International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-2, December, 2019

Closed Loop Control of Wind Power Based on Trans Quasi-Zsourceinverter

Santosh Sonar

Abstract: ***The paper presents a wind generator output power appropriately monitored using a closed loop controller engaging the buck-boost competency of Trans qZSI and is fed to grid. The converter getting all benefits of conventional ZSI and exchanges the traditional inverter in the arrangement. Moreover, the Trans qZSI has the exceptional benefits of minimum component count and lower component ratings. The feed forward controller cautiously controls the wind generator output power. It monitors the short circuit duty cycle of inverter using third harmonic injected control technique to create a boosted output. Simulation of the complete circuit is performed on MATLAB and results are discussed. It offers an exclusive voltage regulation by creating proper choice of shoot through duty ratio under variable wind speed. The proposed control system is suitable for transient and steady state operation retaining the preferred level of output.***

Index Terms— PMSM wind generator, Trans quasi z-source inverter, closed loop control, short circuit.

Abbreviations used;

MCBC	***Maximum constant boost control***
PWM	***Pulse width modulation***
MBC	***Maximum boost control***
PMSM	***permanent magnet synchronous machine***
ZSI	***Impedance source inverter***
CSI	***current source inverter***
M	***Modulation index***
G	***Gain***
VSC	***voltage source converter***
SBC	***Simple boost control***

I. INTRODUCTION

Now a days Wind based power system is one of the fast growing energy systems. The power generation due to variable wind velocity is governed by the density of air and the area swept by the rotor .But power output relies on various parameters like rotor construction and the superiority of blade. It also depends on other losses like friction, pump and losses in the other related components. Mainly three wind power drive systems are available in literature [1]. PMSM centred wind drive system is one of the most favourable techniques especially for advantages as lesser size, rugged and less weight. It has modest and flexible design. As the PMSM wind generator operates with flexible speed, a back-to-back converter arrangement as a grid interface becomes essential. At the generation side, either a controlled or uncontrolled rectification is done to convert the generated AC energy to DC, as illustrated in Fig. 1. An inverter is connected to the grid through a capacitor.

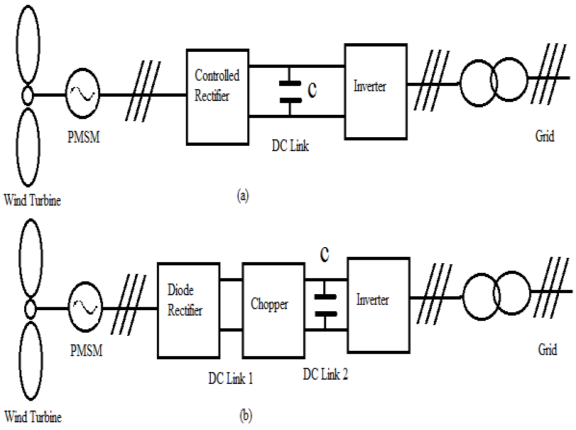

Fig. 1.TraditionalPMSM-based wind power converters (a) PWM back-to-back (b) using DC chopper

A number of high power-converter circuits are reported in different literatures for direct driven PMSM-based generators [2]–[10]. The most widespread topology is the back-to-back VSC [3].In case of over voltage burden across the switches, the series connection of active switches becomes essential. Multilevel voltage source converters as for example three-level NPC converter [5], [6] and multi-modular H-bridge in cascade connected converter [6] are also proposed as alternative options. The multilevel Inverters support the low-voltage rating switches. It provides better waveform with reduced harmonics but with increased number of switches and complexity.

All the above topologies uses pulse width modulation (PWM) in both rectification and the inversion, getting torque control and speed as well of the generator and sinusoidal voltage on the grid region. In its place of PWM converters, a diode bridge rectifier is employed at generator-side rectifier. It is economical and complexity is reduced. In the inverter connected to the grid, either a voltage source inverter or a current source inverter is used [3], [7], [8].Also, a current controlled VSI has been discussed in [9]. For VSI, the inverter size is increased to get appropriate power arrest at low speed In turn it increases the cost of the system .The solution to this problem is to use a DC boost chopper between the diode rectifier and the voltage source inverter [12], [13]; however, complexity in circuit and losses are increased.

Revised Manuscript Received on December 30, 2019.

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Impedance (z) source inverter has potential to replace the traditional inverters. The buck-boost competencies of ZSIs monitor the output voltage of generator and variations across the load [12]. Various uses of ZSIs are offered, it comprises of motor drives [13], fuel cell [14] and solar applications are found in [15,19].

