Design and Analysis of Grid Connected ZSI under Non-Linear Load with PV Applications

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Abstract: - The voltage-fed Z-source inverter with battery operation (ZSI) has been presented suitable for photovoltaic (PV) Applications mainly because of its single-stage buck and boost capability and improved reliability. This paper further address an impact of nonlinear loads on PV connected distribution system. Minimum switching stress on devices can be achieved by choosing a proper capacitor voltage reference. Two strategies are proposed with the related design principles to control the new energy-stored ZSI when applied to the PV power system. They can control the inverter output power, track the PV panel's maximum power point, and manage the battery power, simultaneously. The voltage boost and inversion, and energy storage are integrated in a single-stage inverter. Simulations results are carried out with the help of Matlab/simulink software. Experimental results are presented for validation of the theoretical analysis and controller design.

Keywords – PV Array, Single Phase, Z-Source Inverter,THD

I. INTRODUCTION

In recent years, due to energy crisis, renewable energy distributed power generators (DGs), such as wind turbine, photovoltaic (PV) cell, fuel cell, and thermoelectric generation (TEG) modules, are becoming more and more popular in industrial and residential applications. Much renewable energy DGs such as PV cell, fuel cell, and TEG module can only output dc voltage, so an inverter interface has to be utilized for grid-connected applications .Many inverter topologies have been proposed and reviewed recently. Based on galvanic isolation, these inverters can be divided into two categories: isolated inverters and non isolated inverters. Isolated inverters usually utilize a line frequency or high frequency transformer for electrical isolation. Due to size, weight, and cost considerations, high-frequency transformers are inclined to be used for future applications. Transformer-isolated topologies usually have higher voltage gain and safety advantages, but they require more switches with relatively high cost, high complexity, and low system efficiency. A non isolated a full-bridge inverter with line frequency switched devices is used to reduce the cost and the switching loss. To further simplify the system complexity and to reduce the cost, single-stage inverter[2] topologies are investigated. However, for the transformer less inverter topologies, if the input dc-source and the grid do not share the same ground, the input dc source, especially for PV cell, may have large leakage current, which will cause safety and electromagnetic interference problems.

In order to solve this problem, either extra switches have to be added to the existing topology which will inevitably increase the cost and system complexity or doubly grounded topologies have to be used. Therefore, for the considerations of safety, cost, and system simplicity, the doubly grounded non isolated inverter topologies are preferred topologies for the renewable DG in grid-connected application.

To reduce the cost and to increase the system reliability, Z-source as a single-stage transformer-less inverter topology is proposed. By utilizing the unique LC network, a shoot-through zero state can be added to replace the traditional zero state of the inverter and to achieve the output voltage boost function.

Block Diagram

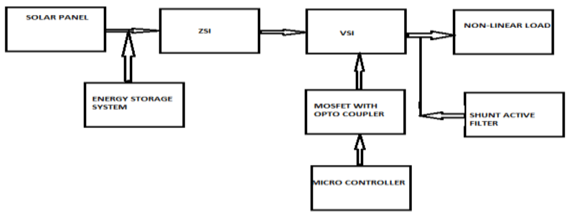

Fig.1

With a set of new topologies of the impedance networks, a class of Z-source inverter applied to DG applications. In fig.1, As insolation keeps on varying throughout the day,its important to observe its effects on PV characteristics. Photo generated current depends directly on insolation. Solar panel converts solar energy into electrical energy. The output of solar panel after converting to AC is fed to non-linear loads. The panel output in excess of load requirement used to charge the battery.

The Z-source network performs the voltage boost ability. Z-source inverter is a combintion of Z-source network and voltage source inverter. ZSI is used to provide shoot-through effect and minimizes voltage stress across the switches. It reduces the harmonics [2]present in the output. A single phase ZSI [6] with input and output sharing the same ground. This topology can be used in distributed power systems where dual grounding is needed.

ZSI output is given to the non-linear load. The shunt active filter is connected across the non-linear load. Non-linear loads produces harmonics. These harmonics can be eliminated by Shunt active filters.

A voltage-fed ZSI was proposed for PV applications because of continuous input current and reduced passive component (capacitor) rating-capacitor voltage[6] is much less than that on another parallel capacitor during operations and this feature leads to lower manufacture cost.

