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A Novel Control Strategy For Modified SL-QZSI With Three Phase AC Grid Connected System

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ABSTRACT

This paper proposes the Modified Switched Inductor Quasi Z Source Inverter (MSL-QZSI) for extracting maximum solar power generation. The Z source inverter uses LC impedance network to couple the main converter circuit to the power source, which provides the boosting of input voltage. It is not possible in traditional voltage-source inverter (VSI) and current-source inverter (CSI). The proposed dynamic model of Single diode Photovoltaic Array was found to be better and accurate irradiance and temperature variation. The current source based Modified SL – QZSI has been presented suitable for photovoltaic (PV) application mainly because of its single-stage boost capability and improved reliability. These proposed inverters possess high boost voltage inversion ability and a lower voltage stress across the active switching device which compared with a conventional switched-inductor ZSI, the proposed MSL-qZSIs for the same input and output voltage used to provide continuous input current and reduced voltage stress on the capacitors. A novel control strategy of reference current generation has been analyzed under PQ theory for AC grid connected system. The design of grid-connected inverter with LCL filter was proposed for improvement of system efficiency and power supply quality of the output and also, it is often used to interconnect an inverter with utility grid; In order to filter the harmonics produced by the inverter. In addition, the performance of proposed topology is verified by using MATLAB/Simulink environment.

Keywords: AC Grid, PQ theory, Switched Inductor Quasi Z Source Inverter (SI-QZSI), Photovoltaic System, LCL filter, Reference Current Generation

1. INTRODUCTION

An employed new Z source inverter topology used to boost the dc input voltage without necessity of step up transformer/dc dc boost converter. A survey of z source inverters are suitable for low and wide varying input voltage system called as PV applications, fuel cell and wind energy generation. These are various type of Z source technology discussed with conventional system for performance improvement. Here, the two topology of ripple input current switched-inductor quasi-Z-source inverter (rSL-qZSI) and continuous input current switched-inductor quasi-Z-source inverter (cSL-qZSI) given as high step-up inversion ability, lower voltage stress on the capacitor and lower input current ripple [N.R. Sreeprathab *et al* 2014]-[M.-K. Nguyen *et al* 2012]. It can be often reduced voltage stress on the capacitors, suppress the start-up inrush current while damage the devices and also smoothly without need to add external second-order filters. The proper implementation of impedance source network based on power converter compared with various applications [Yam P *et al* 2014]. Comprehensive surveys of various impedance sources converter/inverter are discussed by modeling and control techniques.

Switched inductor Z source inverter increases the voltage boost inversion ability significantly obtain high voltage conversion ratios under the short shoot-through zero state is required. Here, the modified SL-QZSI

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also represent extended switched inductor quasi Z source inverter is discussed. It combines the SL-qZSI with the traditional boost converter as well improve the switched inductor cell to reduce the voltage stress of capacitor, power device and diode for the same input and output voltage. It can be most applicable for the distributed generation application with low voltage source such as fuel cell, photovoltaic and so on [Miao ZHU *et al* 2010]-[Kai Deng *et al* 2014]. The detailed dynamic modeling and control issue of a quasi Z source inverter are used to boost capability and improved reliability at distributed generation (DG), such as PV and fuel cell power conditioning [Yuan Li *et al* 2011]. In order to choose a proper capacitor voltage reference, due to the mutual limitation between the modulation indexes and shoot through duty ratio of qZSI and also the constant capacitor voltage control method has been proposed.

The performance improvement of switched inductor quasi Z source inverter can be capable of increasing the output voltage level in comparison to the other structure of Z-source inverter in lower duty cycle. The proposed topology of maximum boost control method is analyzed by mathematical relations for distributed generation with renewable resources [Shima Rashidi Aghdam *et al* 2013]. The various control strategy have been discussed with application point of view. An improved control technique is based on the reference current generation. Under the various control studies are considered as instantaneous real/reactive power theory (PQ), Synchronous Reference Frame (SRF) theory and Discrete Fourier Transform (DFT) algorithm. The valuation of results are carried out by under three phase balanced and unbalanced non-linear load condition [Sushil Karvekar *et al* 2013].

The single diode dynamic model of photovoltaic array has been designed and analyzed in both software and hardware simulators. This kind of survey gives a novel PV cell modeling algorithm that has small error for any kind of PV cell types of material with little time required for computation. The valuation of these model parameter at real condition of irradiance and temperature of the direct PV module are determined by according to their initial values [Hyeonah Park *et al* 2013]-[M. Abdulkadir *et al* 2012]. The proposed model gives the relationship between module parameter and circuit performance. These involve the step by step method for PV modeling in MATLAB Simulink.

This paper proposes a novel control strategy of modified switched inductor quasi Z source inverter is presented in AC grid connected system. The dynamic modeling of photovoltaic system is analyzed based on hybrid structure for extracting maximum power. The proposed scheme to compare with a conventional switched-inductor ZSI to achieving a continuous input current and can be also reduced voltage stress on the capacitors. PQ theory based reference current generation can be applicable for three phase AC grid connected system. The improvement of system efficiency and power supply quality of the output can be achieved by using LCL filter. The performance improvement of proposed topology can be obtained by using total harmonic distortion in MATLAB/Simulink platform.

2. RELATED WORK

Distributed MPPT based current source inverter topologies are discussed with extracting maximum power for PV applications. In hybrid design of current fed switched inverter is used to combine the high gain property of ZSI and low passive component count of SBI. Also, the transformer less current fed scheme can be applicable for reduction current in hybrid system [Rajeswari .R 2015]. The mathematical models of L and LCL filter design are demonstrated for three-phase PV grid-connected inverters. Here, the proposed filter design obtained by using trial and error method. The LCL filter can be getting better filtering effect when the damping resistor is parallel connected rather than series. Also, it used to interconnect an inverter to the utility grid in order to filter the harmonics produced by the inverter [Xu Renzhong *et al* 2013]-[A. Reznik *et al* 2014]. This survey gives to conduct a comprehensive analysis and modeling of the three phase LCL filter for non-galvanic isolated inverter, suitable for wind energy and photovoltaic applications.

