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SVPWM Model based Predictive Control of a Dual-Mode Operated Quasi Z-Source Multilevel Inverter for Renewable Energy Application

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Abstract- A three-phase modified quasi-Z-source multi level ac–ac converter is proposed in this examination. The proposed converter has the main features in that the output voltage can be bucked or boosted and be both in- phase and out-of-phase with the input voltage. The input voltage and output voltage share the same ground, the size of a converter is reduced, and it operates in a continuous current mode. A safe commutation strategy for the modified three-phase quasi-Z-source multi level ac–ac converter is used instead of a snubber circuit. The simulation results verified that the converter has a lower input current total harmonic distortion, a higher input power factor, and a higher efficiency in comparison to a conventional three-phase Z-source multi level ac–ac converter. In addition, the simulation results show that the use of the safe-commutation strategy is a significant improvement, as it makes it possible to avoid voltage spikes on the switches.

Keywords - Model Predictive Control, SVPWM, Dual-Mode Operations, Grid-Connected Multi Inverter

I. INTRODUCTION

Converting electrical energy from type to type becomes very important and necessary day by day due to many new renewable energy sources. There are traditional voltage-source inverters as in Fig 1.1, which is supported by DC source. The DC voltage source can be a battery, fuel-cell stack, diode rectifier, and/or capacitor. Six switches are used in the main circuit; each is traditionally composed of a power transistor and an antiparallel (or freewheeling) diode to provide bidirectional current flow and unidirectional voltage blocking capability.

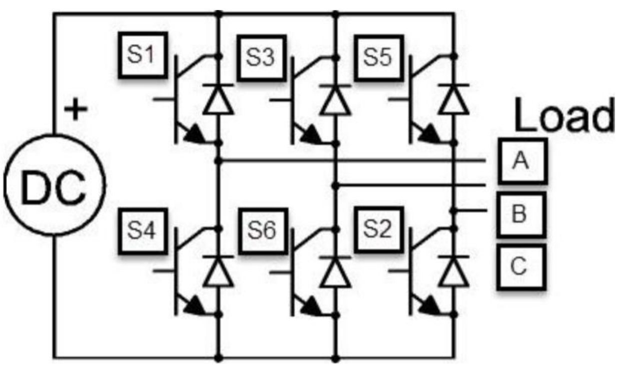

Fig. 1.1 Traditional Voltage-Source Inverter

The AC output voltage is limited below the DC-rail voltage. Therefore, the V-source inverter is a buck (step-down) inverter for DC-to-AC power conversion. For applications where over drive is desirable and the available DC voltage is limited, an additional DC-DC boost converter is needed to obtain a desired AC output. The additional DC-DC boost converter stage increases system cost and lowers efficiency.

The upper and lower switches of each phase leg cannot be gated on simultaneously. Otherwise shoot-through (i.e., a state occurs when two switches at the same leg are turned on) would occur and destroy the devices.

An output LC filter is needed for providing a sinusoidal voltage, which causes additional power loss due to the small but non-zero resistance within the components and connecting wires.

To overcome the previous problems of the traditional V-source inverters, an impedance-source power converter (abbreviated as Z-source inverter) was developed as in Fig. 1.2 which shows the general Z-source inverter structure. It employs a unique impedance network (or circuit) to couple the inverter main circuit to the power source, load, or other converter to provide unique features that cannot be observed in the traditional V- source inverters where a capacitor and inductor are used respectively.

A unique feature of Z source inverter is the shoot through state, by which two semiconductor switches of the same phase leg can be turned ON simultaneously. Therefore, no dead time is needed and output distortion is greatly reduced and thus reliability is greatly improved. This feature is not available in the traditional voltage source and current source inverters.

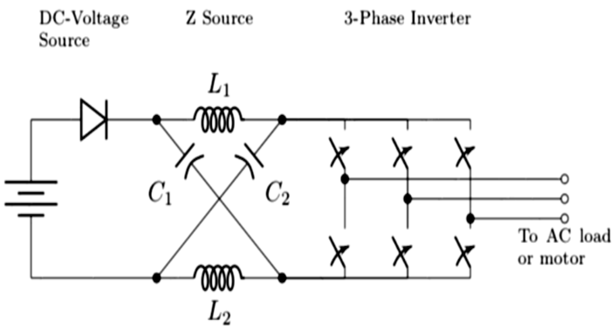

Fig. 1.2 Z-Source Inverter.

Z source inverters are mainly applied for loads that demand a high voltage gain such as motor drives and as a power conditioning unit for renewable energy sources like solar, fuel cells, etc to match the input source voltage differences.

The development in Z source inverter topologies provides a consecutive enhancement in voltage gain and output waveforms. A tradeoff between the boosting capability and component count is always a major concern to keep the cost stable.

II. THEORY OF SVPWM

a. Space Vector Modulation

The FOC controlling system is consist of three mainly parts: mathematical transformations (Clarke transformation and Park transformation), pulse width modulation (PWM) generator and proportional-integral-derivative controller (PID controller). Compare with other PWM technique, space vector pulse width modulation (SVPWM or SVM) has become the most important PWM technique for the 3-phase voltage source inverter or current source inverter (VSI or CSI). This examination focuses on a SVPWM technique for Z-source inverter.

The reason of choice SVPWM is because of some advantages shown below:

High utilization from DC bus (15.5% higher output voltage compared to SPWM)

- Lower switching losses
- Less total harmonic distortion (THD)
- Space Vector Pulse Width Modulation

b. Space vector PWM

Space vector PWM (SVPWM) is a technique designed for three phase ac motor inverter control, it work depending on their special switching sequence and effect of combination of different pulse width. As a result, the windings in the ac motor will generate the three- phase sinusoidal waves which have 120°phase shifts and less harmonics. Compare with

SPWM, SVPWM have three main advantages:

- Higher dc voltage utilization
- Higher fundamental component and less harmonics
- SVPWM is better control the ac motor by digital control system

c. Principle of SVPWM

The three-phase voltage source inverter basic circuit shows in the Fig. 2.1. Let’s say the six letters a, b, c and a’, b’, c’ represent the status of six switches in this circuit. When a, b and c equal to 1, it mean that upper switches open in the inverter, at the same time, the lower switches close and a’, b’, c’ equal to 0; vice versa, the upper switches close and a, b and c equal to 0. Therefore, the three-phase inverter controlled by six switches that have eight configurations.

