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Renewable Energy Resources Interfacing to Grid at Distribution Level Using I_d-I_q Current Control Strategy for Power Quality Improvement

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ABSTRACT

Electric utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Urbanization and industrialization have changed the lifestyle of human society and the need for electrical energy has enhanced significantly. As the conventional energy sources are not capable of serving the purpose, the researchers have turned their face towards Renewable Energy Sources (RES). Energy sources are scattered across the globe, therefore the available green energy at the distribution level is also used to generate electricity. The hybrid combination of wind/solar systems has proved to be a reliable source to the utility. For extracting maximum power from the RES, battery bank is connected across it. Due to the problem associated with the chemical batteries the wind/solar hybrid combination is directly connected to the grid. There are many issues related to the interconnection of RES to the grid which are addressed with the growth in power electronics field. However the power quality issue occurs due to the presence of non-linear loads at the point of common coupling . Shunt active filter has proved to mitigate the problems associated with the non-linear loads. Researchers have limited their work to interconnection of RES to ideal grid voltages which is not the practical case. In this paper the wind/solar hybrid system is modeled and is interconnected to the unbalanced and distorted grid. Also, RES interfacing inverter is added with shunt active filter functionality and hence overall cost curtailment of the project can be achieved.

Keywords: *renewable energy; wind-solar hybrid system; grid integration; shunt active filter; power quality; unbalanced and distorted grid.*

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 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. 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.

Most of the time the grid to which RES is to be interconnected may not be ideal and at the worst case grid voltages could be both unbalanced and distorted also. These kinds of grid conditions will affect linear loads by supplying harmonics into it. Incorporation of series active filter to the system will mitigate the problems associated with the unbalanced and distorted grid. There is a need to simulate the control system under such severe practical conditions [2].

The block schematic of the system studied is shown in Fig.1. The objective of this work is to add additional responsibility of shunt active filtering to the interfacing four leg inverter, by using suitable control strategy which works well in the unbalanced and distorted voltage conditions. Inverter thus reduces THD of the source current, provides reactive power compensation and neutral current compensation at the source end.

Three cases are considered i.e., RES=0, Load demand>RES>0 and RES>Load demand. For all the cases the four leg inverter does the multitasking of interfacing real power from RES to the grid as well as shunt active filtering.

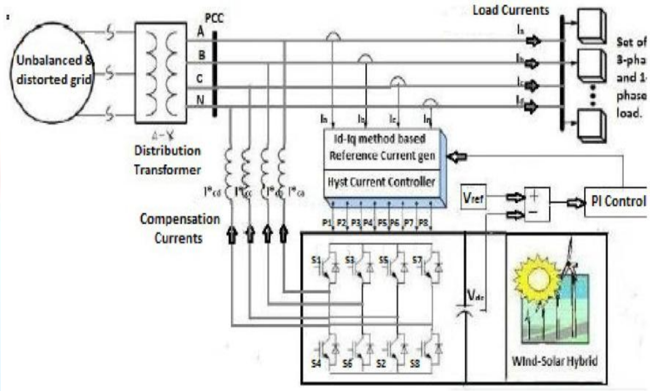

Fig.1 Schematic of proposed renewable based distributed generation system

II. Wind-Solar Hybrid System Grid Integration

The wind turbine (WT) converts wind energy to mechanical energy. The power output of a wind turbine can be expressed as shown in (1), and the aerodynamic torque is given by (2) [3-5].

$$P_W=0.5C_P\rho A v_W^3 \quad (1)$$

$$T_W = \frac{P_W}{\omega_W} \quad (2)$$

Where, PW=Wind Turbine Power (W), η=Efficiency of Turbine, ρ=Air density (kg/m3), CP=Power Co-efficient, A=Rotor area (m2), vw = Velocity of wind (m/s), w=Turbine rotor speed (rad/s).

