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PV Based Active Harmonic Power Filter for Power Quality Analysis

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Abstract:
In the present world, the photovoltaic system shows a leading role in the power distribution system as a most significant renewable energy source. The improved power quality and harmonics mitigation are the key consideration in our presented grid-connected PV system.This paper presents the performance analysis of active power filter (APF) to eliminate harmonics currents, power factor correction, and compensate reactive power to get maximum efficiency. To supply maximum power from PV system to grid, a DC-DC boost converter is used that is controlled by P & O algorithm for maximum power point tracking. The APF system is based on a two-stage voltage source inverter that is driven by hysteresis current controller and a PI controller to extract reference current.The proposed system is simulated using MATLAB Simulink and this research reduces the total harmonic distortionof 3.83%thus increasing the overall efficiency of our proposed PV system.The proposed design with an active filter can be used in both standalone and grid connections for residential or industrial power generation.

Key Word*:Active power filter; P&O algorithm; PV system; harmonic analysis.*

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I. Introduction

Energy has emerged as the backbone of the economic and technological development of the world during the past few years. According to the surveys, the population growth has become 1% in the recent years. However, the gross domestic product (GDP) rise is estimated to be approximately 3%. Moreover, considering GDP per capita as the global energy demand indicator, the escalating requirement for energy sources is continuous [1]. Therefore, with an increase in the energy requirement of the world and the exhaust of fossil fuels (like coal, natural gas and petroleum), the emphasis on renewable energy sources is pre-dominant [2]. Also the main factor for the inclination on the way to utilize the renewable energy is the increasing carbon footprint. In order to build a large energy base, there is a need to fully exploit the available renewable energy resources. Currently, the contribution by renewable energy sources is around 18% of the world's energy demand. However, according to an estimate by the International Energy Agency (IEA), the overall energy requirement of the world is expected to increase by 50% in the near future [3].

With the increasing power demand and the reduction in pollution, the power generation sector is interested in using fossil fuels. The PV system is the most common renewable energy source used in power generation. The PV cell uses sunlight to produce electrical energy by converting the direct solar radiation into DC supply. The PV cell is connected with the utility grid or can be connected with a standalone system. The well-balanced power quality of the power system is crucial because it keeps the system regulated and maintains efficiency. Poor power quality can affect the efficiency and regulation of the system [4].

Nonlinear loads, like saturated transformers, arc furnaces, adjustable speed drives, high voltage dc transmission system etc. actively participate in the electric power network which creates power quality issues [5]. These nonlinear loads draw non-sinusoidal source currents from the utility which are responsible for not only additional power loss in the line but also cause malfunctions of the grid equipment. Poor power quality of an electric power network causes inappropriate functioning of the utility grid. It may even cause a total breakdown of the system. Therefore, there is a need that a standard power distribution system must deal with reactive power support and harmonics. Although passive filters which consist of tuned L–C components can be conditioned to reduce, but suffer from many disadvantages like instability, large size, resonance between load and utility impedances and mistuning [6]-[7]. Moreover, the conventional passive filters might become unable to meet future revisions of a particular standard due to strict regulatory requirements. So, active filtering or suppression of harmonics by power electronics devices have become an alternative solution in supply networks at medium or low voltage distribution level [8]-[13].

