Design of Hybrid Grid-Connected Inverter for Renewable Energy Generation with Power Quality Conditioning

Amir Mushtaq Palla, Nipun Aggarwal

Abstract :- ***This research paper presents a new model of hybrid grid connected inverter (HGCI) which replaces the use of capacitive-coupled grid connected inverter (CGCI) and inductive-coupled grid connected inverter (IGCI). As CGCI have narrow operation range and IGCI needs more PV panels thus HGCI overcomes the limitations of both inverters by providing wide operation range and less PV panels are required. The proposed model has a three-phase full-bridge DC/AC electrical converter with a thyristors-controlled LC (TCLC) filter to transfer active power and performs reactive power compensation and also harmonic compensation. At the end results, parameter design and performance of HGCI have been verified by MATLAB/Simulink.***

Index Terms :- active power, dc-link voltage, HGCI, PV, reactive power

I. INTRODUCTION

Around the world there's a growing attention in renewable energy. New ways are developed for management and better operation of electricity grid to increase the range of the renewable energy sources and maximize the benefit of distributed generators which improves reliableness and quality. The alternative energy is commonest renewable energy as an example the global solar power capability is foreseen to achieve 613 GW in 2020. To utilize solar renewable energy for contemporary grids intensive analysis is completed on the way to enhance the structure style and management ways of electrical phenomenon DC/AC inverters. The analysis work is regarding HGCI a replacement sort of DC/AC electrical converter for electrical phenomenon power generation with power quality acquisition that consists of a three-phase full-bridge DC/AC inverter coupling with facility grid nonparallel with the thyristor-controlled LC filter.

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On comparing the projected HGCI with the traditional capacitive-coupled grid-connected inverter (CGCI inductive-coupled grid-connected inverter (IGCI) the HGCI has unique features such as low DC-link voltage and reduced operational cost. Moreover, it transfers active power and compensates the unbalanced power, harmonic power and reactive power at simultaneously.
Hybrid energy system is the combination of typical and renewable energy sources such as solar, wind and hydro which provides sustainable and eco-friendly energy. These hybrid systems can be in standalone or grid connected. The grid connected hybrid system is very much reliable source as it delivers continuous power to the grid thus if there's any fault or power shortage then the masses are connected directly to the grid. Since the wind and daylight aren't constant so various controllers and tracking methods are employed such as FACTS, MPPT, STATCOM, UPFC, IPFC, SVC etc. Controllers and tracking methods are used for reliability, maximising power transfer and enhancing controllability and stability of the system while as MPPT (maximum power point tracking) is used by PV solar systems and wind turbines to maximize its power transfer. There is a growing interest and shift in Renewable energy round the world. New methods and designs are employed for better operation of electricity grid by which renewable energy sources are fully used so that quality of power system gets improved.

1.1 *On-Grid, Off-Grid and Hybrid Systems*

PV system can be connected in three modes which are ON-Grid, OFF-Grid and Hybrid-Grid discussed as under:

A. *On Grid System*

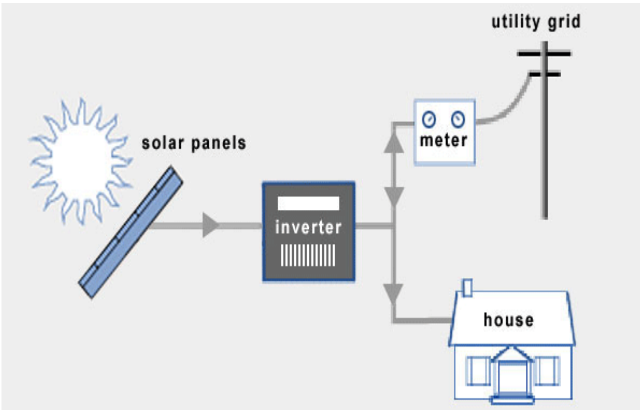

Fig. 1. ON-Grid system

On-grid solar system also known as utility-interactive, grid backfeeding, grid intertie or grid tied system. It saves more money by using net metering as homeowners can send the surplus energy to utility grid instead, they store the energy in batteries thus utility grid acts as a virtual battery.

