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Simulation Analysis of Harmonic Mitigation in Solar Photovoltaic Based Microgrid System

Jaspreet Kaur* and Anita Khosla

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Abstract: The increasing concern on contamination and a perilous atmospheric deviation has provoked the Photovoltaic (PV) framework as one of the conceivable, inexhaustible and clean energy in power framework generation. Power quality problems like Total Harmonic Distortion (THD) have become an inexorably genuine problem as more Photovoltaic setups are coordinated into the grid framework. This urges a broad analysis to distinguish the challenges in power system organization. The proposed microgrid model consists of MPPT-Maximum Power Point Tracking system, a converter, and a multi-stage inverter. In this study, power active and passive filters are utilized; further cases are analyzed for power quality issues to reduce the harmonics using MATLAB simulation.

Keywords: *Active filter, Passive filter, Single tuned filter, Double Tuned Filter, Fuzzy Logic Controller, Pulse Wave Modulator inverter, Maximum Power Point Tracking system.*

1. Introduction

In last few decades, Photovoltaic (PV) innovation has been one of the promising environmental friendly powers because of its capacity to create power with no contamination in the climate. Additionally, government bolsters a large portion of the developed nations; the PV framework cost has diminished consistently throughout the long term, particularly for the grid-associated PV framework. This has brought about sudden rise in PV market development in recent years [1].

Power electronic appliances and gadgets utilized in power converters make power quality issues, for example, harmonics distortion [2]. PV framework execution as far as power quality rigorously relied upon the utilization of the inverters, solar-based irradiance, and temperature that may influence the power created voltage, and current profile [2][3]. In this paper, the harmonics will be reduced which are caused due to nonlinear loads and converters as well. Mitigation of harmonics is a fundamental work of an optimized power framework, reduction of harmonics additionally leads to lower downtime and in this manner, the higher revenues can be earned by satisfied consumers. Harmonic mitigation can be done by using various filters. This paper depicts reduction in harmonics in the grid associated solar-based power plant. Hence, exhaustive insights about harmonics reduction procedures are to be built for the productivity and effectiveness of a solar-based power plant.

1.1 Description of passive filters (PFs) to reduce the Harmonics

Passive filters utilizes a combination passive parts like resistors (R), inductors (L), and capacitors (C) and doesn't need an outer energy source or dynamic device like semiconductors. There is a pre-defined frequency range for passive filters which is around 3000 Hz, hence, the signal energy cannot get extended [3].

1.1.1 Single Tuned Filter (STF):

The STF is an efficient filter and these are tuned for a specific signal. These filters are used oftentimes for reduction or mitigation of harmonics. Even if this is the simplest type of filter, it requires a strict eye while designing so that all the segments must not get burden with over-voltages. While associating many single tunes filters, each and every filter is designed and assembled for a particular signal or frequency.

1.1.2 Double Tuned Filter (DTF)

A DTF consists of two Single Tuned filters (STF). At paramount frequencies the power loss is comparatively lesser if two single tuned filters are being used. To full drive voltage, one inductor rather than two is exposed. This gives advantage to High Voltage applications. Two Single Tuned Filters of different frequencies in just one Double Tuned Filter. Fundamentally both the double tuned filter and two single tuned filters are used at two particular frequency harmonics.

1.1.3 High Pass Filter (HPF)

A High Pass Filter is an electronic filter that passes a signal with frequency (F) higher than a predefined range and attenuates signal that has lesser amplitudes. It prominently passes signal of specific cut-off frequency and weakens the remaining signals. The signal attenuated depends on pre-defined setup and utility of the filter. Basically a high pass filter has time-invariant framework. High pass filter is technically known as Low Profile Filter

Manav Rachna International Institute of Research and Studies, Faridabad, India.
*(*Corresponding author's e-mail: jaskaur21309@gmail.com)*

or a Band-cut filter and has numerous applications like sound designing, DC impeding from circuits and radio recurrence frameworks. These are quite helpful for designing band pass channels when get associated with a low-pass channel.