Basic Equation of a photovoltaic cell is given by (3),[4-5].

$$I = I_{PV} - I_0\left(e^{\left(\frac{V+IR_S}{V_t a}\right)} - 1\right) - \left(\frac{V+IR_S}{R_P}\right) \quad (3)$$

Where, I_{PV}=Photovoltaic Current, I_0 = Saturation Current. V_t=Thermal Voltage of the cell, K=Boltzmann Constant, T=Temperature in K, q=Charge of electron.

DC output is produced by the PV system whereas ac output voltage is generated by WTG. For connecting these two sources to grid, different topologies are reported in the literature; however Grid-connected DC-shunted Hybrid Wind-Solar power system topology as shown in Fig. 3 is used in this work [6]. In this DC-shunted topology, the PV array output which is unregulated DC is regulated using DC-DC boost converter. In the first stage, uncontrolled rectifier rectifies wind energy system AC output voltage and then DC link voltage is controlled by DC-DC boost converter. DC-DC Boost converter is modeled as shown in Fig. 2 [5]. A PI controller based voltage feedback is designed for keeping the output DC voltage constant. PI controller is tuned by trial and error method.

The inverter with additional function of shunt active power filter is used to interconnect the PV-Wind hybrid model to the grid [6-7].

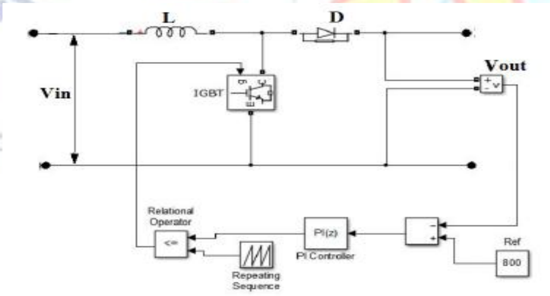

Fig: 2 DC-DC Converter

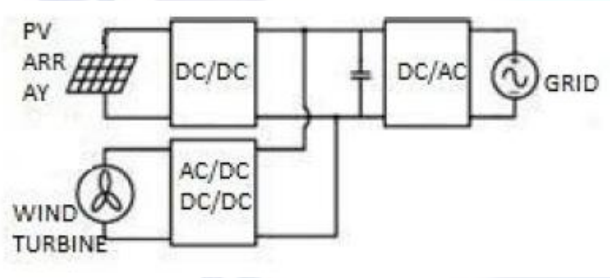

Fig: 3 Block Diagram of Hybrid Wind-Solar Energy System

III. Traditional Control Strategy of Grid Interfacing Inverter

The dc link voltage, Vdc is sensed at a regular interval and is compared with its reference counterpart Vdc*.The error signal is processed in a PI-controller. The output of the pi controller is denoted as Im. The reference current templates (Ia*,Ib*,and Ic*) are obtained by multiplying this peak value (Im) by the three-unit sine vectors (Ua , Ub and Uc) in phase with the three source voltages. These unit sine vectors are obtained from the three sensed line to neutral voltages. The reference grid neutral current (In*) is set to zero, being the instantaneous sum of balanced grid currents. Multiplication of magnitude Im with phases (Ua ,Ub, and Uc) results in the three phase reference supply currents (Ia*,Ib*,and Ic*).

