International Journal of Scientific Research in Science and Technology
Print ISSN: 2395-6011 | Online ISSN: 2395-602X (www.ijsrst.com)
doi : https://doi.org/10.32628/IJSRST

Construction And Performance Analysis of PV-ZSI Based Shunt Active Filter for Power Quality Enhancement in Grid Connected Systems

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Article Info

Publication Issue
Volume 10, Issue 1
January-February-2023

Page Number
223-231

Article History
Received : 10 Dec 2022
Accepted: 10 Jan 2023
Published: 30 Jan 2023

ABSTRACT

In this research work presents a single stage solar photovoltaic (PV) connected Z-source inverter (ZSI) based shunt active filter for power quality improvement. The power quality plays virtual role in distribution and transmission systems. Because of power quality issues system stability effected, to overcome these issues here introduced a PV-ZSI shunt active filter. The ZSI is more accurate in operation compared to VSI. The ZSI have a unique feature there is no need of additional boost converter compared to conventional two stage solar photovoltaic (PV) connected voltage source inverter (VSI). Here employed PI regulator to produce reference current, this current and actual current are given as inputs to the hysteresis current controller to produce gate pulses for ZSI. In this work presents comparison between single stage solar photovoltaic connected Z-source inverter based shunt active filter and two stage solar photovoltaic connected voltage source inverter also. The entire proposed system Implemented and tested in MATLAB/SIMULINK software.

Keywords: photovoltaic (PV), Z- source inverter, power quality, voltage source inverter (VSI), shunt active harmonic power filter (SAHF).

I. INTRODUCTION

Power demand has increased significantly over the past few decades, prompting decision-makers to explore for alternative power sources like renewables. Generally speaking, the market for solar energy is expanding, particularly when it is directly converted into electricity. The major goal was to maintain a weak power grid or power off-grid locations. Other uses are now being developed, which increases the value and appeal of renewable energies. Power grids now have to satisfy more stringent standards for power quality due to the widespread use of power electronics devices. The majority of receivers are nonlinear loads, which results in large harmonic currents that could overheat equipment, increase line losses, saturate distribution transformers, and disrupt nearby communication systems. The problem gets worse if the load or the voltages in the power supply are out of balance [1].

Problems with current and voltage quality are at the heart of power quality issues. Shunt type active power filters (SAPFs) are used to solve current quality problems whereas series type active power filters are used to solve voltage-related difficulties. According to reports, hybrid filters, which combine active and passive filters, are also used in conjunction with active filters to improve power quality. In essence, active filters inject the proper current into the grid for reactive power adjustment and harmonic reduction. The SAPF's most crucial role is to find the load harmonic component in order to do the compensation. The control approach solely determines how to extract the harmonic components of the load current. The dynamic performance of the SAPF is accelerated by a quick, easy, and precise extraction of load current harmonics utilising a control technique. As a result, the SAPF's response time and overall performance are determined by the choice of an appropriate control technique [2].

DC electricity is generated by photovoltaic systems when sunlight hits the PV array. An inverter, which is utilised in several applications such as battery charging, water pumping, street lighting, etc., may transform the DC power generated into AC power. There are two types of solar PV systems: grid-connected PV systems and stand-alone PV systems. Stand-alone systems are independent and not connected to any utility power lines. The utility grid will interact with a PV system that is connected to it. The benefit is that power can be obtained from the utility grid and that PV systems can provide backup power when the grid is down. As of right now, solar panels are not particularly effective at converting sunlight into electrical power; efficiency may further decline as a result of factors including solar radiation, temperature, and load conditions [3].

To solve the aforementioned issue, a dc-dc boost converter is suggested to be used between the inverter and dc link capacitor. Applying a Boost converter results in an increase in volume, cost, and system integration, as well as a drop in efficiency and an increase in losses. The ZSI is a brand-new inverter that was just introduced as an alternative to traditional inverters. It has certain unique features. The investigation of ZSI-based DVR for in-phase voltage sag compensation. Here, the ZSI's boost capability is exploited to make up for the voltage drop in the energy storage element. Due to the ZSI's straightforward control mechanism, this system requires too many power electronics components and huge passive parts, resulting in high voltage stress levels. As a result, high power switches are needed [4]. The system's main component is the control. ZSI is managed by both the AC side and the DC side. Due to the fact that the input comes from distributed generators, which do not provide constant power, it is crucial to maintain a constant voltage by adjusting the capacitor voltage in the ZSI impedance network, which generates a shoot-through signal that is fed to the logic circuit. Similarly, AC side control is carried out to provide the systems' modulation index [5].

