Improve the Power Quality for A Grid Connected Inverter with Local Load by Using Z Source Network

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Abstract: **This paper is proposed for inverters to simultaneously improve the power quality of the inverter local load voltage and the current exchanged with the grid. It also enables seamless transfer of the operation mode from stand-alone to grid-connected. The control scheme is done by z source network. This leads to a very low total harmonic distortion in both the inverter local load voltage and the current exchanged with the grid at the same time. The proposed control strategy can be used to single-phase inverters and three-phase four-wire inverters. It enables grid-connected inverters to inject balanced clean currents to the grid even when the local loads are unbalanced and/or nonlinear. Experiments under different scenarios, with comparisons made to the current repetitive controller replaced with a current proportional–resonant controller, are presented to demonstrate the excellent performance of the proposed strategy.**

Keywords: Harmonics, Power quality, ZSI

I INTRODUCTION

The application of distributed power generation has been increasing rapidly in the past decades. Compared to the conventional centralized power generation, distributed generation (DG) units deliver clean and renewable power close to the customer's end. Therefore, it can alleviate the stress of many conventional transmission and distribution. As most of the DG units are interfaced to the grid using power electronics converters, unbalanced utility grid voltages and voltage sags, which are they have the opportunity to realize enhanced power generation through a Flexible digital control of the power converters.

On the otherhand, high penetration of power electronics based DG units also introduces a few issues, such as system resonance, protection interference, etc. In order to overcome these problems, the microgrid concept has been proposed, which is realized through the control of multiple DG units. Compared to a single DG unit, the microgrid can achieve superior power management within its distribution networks. In addition, the islanding operation of microgrid offers high reliability power supply to the critical loads. Therefore, microgrid is considered to pave the way to the future smart grid. It is advantageous to operate inverters as voltage sources because there is no need to change the controller when the operation mode is changed. A parallel control structure consisting of an output voltage controller and a grid current controller was proposed in to achieve seamless transfer via changing the references to the controller without changing the controller. Another important aspect for grid connected inverters or micro grids is the active and reactive power control and for more details. As nonlinear and/or unbalanced loads can represent a high proportion of the total load in small scale systems, the problem with power quality is a particular concern in microgrids. Moreover, unbalanced utility grid voltages and utility voltage sags, which are two most common utility voltage quality problems, can affect micro grid power quality.

II RELATED WORK

2.1. Harmonic Distortion

Harmonic problems are almost always introduced by the consumers' equipment and installation practices. Harmonic distortion is caused by the high use of nonlinear load equipment such as computer power supplies, electronic ballasts, compact fluorescent lamps and variable speed drives etc., which create high current flow with harmonic frequency components. The limiting rating for most electrical circuit elements is determined by the amount of heat that can be dissipated to avoid overheating of bus bars, circuit breakers, neutral conductors, transformer windings or generator alternators. Ratio of the square root of the sum of squares of the rms value of harmonic component to the rms value of the fundamental components defined as Total Harmonic Distortion (THD) If the waveform under discussion is current, then the THD definition is called Current Harmonic Distortion. If the waveform under discussion is voltage, then the THD definition is called Voltage Harmonic Distortion.

2.2 Z SOURCE INVERTER

Z-source inverter is thought to be a one-stage boost-buck inverter and one-stage topology is somewhat considered to has higher efficiency over its counterpart of two-stage. Shown in Fig.2, Z-source inverter has a special impedance network between the bridge and the input voltage source. This special circuit structure makes ZSI has an additional shoot-through (*ST*) switching state in which the upper DC rail and lower DC rail are shorted together. In ST state the two inductors are being charged by the capacitors and in non-shoot-through (NST) states the inductors and input DC source transfer energy to the capacitors and load. This process is similar to the boost converter. Seen from the AC side the ST states are the same with null states, so by replacing the null states with ST states, the boost function of ZSI is achieved. There are typically two categories of PWM strategies for ZSI according to the different ST state insertion methods. The first category of PWM strategy is proposed. The principle of this method is that the ST states are inserted at every transition by overlapping the upper and lower driver signals. Shown in Fig.3 (a), the upper and lower driver signals can be derived by properly level shifting the modulation signals of voltage source inverter (VSI). The shifting values are set properly so as to ensure the occupied duration of the two null states are the same. The feature of this modulation strategy is that the transition times in one switching cycle is the same with VSI, the ST state is divided into six parts and the equivalent switching frequency of impedance network is six times of switching frequency so the volume of inductors could be reduced dramatically.

The other category of PWM strategy is based on the principle that the ST state directly replace the null states 111 and 000.It can be realized by two straight lines and the modulation signals of VSI, the feature of this modulation strategy is that the ST duty cycle is evenly divided into two parts in one switching cycle and at each part all three phase are in ST state, so the ST current is distributed evenly in three legs. On the other hand, the ST state introduces additional switch transitions, as a result in each leg there are two more transitions than VSI in one switching cycle.