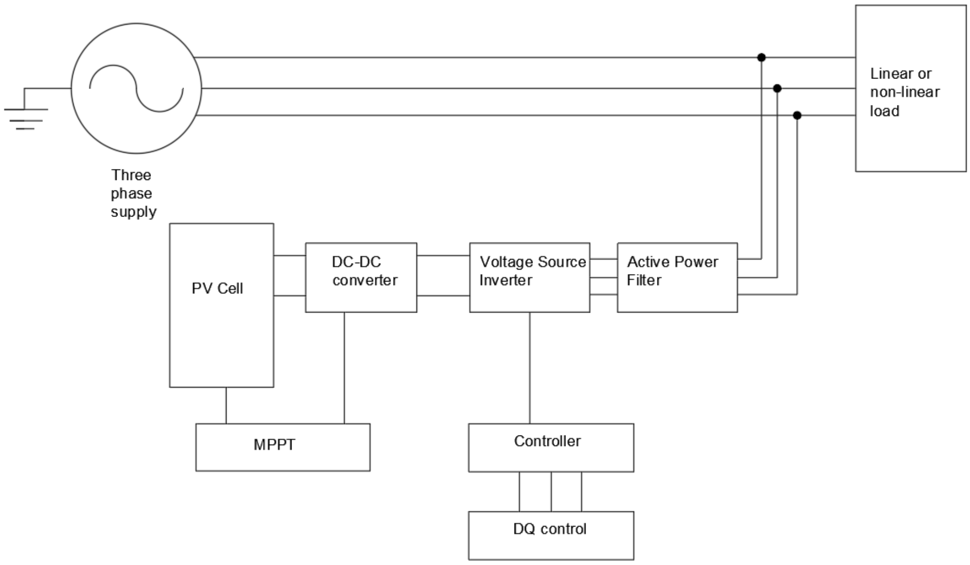


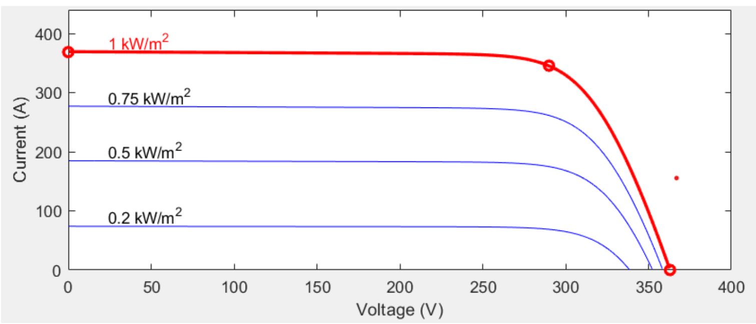
Figure 1: Block diagram of the proposed photovoltaic system

In present times active filtering is also used at high voltage distribution level for voltage control and/or reactive power control.Active filters can be two wires for single phase loads like domestic light, air conditioners etc. [14]-[15]. And three wires or four wires for three phase nonlinear loads like adjustable speed drives [16]. Active filters in shunt or series connection or a hybrid connection named as active power quality conditioners and even in combination with passive filters are generally in use.

Non-linear loads, static power converters and non-sinusoidal currents introduce harmonics to the system. Loads and components connected to the system are affected by the higher or lower order harmonics [17]-[20]. To mitigate the harmonics, power filters are used in the generation model. The Perturb & Observe MPPT method is used to get the maximum power from the dc-dc boost converter. The boosted dc voltage is inverted with a three-phase voltage source inverter. The current and voltage distortion created from the inverter is mitigated with an active power filter connected with the system.

II. Methods

A photovoltaic array with irradiation of [1000 750 500 200] W/m^{2}and temperature of 25℃ is used for simulation. The model of the photovoltaic system connected to the grid is shown in Figure 1. A dc-dc boost converter maintains the dc voltage to a required level. The maximum power point in the I-V curve is shown Figure 2. A three-phase voltage source inverter receives the output of the converter and feds it to the filter to reduce the current harmonics. The filter is connected to the interconnection of an R-L load and the grid.