SIMULATION DIAGRAM:

ZSI UNDER LINEAR LOAD (HIGH VOLTAGE):

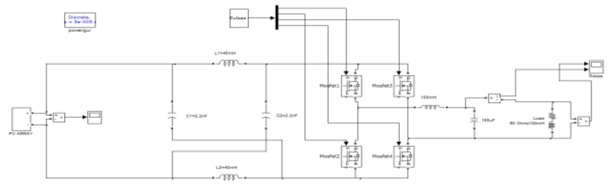

Fig.2

In fig.2, high voltage 208V is given as an input to the ZSI by using PV array. Ten PV panels are connected in series in PV array. Load voltage and load current output are taken across the linear load.

EQUIVALENT CIRCUIT OF SINGLE PV PANEL:

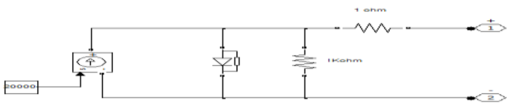

Fig.3

Fig.3 shows a subsystem of a single PV Cell. This equivalent circuit produces 20.8V. Like that ten equivalent circuit are connected in series. Therefore a high voltage of 208V is obtained.

SINGLE PANEL OUTPUT (OUTPUT VOLTAGE=20.8V):

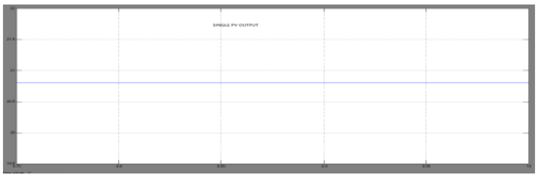

Fig.4

Fig.4 shows a single PV Cell output which produces 20.8V DC output.

ARRAY OF PV PANEL (OUTPUT VOLTAGE=208V)

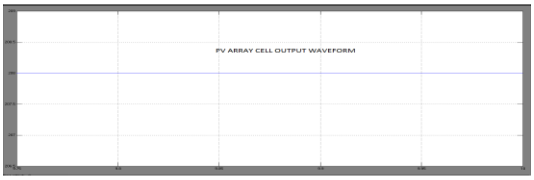

Fig.5

Fig.5 shows the 208V DC output which is produced by an array of ten PV cell that are connected in series.

OUTPUT WAVEFORMS FOR LINEAR LOAD: (OUTPUT VOLTAGE=320V, OUTPUT CURRENT=5.6A)

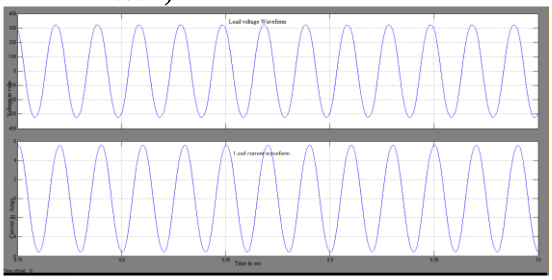

Fig.6

Here by using linear load, ouput voltage of 320V and output current of 5.6A is obtained across the load.

FFT ANALYSIS: (THD= 1.81%)

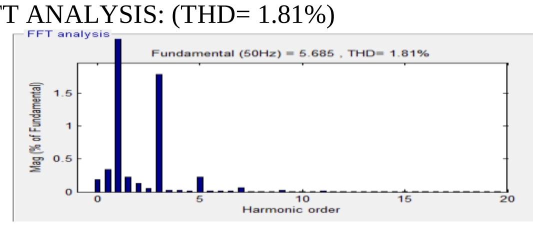

Fig.7

Fig.7 shows the FFT Analysis of load current for the two cycles of an input waveform and according to an input waveform, 1.82% of total harmonic distortion is obtained.

NON-LINEAR LOAD WITHOUT ACTIVE FILTER:

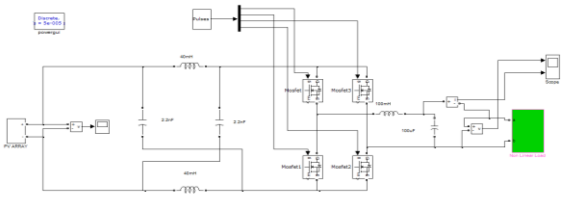

Fig.8

Here using non-linear load without shunt active power filter, simulation circuit is obtained. High input voltage 208V DC is given and the ouput load voltage and load current are taken across the non-linear load.

