COMPARATIVE ANALYSIS OF LC, LCL AND SHUNT ACTIVE POWER FILTERS IN ENHANCING THE POWER QUALITY IN A MICROGRID

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Abstract: Increasing need for power day by day has led to a new way of generating power locally. Microgrids are those networks which generate power at distribution level. Microgrid combines distributed generators, loads, energy storage devices and control devices. They work in connection with the grid and isolated with the grid. The distributed energy sources in microgrid such as solar, wind etc., are irregular in nature and cause various power quality issues like as voltage variations, harmonics etc., In this paper, microgrid with photovoltaic source connected to grid is considered to which LC, LCL and Shunt Active Filter are applied and their performance is analyzed. The results are verified using MATLAB/Simulink.

***Index Terms* – Distributed Generation, MPPT, Power Quality, LC, LCL, Shunt Active Filter, THD.**

I. INTRODUCTION

Conventional electric grid has many draw backs such as poor energy efficiency, depletion of fossil fuels, environment pollution and energy crisis due to the increasing demand. These drawbacks led to the trend of power generation at distribution voltage level by using renewable energy sources such as Solar, Wind, Fuel Cells, Biogas, Natural Gas, Microturbines etc., This type of power generation is called Distributed Generation and the micro sources which generate such low power are called Distributed Generators. Microgrid is a combination of such distributed generators, storage devices and control devices. These combined networks are connected as a single entity to the distribution grid through a point of common coupling (PCC). Microgrid operates in grid connected and islanded mode. Some of the DG technologies generate power in such a way that they require power electronic devices to convert the energy into grid compatible AC power. This kind of integration introduces several technical problems in the operation of the grid such as steady state and transient over & under voltages at point of connection, protection malfunctions, power quality problems such as voltage variations, harmonics, flicker etc.,

The aim of this paper is to reduce the total harmonic distortion (THD) in the microgrid system using filters. The performance analysis and simulation of grid connected solar PV feeding nonlinear with different filters such as LC, LCL and Shunt Active Filter is presented. Section II describes the modelling of PV array, Boost Converter and VSI. Section III shows the design of LC, LCL and Shunt Active Filters. Section IV presents simulation outcomes and conclusions are summarised in section V.

II. PROPOSED SYSTEM MODEL

In this paper, a 500KW microgrid is modelled which consists of PV array, DC-DC converter with MPPT, VSI with PLL and grid.

A. PV Array:

PV cell converts solar energy into electricity. A PV cell consists of p-n junction in a thin wafer of semi-conductor. Number of series connected cel to form one module. These modules are connected in series to form a string. A group of strings form an array. Many cells are connected in series or parallel to get required voltage or current.

The circuit of PV cell with one diode model is as shown below:

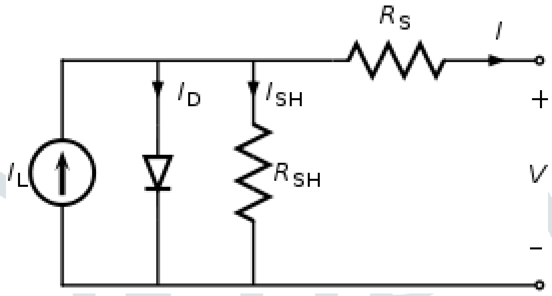
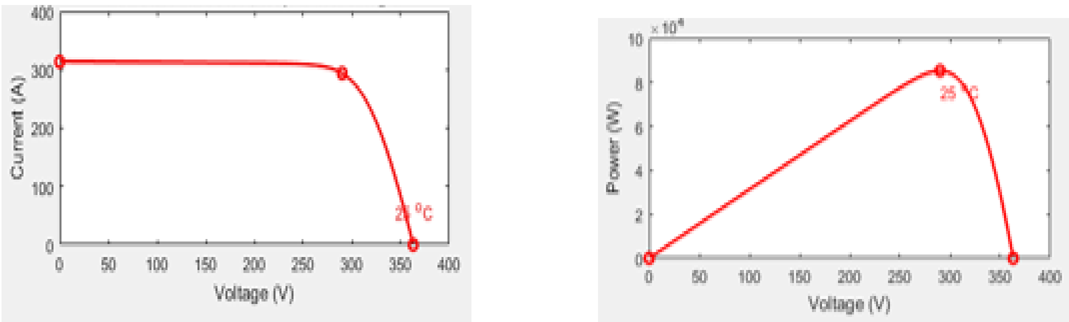


Fig1: Internal Circuit of PV Cell

The PV cell output depends on the temperature and Solar Irradiance. The V-I characteristics of solar cell with Irradiance 1000W/m2 and temperature 25^0 C are



V-I Characteristics P-V Characteristics

Fig2: V-I and P-V Characteristics of Solar Panel

Following is the detailed modelling of PV Array designed to generate 500KW power:
Maximum Power Pmax = 250W
Open Circuit Voltage Voc=30.5V
Short Circuit Current Isc=8.55A
Voltage at maximum point Vmp=30V
Current at maximum point Imp=8.33A
No. of series connected modules per string Ns=10

Vo=300V

Io=500*103/300=1666.667A

No. of parallel strings Np= 1666.667/8.33=200

B. DC-DC Boost Converter:

A boost converter consists of inductor(L), power switch(B), diode(D), Capacitor(C) connected as shown in figure. It operates in two modes: i) When switch is ON and diode OFF ii) When switch is OFF and diode ON. When switch is ON, inductor stores energy. When switch is OFF inductor discharges and capacitor charges and the voltage will be Vin+VL.