Based on the inhibiting resonance by using damping resistance, dual-loop control strategies for grid-connected inverter with LCL filter were proposed in this survey. It gives to improve the system efficiency and power supply quality of the output. The LCL filter with grid-connected inverter has a stronger ability of harmonic suppression [Qiubo Peng *et al* 2013]. The unified power quality conditioner (UPQC) can be followed to compensate current

and voltage-quality problems of sensitive loads using novel reference signal generation method. The both side converter has been used for harmonics originating from the nonlinear load side and used to mitigate voltage sag/ swell originating from the supply side. These all design of converter configuration based on the reference current and voltage generation method [Ahmet Teke*et al* 2011].

An improved switched inductor Z source inverter is used to [Deng Kai *et al* 2013] overcomes the boost limitation of the classical ZSI with size saving and high power density. The current ripple of the DC voltage source is inhibited and also the voltage stress capacitor, diodes, power devices are reduced for distributed generation application. In order to verify the topology under by both the simple boost and maximum boost control methods [Kai Deng *et al* 2014]. Another type of modified two switched inductors quasi Z source inverter is discussed with theoretical results. It has been slightly improving in capacitor stress compared to similar classic one cSL-qZSI [Abualkasim Bakeer *et al* 2015]. In order to improve the performance of the topology in reduction the total harmonics distortion in the output of the inverter and also low size filter is used to get sinusoidal output voltage.

The compensation of reactive power and current harmonic can be achieved by using active power filter (APF). It effectively based on the generation method of reference current using modified classical PQ instantaneous method are discussed. The dynamic behavior of the system [M. Benghanem *et al* 2006] was established by compensating the reactive power and current harmonic components generated by three-phase bridge rectifier. The voltage regulation of substation can be obtained by using the robust current controller based solar-inverter system. This control survey offers the powerful tools to design controllers with uncertainties accounted for in the design process. The approximated filters design of each controller device is used to improve the current harmonic profile [Mohit Chhabra *et al* 2014]. In this paper, use to understand the hybrid power transfer under by the proposed topology and working condition of novel control strategy was used here.

3. MODIFIED SWITCHED INDUCTOR QUASI Z SOURCE INVERTER (MSI-QZSI)

A new topology of Z source inverter (ZSI) has been developed to overcome the problem of conventional voltage source inverter (VSI) and current source inverter (CSI). The more novel member in the family of QZSI topology is three phase switched inductor quasi Z-source inverter (SL-QZSI) which limit the ratings of the inductors and capacitors used in the Z- network to a greater stage. The higher rating of voltage gain can be achieved to fulfill the applications which require a large gain range, especially for renewable energy system. It is discovered the SL-QZSI draws a constant current from the source which is most suited for Photovoltaic (PV) application.

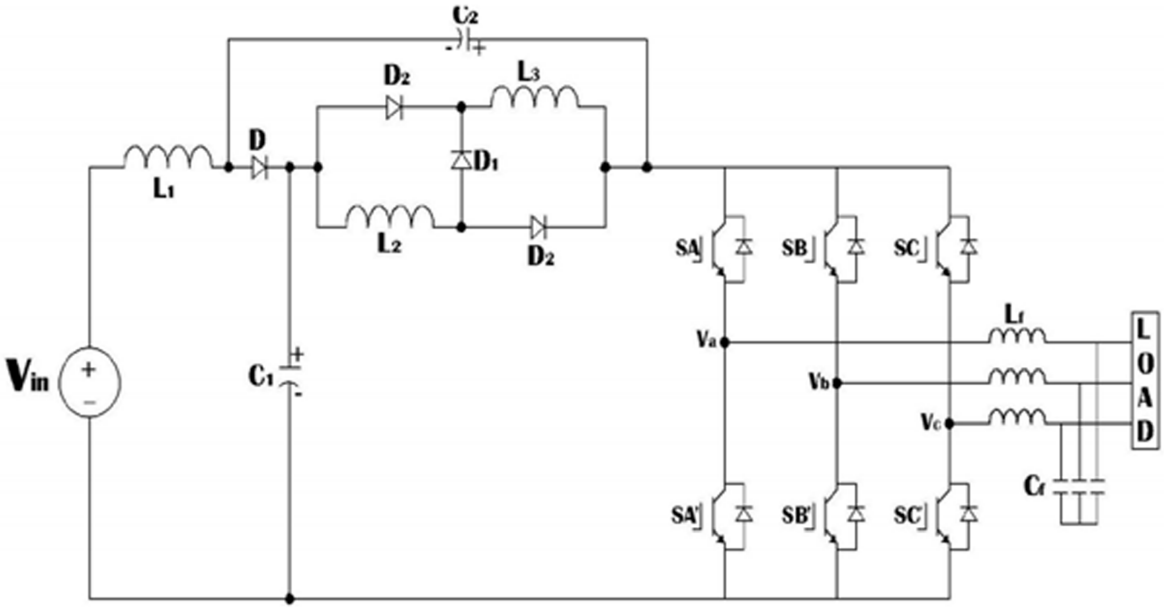

Figure 1: Conventional Circuit Diagram of SL- QZSI

The conventional topology of SL-QZSI differs from the former quasi-Z-source inverter by the impedance network. The SL-QZSI scheme has a passive network and an inverter bridge with six switches (S1, S2, S3, S4, S5, and S6). The passive network has inductors (L1, L2, and L3) capacitors (C1 and C2) and diodes (D1, D2, D3 and Din) are arranged as conventional circuit configuration shown in Fig.1.

