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# Grid Interconnection of Renewable Energy Sources with Power-Quality Improvement

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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 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.

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

## 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 [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.

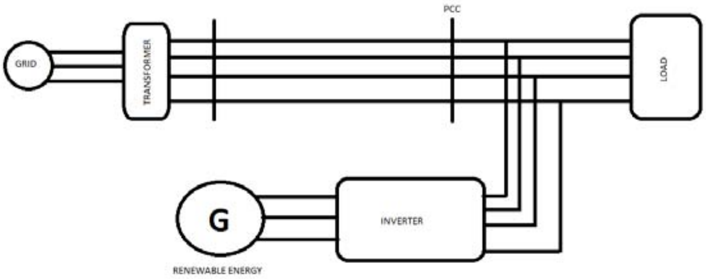


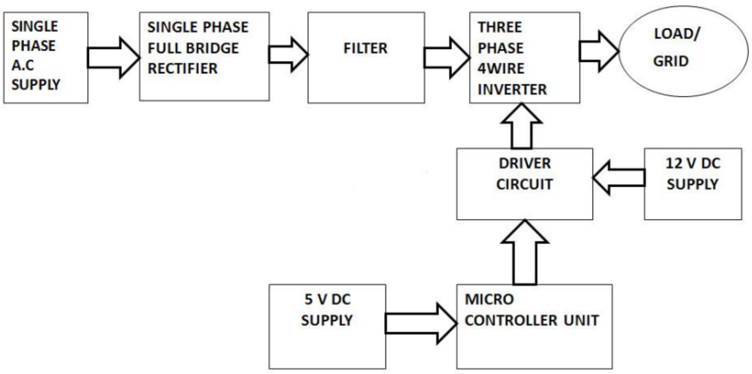

**Fig.1:** Schematic diagram of renewable energy distributed system

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. Extensive experimental results are discussed in Section IV and, finally, Section V 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 Fig. 1. 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. The dc-capacitor decouples the RES from grid and also allows independent control of converters on either side of dc-link.

### A. BLOCK DIAGRAM




### *B. WORKING*

In the above block diagram, the single phase A.C. supply is the supply from the "wind mill" which is a renewable source of power generation. This A.C. power output of the windmill is fed to the Single phase full bridge rectifier circuit. The output of the rectifier is the D.C. source. The filter circuit is used to remove the ripples from the circuit. Now, the D.C. supply is converted into 3-ɸ A.C using the grid interfacing inverter to take load connected to the grid. As the inverter is made up of MOSFET, we have to drive the MOSFET at a particular time,the Microcontroller satisfies this condition. The microcontroller needs a 5V VCC supply; it is given through a battery. The output of the microcontroller is 5V. But to drive a MOSFET we require 10V supply. Thus, a driver circuit is a pulse amplifier which amplifies 5V from microcontroller to 10V

## C. DESIGN CALCULATION

### a. FILTER DESIGN

r = 1% = 0.01
f = 50Hz
R = 10Ω
r = 1/ 4√3 fCR
0.01= 1/4√3*50*C*10
C= 0.02886µF

### b. INVERTER DESIGN

*i. 1-Φ INVERTER DESIGN*

$f_0$ = 50Hz
T = 1/ $f_0$
T = 1/50= 0.02secs= 20ms
Pulse width (PW) = T/2 = 10ms

*ii. 3-Φ INVERTER DESIGN*

*1. 120 MODE*

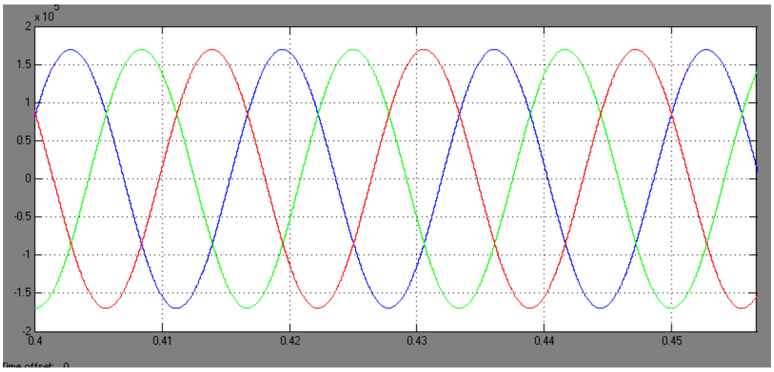
$f_0$= 50Hz
T= 1/ $f_0$
T= 1/50= 0.02secs= 20ms
Pulse period(x) = 120*20/ 360
= 6.66ms