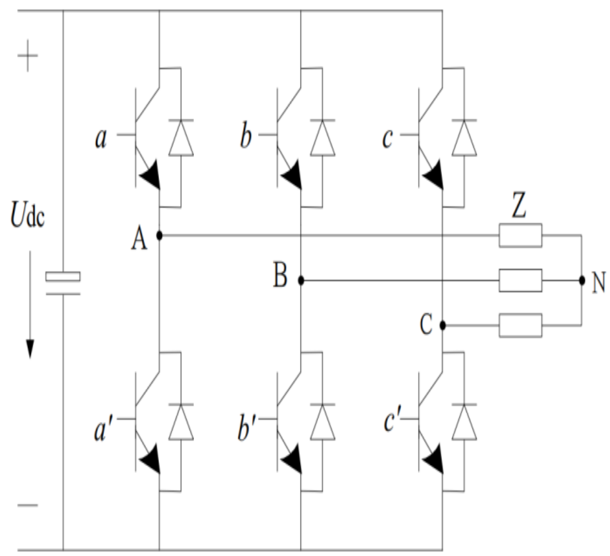

Fig. Three- phase voltage source circuit.

III. MODELING OF PROPOSED MULTI LEVEL Z-SOURCE INVERTER

A multilevel inverter is used to achieve a desired yield voltage from several voltage levels of a input DC voltage sources. The inverter voltage yield waveform becomes nearly sinusoidal waveform, to increase number of dc voltage sources. When contrasted with conventional two level inverters, the multilevel inverters have more advantages which incorporate lower semiconductor voltage stretch, low electromagnetic interference (EMI), lower switching losses and better harmonic performance. In spite of these points of interest, multilevel inverters output voltage amplitude is limit to DC sources voltage summation. For the boost or buck of multilevel output voltage alternate converters as a DC/DC converter is required. Occurring of short circuit can harm multilevel inverters; along these lines multilevel inverters need to work with dead-time protection. To resolve the above concern, a SVPWM model predictive control of dual-mode operations Z-Source multi inverter islanded and grid-connected is reported in this examination work.

Figure 3.1 shows the model multilevel of ZSI circuit subjected to be analyzed implemented in MATLAB SIMULINK. As analyzed before, there are three states for the operating of Z-source inverter. In traditional modeling method, only two states were considered in the modeling process, which is shoot- through state and non-through state. However, in non-shoot-through state, there are two separate states: one is null state; the other state is active state. Because null state is short and no power transmission, usually combine it together with active state.

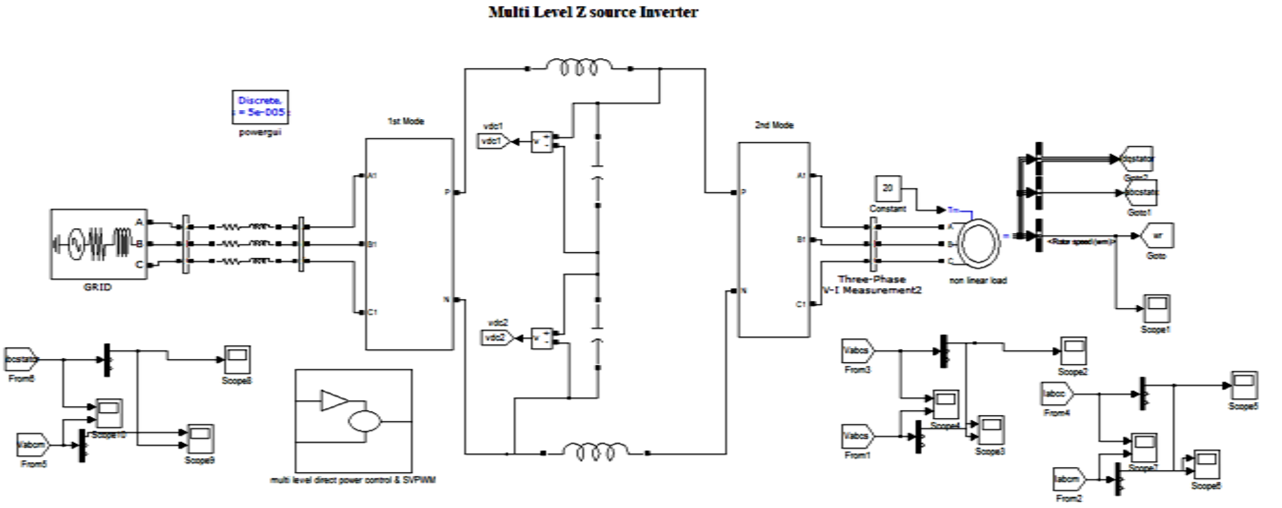

Fig.3.1 Main Circuit Grid Connected Model.

A controller in the proposed model has been configured with a harmonic compensator to regulate the microgrid voltage in the islanded mode and to control the current in the grid-connected mode with series RLC loads as shown in Fig. 3.2 proposed multilevel Z source inverter main circuit islanded model.

Any three-phase entities, such as three-phase voltages or currents can be represented by a space vector in d– q plane through Park's transformation. The vector begins from the source and finishes at one point with the destination that the length and phase edge of vector together represents the immediate estimations of specific three-phase entity. On the other hand if the three-phase entities are sinusoidal elements of time and are symmetrical, the vector will turn at a steady angular speed with a consistent length and, along these lines, the locus of vector frames a circle.

