Article

Reactive Power Compensation and Power Injection through Distributed Generation Sources

Vinay Kumar[1], Pankaj Kumar[2], Nagendra Kumar Swarnkar[3]

Abstract

Renewable energy resources are connected in distribution systems to achieving benefits. A control strategy to consummate favor from these grid-interfacing inverters when installed in 3-phase 4-wire distribution systems is presented here. This inverter is designed to perform multi-functions by incorporating active power filter functionality. The inverter can thus be used as: 1) power converter which injects power originated from wind to the grid, and 2) shunt APF to compensate unbalance current, load reactive power demand, load current harmonics, and load neutral current. All of these functions can be done either individually or simultaneously. With this control strategy, 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 concept is verified with spacious MATLAB/Simulink simulation studies.

Keywords: Voltage Stability, Wind Turbine, GRID, Sunt Active Power Filter (APF), Point of Common Coupling (PCC), MATLAB, Renewable energy source (RES), Distributed Generation (DG), power-quality (PQ)

Introduction

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 MATLAB/Simulink simulation studies. 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.

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Distributed Generation

The term Distributed Generation is sometimes used interchangeably with the term Distributed Resources (DR). But DR is intended to encompass non generating technologies such as power storage devices like batteries and flywheels in addition to generators, while DG is limited to small scale (less than 20 MW) electrical generation located close to point of use. Unlike central power plant generation, DG often utilizes the waste heat from the generation process as an additional form of energy for space or process heating, dehumidification, or for cooling through absorption refrigeration.

Distributed generation most commonly involves solar photovoltaic (PV), but can also include small hydroelectric, small-scale biomass facilities, and micro-wind. There are several advantages to distributed generation when good policies are implemented. Foremost is that the bulk of the economic benefits of widely distributed, locally controlled, and locally produced clean energy go directly to ratepayer generators and property owners through mechanisms such as the feed-in tariff, a generous per-kilowatt-hour payment made to ratepayers who generate clean power on their homes and businesses. Distributed generation generally refers to small-scale (typically 1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. Distributed generators include, but are not limited to synchronous generators, induction generators, reciprocating engines, micro turbines (combustion turbines that run on high-energy fossil fuels such as oil, propane, natural gas, gasoline or diesel), combustion gas turbines, fuel cells, solar photovoltaic, and wind turbines.

Reactive Power Management

Active and Reactive power control is very important for the propper functioning of the power system as it is the explanation and required process for the voltage to be maintained with in permissible limits. Also the system stability increases the increased utilization of the transmission line. There is always a problem of maintaing the voltage within the limits because of the variety of loads are attached to the power system and has the capability to make it unstable at any time. The requirement of the reactive power changes as the load connected to the power system chsnges, hence requires more attention. So, it is a major challenge of controlling the reactive power in the power system. Such requirement is meet through the application of the power electronics devices such as STATCOM, SVC etc.

Simulation

The proposed system consists of RES connected to the dc-link of a grid-interfacing inverter as shown in Figure 4.1. In distributed system, renewable energy resources are increasingly incorporated using power electronics interfaces. Extensive use of power electronics devices generate harmonic current and may reduce quality of power. Renewable energy source integrated at distribution level is termed as distributed generation. The utility is concerned due to the high penetration level of intermittent renewable energy resource in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality 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 distributed generation systems can now be actively controlled to enhance the system operation with improved power-quality at point of common coupling. However, the extensive use of power electronics based equipment and non-linear loads at point of common coupling generate harmonic currents, which may deteriorate the quality of power. In my dissertation work, renewable energy resources are to be connected to the grid through a grid interfacing inverter for power quality improvement. The grid interfacing inverter is then connected to a 3-phase 4-wire system and hysteresis current control method will be used to generate gate pulses. Here renewable energy resource will be represented by a dc source. The grid interfacing inverter has the capability of injecting RES power to the grid and also reduces load unbalance, load harmonics and reactive power demand is compensated. Total Harmonic Distortion of the grid connected system is analyzed. The simulation work is carried out on MATLAB/Simulink platform.