1.2 Description of APFs (active power filters) to reduce the Harmonics

The higher and lower harmonics both can be eliminated or mitigated with the proper and pre-defined functioning of Active power filters. The Active Power Filters reduce harmonics by infusing dynamic power with an equal frequency subsequently opposite phase to drop that harmonics. This quality of APFs makes them easier and convenient for user to enhance a wider scope of harmonics.

1.2.1 Series active filter

The voltage V_f is induced in the line and it counterbalances the deviation occurring in voltages due to presence of nonlinear load in system. An arrangement of APF is most likely used for the harmonics balance of diode rectifiers, the variation of the voltage goes against the DC voltage for the inverter coming from the capacitor.

Figure 1. shows the circuit of series active power filter.

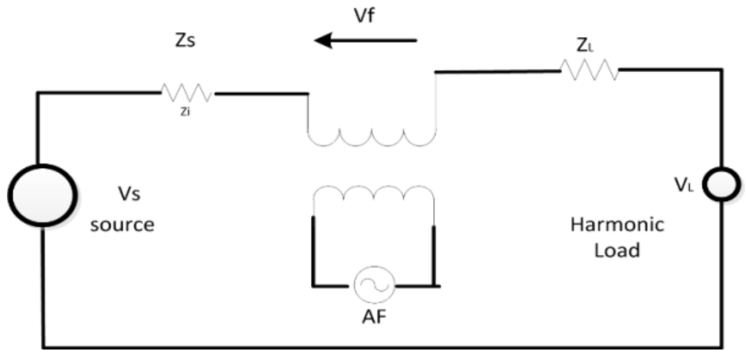


Fig 1. A Series Active Power Filter

Figure 2 shows the equivalent circuit of series active power filter for harmonic current load.

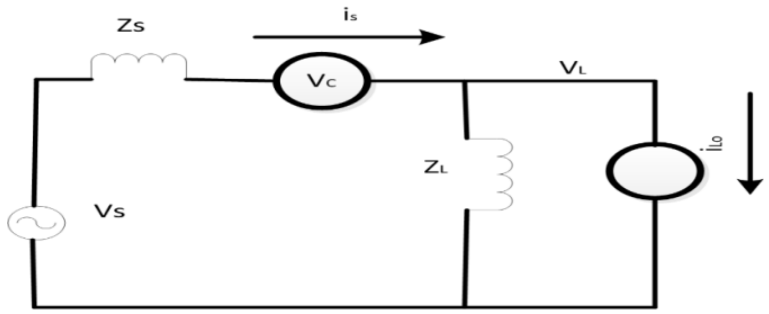


Fig 2. Series APF for the harmonic current load

Figure 3 shows the equivalent circuit of series active power filter for harmonic voltage load.

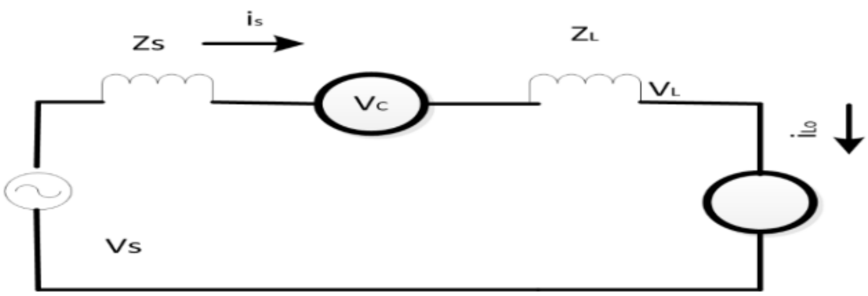


Fig 3. Series APF with harmonic voltage load

1.2.2 Shunt Active Power Filter

The zero impedance in any strong network maintains no voltage disturbance scenario whether there are some voltage disturbances in a weak network. Therefore, to maintain a non-sinusoidal voltage, appropriate harmonics current has to be induced. The Norton identical circuit is being introduced here which is a harmonics current source that carries out with a pulse width modulation (PWM) inverter to contourbalances the harmonic current of nonlinear burden into this power framework, however of harmonics of inverse phase. A shunt association appears in Figure 5. After inducing harmonic current in the network, the load current will be sinusoidal and now, the source impedance is lower than the load impedance. Figures 4 shows the shunt circuit of parallel Active Power Filter for harmonic current source and Figures 5 shows the shunt circuit of parallel Active Power Filter for harmonic voltage source [3-5].