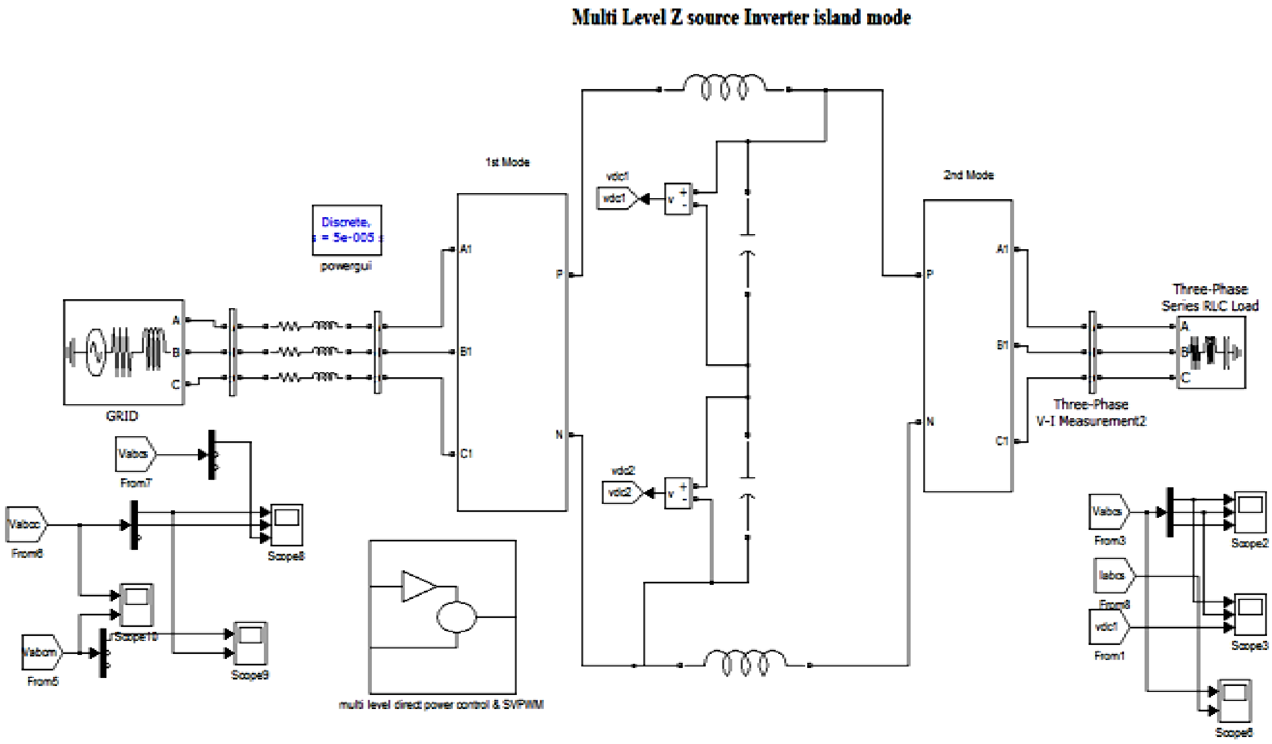

Fig.3.2 Main Circuit Islanded Model.

The algorithm in SVPWM (space vector pulse width modulation) system combines space vector modulation (SVM) scheme with pulse width modulation (PWM) scheme, named SVPWM utilized in proposed work. Fig. 3.2 illustrates direct power control & SVPWM based control loop for dual mode converter. SVPWM method for shoot-through state control of trans-Z-source inverter reported in this work has Z-source network makes the shoot-through zero state possible. This method employs two extra straight lines as shoot-through signals, VSC and —VSC. This shoot-through zero state gives the remarkable buck-boost highlight to the inverter. The new topology has the upside of its lessened number of devices contrasted with ordinary cascaded H-bridge staggered inverter. Fig 3.3 shows the Simulink model for proposed Direct power control & SVPWM based control loop for dual mode converter topology.

