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Grid synchronized Renewable Energy Sources for Power Quality Improvement at 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 3-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 (SAPF) 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 3-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 MATLAB/SIMULINK simulation studies and results.

KEYWORDS *— Shunt Active power filter (SAPF), Distributed Generation (DG), Distribution System, Grid synchronization, Power quality (PQ), Renewable Energy Sources (RES)*

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.

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 cur rents, which may deteriorate the quality of power [1], [2]. 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 [3] 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 [4]. In [5], 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 under consideration and the controller for grid-interfacing inverter. A digital simulation study is presented in Section III. Section IV concludes the paper.

II. SYSTEM DESCRIPTION

The proposed system consists of RES connected to the dc-link of a grid-interfacing inverter as shown in Figure 1.

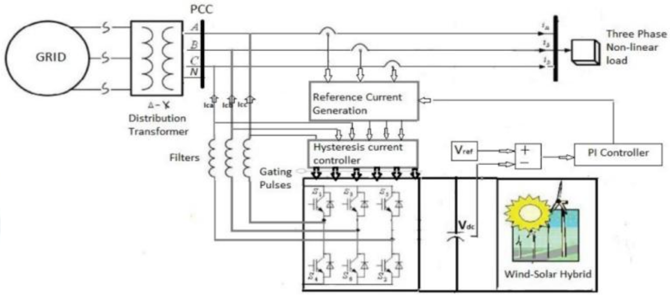

***Figure 1** Schematic of proposed RES based DG system*

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 [6]–[8]. The dc-capacitor decouples the RES from grid and also allows independent control of converters on either side of dc-link.

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. Figure 2 shows the systematic representation of power transfer from the renewable energy resources to the grid via the dc-link.

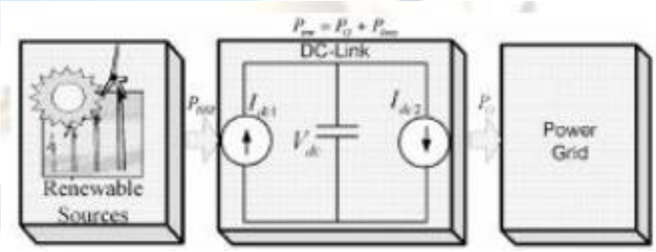

Figure 2 DC-Link equivalent diagram

The current injected by renewable into dc-link at voltage level V_{dc} can be given as

$$I_{dc1} = \frac{P_{RES}}{V_{dc}} \qquad (1)$$

Where P_{RES} is t ;enerated from RES. The current flow on the other side of dc-link can be represented as

$$I_{dc2} = \frac{P_{inv}}{V_{dc}} = \frac{P_G + P_{Loss}}{V_{dc}} \qquad (2)$$

Where P_{inv}, P_G and 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

$$P_{RES} = P_G \qquad (3)$$

B. Control of Grid Interfacing Inverter

The control diagram of grid - interfacing inverter for a 3-phase 3-wire system is shown in Fig. 3. 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 (P_L) 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. 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 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 and U_c) generates the reference grid currents Ia^*, Ib^* and Ic^* The reference grid neutral current (In^*) 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 generate unity vector template as [9]–[11].

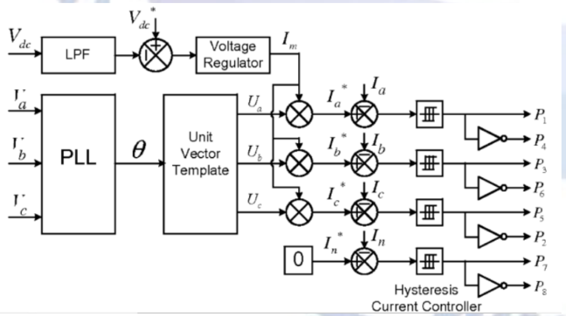

Figure 3 Block diagram representation of grid-interfacing inverter control

The actual dc-link voltage is sensed and passed through a first-order low pass filter (LPF) to eliminate the presence of switching ripples on the dc-link voltage (Vdc) and in the generated reference current signals. The difference of this filtered dc-link voltage and reference dc-link voltage (Vdc^*) is given to a discrete PI regulator to maintain a constant dc-link voltage under varying generation and load conditions.

III MATLAB/SIMULINK MODELING AND SIMULATION RESULTS

The system is described as shown in figure 1. Three phase balanced and undistorted source voltage is considered to represent ideal grid supply. Three phase diode bridge rectifier with RL load is considered as a non-linear load. Wind, FC and PV based hybrid model is synchronized to the grid at the PCC. Three leg inverter is used as an interface between HES and grid and is incorporated with SAPF feature. Simulation is carried out as per practical conditions i.e. for P_{RES} = 0, P_{demand} > P_{RES} > 0 and P_{RES} > P_{demand}.