The operation of SL-QZSI can be explicated with the help of two states called as shoot through state and non shoot through state. The boost factor of the SL-qZSI can be given as [Deng Kai*et al* 2013] follows,

$$B = \frac{1+D}{1-2D-D^2} \tag{1}$$

As seen, when O < (l-2D-D2) <1, the boost inversion of SL-QZSI will be increased. Thus, to obtain the same boost gain, the SL-qZSI needs to less shoot-through duty ratio than both the original ZSI and the qZSI, while to improve the output voltage profile. The modified switched inductor quasi Z Source inverter (MSL-QZSI) consists of limited counting of inductance and capacitance combination. The proposed circuit configuration for single stage system is shown in fig 2.

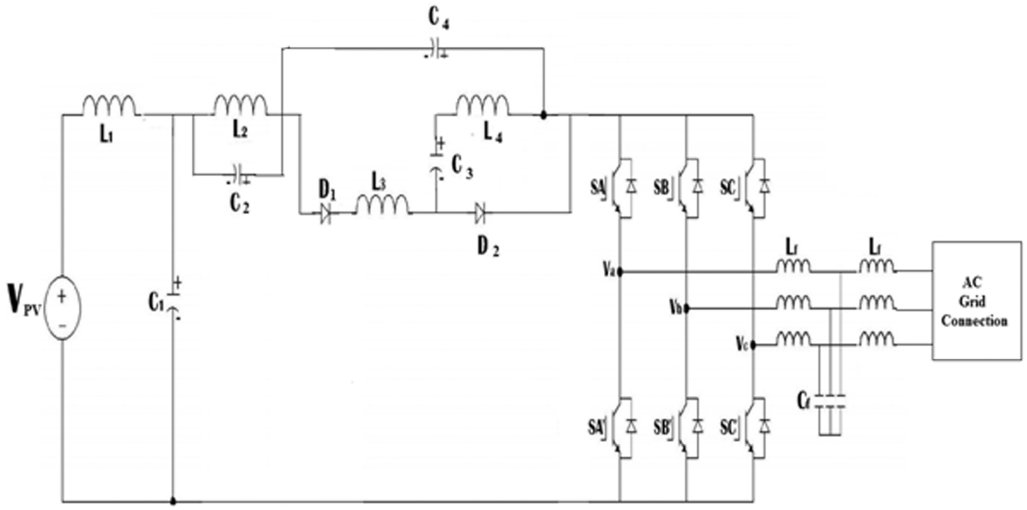

Figure 2: Proposed Circuit Configuration of MSL-QZSI

Here, the proposed system consists of photovoltaic energy; improved current fed based Z source inverter called as Modified Switched inductor Z Source inverter and LCL filter with AC grid connected system. It is seen by only for single source system consideration for understanding the proposed topology. By comparing to conventional type of SL-QZSI, gives fewer requirements of components and higher voltage gain. To increase voltage gain of the qZSI, one can increase either the shoot-through duty ratiod_0 and modulation index M. It can be [Yuan Li *et al* 2011] represented by the equation given below,

Simple Boost, $M \le 1 - D_0$ (2)

Maximum Constant Boost, $M \le \frac{2}{\sqrt{3}}(1 - D_0)$ (3)

Maximum Boost, $M \le \frac{2\pi}{3\sqrt{3}}(1 - D_0)$ (4)

The design of large L and C is preferred for low steady-state current and voltage ripples, tradeoffs need to be made for proper transient responses. To operate grid connected mode and distributed generation in standalone mode should be the follow a current reference to control the output active and reactive power.

4. PROPOSED AC GRID CONNECTED SYSTEM

The proposed circuit configuration of Modified Switched Inductor Z Source Inverter (MSL-QZSI) has been analyzed for AC grid application. A novel control strategy of PQ theory based reference current generation used to regulating the hybrid structure across the inverter. In proposed Z source topology used to extracting the maximum power from the photovoltaic system. The dynamic analysis of single diode model can be obtained and verified with results of simulation under MATLAB environment. Design of LCL filter used for eliminating the harmonics and regulating the AC voltage.

4.1. Photovoltaic System

The operation of a PV simulator and PV cell modeling have very small error even in various types of material such as thin-film type, Cr-Si type and Tandem type are required. In fig 3 shows representation of the PV cell equivalent circuit for PV cell modeling. The valuation of these model parameters [M. Abdulkadir *et al* 2012] at real condition of irradiance and temperature of the target PV module is determined according to their initial value.