Traditional inverters with voltage and current sources have drawbacks such they can't be shorted or open circuited, respectively. As a result, ZSI is free of this issue. An impedance network made up of two inductors and two capacitors is a component of the ZSI. For the opposite operation of ZSI, proper impedance network design is crucial, and as a result, the values of the inductor and capacitor are assessed using steady state equations. To achieve the desired operation of power electronic converters, an adequate control approach is necessary [6].

V-source converters are frequently employed. However, it has the following theoretical and conceptual constraints.

- The original dc voltage that powers the dc inductor must be greater than the ac output voltage for the dc voltage to be produced; otherwise, the dc voltage is always less than the ac input voltage. As a result, the I-source converter is a buck rectifier (also known as a buck converter) for converting ac to dc power and the I-source inverter is a boost inverter for converting dc to ac power. An additional dc-dc buck (or boost) converter is required for applications where a large voltage range is desired. The extra stage of power conversion raises system costs and decreases efficiency.

- At all times, at least one of the higher devices and one of the below devices must be gated on. If not, the gadgets would be destroyed by a dc inductor open circuit. The open-circuit issue caused by the misgating-off of EMI noise is a significant reliability issue for the converter. The I-source converter requires overlap time for safe current commutation, which also results in waveform distortion and other problems [7].

The ZSI operates in two zero states, when the input terminals short circuited and also operates in six active states when dc voltage connected across three phase load. The load terminals are shorted by both the upper and lower switching devices of any phase leg, resulting in the ninth state, or the ST state (this state is forbidden in the traditional inverters to avoid ST fault). There are seven different ways to reach this ST state, which is occasionally also referred to as the "third zero state": ST through any phase, any two-phase leg combinations, and all three-phase legs [8].
In this research work ZSI is implemented Because of these unique features. This paper is organized as follows: In Section 2, the system description about PV and SAHF model, PV based SAHF system, Section 3. Proposed methodology, 4. Results and discussion.

II. SYSTEM CONFIGURATION

1) PV AND SAHF MODEL:

To make the voltage level adequate for the shunt active harmonic filter (SAHF) system, a DC-DC boost converter is attached to the output of the PV module, which is DC. By injecting an AC current with the same amplitude as the harmonics but phase-shifted by 180°, shunt AHF demonstrates to be a successful method of eliminating harmonics. This cancels out any harmonics in the source current.

A. Generalised PV Model

A solar module makes up a photovoltaic system, which uses the photoelectric effect to transform solar light energy into electrical energy. Figure 1(a) shows the equivalent circuit diagram for a solar cell, where Rse and Rs stand for series and shunt resistance, respectively. Figures 1(b) and 1(c) show the -V and P-V properties, respectively. The maximum power point of the PV cell, where the cell is at its most efficient, is represented by the points Vmp, Imp, and Pmax.

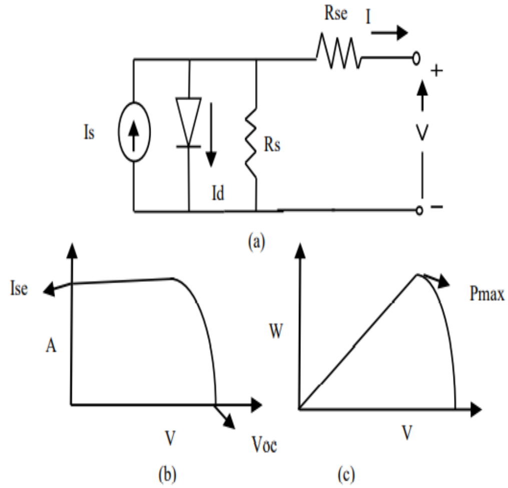


Fig. 1. (a).Simplified equivalent circuit diagram of PV cell (b) I-V characteristics of PV cell and (c) P-V characteristics of PV cell