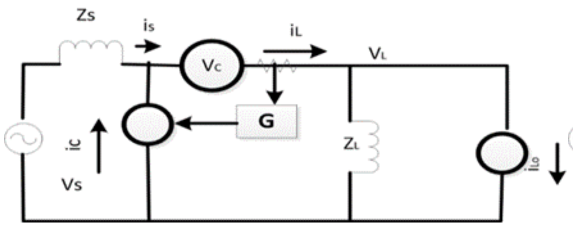


Fig 4. Shunt APF for harmonic current load

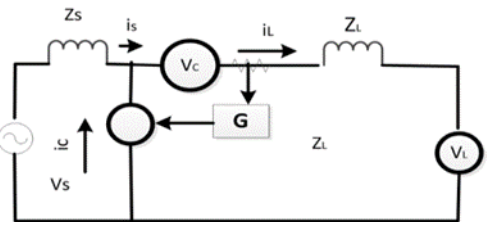


Fig 5. Shunt APF for the harmonic voltage load

2. Methodology

The proposed microgrid system comprises a 500V Photovoltaic based distribution generation plant that integrate with a 15-km feeder as shown in Figure 6. The PV system is connected with an independent utility microgrid which directly feeds power into the community grid. The scheduled power can be provided by a PV generating system, which depends on whether the attributed power output is evaluated separately from the power consumption (feed-in tariff). The simulation subsystem block providing the active power (P in kW), reactive power (Q in kVA), power factor (PF), THD (in %), and MPPT measurements. In this paper, The PV plant having 2-inputs, the first input allows you varying sun irradiance (in W/m2) and the second input is the temperature (in degree C).