III PROPOSED METHOD

Three phase inverters are normally used for high power applications. Three single-phase half or full bridge inverters can be connected in parallel to form the configuration of a three phase inverter. The gating signals of single phase inverters should be advanced or delayed by 120° with respect to each other in order to obtain three phase balanced voltages.

The three phase output can be obtained from a configuration of six switches and six diodes. Two types of control signals can be applied to the switches: 180°conduction or 120°conduction.

3.1 180° Conduction

Each switch conducts for 180°. Three switches remain on at any instant of time. When switch 1 is switched on, terminal 'a' is connected to the positive terminal of the dc input voltage. When switch 4 is switched on, terminal 'a' is connected to the negative terminal of the dc source. There are six modes of operation in a cycle and the duration of each mode is 60°. The switches are numbered in the sequence of gating the switches 123, 234, 345, 456, 561, 612. The gating signals are shifted from each other by 60° to obtain three phase balanced voltages.

3.2 120°Conduction

Each switch conducts for 120°. Only two switches remain on at any instant of time. The conduction sequence of switches is 61, 12, 23, 34, 45, 56, and 61. There are three modes of operation in a half cycle.

During mode 1 for $0 \leq \omega t \leq \pi/3$ switches 1 and 6 conducts.

$$Van = Vs/2$$

$$Vbn = -Vs/2$$

$$Vcn = 0$$

During mode 2 for $\pi/3 \leq \omega t \leq 2\pi/3$, switches 1 and 2 conduct.

$$Van = Vs/2$$

$$Vbn = 0$$

$$Vcn = -Vs/2$$

During mode 3 for $2\pi/3 \leq \omega t \leq 3\pi/3$, switches 2 and 3 conduct.

$$Van = 0$$

$$Vbn = Vs/2$$

$$Vcn = -Vs/2$$

The line to neutral voltages can be expressed in Fourier series as given in equations 2.1 to 2.3.

$$Van = \sum_{n=1, 3, 5 \ldots}^{\infty} 2Vs/n\pi \cos n\pi/6 \sin n(\omega t + \pi/6)$$

$$Vbn = \sum_{n=1, 3, 5 \ldots}^{\infty} 2Vs/n\pi \cos n\pi/6 \sin n(\omega t - \pi/2)$$

$$Vcn = \sum_{n=1, 3, 5 \ldots}^{\infty} 2Vs/n\pi \cos n\pi/6 \sin n(\omega t - 7\pi/6)$$

The a to b line voltage is $Vab = \sqrt{3}\, Van$ with a phase advance of 30°. There is a delay of $\pi/6$ between the turning off switch 1 and turning on of switch 4. Thus there should be no short circuit of the dc supply through one upper and lower switch. At any time, two load terminals are connected to the dc supply and the third one remains open. The potential of this open terminal will depend on the load characteristics and would be unpredictable. Since one switch conducts for 120°, the switches are less utilized as compared to that of 180° conduction for the load condition. The control of output voltage is done using pulse width modulation. The commonly used techniques are Single pulse width modulation.

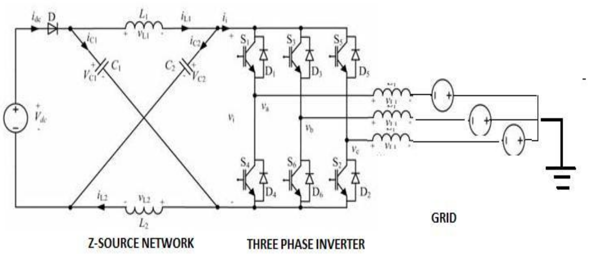


Fig 1: Sketch of a grid-connected three-phase inverter using the proposed strategy.

It is worth noting that it is quite a challenge to work with low-voltage inverters to improve the voltage THD, because, in general, the higher the voltage, the bigger the value of the fundamental component. Moreover, the impact of noises and disturbances is more severe for low-voltage systems than for high-voltage ones. Hence, it should be easy to apply the strategy proposed in this paper to inverters at higher voltage and higher power ratings.

IV SIMULATION RESULTS

The above-designed controller was implemented to evaluate its performance in both stand-alone and grid connected modes with different loads. The seamless transfer of the operation modes was also carried out.The $H\infty$ repetitive current controller was replaced with a Z source network for comparison in the grid-connected mode. In the stand-alone mode, since the grid current reference was set to zero and the circuit breaker was turned off (which means that the current controller was not functioning)

4.1 State-Space Model of the Plant P_i

Since it can be assumed that $u_o = u_{ref}$, there is $u_o = u_g + u_i$ or $u_i = u_o - u_g$ from Figs. 3 and 4, i.e., u_i is actually the voltage dropped on the grid inductor. The feed forwarded grid voltage u_g provides a base local load voltage for the inverter. The same voltage u_g appears on both sides of the grid interface inductor L_g, and it does not affect the controller design. Hence, the feed forwarded voltage path can be ignored during the design process. This is a very important feature. The only contribution that needs to be considered during the design process is the output u_i of the repetitive current controller.

