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Power Quality Improvement at Distribution Level for Grid Interfacing Applications

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***Abstract*: Integration of Renewable Energy Sources into the grid are much more common nowadays. This article will introduce a new control approach to maximize the use of this grid-based inverter interface installed in a 3-phase 4-wire distribution system. the Inverter is controlled such that it can function as an active power filter. In this way, the inverter can be used as: 1) injecting active power from renewable energy sources to the grid at point of common coupling. 2) power filters to compensate for current unbalance, load harmonics, reactive power requirements of the load and neutral load currents. It can perform all these functions either separately or simultaneously. In such a case, the control combination of an inverter network interface and a 3-phase 4-wire linear or non-linear unbalanced load at the point of common contacts looks like a balanced load to the grid. This new control concept is mapped using extensive research, simulated in MATLAB/Simulink and confirmed using a digital signal processor-based laboratory experimental result.**

***Keywords*: renewable energy sources, interfacing inverter, active power filter, point of common coupling.**

1. Introduction

Companies in the electric power industry and the end-users of electricity are worried to a greater extent with the increasing demand for electricity. Seventy-five per cent of the world's total energy required is obtained by the burning of fossil fuels. However, the rising pollution, air pollution, global warming, the decrease of the fuel reserves and their rising costs are forcing to shift the focus towards renewable energy as the future solution. Over the past few decades, there has been a great deal of interest in the area of renewable energy sources for electricity generation in many countries. The Liberalization of market, incentives of the government have hastened the development of renewable energy sector. Renewable source of energy, integrated at the distribution level is named as Distributed Generation. The usage is concerned because of the high level of the intermittent RES in this distribution system, in which the most at risk is the v system stability, voltage regulation and the power quality. Hence the distributed system must follow the considerable technical and regulatory frameworks to ensure safe, reliable and efficient operation of the whole network. With the development of power electronics and digital control techniques, the distributed generation systems can now be actively managed in order to improve the operation of system with enhanced power quality at point of common coupling. However, the widespread use of power electronics-based equipment and non-linear loads at point of common coupling creates harmonic currents, which can reduce the quality of electricity.

Typically, current controlled voltage source inverters are utilized to interface the intermittent renewable energy source in distribution system. Recently, several grid-based approaches have been proposed for the inverter incorporating power quality solution.an inverter serves as an active inductor of a certain frequency to absorb the energy losses due to harmonics. However, the exact computation of network inductance in real-time, is hard in order to verify the performance. With the same method, a shunt active filter acting as an active conductance to reduce the harmonics in the distribution network is proposed. A management strategy for a renewable synergetic inverter is proposed, based on p-q theory. With this approach, both the load and inverter currents require sensing to compensate for harmonic load currents.

The non-linear load current harmonics can lead to harmonics in voltage, and it can cause severe power quality problems in power system network. The active power filters (APF) are used in order to compensate for the energy losses due to harmonics, and electrical imbalance at the distribution level. This results in additional costs associated with the equipment. But in order for this to work, the authors have included a conventional inverter that is interfacing with the grid, without any extra cost for the equipment. The basic idea is the maximize usage of inverter rating, where most of the time is under-utilized because of the nature of Renewable energy sources. It is clear in the paper that the grid inverter and its interface can be effectively used in order to carry out the following key features, (1) the transfer of active power developed from renewable energy sources. (2) load reactive power demand assistance. (3) Compensation of

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current harmonics at the Point of common coupling; and (4) Neutral current compensation and unbalance in the current in case of 3-phase 4-wire system. In addition, with sufficient control of grid interfacing system, all of the four tasks can be carried out either individually or at the same time. Therefore, the power quality constraints at the point of common coupling can be strictly maintained without any additional cost of the equipment.

2. Description of the Proposed System

The main part of the proposed system is the Voltage Source Inverter that is interfacing the Renewable Energy Sources with the main utility grid. This VSI has an important role as it delivers the active power generated by the Renewable Energy Sources to the main utility grid. The proposed system also contains a DC-link which is coupled between the RES and the interfacing inverter (VSI). The Renewable Energy Sources may be of AC or DC (Ex: the output of a wind turbine is a variable AC as we cannot control the speed of the wind that is turning the turbine blades, the output of a solar panel is also a variable DC because the intensity of the light varies over the day). Thus, conditioning of power is required for RES.

The DC-link has a role of transferring this variable power from the Renewable Energy Sources to the inverter and then to the utility grid. The main assumptions in this system are as follows:

1. The Voltage Source Inverter is lossless.
2. The Renewable Energy Sources are treated as current sources.
3. $P_{RES} = P_G + P_{loss}$; $P_{loss} = 0$

Where,
P_G = Active power supplied to the main utility grid
P_{loss} = Losses in the inverter
P_{RES} = Generated power from Renewable Energy Sources.

