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RESEARCH ARTICLE OPEN ACCESS

Solar Energy as a Reactive Power Compensatoron the Four Wires Three-Phase Power System

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ABSTRACT
This paper presents a reactive power compensation modeling using renewable energy from sunlight through photovoltaics. The target is to eliminate harmonic signals on the power grid using an active power filter. The filter injects a compensatory current into the grid. The energy injected into the grid comes from the photovoltaic link direct current output voltage stored in the capacitor via a Voltage Source Inverter switch. The compensation energy level is regulated by the controller to keep it at a value that matches the network requirements. Integral Proportional Controller is implemented for steady state handling. It takes four insulated gate bipolar transistor devices for the Voltage Source Inverter on the power grid and to compensate for the reactive power to the power system. The reference signal generation uses the synchrounous reference frame method, while the controller is used as a direct current link controller. Simulation modeling by Matlab Simulink Tools. The simulation shows a significant reduction in Total Harmonic Distortion, where the electricity network before compensation is around 30.04% and after injection is 2.92%. So that this modeling deserves to be proposed as an active filter in a power system.

Keywords-Harmonics, photovoltaic, reactive power compensator, shunt active filter,syncronous reference frame

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I. INTRODUCTION

Various forms of electric power that are consumed by loads on an electrical network both on a single-phase power grid and a three-phase grid sometimes have patterns that change. This is caused by changes in load properties, namely from linear loads to non-linear loads. The use of non-linear loads such as power electronic devices, motor speed drives, electronic converters, energy saving lamps, results in distortion of the line current waves. This results in the emergence of harmonic waves which have a frequency that is a round multiple of the fundamental frequency, which is called the mesh disturbance due to harmonics .[1][2][3][4].

In a linear load, the energy that is attracted by the load has the same shape as the power transmitted by the source, which is in the form of a sinusoid. However, in non-linear loads, the form of electric current consumed has a non-sinuoside form. So that this defective wave format can reduce the power factor and the resulting adverse effects are very detrimental, including increased overheating of distribution transformers, disruption of the performance of electrical equipment, interference to telecommunication lines with neutral wires, and the possibility of power cut. This serious problem must be addressed immediately, including preventing the occurrence of harmonics generated by the use of electronic equipment with a filter.

Several researchers have developed the use of renewable energy as a compensator for reactive activity in power systems in reducing the harmonic content. Photovoltaic is used as a converter of sunlight to a DC voltage source and used to inject active power has succeeded in reducing the THD level by 2.01% [1]. Other researchers designed a fuzzy logic-based control to control the compensatory current from active filters connected to renewable solar energy, and provide an uninterrupted power supply for consumers. In theirpaper designed a level three active filter to reduce the consumption of utility by sharing the same load with photovoltaics to generate real power to meet the load demand. The THD index can be lowered by 2.12%. [2]. Scientists further developed the active filter method connected to photovoltaics to balance the power and reduce the reactive power of the system. The result is that at irradiance above 800 the filter works well in providing active power to the load and at radiance below 400 the active filter acts as a harmonic filter.[12]. This research presents a parallel active power filter in a three-phase four wire power system to eliminate the effect of harmonics due to the use of non-linear loads with a PV module compensator. The simple method of this filter is to inject an antiharmonic signal through a Voltage Source Inverter (VSI) circuit which acts as a parallel active filter. The compensation current that is injected into the grid comes from the energy storage (battery) which is charged by photovoltaics using the help of sunlight. The photovoltaic voltage regulation is controlled by the PI controller. Mathematically, this active filter can be expressed as the relationship of three electric currents which are stated in equation 1 below:

$$I_S = I_L - I_C \qquad (1)$$

where

I_S = current source
I_L = load current
I_C = compensation current

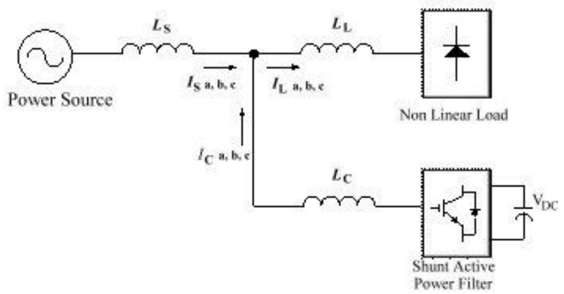

Figure 1. Parallel active power filter concept

Shown in Figure 1 is a simple concept of a parallel active filter, consisting of three main parts, namely a three-phase line voltage source, a non-linear load in the form of a three-phase diode rectifier and a voltage source inverter as an active power filter arranged in parallel with the load. Ic is the current that comes from the money-saving battery charged by the PV module.