Equipment's needed are: -

Micro inverter

Power meter

B. Off-Grid System

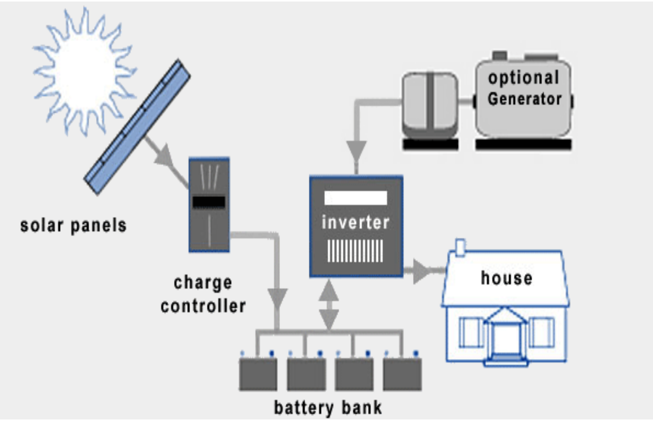

Fig. 2. OFF-Grid system

Off-grid needs battery bank and a backup generator which are expensive thus overall efficiency of off-grid gets decreased.

Equipment's needed are: -

Battery storage

Generator

Inverter

Solar charge controller

C. Hybrid Grid System

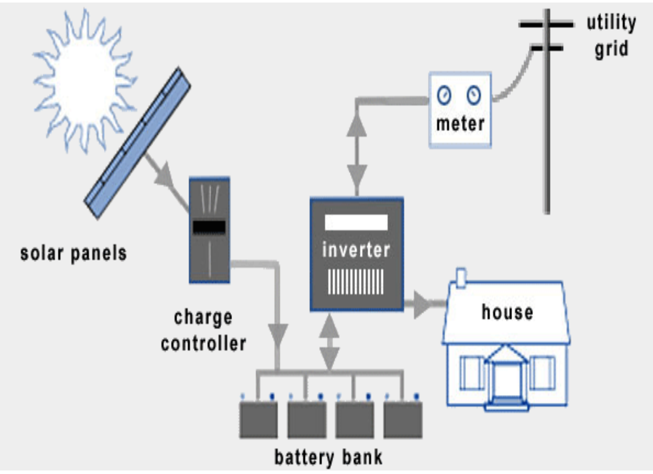

Fig. 3. Hybrid Grid system

It combines the advantages of both grids into single grid. It is cheaper than off-grid system as it needs less equipment than off-grid. OFF-grid systems are not affected by the power failures and faults on the utility grid

Equipment's needed are: -

Battery based grid tie inverter

charge controller

power meter

Battery bank

1.2 *Issues In Grid Connected Power System*

Due to intermittent and the random nature of renewable resources we face the difficulty of its integration with grid. Following are some issues discussed.[9]

1. Problems with power quality

As we integrate the distributed generator to the grid with the help of electronic converter, harmonics gets injected into system. Harmonics is injected because of the switching mechanism of the power switches due to which customer gets poor quality of power. For this problem, filters and soft switching are used.

2. Reverse power flow

It effects the operation of protection circuits.

3. Storage

During daytime we gets ample of energy generation from PV so battery banks are needed to store at daytime and to be used later.

4. Islanding

In this case distributed generators continuously supply the load but electrical grid is disconnected which leads to abnormal voltages and abnormal frequencies. A common example is Chernobyl disaster which was a failed islanding test.

To control this, anti-islanding technique has been developed which uses under-frequency relay, over-frequency relay, under-voltage relay and over-voltage relay.

5. Protection issues

Due to revers power flow and lack of sustained fault current the protection of network is complex.

II. PROBLEM DEFINITION

As it is matter of fact that PV energy generation cannot be obtained throughout year and also at night due to varying nature of sun in different seasons and non-availability of sunlight in night. Also, we get little sunlight during rainy season and cloudy days so connected grid gets only active power from PV arrays Which is non-economical and non-efficient mechanism. Thus, we need to develop such a mechanism or design a PV generation system so that besides providing active power it should provide reactive power compensation, unbalanced power compensation as well as current harmonic compensation. Thus, this paper designs an inverter by the name HGCI (hybrid grid-connected inverter) which can fulfil these demands. On comparing the projected HGCI with the traditional capacitive-coupled grid-connected inverter (CGCI) and inductive-coupled grid-connected inverter (IGCI) the HGCI has unique features of wide operational range and low DC-link voltage. Due to these peculiar features of HGCI, system cost and operational cost can be reduced.