A. Voltage source inverter control

The inverter is controlled in such a way that active power generated by the RES is injected into the grid, the reactive power demand of the load is satisfied and the harmonics in the load currents are reduced thereby balancing the load. We use the fourth leg of inverter to compensate for the neutral current.

the DC-link voltage (V_{DC}) is measured and is taken as one of the inputs to the controller, this measured value is then subtracted from a reference value (V_{DC}*) and the resultant error signal is passed through a PI (Discrete) controller block. The output of this block results in active current (I_a), multiplication of this component with the outputs of the unity vector template (K-R, K-Y, K-B) gives the reference values of the main utility grid currents (I-R-ref, I-Y-ref, I-B-ref). The function of the second order filter is to filter out the ripples (i.e., generated due to switching) from entering into the controller block.

$$V_{DC-error} = V_{DC} - {V_{DC}}^*$$

PI (Discrete) controller output:

$$I_{a(n)} = I_{a(n-1)^{th}} + 0.05 * V_{DC-error(n)} + 10(V_{DC-error(n)} - V_{DC-error(n-1)^{th}})$$

The phase locked loop is used to generate the synchronizing angle of the grid (φ) which is used as an input for the unity vector template.

Unity vector template output:

$$K_R = \sin(\varphi)$$
$$K_Y = \sin(\varphi - 120^0)$$
$$K_B = \sin(\varphi + 120^0)$$

The reference values of the main utility grid currents:

$$I_{R-ref} = I_a * K_R$$
$$I_{Y-ref} = I_a * K_Y$$
$$I_{B-ref} = I_a * K_B$$

Note: The reference value of the neutral current is set to zero ($I_{N-ref} = 0$).

Therefore, the final error values for the grid currents are given as follows:

$$I_{R-err} = I_{R-ref} - I_R$$
$$I_{Y-err} = I_{Y-ref} - I_Y$$
$$I_{B-err} = I_{B-ref} - I_B$$
$$I_{N-err} = I_{N-ref} - I_N$$

The hysteresis controller takes these error currents of grid as input and generates the appropriate pulses(G_1-G_8) for switching the IGBT's in the voltage source inverter. From figure 1 we can model the state space equations as follows.

$$\frac{d(I_{Rinv})}{dt} = \frac{V_{R(inv)} - V_R}{L}$$
$$\frac{d(I_{Yinv})}{dt} = \frac{V_{Y(inv)} - V_Y}{L}$$
$$\frac{d(I_{Binv})}{dt} = \frac{V_{B(inv)} - V_B}{L}$$

Where, $V_{R(inv)}, V_{Y(inv)}, V_{B(inv)}, I_{R(inv)}, I_{Y(inv)}, I_{B(inv)}$ are output voltages and currents of grid interfacing Voltage Source Inverter.

The relation between inverter output voltages and the switching pulses is given as follows

$$V_{R(inv)} = \frac{P_1 - P_4}{2} * V_{DC}$$
$$V_{Y(inv)} = \frac{P_3 - P_6}{2} * V_{DC}$$
$$V_{B(inv)} = \frac{P_5 - P_2}{2} * V_{DC}$$
$$V_{N(inv)} = \frac{P_7 - P_8}{2} * V_{DC}$$

3. Simulation Results

The waveforms of grid voltages and currents ($V_{Rload}, V_{Yload}, V_{Bload}, I_{Rload}, I_{Yload}, I_{Bload}$) inverter currents ($I_{Rinv}, I_{Yinv}, I_{Binv}$) and load currents ($I_{Rload}, I_{Yload}, I_{Bload}$) are shown in figure (3). The real and reactive power of grid (P_{Grid}, Q_{Grid}) load (P_{load}, Q_{load}) and inverter (P_{inv}, Q_{inv}) are shown in figure 4. Note that the active and reactive power flowing from grid to point of common coupling or from inverter to point of common coupling or when they are absorbed by the load are considered to be positive and vice versa for negative.