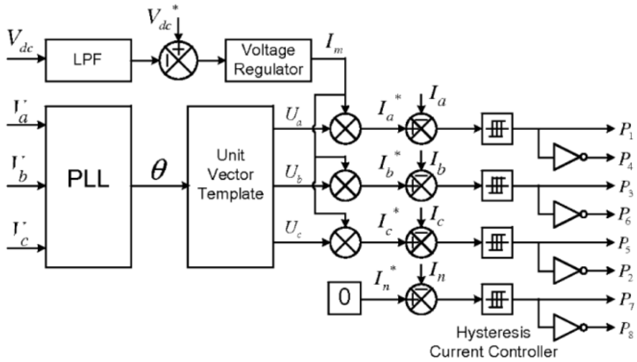

Fig.4. Traditional Control Scheme

IV. Proposed Control Strategy of Grid Interfacing Inverter

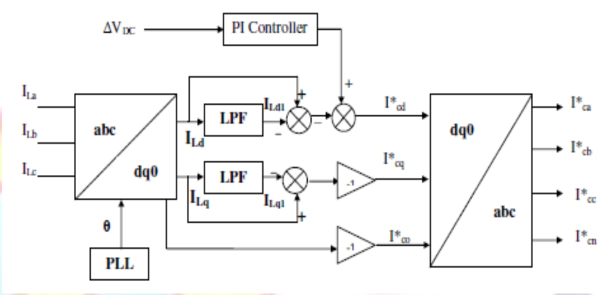

Fig 5 : Block diagram representation of grid-interfacing inverter control

The generation of reference currents needs the extraction of load current harmonics. For the extraction of harmonics several control strategies are listed till date, among them most prominent control strategies are PQ and Id-Iq methods. In this paper the latter one is used because of its simplicity and good result in distorted voltage condition [11]. Voltage at DC link should be kept constant for satisfactory performance of the system. Fig. 5 displays the Id-Iq control. In this method, DC link voltage is compared with the reference voltage, and the error (ΔVDC) is then controlled with the PI controller. PI controller is tuned by trial and error method. Proportional and integral gains are varied and observed the output of the controller. Gains are fixed when satisfactory overshoot and settling time is attained. Three phase load current is sensed and converted to d-q frame. A PLL is used for synchronizing the circuit with grid voltage. Id represents the active current whereas Iq represents the reactive current. The fundamental components of Id & Iq are calculated using low pass filters, and then harmonic components are found out. Obtained harmonic component currents are multiplied by -1 as these currents are to cancel the harmonic components in the system. The PI controller output of DC link voltage controller is added with the d axis component of current, and thus obtains the reference currents for the inverter. The calculated reference currents are transformed to abc frame and given to current controller.

Hysteresis Current Controller is used most commonly for comparing actual and reference currents and to generate switching pulses. These pulses are given to inverter switches [10].

V. Simulation Results

In this paper ideal grid supply voltage conditions are considered to represent ideal distribution level. Three phase diode bridge rectifier with RL load is considered as a three phase non-linear load and single phase diode bridge rectifier with RL load is considered as a single phase non-linear load and is connected between c phase and neutral. Wind-solar model with rated wind speed of 12 m/s and nominal solar irradiation level of 1000 W/m2 is modeled and is interconnected to the grid at the PCC. The model which is built is tested under three possible cases of RES=0, Load Demand>RES>0 and RES> Load demand. The parameters which are used to model the system are displayed in Table 1.

Case 1: RES=0

This is the case when Wind-Solar hybrid energy system is not pumping any real power into the grid. Entire real power requirement of the load is been supplied by the grid alone. Grid interfacing inverter instead of setting idle acts as shunt active filter and improves power quality of the system. Matlab/Simulink model is simulated for 1s and the results obtained are plotted as follows