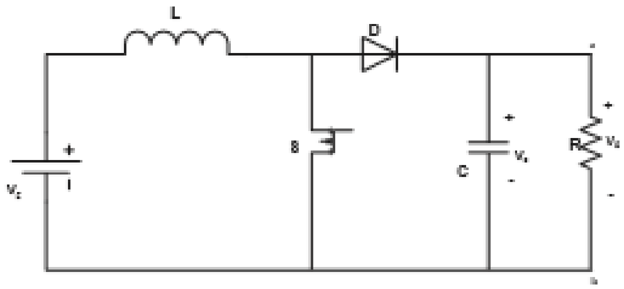


Fig3: DC-DC converter

The boost converter in this paper is modelled as shown below:

Duty Cycle D = 1-Vin/Vo

Input Voltage Vin = 300V,

Output Voltage Vo = 700V,

Switching frequency fs = 25KHz

30% current ripple is considered for inductance L,

1% voltage ripple is considered for capacitance C.

MPPT (P&O):

Due to the intermittent nature of the PV array the output of the system varies throughout the day. In order to have the efficient use of the source, maximum power from the source should be tracked. In this paper Maximum Power Point Tracking (MPPT) using Perturb and Observe(P&O) technique is used.

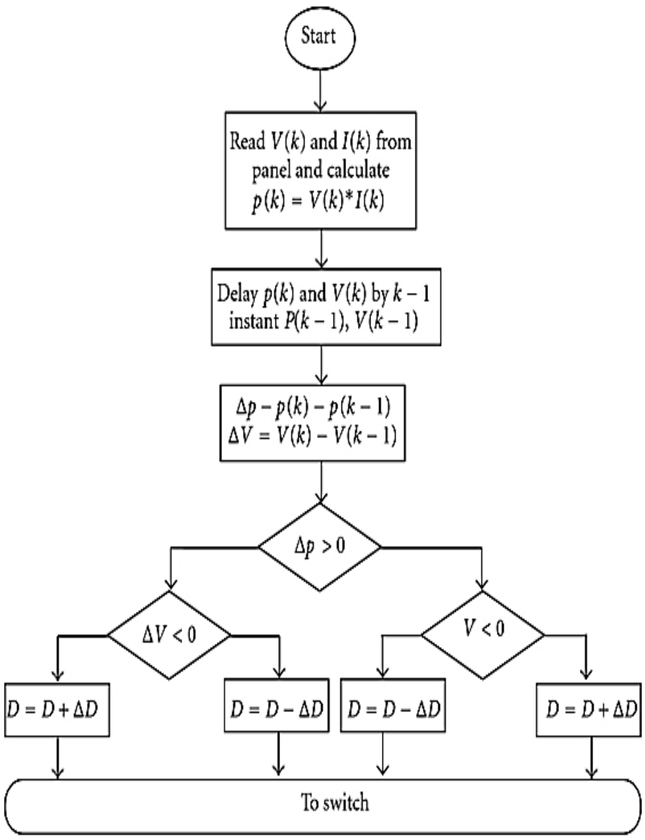


Fig4: MPPT Flow chart

C. (DC-AC Converter) Voltage Source Inverter:

An inverter converts DC power to AC at required frequency and voltage. Voltage source inverters are classified according to their output voltage and level. It has zero impedance at the input terminal of the inverter.

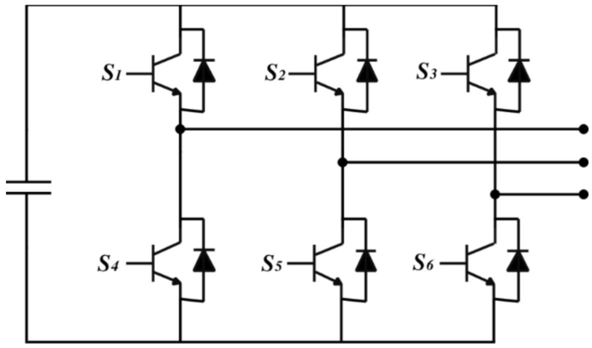


Fig5: Three phase VSI

In this paper, a three phase VSI is used to convert the output of the boost converter to AC. It consists of three arms with each arm containing two switches. It operates in 1800 conduction mode. In order to synchronize with the utility grid, the gate pulses are provided from Phase Locked Loop.

Phase Locked Loop (PLL):

PLL is an electronic module that locks the phase of the output with the input. It has voltage or current oscillator that detects the phase error and constantly adjusts to match with the frequency of the input.

In this paper, Synchronous reference frame PLL (SF-PLL) is used where the instantaneous phase angleθ is detected by synchronizing the PLL rotating reference frame to the utility voltage vector.