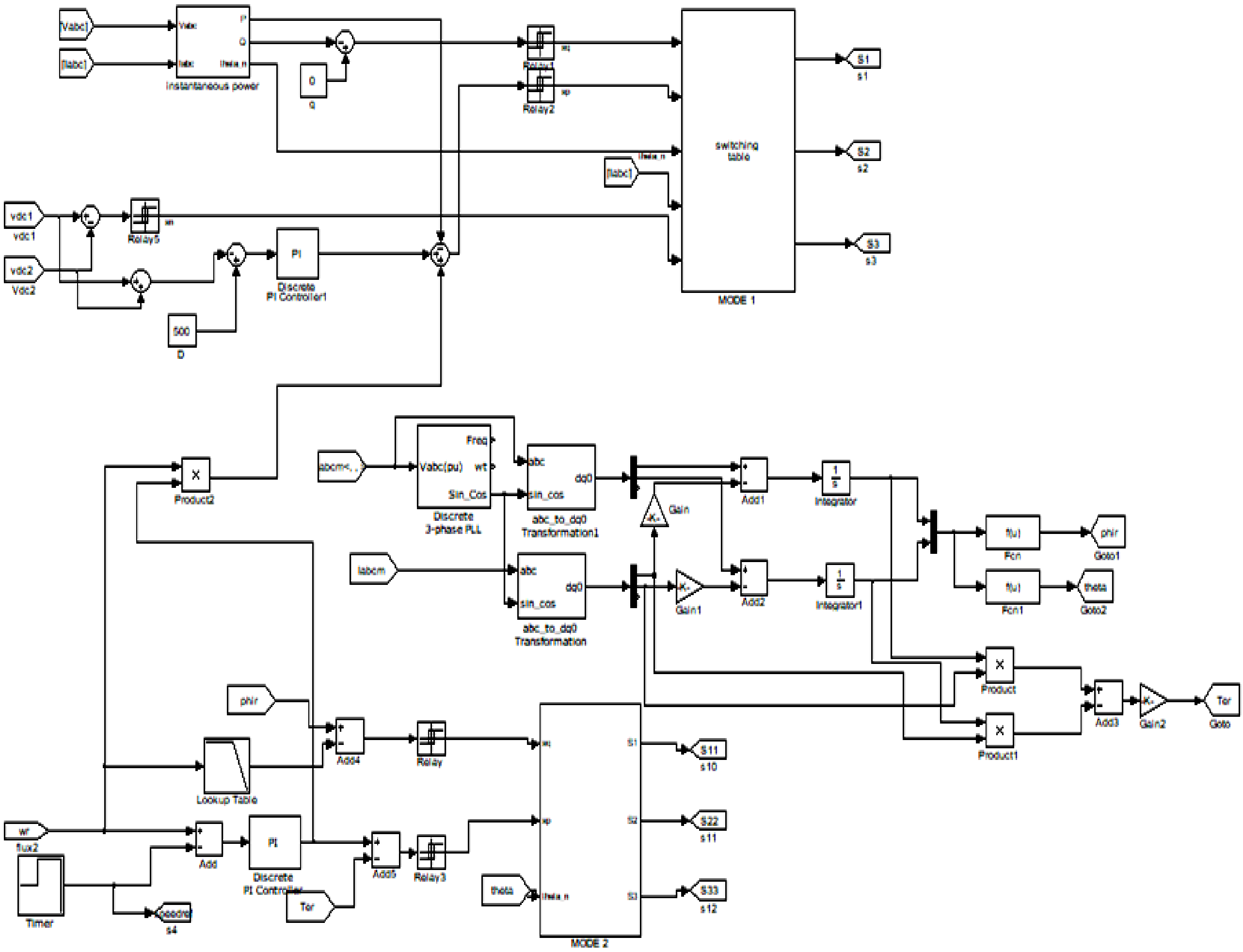

Fig.3.3 Direct power control & SVPWM based control loop for dual mode converter.

Predictive control mode has been used in the proposed system to predict future behavior of each of the output currents or voltage for effective control over harmonics and current distortions. A predictive control of dual-mode operations is actualized as a repeated circle for each voltage vector to anticipate the values, assess the cost capacity, and store the base value and the index value of the relating switching state.

Normally, there are eight switching statuses (vector) in the three-phase SVPWM control system, six active statuses and two zero statuses. But there are total nine statuses in Z- source inverter, eight statues is as the same with traditional three-phase inverter and one extra zero status. In this extra zero status, the circuit between inverter and DC source are shorted by upper and lower switches turn on at same time in any one bridge, any two bridges or all bridges. All the SPWM or SVPWM control pattern can be used in the Z-source inverter because their switching sequence also work in the Z-source inverter without the extra zero status.

IV. SIMULATION RESULTS ANALYSIS

To verify the theoretical analysis and confirm the proposed MPC technique of Z-source inverter, simulation and experiments have been conducted with the configuration. The parameters for both simulation and experiments are given. Simulations have been performed to prove the capabilities of proposed SVPWM model predictive control of dual-mode operations Z-Source multi inverter islanded and grid-connected algorithms and comparison of them for previous work table 1 shows the parameters and comparative analysis of proposed work over previous work. The whole SVPWM control system has six main subsystems: 1. three-phase sinusoidal signal generator, 2. Clarke's transformation, 3. Reference angel sector, 4. duration time calculation block, 5. space vector modulation signal generator and 6. PWM signal generator. The SVPWM control system model is used to generate the SVPWM control signal for inverter and verify the output results are shown. SVPWM control method is be used in the Z-source network inverter the system parameters are listed in Table 1.

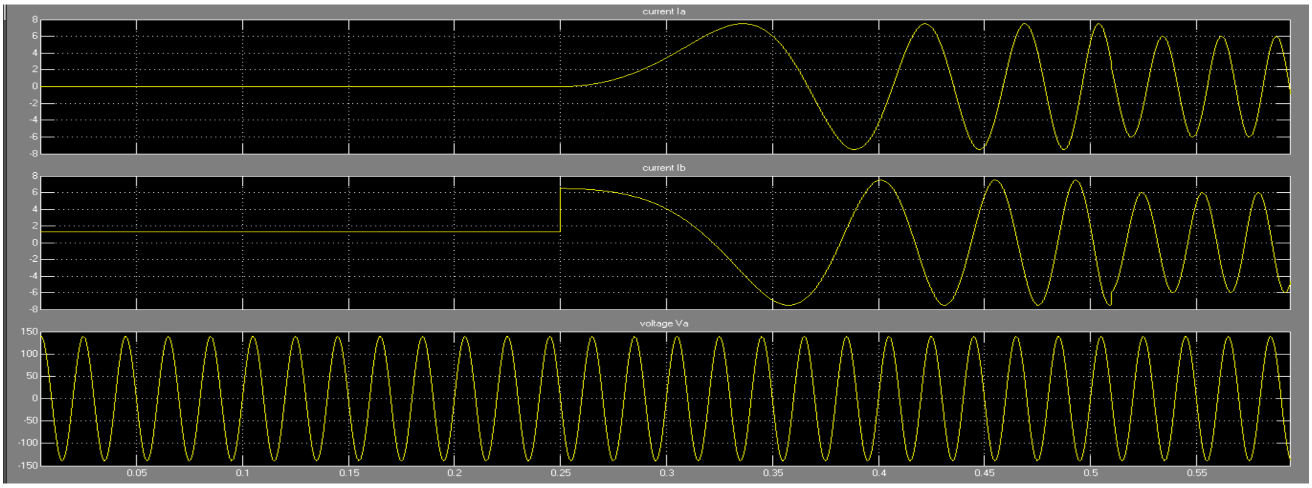

Fig.4.1 Grid Connected Mode Stator Current and Source Voltage.

