EEEE

Analysis and Mitigated of Total Harmonic Distortion from Solar Panel into Smart Grid

Muhammad Abol Hassan Muhamad Diah[1], Suhaimi Saiman[1]*

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

Abstract: The advantage of this boost converter using after MPPT is to step-up an input voltage to some higher level as required by a load and the inverter is to convert DC to 3 phase AC source. The objective of this research was to simulate the power electronic circuit in a smart grid using MATLAB/Simulink software. Also, this research wants to analyze the harmonic distortion that can directly cause a smart grid. The result of this research showed the data of harmonic distortion before a smart grid. Also, the comparison results without using harmonic filter and harmonic filter are also shown in this paper.

Keywords: Harmonic Distortion, Solar Panel, Smart Grid

1. Introduction

Renewable energy is being used to help the problem of global warming. However, renewable energy is hard to control and if stays in large quantities it can give impact frequency fluctuations through the entire power system and also cause voltage fluctuations. Also, grid-connected photovoltaic (PV) systems have become a viable option in low-voltage networks due to the introduction of lucrative policy frameworks such as metering and significant cost reduction in PV system installation [1].

1.1 Total harmonic distortion

Firstly, it is about the destructive effects of harmonic distortion. When harmonic distortion enters a power system, its capacity to function at peak levels is harmed. Because of the increasing power demand, causes inefficiencies in equipment operations. Increased total current requirements result in greater installation and utility expenses, as well as increased heating and decreased profitability.

Harmonic distortions are usually voltage also the current abnormalities in electrical distribution networks happen by frequency fluctuations [2]-[4]. There are aberrations from the conventional sinusoidal changes in voltages or currents in the circuit. Nonlinear loads, such as those found in power electronic converters, are the primary source of harmonics. Harmonic distortions are becoming prevalent that happen in construction cause of the widespread use of computers and other power

devices. Harmonic distortions, in particular, can create many other problems added with damages, also in addition to wire overheating and power loss.

The nonlinear load and nonlinearity features of the electronic components are the major causes of harmonic distortions. The impedance of a nonlinear load varies with the supplied input voltage. As a result, distortions appear in the output signal. The nonlinearity characteristics of the components used in the circuit are also visible. This causes the harmonics in the output to develop as well. Due to harmonic distortions, the circuit generates heat and produces an output that is not equal to the input. Any circuit will be harmed by this impact.

2. Methodology

The first objective of this project is to simulate a power electronic circuit in a smart grid using MATLAB/Simulink software. Before deciding the value for every component in this circuit, need to calculate the best value from the PV array, boost converter, inverter and, 3 phase filter. After that, the simulation will be done.

2.1 Methods

The design and analysis of this project are separated into two stages, firstly, need to calculate the value of every component. After that, the simulation part will be done to analyze the output of the harmonic distortion. Firstly, from the PV array, it had set up the following properties: Maximum power Pmax is 213.15, maximum voltage Vmax is 12 volts, maximum current Imp is 7.35 amps, open-circuit voltage VOC is 36.3 volts and short circuit Isc is 7.84 amps. After that, the selection of one inductor and one capacitor with a resistor load is the first step in the design of a boost converter.

Input voltage, Vi = 32V

Output voltage, Vo =40V

Output power, Po = 200W

After that, from the equation, $Vo = \frac{Vs}{1-D}$, which is D represented as duty cycle was calculated to be 0.1. The value for the resistance as $R = \frac{Vo^2}{P} = \frac{40^2}{100} = 0.4\Omega$, the value of inductance as $L = \frac{D(1-D)^2(R)}{(2)(fs)} = 20\mu H$ and the value capacitance as $C = \frac{D}{(r)(R)(fs)} = 456\mu F$. Lastly, the switching frequency is chosen as Fs = 20kHz with time, $T = 0.02 \; x \; 10^{-3} s$.

At the output voltage that is 40V, so can continue to calculate for 3 phase inverter, at 180 degree, firstly for line voltage, use Van = V(3) which is 40(3) = 120V, Vbn = -2V/3 = -26.667mV and Vcn = V/3 = 13.333V. At 120 degrees, for line to line voltage, use Vab = V = 40V, Vbc = -V/2 = -20V and Vca = -V/2 = -20V.