Case 1: (P_{RES}=0) This is the case where there is no wind flow or sunlight, i.e. wind speed=0 m/s and solar irradiation is 0 W/m^2 charge in the battery is also assumed as 0. Entire real power requirement of the load is been supplied by power grid alone, whereas the interfacing inverter instead of sitting idle does the job of SAPF by supplying reactive power required by the load and compensating the load current harmonics.

Case2: (P_{demand} > P_{RES} > 0) In this case, wind speed considered as 5 m/s and solar irradiation considered is 50 W/m^2. In this case HES start feeding real power to the power grid. Hence part of the real power requirement of the load is been supported by HES and rest will be supplied by the power grid. Along with harvesting real power to the grid interfacing inverter does the job of supplying reactive power to the load as well as to compensate load current harmonics.

Case3: (P_{RES} > P_{demand}) Here the excess power from the HES has been supplied to the power grid at UPF. Three leg inverter does the job of supporting reactive power to the load as well as compensating load current harmonics.

Figures 4 & 8 show that the supply current is almost sinusoidal and is in phase with the source voltage for the Cases 1 & 2 respectively. But for the last case source current is 180^0 out of phase and is almost sinusoidal. Supply current is same as load current before compensation and is shown in Figure 5. Figures 6, 9, 12 shows the DC link voltage is maintained constant with the help of Proportional and Integral controller. Figures 7, 10 and 13 shows the compensation current generated by grid-tie inverter for the respective cases.

Table 1 shows the summary of the simulation results. Three leg inverter is capable of handling the dual responsibility of harvesting real power to the grid and improving power quality of the distribution system. In all the three cases it can be observed that the source current THD is less than 5% which is the requirement to be satisfied as per IEEE standards. Supply current is in Phase with supply voltage in all the cases, hence maintaining UPF across the grid.

