage and Power Control Operation

Because of the intermittent nature of RES, the generated power is of variable nature. The dc-link connected aids in transferring this variable power from RES 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

$$I_{dc1} = P_{res} / V_{dc} \qquad (1)$$

where Pres is the power generated from RES.The current flow on the other side of dc-link can be represented as,

$I_{dc2}=P_{inv}/V_{dc}= +P_{Loss}/V_{dc}$ (2)

where Pinv, PG and PLoss 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

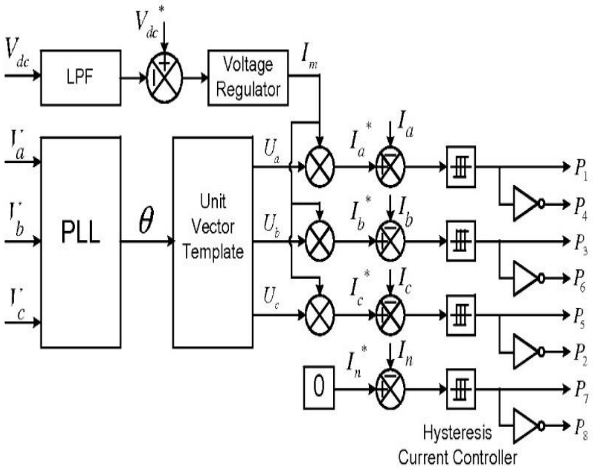

Fig.1.Block diagram representation of grid-interfacing inverter control

B. Control of Grid Interfacing Inverter

The control diagram of grid- interfacing inverter for a 3- phase 4-wire system is shown in Fig. 2. To compensate the neutral current of load, a fourth leg is provided to theinverter. The proposed approach is mainly concerned about the regulation of power at PCC during three conditions like, when 1) PRES = 0; 2) PRES < total power (PL); and 3) PRES > PL. During the power management operation, the inverter is controlled in such a way that it always draws/ supplies fundamental active power from/ to the grid. 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. By the control, duty ratio of inverter switches are varied in a power cycle in order to get the combination of load and inverter injected power to be appearing as balanced resistive load to the grid. The exchange of active power in between renewable source and grid can be obtained from the regulation of dc-link voltage. Thus the output of dc-link voltage regulator results in an active current (*I*m). The multiplication of this active current component (*I*m) with unity grid voltage vector templates (*Ua, Ub, and Uc*) generates the reference grid currents (I*a, I*b, and I*c) for the control process. The reference grid neutral current (I*n) is set to zero, being the instantaneous sum of balanced grid currents. Phase locked loop (PLL) is used to generate unity vector template from which the grid synchronizing angle (0) is obtained.

$U^a = \sin()$ (3)

$U_b = \sin(-2/3)$ (4)

$U_c = \sin(+2/3)$ (5)

To eliminate the presence of switching ripples on the dc-link voltage and in the generated reference current signals, the actual dc-link voltage (Vdc) is sensed and passed through a first-order low pass filter (LPF). 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 error in the dc-link voltage Vdcerr (n) at the sampling

$$V_{dc\ err(n)} = V^{*}_{dc(n)} - V_{dc(n)} \qquad (6)$$

III.HYSTERESIS CURRENT CONTROL

The hysteresis current control (HCC) is the easiest control method to implement; it was developed by Brod and Novotny in 1985. The shunt APF is implemented with three phase current controlled VSI and is connected to the ac mains for compensating the current harmonics. The VSI gate control signals are brought out from hysteresis band current controller. A hysteresis current controller is implemented with a closed loop control system and waveforms are shown in Fig .3. An error signal is used to control the switches in a voltage source inverter. This error is the difference between the desired current and the current being injected by the inverter. If the error exceeds the upper limit of the hysteresis band, the upper switch of the inverter

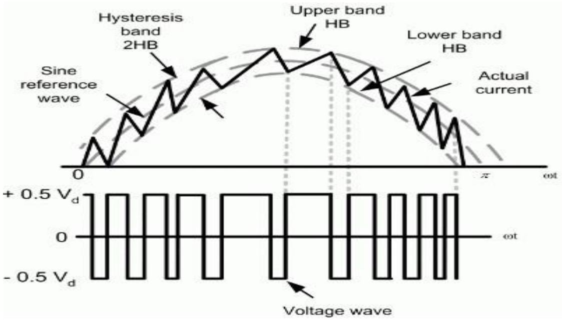

Fig.2. Waveform of Hysteresis current controller

If the error crosses the lower limit of the hysteresis band, the lower switch of the inverter arm is turned off and the upper switch is turned on. As a result, the current gets back into the hysteresis band. The minimum and maximum values of the error signal are $\mathbf{e_{min}}$ and $\mathbf{e_{max}}$ respectively. The range of the error signal $\mathbf{e_{max}}$ -$\mathbf{e_{min}}$ directly controls the amount of ripple in the output current from the VSI.

