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Performance and Analysis of Grid Connected Renewable Energy Based Distributed Generation System

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Abstract: World is leading towards the modernization & day-to-day lifestyle requires energy sources. Increasing population needs extra energy to be produced, but the limited amount of resources like coal, petroleum, natural gas etc., interrupts the flow of energy being supplied. The alternate ways to satisfy this demand and the best for practices against the risk of climatic changes are renewable sources. Solar energy is the most effectual and the clean source of energy used in distributed generation's unit which is seen to be as a local and micro capacity energy generating units. These are placed at distribution part of the power system. Non-renewable sources along with the renewable resources can be an imperishable method for yielding power, and as the development and the research becoming successfully implemented to the ground we are set to go for totally renewable based energy. Hybrid systems are also at next level in producing power, this has the advantage that each could stand inspite of other in the grid tied state when one of them is not in a state of producing enough power which is being demanded by the load. This paperwork has briefly discussed about the two stages, three phase inverter interfacing Solar PV DG system and Grid. DC-DC boost converter has an edge of operating at maximum power point to harness enhanced output voltage. Maximum power is being extracted by enacting perturbation & observation algorithm to provide a controlled Duty Cycle to the boost converter. The DC-AC power converter is controlled by dq conversion, Proportional-Integral, Phase Locked Loop controller and Single Pulse Width Modulation technique employed. LCL filter enhance power quality which is measured by THD analysis in MATLAB/SIMULINK

Keywords: Renewable Energy, Distributed Generation, DC-DC Converter, MPPT, Filter, THD

I.INTRODUCTION

Under current situation, world is facing energy crises because conventional sources of energy are not enough to complete human greed's. The global CO2 emission outstretch at its all-time peak in 2021, and energy market were already showing signs of concerns. Simultaneously investment in clean energy will help us to gain carbon-neutrality. The most advantageous way to conserve the energy is start using sustainable energy sources like wind, solar, tidal, biomass etc. out of which solar energy is the most universally available and free of cost since prehistoric times. The use of renewable energy resources for power generation process contributing a vital role to the environment and cost of generation. It is the term used when electricity is produced from the sources which are being harvested from renewable resources near the point of use rather than rationalized generation sources from power plant. There are various renewable energy resources available in the system which is used to generate electricity and this concept is known as Distributed Generation system. Distributed generation gaining popularity due to many reasons. The first and foremost reason is increase of worries about the climatic changes and global warming. One more reason is increase in demand of consumption of energy in the world and the terminating reason is that fossil fuel is estimated to reach to the end in near future & this further leads to replacement of conventional system. The advantage of connecting DG systems to grid is to fishout safe energy and mitigate the problem of environmental changes like CO2 emission because of fossil fuel. It has been observed that DG sources in the network provides a low power loss and improve voltage profile. A huge reactive power demand during the peak load time at the distribution side and line reactance are the vital factors which is responsible for increasing the local area voltages all way up to the definite limits. Due to variations in load during peak and off-peak load time, voltage fluctuations are commonly happening which leads to distortion of the quality of power and damages the critical loads This can be avoided by having an inverter in a DGS supply where the load reactive power demand is greater than supply. Previously most inverters used in Distributed Generation system transmits true power control loop and only transmits true power to the grid. But it will be more fruitful if connected inverter are able to provide reactive power hence, grid voltage doesn't fluctuate below the nominal value. Reactive power has the major impact on the voltage so, it is a quite