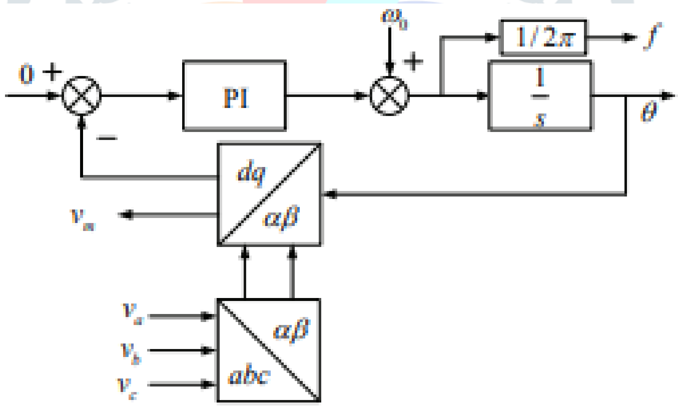


Fig6: SF-PLL

III. FILTER DESIGN

The integration of distributed generators which use power electronic devices cause power quality issues in the system. Harmonics are one of the important power quality issues that affect the performance of the system. In order to mitigate these harmonics, various filters are designed in this paper and the THD of system is compared.

A. LC Filter:

It is the second order passive filter which contains inductor and capacitor connected in parallel. The high frequency components are blocked by the inductor and low frequency components are blocked by the capacitor.

Capacitor impedance inversely varies with the frequency and for inductor it is directly proportional. This way the high frequency components are blocked and harmonics are reduced.

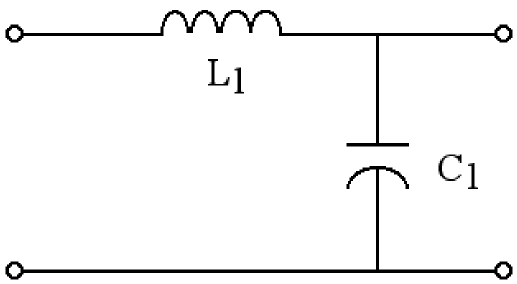


Fig7: Simple LC Filter

The block diagram of LC filter incorporated microgrid is

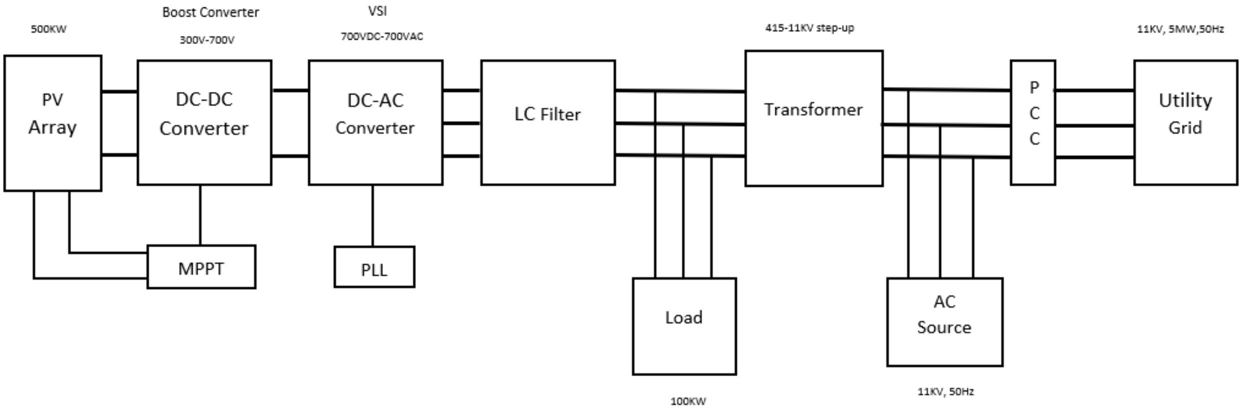


Fig8: Block diagram of microgrid with LC filter

Calculation for design of LC filter:
Rated power P= 500KW
Switching frequency of the inverter fsw = 5Khz
Frequency of the grid fg = 50Hz
Vdc = 700V
Vph = 338.84V
For 10% current ripple,
$L = Vdc/16fsw\Delta Imax = 1.275e\text{-}4H$
$C = 0.05Cb = 2.310e\text{-}4F$

B. LCL Filter:

It achieves higher attenuation with low cost compared to other filters. LCL filter consists of two inductors L1 (inductor side), L2 (grid side), a capacitor C and a damping resistor Rd to damp the oscillations in the system.