Various switching techniques are available in literature to control Impedance source converters to control the short circuit and non-shoot through states [16, 18]. The techniques are SBC [13], MBC [17], constant boost control [18, 19] etc. Moreover with the current developments of ZSIs, the key focus of this paper is to use Trans qZSI in place of traditional VSI .It converts the DC input to a three phase controlled AC source using feed forward control system.
Trans quasi impedance source topology shown in Fig.2 is reported in[19].It is the modified version of traditional Impedance source inverter. The Trans quasi impedance source inverter have some merits compared to traditional one like lesser size of passive component used and less component count. It shares same dc ground with inverter and source. In case of turns ratio greater than one, the trans-qZSI provides a greater value of boost factor with common short circuit duty ratio and modulation index in comparision to conventional Impedance based converter. It reduces the voltage across inductor and capacitor. In turn it reduces the rating of the switches used in comparision to traditional ZSI. The system is closed system based on voltage control for wind power and for that the use of voltage-fed trans qZSI instead of traditional PWM converter is explored. Its suitable switching and control techniques are selected.

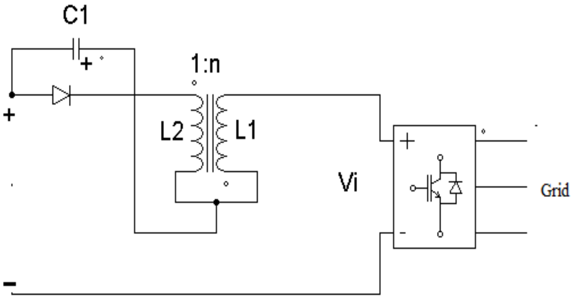


Fig.2.The circuit of the Trans QuasiZ-source inverter

II. PROPOSED SYSTEM

A. Selection of suitable topology

Trans quasi impedance inverter has an exceptional impedance (z) network comprising two inductors and one capacitor. These are not connected symmetrically unlike conventional Impedance source converters, which are attached between the Inverter switches and the dc input with a common DC rail.
Suppose the inverter is in the shoot through zero states for a small duration in a switching period of T, when both the switches in the inverter leg are switched on. Then from the Fig. 3(b)one has

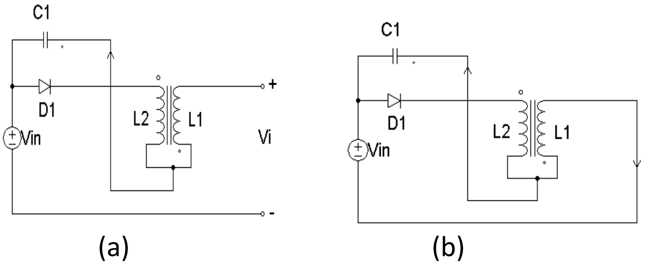
$$V_{L1} = V_{in} + V_{C1} \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$V_{L2} = nV_{C1}$$

Where V_{in} is the dc source voltage, V_{L1} and V_{L2} inductors voltage $L1$ and $L2$ respectively, V_{C1} is capacitor voltage across $C1$, $n:1$ is the transformer ratio from $L1$ to $L2$ .Diode drop is neglected here. Considering D and T as the shoot through duty ratio and total time period respectively. In non short circuit state for $(1-D)T$, the bridge circuit of the inverter is modeled and an equivalent circuit is presented in Fig 3(a) and voltage across $L1$, $L2$ are

$$V_{L2} = -V_{C1}$$

$$V_{L1} = \frac{1}{n}V_{L2} = -\frac{1}{n}V_{C1} \ldots\ldots\ldots\ldots(2)$$



(a) (b)

Fig. 3.TransqZSI (a) non short circuit condition (b) short circuitcondition

Applying voltage second balance, in a complete time period the average voltage of an Inductor should be zero. From (1) and (2)

$$V_{L1} = \frac{1}{n}V_{L2} = -\frac{1}{n}V_{C1} \ldots\ldots\ldots\ldots(2)$$

$$V_{C1} = \frac{nDV_{in}}{1-(1+n)D} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Voltage across the inverter bridge in the non-shoot through state is expressed as

$$\overline{V_{L1}} = \frac{(V_{in} + V_{C1})DT + (-\frac{1}{n}V_{C1})(1-D)T}{T} = 0$$

$$V_i = V_{in} - V_{L2} - V_{L1} \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