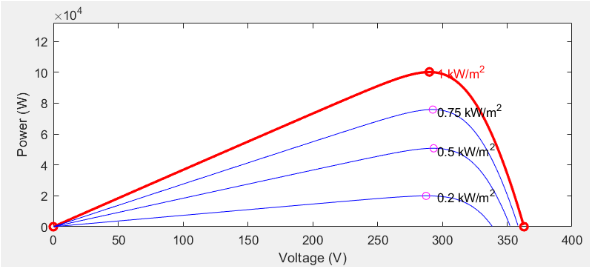


Figure 2: I-V curve for used module

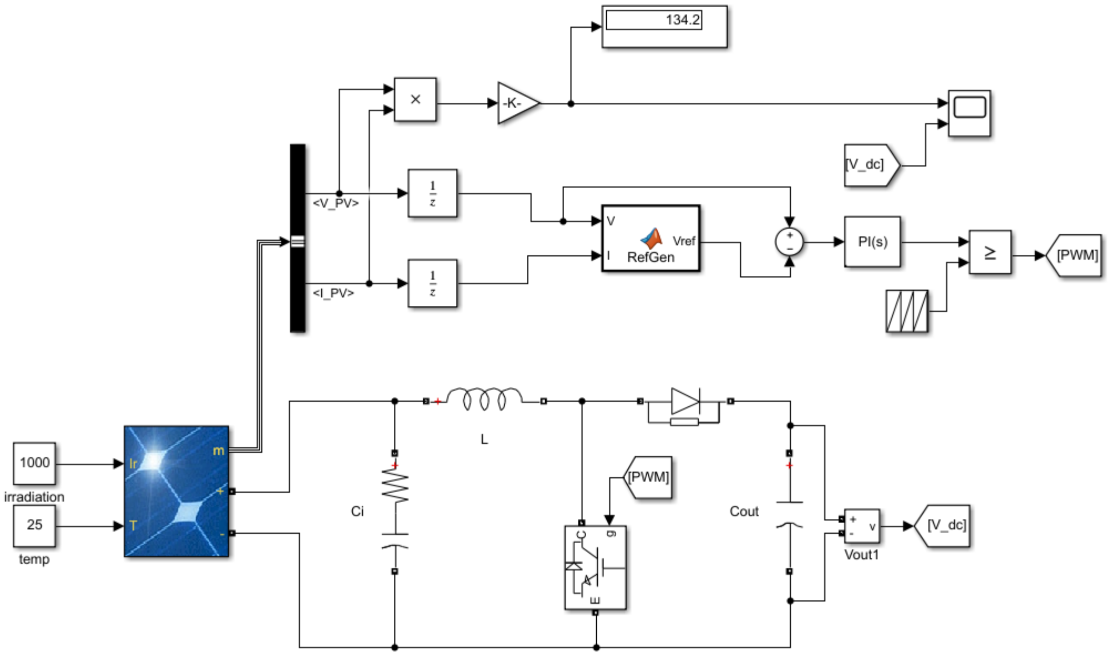


Figure 3: Control of DC-DC Boost Converter

DC-DC Boost Converter

The dc converter increases the voltage taken for the solar cells to a certain level. An IGBT switch is used in the circuit shown in Figure 3. As the switch closes, the diode operation is blocked by the inductor and the capacitor delivers load current. The terminal dc voltage from the boost converter is determined by the input voltage and the duty cycle after the diode is in conduction. The output voltage of the converter is dependent on duty cycle D that is expressed as follows:

$$V_{ouput} = V_{input}\left(\frac{1}{1-D}\right) \tag{1}$$

MPPT control

MPPT was used to keep the PV cell operated at maximum power point. Among the different MPPT methods, Perturb and Observe (P & O) method is the simplest. MPPT algorithm is presented by a flow chart that is shown in Figure 4.Though the cost of MPPT is high using it can help the system to operate at maximum voltage. The algorithm is described in brief:

Power condition	Voltage condition	Voltage status
Case1: Power change>0	Voltage change> 0	increase voltage
	Voltage change<0	decrease voltage
Case2: Power change<0	Voltage change> 0	decrease voltage
	Voltage change<0;	increase voltage.

Three-phase voltage source inverter

The inverter transforms the DC current output from the boost converter into AC current. Figure 5 shows the inverter circuit. The inverter is a three-phase inverter.