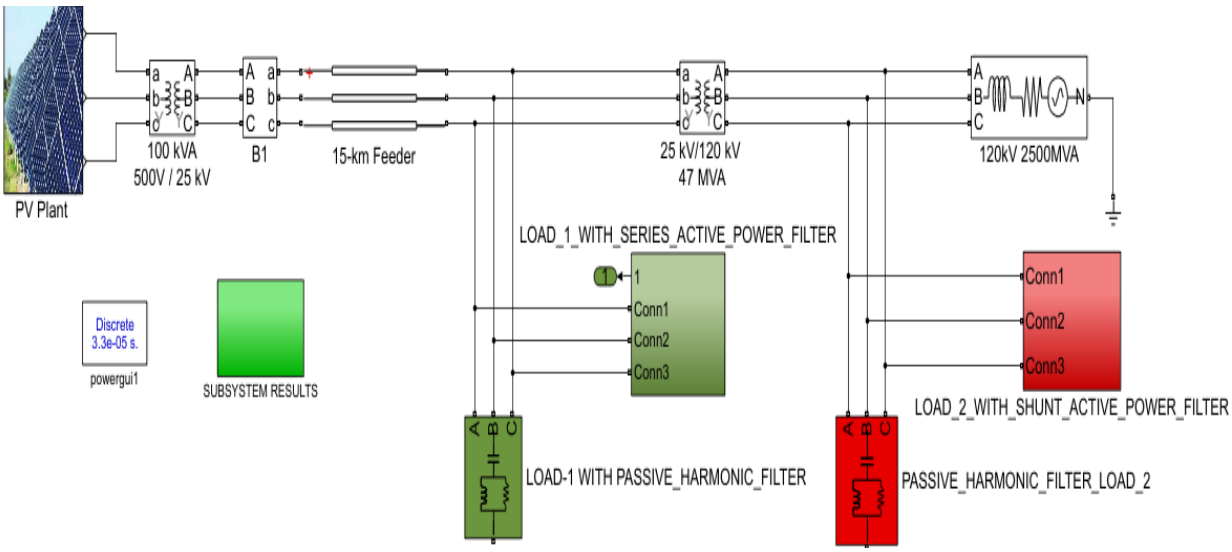


Fig 4. Simulation Setup of the proposed model in MATLAB toolbox

The rating of the proposed PV plant array is 100kW, which is coupled to the power grid through a boost converter (DC to DC) and further a 3Φ, 3 levels VSC. The proposed MPPT (Incremental Conductance method and Integral Regulator based technique) is employed in the boost converter. The duty cycle (Ţ) of MPPT is being adjusted to get maximum power by producing the necessary voltage. Another MPPT controller is based on the 'Perturbation & Observation' method, which applies the average models for DC to DC voltage source converters. Table 1 shows the considered parameters of the proposed microgrid.

2.1 VSC control system: The proposed VSC control system utilizes 2 control loops: The external-based control loop that regulating the DC link voltage. The internal control loops that regulating the grid active currents and reactive current (I_q and I_d) components. Where, I_d is the output current of the DC voltage external controller, and I_q is the reference value of current that is established to zero to keep unity PF. While the voltage outputs (V_d and V_q) of the current-based controller that converting to U_{bc_ref3} modulating signals which are generated by the PWM based Generator. In PLL based synchronization unit, sample time of 100-µs for current and voltage controllers. The Pulse generators of boost and VSC utilize a rapid sample time of 1-µs to get a suitable resolution of PWM waveforms. In Table 1, capacitor bank filtering the harmonics which are produced from VSC [4-5].

S.no.	Subsystem model	Rating/capacity
1	PV Panel	Maximum irradiance is 100 w/m^2, 100kwatt, PV voltage 273-to-500 volt DC, the 66 strings of 5 series- connected (66 x 5 x 305.2 W= 100.7 kW), Vo.c is 64.2 volt and Is.c is 5.96 amp Vm.p is 54.7 volt and Im.p is 5.58 amp.
2	Coupling transformer	100-Kva rating, 260V to 25kV
3	DC to DC boost converter	2.5kHz
4	Voltage source converter	3Φ, 3 level VSC, 500-volt DC to 260-Volt AC, keeping PF 1.
5	Capacitor bank	10-kvar
6	Utility grid	25-kV power distribution feeder, 120 kV equivalent transmission system.

Table 1. Proposed model description [6].

2.2 Types of load profile connected to the grid

The PV plant has been integrated into a grid with two types of load (balanced and unbalanced load). The load configuration is referred in Figure 6. The unbalanced load A is being series coupled with an active power filter for harmonic mitigation. This load comprises a universal bridge with 100Ω snubber resistance and capacitance of 0.210mF. While load B comprises a 3Φ active bridge configuration of diode rectifier with resistance 0.1Ω. The passive harmonic filter is configured as a Hybrid Filter (HF) as it comprises of single tuned and double-tuned filters. For a complete balanced power system dynamic, the current on the 3Φ system should be equal to 120° phase angle to avoid power loss. In Figure 6, load B circuit divided into nonlinear load and shunt active power filter (p-q based subsystem) with a sample time of 5µs [6-9].

3. Simulation Results

The simulation results are achieved in the MATLAB tool with a simulation time of 0 to 4 seconds. The solar irradiance taking an order from 900 to 1000 w/m^2, while the temperature is taking a step function. Based on generated PV power we realize the total harmonic analysis also implementing appropriate filters to mitigate higher harmonics.