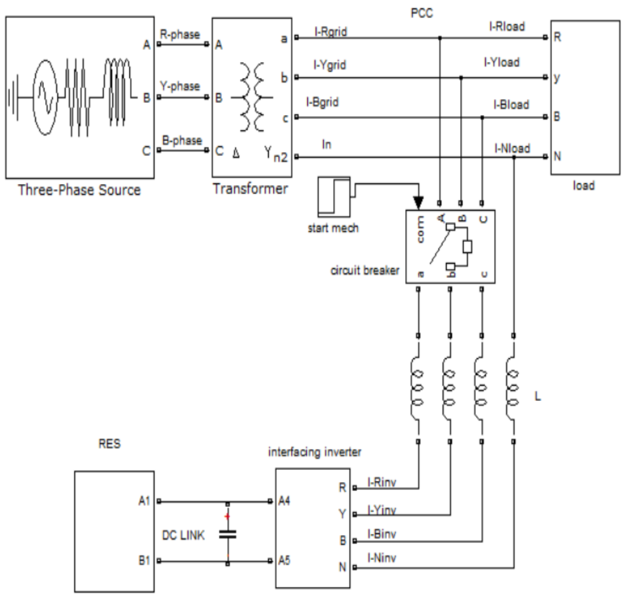

Fig. 1. Block diagram

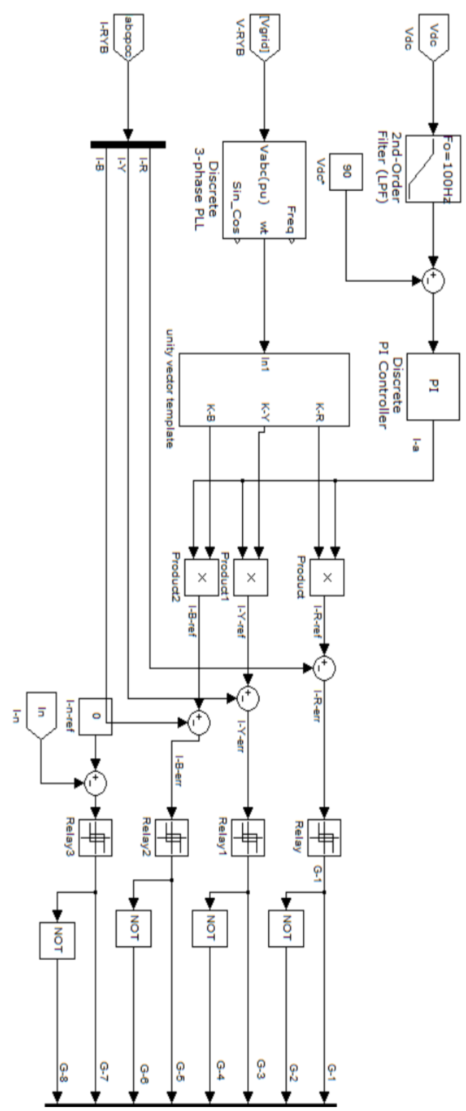

Fig. 2. Controller logic diagram for grid interfacing VSI

From figure 1 we can observe that there is a circuit breaker (which is initially open) between the interfacing inverter and the point of common coupling. The circuit breaker is signaled to close at t = 0.85s i.e., at t < 0.85s the load currents are identical to grid currents and the total load demand is completely satisfied by the main utility grid. At t >= 0.85s the circuit breaker is closed and the grid interfacing inverter starts injecting active power into the main supply line (i.e., whether it is to the load or back to the grid). At the same time the inverter also takes care of the reactive power demand by the load and also makes sure that the load appears as balanced to the grid (i.e., grid currents become balanced sinusoidal current as shown in figure (3). Note that once the inverter starts acting on the grid the neutral current becomes zero. From figure 4, it is evident that P_{Grid} is negative at t > 0.85s that is power is flown back to the grid, thus it can be explained as the power generated from RES is greater than the actual load demand therefore the excess power is flown back to the grid. In order to evaluate the performance of the system the active power generated from RES is increased (t = 0.88s) and then decreased (t = 0.94s) this response can be observed from figure 4.