III. METHODOLOGY

This work can adopt a research methodology that mixes the idea model with empirical analysis and refinement of the planned theme on MATLAB simulation tool. MATLAB could be helpful high-level development surroundings for systems that need mathematical modeling, numerical computations, information analysis, and improvement ways.

The following figure shows the basic circuit diagram of projected HGCI with following elaborated symbols used in analysis.
V_S (V_{Sa} , V_{Sb} , V_{Sc}) = supply voltages
I_S (I_{Sa}, I_{Sb}, I_{Sc}) = supply currents
I_L (I_{La}, I_{Lb}, I_{Lc}) = load currents
I_L (I_{Ca}, I_{Cb}, I_{Cc}) = Injecting currents
L_S = electrical resistance of cable
L_C = coupling inductance
C_{PF} = parallel electrical condenser
L_{PF} = thyristors-controlled reactor
V_{invxf} = inverter voltage
V_{sxf} = source voltage
P_{cxf} = active power that the grid absorbs or injects
Q_{cxf} = reactive power that the grid absorbs or injects
S_{baseH} = base power of HGCI
X_{TCLC} = impedance of thyristor-controlled LC filter

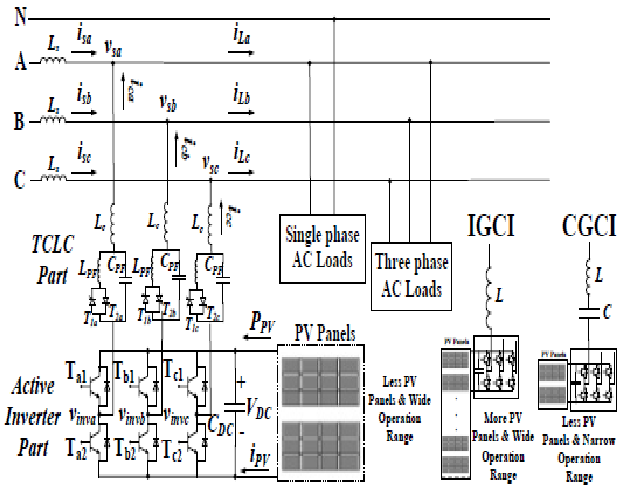

Fig. 4. The structure of proposed HGCI, traditional IGCI and CGCI for PV energy generation

The HGCI consists of a TCLC, Converter, PV panels, Loads, Inductors and Capacitors. The TCLC consists of a coupling inductance (Lc) a parallel electrical condenser (C_{PF}) and a thyristors-controlled reactor (L_{PF}). The TCLC half provides a large and continuous inductive and electrical phenomenon reactive power compensation by varying the firing angles of the thyristors. The active electrical converter consists of a DC/AC voltage supply inverter (VSI) with a DC-link electrical condenser and a DC-link voltage (V_{DC}) employed for injection of active power, compensation of harmonics and to improve the TCLC performance.
we can calculate the ratio of V_{invxf} /V_{sxf} in terms of P_{cxf} and Q_{cxf} by using the equation (1)

$$\frac{V_{invxf}}{V_{sxf}} = \sqrt{\frac{P_{cxf}^4 + P_{cxf}^2 Q_{cxf}^2}{\left(P_{cxf}^2 + Q_{cxf}^2\right)^2}} \qquad (1)$$

To study the behavior of CGCI, IGCI and HGCI in MATLAB a graph has been plotted based on equation (1)