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influencing parameter. As the reactive power compensation is controllable the system becomes sustainable. Capacitors have the properties over-voltages. For this reason, a power converter connected to the grid should be designed for the flow of reactive power when required in DGS system. There are different technologies of renewable resources, and they have their own advantages and disadvantages. Among them solar energy is the most popular not because it is free of cost, but it has many advantages such as low carbon emission and due to static nature, it has least maintenance [1], During off peak load time situation of light load, the capacitor will contribute to the increase of voltage. In case of short circuit, capacitors can be hazardous because they come up with a situation of over-voltages. For this reason, a power converter connected to the grid should be designed for the flow of reactive power when required in DGS system. There are different technologies of renewable resources, and they have their own advantages and disadvantages. Solar energy can be avail in two ways, as Solar thermal, and Solar electricity (solar PV). The PV works on the technology that it converts sun's heat to produce electricity. The output of the PV cells relies on temperature and illumination intensity of sunlight. As the solar irradiation and temperature changes throughout the day, voltage and current characteristics vary accordingly. So, to achieve maximum power from the panel it is necessary to optimize voltage and current value is to set to get the maximum power at the output. The aid of getting maximum power at the output of solar PV is called as Maximum Power Point Tracking (MPPT).

Table I. Indian Installed Generation Capacity as on 30/05/22 according to Central Electricity Authority

Category	*Installed Generation Capacity (MW)*	*% Of share in total*
FOSSIL FUEL		
Coal	2,04,080	50.7%
Lignite	6,620	1.6%
Gas	24,879	6.2%
Diesel	510	0.1%
Total Fossil Fuel	2,36,088	58.6%
NON-FOSSIL FUEL		
Hydro	46,723	11.6%
Wind	1,13,226	28.1%
Solar	56,951	10.1%
Waste to Energy	477	0.1%
Small Hydro Power	4,886	1.2%
Nuclear	6,780	1.7%
Total Non- Fossil Fuel	1,66,729	41.4%
Total Installed Capacity	4,02,817	100%

II.GRID CONNECTED DG SYSTEM

With increase in the consumption of fossil fuel, rapid decaying of their reserves has been seen and various initiatives has been taken by the government for improving the air quality which led to increase the generation of renewable energy resources [2]. The PV system provides us direct current energy which is not suitable for transferring the power to the grid.

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So, a suitable conversion of power is required and for that three-phase grid connected inverter plays a key role [3]. Harvested energy from the renewable energy resources is usually transmitted towards the grid with the limitations of the effiency, cost of the storage system. Energy from the DC-link on the road to grid is normally transferred by means of power converters. DC to AC converters is usually used for the particular purpose, and a single phase or three phase is achieved from DC source. Three phase inverter allows to control the amplitude, phase, and frequency of the harvested voltage. There are various applications in which inverters used as the current and voltage source inverter like wind and solar power generator, active filters, FACTS, DVR. In many industrial applications the most common converter used for DC to AC conversion is Voltage Source Converter (VSC) [4]. According to power quality norms & grid synchronization (std 1547, 2005 and 2015) grid tied inverters are designed. And by considering these standards Total Harmonic Distortion for grid must be less than 5%. Various literature proposed different modulation and control strategies for three phase grid tied system. The one of the important requirements of grid tied inverters is synchronization of grid current with grid voltage which is being performed by Phase-Locked Loop (PLL) algorithm so, can get information about phase angle which is further used for transformation of voltage and current for dq reference frame [5]. Distributed generation systems are breaking down into two categories freestanding, and grid tied system. In case of freestanding systems, battery storage is used to facilitates us with the storage of energy harvested from these irregular sources. To couple a DG (Distributed generation) system to the grid, there are some of standards that are proposed by IEEE, IEC, NEC and EN to ensure safe interconnection and system operation and to assert the power quality of the utility grid. First, the most pertinent standards that are existing and then the control structure of the inverter which incorporates grid synchronization, control loops & PWM generation, and filters out those that are not used for a grid connected PV system are considered.