1.1. TOTAL HARMONIC DISTORTION (THD)

Total Harmonic Distortion (THD) is the percentage value between the total harmonic components and its fundamental components. The greater the THD percentage, the greater the risk of damage to equipment damage to the current and voltage. The THD value permitted internationally is a maximum of 5% of the fundamental frequency voltage or current.[13][14] To find the THD value of the voltage, the equation can be used [15][16]:

$$THD = \frac{\sqrt{\sum_{h>1}^{h_{max}} M_h^2}}{M_1} \qquad (2)$$

WhereM_h is the rms value of the harmonic component h in the sum of M.

II. RESEARCH METHODS

This research was conducted by making a parallel active power filter system modeling using the Simulink Matlab Tools. There are two main simulated models, namely the system model which is loaded with nonlinear loads when it has not been injected with the recreational power and the system model when the reactive power is compensated. The proposed active filter design is shown in Figure 2 which consists of several main parts, namely, three-phase four-wire voltage source, non-linear loads in the form of a diode rectifier, photovoltaic module, battery, Dc-DC converter, voltage source inverter, voltage and current sensor block, as well as the power filter controller section. In the system model before injection, reactive power only consists of two main parts, namely a three-phase four-wire voltage source and a non-linear load of the diode rectifier, while in the power filter circuit modeling after injection it is the connection of all parts of the circuit.

Table 1. System Design Parameters

Power system discription	Value
PV Voltage	213 V
Baterrai Voltage	500.5 V
Capasitor voltage	500 V
Power Source	220/380 V
Load	Diode rectifier R= 10 ohm, L = 10 mH
Reactor	3.3 mH
Source Impedance	0.1 ohm 0.1 mH

The parameters of the simulation results to be analyzed are the channel current waveform, load current, compensation current and THD index.

2.1. Photovoltaic and DC Link

Photovoltaic is a power electronic device capable of converting solar energy into electrical energy. PV micro inverters are attractive and are a focus of extensive research in both academia and industry.[17][18]. PV technology offers many advantages: immaculate, renewable, ease of implementation and subject to impotent external noise since there are no moving components [12] .Some of the supporting equipment needed in the conversion process needs to be added to this series. The finding suggests the current quality from the inverter is highly dependent on the level of inverter output.[19]. The goal is that the resulting voltage and current are in a stable condition both when the device is exposed to sunlight or not. The supporting components include:

1. Accu as Energy Storage or electrical energy storage with power capabilities that are tailored to the energy requirements demanded by the load.

2. Solar Charge Controller (SCC) functions to regulate charging of electric current to the battery generated by the PV module.
3. Voltage Source Inverter (VSI) is a unit for converting direct electricity (dc) into alternating electricity (ac). The capacitor is installed in parallel with the VSI to drain the electric charge from the battery in the form of fluctuating reactive power to the nets, meaning that the power supplied is in two cycles, namely a positive cycle and a negative cycle.
4. Position Panel Regulator is a supporting element for adjusting the position of the PV module so that it can receive maximum sunlight.