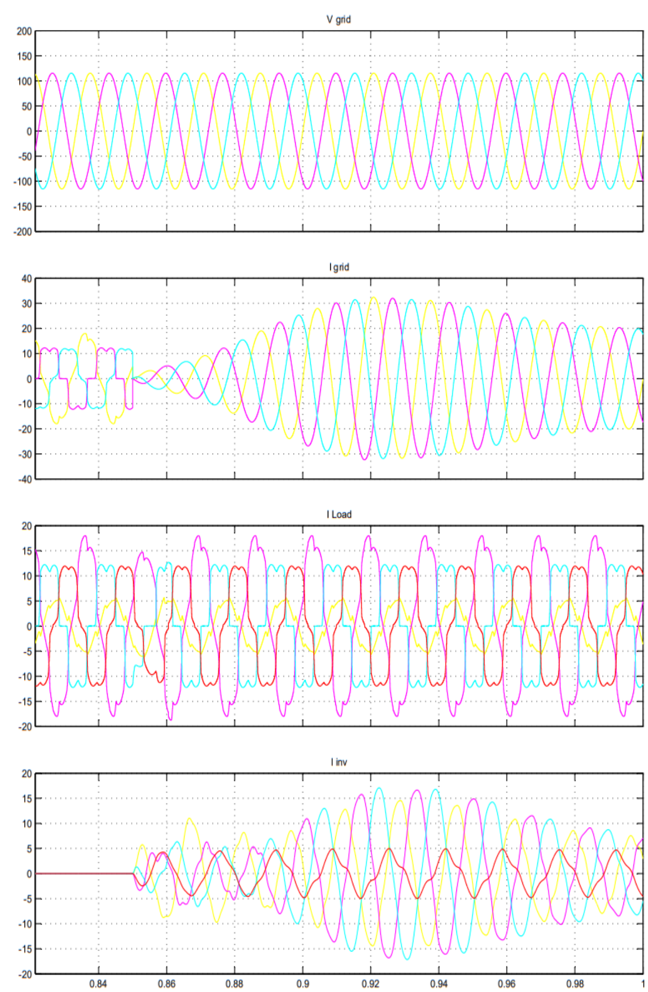

Fig. 3. Simulation results: (a) Grid voltages, (b) Grid Currents (c) Unbalanced load currents, (d) Inverter Currents

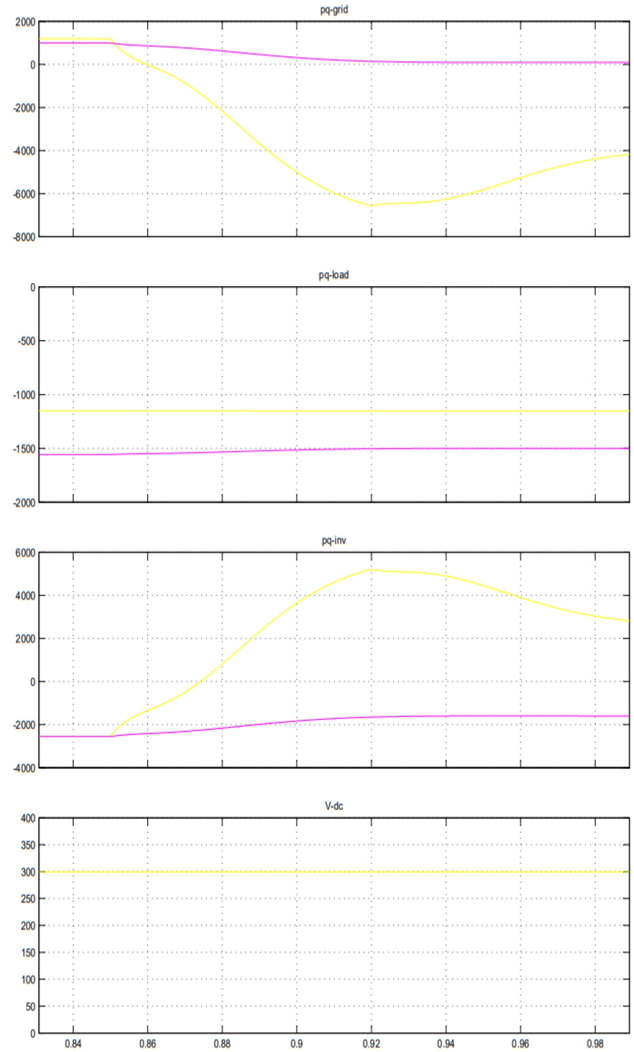

Fig. 4. Simulation results: (a) pq-grid, (b) pq-load, (c) pq-inverter, (d) dc-link voltage

4. Conclusion

In this paper we present you the new controls available for the existing grid interfacing inverter, in order to improve the power quality at point of common coupling for a 3-phase 4-wire system. It is shown that the grid interfacing inverter can be effectively used as a power conditioning device, without affecting the normal operation of real power transfer. Hence, this approach eliminates the need for special equipment in power conditioning thereby improving power quality at PCC. Extensive MATLAB/Simulink, analysis, as well as the experimental results based on DSP is used to confirm the proposed approach and show that the interfacing inverter can be used as a multi-functional device. The fourth leg of the inverter is used to compensate for the neutral current of the load also When the power generated from renewable energy sources is greater than the total load demand, the interfacing inverter with the proposed control strategy should not only satisfy the total load (active and reactive power) but also provide excess harmonic free active power with UPF back to the main utility grid.

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