Lastly, for calculating total harmonic distortion, the formula use is $V_{THD} = \frac{\sqrt{v2^2+v3^2}}{V^1}$ and $I_{THD} = \frac{\sqrt{I2^2+I3^2}}{I^1}$. From the calculation at Simulink, we get the THD volt equal to 37% and THD current equal to 0.32%.

Before design, we need to know the block diagram of the power electronics circuit. Figure 1 shows the block diagram to create this circuit.
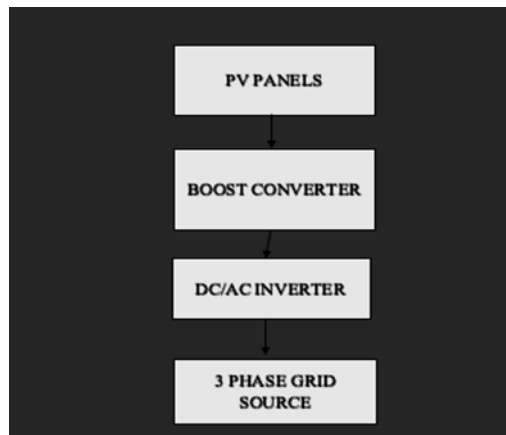
Figure 1: Block diagram of power electronic circuit

After knowing the block diagram, proceed to design the circuit. At first, planning design for PV panel, MPPT, Boost converter, inverter, and lastly for 3 phase filter. This design need to refer based on the calculation that has already been made. Figure 2 shows the setting and operating circuit using MATLAB/Simulink software.
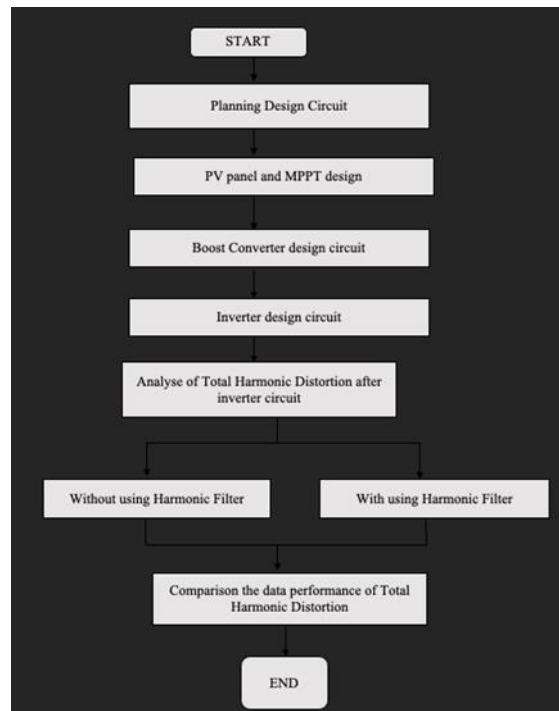

Figure 2: Setting and operating circuit using MATLAB/Simulink software

2.2 Simulation methods

Firstly, this chapter explains the creation of circuit using Simulink software. Every part of the PV panel, MPPT, buck converter, inverter was created part by part. Simulink software function is a computational unit that calculates a set of outputs when provided with a set of inputs. From the start, need to choose the Simulink in the MATLAB software and then find all the components in the block library. The process needs to do part by part based on the design were created before. Figure 3 shows the start of the simulation process.

Next, design and analysis of this power electronic circuit. Starting with creating a PV panel, then going to MPPT coding. After that, create a boost converter circuit and inverter circuit. After completing