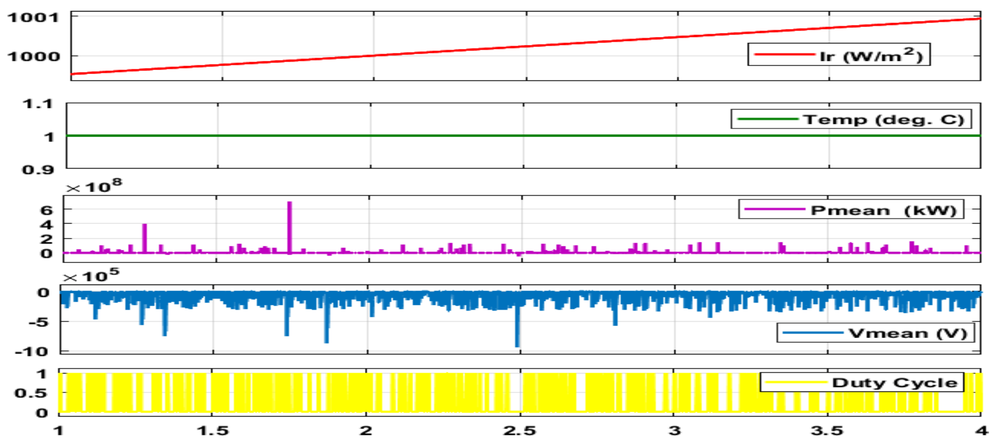


Fig 5. Characteristics of irradiance, temperature, mean value of PV power & voltage, and duty cycle

In this paper, the solver is utilized to simulate Runga kutta-based approach with a fixed step size. The layout is designed of solver parameters for input as well as output data to get a maximum number of data points taking as 1100. The FFT analysis calculates the DFT of a sequence, or its inverse (IDFT). The Fourier assessment transforms the indication after its initial domain to a description in the occurrence domain [15]. The FFT analysis for voltage and current waveform performed such that one filter is activated at a single time or no one other filters are effective in the allotted time duration [16]. In this paper, we have considered cases in which different filters are connected and their dynamics performance are displayed in Figure 8-14.

The proposed sequence or cases for connecting the filter are:

1. No filters are connected,
2. One Shunt Active Power Filter is connected,
3. One Series Active Power Filter is connected,
4. Single tuned passive filter is coupled with load A,
5. Double tuned Passive Filter is coupled with load A,
6. HPF-High Pass Filter is coupled with load A,
7. Single tuned passive filter is coupled with load B,
8. A double-tuned passive filter is coupled with load B,
9. A high pass filter is coupled with load B.

Here, a single tuned-based filter coupled with load A is tuned for frequency of 5th harmonics, on the other hand, the double-tuned filter is tuned for 5th and 7th harmonics. The HPF coupled with load A and 180 Hz cut-of-frequencies for third harmonic. The single tuned filter is coupled across load B, which is tuned for harmonic of second order. For the 2nd and 5th harmonic, the double-tuned filter tuned was employed. For the 2nd harmonic, the HPF coupled with load B has a cut-off frequency of 120-Hz. Figure 7 showing the graph of considered sun radiation, temperature, power mean, voltage-mean, and duty cycle. Table 2 shows the comparison among different filters in terms of THD in current and voltages.

CASE 1. No filter coupled to Load A; load current (I_L) and load voltage (V_L)