The transitions from grid-connected mode stator current and source voltage are firstly examined and shown in Fig. 4.1. Waveforms for this transition are shown in the Matlab scope screen shots in Fig.

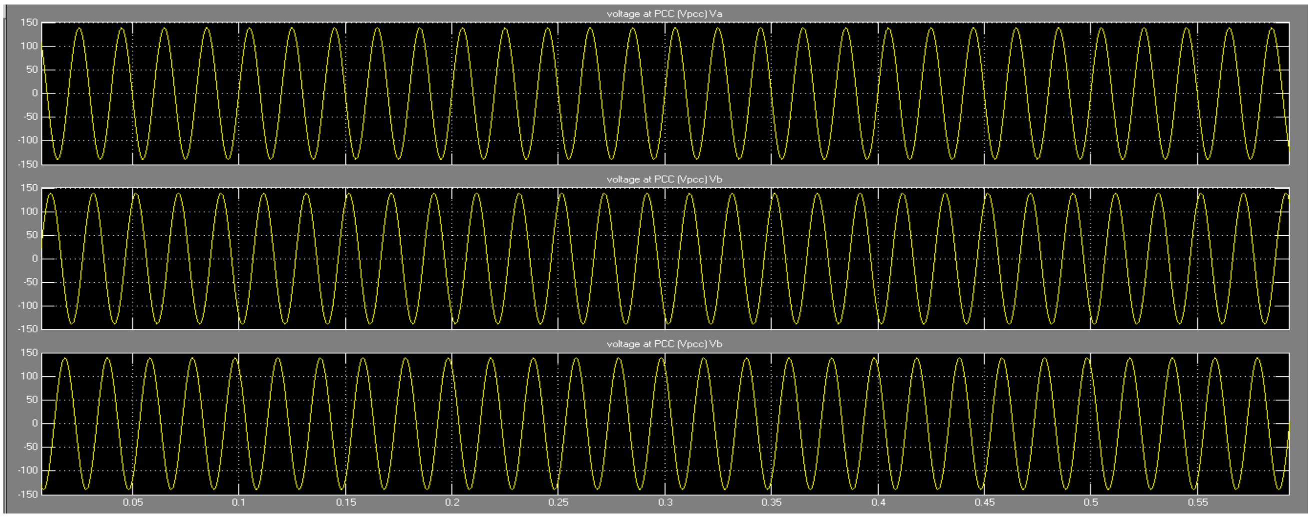

Fig.4.2 Grid Connected Mode PCC and Source Voltages.

Grid connected mode PCC and source voltages scope waveform screen is shown in Fig. 4.2 the execution of the proposed controller is assessed by investigating critical legitimacy criteria: consistent progress between grid-associated mode and islanded mode, consistent change between grid-associated mode with mode PCC and source voltages is appeared in figure. Fast dynamic response of active and reactive power due to change in level or change in reactive power required by the grid at PCC.

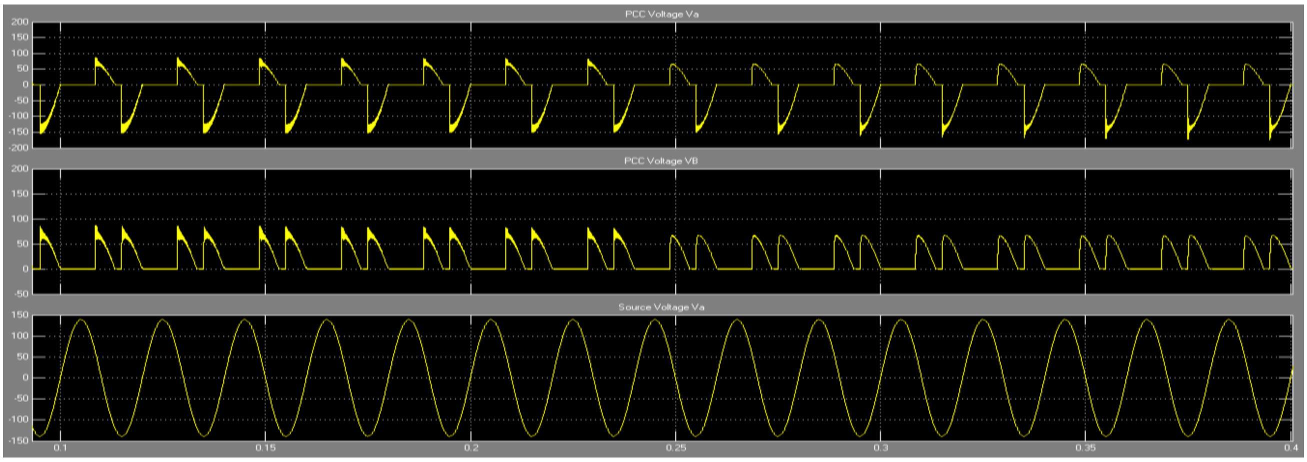

Fig.4.3 PCC and Source Voltages in Islanded Mode.

Scope waveform of PCC and Source Voltages in Islanded Mode is shown in Fig. 4.3. A grid is framed by adjusted energy generators associated with a point of common coupling (PCC) that feeds nearby loads and can work alone or associated with the mains. Islanding is where the DG stays working in the distribution system with the utility disconnected.