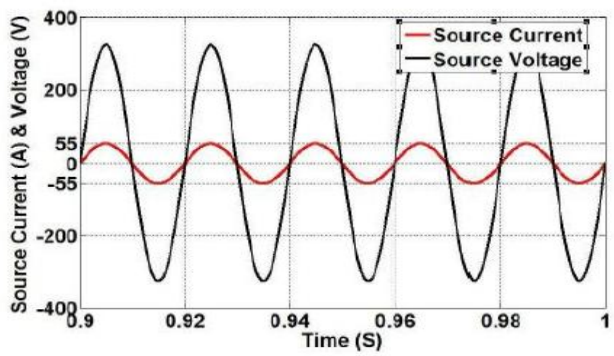

Fig.6. Source Voltage and Current

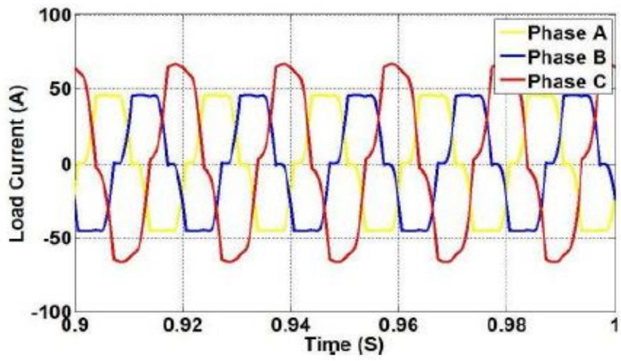

Fig.7. Load Current

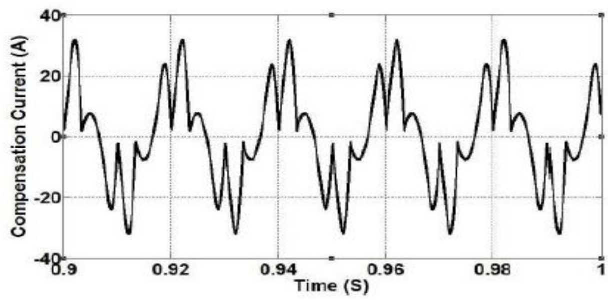

Fig.8. Compensation Current

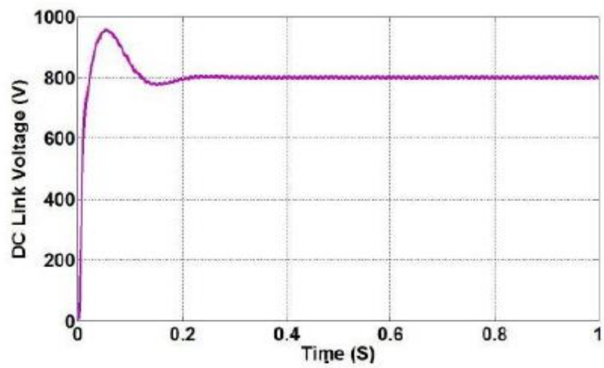

Fig.9. DC link Voltage

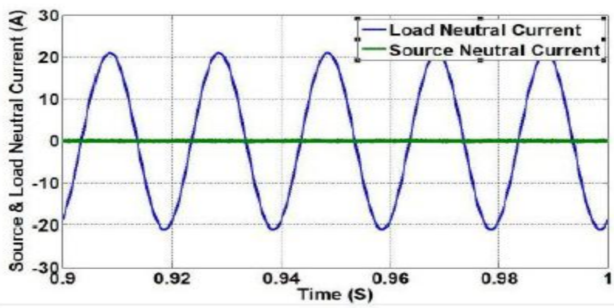

Fig.10. Load and Source Neutral Current

Fig 6 indicates that source current is sinusoidal and is in phase with the source voltage hence depicts shunt active power filter functionality of the inverter. Fig 7 shows the load currents of all the phases and it shows that it is rich in harmonics. Fig 8 depicts the compensation current synthesized by the VSI. Fig 9 shows that DC link voltage is maintained constant with the help of PI controller. Fig 10 shows that source neutral current is compensated and is made equal to zero by the fourth leg of the inverter.

Case 2: Load demand>RES>0.

In this case Wind speed is chosen as 6 m/s and solar irradiation is considered as 50 W/m2. RES start feeding real power into the system, hence part of the real power requirement of the load is been supplied by RES and rest is supported by grid. Along with harvesting real power from RES to grid four leg inverter does the job of power quality improvement as well.

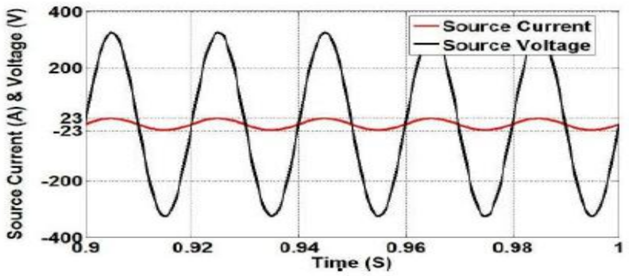

Fig.11. Source Voltage and Current.