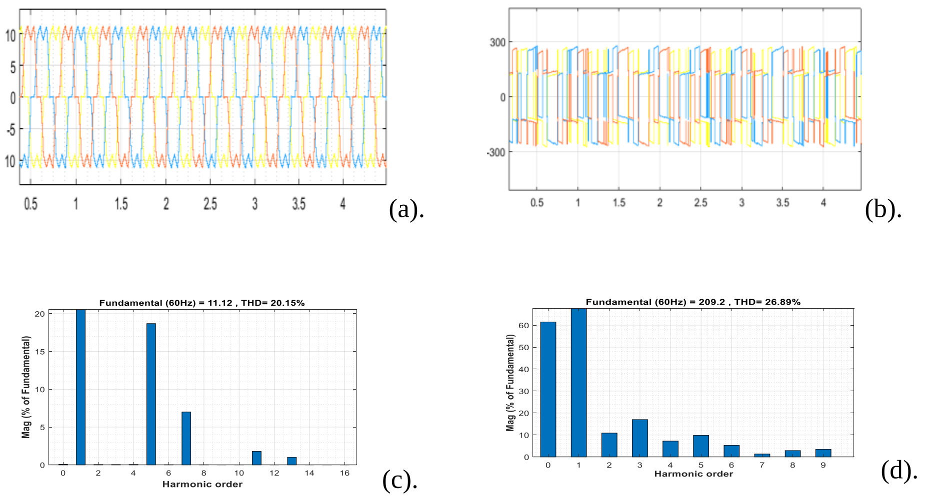
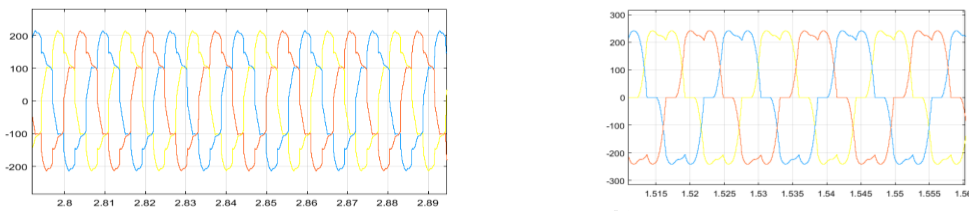
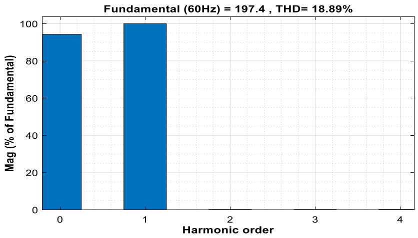


Fig 8. (a) Load current (I_L), (b) Load voltage (V_L), (c) THD analysis using FFT window of load current(I_L),(d) THD analysis using FFT window of load voltage (V_L)

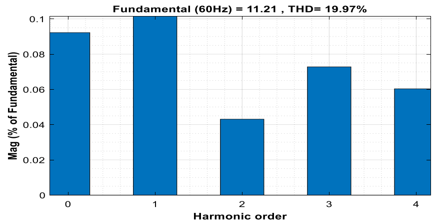
CASE 2. No filter coupled to Load B; load current (I_L) and load voltage (V_L)



(a). (b).



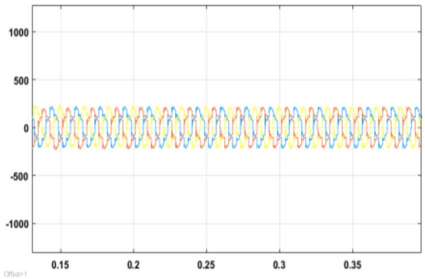
(c).



(d).

Fig 9. (a) Load current (I_L), (b) Load voltage (V_L), (c) THD analysis using FFT window of load current(I_L), (d) THD analysis using FFT window of load voltage (V_L)

CASE 3. Load A coupled with series active power filter then waveforms of load current (I_L) and load voltage (V_L)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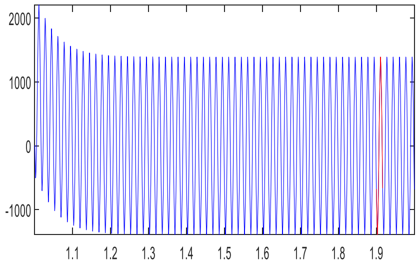
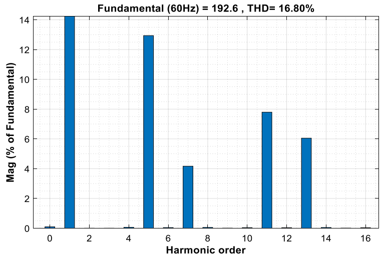
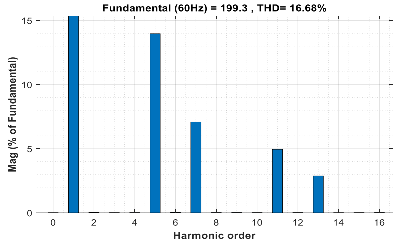

(b).