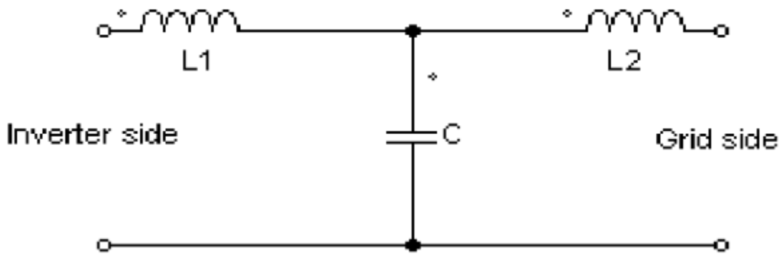


Fig9: Simple LCL Filter

The block diagram of LCL filter incorporated microgrid is

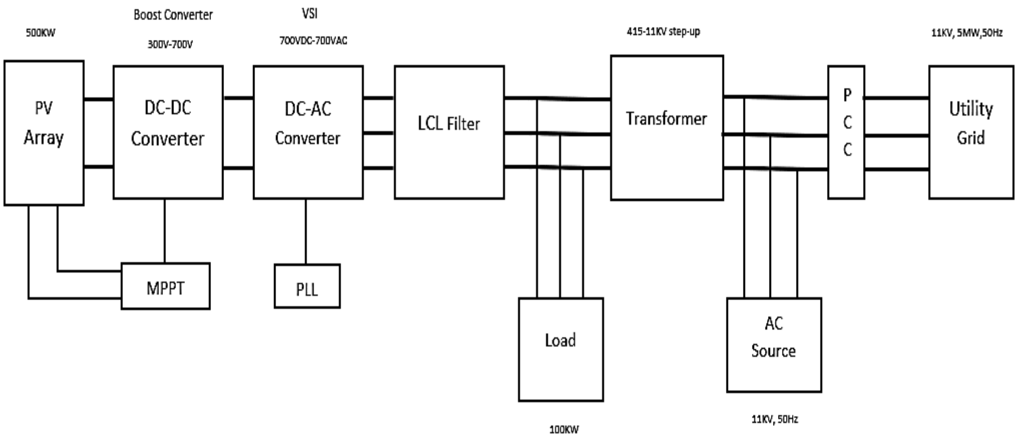


Fig10: Block diagram of microgrid with LCL filter

Calculation for the design of LCL Filter:

Rated power P= 500KW
Switching frequency of the inverter fsw = 5Khz
Frequency of the grid fg = 50Hz

$C = 0.05C_b = 2.310e\text{-}4F$

Where, Cb is Base Capacitance.

For 10% current ripple,

$L1 = V_{dc}/16 f_{sw} \Delta I_{max} = 1.275e\text{-}4H$

For 20% attenuation, ka = 0.2

L2 = 2.236e-5H
R = 0.0955

C. Shunt Active Filter:

It consists of a VSI connected with capacitor connected across it and a control circuit to inject the harmonic current required for the load. It provides harmonic compensation by injecting equal but opposite harmonic compensation current.

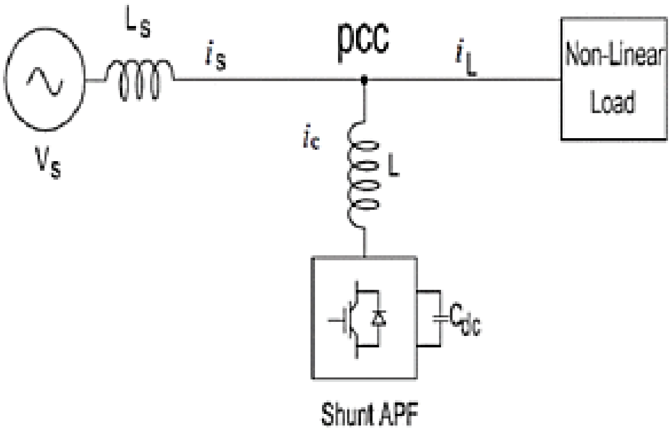


Fig11: Shunt Active Power Filter

Synchronous Reference Theory:

Synchronous reference theory is used in this paper to calculate the reference current in order to compensate harmonics. This theory uses Park's transformation.

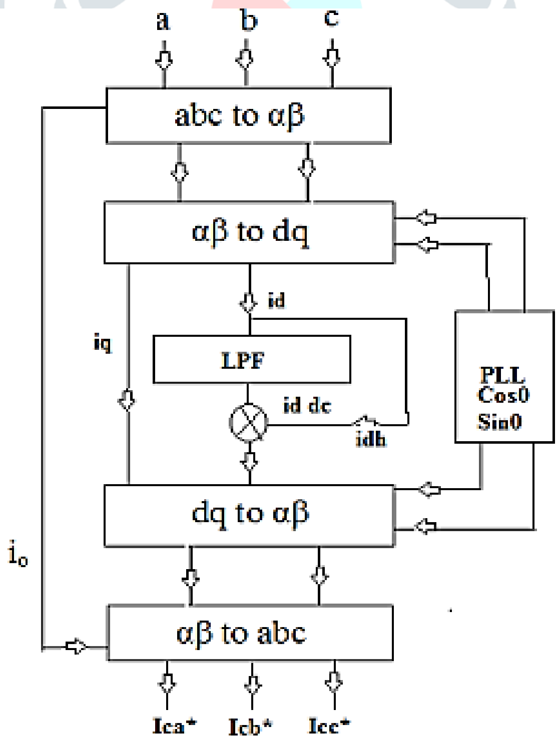


Fig12: dq theory flow chart

The block diagram of Shunt Active filter incorporated microgrid is

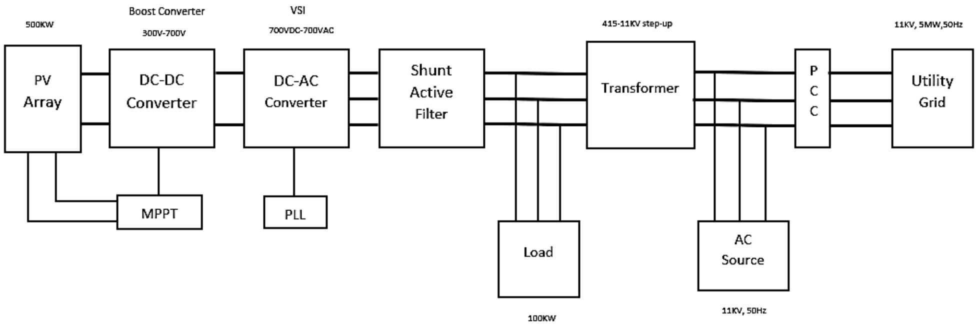


Fig13: Block diagram of microgrid with Shunt active filter

DC Voltage regulator (PI Controller):

The control scheme of the system consists of a PI controller. The voltage at the capacitor and reference voltage value are applied to generate an error signal. This error is fed to the PI controller whose parameters are calculated.