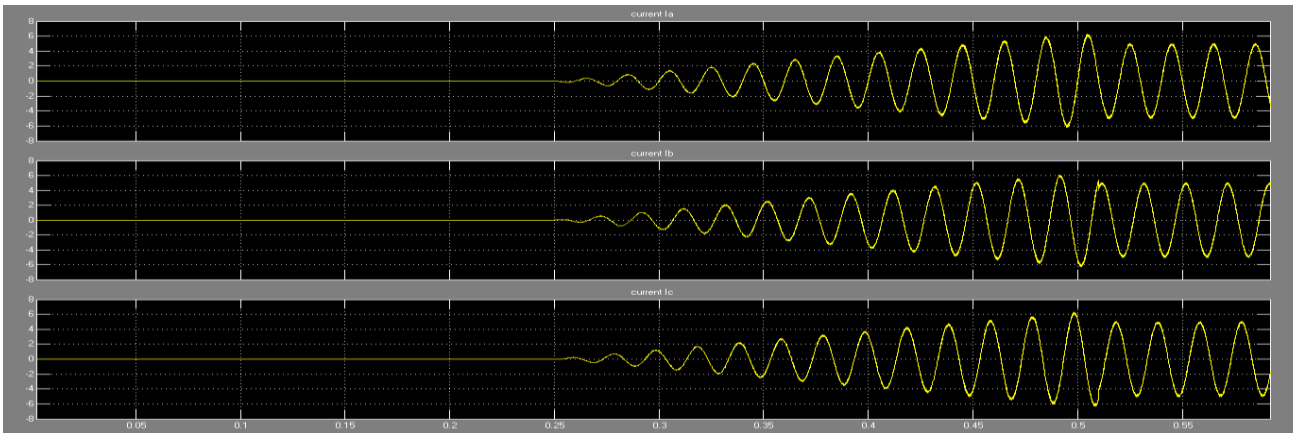

Fig.4.4 Grid Input Currents in Grid Mode.

Grid Input Currents scope waveform screen in grid mode is shown in Fig. 4.4 three individual waveforms represents three phases of input currents. A source voltage, source current and grid DC voltage in grid mode scope waveform has shown in Fig. 4.5. In order to demonstrate the flexibility and reliability of the proposed controller the local loads in islanded mode are assumed to operate.

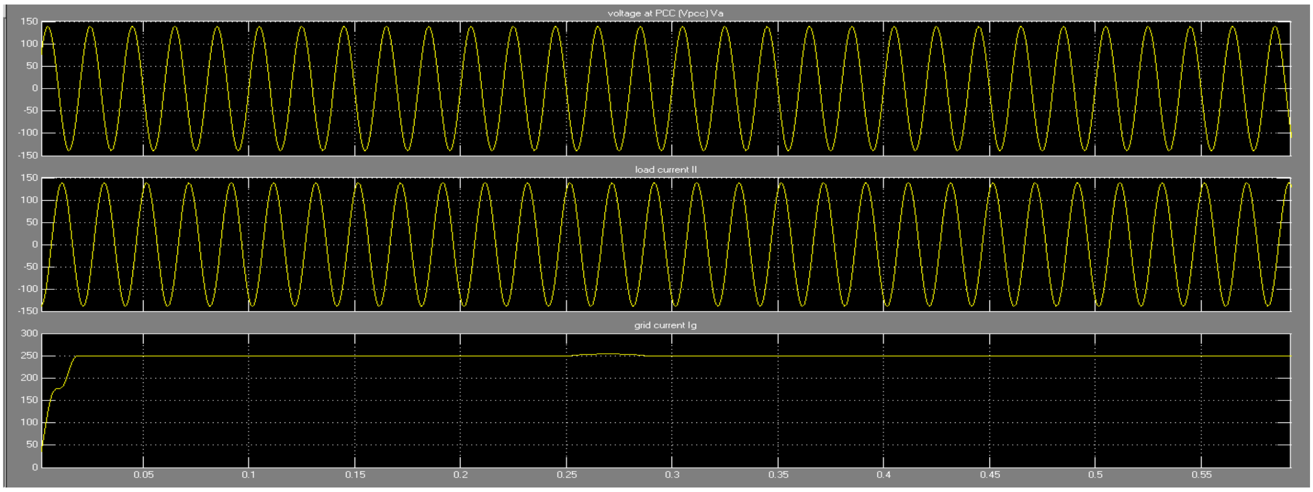

Fig.4.5 Source Voltage, Source Current and Grid DC Voltage in Grid Mode.

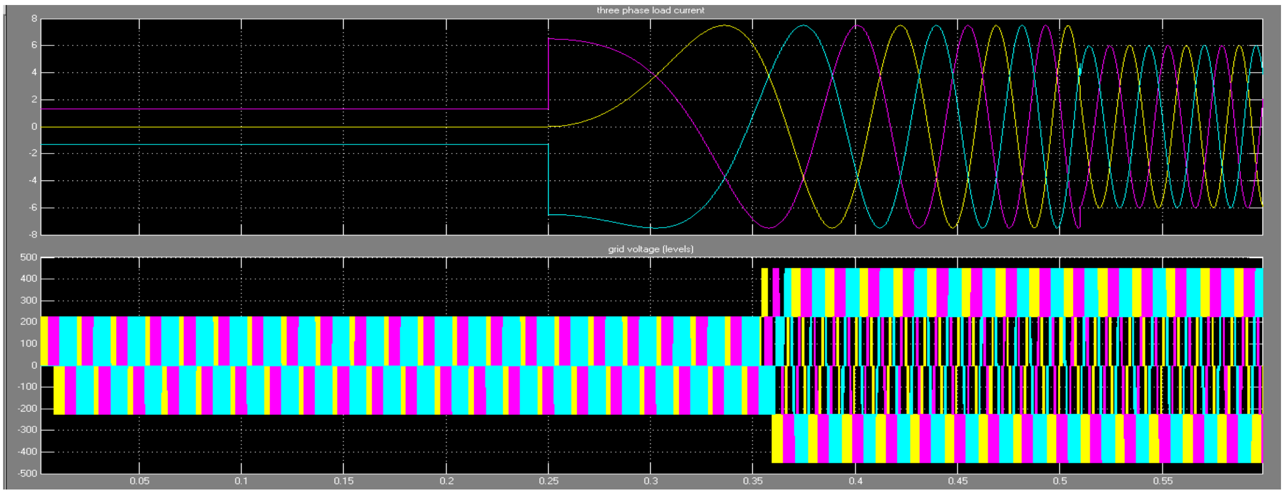

Fig.4.6 Three Phase Load Currents and voltages in Grid Connected Mode.