2. *180 MODE*

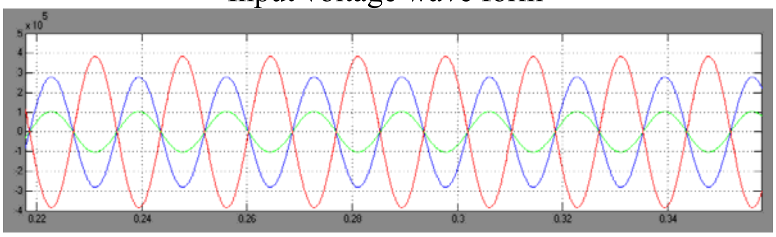
$f_0$= 50Hz
T= 1/ $f_0$
T= 1/50= 0.02secs= 20ms
Pulse period(x) = 180*20/ 360
= 10ms

## III. SIMULATION RESULTS

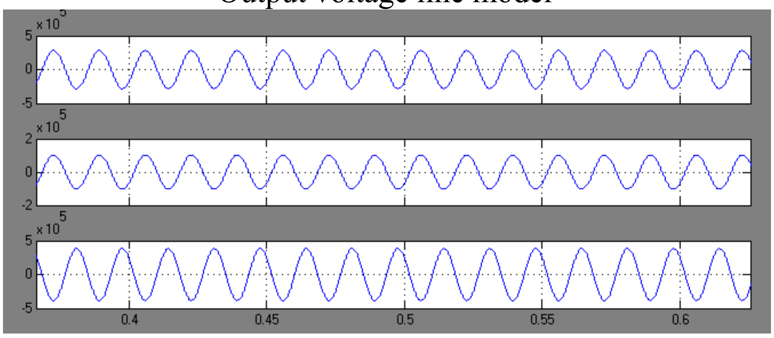
In order to verify the proposed control approach to achieve multi-objectives for grid interfaced DG systems connected to a 3-phase 4-wire network, an extensive simulation study is carried out using MATLAB/Simulink. A 4-leg current controlled voltage source inverter is actively controlled to achieve balanced 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( $I_l$a,$I_{lb}$,$I_{lc}$,$I_{ln}$) and inverter currents are shown in Fig. 4. The corresponding active-reactive powers of grid ($P_{grid}$, Qgrid),load ($P_{load}$, Qload) and inverter ($P_{inv}$, Qinv) are shown in Fig. 5. 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.