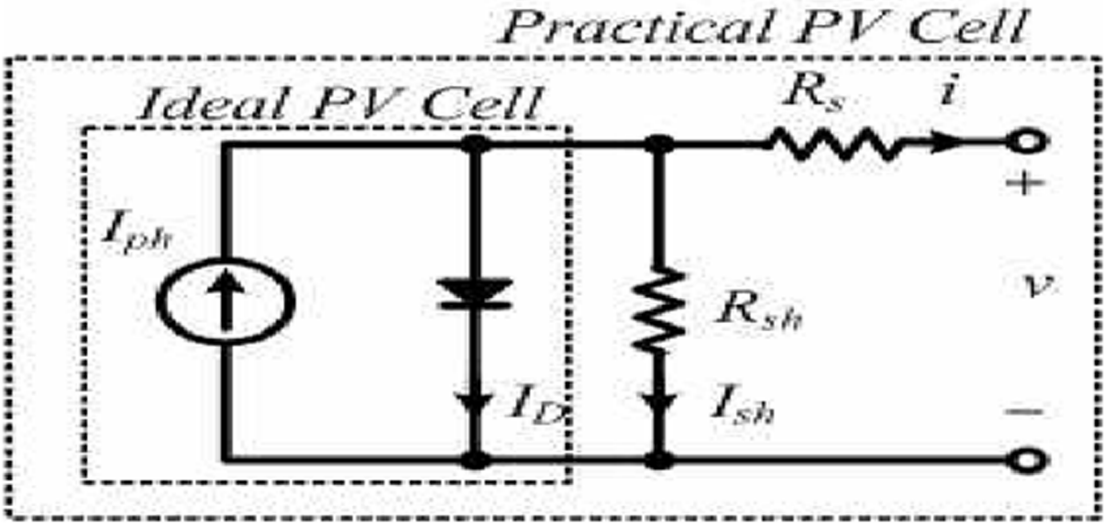

Figure 3: Equivalent Circuit of PV Module

In V-I characteristics of PV system can be written as,

$$I = I_{PV,Module} - I_{0,Module}\left[\exp\left(\frac{qv}{akT}\right) - 1\right] I_d \tag{5}$$

There are required parameters referred by the above equation depends upon the incident solar irradiance, the cell temperature. It makes suitable power electronics designer. It can be easy and effective model for the simulation on photovoltaic devices with power based converter.

$$I = I_{PV}, Module - I_{0,Module}\left[\exp\left(\frac{V + R_S I}{V_{ta}}\right) - 1\right] - \frac{V + R_{SI}}{R_p} \tag{6}$$

Where $I_{PV}, Module$ and $I_0, Module$ is photovoltaic and saturation current of array respectively, $V_t = N_S KT / q$, array is composed by N_p parallel connection of cell, the photovoltaic and saturation current can be written as $I_{pv} = I_{pv,Module} N_p$, $I_0 = I_{0,Module} N_p$.

4.2. AC Grid Connected PV System

Generally, three phase inverter change the DC input voltage from the PV to AC voltage for the grid. Here, the inverter sits around between the solar array and the grid draws energy from each, and might be a large stand-alone unit attached to individual solar panels. The grid connected PV system provides the better voltage regulation and power quality improvement while compared to other connection of PV array. In fig 4. Shows the block diagram of proposed AC grid connected PV system

In photovoltaic application of the grid interface between source (solar array) and load (utility grid) is attained by a three phase inverter. In order to maximize the system efficiency, the inverter must be optimized in design and control. The harmonic mitigation plays an important role in grid-connected PV system. To overcome this problem using by LCL filter across the AC utility grid. Above diagram mention, if there is no energy source connected to the capacitor, it will be charged with energy from the AC grid. Otherwise, when the capacitor is fed by the DC-DC converter across the capacitor is charged with part of input energy. The remaining energy is not stored in the capacitor and also is fully delivered as active power to the AC grid.

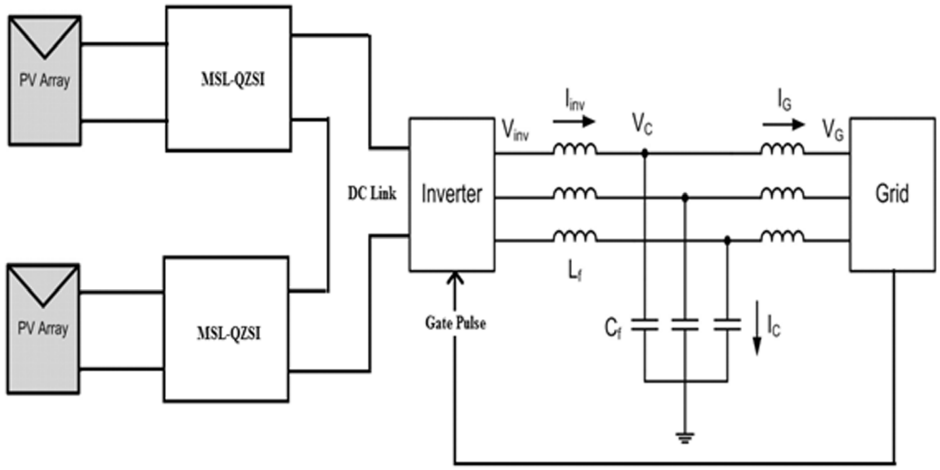

Figure 4: Block Diagram of Proposed Topology

4.3. LCL Filter Design Configuration

The design of LCL filter used to achieve the better performance and also it indicates the impacts on the stability and filtering property from the parallel resistor or series resistor. Per phase equivalent circuit of LCL filter design referred by [A. Reznik *et al* 2014] the authors and shown in fig 5.

In order to accomplish the best performance of LCL filter, the low frequency range of current should be maintained as smooth as possible and also the high frequency range of intensity rate should be as fast as possible. According to surveying, when the resonant frequency of filter capacitance and inductor inside the range can be maintained at 1/4 to 1/5 of carrier frequency, to become the filtering performance is best. Here, the resonant frequency of LCL filter could be depicted as given below,

$$f = \frac{1}{2\Pi}\sqrt{\frac{L_1 + L_2}{L_1 L_2 C}} \tag{7}$$

In general, the resonant frequency is bigger than 10 times of the power frequency and smaller than 1/2 times of the switching frequency. The corresponding filter capacitance can be written as,