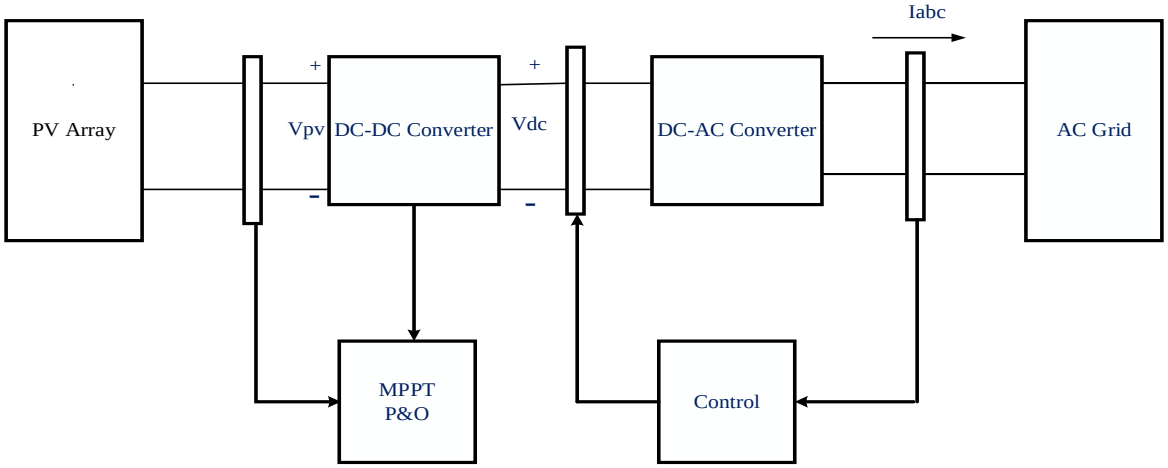
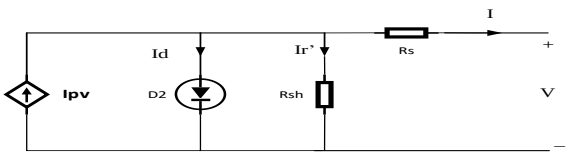


Fig 1: Grid Connected Distributed Generation System

- **PHOTOVOLTIC SYSTEM**

Photovoltaic technology facilitates us with a smart ways of power generation and matches with the criteria of clean energy and sustainability [6]-[9]. Sunlight from the sun have been crescively used in the generation of electrical energy, either it is providing electricity in the region where there is self-sustained systems or grid-tied systems. Not simply like fossil fuels, harnessing solar energy doesn't result out to be the source of dangerous CO2 radiations, it generally takes a lower cost and high efficiency during energy conversion process [10]-[12]. This thesis is focused on accomplishment of grid-tied three phase inverter system. We also focused on active and reactive power of the PV generation system to a grid. The single- diode model of PV panel is proposed here due to the reason it is accurate and simple.



The PV current is directly proportional to solar irradiation. Equation for terminal current w.r.t to the different parameters of the PV cell is,

$I_{pv} = I_D + I_r' + I$

$I = Ipv - I_D - Ir'$

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The Output current at the terminal,

$$I = Ipv - Is\left(e^{\frac{Vd}{\eta VT}} - 1\right) - \frac{V+Ir}{r'} \quad \ldots\ldots\ldots (1)$$

$$VT = \frac{K\,T}{q}$$

Reverse saturation current is,

$$Is = K\,T^{m} e^{\frac{-Veg}{\eta\,VT}} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Veg = 1.16 to 1.21 for Si

Ipv directly depends upon environmental conditions such as irradiance and temperature is given as;

$$Ipv = (Isc + \beta i(T - 298))\frac{G}{1000}$$

Where,
G = Irradiance (w/m^2)
Ipv = Photovoltaic current (Amp)
I_D = diode current
βi = Tempt. Coefficient (V/ºC)
I = output panel current
V_T = *Volt equivalent of of temperature*
K = Boltzmann constant
T =Tempt (Kelvin)

According to "Maximum Power Theorem" to produce maximum power load resistance is equal to the available source resistance. Solar PV persuade this condition at a point known as Maximum Power Point. And when it comes to the preference of solar PV the peak power operating point becomes important. As we would prefer to operate the PV cell at this operating point, due to the reason it gives max power when operating in this region and there by utilizing to its fullest.