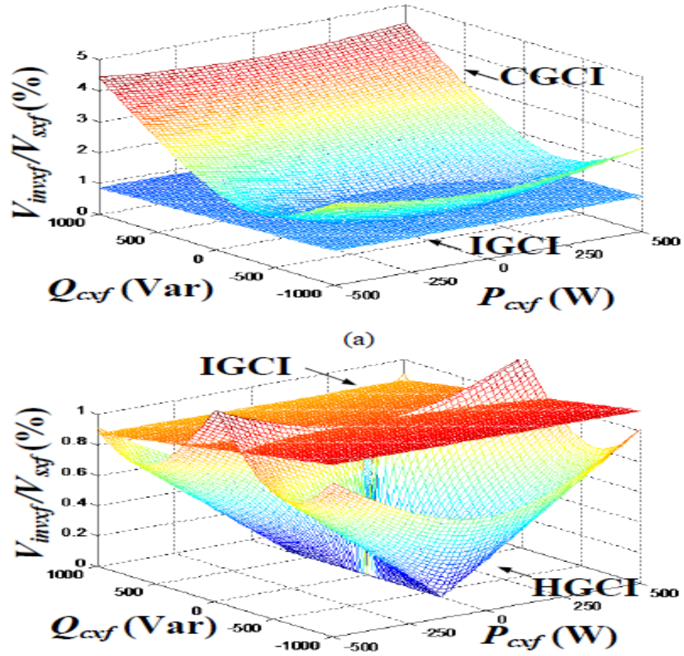

Fig. 5. ratio of V_{invxf} /V_{sxf} w.r.t. P_{cxf} and Q_{cxf} for (a) CGCI and IGCI (b) Proposed HGCI and IGCI

For IGCI

$\frac{V_{invxf}}{V_{sxf}} > 1$ means load is inductive

$\frac{V_{invxf}}{V_{sxf}} < 1$ means load is capacitive

Generally, load remains close to unity because coupling inductor has small value.

For CGCI

$\frac{V_{invxf}}{V_{sxf}} < 1$ for small reactive power

$\frac{V_{invxf}}{V_{sxf}} > 1$ for large values of reactive power

For Projected HGCI

If S_{baseH} remains within limits i.e. it belongs to [$\frac{V_{sxf}^2}{X_{TCLC}}$ at angle 180°, $\frac{V_{sxf}^2}{X_{TCLC}}$ at angle 90°] $\frac{V_{invxf}}{V_{sxf}}$ remains lesser or equal to one .

$$\frac{V_{invxf}}{V_{sxf}} = \sqrt{\frac{P_{cxf}^2}{S_{baseH}} + \left(\frac{Q_{cxf}}{S_{baseh}} - 1\right)^2}$$
$$= \sqrt{\frac{P_{cxf}^4 + P_{cxf}^2 Q_{cxf}^2}{\left(P_{cxf}^2 + Q_{cxf}^2\right)^2}} \leq 1 \quad (2)$$

The main role of HGCI is to inject Pcxf and compensate Qcxf at the fundamental frequency to the power grid during daytime. At night HGCI mechanism provides Qcxf compensation due to which PV generation system becomes more cost-effective. Also, another feature of HGCI is that V_{invxf} /V_{sxf} can be made zero when HGCI provides *Qcxf* compensation shown in equation (3)

$$\frac{V_{invxf}}{V_{sxf}} = \lim_{P_{cxf}\to 0} \sqrt{\frac{P_{cxf}^4 + P_{cxf}^2 Q_{cxf}^2}{\left(P_{cxf}^2 + Q_{cxf}^2\right)^2}} = 0 \qquad (3)$$

As compared to IGCI and CGCI, HGCI needs the low rated inverter voltage $Vinvf$ to inject $Pcxf$ to the power grid during daytime and compensate $Qcxf$ during daytime as well as nighttime.

Table- I: Comparision Between The Proposed HGCI, CGCI And IGCI

Model	PV panels needed	Operation range
IGCI	More	wide
CGCI	Less	narrow
HGCI	Less	wide

IV. RESULTS AND ANALYSIS

Traditionally used Grid-connected inverters were not so efficient to get satisfied power quality mechanism. Conventionally used inverters are IGCI and CGCI which cannot provide economical and smart mechanism for PV generation due to their limitations. As far as IGCI is concerned, it needs large number of PV panels for its functioning whereas CGCI can operate only within a narrow range. Thus modified and smart mechanism i.e. HGCI have been designed to overcome the issue of operation range of CGCI the issue of more capital needed by IGCI due to more PV panels. HGCI takes both limitations or issues in consideration thus provides quite smart and efficient mechanism by reducing the number of PV panels and expanding the operation range. Besides injecting active power, HGCI also compensates the unbalanced, reactive and harmonic power. HGCI can be used with MPPT to maximize the output usable power.