$$C = \frac{1}{4\Pi^2 f^2 L} \tag{8}$$

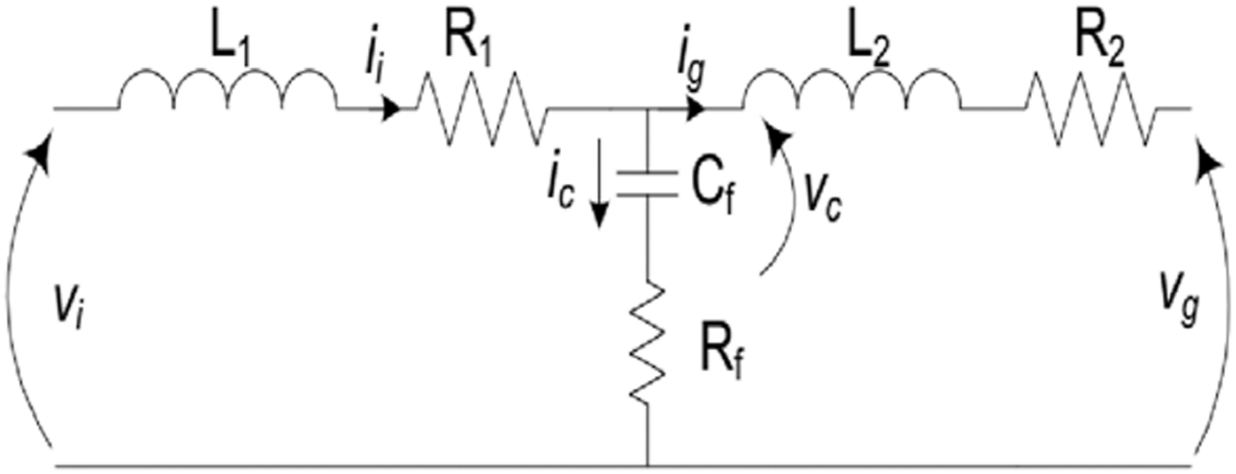

Figure 5: Per Phase Model of LCL Filter

$$C \le \frac{\lambda P}{6\Pi f E_m^2} \tag{9}$$

In order to avoid the power factor correction of AC grid-connected inverter is over lower, the reactive power is absorbed by filter capacitor should not be exceed 5% of the rated active power. In this paper C = 0.09μF and L = 5mH was used. Some order of current harmonic create from the PV grid connected inverter, may be cause the sudden increase rapidly. Here, to recover this problem when adding the damping resistance into filter to suppress the resonances.

5. CONTROL STRATEGY

The proposed Novel control scheme has been implemented in the active power filter supplies the harmonic power as well as reactive power. The compensating current can be generated by the active power filter and also according with the PWM switching signals that can be change with respect to the load voltage and current. There are different kind of switching control techniques referred as [Sushil Karvekar *et al* 2013] like hysteresis control, neural control, deadbeat control and adaptive hysteresis control employed for generating the reference current required for harmonic and reactive power compensation. The basic of instantaneous reactive power theory is used to calculate the desired compensating current. These corresponding equations are referred by above mention the survey. Final expression can be written as,

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \tag{10}$$

$$p_0 = v_0 \times i_0,\ p = \bar{p} + \tilde{p},\ q = \bar{q} + \tilde{q} \tag{11}$$

$$\begin{bmatrix} i^*_{S\alpha} \\ i^*_{S\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} + p_0 + \bar{p}_{loss} \\ 0 \end{bmatrix} \tag{12}$$

The block diagram representation of control strategy is shown above in fig 6. The real and imaginary power include AC and DC components are considered as p and q consists of positive sequence components represent the DC and harmonics with negative sequence represent the AC components. The above equation can be transferred to abc three phase system given below,

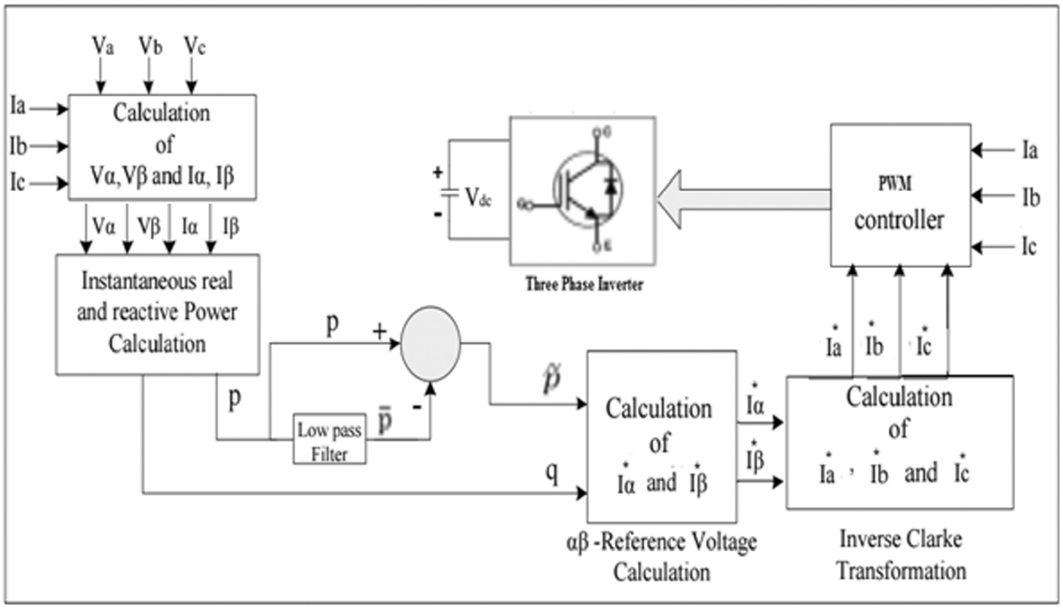

Figure 6: Configuration of reference current generation technique

$$\begin{bmatrix} i_{Sa}^{*} \\ i_{Sb}^{*} \\ i_{Sc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{S0}^{*} \\ i_{S\alpha}^{*} \\ i_{S\beta}^{*} \end{bmatrix} \tag{13}$$

The reference current generation in three phase system ($i_{Sa}^{*}, i_{Sb}^{*}, i_{Sc}^{*}$) are determined to compensate the neutral, harmonic and reactive current/voltage in the load. The switching signals are used to comparing the reference current and actual line currents using PWM control techniques. The three phase pq theory has different features consist such as elimination of power oscillations, improvement of power factor, elimination of current harmonics and harmonic damping.