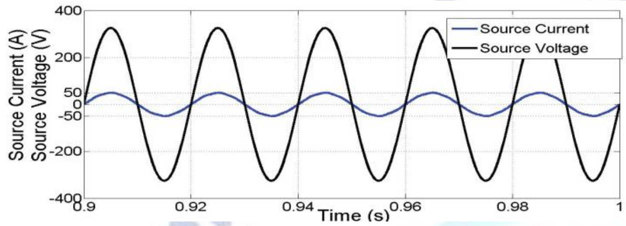

Figure 4 Source current and Source voltage

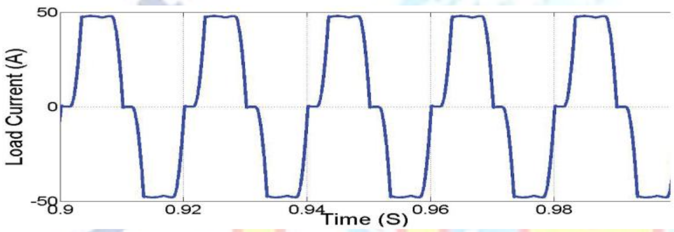

Figure 5 Load Current

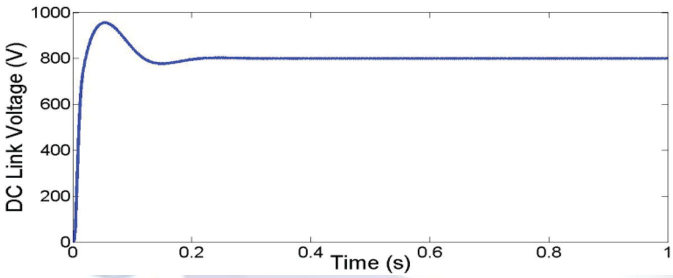

Figure 6 DC link Voltage

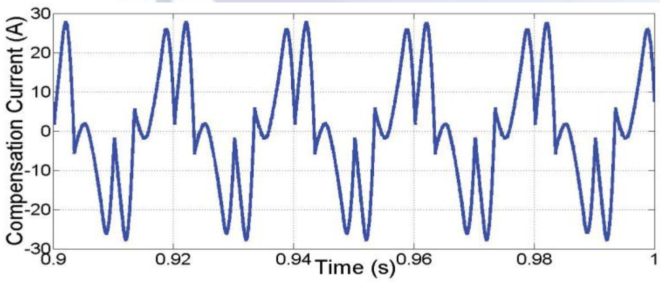

Figure 7 Compensation Current

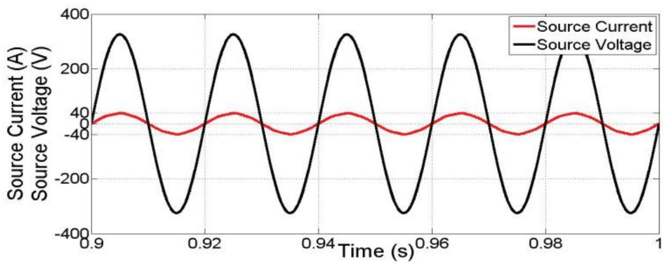

Figure 8 Source current and Source voltage

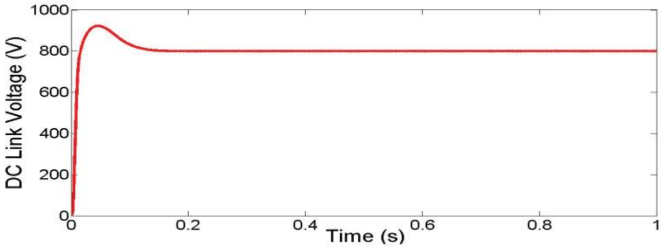

Figure 9 DC Link Voltage

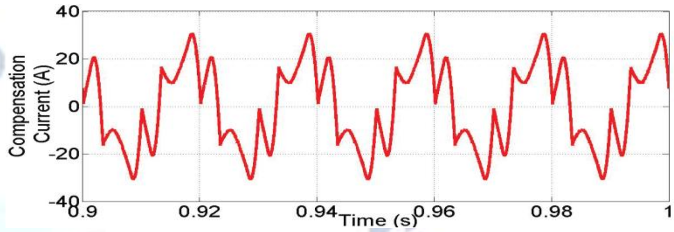

Figure 10 Compensation Current

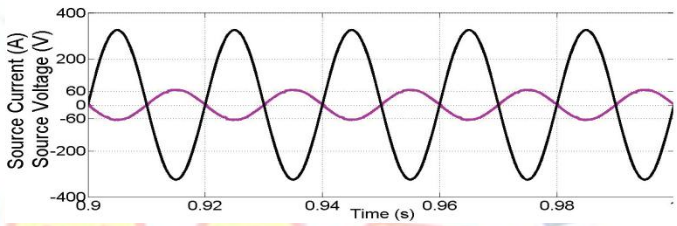

Figure 11 Supply Current and Supply Voltage

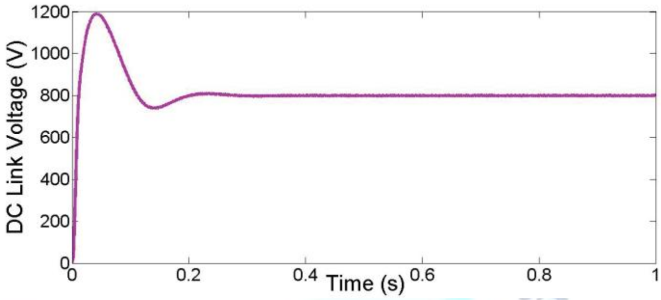

Figure 12 DC Link Voltage

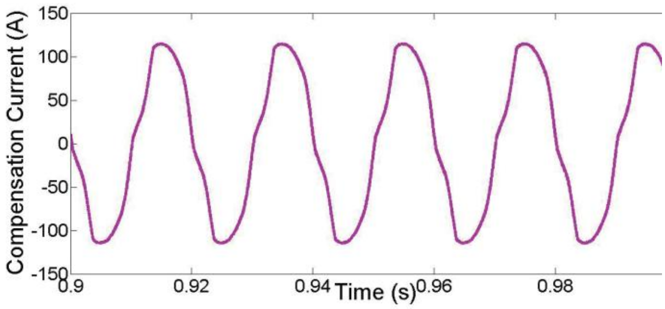

Figure 13 Compensation Current

Table 1 Results

Cases	Supply Current THD (%)	Load Current THD (%)	Power factor of load	Power factor of ***grid***
Case 1 : $P_{RES} = 0$	1.94	18.65	0.977	1
Case 2 : $P_{demand} > P_{RES} > 0$	2.34	18.65	0.977	1

Case 3: $P_{RES} > P_{demand}$	1.80	18.65	0.977	1

IV. CONCLUSIONS

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 3-wire DG system. It has been shown that the gridinterfacing 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:

i) inject real power generated from RES to the grid, and/or,

ii) operate as a shunt Active Power Filter (SAPF).

This approach thus eliminates the need for additional power conditioning equipment to improve the quality of power at PCC. It is further demonstrated that the PQ enhancement can be achieved under three different scenarios: 1) P_{RES} = 0, 2)P_{RES} < P_{Load}, and 3)P_{RES} > P_{Load}. 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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