The results are very important for research and development work to prove the problem definition practically. The results obtained are described below:

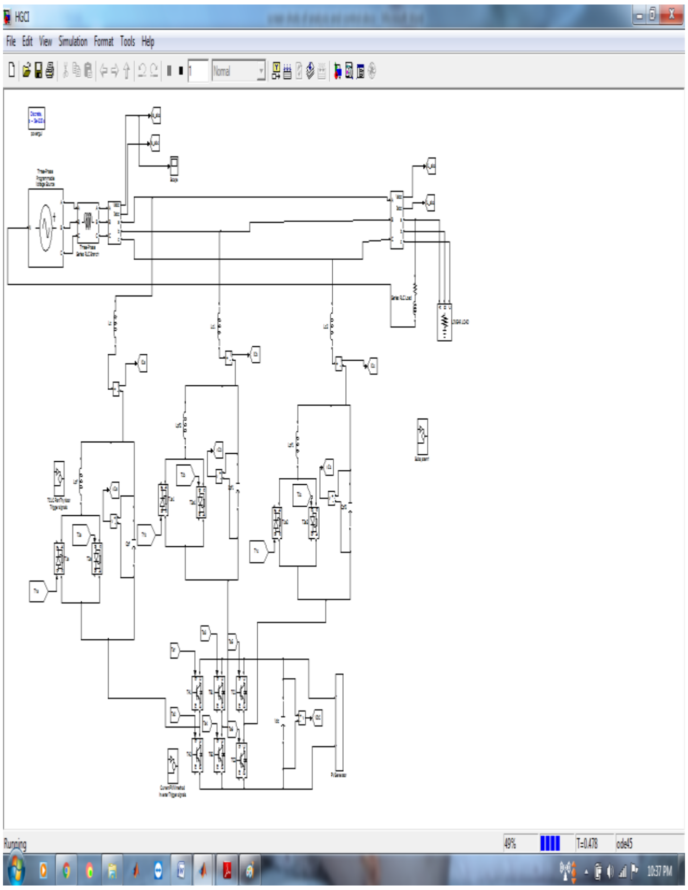

Fig. 6. HGCI model

balanced linear loading compensation of HGCI operation with simulation results

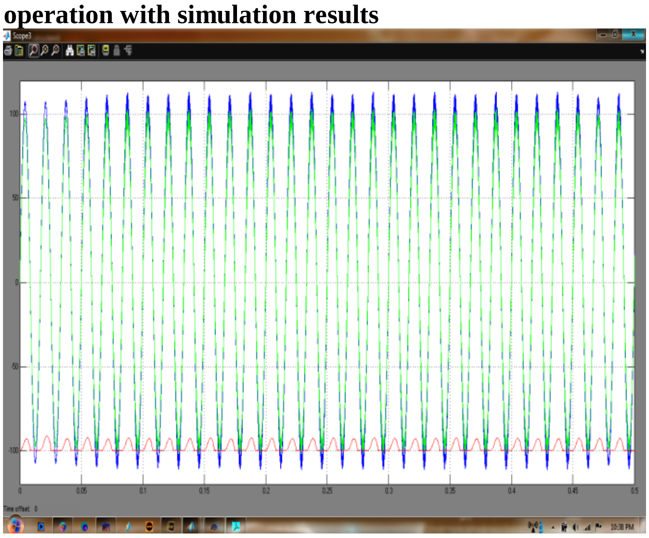

Fig. 7. Voltage Current and Vdc

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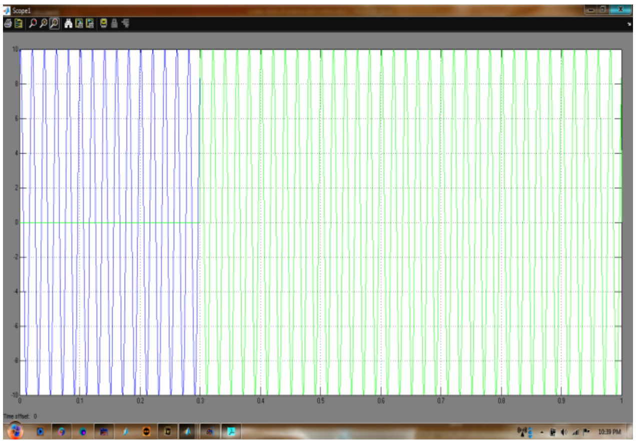