The transfer function is $\frac{Vd}{vdr} = \frac{Kp \times Ki/C}{s^2 + \frac{Kp}{Cs} + Ki \times Kp/c}$ ………………. (1)

It is a second order transfer function given by $\frac{Vd}{vdr} = \frac{\omega n^2}{s^2 + 2\xi\omega ns + \omega n}$ ………...(2)

By comparing both the equations, $Kp = 2\xi\omega nC$ and $Ki = \frac{\omega n}{2\xi}$

For ξ= 0.707, Kp =0.28, Ki =35.3

Hysteresis Band Current Control:

Gate pulses are generated through the hysteresis band current controller in order to control the VSI of the Shunt active filter. The error signal is generated by subtracting actual filter current to reference current and is given as input to the hysteresis band.

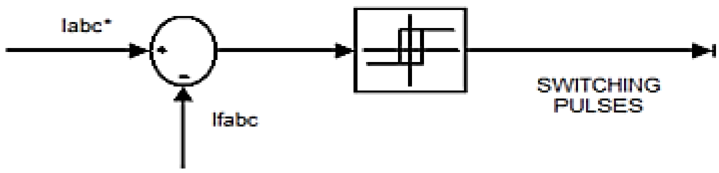


Fig14: HB Current controller

IV. SIMULATION AND RESULTS

The microgrid here consists of a PV array with Irradiance=1000W/m2, T=25^0 C generating power of 500KW with voltage 300V. The output of the PV array is fed to DC-DC(Boost) converter is designed such that switching frequency is 25KHz, L=31.9µH, C=2326µF to boost up the voltage to 700V. A voltage source having switching frequency 5KHz is connected to the boost converter to convert 700VDC to line voltage of 700VAC whose output is stepped up to 11KV using a transformer. A load of 100KW is connected across VSI. The above system is connected to a utility grid of 5MW, also a three phase AC source of 11KV is connected at the PCC. In order to have proper grid synchronization, VSI is controlled by PLL. In order to reduce the harmonics, the output of the inverter is filtered using filters like LC with L= 125.7µH, C= 231µF, LCL having Inverter side inductor L1= 125.7µH, grid side inductor L2= 22.38 µH, C= 231µF, damping resistor Rd=0.09 and shunt active filter is designed based on synchronous reference frame theory.

The block diagram of the microgrid operation is as shown in the figure.

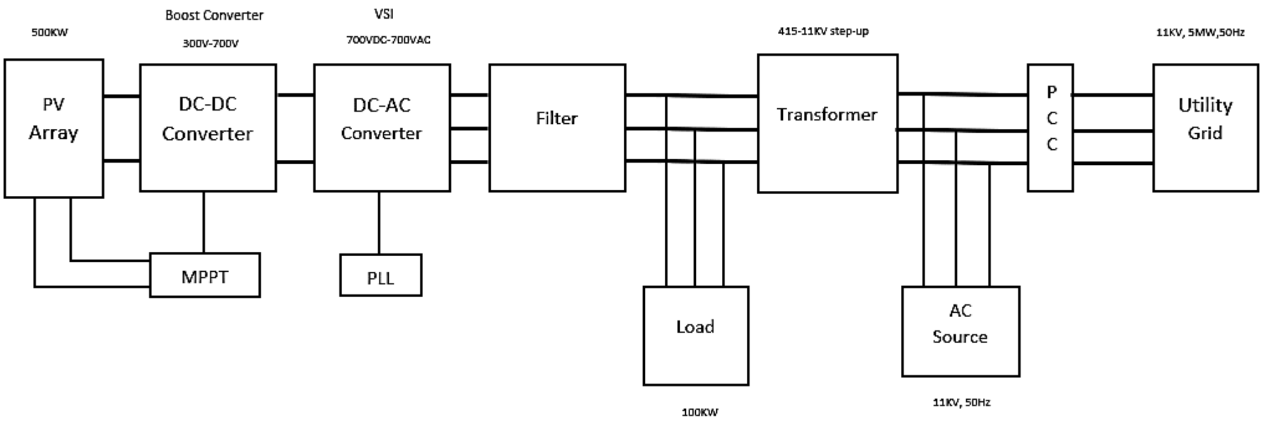


Fig15: Block diagram of microgrid

This microgrid is operated in different modes at different intervals of time as shown in the table below. From 0.0-0.1 sec, AC source and grid are connected alone, from 0.1-0.3 sec, solar source is connected, from 0.3-0.4 the grid is disconnected and the microgrid is now operating in isolated mode. At 0.4sec, AC source is disconnected, and solar PV alone is supplying power to the load.