- **DC-DC CONVERTER**

The converters have a very widely used in PV systems. power converter can be seen as a very important component when it comes for the maximum power point. In this thesis work boost converter is utilized to change the terminal voltage up to the desired value. Boost converters employ here to convert output voltage to increased the voltage value. working principle of step-up converter is it increased the output voltage depends on the switching frequency of control switches. pends upon switching. Basically, the controller is used to generate the duty cycle and that controls the switching frequency which results to deals with the controlling process of the output voltage. Fig (2) shows a boost converter circuit. Output voltages can be calculated from the equation mentioned below.

$$v_0 = \frac{v_{in}}{1-D}$$

Where,

Vin= Input Voltage (output voltage of PV array)
Vo= Output voltage
D= Duty cycle

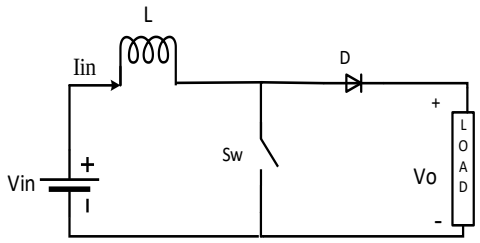

Fig 2: Equivalent Circuit Diagram of Boost Converter.

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- **DC-AC CONVERTER**

DC-AC converter is basically known as inverter, now a days inverters used in PV systems are self-commutated. The switches used in inverter are basically power BJT, MOSFET, IGBT, according to the switching frequency. Inverter mentioned for this work is a bidirectional DC-AC Converter with Pulse Width Modulation (PWM) technique. Working of 3-phase inverter is to convert Direct Current Power into Alternating Current Power at desired frequency & voltage. And this can be brought off by using various topologies and control scheme which having their own pron and cons. Here, this thesis proposed PV Grid -tied inverter whose input is DC which is coming out of SPV and output of three phase AC power interfaced with the grid via LCL Filter. Bidirectional property of inverter facilitates the flow of active (P) and reactive (Q) power from generator to the load and vice versa, according to application. Inverter's designs consist of six switches arranged in three parallel strands; each strand consist of two transistors switches with anti-parallel diode. The upper and lower strands of the inverter supplied by DC as its input and the 3-phase output generation takes places b/w the two switches of each strand. IGBT with anti-parallel diode used as a switching network, which allow bidirectional flow of current and unipolar property. PWM technique is used for switching of inverter in a proper sequence to build unfiltered output voltage.

- **MAXIMUM POWER POINT TRACKING**

MPPT main work is to track the maximum power which is coming out from the solar PV panel. As the temperature and irradiation varies maximum power also varies. MPPT application is necessary in DC-DC converter lying in between the load governed by an algorithm based on tracking phenomena and the photovoltaic modules [13-16]. There are various algorithm used in Maximum Power Point Tracking, but the most common ones are Perturbation & observation, Constant Voltage method, Incremental Conductance, Fuzzy Logic, Artificial Neural Network, PSO, etc.

- **CONTROL SCHEME**

The control scheme prosecutes here consist of two cascaded loops, current control loop which is proposed here to synchronize the grid current and the voltage control loop which tunes DC-link voltage. The DC-link voltage controller is delineated for maintaining the power flow in the system and the current control loop is responsible for power quality issues (PQ). All the measured variables are given in ac domain, and we preferred control in dc domain. So, for that we require Clark and Park transformation to transform variable 'abc' to rotating reference frame "dq'. Inverse Clark and Park transformation are employed to convert 'dq' variable to 'abc' variable. V_{dc} which is DC-link voltage depends upon the solar output voltage. Its output acts as a reference for current controller. The direct axis current and quadrature axis current are subtracted from their references to generate an error. The error is further fed into Proportional-Integral controller, to extract the voltages Vd and Vq. Hence, we product Vd and Vq with $2/V_{DC}$ to procure Eq and Ed, it will further transform to V_{abc} for the PWM Generator.