all the circuits, then the simulation will show the result of the output harmonic distortion after the inverter and can be analysed from it. Figure 3 shows Simulink interface and Figure 4 depicts the completed circuit using MATLAB software.
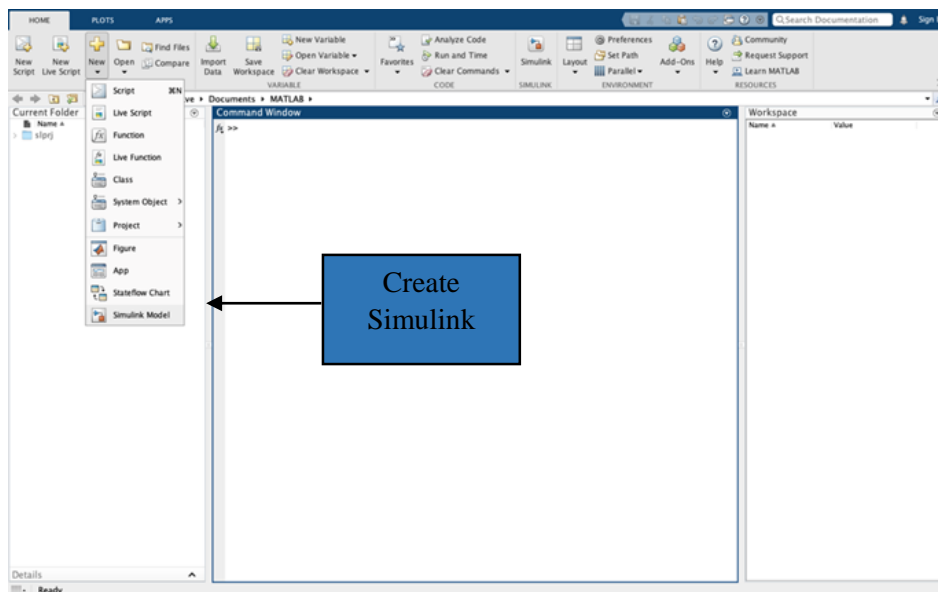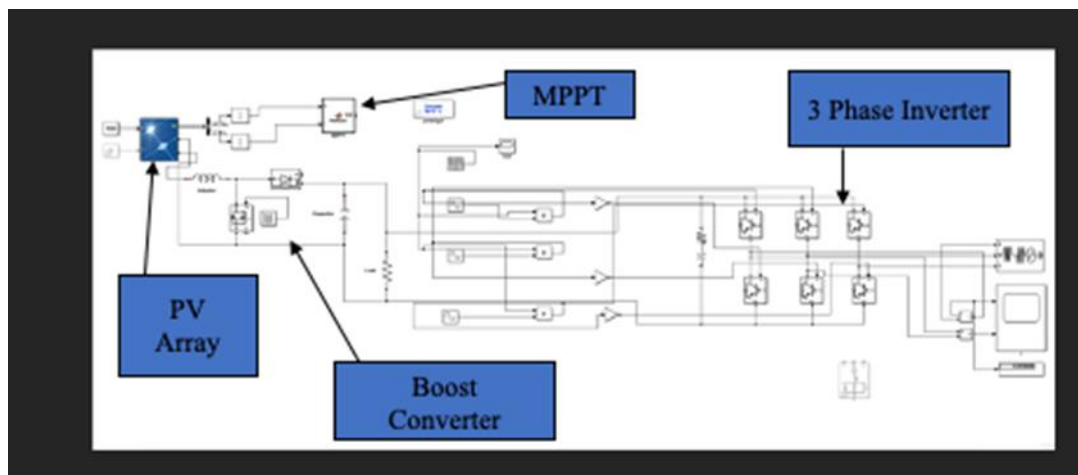

Figure 3: Simulink interface

Figure 4: Power electronic circuit using Simulink software

3. Results and Discussion

Figure 5 and Figure 6 show the data for total harmonic distortion that has been calculated. From Figure 4, input 2, that connected after the inverter shows the voltage harmonic after the 3 phase inverter. The THD is 0.32%. From Figure 5, at input 1, shows for current harmonic after the 3 phase inverter and the THD is 37.66%.

Figure 5, shows the sine wave of the current after the inverter. The input 2 selected measures the current after the inverter. The THD shows the value of 0.32% and the data shows the harmonics at harmonics from 2nd to 19th.

