GRID INTERCONNECTION OF RENEWABLE ENERGY SOURCES AT THE DISTRIBUTION LEVEL WITH POWER-QUALITY IMPROVEMENT FEATURES USING PR CONTROLLER

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Abstract- **This project focuses on the control of an existing grid interfacing inverter to improve the quality of power at point of common coupling for 3-phase 4-wire Distribution systems. The grid integration of distributed generator system normally poses many connection issues leading to discouraging the use of distributed generator. Hence a novel control strategy is presented for improving the efficient power quality to the interconnection of distributed generator with a grid. The grid-inter facing inverter can be effectively utilized for power conditioning without disturbing its regular operation of real power transfer. The grid-interfacing inverter with the proposed approach can be utilized to: i) inject real power generated from Renewable energy source to the grid, and/or, ii) operate as a shunt Active Power Filter. To compensate current unbalance, load current harmonics, load reactive power demand and load neutral current by the Proportional Resonant controller (PR). This approach consequently eliminates the need for additional power conditioning equipment to improve the quality of power at Point of common coupling. General MATLAB/Simulink simulation as well as the Digital Signal Processing based experimental results have validated the proposed approach and have shown that the grid-interfacing inverter can be utilized as a multi-function device.**

Index Terms— **Active power filter (APF), distributed generation (DG), distribution system, grid interconnection, power quality (PQ), renewable energy.**

I. INTRODUCTION

Power quality is an important issue for distribution network companies. They must guarantee the electricity supply for the customers, while fulfilling certain quality requirements. Public institutions are involved in this topic as well. There are European standards and, usually, every country has specific regulations for power quality too. One of these requirements is the voltage level. It has to be kept between the established limits. In order to do that, the distribution network companies should decide the best strategy using the technology within reach. In that case, thinking of the voltage, the transformers are the main tool, especially transformers with tap changer. Based on the real data, we build the models and we run several simulations of them. Once we have the results of the simulations, we analyze them in order to discover potential problems. Then, we modify the settings of the model, especially in the transformer side, to investigate any change in the system that could improve the voltage quality. Another aim of this thesis is to confirm theoretical aspects of the voltage, related to the set point and the deadband. So, with help of the simulation results, we look for relations between the voltage and others parts of the system like the losses or the tap changer operation. Power quality has become major concern to both electric utilities and customers. In many countries, the effects of lack of power quality have been resulting in wastage of several billions of dollars every year. This is due to carelessness of most industries in not upgrading their plants which result in very high cost due to loss of products, loss of production time, clean up and recalibration of the process. The use of complexity and sensitivity of new technologies in electric equipments is one of the major causes of power quality problems such as voltage disturbances on the supply network. Power electronic equipments are more sensitive to voltage disturbances and leads to large growth of voltage disturbances.

The use of distributed generation (DG) sources is currently being considered as a solution to the growing problems of energy demand. Apart from the consequent reduction in the size of the generating plants and the possibility of modular implementation, DG systems based on renewable energy sources (photovoltaic, fuel cells, and storage systems such as ultra capacitors and batteries) are of great interest due to their low environmental impact and technical advantages such as improvements in voltage levels and reduced power losses when a DG system is installed in radial lines. DG systems also promote cogeneration and improve overall system efficiency. A DG system operating at high performance requires a detailed evaluation of the feeder where the DG will be installed, plus an assessment of the load type the DG must supply locally and its working regime. Without these requirements, the effects of DG may be more harmful than beneficial: the insertion of new generation sources in the distribution system may cause transient effects due to switching operations, changing short-circuit levels, lower margin of stability, and inversion of the power flow through the distribution system, causing erroneous operations of the protection devices and is landing in part of the system.

II. POWER QUALITY PROBLEMS

The electric power network has undergone several modifications from the time of its invention. The modern electric power network has many challenges that should be met in order to deliver qualitative power in a reliable manner. There are many factors both internal and external that affect the quality and quantity of power that is being delivered. This chapter discusses the different power quality problems, their causes and consequences.

A. Interruptions:

It is the failure in the continuity of supply for a period of time. Here the supply signal (voltage or current) may be close to zero. This is defined by IEC (International Electro technical Committee) as “lower than 1% of the declared value” and by the IEEE (IEEE Std. 1159:1995) as “lower than 10%”. Based on the time period of the interruption, these are classified into two types. They are,

i) Short Interruption: If the duration for which the interruption occurs is of few mille seconds then it is called as short interruption.

ii) Long Interruptions: If the duration for which the interruption occur is large ranging from few mille seconds to several seconds then it is noticed as long interruption. The voltage signal during this type of interruption is shown in Fig.2.