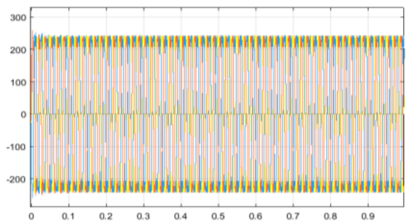
(c).



(d).

Fig 10. (a) Load current (IL), (b) Load voltage (V_L), (c) THD analysis using FFT window of load current (I_L), and (d) THD analysis using FFT window of load voltage (V_L)

CASE 4. No filter coupled to Load A; load current (I_L) and load voltage (V_L)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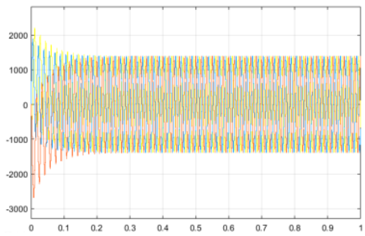
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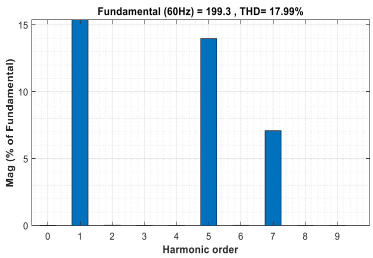

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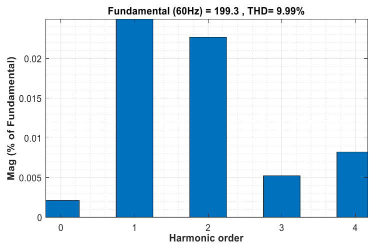
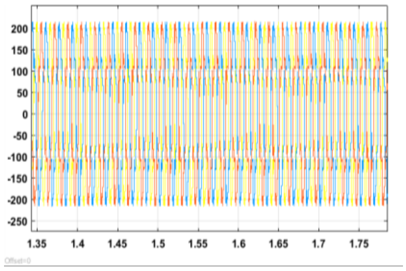


(d).

Figure 11. (a) Load current (I_L), (b) Load voltage (V_L), (c) THD analysis using FFT window of load current (I_L), and (d) THD analysis using FFT window of load voltage (V_L)

CASE 5. Load A coupled with single tuned filter (for 2[nd] harmonic frequency) then waveforms of load current (I_L) and load voltage (V_L)



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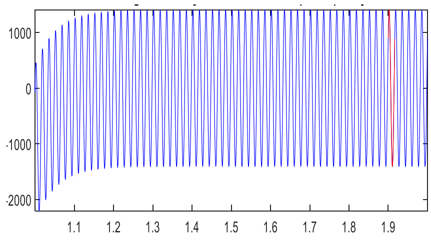

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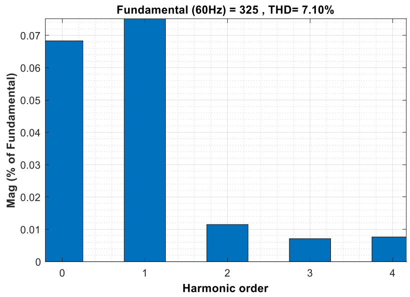

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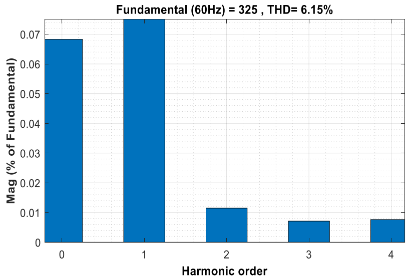
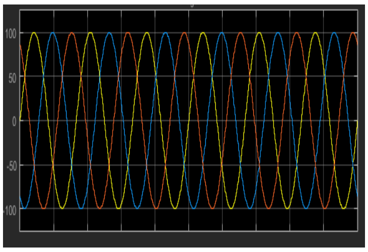


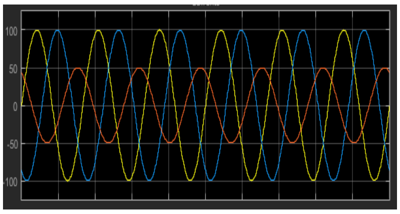
(d).