TABLE I
PARAMETERS OF THE INVERTER

Parameter	Value	Parameter	Value
L_f	$150\mu H$	R_f	0.045Ω
L_g	$450\mu H$	R_g	0.135Ω
C_f	$22\mu F$	R_d	1Ω

The grid current i_2 flowing through the grid interface inductor L_g is chosen as the state variable $x_i = i_2$. The external input is $w_i = i_{ref}$, and the control input is u_i. The output signal from the plant Pi is the tracking error $e_i = i_{ref} - i_2$, i.e., the difference between the current reference and the grid current. The plant P_i can then be described by the state equation

$$\dot{x}_i = A_i x_i + B_{i1} w_i + B_{i2} u_i$$

and the output equation

$$y_i = e_i = C_{i1} x_i + D_{i1} w_i + D_{i2} u_i$$

Where

$$A_i = -\frac{R_g}{L_g} \quad B_{i1} = 0 \quad B_{i2} = \frac{1}{L_g}$$

$$C_{i1} = -1, \quad D_{i1} = 1, \quad D_{i2} = 0.$$

The corresponding transfer function of Pi is

$$P_i = \left[\begin{array}{c|cc} A_i & B_{i1} & B_{i2} \\ \hline C_{i1} & D_{i1} & D_{i2} \end{array}\right].$$

As an example, the controllers will be designed in this section for an experimental setup, which consists of an inverter board, a three-phase LC filter, a three-phase grid interface inductor, a board consisting of voltage and current sensors, a step-up wye-wye transformer (12 V/230 V/50 Hz), a dSPACE DS1104 R&D controller board with Control Desk software, and MATLAB Simulink/SimPower software package. The inverter board consists of two independent three-phase inverters and has the capability to generate PWM voltages constant 42-V dc voltage source. was used to generate a stable the three-phase inverter.

The generated three-phase voltage was from a connected to the grid via a controlled One inverter circuit breaker and a step-up transformer. neutral line for

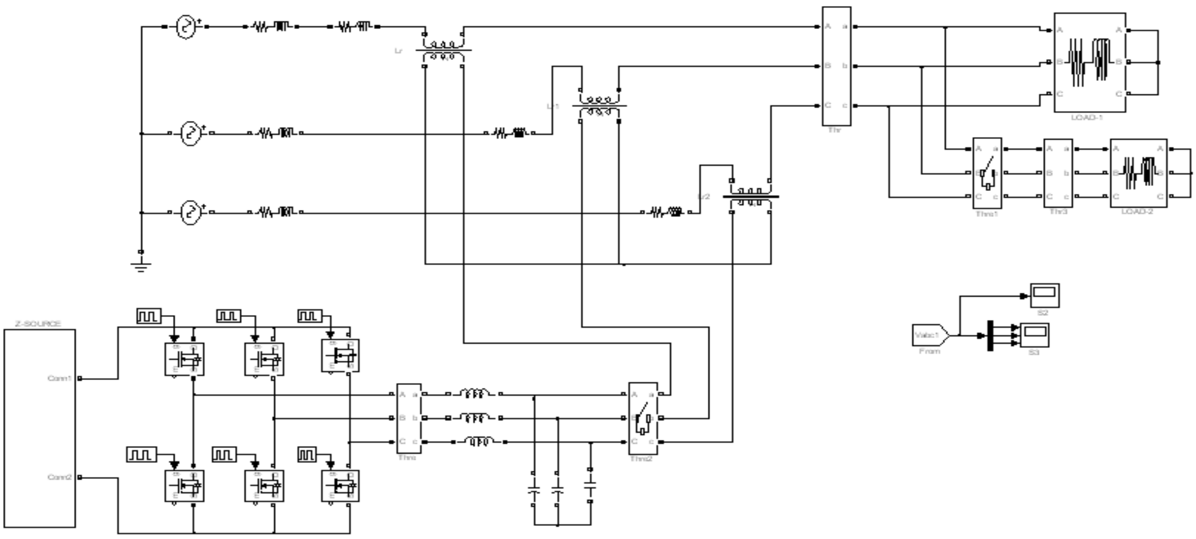
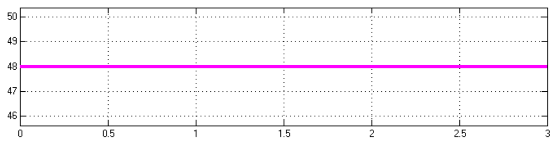
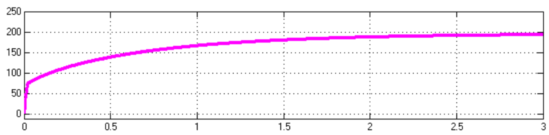