Figure 6, shows the sine wave of the current after the inverter. The input 1 selected measures the voltage after the inverter. The THD shows the value of 37.66% and the data shows the harmonics at harmonics from 2nd to 19th. The percentage of THD is high and at 5th with 8.54%.
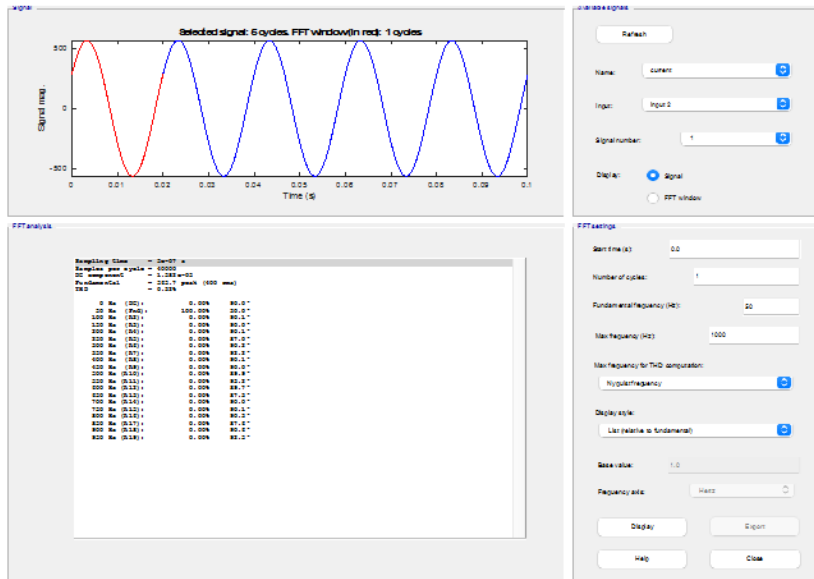
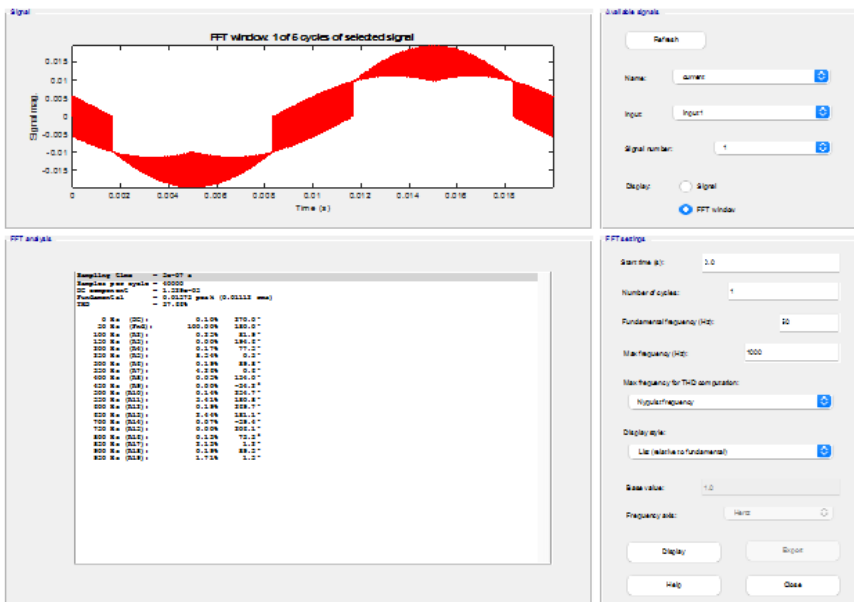**Figure 5: Current total harmonic distortion**

Figure 6: Voltage total harmonic distortion

3.1 Phase harmonic filter

For this project, use the passive harmonic filter. Figure 7 shows the new placement of power electronics which is 3 phase harmonic filter also known as bandpass filter been used. This power electronic is use to help reduce the harmonic distortion that occurs after the 3 phase inverter. This power electronic connected to 3 phase line to the load.

Figure 8 and Figure 9 shows the data for total harmonic distortion that has been calculated. For input 2, it shows the voltage harmonic after the 3 phase inverter. The THD is 0.25%. For input 1, it shows for current harmonic after the 3 phase inverter and the THD is 22.95%.