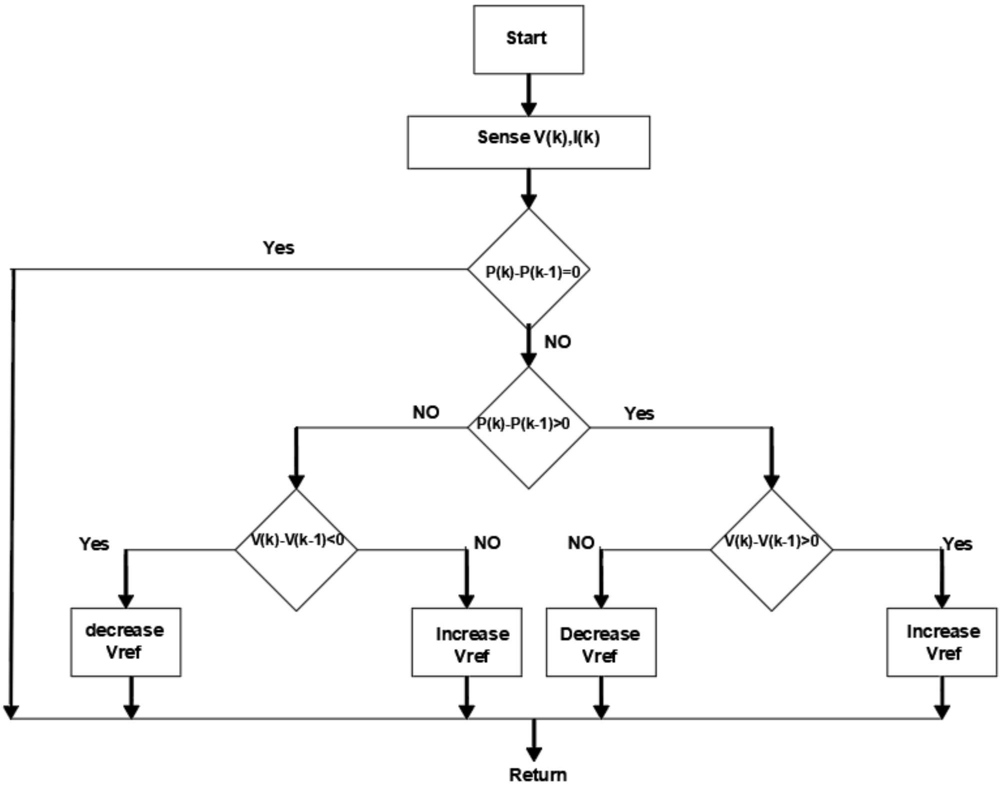


Figure 4: MPPT Flow Chart

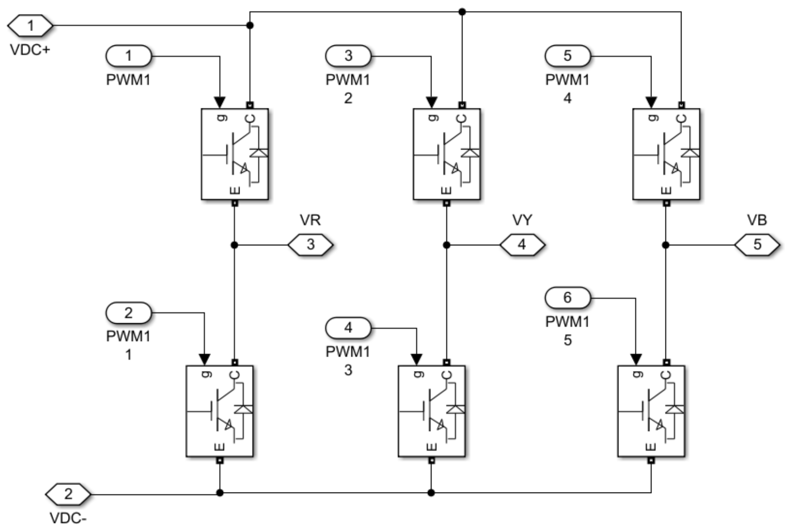


Figure 5: Three-phase voltage source inverter.

IGBT is used as the switch, which gets the pulse from the pulse generator using DQ frame theory. Figure 6 and Figure 7 show the circuits for the generation of pulse and control with DQ. Six pulses are generated for 6 IGBT switches.

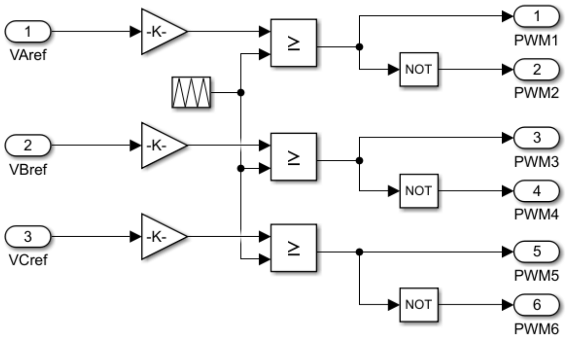


Figure 6: Pulse generation circuit

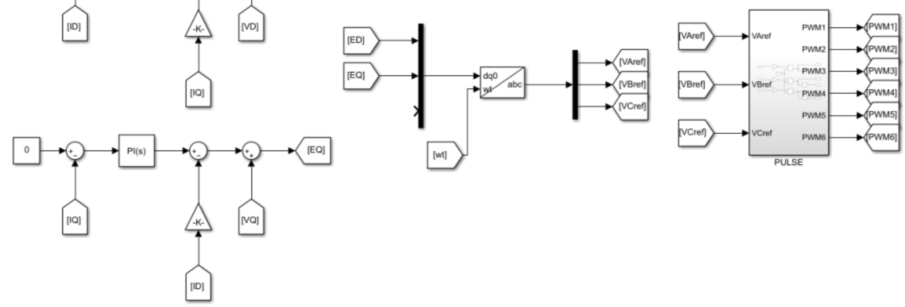


Figure 7: PWM generator and current control

Active Power filter

The task of an active filter is to cancel the harmonics delivered to the system. In case of high power loads, active filter is more suitable. The control scheme for active power filter is shown in Figure 8.