6. SIMULATION RESULTS AND DISCUSSION

The merits of the proposed MSL-QZSI are provided to compare with traditional topology performance of SL-QZSI and QZSI. This inverter supplies two independent voltage sources with multiple relationships and performs the novel control strategy in order to extract the maximum output power from the solar cell array. Here, the three phase inverters is used to convert the DC power into high quality AC power and feeds it into the utility grid and also to regulate the voltages by using LCL filter. The dynamic model of single diode PV interface with proposed AC grid connected system. To simulate the reference current generation method above discussion, MATLAB/Simulink is used. The overall proposed system configuration and representation of circuit diagram are shown in fig 7.

The input of corresponding switched inductor Quasi Z Source inverter is taken from photovoltaic system. PV voltage and current waveform is shown in fig 8. By comparing the proposed topology, conventional DC-DC converter, Z-source inverter and switched-inductor structure with maximum boost control method. Because it is able to generate higher amount of voltage boost factor and also provide the higher value of voltage gain under the condition of modulation index and duty cycle.

The most advantage of proposed MSL-QZSI topology is used to increase the voltage gain and generation output waveforms without any distortion by adding some set elements to the switched inductor Z source inverter. The DC link across the voltage is used to reduce the higher amount of voltage stress on the scheme while increasing the voltage gain. The DC capacitor across the voltage is shown in fig 9.