Figure 8 shows the sine wave of the current after the inverter. The input 2 selected it measures the current after the inverter. The THD shows the value of 0.25% and the data shows the harmonics at harmonics from 2nd to 19th. The value of THD is decreased after the bandpass filters was connected.
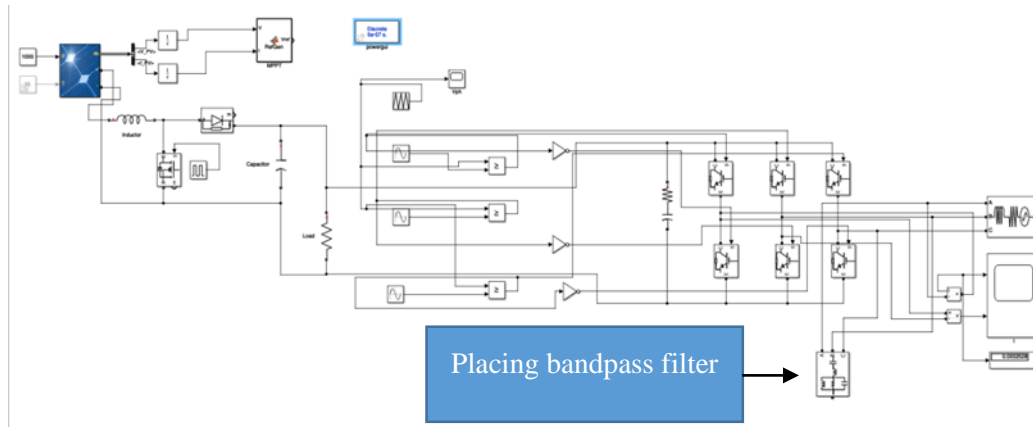
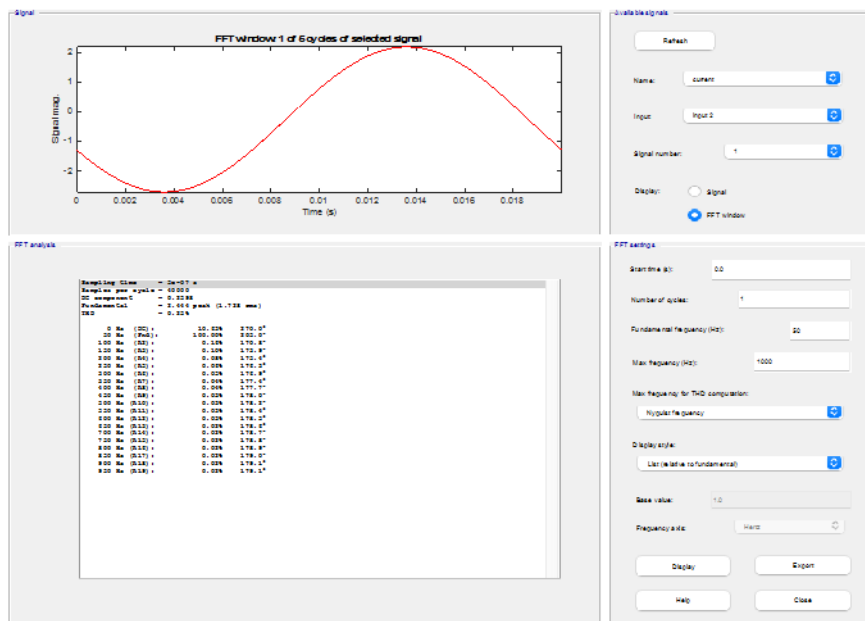**Figure 7: Power electronic circuit with 3 phase harmonic filter**