Fig 12. Load current (I_L), (b) Load voltage (V_L), (c) THD analysis using FFT window of load current (I_L), and (d) THD analysis using FFT window of load voltage (V_L)

CASE 6. Load coupled with high pass filter (HPF) with 180 Hz (cut off frequency) then waveforms of load current (I_L) and load voltage (V_L)



(a).



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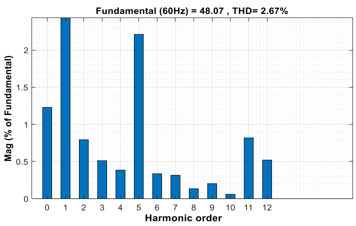

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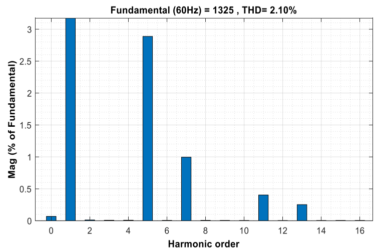

(d).

Fig 13. (a) Load current (I_L), (b) Load voltage (V_L), (c) THD analysis using FFT window of load current (I_L), and (d) THD analysis using FFT window of load voltage (V_L).

The harmonic mitigation capabilities of HPFs were much better than the single-tuned and double-tuned filters. In this paper double tuned filter could mitigate the higher-order harmonics referred in to table 2 and 3. For the effective active power managed by a single tuned filter which is lower than the harmonic mitigated by double tuned. This proposed result showed that a great improvement of high pass filters compared to the different configurations of filters. For further improvement, we can employ artificial intelligent controllers fuzzy-logic/fractional order-based controller/neural-based control methodology [12-1].

THD (in%)	Load A Without filter	With series active filter	Single tuned filter			Double tuned filter	High pass filter
			for 2nd harmonic frequency	for 5th harmonic frequency	for 5th & 7th harmonic frequency		
I_L	20.15%	16.80%	7.10%	8.67%	9.30%	4.07%	2.67%
V_L	26.89%	16.68%	6.15%	8.88%	8.88%	5.50%	2.10%

Table 2. Showing the comparative THD analysis for different configuration of proposed filters associated with load-A

THD (in%)	Load B Without filter	With shunt active filter	Single tuned filter			Double tuned filter	High pass filter
			for 2nd harmonic frequency	for 5th harmonic frequency	for 5th & 7th harmonic frequency		
I_L	18.89%	17.99 %	5.11%	7.99%	7.66%	5.30%	3.02%
V_L	19.97%	9.99%	25.82%	7.10%	9.01%	4.29%	2.82%

Table 3. Showing the comparative THD analysis for different configuration of proposed filters associated with load-B

4. Conclusions

In this paper, proposed passive-based power filters have been achieved the best performance if tuned suitably but these are incompetent to compensation of dc component of voltage and current. While active-based power filter has been achieved best in all cases but the series active power filter is suitable for mitigation of voltage sags than harmonics mitigation. When not tuned appropriately then passive-based power filters acted as a source of harmonic generation rather than harmonic reduction. In future research, multiple higher-order generalized Loop circuits can be used to recover the harmonics level within the IEEE Standards with higher tuned filter active such as C-type filter [17-18]. These proposed STF, DTF, and HPF topologies can be further modified the implement the real-time control strategy. The proposed simulation results further can be analyzed using the PSCAD simulation toolbox.

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