Time Duration	Solar	Ac source	Grid
0.0-0.1	OFF	ON	ON
0.1-0.3	ON	ON	ON
0.3-0.4	ON	ON	OFF
0.4-0.5	ON	OFF	OFF

Table1: Operating modes of microgrid

Results:

A. Without Filter:

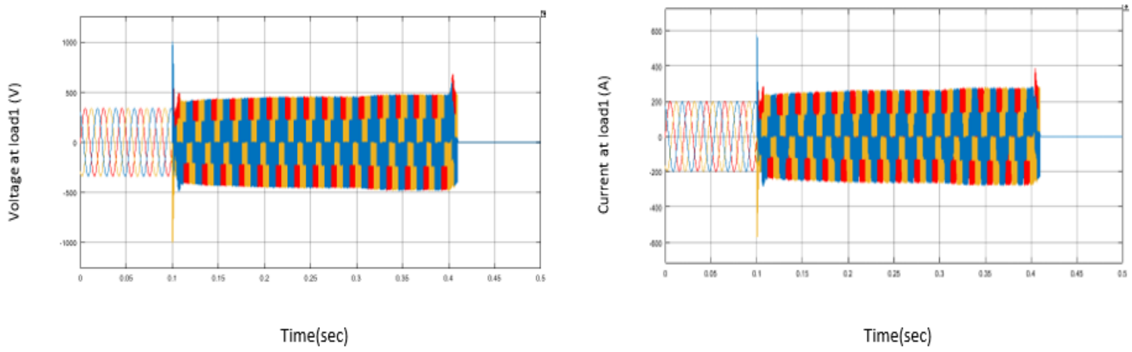


Fig16: Voltage and current at load1 without filter

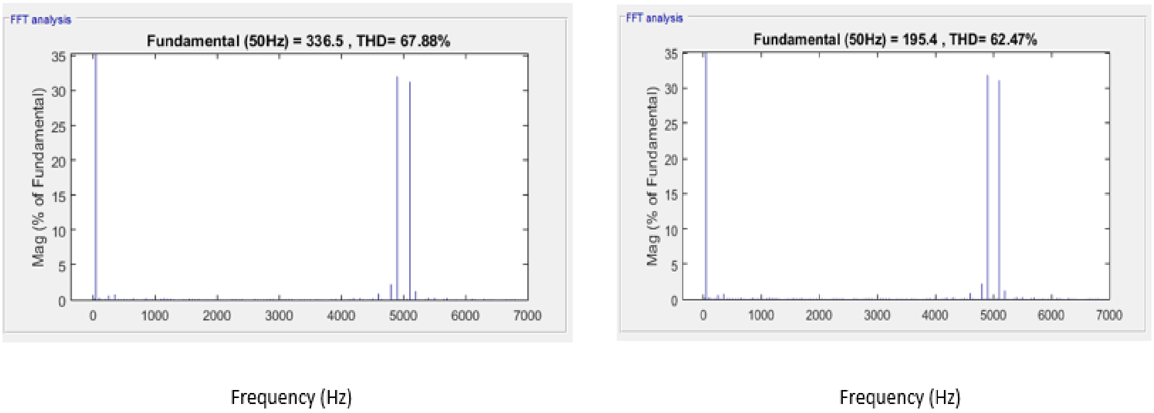


Fig17: THD of voltage and current at load1 without filter

Without Filter THD (%)	Time (Secs)	0.00-0.1	0.1-0.3	0.3-0.4	0.4-0.5
	Voltage (V)	0.05	69.03	67.17	0.00
	Current (A)	0.00	63.57	62.17	0.00