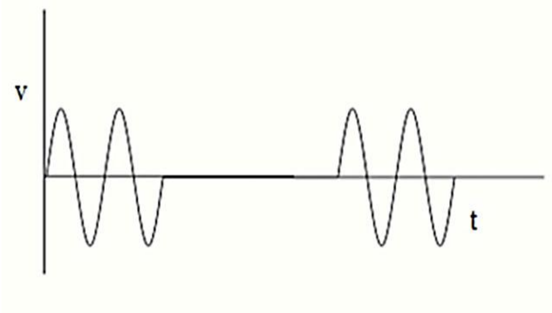

Fig.2 Voltage Signal with Long Interruption

B. Waveform Distortion:

The power system network tries to generate and transmit sinusoidal voltage and current signals. But the sinusoidal nature is not maintained and distortions occur in the signal.

C. Frequency Variations:

The electric power network is designed to operate at a specified value (50 Hz) of frequency. The frequency of the framework is identified with the rotational rate of the generators in the system. The frequency variations are caused if there is any imbalance in the supply and demand. Large variations in the frequency are caused due to the failure of a generator or sudden switching of loads.

D. Transients:

The transients are the momentary changes in voltage and current signals in the power system over a short period of time. These transients are categorized into two types impulsive, oscillatory. The impulsive transients are unidirectional whereas the oscillatory transients have swings with rapid change of polarity.

E.Voltage Sag:

The voltage sag is defined as the dip in the voltage level by 10% to 90% for a period of half cycle or more. The voltage sag as shown in Fig. 3.

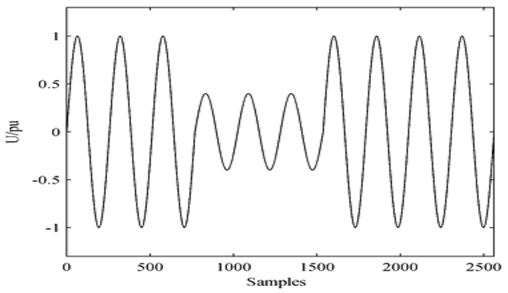

Fig.3 Voltage Sag

F. Voltage Swell:

Voltage swell is defined as the rise in the voltage beyond the normal value by 10% to 80% for a period of half cycle or more. The voltage swell as shown in Fig.4.

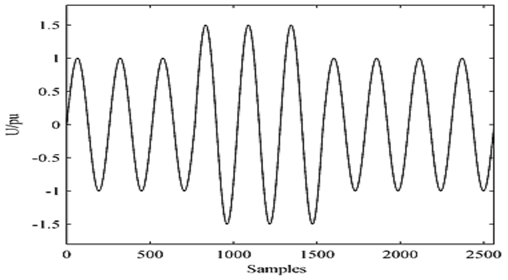

Fig.4 Voltage Swell

G. Voltage Unbalance:

The unbalance in the voltage is defined as the situation where the magnitudes and phase angles between the voltage signals of different phases are not equal.

H. Voltage Fluctuation:

These are a series of a random voltage changes that exist within the specified voltage ranges. Fig.5 shows the voltage fluctuations that occur in a power system.

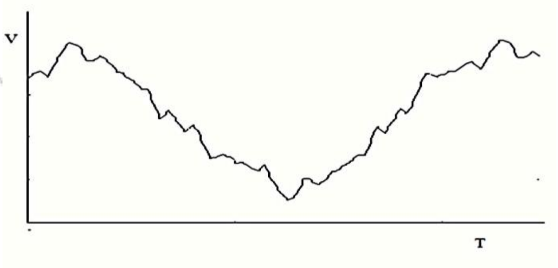

Fig.5 Voltage Fluctuation

III. SYSTEM MODELING

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. 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. 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. 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 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 a control strategy for renewable interfacing inverter based on p - q 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. The proposed system consists of RES connected to the Dc-link of a grid-interfacing inverter as shown in Fig. 6. The voltage source inverter is a key element of a DG systemas 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.