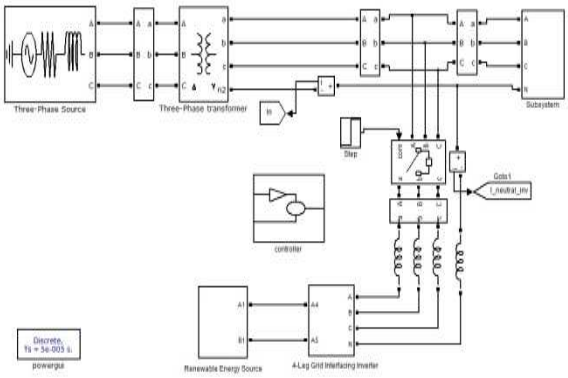

Figure 1.Simulation Diagram for Proposed System

MATLAB Simulink blocks are used to simulate the proposed power system network to integrate the RES power to the GRID as shown in Figure 1. System is supposed to inject the required extra power by the load and to share the load to decrease the burden on the GRID.

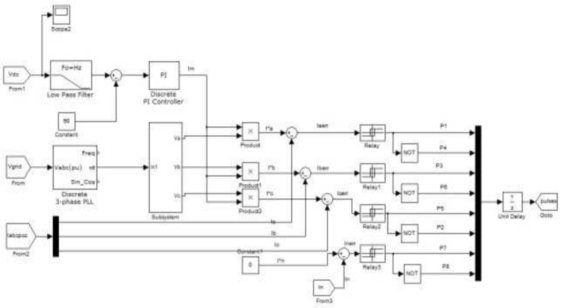

Figure 2.Simulation Diagram for Proposed Controller

Results

On MATLAB / Simulink platform a simulation study is performed to check the behavior of the controller's control output to control the current controlled VSI. Current controlled VSI is injecting the RES power to the GRID for balancing the unbalancing caused by unbalanced load or to reduce the burden on the GRID as a result of overloading. 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.

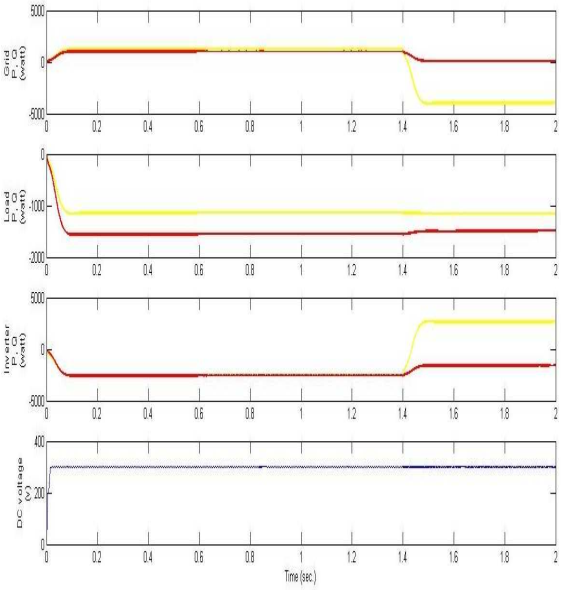

Figure 3.Active Power (P), Reactive Power (Q), P_g, Q_g-GRID, (ii) P_{inv}, Q_{inv}-Inverter, (iii) P_L, Q_L -Load, (iv) DC

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 corresponding active-reactive powers of grid, load and inverter are shown in Figure 3. An FFT analysis is done for harmonic calculation represented in Figure 5 to 7 and the valuable values are kept in table 1 and.

Active Power (P), Reactive Power (Q) supplied or consumed by GRID (P_g, Q_g), Load (P_L, Q_L) and Inverter (P_{inv}, Q_{inv}) are shown in Figure 3.

Positive value of P and Q in Figure 3. is showing the power supplied to load and their negative value is showing the power absorption. During the starting period current controlled VSI is not connected in the system, it means the load power demand is only supplied by the GRID. At time 1.4 sec. current controlled VSI is connected at the PCC. At this time the current controlled VSI starts injecting the power at the PCC to share the load demand and making the GRID current profile balanced linear sinusoidal. Active power generated from the RES is in the DC form which is the input to the current controlled VSI and applied to the PCC. As the total power supplied at PCC is more than the load demand, which makes the GRID to absorb the extra power as shown in Figure 3. & 4. The negative sign of GRID active power represents the power absorption by the GRID. Reactive power is too supplied by the current controlled VSI as shown in Figure 3.

Waveforms of the GRID Voltage-$V_g$abc, GRID Current-$I_g$abc, Load Current-$I_L$abc and Inverter Current-I_{inv}abc corresponds to the Active Power (P), Reactive Power (Q) supplied or consumed by GRID (P_g, Q_g), Load (P_L, Q_L) and Inverter (P_{inv}, Q_{inv}) as shown in Figure 3. & 4. for a period of 0.0 sec to 2.0 sec. In Figure 4 (ii) the GRID current-$I_g$abc is discontinuous before time 1.4 sec. i.e. before the connection of VSI at PCC as represented through Figure 4 (iv). After the time 1.4 sec. waveforms starts building up in Figure 4 (iv) means that the VSI is now get connected at PCC and started sharing requirements of the load. This results in reducing burden on GRID and the GRID current-$I_g$abc waveform becomes uniform sinusoidal as shown in Figure 4 (iv).