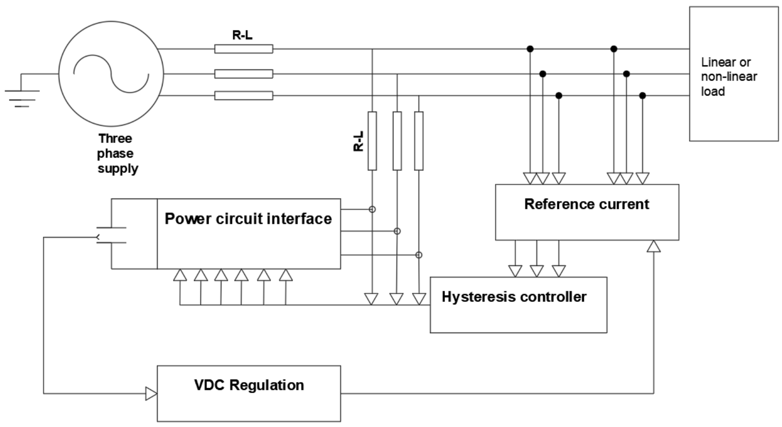


Figure 8: Active power filter control structure

An external supply is required as it is an active filter. The filter adds a harmonic that is opposite and equal to the load current and eliminates the load current harmonics. The operation is similar to the static compensators. In the controller circuit, αβ is transformed into DQ. The controller and the main circuitfor active filter is presented in Figure 9 and Figure 10 respectively.

From abc to dq transformation

$$i_a = i_d cos\theta - i_q sin\theta \tag{2}$$

$$i_b = i_d \cos(\theta - {}^{2\pi}/_3) - i_q \sin(\theta - {}^{2\pi}/_3) \quad (3)$$

$$i_c = i_d \cos(\theta + {}^{2\pi}/_3) - i_q \sin(\theta + {}^{2\pi}/_3) \quad (4)$$

From dq to abc transformation

$$i_d = \frac{2}{3}[i_a cos\theta + i_b \cos(\theta - {}^{2\pi}/_3) + i_c \cos(\theta + {}^{2\pi}/_3)] \quad (5)$$

$$i_q = \frac{2}{3}[i_a sin\theta + i_b \sin(\theta - {}^{2\pi}/_3) + i_c \sin(\theta + {}^{2\pi}/_3)] \quad (6)$$

Eq. 1, 2, and 3 are implemented in the subsystem abc-dq. Similarly, the corresponding subsystem of eq. 4 and 5 is dq-abc.