From (2) and (3), the equation (4) becomes

$$V_i = \frac{1}{1-(1+n)D}V_{in} = BV_{in}$$

Where the boost factor

$$B = \frac{1}{1-(1+n)D} \ldots\ldots\ldots(5)$$

$$V_i = \frac{1}{1-(1+n)D}V_{in} = BV_{in}$$

For SBC technique employed in Trans quasi topology , from (5) one has,(as $D = 1 - M$)

Voltage gain $G = MB = \frac{M}{2M-1}$

Voltage stress across the switch $V_S = BV_{in} = \frac{V_{in}}{2M-1}$

Output phase voltage peak $V_{ph} = MB\frac{V_{in}}{2} = \frac{MV_{in}}{4M-2}$,

Retrieval Number: B4106129219/2019©BEIESP
DOI: 10.35940/ijeat.B4106.129219
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Now if MBC technique is used in the Trans qZSI topology, one has

$$B = \frac{1}{1-(1+n)D} = \frac{2\pi}{3\sqrt{3}M(1+n)-2\pi n}$$

Where D= $\dfrac{2\pi - 3\sqrt{3}M}{2\pi}$

$$MB = \frac{2\pi M}{3\sqrt{3}M(1+n)-2\pi n}$$

Maximum achievable modulation index

$$M_{\max} = \frac{2\pi n}{3\sqrt{3}(1+n) - \dfrac{2\pi}{G}}$$

Switching stress

$$V_S = BV_{in} = \frac{2\pi V_{in}}{3\sqrt{3}M(1+n)-2\pi n}$$

Output phase peak voltage

$$V_{ph} = MB\frac{V_{in}}{2} = \frac{\pi M V_{in}}{3\sqrt{3}M(1+n)-2\pi n}$$

When the MCBC technique is applied the shoot through ratio is $D_{sh} = (1 - M\dfrac{\sqrt{3}}{2})$

$$B = \frac{1}{1-(1+n)(1-M\dfrac{\sqrt{3}}{2})} = \frac{2}{\sqrt{3}M(1+n)-2n}$$

Gain of the system therefore can be expressed as

$$G = \frac{M}{1-(1+n)(1-M\dfrac{\sqrt{3}}{2})}$$

Switching stress

$$V_S = BV_{in} = \frac{V_{in}}{1-(1+n)D}$$

Peak value of the output phase voltage

$$V_{ph} = MB\frac{V_{in}}{2} = \frac{MV_{in}}{2-2(1+n)D}$$

Now if the turns ratio is made one then the boost factor is $B = \dfrac{1}{1-2D}$ which is equal to the traditional ZSI boost factor having less no of components. If the turn's ratio is greater than one, the DC input to inverter is more. So to get same ac output as compared to traditional impedance source converter, comparatively smaller shoot through duty ratio is needed.

In the shoot through state $\dfrac{V_{L1}}{V_{in}} = \dfrac{(1-D)}{1-(1+n)D}$

In the non-shoot through state $\dfrac{V_{L1}}{V_{in}} = \dfrac{-D}{1-(1+n)D}$

So $\dfrac{V_{L1}}{V_{in}}$ can be expressed by S_f, which is short circuit function .

$$\frac{V_{L1}}{V_{in}} = \frac{(1-D)}{1-(1+n)D}S_f + \overline{S_f}\frac{(-D)}{1-(1+n)D} = \frac{1}{1-(1+n)D}(S_f - D)\text{.............}(6)$$

Similarly $\dfrac{V_{L2}}{V_{in}}$ can be expressed as

$$\frac{V_{L2}}{V_{in}} = \frac{n(1-D)}{1-(1+n)D}S_f + \overline{S_f}\frac{(-nD)}{1-(1+n)D} = \frac{n}{1-(1+n)D}(S_f - D)\text{..............}(7)$$

It is clear from (6) and (7) that in case of n >1, the stress on the passive components decreases resulting in reduced size of inductors.

B. Selection of switching control

Various PWM control techniques for shoot through insertion process exists in the literature. To get the suitable technique for the proposed system, SBC,MBC and MCBC technique is analysed and compared. These are presented in Table1. The parameters are calculated at modulation index (0.9) and DC input voltage 200 V. Moreover it is found that the MBC compromises maximum gain for a given M . SBC offers relatively high $(\dfrac{V_S}{D})$ as some traditional zero states are not fully employed. Moreover maximum boost technique offers reduced voltage stress to duty ratio but produces current ripple of lower frequency which is reflected in inductor current and capacitor voltage. It increases the size of Inductor and capacitor used. This problem can be removed using MCBC technique at constant short circuit duty ratio.