10 cycles are selected again during FFT analysis for the calculation of harmonic percentage. The percentage harmonic value in the phase 'a' voltage between the time 1.4 sec. to 1.6 sec., 50 Hz as fundamental frequency is 0.21 %. All the details for the same and other phases are noted under table – 1.

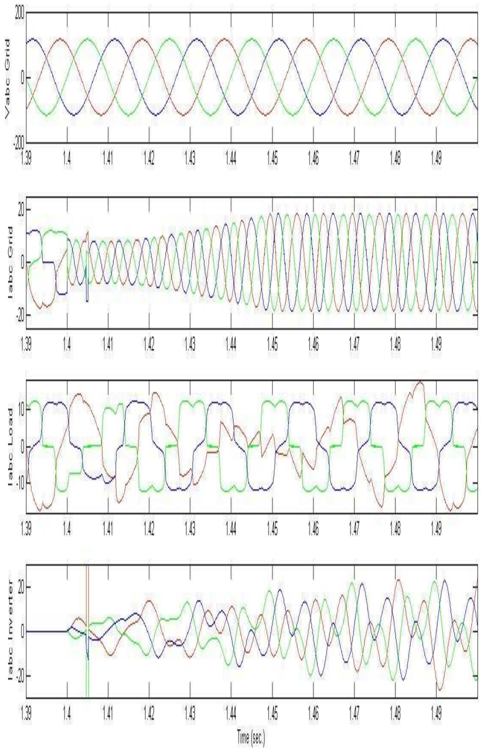

Figure 4.(i) GRID Voltage-$V_g$abc, (ii) GRID Current-$I_g$abc, (iii) Load Current-$I_L$abc, (iv) Inverter Current-I_{inv}abc

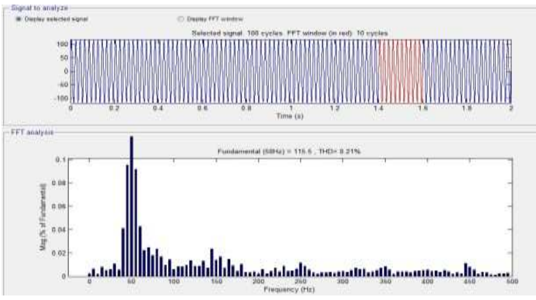

Figure 5.Harmonic percentage in voltage for phase-a

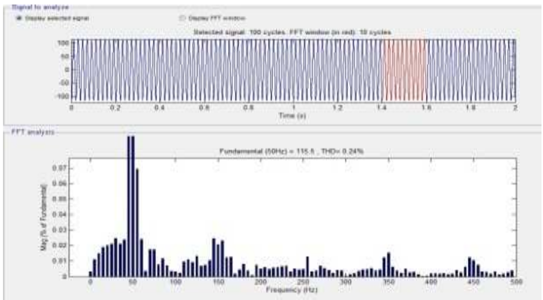

Figure 6.Harmonic percentage in voltage for phase-b

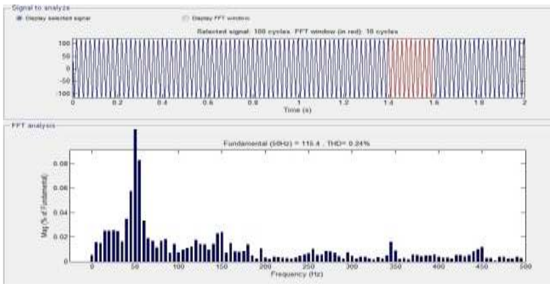

Figure 7.Harmonic percentage in voltage for phase-c

Table 1.% Harmonics in each phase

PHASE	Fundamental Frequency (Hz)	Time (Sec.)	Number of Cycles	Harmonic (%)
a	50	1.4 – 1.6	10	0.21
b	50	1.4 – 1.6	10	0.24
c	50	1.4 – 1.6	10	0.24

Conclusion

Satisfactorily, detailed performance characteristics of the proposed system in MATLAB is verified for the desired results. At the time of connection of the shunt APF at the PCC the shunt APF compensate the unbalanced current, load's reactive power demand, load current harmonics and load neutral current. With this control strategy, 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.

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