- **FILTER DESIGN**

The inverter's characteristic of switching forbids it from being connected to the grid directly. This is the cause of the inverter's harmonic generation, which degrades the quality of the power. The rules and standards specified in [17], [18], and [19] each determined an unique restriction on the number of harmonics that might be inserted into the grid. The system could be connected to the grid via a transformer [20]. The transformer's windings aim to act as an inductance, which further decreases the harmonics in the current waveform. However, transformers are expensive and bulky as well, which is little expensive. As a result, a transformer-less solution has been developed to connect inverters to the grid; therefore, we would rather to use a filter circuit as the interface. Passive filters can be grouped into three types: L, LC, and LCL. The figure illustrates these filters (3). LCL filter is accomplished here because it facilitates us with the advantage that it requires energy storing elements of less rating to reduce the same amount of disturbances from than LC filter.

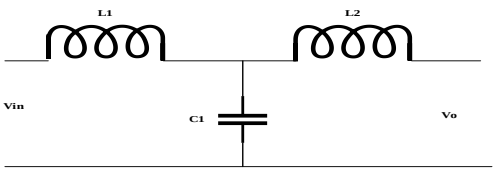

Fig 3: LCL Filter

III.SIMULATION RESULTS

The blueprint of the grid-connected Photovoltaic System proficient of operating in grid-connected mode was developed and analyzed using the MATLAB/SIMULINK software's Sim Power Systems module. This simulation runs for about 3secs. Input to PV array is Irradiance and Temperature. The two-stage power conversion is used here first one is DC-DC

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boost converter stage along with the Maximum Power Point control by perturbation and observation algorithm and the second stage is Inversion of power from DC-AC. This section mainly discusses about the simulation results of the boost converter o/p voltages, Solar o/p voltage & current, three-phase grid voltage and current, Active (KW) and Reactive Power (Var) to the Grid. The input to solar PV array is irradiance and temperature which is shown below in the simulation results, irradiance we have taken is 1000 W/m^2 and temperature is 25ºC. The avg power of PV is calculated and observed that PV voltage and current are proportional to its output power. Output current is directly proportional to the irradiation and PV output power is inversely proportional upon temperature and closely associated to irradiation. The finding demonstrate that PV output power is inversely dependent upon temperature and closely associated to irradiance.