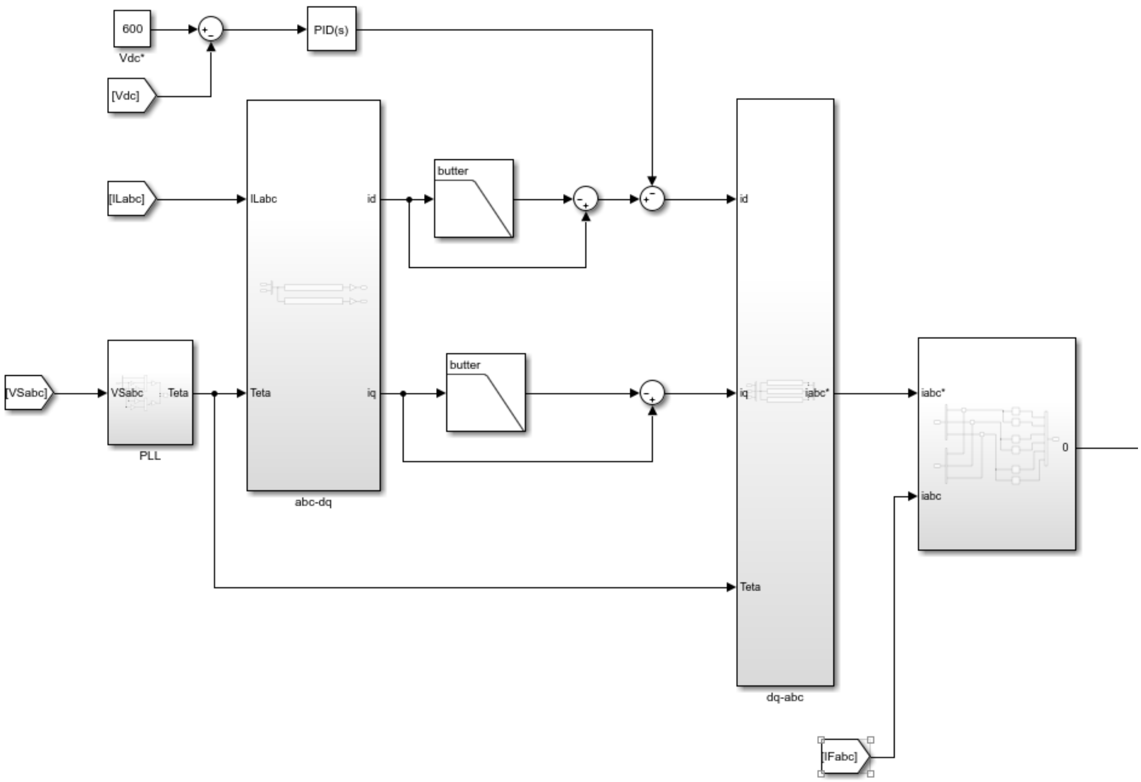


Figure 9: Controller for Active Power Filter

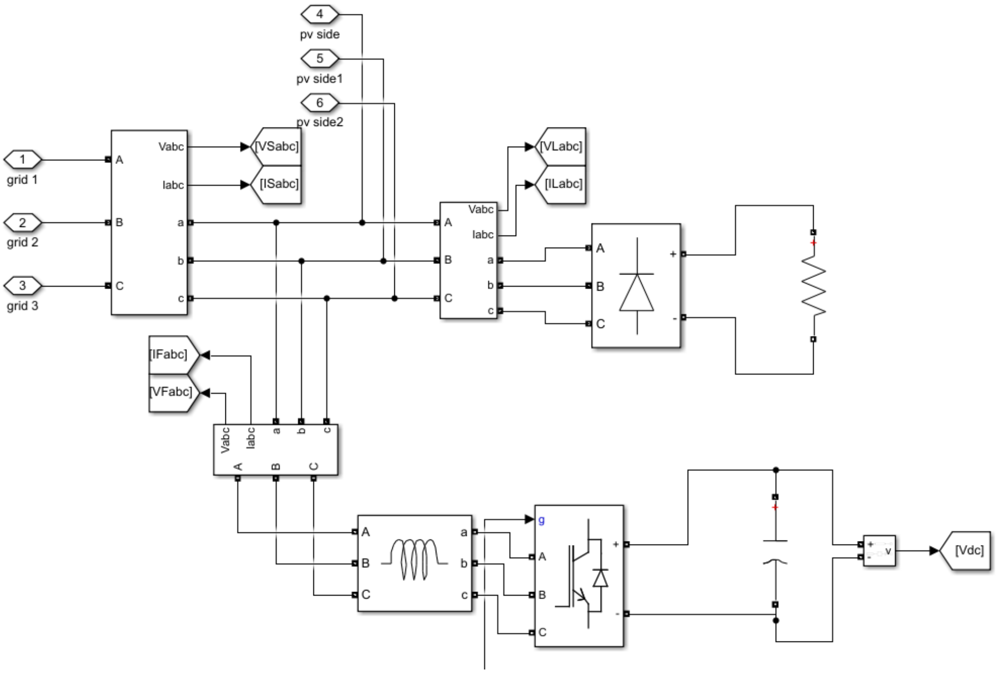


Figure 10: Simulation Circuit of Active Power Filter

Active power filter connected with the photovoltaic system

Figure 11 represents the circuit from PV panel to utility grid. It follows the block diagram in Figure 1

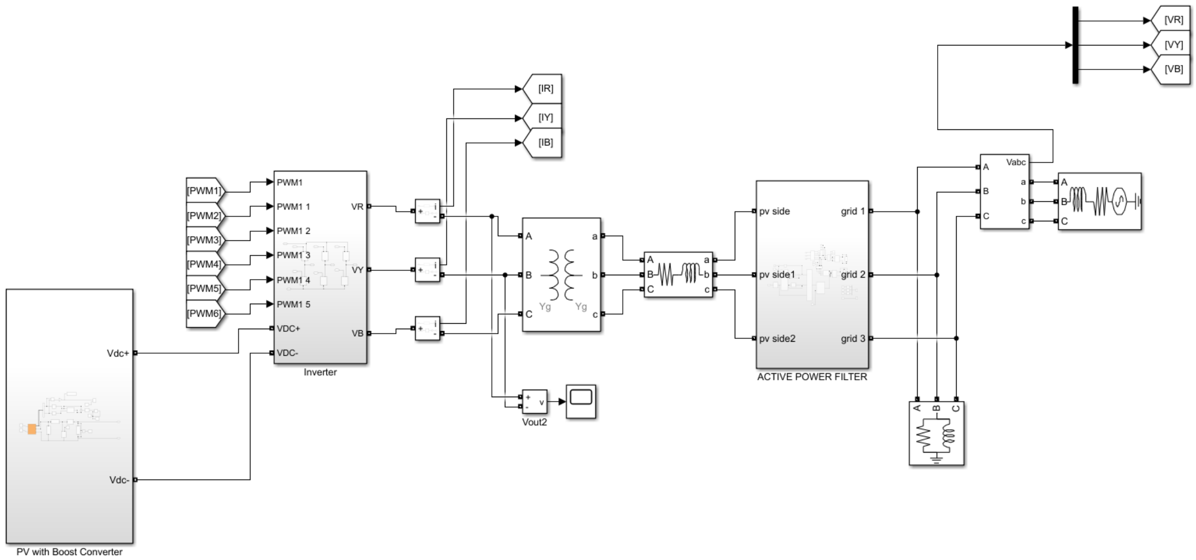


Figure 11: Photovoltaic circuit with Active Filter.