The diode current given by Shockley equation is:

$I_d = I_S$[exp (qv/nkt)-1] (1)

Two limiting components of PV module i.e., Voc and Isc are determined by first setting V=0 to obtain Isc and then Voc is obtained by setting cell current I=0, thus equation (2.1) leads to:

$V_{oc} = nkt/$ Q ln $[\frac{I}{I_0}]$ (2)

The PV cell output varies with the sun irradiance, thus to ensure that the PV system is working at its maximum efficiency MPPT tracking algorithm is used. The maximum voltage point is obtained by:

D (V*I)/DT = 0 thus

$V_{mp} = V_{oc} - KT/$q ln [(V_{mp}/n KT/ q) +1] (3)

Form factor which is a measure of cell junction quality is given by

FF= ($V_{mp} * I_{mp}$)/ ($V_{oc} * I_{oc}$) (4)

The closure the value of form factor is to unity higher is the quality. Finally the efficiency of the PV module is given by:

η=FF$*\, V_{oc} * I_{sc}/P_{in}$ (5)

B. Generalised Active Power Filter

The non-linear load introduces harmonics components which are the integral multiple of fundamental component of the current. A SAHF compensates the harmonic by injecting current having same magnitude as the harmonics but having phase shifted by 180°, thus cancelling the harmonics and thus the load current becomes free of harmonics components.

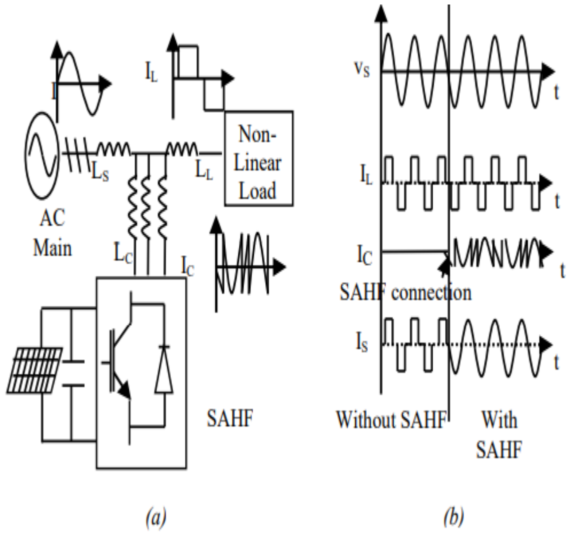


Fig. 2. (a).Schematic diagram of SAHF and (b). SAHF waveform

The instantaneous supply voltage is:

$V_s(t) = V_{sm} sin\omega t$ (6)

Source current is given by nodal analysis at PCC:

$I_s(t) = I_L(t) - I_h(t)$ (7)

I_L (t) is represented as

$I_L(t) = I_1 \sin(\omega t + \phi_1) \sum_{h=2}^{\infty} I_h \sin(n\, \omega t + \phi_t)$

(8)

Here the second term is harmonics component. The Instantaneous value of load power can be calculated from load current and supply voltage. The total Load power is calculated as:

$P_L(t) = I_L(t) * V_s(t)$ (9)

The real power is deduced from the load power, given as:

$P_f(t) = V_{sm} I_1 sin^2\omega t * cos\phi_1 = V_s(t) * I_s(t)$

(10)

The source current after compensation is:

$I_s(t) = \frac{P_f(t)}{V_s(t)} = I_1 \cos \emptyset_1 \sin \omega t = I_m \sin \omega t$

(11)

Here Ism is the peak amplitude of source current.

2) PV based SAHF system:

The block diagram of the PV-SAHF system is shown in Fig. 3. The SAHF system, which is connected in a shunt configuration with the nonlinear load, is powered by a PV array system that is implemented with a P&O MPPT controller. PWM-VSI controller is used to implement the SAHF. The switching pulse for VSI is produced using an adaptive hysteresis controller. The reference current is taken by the PI controller, which compares it to the supply current to produce a switching pulse. The supply current's harmonic components are introduced by the nonlinear load. In order to cancel the harmonics present in the source current and make it sinusoidal and in phase with the source voltage, the SAHF generates compensatory current that is of same amplitude to the source current but with a 180° phase shift. Sensing the reference current taken from the supply mains generates the compensatory current.