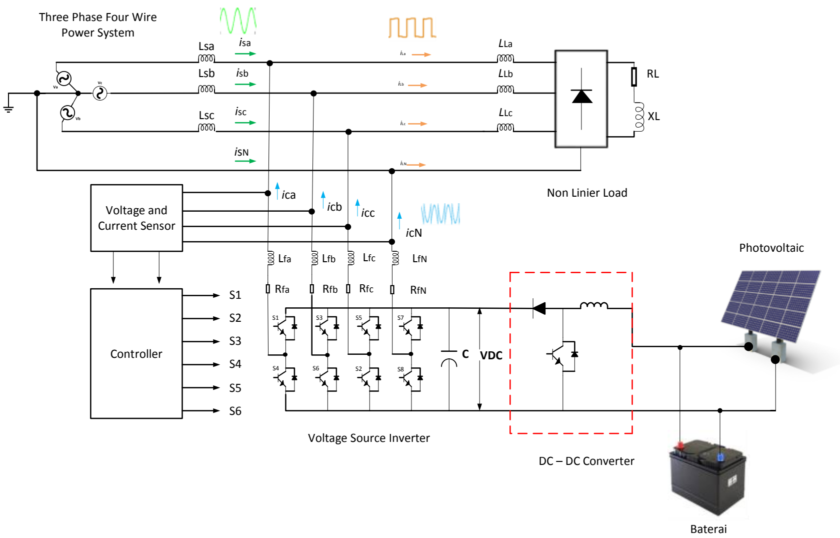

Figure 2. Photovoltaic Integrated Active Power Filter System

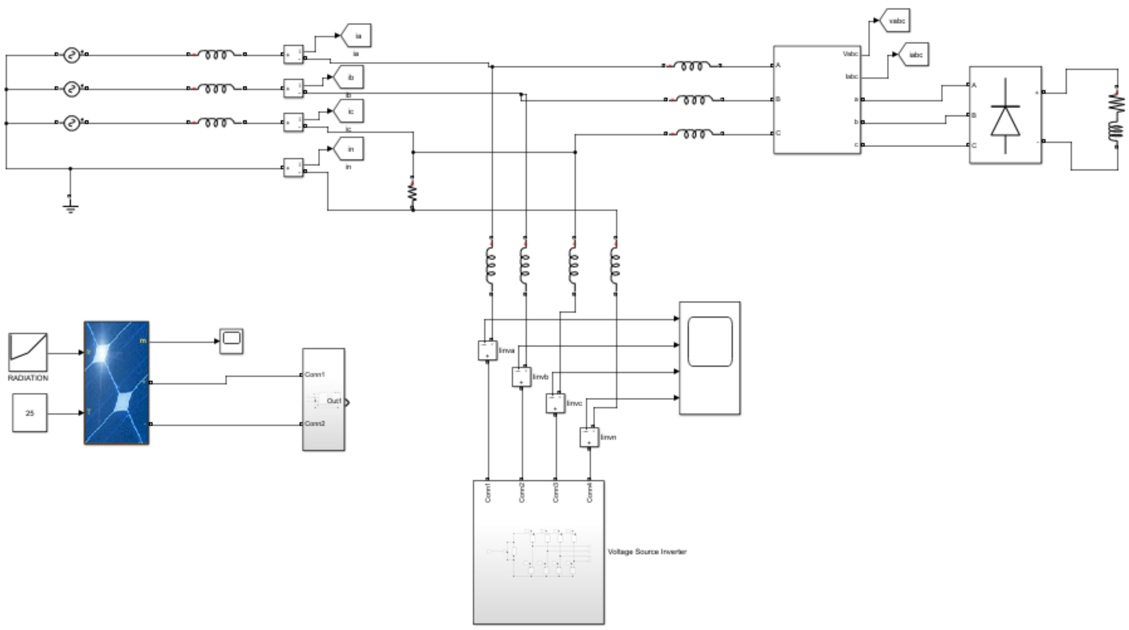

Figure 3 Modeling of active power filter system using solar cell

Figure 3 shows the modeling of a system built using the Matlab Simulink tool.

Figure 2 Photovolatic converts solar energy into a DC electricity source which is then stored in a battery storage medium. The DC-DC converter serves to increase the DC voltage of the battery and keep the DC link voltage constant (800 V). During the daytime PV is designed to compensate the distribution system, while at night the task is taken over by the battery. The energy delivered by PV is only for compensation for reactive power, but when compensation is no longer needed this power is channeled to the battery for storage. The compensation current is obtained from the process of sending (discharging) and absorbing (charging) the energy of the chlorine charge which works to form a certain pattern with a fluctuating voltage.

2.2. Voltage Source Inverter (VSI) and Controller

VSI uses 8 IGBT transistors to distribute the compensating current from the capacitor to the grid. Three pairs of switches are connected to the phase wire line and one switch pair is connected to the neutral wire line. On the DC link side, two series capacitors are installed to serve and create an alternating current compensating wave pattern, and are connected in parallel with VSI. The generation of reference currents uses the Synchrounous Reference Frame (SRF) theory. PI controller is used to maintain the capacitor dc voltage so that it is always greater than or equal to the source voltage. The PI controller together with the hysteresis control are used to generate ignition pulses for 8 VSI switches in injecting the compensation current into the power system wire line.