This case study demonstrate the capability of the proposed system to seamlessly transfer to islanded mode while the local load frequency is different than the grid frequency. Fig . 4.6 shows three phase load currents and voltages in grid connected mode. Whereas Fig. 4.7 shows three phase load currents and voltages in islanded mode.

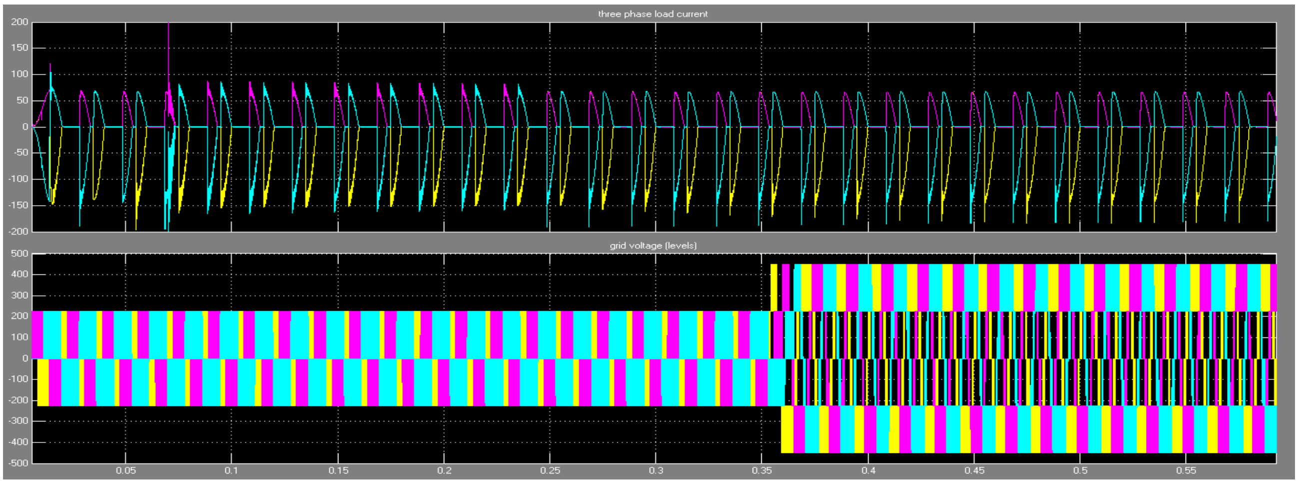

Fig.4.7 Three Phase Load Currents and voltages in Islanded Mode.

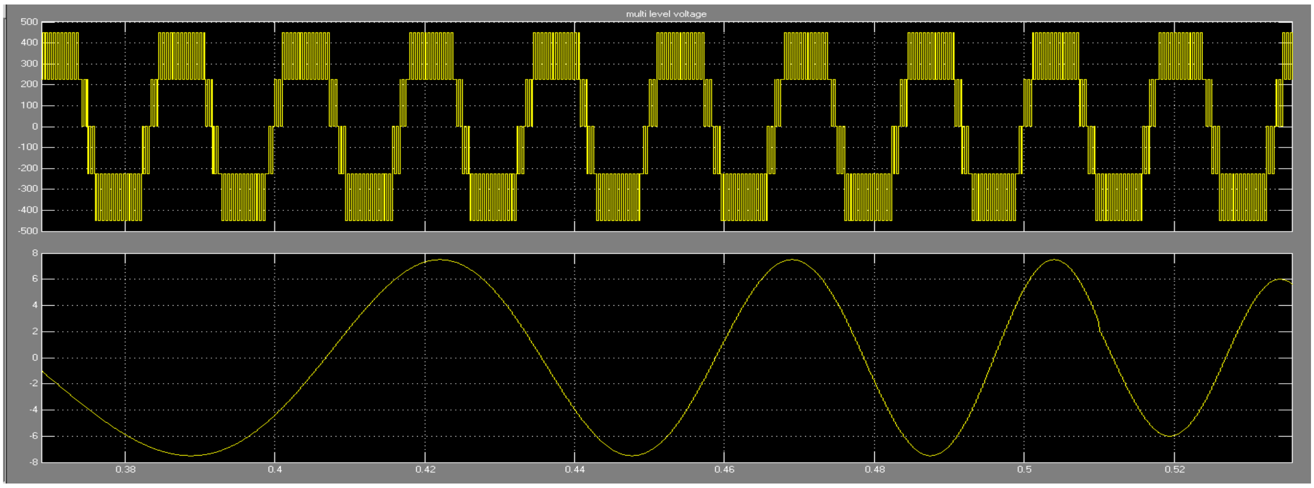

Fig.4.8 Multi Level Voltage and Stator Current in Grid Connected Mode.

The generator generate output pulses Fig. 4.8 shows multi level voltage and stator current in grid connected mode. those pulses generated are to drive the devices in to ON for a multilevel level inverter of the proposed topology a multi level voltage and stator current in islanded mode is shown in Fig. 4.9.