Fig. 8. I_{Ca}*, $I_{C}a$

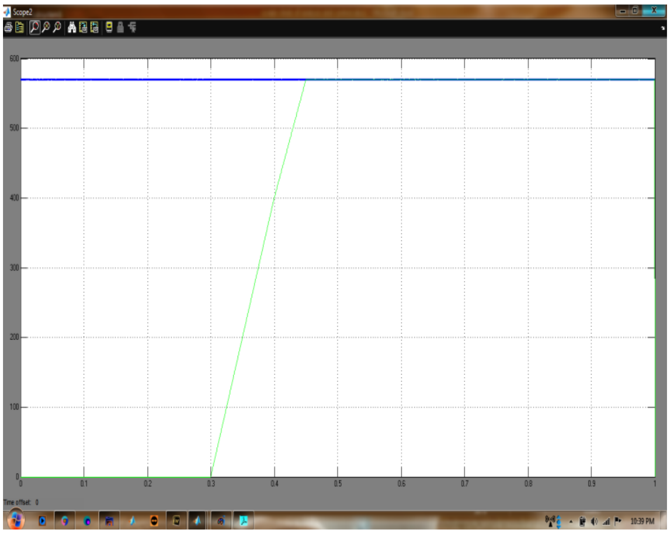

Fig. 9. Reactive Power

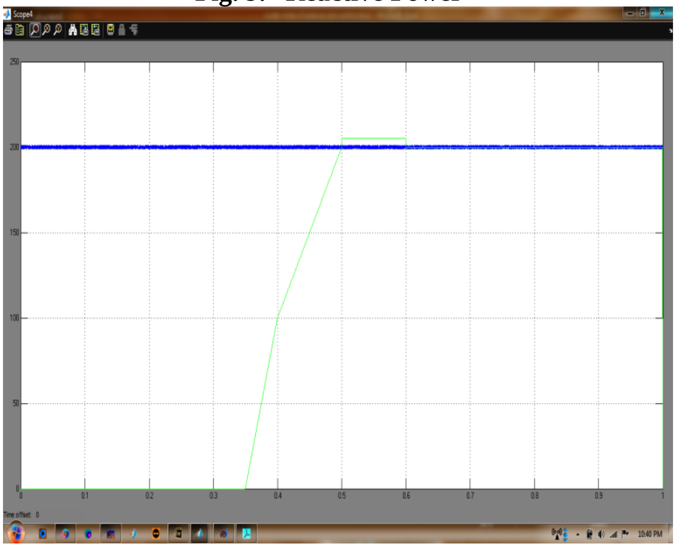

Fig. 10. Active power

HGCI with MPPT mechanism and their Simulated waveforms

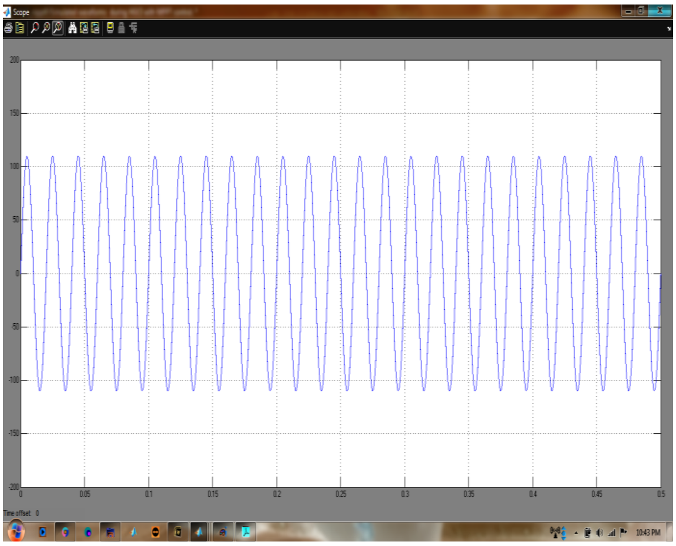

Fig. 11. Load Voltage

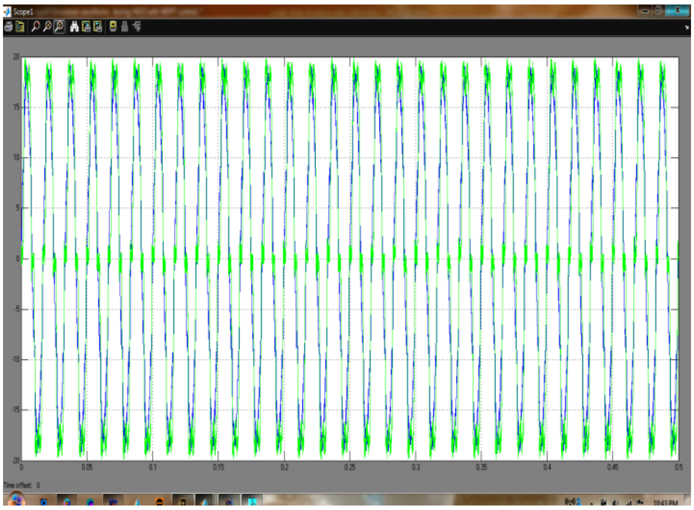

Fig. 12. Load and Source Current