2.3. Synchrounous Reference Frame (SRF) method for generation of Reference Flow

In the SRF theory, the load current is converted to dq coordinates using Clark's transformation. Calculation of the $i_{ca}, i_{cb}, i_{cc}, i_{cn}$ reference currents used to build a VSI switch gate ignition signal using the Synchrounous Reference Frame (SRF) method. Shown in Figure 4 the flow block and control signal generation reference system[4][5][9][20][21][22][23][24]

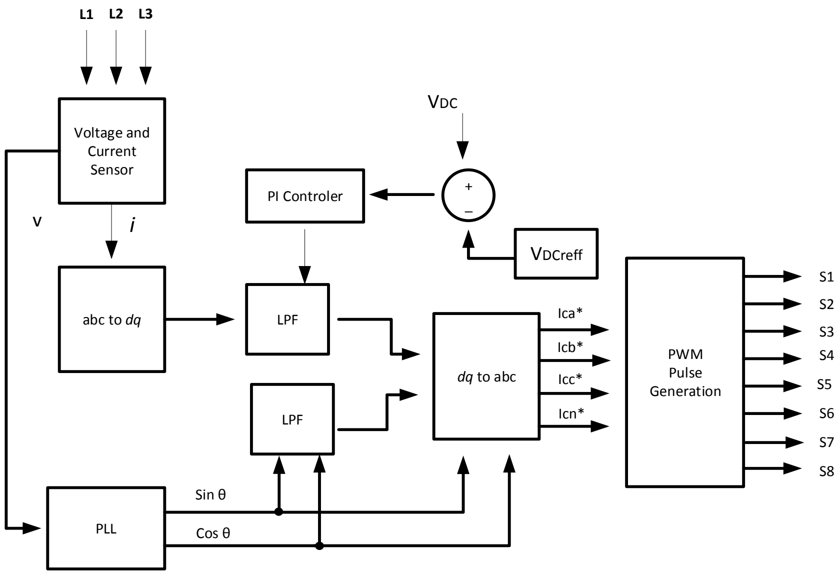

Figure 4. Generating reference current using the SRF method

The step of this method is to transform the source current magnitude (i_{Sa}, i_{Sb}, i_{Sc}) which is measured using a current sensor to obtain the magnitude of the instantaneous active component i_d and the instantaneous reactive component i_q through a calculation transformation in the abc coordinates converted to α-β coordinates. Equation 1 below shows the relationship between the ii_d, i_q and i_0 quantities with (i_{Sa}, i_{Sb}, i_{Sc}):

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin\omega_{st} & \sin\left(\omega_{st} - \frac{2\pi}{3}\right) & \sin\left(\omega_{st} + \frac{2\pi}{3}\right) \\ \cos\omega_{st} & \cos\left(\omega_{st} - \frac{2\pi}{3}\right) & \cos\left(\omega_{st} + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix}$$

…… (3)

Where $\boldsymbol{\omega_{st}}$ is the positive voltage sequence phase obtained from the Phase Locked Loop (PLL) section. PLL is a unit generating $\sin\omega_{st}$ and $\cos\omega_{st}$ functions at the fundamental frequency, which is harmonized with the basic component of the voltage measured from the voltage sensor. Active and reactive current components can be composed of DC and AC values in equation 2 below:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} i_{d_{dc}} \\ i_{q_{dc}} \end{bmatrix} + \begin{bmatrix} i_{d_{ac}} \\ i_{q_{ac}} \end{bmatrix} \quad (4)$$

$i_{d_{dc}}$ and $i_{q_{dc}}$ are the components supplied by the source while $i_{d_{ac}}$ and $i_{q_{ac}}$ are the harmonic components of the load current.