Table2: T.H.D for Grid connected solar PV system without filter

B. With LC Filter:

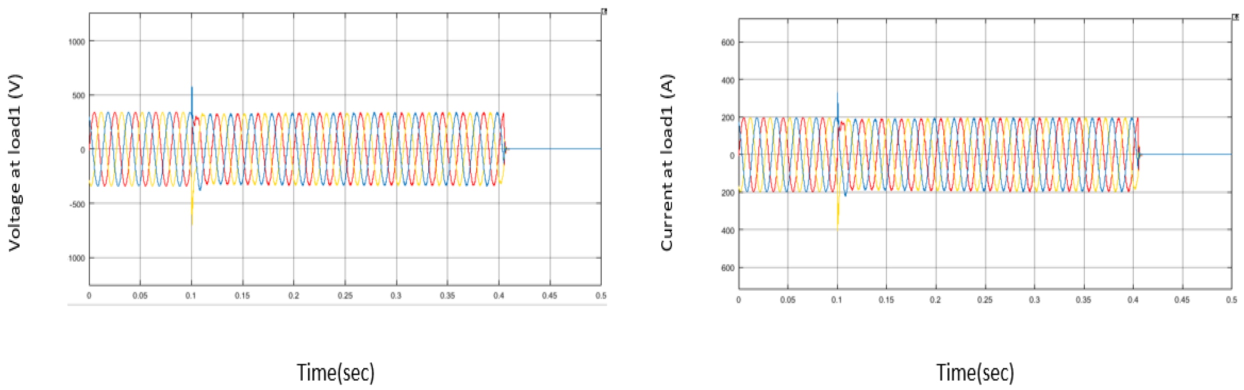


Fig18: Voltage and current at load1 with LC filter

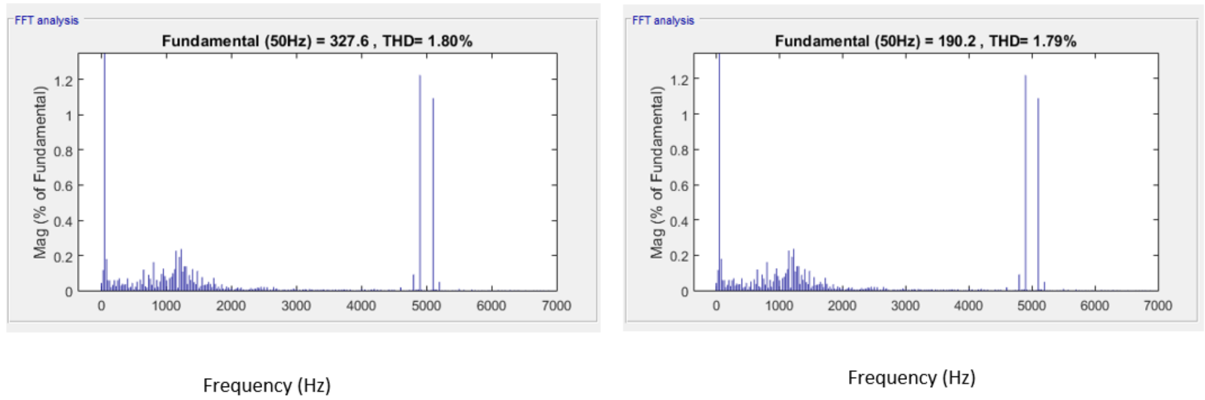


Fig19: THD of Voltage and current at load1 with LC filter

Time(sec)		0.0-0.1	0.1-0.3	0.3-0.4	0.4-0.5
THD Without Filter	Voltage (V)	0.05	69.03	67.17	0.00
	Current (I)	0.00	63.57	62.17	0.00
With LC Filter	Voltage (V)	0.00	1.86	1.78	0.00
	Current (I)	0.00	1.83	1.77	0.00

Table3: T.H.D for Grid connected solar PV system with LC filter

C. With LCL Filter:

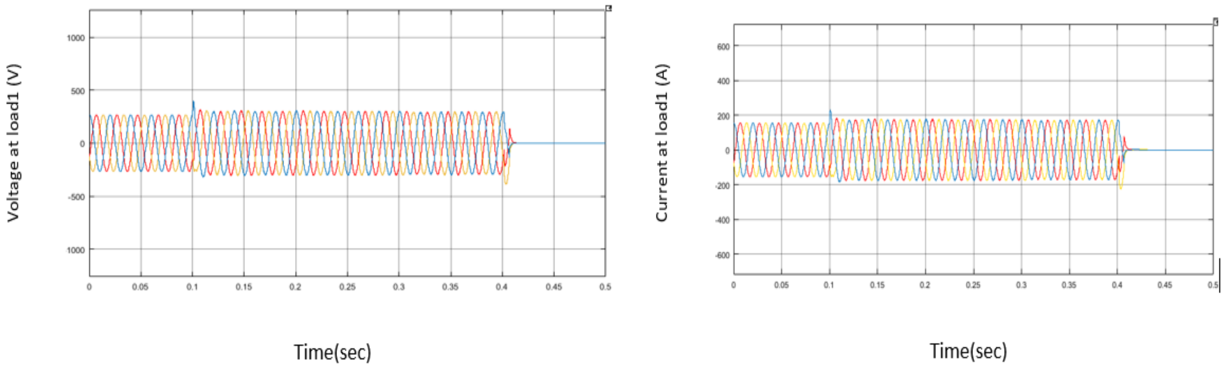


Fig20: Voltage and current at load1 with LCL filter

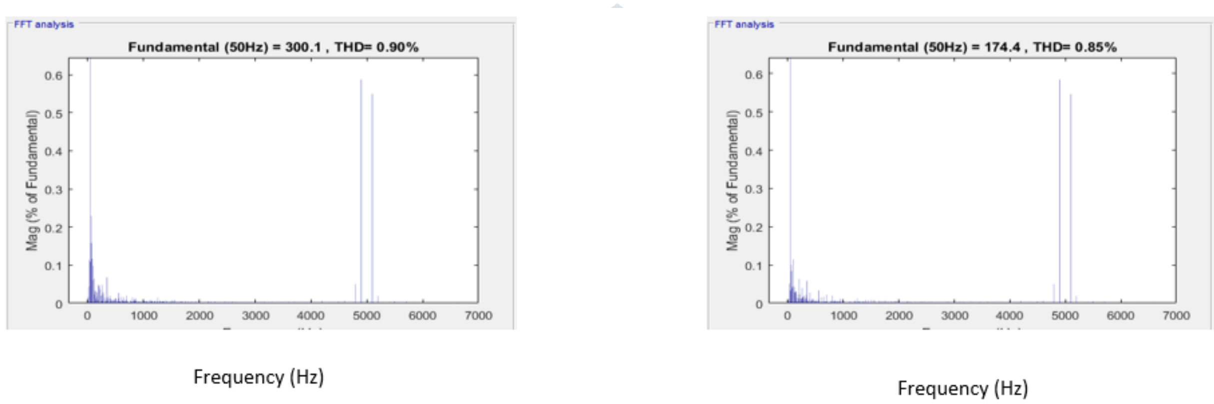


Fig21: THD of Voltage and current at load1 with LCL filter

Time(sec)		0.0-0.1	0.1-0.3	0.3-0.4	0.4-0.5
THD Without Filter	Voltage (V)	0.05	69.03	67.17	0.00
	Current (I)	0.00	63.57	62.17	0.00
With LCL Filter	Voltage (V)	0.00	1.17	1.16	0.00
	Current (I)	0.00	1.13	1.10	0.00