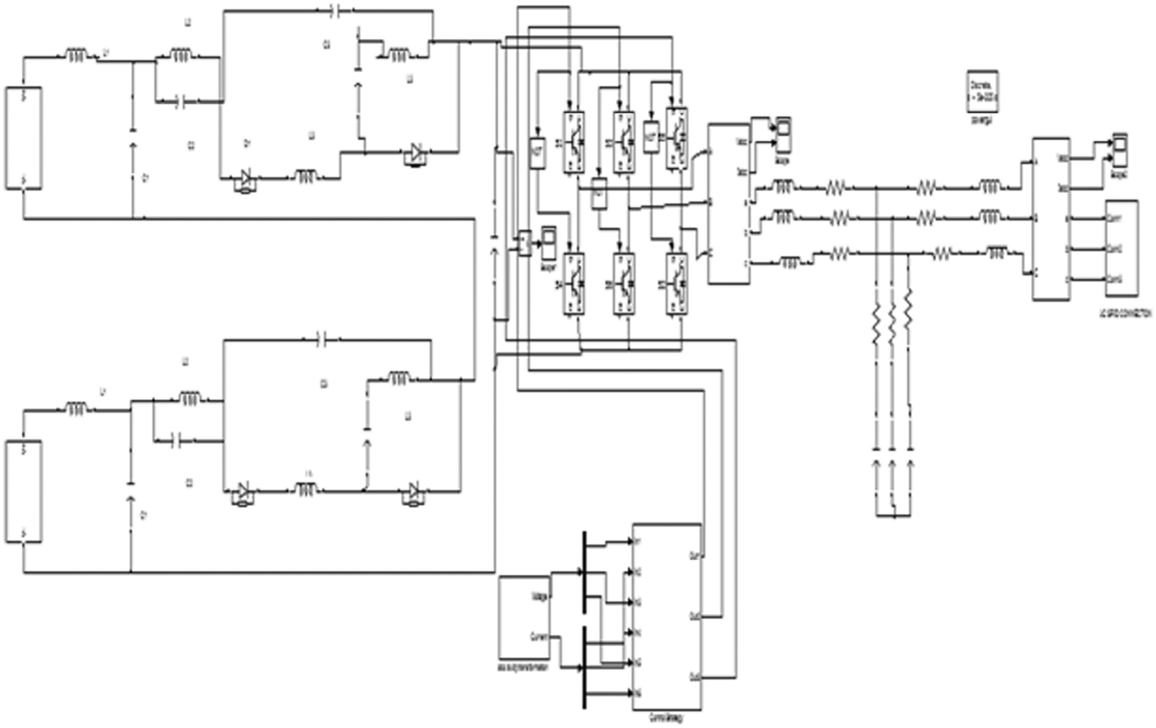

Figure 7: Simulink Diagram of proposed system configuration

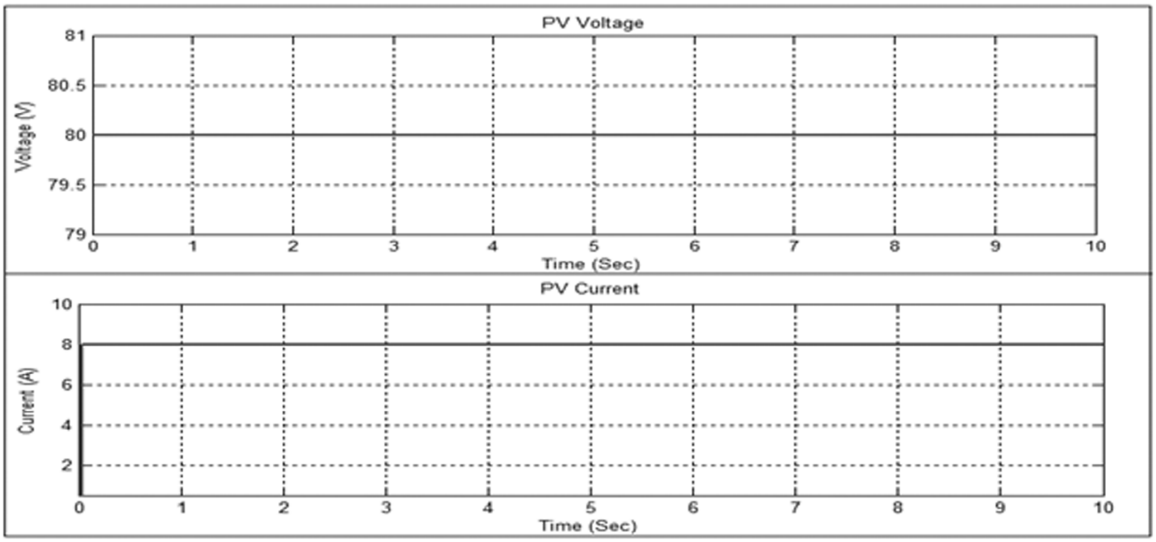

Figure 8: Photovoltaic Voltage and Current Waveform

The control strategy of proposed topology is developed based on the reference current generation resulting as the instantaneous reactive power theory. It consists of an algebraic transformation (Clarke transformation) of three-phase voltage and current in the abc coordinate to theáâ0 coordinate. By using LCL type grid connected inverter, to achieve the efficiency of the system and power supply quality of the output. The three phase output voltage and current waveform under with/without filters are shown in fig 10 and 11.

The output current of three phase AC grid connected inverter with LCL filter can be obtained the higher quality by using proposed control technique. It has substantial ability of harmonic suppression. In this paper, the simulink model for the LCL filter with PV grid connected inverter is designed. This proposed scheme can be verified with the simulation result of total harmonic distortion and power factor correction. The corresponding waveform is shown in fig 12 and 13.