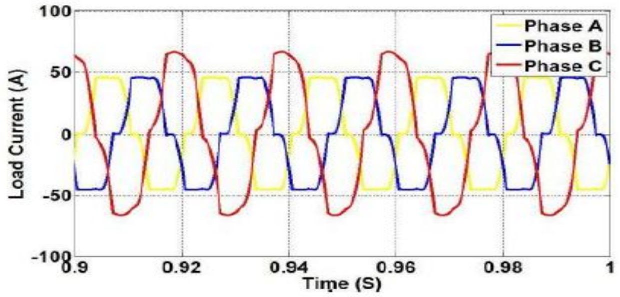

Fig.12. Compensation Current

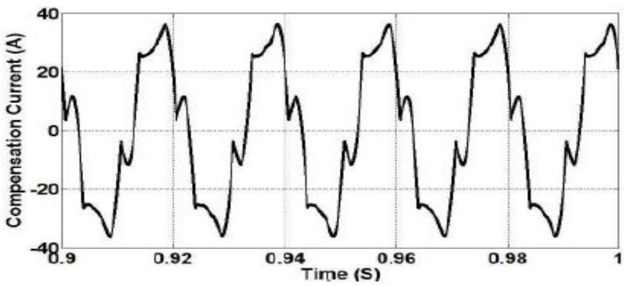

Fig.13. Compensation Current.

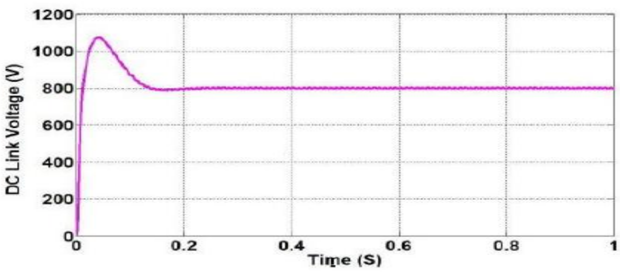

Fig.14. DC Link Voltage

Fig 11 indicates that source current is sinusoidal and is in phase with the source voltage hence depicts shunt active power filter functionality of the inverter. Magnitude of source current in this case is less than that of the earlier one demonstrating real power sharing of RES with the grid. Fig 12 shows the load current of all the phases. Fig 13 depicts the compensation current synthesized by the VSI. Fig 14 shows that DC link voltage is maintained constant with the help of PI controller.

Case 3: RES > Load demand.

In this case RES power supply exceeds that of the load requirement and excess real power is fed to the grid with unity power factor. In this case wind speed considered is 8 m/s and solar irradiation is 50 W/m2. Along with harvesting real power from RES to grid four leg inverter does the job of power quality improvement as well.