OUTPUT VOLTAGE WAVEFORM FOR NON-LINEAR LOAD:(OUTPUT VOLTAGE=310V, OUTPUT CURRENT=5.6A)

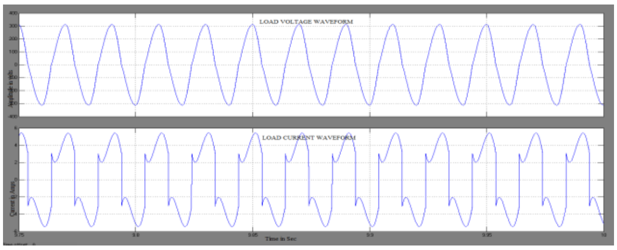

Fig.9

Fig.9 shows an output waveform of non-linear load without shunt active power filter, ouput voltage of 310V and output current of 5.6A is obtained across the load.

FFT ANALYSIS: (THD=36.04%)

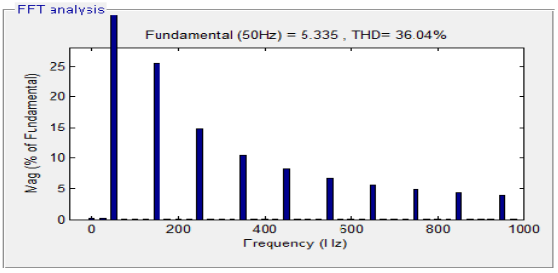

Fig.10

Fig .10 shows the FFT Analysis of load current for the two cycles of an input waveform and according to an input waveform, 36.04% of total harmonic distortion is obtained.

GRID CONNECTED NON-LINEAR LOAD WITH SHUNT ACTIVE FILTERS

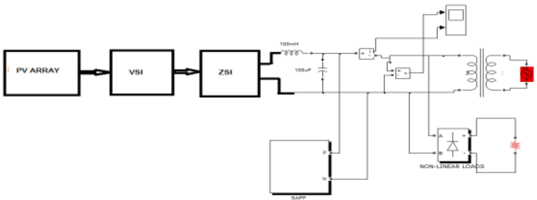

Fig.11

Here, using grid connected, non-linear load with shunt active power filter, simulation circuit is obtained. High input voltage 208V DC is given and the ouput load voltage and load current are taken across the non-linear load.

OUTPUT VOLTAGE AND CURRENT WAVEFORM: (OUTPUT VOLTAGE=316V, OUTPUT CURRENT=480A)

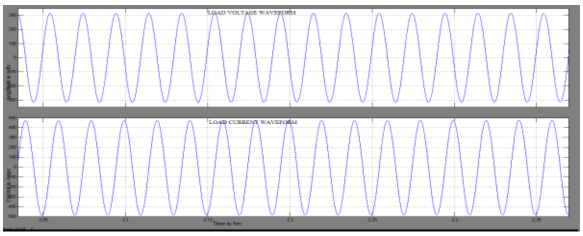

Fig.12

Fig.12 shows output waveform of non-linear load with shunt active power filter, ouput voltage of 316V and output current of 480A is obtained across the load.

FFT ANALSIS: (THD=0.02%)

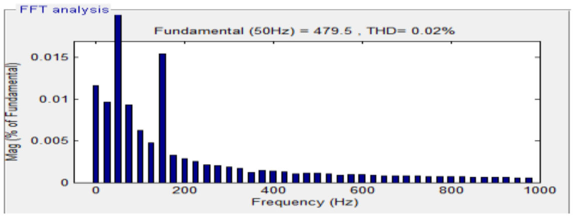

Fig.13

Fig.13 shows the FFT Analysis of load current for the two cycles of an input waveform and according to an input waveform, 0.02% of total harmonic distortion is obtained.