IV. SIMULATION RESULTS

In order to verify the proposed control approach to achieve multi-objectives 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 varying renewable generating conditions. A RES with variable output power is connected on the dc-link of grid-interfacing inverter. An unbalanced 3- phase 4-wire nonlinear load, whose unbalance, harmonics, and reactive power need to be compensated, is connected on PCC. The waveforms of grid voltage grid currents 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=0.1 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 unbalanced non linear to balanced sinusoidal current as shown in Fig. 4(b). As the inverter also supplies the active power from RES is increased to evaluate the performance of system under variable power generation from RES. This results in increased magnitude of inverter current. As the load power demand is considered asconstant, this additional power generated from RES flows towards grid, which can be noticed from the increased magnitude of grid current as indicated by its profile.

The active and reactive power flows between the inverter, load and grid during increase and decrease of energy generation from RES can be noticed from Fig. 5. The dc-link voltage across the grid- interfacing inverter (Fig. 5(d)) during different operating condition is maintained at constant level in order to facilitate the active and reactive power flow. Thus from the simulation results, it is evident that the grid-interfacing inverter can be effectively used to compensate the load reactive power, current unbalance and current harmonics in addition to active power injection from RES. This enables the grid to supply/ receive sinusoidal and balanced power at UPF.

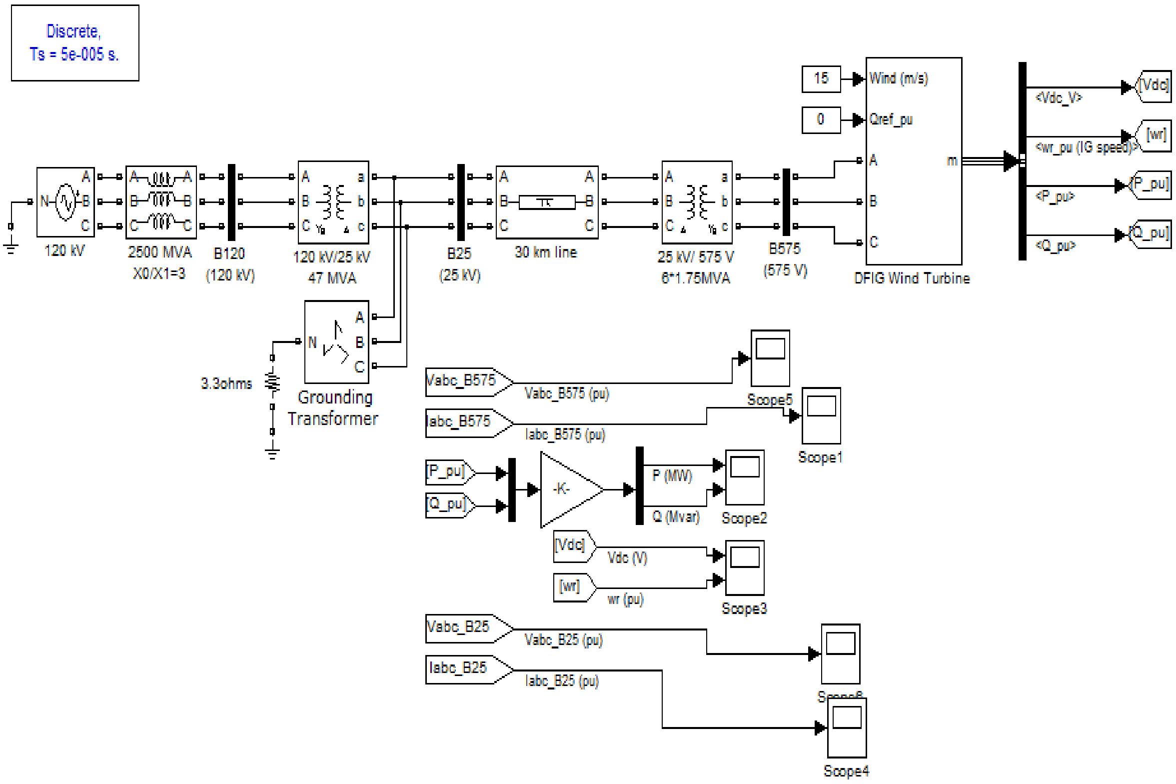

Fig.3. Model

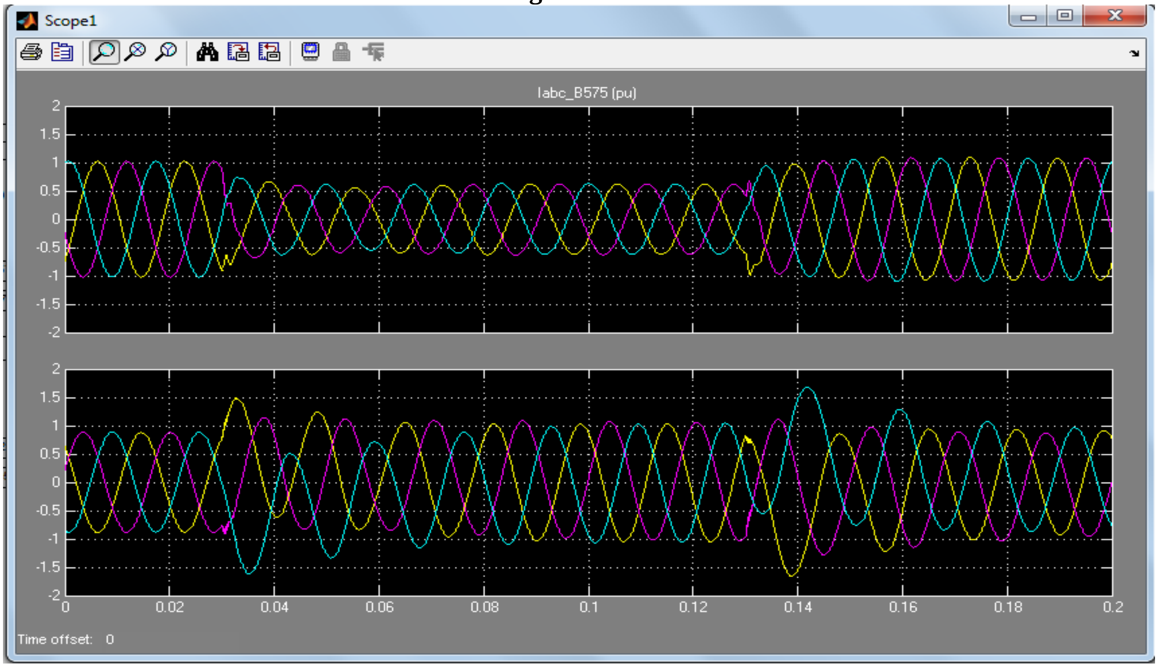

Fig.4. Load Voltage and current

The waveforms of grid voltage (Va, Vb and Vc) grid currents (Ia, Ib, Ic, In), unbalanced load currents (Ila, Ilb, Ilc, Iln), and inverter currents (IInva, IInvb, IInvc, IInvn), The corresponding active-reactive powers of grid (Pgrid, Qgrid) load (Pload, Qload) and inverter (Pinv, Qinv) are shown in Fig.4.3. 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. Therefore, before time t = 0.72 s, the grid current profile in Figure. 4(b) is identical to the load current profile of Fig.4.3(c). At t = 0.72 s, the grid-interfacing inverter is connected to the network.