Table 1 Comparative analysis of switching techniques

Para-meters	SBC technique		MBC technique		MCBC technique (THI)	
	Mathematical Expression	Numerical values	Mathematical Expression	Numerical values	Mathematical Expression	Numerical values
D	$1-M$	0.1	$\dfrac{2\pi-3\sqrt{3}M}{2\pi}$	0.26	$\dfrac{2-\sqrt{3}M}{2}$	0.22
G	$\dfrac{M}{2M-1}$	1.125	$\dfrac{\pi M}{3\sqrt{3}M-\pi}$	1.84	$\dfrac{M}{\sqrt{3}M-1}$	1.61
V_S	$(2G-1)V_{in}$	250	$\dfrac{3\sqrt{3}G-\pi}{\pi}V_{in}$	408.7	$(\sqrt{3}G-1)V_{in}$	357.7
$\dfrac{V_S}{D}$	$\dfrac{V_{in}}{3M-2M^2-1}$	2500	$\dfrac{2\pi^2 V_{in}}{9\sqrt{3}M\pi-27M^2-2\pi^2}$	1571.8	$\dfrac{2V_{in}}{3\sqrt{3}M-3M^2-2}$	1626

C. CLOSED LOOP CONTROL

The elementary components needed to design the system are as given below

i) Wind turbine – It converts the wind energy to rotationary mechanical energy

ii) PMSM is used as AC generator directly coupled to wind turbine

iii) Diode rectifier rectifies the PMSM output produces variable dc link voltage depending on conversion parameters

iv) Trans quasi Z–network – Connected between DC input and inverter switches

The block diagram of the complete model is presented in Fig. 4.The variable output voltage of the system is first rectified and then inverted using trans quasi z-source network. A suitable controller is developed to boost the generated voltage to feed the grid. The closed loop controller senses the capacitor voltage with the help of a voltage sensor. It is then compared with a desired parameter. Then resulting difference is served to proportional and integral controller. Resulting value of PI controller is fed to a comparator. Where it is compared to high frequency triangular waveform to develop short circuit switching pulses. If the triangular signal is higher than the PI controller output, D (short circuit duty ratio) and B(boost factor) will increase. To generate a set of modulating signal, three sine wave signals having 120 degree phase difference is its third harmonic components with 16.67% amplitude as shown in Fig 4.

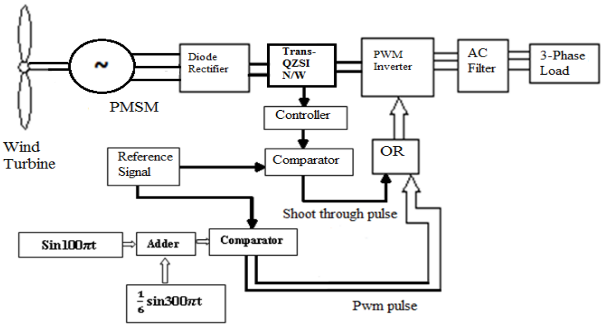


Fig. 4. Block diagram of the complete system

To verify the stability, transfer function of the complete system is obtained from MATLAB SIMULINK using input and output linearization points of the Simulink model. Transfer function of the complete system is shown in (8).

$$T(S)=\frac{-3.97\times10^{-8}(S+8.9\times10^{-5})(S+1.8\times10^{-5})(S^{2}+2\times10^{6}\times S+4\times10^{12})}{(S+254)(S+1.7\times10^{-5})(S^{2}+210.8S+2.3\times10^{5})}$$

……………………………………………………(8)

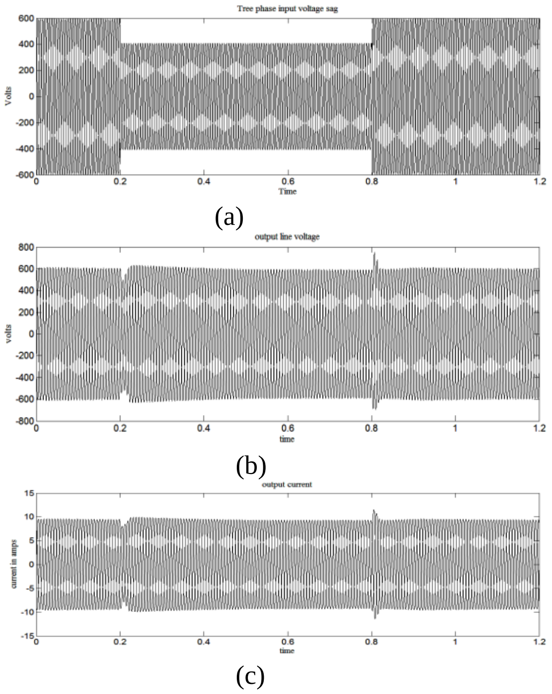
From (8) , it is observed that all the poles lies in left hand side of s-plane hence the system is stable.