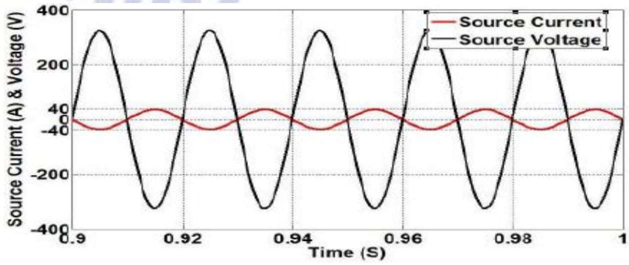

Fig.15. Source Voltage and Current

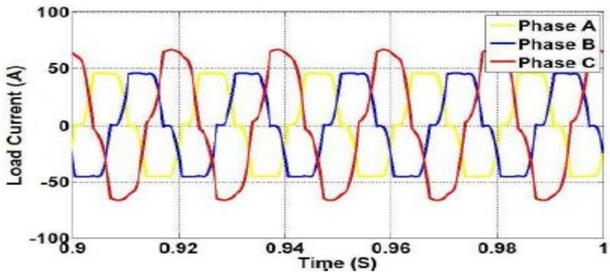

Fig.16. Load Current

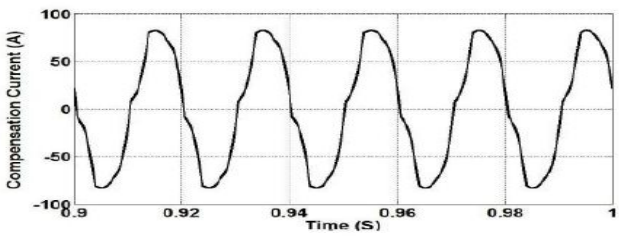

Fig.17. Compensation Current

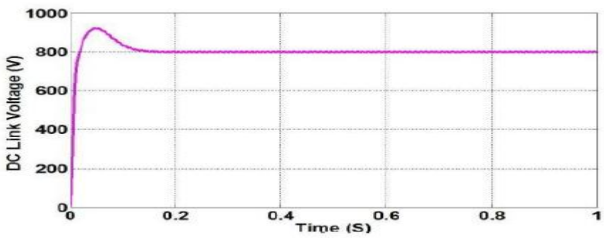

Fig.18. DC Link Voltage.

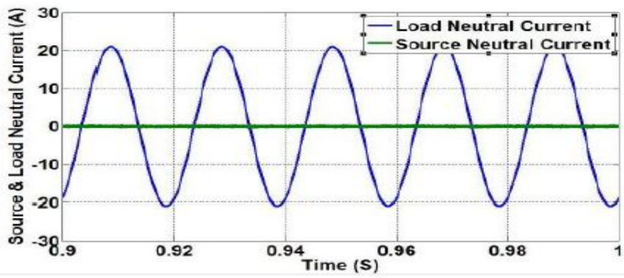

Fig.19. Load and Source Neutral Current

Fig 15 indicates that source current is sinusoidal and hence depicts shunt active power filter functionality of the inverter. Source current is out of phase with the supply voltage which indicates the flow of real power from RES to grid where grid acts as a linear resistive load. Load current is same as that of the earlier case and is shown in fig 16.

Fig 17 depicts the compensation current synthesized by the VSI. Fig 18 shows that DC link voltage is maintained constant with the help of PI controller. Fig 19 shows that source neutral current is compensated and is made equal to zero by the fourth leg of the inverter.

Table.1. Harmonic Compensation by Four leg VSI.

Cases	Source Current THD before compensation		Source Current THD after compensation
	Phase A & B	Phase C	Phase A,B & C
RES=0	15.5 %	11.03 %	1.01 %
Load Demand>RES>0	15.5 %	11.03 %	2.17 %
RES > Load Demand	15.5 %	11.03 %	1.52 %

Table.2. Reactive Power Compensation by four leg VSI.

Cases	System Power factor before compensation	System Power factor after compensation
RES=0	0.87731	1
Load Demand>RES>0	0.87731	1
RES > Load Demand	0.87731	-1

The results are displayed as shown in Table 2 and 3. It shows that for all the cases interfacing inverter acts as a shunt active filter. Obtained results indicate that source current Total Harmonic Compensation (THD) is well within IEEE 519 standards which demands source current THD to be within 5%. Reactive power Compensation is taking place and system power factor is raised to unity in all the cases. Negative power factor in the last case indicates that the real power is flowing from RES to the grid. Source neutral current is compensated with the help of fourth leg of the inverter.

VI. Conclusion

A Hybrid Wind-Solar system is modeled and simulated in MATLAB. Grid interconnection of Renewable System is done using DC-DC converter and grid interfacing inverter. Inverter is controlled in such a way that it act as a grid interfacing unit as well as a shunt active filter. Non linear loads are connected at point of common coupling. Various Renewable Energy generation conditions with unbalanced and distorted grid conditions are simulated and found that system works well for different conditions. Thus grid interfacing inverter with additional functionality of shunt active power filter can be utilized in distribution systems for cost effective distributed generation with power quality improvement features.

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