The reference currents i_{ca}, i_{cb}, i_{cc} are obtained from back transformation into the abc coordinates, as shown in equation 3.

$$\begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} = \begin{bmatrix} \sin\omega_{st} & \cos\omega_{st} \\ \sin\left(\omega_{st} - \frac{2\pi}{3}\right) & \cos\left(\omega_{st} - \frac{2\pi}{3}\right) \\ \sin\left(\omega_{st} + \frac{2\pi}{3}\right) & \cos\left(\omega_{st} + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} i_d^* \\ i_q^* \end{bmatrix} \quad (5)$$

While $i_{cn} = i_{ca} + i_{cb} + i_{cc}$ (6)

2.4. PI controllers

PI control is a control whose control action has proportional and integral properties to the error signal. In a system design that is built, the DC link voltage (VDC) capacitor regulates the peak value of the reference current. The capacitor voltage (VDC) compared to the reference voltage (VDCref) coming from the PV results in an error value. This error value is processed by the PI controller to produce a zero steady error in each reference current pattern. The output of this PI control is a peak value consisting of the active power component of the load and the loss component of the power filter to keep the capacitor voltage constant.

2.5. VSI Gate Startup Pulses

VSI requires a trigger signal to start working to flow the compensation current to the power system network. The signals is obtained from the processing of the reference current by the hysteresis current control unit. This controller is used to compare the actual source currents ($i_{Sa}, i_{Sb}, i_{Sc}, i_{Sn}$) and the compensating reference currents (i_{ca}, i_{cb}, i_{cc}) to obtain the trigger pulses for VSI. Figure 5 illustrates that the generation of gate pulses .The current control hysteresis method works based on the PWM (Pulse Width Modulation) rules. This controller will issue a single logic pulse if the actual current is greater than the carrier current (PWM carrier) and will issue a logi-1 pulse if the actual current is smaller than the carrier current. These trigger pulses are at the reference current bandwidth. (1). To serve a complementary VSI switch pair, the output pulses from this controller are reversed with a NOT gate. Thus, it takes four pairs of hysterical current controllers that produce eight kinds of trigger pulses.

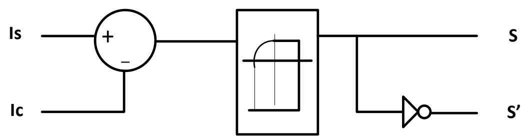

Figure 5. The method of controlling the width of the hysteresis current

The on and off times of the four switch pairs form a pattern of injection current flow from the DC VSI link voltage source. [7][25]

III. SIMULATION RESULTS AND DISCUSSION

Observations of the system modeling simulation before injection are in the form of line current waves and load currents that have a defective or distorted sinusoidal format.

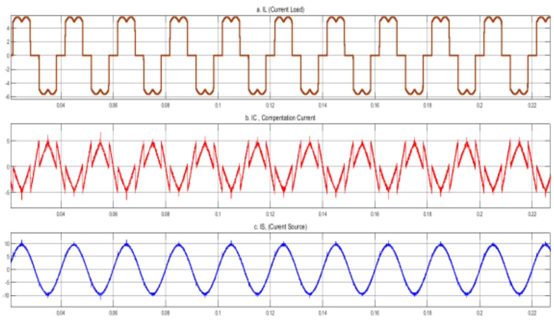

Figure 6. Load Current, Compensation Current, Line Source Current

Figure 6a explains that the load current is in the form of a sinusoid current that is not smooth (pure sinusoid). This shape resembles a square wave which is defective at the peak of the positive cycle and the peak of the negative cycle. This defective wave is caused by harmonic currents that arise due to the performance of the diode in rectifying the voltage source. The harmonic current has an odd multiple of frequency to the frequency of the input voltage source with a certain amplitude, so that the source channel current becomes no longer sinusoid. Figure 6b is the compensation current generated by the performance of the VSI switch in the form of a curved taper wave with the same frequency as the harmonic wave but with a 180^0 phase difference.This current comes from the charge flow of the DC Link capacitor which transmits energy to the mesh. This compensating current wave is a fluctuating capacitor voltage pattern and is determined by the time the VSI switch is on and off or ON - OFF. Whereas in Figure 6c is the source channel current wave which is kept in a sinusoidal format. Although this source line current is not smooth sinusoidal, and there is little ripple, the existence of this defect is still allowed in a power system. In this study, the wave defect is only found in the line current while the source line voltage is maintained in the form of a smooth sinusoid. So it can be said that current harmonics do not always result in voltage harmonics, but voltage harmonics will always result in current harmonics.