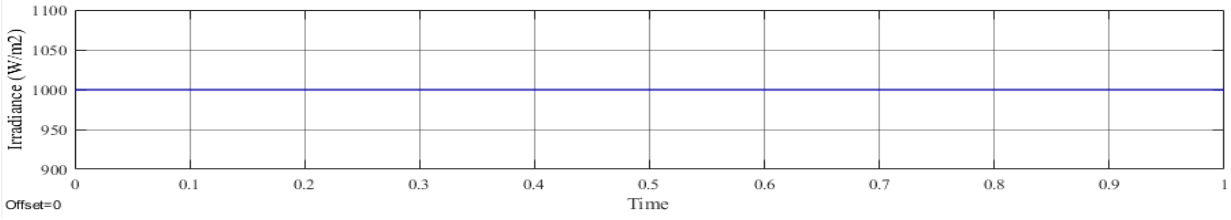

Fig 5: Solar Irradiance

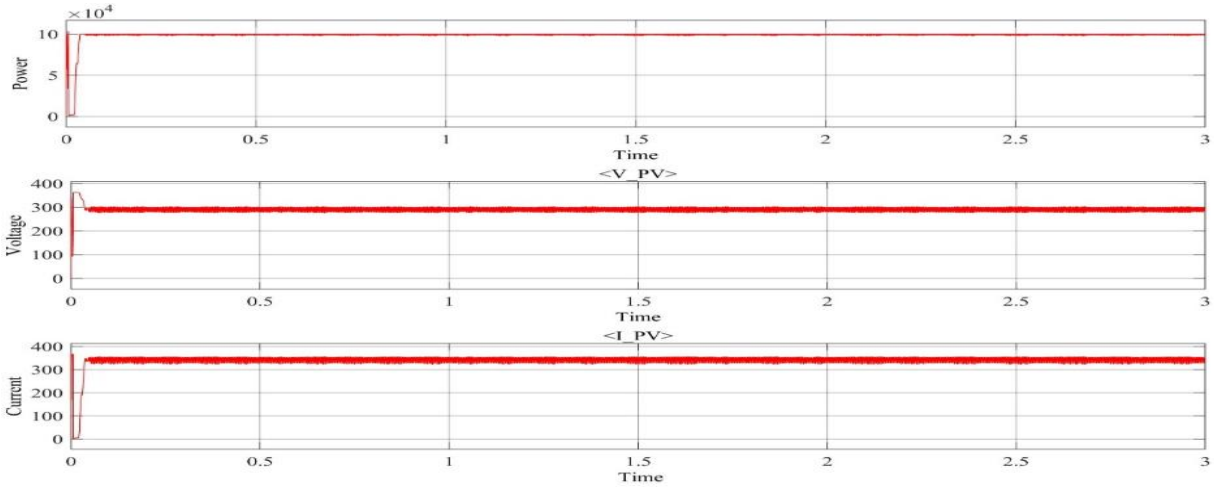

Fig 6: Photovoltaic Output Power, Voltage & Current

The first stage of conversion is stepping out the voltage which is coming out of the solar PV array. Below given plot presents the o/p voltage of Boost converter which is coming out to be 705.9V. The Duty cycle which is controlled by MPPT is shown in fig (7).

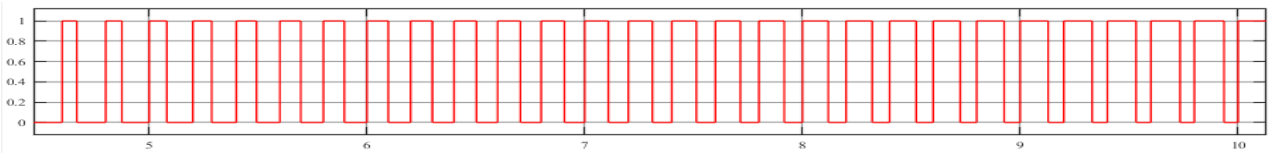

Fig 7: Duty Cycle controlled by MPPT

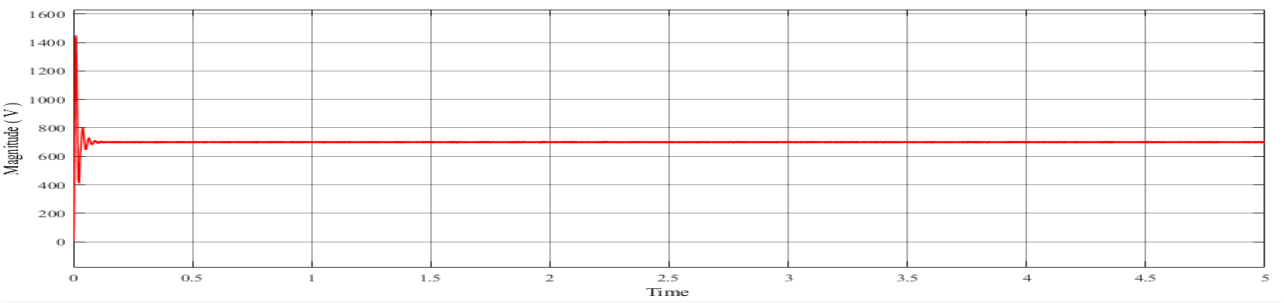

Fig 8: Output Voltage of Boost Converter

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The waveform shown below is 3-phase voltages and current waveforms beginning out of the inverter injecting onto the grid.