III. Result

The grid is connected with an RL load.Figure 12 shows the grid voltage of the photovoltaic system. The current from filter is a reference current which reduces the harmonics from 30.75% to 3.83%.

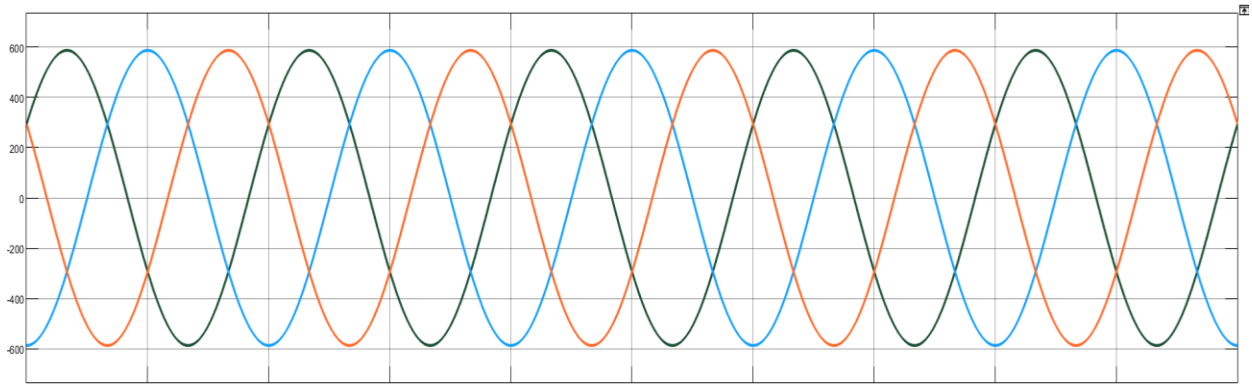


Figure 12: Three phase Grid Voltage.

The active filter designed to mitigate the harmonic, shows source current, load current and the filter currentfor a single phase in Figure 13, the filter current acts as a reference when connected to the grid to reduce the current harmonics. A photovoltaic system without active filter has higher percentage of current distortion in the system. When the filter is interconnected with the system it creates a reference current which is equal and opposite of the load current. Thus the load current is compensated.

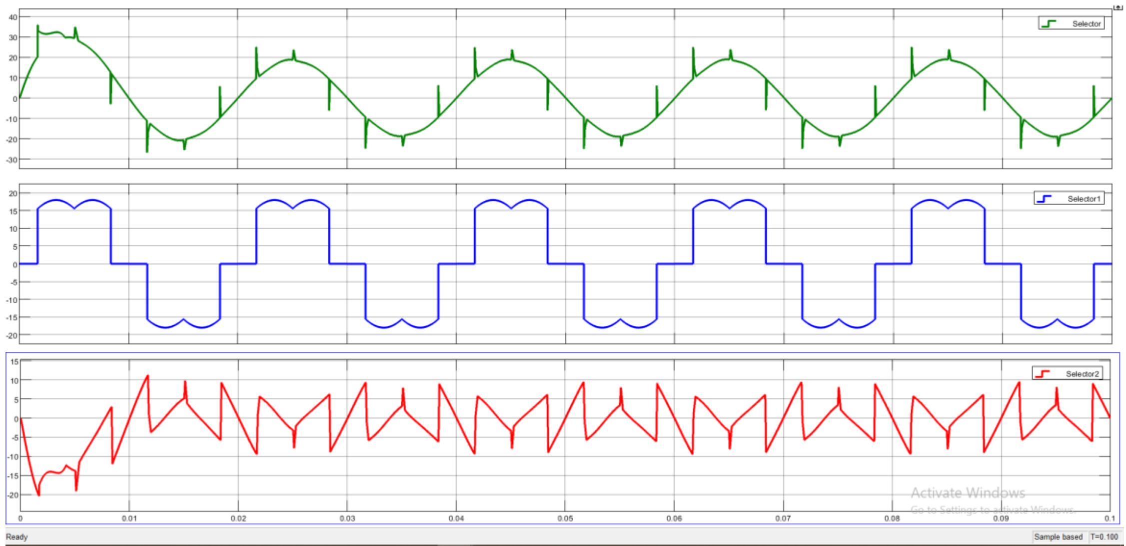


Figure 13: Active filter simulation; (a) Source current, (b) Load current, (c) Reference current from active filter.