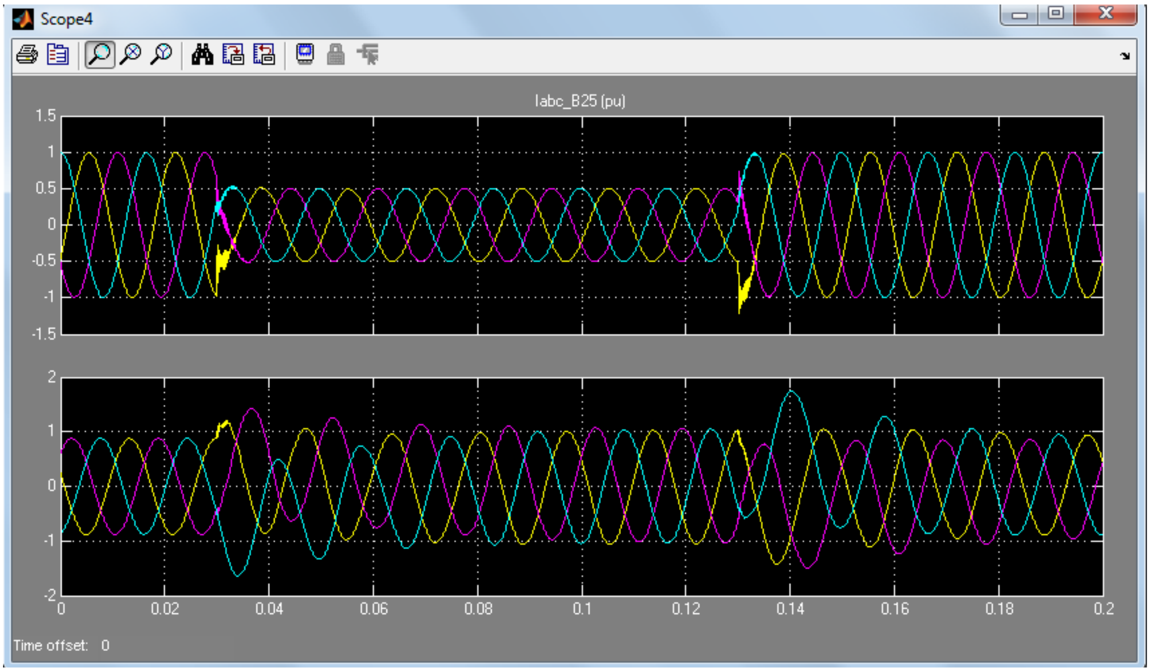

Fig.5. Inverter voltage and current

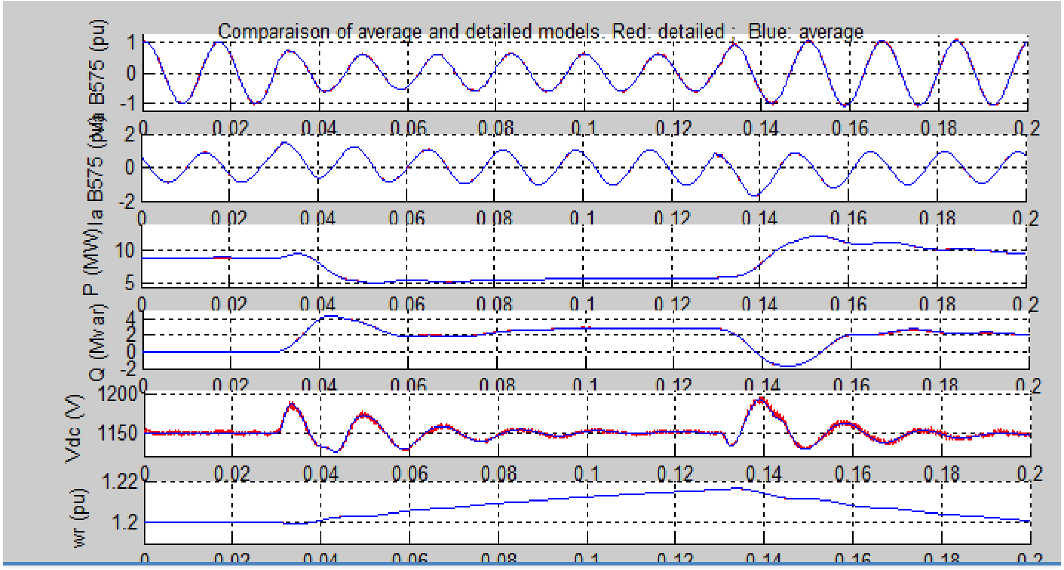

Fig.7.(a) PQ-Grid, (b) PQ-Load, (c) PQ-Inverter, (d) dc-link voltage

V. 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/or,
- Operate as a shunt Active Power Filter (APF).

This approach thus eliminates the need for additional power conditioning equipment to improve the quality of power at PCC. Extensive MATLAB/Simulink simulation as well as the DSP based experimental results have validated the proposed approach and have shown that the grid-interfacing inverter can be utilized as a multi-function device. It is further demonstrated that the PQ enhancement can be achieved under three different scenarios: 1) PRES = 0, 2) PRES < PLOAD, and 3) PRES > PLOAD. The current unbalance, current harmonics and load reactive power, due to unbalanced 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. Moreover, the load neutral current is prevented from flowing into the grid side by compensating it locally from the fourth leg of inverter. When the power generated from RES is more than the total load power demand, the grid-interfacing inverter with the proposed control approach not only fulfills the total load active and reactive power demand (with harmonic compensation) but also delivers the excess generated sinusoidal active power to the grid at unity power factor.

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