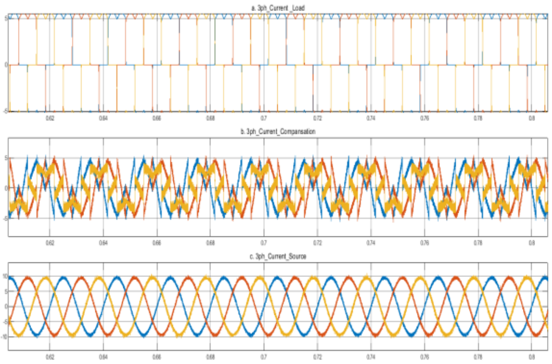

Figure 7. Load Current, Compensation Current, Three-phase source line current

Figure 7a is the three waves of load current, compensating current, and three-phase source channel current where each wave has the same shape, amplitude and frequency, but has different phases by 120^0. Neutral current is very small and almost close to zero. Figure 7b is the four components of the $i_{ca}, i_{cb}, i_{cc}, i_{cn}$ compensation currents which have almost the same pattern apart from the neutral current compensating current. The maximum amplitude is around 7 A. Figure 7.c shows the channel current waveform of each channel source which is close to a sinusoid and has 120^0 phase differences.

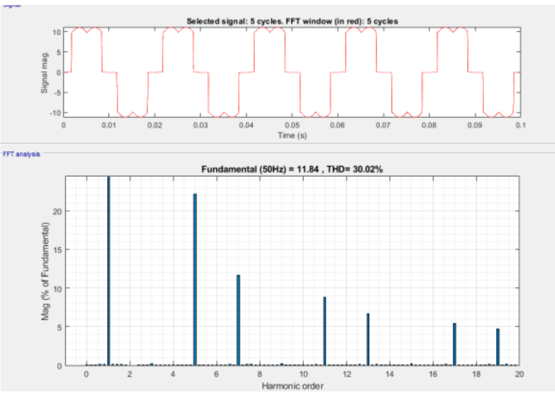

Figure 8. THD index before injection

Figure 8 shows that the THD index of the power system current is 30.02%. This quantity is the THD level of the power system before injection and the value is quite large. The harmonic waves that introduce the mesh are in the order 5,7,11,13, 17 and 19 or at frequencies (250 Hz, 350 Hz, 550 Hz, 650 Hz, 850 Hz and 950 Hz). The comparison of the amplitude of the harmonic wave to the amplitude of the source line voltage is 22.5%, 11.25%, 9%, 6%, 6.5% and 4.5%, respectively.

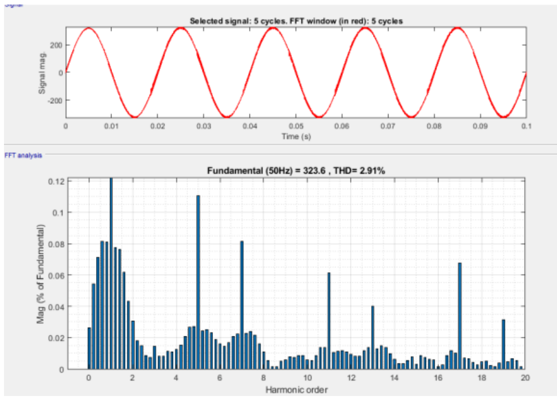

Figure 9. THD index after injection

Figure 8 shows that the THD of the power system after injection decreased significantly by 2.91%. The amplitude of the harmonic wave can also be reduced to a very small level below 1% of the amplitude of the source channel wave. It appears that the amplitudes of the 5,7, 11,13,17, and 19 harmonics are at the level of 0.104%, 0.085%, 0.063% and so on. So it can be said that this modeling has succeeded in reducing the THD of the system very significantly.

IV. CONCLUSION

Active power filter system modeling using solar energy sources as a compensator for reactive power has been simulated successfully. The solar energy is converted using photovoltaic into a DC current source and stored in the battery which is used to inject reactive power into the mesh through a DC link capacitor on the Voltage Source Inverter (VSI). The voltage generated by the battery is amplified by the booster unit at 500.5 V DC. The filter system can work normally if the minimum battery voltage value is the same as the DC link capacitor voltage. Reactive power compensation can only occur during the day. The simulation results show that the system's THD can be significantly reduced, from 30.02% down to 2.91%. This indicates that this modeling is feasible to be implemented as a power system. For further research, this power filter system can be developed to make the reactive power compensation control valid throughout the day, namely during the day and night. Research development on this topic can also be applied to single-phase power systems.

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