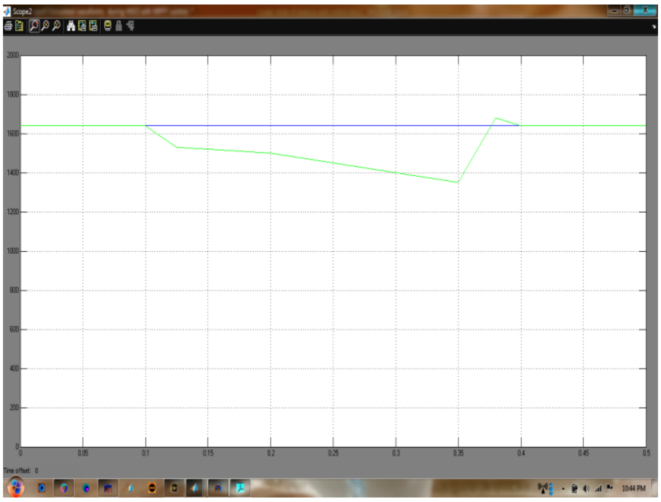

Fig. 13. Load and Injected Reactive Power

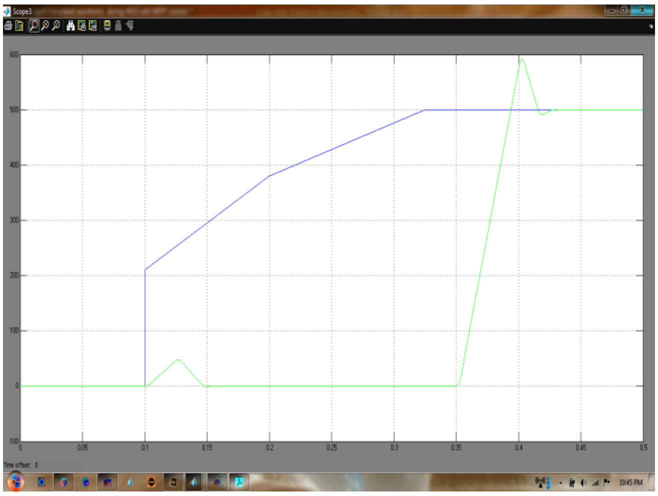

Fig. 14. Active Power

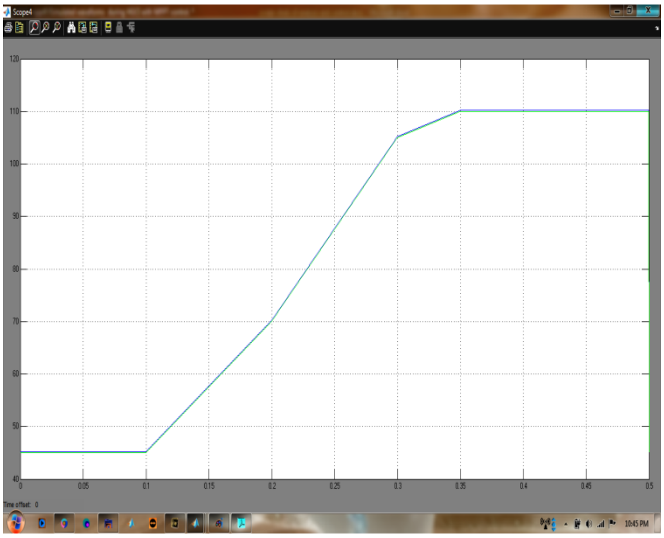

Fig. 15. PV and DC-link Voltage

balanced non-linear loading compensation with simulation results of active power, reactive power and simulated waveforms of current, voltage