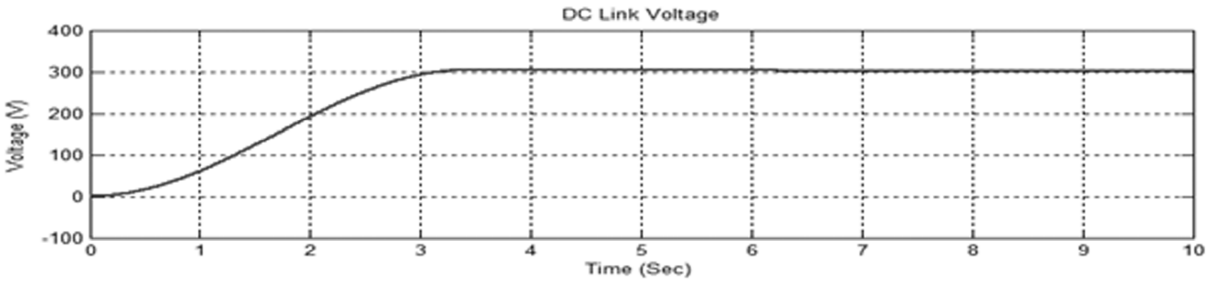

Figure 9: DC Link Capacitor across Voltage Waveform

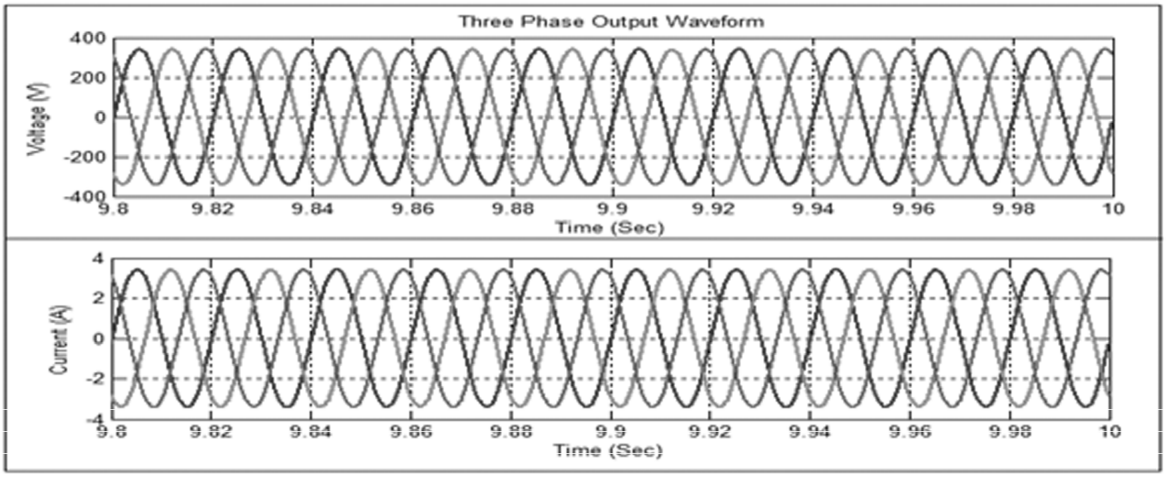

Figure 10: AC Grid Connected system with LCL filter

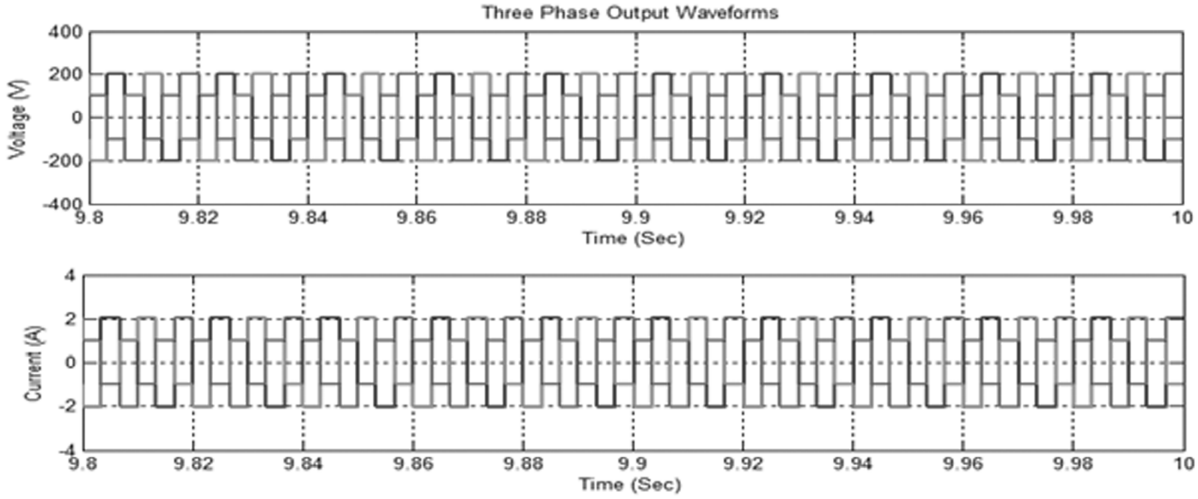

Figure 11: AC Grid connected System without LCL filter

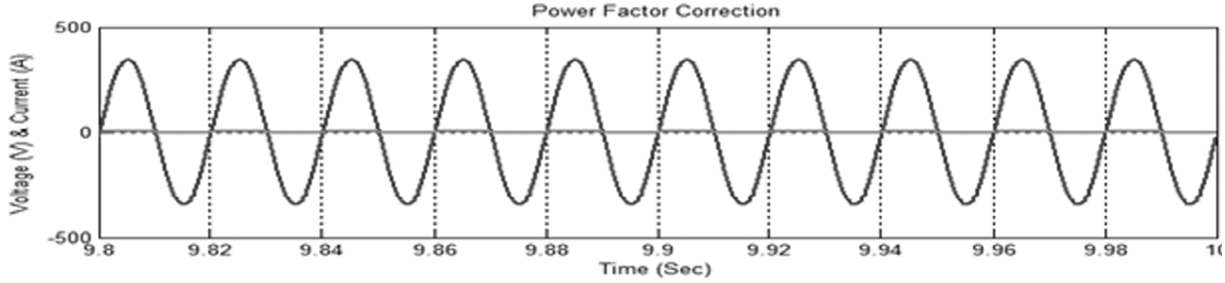

Figure 12: Power Factor Correction (PFC)

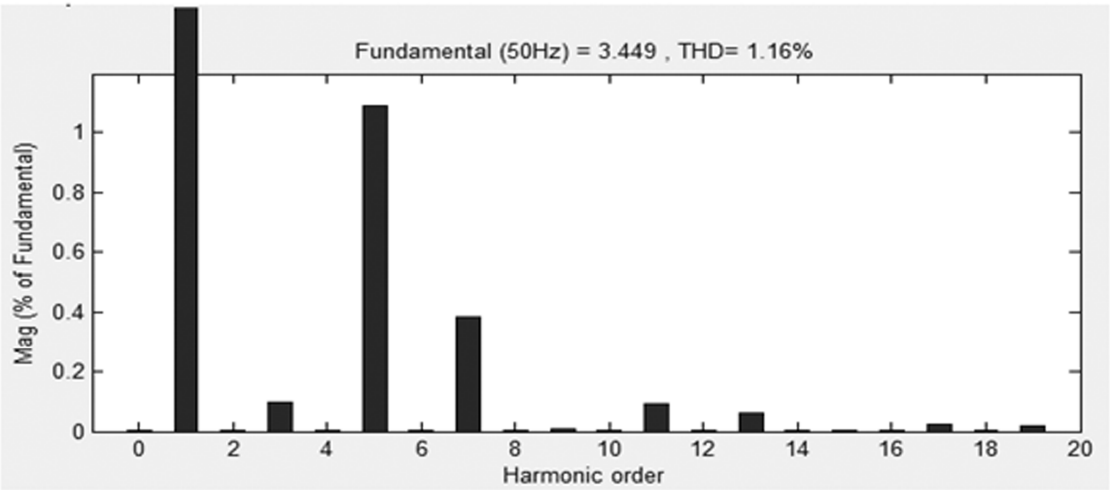

Figure 13: FFT analysis of output current waveform

Table 1
Specification of Simulation Parameters

Parameters	Values
PV Voltage (Vin)	80V
PV Current (Cin)	8A
Converter Switching Frequency (f_{sw})	50HZ
DC voltage (V_{dc})	300V
Filter of L (L_f)	5mH
Filter of (C_f)	0.09μF

In this LCL filter design can be achieved better performance while compared to other L and LC filter for small and medium power PV grid connected inverter. In order to achieve the value of THD is 1.16% in this proposed topology. The simulation circuit parameter specifications are mentioned in Table 1.

7. CONCLUSION

This paper presented a modified switched inductor quasi Z source inverter has been analyzed for AC grid connected system, when compared to other conventional DC/DC converter, SL-QZSI the proposed scheme offers the capacitor across low voltage stress, diode reverse voltage and input current ripple in the switching device with the same input and output voltage. The novel control strategy can be designed using reference current generation by instantaneous PQ theory. This control method used to extract the maximum power from photovoltaic array. The three phase gating signals are determined using PWM technique for AC utility grid. The detailed verification of proposed topology with LCL filter provides the better power supply quality of the output, lower harmonics because have high harmonic suppression and improve the system efficiency. Moreover, the proposed topology will be applicable for high conversion efficiency for distributing generation with low voltage sources. The proposed scheme has been verified with simulation results of total harmonic distortion and power factor correction for AC grid connected system. However, the voltage stress of the components, stability analysis and other properties of the proposed topology still needs without filter research in the future.

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