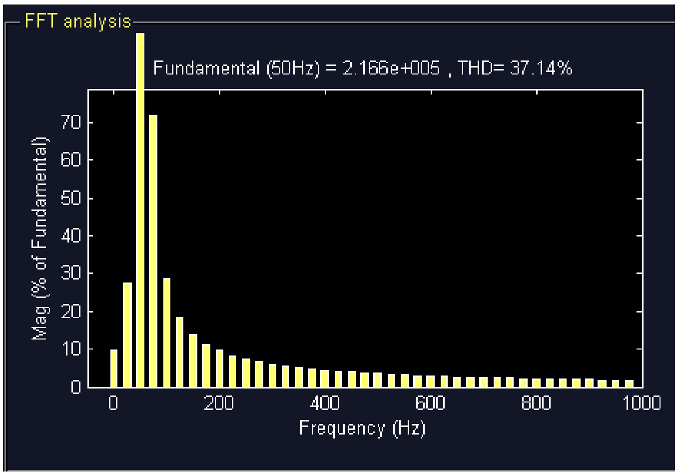

Input voltage wave form



Output voltage line model



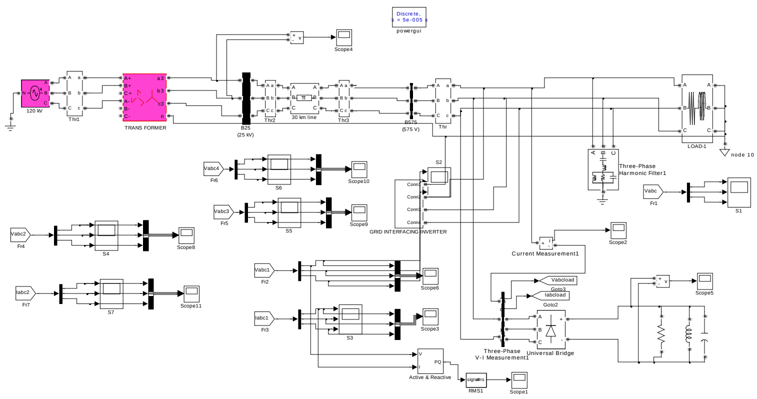

Output voltage of line model



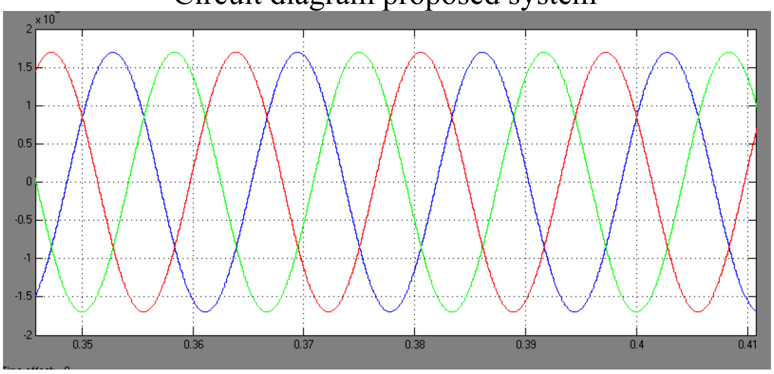

THD for line model

## IV. DRAWBACKS OF CONVENTIONAL CIRCUIT

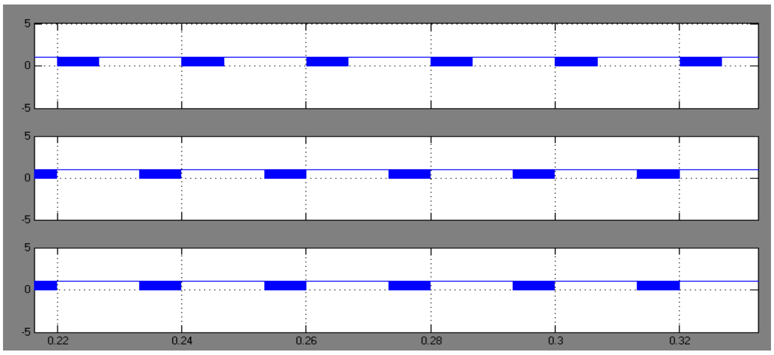
- More harmonics
- Less input power factor
- No shoot through capability
- Less reliability



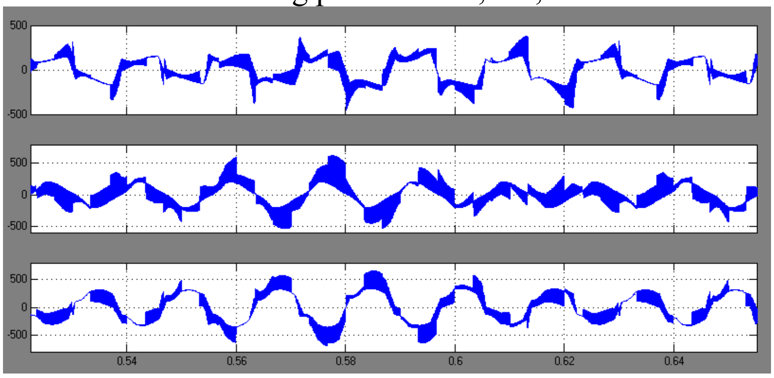
Circuit diagram proposed system



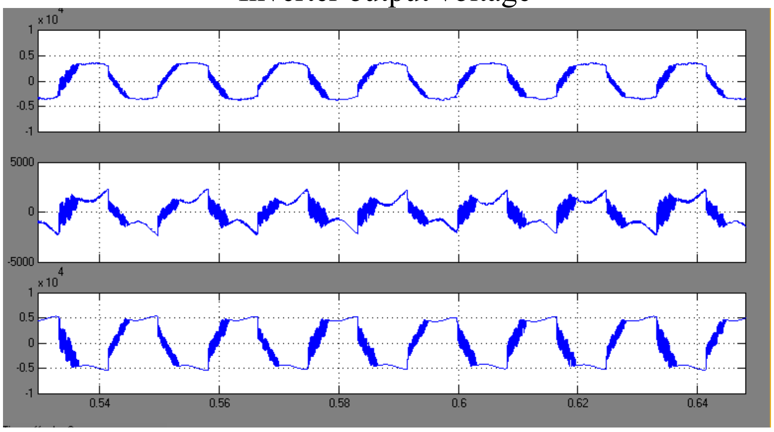

Input voltage wave form



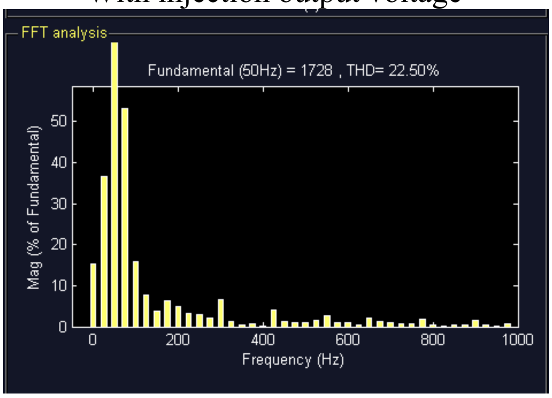
Switching pulse for m1, m2, m3



Inverter output voltage



With injection output voltage




THD for with compensation

## V. ADVANTAGES OF PROPOSED CIRCUIT

- Improve the input power factor
- Less harmonics.
- Fast response.
- High reliability due to shoot through capability.
- Better voltage and frequency control

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