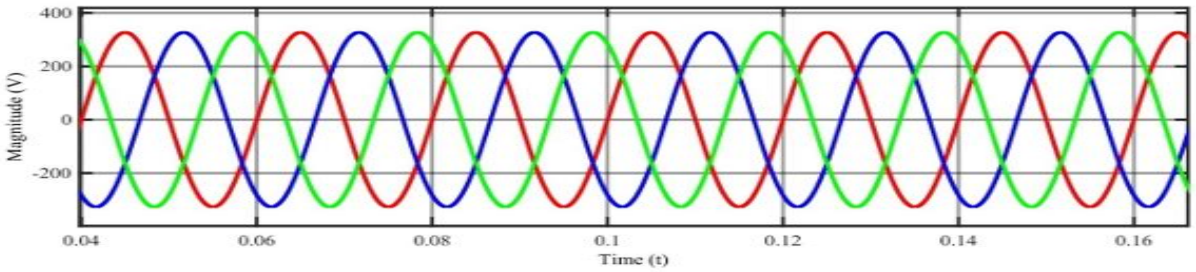

Fig 9: 3-Phase Voltage injecting to the Grid on insolation of 0.1KW/m^2

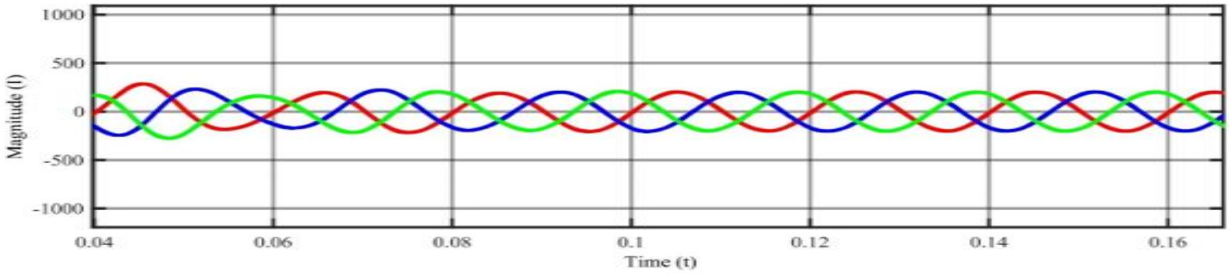

Fig 10: 3-Phase Current injecting to the Grid on insolation of 0.1KW/m^2

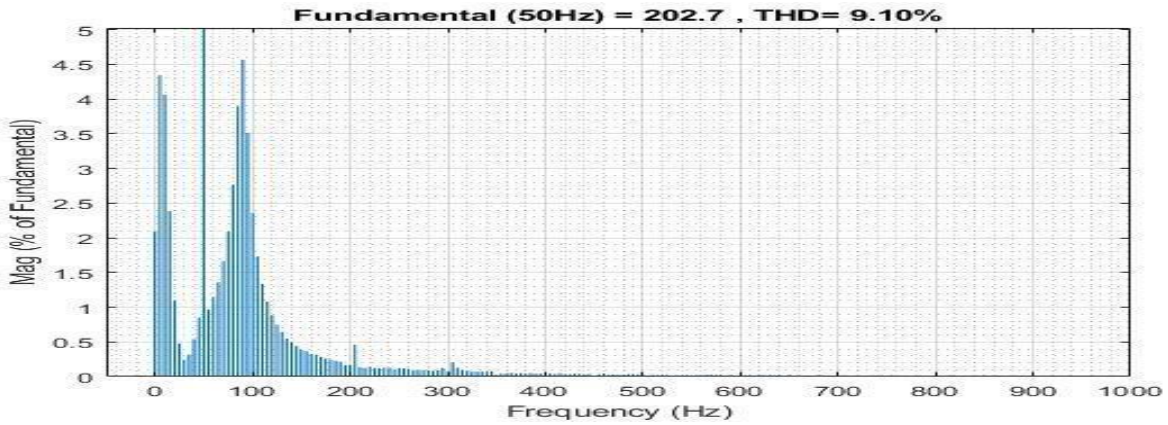

Fig 11: Total Harmonic Distortions of phase 'a' Grid current without LCL Filter

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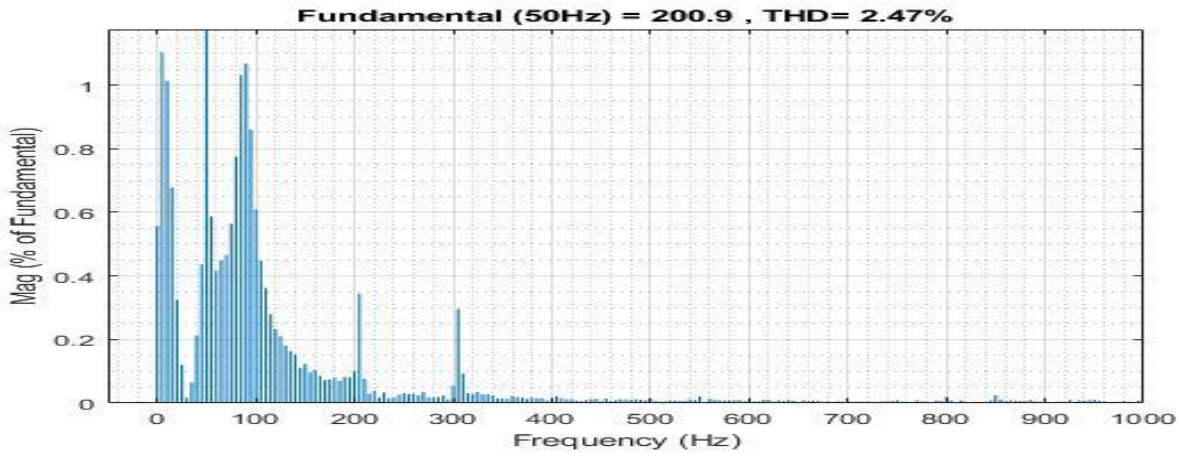

Fig 12: Total Harmonic Distortion of phase 'a' Grid current with LCL filter

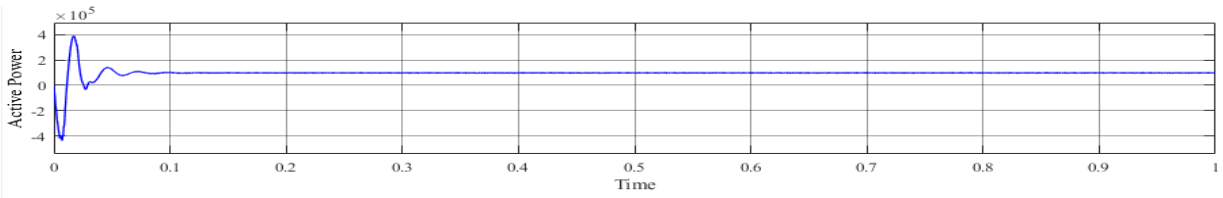

Fig 13: Active Power transferred towards the Grid

Table II represents the simulation parameters of Grid connected Distributed Generation system. Above mentioned fig (11) and fig(12) are the harmonic analysis with and without LCL filter. It can be easily observed that the proposed technique improves the harmonic mitigation.

Table II : Simulation Parameters

Parameters	Value/Unit
Nominal Voltage	400 V
Grid Frequency	50 Hz
Max Power of PV	100 KW
Max Voltage of PV	29 V
Max Current of PV	7.36A
Open Circuit Voltage	36.4 V
Short Circuit Current	7.76 A
No. of cells in series	60
Grid side Inductor (L_G)	0.5mH
Inverter Side Inductor (L_I)	1mH
Filter Capacitance (C_F)	$100uF$
Switching Frequency	5KHz
K_P	0.005
K_i	0.001

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IV.CONCLUSION

In this paper , 3-phase Grid Connected Distributed Generation system is studied in detail .The control strategy consist of two cascaded loop current control loop and DC-link voltage control loop and these control strategies are verified through simulation studies on 100KW Grid Connected DG system. This includes dual power conversion stages, DC-DC boost converter which involved to step up the photovoltaic output voltage up to a desired limit along with that an algorithm perturbation & observation is utilized for tracking maximum power point. So, that system can be controlled at its peak rating for local ecological condition. The LCL Filter facilitates with the advantage of mitigating harmonics which is present in the grid current due to power electronics inverter switching. The THD according to IEEE standard must be 5% and this paper accomplished with 2.47% of THD in grid current for solar insolation level of 0.1KW/m^2.

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