ZSI UNDER NON-LINEAR LOAD FOR LOWER VOLTAGE VALUES

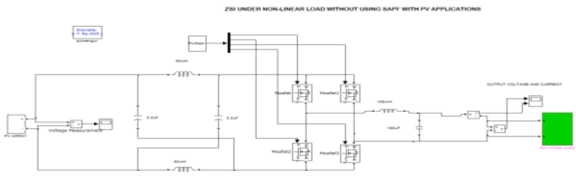

Fig.14

Here, low voltage 18V given as a input to the ZSI by using PV array. Ten PV panels connected in series in PV array. Load voltage and load current output are taken across the linear load.

INPUT VOLTAGE WAVEFORM: (INPUT VOLTAGE= 18V)

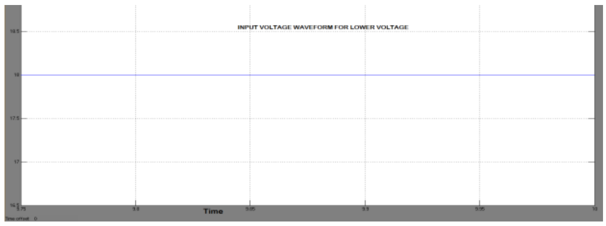

Fig.15

Fig.15 shows a single PV panel output waveform which is 1.8V DC output and the array of ten PV panel produces 18V DC.

OUTPUT WAVEFORM: (OUTPUT VOLTAGE = 28V, OUTPUT CURRENT=0.5A)

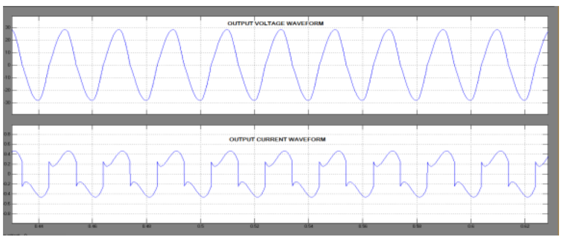

Fig.16

Here by using non-linear load without shunt active power filter, ouput voltage of 28V and output current of 0.5A is obtained across the load.

FFT ANALYSIS: (THD=34.24%)

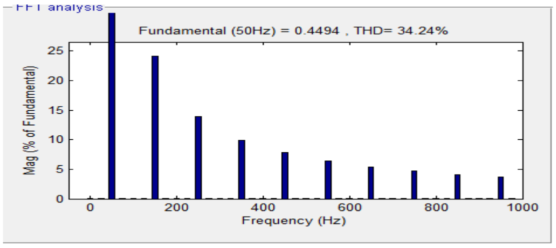

Fig.17

Fig .17 shows the FFT Analysis of load current for the two cycles of an input waveform and according to an input waveform, 34.24% of total harmonic distortion is obtained.

GRID CONNECTED ZSI UNDER N0N-LINEAR LOAD WITH SAPF:

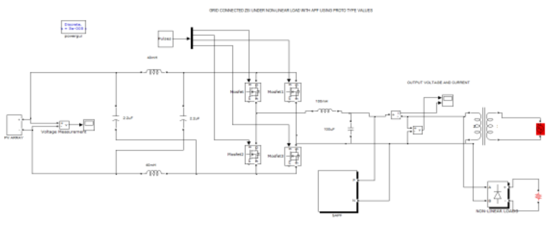

Fig.18

Here, using grid connected, non-linear load with shunt active power filter, simulation circuit is obtained. Low input voltage 18V DC is given and the ouput load voltage and load current are taken across the non-linear load.

OUTPUT WAVEFORM: (OUTPUT VOLTAGE=24V, OUTPUT CURRENT=38A)

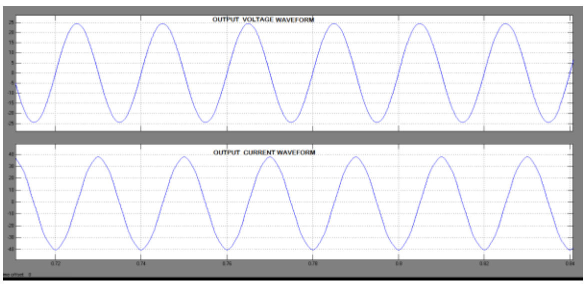

Fig.19

Fig.19 shows an output waveform of non-linear load with shunt active power filter, ouput voltage of 24V and output current of 38A is obtained across the load.