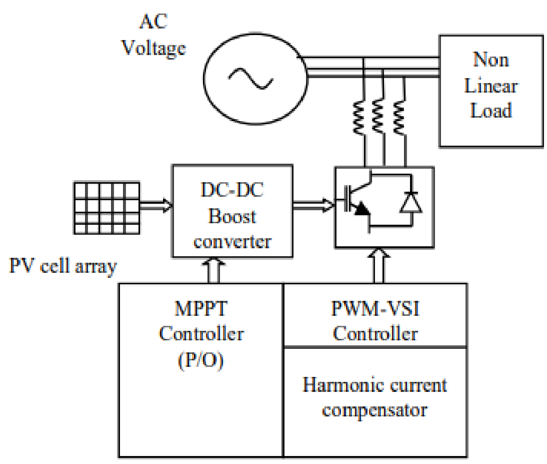


Fig. 3. Block diagram of PV- APF system

A. DC-DC Boost Converter

IGBT in a DC-DC step up converter is managed by a PWM signal produced by an MPPT controller. It is made up of an inductor and a conductor, both of which store energy. The current flows through the inductor and charges it by creating a magnetic field when the switch employing IGBTs is closed. The current decreases while the switch is open. To keep the load current flowing, the energy of the magnetic field generated will decrease. As a result, the inductor's polarity will change. The two sources are thus connected in series, raising the voltage that charges the capacitor through the diode.

The output of the DC-DC boost converter is

$$v_0 = v_S\{\frac{1}{1-D}\} \qquad (12)$$

Here V_o is the output voltage, Vs is the PV module output voltage, and D is the duty ratio of boost converter.

The PV cell output varies with the sun irradiance, thus to ensure that the PV system is working at its maximum efficiency MPPT tracking algorithm is used. The maximum voltage point is obtained by:

D (V*I)/DT=0 and thus,

$$V_{mp} = V_{oc} - \frac{KT}{q}\ln\{\frac{V_{mp}}{n}\text{KT/q}\} + 1 \qquad (13)$$

Here Vmp is the maximum power point voltage, K is the Boltzmann constant, q is the charge carrier, T is temperature in Kelvin and Voc is the open circuit voltage of PV module. The boosted output of PV module is DC which is then passed to a DC- AC converter so that it can be utilised by electrical utilities.

B. DC-AC Converter

In this model a three phase bidirectional dc/ac converter is used, it consists of six leg switches. Three arms of the inverter are delayed with 120° to generate a three phase AC supply. The semiconductor switches of the three arms VSI is gated through PWM pulses generated by SAHF controller. For extracting the reference current PI controller is utilised. The three phases of the supply current are evaluated with the help of unit sine vector template which is in phase with the source voltage.

The unit sine vector template is given as:

$$U_{sa} = \frac{V_{sa}}{V_{sm}} = \sin\omega t$$
$$U_{sb} = \frac{V_{sb}}{V_{sm}} = \sin(\omega t - 120^0)$$
$$U_{sc} = \frac{V_{sb}}{V_{sm}} = \sin(\omega t + 120^0) \qquad (14)$$

PI controller evaluates I_{max}, the magnitude of peak reference current. The evaluated peak current multiplies with the output of unit sine template to produce desired reference current:

$$I_{sa}^* = I_{max} * U_{sa}$$
$$I_{sa}^* = I_{max} * U_{sb}$$
$$I_{sa}^* = I_{max} * U_{sc} \qquad (15)$$

III. Proposed methodology

In this project two converters i.e., voltage source inverter and boost converters are replaced by Z-source inverter.