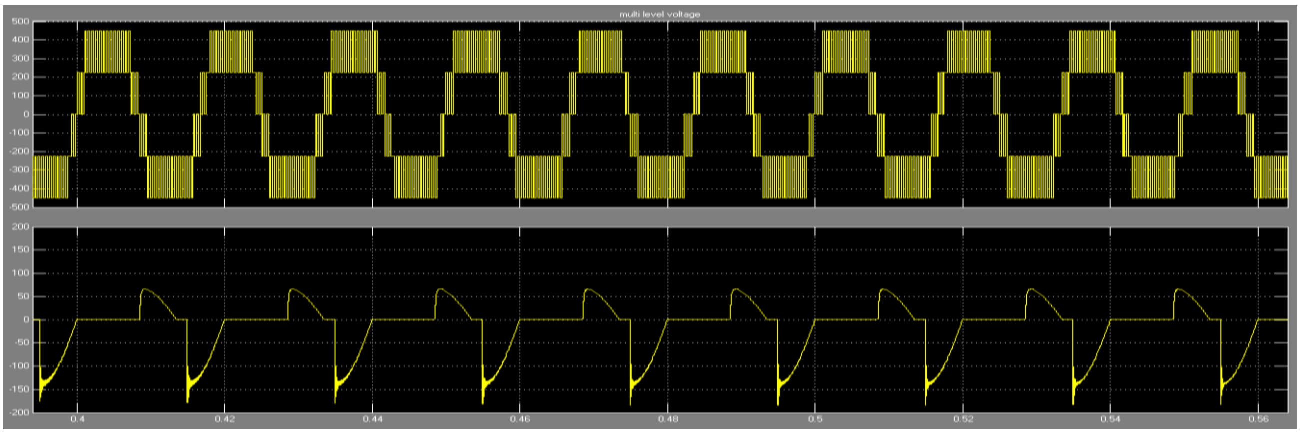

Fig.4.9 Multi Level Voltage and Stator Current in Islanded Mode.

The output currents are controlled independently by the proposed controller and the circulating current flows through the inverter. Although there is a three-phase, inverter can supply the loads with low (0.15%) of total harmonic distortion (THD), as shown in Fig. 4.10.

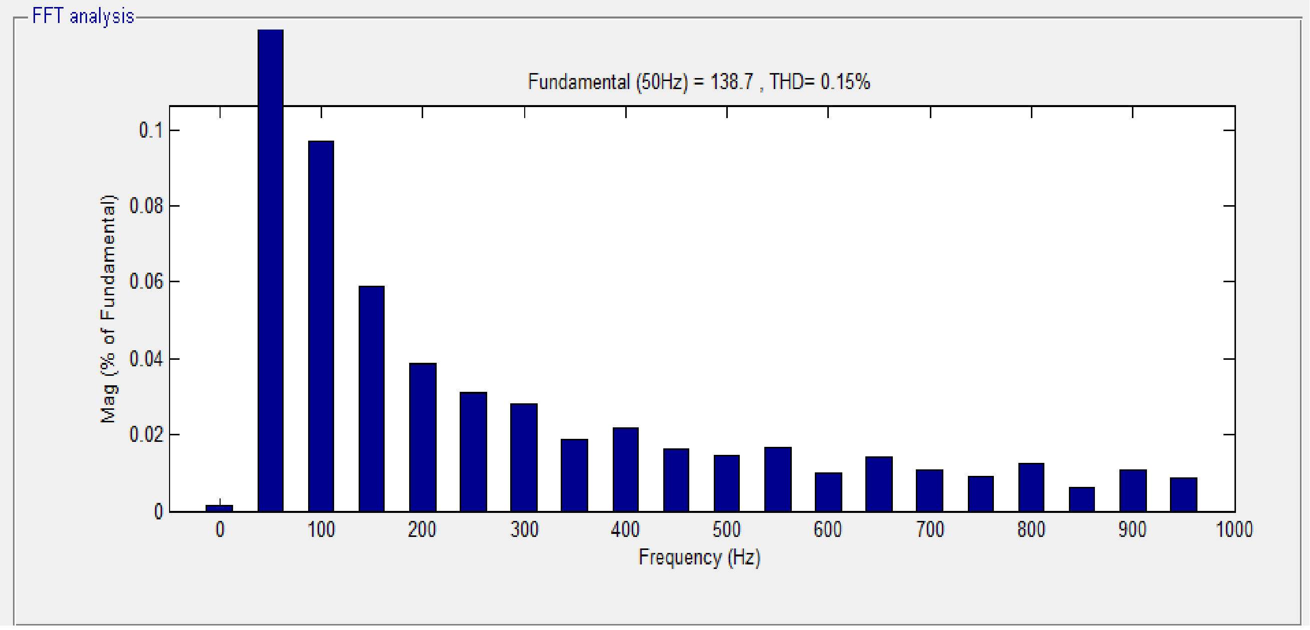

Fig.4.10 Total Harmonic Distortion 0.15%.

The comparative analysis of harmonic performance of proposed work with existing work is shown in Table 1. Where THD of proposed work has been compared with existing work significant improvement in THD are visible.

Table 1: Comparison of Harmonic Distortions

Parameter	***Previous***	***Proposed***
THD %	**2.48 %**	**0.15%**
3rd	0.94 %	0.08 %
5th	0.03 %	0.04 %
7th	0.54 %	0.03 %
9th	0.14 %	0.02 %
11th	0.28 %	0.02 %
13th	0.22 %	0.02 %
15th	0.14 %	0.01 %
17th	0.11 %	0.01 %
19th	-	0.01 %

V. CONCLUSION

In this examination, the PWM sequences have been inserted to SVPWM control signal to achieve dual-mode operations in the Z-source inverter network. To observe the effect when the PWM signal inserted, we used different frequency and duty cycle of PWM added to SVPWM control signal with different modulation index, and the experimental shows a significant results for boost dc-link voltage, and the output waveform have a good shape and less THD. The entire control algorithms are implemented and simulated in MATLAB SIMULINK. These experiments successfully demonstrated all control algorithms for multilevel -Z-Source inverter under low power conditions. Future extension of extension of the proposed model will need to test in hardware prototype at high power condition. After that, it needs to develop hardware into working for specific PV application for both island mode and grid connected mode, with MPPT included.

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