FFT ANALYSIS: (THD=0.20%)

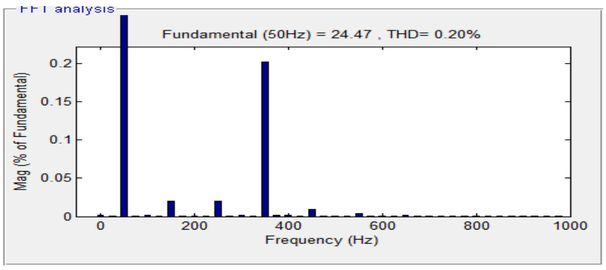

Fig.20

Fig.20 shows the FFT Analysis of load current for the two cycles of an input waveform and according to an input waveform, 0.20% of total harmonic distortion is obtained.

TOTAL HARMONIC DISTORTION COMPARISON TABLE:

Total Harmonic Distortion(%)			
Type of voltage	Type of system	Without Filter	With Filter
High voltage 208V	Linear load	1.82	-
	Non-linear load	36.04	0.02
Low voltage 18V	Non-linear load	34.24	0.20

HARDWARE MODEL:

Fig.21

An input voltage is given to the hardware by solar panel and the ouput is obtained by using oscilloscope and a DC motor is observed to be working when connected to this hardware unit with the output produced. According to irradiation, the solar panel produces a DC output which is given to the Z-source inverter and the produced output is observed by using CRO for both with and without shunt active filter models.

HARDWARE OUTPUT WITHOUT COMPENSATION (20.4V)

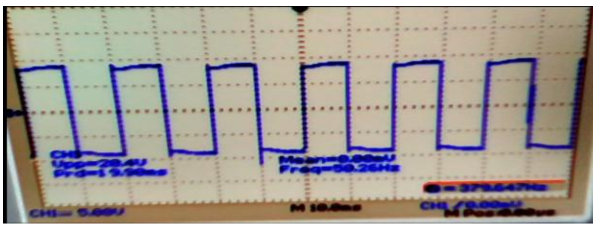

Fig.22

Fig.22 shows the output as seen on the cathode ray oscilloscope when the hardware model not connected with the shunt active power filter.

HARDWARE OUTPUT WITH COMPENSATION(5.24V)

Fig.23

Fig.23 shows the output as seen on the cathode ray oscilloscope when the hardware model connected with the shunt active power filter.

SIMULATION AND EXPERIMRNTAL RESULTS:

To verify the proposed topology and its FFT Analysis, simulation and Experimental Results were given. The parameters were : PV Panel input voltage V_I = 208v, Output Voltage V_o= 310v (50Hz), Z-source inductors L_1=L_2=40mH , Capacitor C_1=C_2= 2200 microF, output Filter L=100mH , C=100 microF and the modulation index is 0.6 for Linear load R=50 ohms and L=100mH.For the above said parameters the total Harmonic distortion is 1.81%. And also hardware lower voltage simulated and the corresponding THD values are calculated.

Compared to Non linear loads with shunt active filters, Non linear load without shunt active filters produces a total harmonic distortion of 36.04% for high voltage. For lower voltage THD is 34.24%.

With Shunt active filters the total harmonic distortions are reduced to a value of 0.02% by choosing a capacitor of value 5000 microF and inductor whose value is 100mH for 208V high voltage. For low voltage THD is 0.20%.

CONCLUSION :

Traditional Single phase inverter topologies cannot achieve a common ground between the input and the output, so they cannot be used in conditions where dual grounding is needed. To solve this problem, a novel single phase Z-Source Inverter topology with an inherent common ground for input and output has been given. The operation principle and reduced total harmonic distortions are analyzed in detail and verified by the simulation and Experimental Results. The total harmonic distortions are calculated for both linear and non-linear loads, with and without filter for non linear load by simulation. Simulations are carried out on the MATLAB SIMULINK platform with and without shunt active power filter for both high, low voltage and the results are presented. Similarly, the hardware prototype was developed. Results were attained through the hardware with and without shunt active power filter.

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