- A Z-source inverter is a type of power inverter, a circuit that converts direct current to alternating current. It functions as a buck-boost inverter without making use of DC-DC converter-bridge due to its unique circuit topology.
- Impedance (Z-) Source networks provide an efficient means of power conversion between source and load in a wide range of electric power conversion applications (dc–dc, dc–ac, ac–dc, ac–ac). Z-source-related research has grown rapidly since it was first proposed in 2002. The numbers of modifications and new Z-source topologies have grown exponentially. Improvements to the impedance networks by introducing coupled magnetics have also been lately proposed for achieving even higher voltage boosting, while using a shorter shoot-through time.
- They include the Γ-source, T-source, trans-Z source, TZ-source, LCCT-Z-source and utilizing high frequency transformer connected in series with two dc-current-blocking capacitors), high-frequency transformer-isolated, and Y-source networks. Among them, the Y-source network is more versatile and can in fact be viewed as the generic network, from which the Γ-source, T-

source, and trans-Z-source networks are derived. The incommensurate properties of this network open a new horizon to researchers and engineers to explore, expand, and modify the circuit for a wide range of power conversion applications.

Three primary factors make the Z-source inverter appealing.

- In voltage source inverter, the control topology is only PWM control but here Z-source inverter have two types control topologies i.e., module index and duty cycle control
- Z-source inverter act as boost converter as well as inverter operation. No need two stage conversion.
- Z-source inverter have more reliability compared to conventional converters.

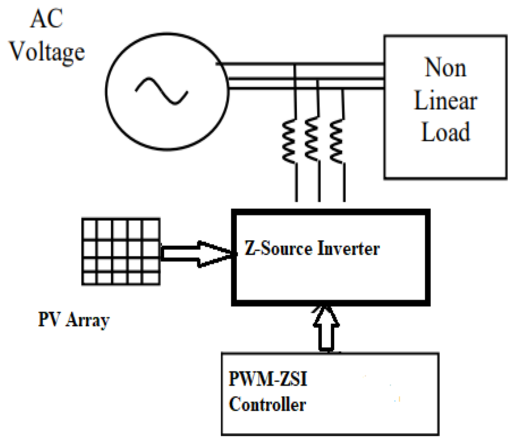
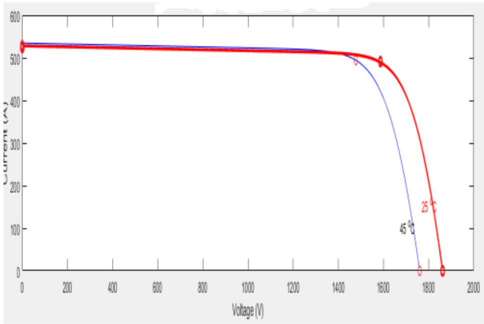


Fig 4. Block diagram of the proposed system

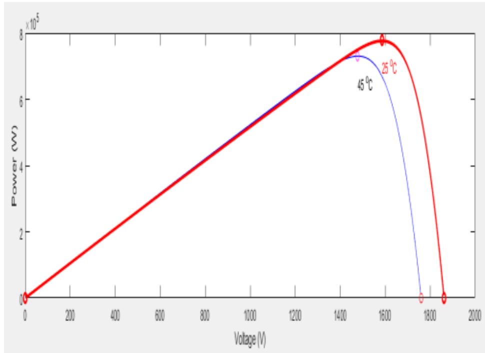
In this research work presents Z-source converter, it has capability of ac-dc-dc-ac conversion with in the single stage conversion.in conventional voltage source converter and current source converter required two stage conversion with single control topology. In ZSI connected inductor and capacitor at source side to provide special feature compared to voltage source converter and current source converter.

IV. Results and discussion

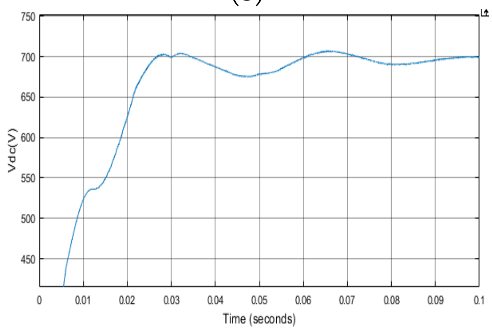
With and without SAHF by using VSI:



(a)



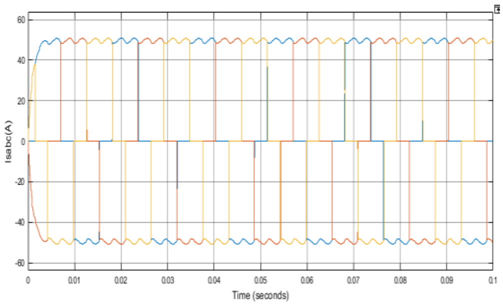
(b)