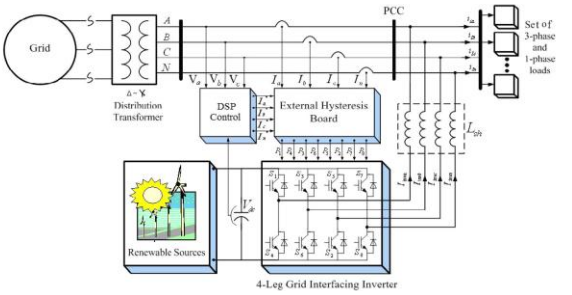

Fig.6. Schematic of proposed renewable based distribution generation system.

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 (v_a,v_b,v_c), Grid currents (I_a,I_b,I_c,I_n) unbalanced load current (I_{1a},I_{1b},I_{1c},I_{1n}) and inverter (I_{inva},I_{invb},I_{invc},I_{invn}) are shown in Fig 7. The corresponding Active-reactive powers of grid (P_{Grid}, Q_{Grid}) and load (P_{load}, Q_{load}) and inverter (P_{inv}, Q_{inv}) are shown in Fig 8. 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.

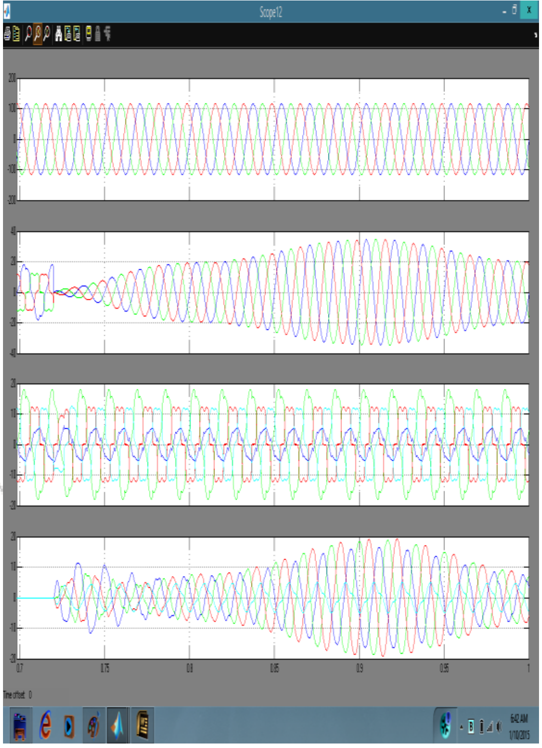

Fig. 7(a) Simulation results of PI controller: (a) Grid voltages, (b) Grid Currents (c) Unbalanced load currents, (d) Inverter Currents

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 as shown in Fig6.2 (a) and in Fig 7 (b).

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 unbalanced non linear to balanced sinusoidal current as shown in fig 7(a) & 7(b). As the inverter also supplies the load neutral current demand, the grid neutral current (I_n) becomes zero after t=0.72 s.

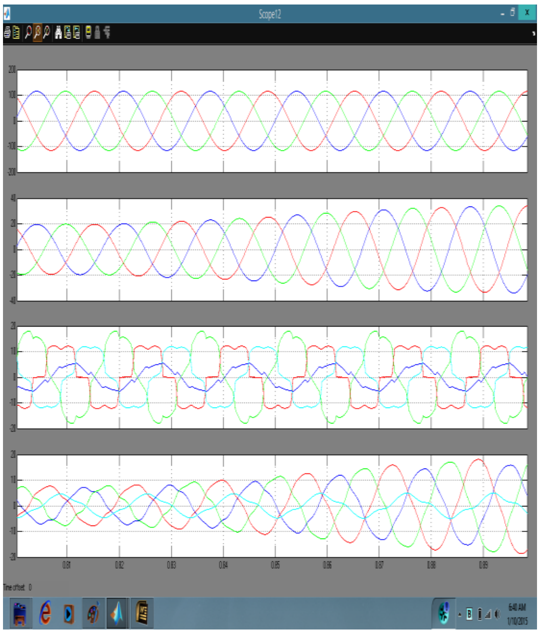

Fig. 7 (b) Simulation results of PI controller: (a) Grid voltages, (b) Grid Currents (c) Unbalanced load currents, (d) Inverter Currents

At t=0.82 s, 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 as constant, 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.