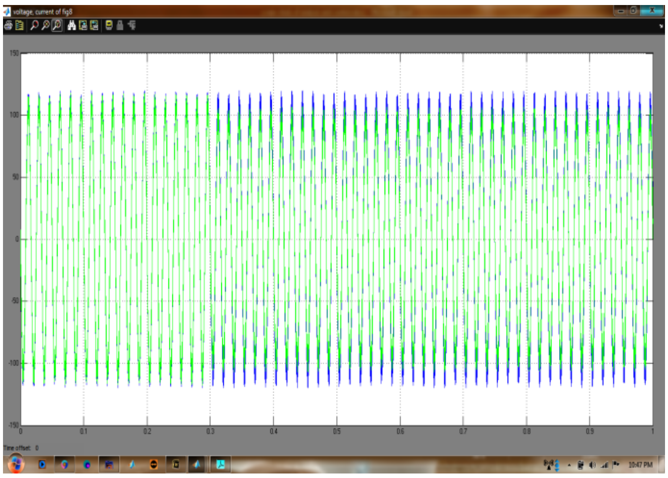

Fig. 16. Current, Voltage

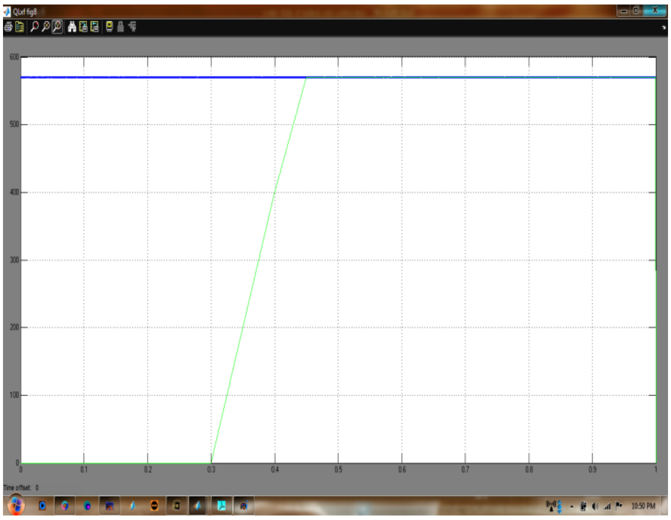

Fig. 17. Reactive Power

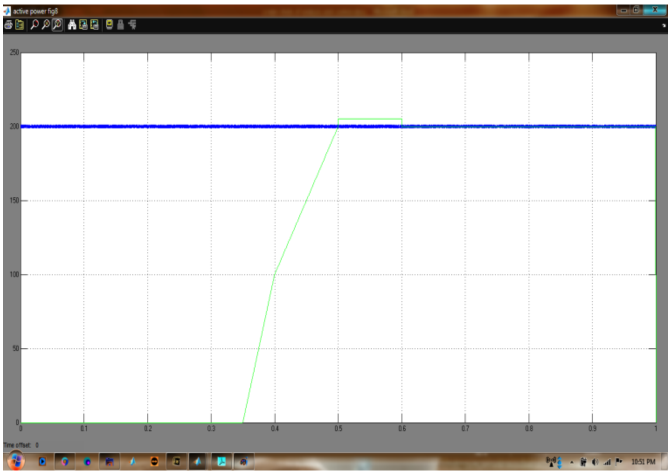

Fig. 18. Active Power

V. CONCLUSION

The paper presents the detailed report by which the parameter designs and structure of HGCI has been analyzed. A new type DC/AC inverter HGCI for PV power generation with power quality conditioning has been proposed and its control methods are studied. HGCI reduces the operation costs as it has wide operation range and needs low DC-link voltage as verified by MATLAB/Simulink.

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