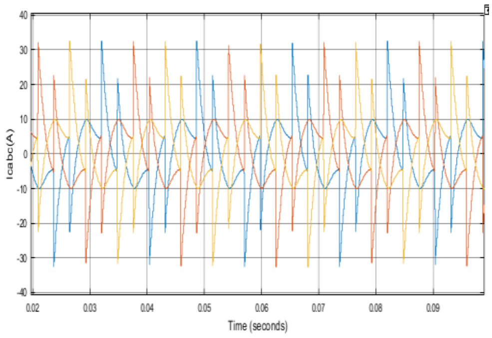
(c)

Fig. 5. (a) I-V (b) P-V characteristics of PV array and (c) Vdc

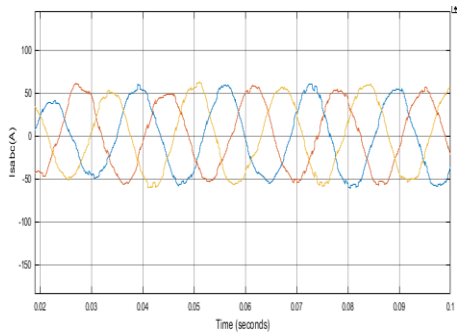
The PV array's P-V and I-V characteristics are shown in Figs. 5a and 5b at cell temperatures of 25° and 45° C, respectively. The obtained point on the graph corresponds to the PV array's peak power. At this point, a P/O MPPT-based controller controls the PV array system for maximum efficiency. The characteristics show that while the open circuit voltage lowers as the temperature rises, the short circuit current increases. The boost converter's dc link voltage is depicted in fig. 5c.



(a) Isabc



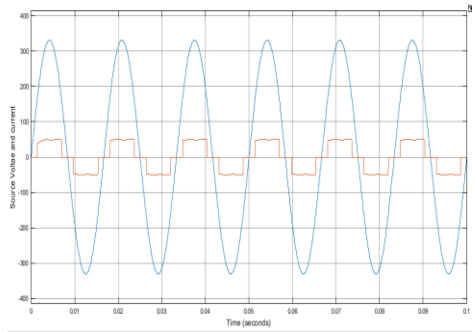
(b)Icabc



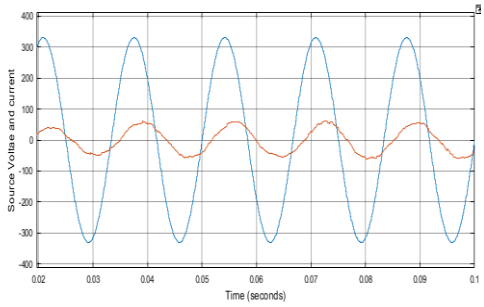
(c)Isabc

Fig. 6. (a) Source current without the connection of SAHF and (b) compensating current and (c) source current with SAHF

The source current of the supply mains is shown in Fig.6 (a) in a shunt configuration without the integration of a harmonic filter. As can be observed, the non-linear load causes the source current to have higher order harmonic components in addition to fundamental components. According to Fig. 6, the PWM-VSI generates the compensatory current to reduce the harmonic components (b). Harmonics are cancelled by a compensatory current that has the same amplitude as harmonic components but a 180° phase shift. Figure 6(c), which depicts the source current following SAHF integration, demonstrates how the source current changes to a sinusoidal shape after SAHF integration, becoming harmonic-free.



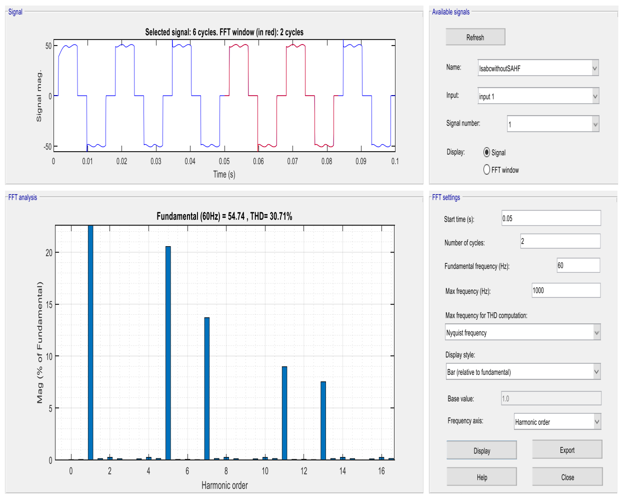
(a)