Fig 2: grid connected mode of a inverter using single pulse width modulation

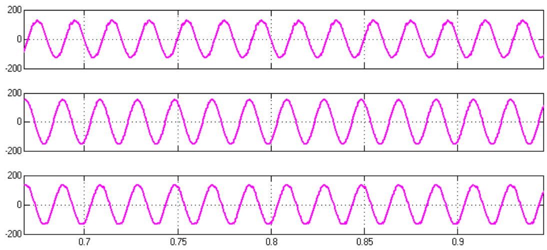


(a)

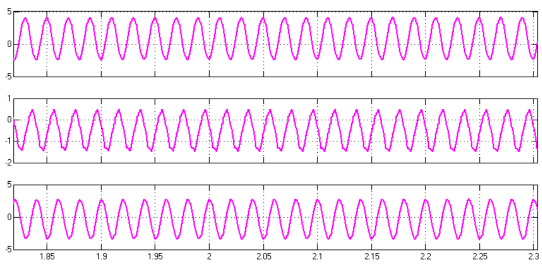


(b)

Fig 3: (a) input voltage of a inverter in gridconnected mode (b)output voltage of z source inverter in grid connected mode.



(a)



(b)

Fig 4: (a)output voltage of inverter (b) output current of a inverter in grid connected mode

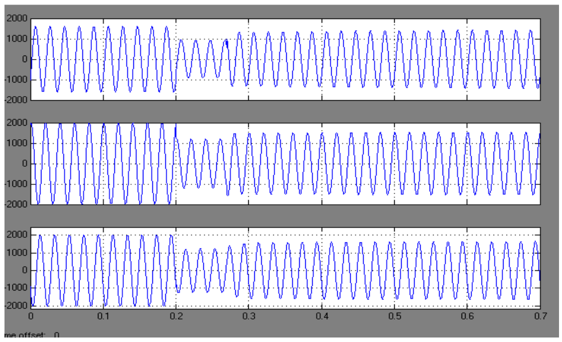


Fig 5: load voltage with compensation circuit

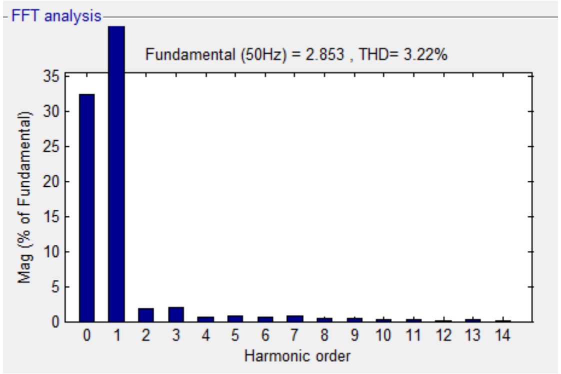


Fig 6: THD value by using single pulsewidth modulation

The recorded THD of the local voltage was 3.22% for the z source network. In this experiment, the proposed controller outperforms the z source current and voltage controller. Note that the grid was cleaner when the z source current-voltage controller was tested. As a result the exixting system THD values is 5.81%with fundamental frequency of 50Hz. The proposed system THD values about 3.22% in the grid connected inverter with z source network by using single pulse width modulation.

V. CONCLUSION AND FUTURE SCOPE

The proposed article shows a cascaded current voltage control strategy has been proposed for inverters in micro grids. It consists of an inner voltage loop and an outer current loop and offers excellent performance in terms of THD for both the inverter local load voltage and the grid current. In particular, when nonlinear and/or unbalanced loads are connected to the inverter in the grid-connected mode, the proposed strategy significantly improves the THD of the inverter local load voltage and the grid current at the same time. The controllers are designed using the z source control in this paper. The proposed strategy also achieves seamless transfer between the standalone and the grid-connected modes.

The strategy can be used for single-phase systems or three-phase systems. As a result, the nonlinear harmonic currents and unbalanced local load currents are all contained locally and do not affect the grid. Simulation results under various scenarios have demonstrated the excellent performance of the proposed strategy.

The graph of Power demand is always is of positive slope and progressive. The power quality problems are also following the same trend in their aspect. There's a need to reduce the complex power problems and supply an efficient and sufficient power to the utilities. There's always a continuous research carried out to improve the power quality. Unified Power Flow Controller is one of such a promising technology.

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