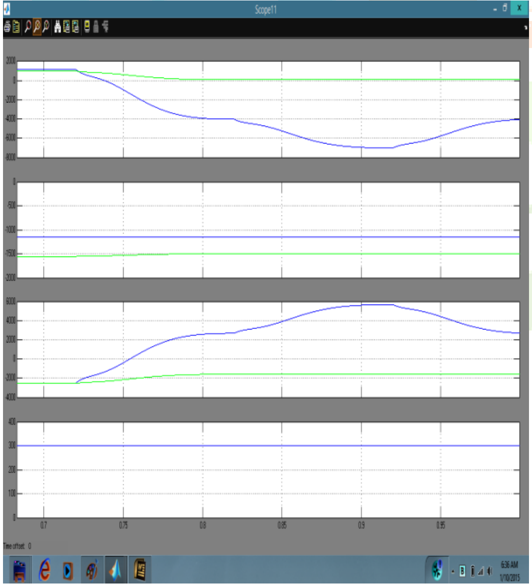

Fig. 8 Simulation results: (a) PQ-Grid, (b) PQ-Load, (c) PQ-Inverter,
(d) dc-link voltage.

At t=0.92 s, the power available from RES is reduced. The corresponding change in the inverter and grid currents can be seen from Fig 8. 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. 8.

To compensate current unbalance, load current harmonics, load reactive power demand and load neutral current by the Proportional controller (PR). This approach consequently eliminates the need for additional power conditioning equipment to improve the quality of power at Point of common coupling. The dc-link voltage across the grid- interfacing inverter 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.

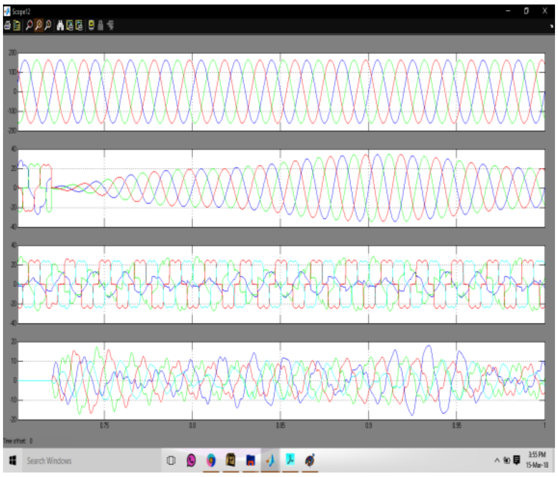

Fig. 9(a) Simulation results of PR controller: (a) Grid voltages, (b) Grid Currents (c) Unbalanced load currents, (d) Inverter Currents

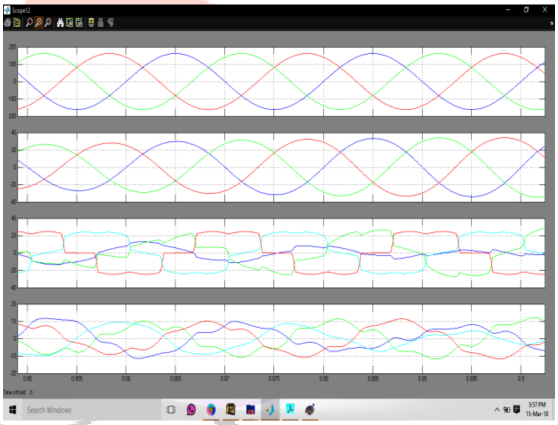

Fig. 9 (b) Simulation results of PR controller: (a) Grid voltages, (b) Grid Currents (c) Unbalanced load currents, (d) Inverter Currents

The proportional-resonant controllers (PR) are introduced and their suitability for current control in both single-phase and three-phase grid converters is demonstrated. They can be tuned to react to a certain frequency that can be chosen to be equal with the grid frequency for a good regulation of the fundamental current and they can be tuned to the harmonic frequency in order to compensate them.

The comparison between for the proposed PI controller and extension PR controller as shown in below table.

	PI	PR
Grid voltages	100	150
Grid currents	35	30
Unbalanced load currents	<20	>20
Inverter currents	20	10

V. CONCLUSION

This proposed system 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:

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

ii) 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) $P_{RES}=0$, 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.

This paper the proportional-resonant controllers (PR) are introduced and their suitability for current control in both single-phase and three-phase grid converters is demonstrated. They can be tuned to react to a certain frequency that can be chosen to be equal with the grid frequency for a good regulation of the fundamental current and they can be tuned to the harmonic frequency in order to compensate them. The PR technique can successfully replaced the typical PI-dq control scheme for three-phase systems exhibiting some advantages like reduced complexity and improved harmonic rejection capability. Also, for single-phase systems it can replace stationary PI control showing better performances in terms of steady-state error and harmonic rejection

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