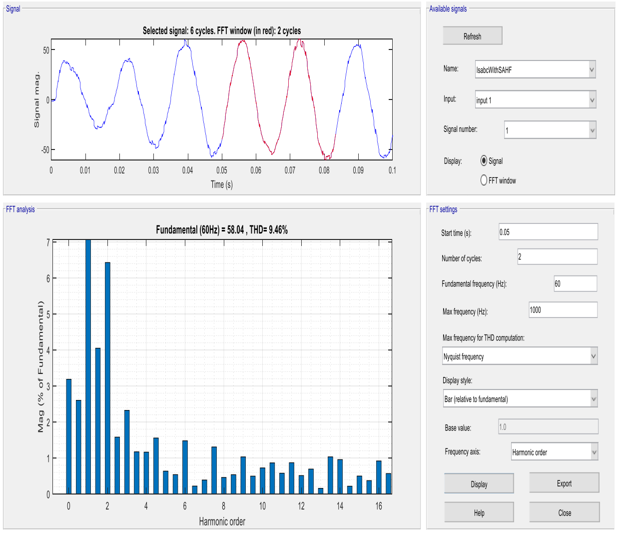
(b)

Fig. 7. Power factor improvement of the supply mains by SAHF (a) without SAHF and (b) with SAHF

Fig. 7 shows the difference between the supply mains' power factor with and without SAHF (a) and with SAHF (b). The source current no longer contains harmonics after the SAHF system is connected, and it also has a greater power factor.



(a)

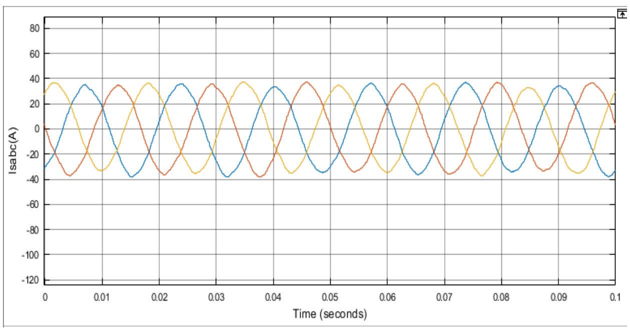


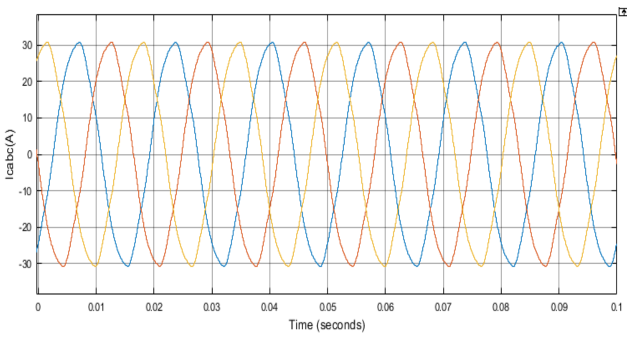
(b)

Fig. 8. THD present in source current (a) Without SAHF (b) With SAHF.

As can be seen from Fig. 8 (a), an odd harmonic component is present in the source current when compensation is not provided, whereas Fig. 8 (b) demonstrates that the odd harmonics are reduced to a satisfactory level after connecting the SAHF. Figure 8 illustrates the magnitude of harmonic current present in the source current before and after connecting the SAHF in percentage of the fundamental component.