Table4: T.H.D for Grid connected solar PV system with LCL filter

D. With Shunt Active Filter:

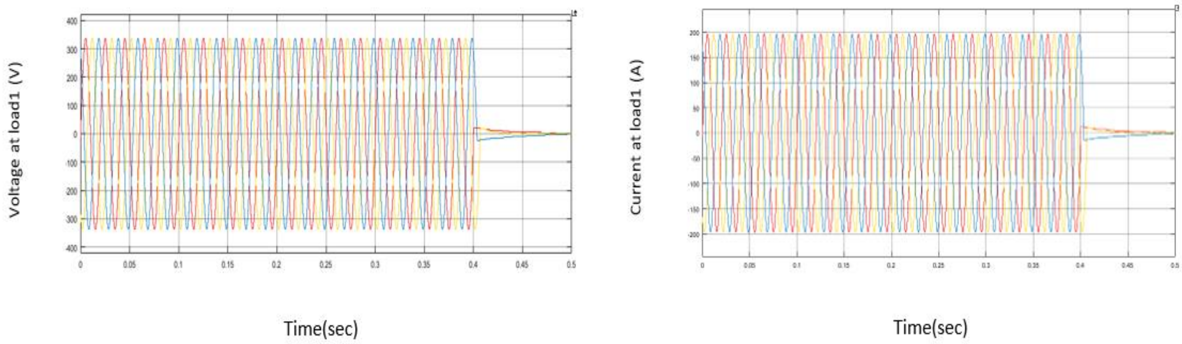


Fig22: Voltage and current at load1 with shunt active filter

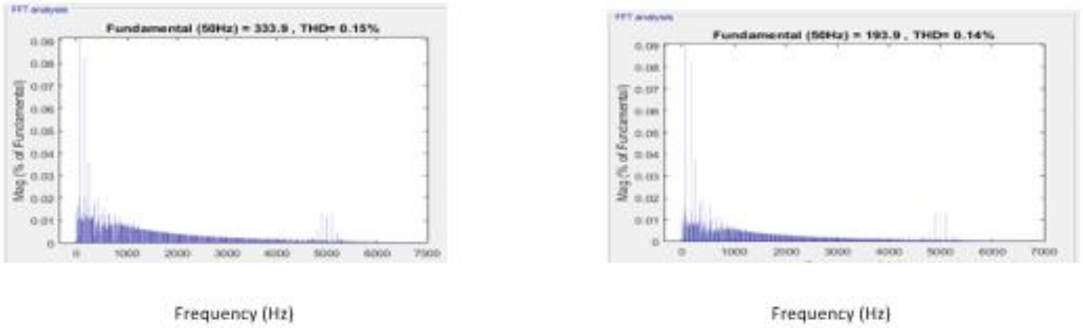


Fig23: THD of Voltage and current at load1 with shunt active filter

Time (Sec)		0.0-0.1	0.1-0.3	0.3-0.4	0.4-0.5
THD without Filter	Voltage(V)	0.05	69.03	67.17	0.00
	Current(I)	0.00	63.57	62.17	0.00
THD with PI_Shunt Active Filter	Voltage(V)	0.00	0.15	0.09	0.00
	Current(I)	0.00	0.14	0.09	0.00

Table5: T.H.D for Grid connected solar PV system with shunt active filter

THD Comparison of LC, LCL and Shunt Active Filters:

Time (Sec)		0.0-0.1	0.1-0.3	0.3-0.4	0.4-0.5
THD without Filter	Voltage(V)	0.05	69.03	67.17	0.00
	Current(I)	0.00	63.57	62.17	0.00
THD with LC Filter	Voltage(V)	0.00	1.86	1.78	0.00
	Current(I)	0.00	1.83	1.77	0.00
THD with LCL Filter	Voltage(V)	0.00	1.17	1.16	0.00
	Current(I)	0.00	1.13	1.10	0.00
THD with Shunt Active Filter	Voltage(V)	0.00	0.15	0.09	0.00
	Current(I)	0.00	0.14	0.09	0.00

V. CONCLUSION

This paper describes the reduction of harmonics with using filters. From the results it was observed that without filter the THD of load voltage was 67.88% and load current was 62.47%, using LC filter the THD of load voltage was reduced to 1.80% and load current was reduced to 1.71%. With LCL filter, the THD of load voltage was further reduced to 0.90% and the THD load current was reduced to 0.85%. It was observed that, using shunt active filter the THD of the load voltage and load current was 0.15% and 0.14% respectively. Hence, the total harmonic distortion was effectively reduced using Shunt active filter.

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