III. RESULTS AND ANALYSIS

To justify the proposed system, simulations are carried out in SIMULINK environment. An LC filter (L= 105mH, C=60μF) is placed used to reduce the output harmonics. For simulation, the parameters of the Trans quasi z- network are selected as C1=50μF and L1 = L2 =0.02μH.

Sinusoidal PWM technique is selected with M(0.9)and frequency (10 kHz). Three-phase variable star connected resistive/inductive load is used for simulation. PI gains obtained by hit and trial technique are k_p=1.23 and $K_i = 0.002$.

To verify the transient operation of the system, sudden rise and fall in generator voltage is created. Initially generator line to line voltage was kept constant,420 volt. Then decreased to 290Vsome duration of time as presented in Fig. 5(a). Likewise, the line voltage was changed from 290V to 420V as depicted in Fig. 6.Then resulting output was found to be 420V as presented in Fig. 5(b) and Fig. 6(b). Fig.5(c) and 6(c) represents the output currents.

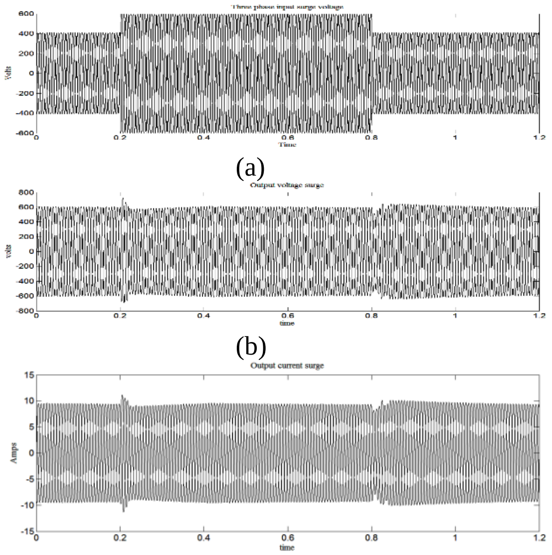


(a)

(b)

(c)

Fig.5.Sag results (a) Input voltage (b) output voltage (c) Output current



(a)

(b)

(c)

Fig.6.Surgeresults (a) Input voltage (b) output voltage (c) output current

Table II shows the output (load) line to line voltages at various dc link voltages. It justifies the operation of the proposed system. The readings are tabulated at unity modulation index. An FFT spectrum of the proposed system without filter is presented in Fig 7.It shows the presence of higher order harmonics.

Table II Output Voltage Under Variable Input Condition (Gridload4 Kw/Phase)

DC link voltag (*volt*)	output with the (simulation) V_{line}(*volt*)	With Traditional PWM inverter V_{line}(*volt*)
260	418	178
280	418	190
300	419	203
320	425	217
340	427	230
360	422	245
380	416	257

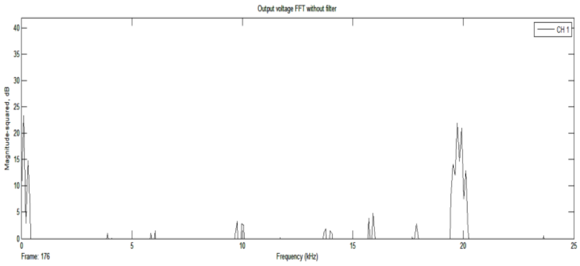


Fig. 7.output voltageFFTwithout filter

IV. CONCLUSION

An inverter closed loop system is analysed and simulation results are presented. It is based on Transquasi impedance (z)-source network with its boosting capability which controls and regulates the generator variable output voltage. The developed controller is suitable for dynamic and steady state operation. Simulation results are presented in support of that. The paper verifies the stability of the proposed system. The existing PWM techniques for impedance source converters are analysed .Maximum constant control technique is found to be more suitable for the proposed system. The system simulation results are presented to verify the suitability to control the grid voltage. The comparative analysis supports that the attained short circuit states of inverter boosts the wind generator voltage. It is then converted to a steady three phase grid voltage.

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