Figure 14 shows the total harmonic distortion without introducing active filter to the system. After using the active filter with the connection from PV panel to grid, the harmonic distortion is reduced by 3.83%. The compensated harmonic output is shown in Figure 15.

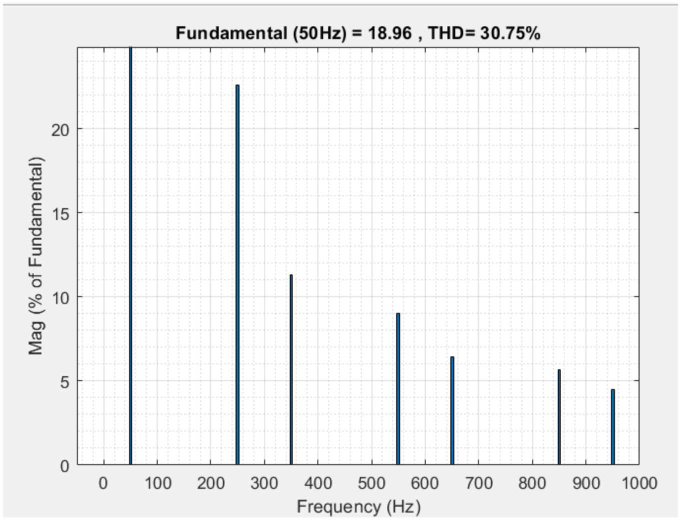


Figure 14: Total harmonic distortion without active filter

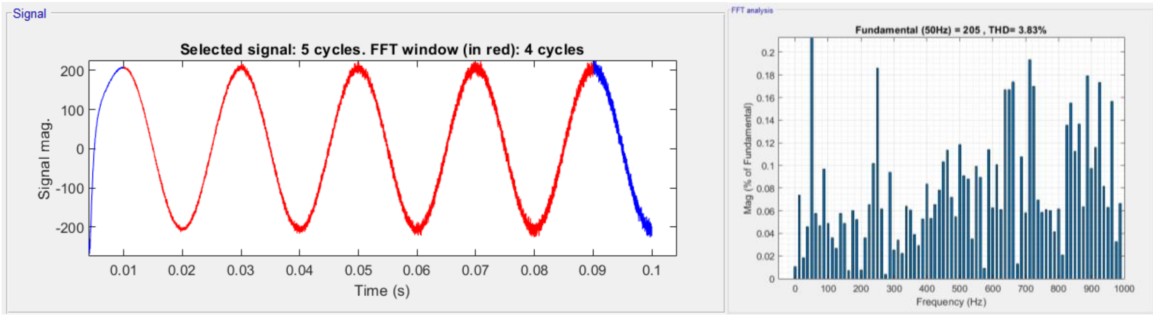


Figure 15: Total harmonic distortion with active power filter

IV. Discussion

Harmonic compensation is one of the most studied subjects in power quality improvement because the distortion of harmonics affects the system and loads harshly. Active filters, along with the PI-controlled voltage source inverters and converters are suitable for dealing with harmonic distortion and power quality of a system.

In the designed system, the DC-DC boost converter amplifies the dc voltage and extracts maximum power with the help of maximum power point tracking control (MPPT). The Perturb & Observe algorithm is used as MPPT. A hysteresis current controller creates perfect reference pulses for the inverters. Linear or non-linear loads can be connected to the system. The load current is fed to the active filter which creates a reference current with a 180° phase difference from the load current. The phase difference cancels the harmonics of the load current mitigating the harmonic distortion.

The FFT analysis in the tools of powergui block in MATLAB Simulink is used to analyze the total harmonic distortion of the signals. The system shows a total harmonic distortion of 30.75% before introducing an active filter. But an active filter connected to the grid eliminates most of the harmonics and shows a total harmonic distortion of 3.83%.

V. Conclusion

The power filters have been studied, improved, and implemented on power systems for a long time to improve the power quality. Both the active and passive filters are used to mitigate voltage and current harmonic distortion, compensating reactive power for better power factor and efficiency. Voltage source inverters that use IGBT for switching operations are being vastly accepted because of their ability to maintain energy standards. The active filter connected to the system reduced the harmonics up to the IEEE standard which is 5%. The components used in the system are regular components used in power generation. That makes the system cost-effective and efficient.

Active filters are popular because of their standard qualities as they do not get excessive loading. They can be of multiple combinations. High input impedance and low output impedance make the filters more compatible than other filters. The active filter is stable and less costly. Therefore, the proposed design with an active filter can be used in both standalone and grid connections for residential or industrial power generation.

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