Simulation results by using Z Source Inverter:





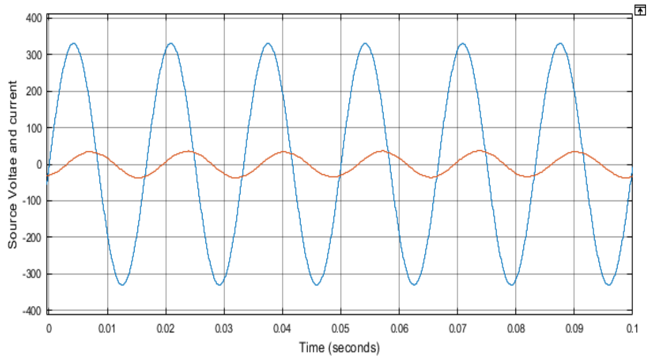


Fig9.Source voltage and source current by using Z source Inverter

According to Fig. 9, the PWM-ZSI generates the compensatory current to reduce the harmonic components (a). Harmonics are eliminated by a compensatory current that has the same amplitude as harmonic components but a 180° phase shift. Using ZSI, Fig.9b displays the supply current.

By utilising a Z source inverter, the shunt SAHF system reduces harmonics while simultaneously improving power factor.

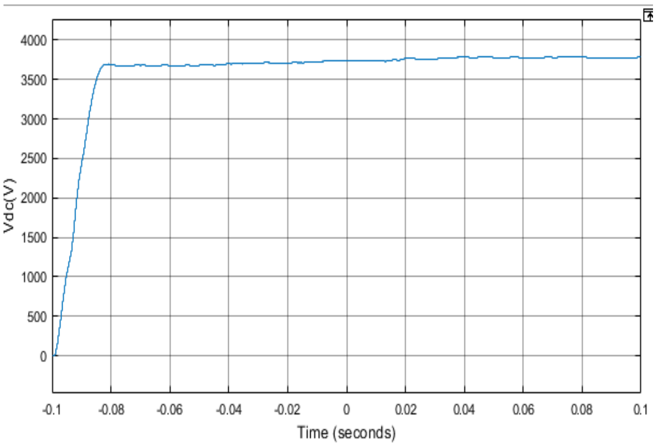


Fig.10. DC link voltage

The ZSI's dc link voltage is depicted in Fig. 10. Compared to VSI, the dc link voltage is maintained steadily.

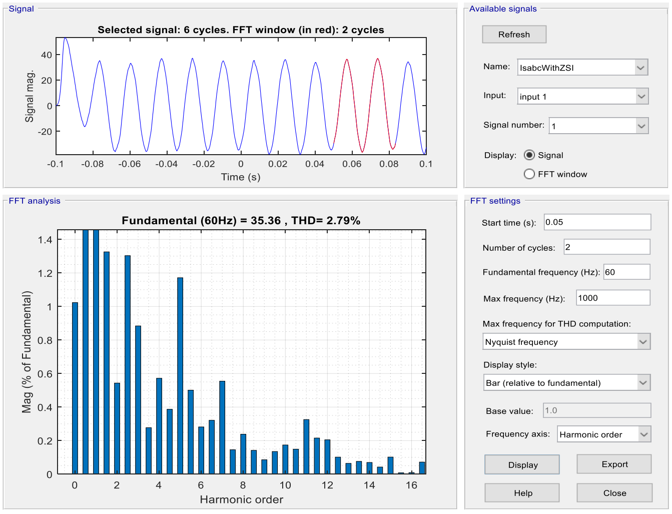


Fig.11.THD of Supply current

Figure above depicts the supply current's THD. ZSI reduces overall harmonic distortion by up to 2.79%

V. CONCLUSION

In this research work implemented a single stage solar photovoltaic (PV) connected Z-source inverter (ZSI) based shunt active filter for power quality improvement by using MATLAB/SIMULINK software. The simulation results shows the ZSI is more accurate in operation compared to VSI. In this work also presented a comparison results between two stage VSI and single stage ZSI for solar connected Grid systems. It shows the ZSI have a unique feature there is no need of additional boost converter compared to conventional two stage solar photovoltaic (PV) connected voltage source inverter (VSI).

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Cite this article as :

J. Chandra, M. Harish Kumar, "Construction And Performance Analysis of PV-ZSI Based Shunt Active Filter for Power Quality Enhancement in Grid Connected Systems", International Journal of Scientific Research in Science and Technology (IJSRST), Online ISSN : 2395-602X, Print ISSN : 2395-6011, Volume 10 Issue 1, pp. 223-231, January-February 2023.

Journal URL : https://ijsrst.com/IJSRST2310123