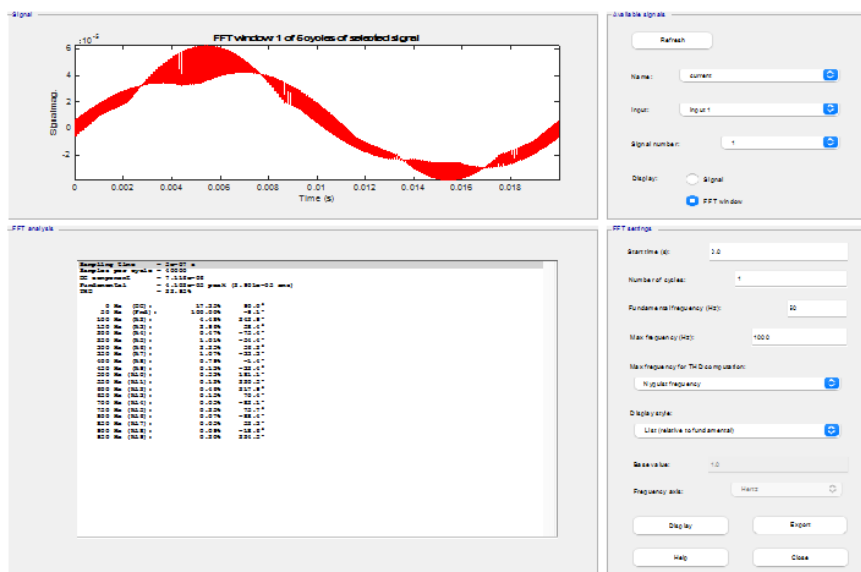**Figure 8: Current total harmonic distortion**

Figure 9: Voltage total harmonic distortion

Figure 9 shows the sine wave of the current after the inverter. The input 1 selected measures the voltage after the inverter. The THD shows the value of 22.95% and the data shows the harmonics at harmonics from 2nd to 19th. The value of THD decreased after the bandpass filters was connected.

Therefore, from Figure 9, the impact of the 3-phase harmonic filter helps reduce the harmonic distortion occur before. When the percentage of harmonic distortion decrease, it will help to improve equipment life, reduce heat loss and reduce utility costs. The table below shows the difference in the circuit after being analyzed. Table 1 shows the efficiency of the bandpass filter to reduce the harmonic distortion.

Table 1: Data of THD in the power electronic circuit

Circuit	Voltage THD(%)	Current THD(%)
Without bandpass filter	37.66	0.32
With bandpass filter	22.95	0.25

3.2 Discussions

This project has shown the difference of result total harmonic distortion in the simulation result. Without using 3 phase harmonic filter, the total harmonic distortion is higher. The percentage of THD is higher after the inverter cause of the change in signal and phase. This is because a voltage or current that is periodic but not purely sinusoidal will get a higher frequency in giving a harmonic distortion signal.

For more general, the stronger the harmonic components are the more harmonic distortion will have. Also, the same with the less than a periodic signal looks like a sine wave. Harmonic distortion is always produced from nonlinear loads by the end-users of electricity usually that is the majority from power electronic devices that draw current in a nonsinusoidal manner. So from this project, using 3 phase harmonic filter will help to decrease the harmonic currents flowing and harmonic voltage distortion in the system. From this project, the passive harmonic filter is selected to help suppress the harmonic disturbance in the system.

4. Conclusion

Based on this report, the conclusion is to analyze and mitigate the harmonic distortion occurs before 3 phase source. This project, using simulation software, shows the reduction of harmonic distortion before and after using 3 phase harmonic filter. The output of harmonic distortion needs to be reduced to reduce equipment life, utility costs, and other else. Therefore, further research analyze and mitigate the harmonic distortion by using another harmonic phase filter can be done to improve the decreasing amount of harmonic distortion.

References

[1]   Ahsan, S.M.; Khan, H.A.; Hassan, N.-U.; Arif, S.M.; Lie, T.-T. Optimized power dispatch for solar photovoltaic-storage system with multiple buildings in bilateral contracts. *Appl. Energy* 2020, *273*, 115253.

[2]   "Investigation into execution of harmonic guidelines for household and office electric applications," *Japanese IEE of Japan SC77A Domestic Committee Report*, 2002.

[3]   T. Key and J. S. Lai, "Analysis of harmonic mitigation methods for building wiring systems," *IEEE Transactions on Power Systems*, vol. 13, no. 3, pp. 890–897, 1998.

[4]   H. Farooq, C. Zhou and M. E. Farrag, "Analyzing the harmonic distortion in a distribution system caused by the non-linear residential loads", *International Journal of Smart Grid and Clean Energy*, pp. 46-51, Jun. 2012.