UACEE International Journal of Advances in Electronics Engineering – IJAEE
Volume 3 : Issue 3 [ISSN 2278 – 215X]
Publication Date : 09 September 2013

Power Quality Improvement Using T-Shape Z-Source Inverter Operating on Maximum Constant Boost Switching

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***Abstract*— An important issue of compensating reactive power to enhance power quality is proposed in this paper. Non-linearity in circuit element characteristics causes reactive power to flow in circuit. A new topology faded with T shape ZSI operating on Maximum Constant Boost switching has been proposed to compensate the reactive power. Reactive compensators are a part of FACTS devices family. Here VAR compensation is being done by T shaped ZSI. We have applied max constant boost switching pattern to generate shoot through stages. To achieve better dynamic performance , as supplementary PI controller has been used to track reference value for zero reactive power and further this controller output signal is used to design switching pattern of maximum constant boost control for T shape ZSI.**

***Keywords*— Maximum constant boost (MCB), Z Source Inverter (ZSI), VAR-volt ampere reactive, PI- proportional integral, Pulse Width Modulation-PWM, Voltage source inverter- VSI**

I. Introduction

Recent significant advancement in power electronics plays a vital role to focus the research in non-conventional. Now a days renewable energy sources have being more popular, with increase in energy demand and eco-friendly nature.

In wind power generation system conventional PWM VSI generally used to convert the dc power to ac power. However it has limitation that the ac output voltage cannot be greater than the dc rail voltage. In some applications a dc-dc boost converter is used between dc supply and inverter to provide a desired ac voltage. Due to this an additional power stage is introduced which increases the cost and decreases the efficiency of the system. Besides this the switching device of the same phase leg cannot be switched on at the same instant either by purpose or by EMI. Otherwise shoot through occur and destroy the device.

As a solution of this Z-Source inverter has been proposed [1]. The z-source inverter uses a unique impedance network to couple the dc supply source to inverter main circuit but the voltage fed ZSI cannot have bidirectional power flow operation until the diode is replaced by a bidirectional flow and unidirectional blocking switch. The dc input voltage in these inverters cannot be less than half of the peak line to line voltage.

Recently some modified impedance networks were proposed among which T shaped Z source inverter [7] has capability to increase the voltage gain with minimum component count. T-Shaped Z-Source consists of one transformer as mutual inductor and a capacitor connected such that a T-Shape is formed Hence the name is T-Shaped. It has capability of bidirectional power flow with single diode and with wider voltage boost range. T shaped Z source inverter can be derived from ZSI. The T shaped Z source inverters inherit their unique feature and the can be controlled by simple PWM methods used for traditional inverters or advance control methodology like simple boost, constant boost control or maximum constant boost control.

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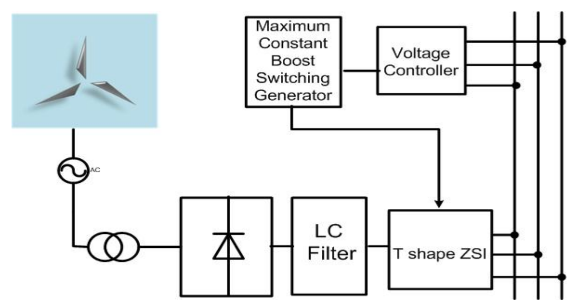

Figure 1. Z-Source Inverter.

A. Z- Source Inverter

Fig.1 shows the circuit diagram of Z source inverter. It has mainly a dc power supply, which can be a fuel cell, pv solar panel or simple battery, an impedance network having a spilt inductor or can be two simple inductors and two capacitors connected in the shape 'X', and three phase inverter. The diode in series with the supply is needed for preventing reverse current flow.

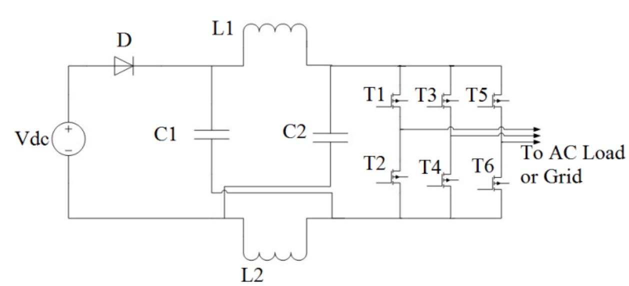

Figure 2. Z-Source Inverter.

The Z –Source Inverter shown in fig.1 has nine permissible switching states (vectors) unlike he traditional voltage source inverter which has only eight - six active switching states during which the dc voltage is imposed across the load, and two zero switching states (vectors) during which the load terminals are short circuited either by upper devices or by the lower devices respectively.

Besides these eight switching states the Z- Source inverter has an extra zero state called as Shoot through Zero state. This Shoot through Zero state provides the unique buck-boost feature of Z source inverter. Shoot through Zero sate can be generated by seven different ways – when the load terminal are shorted by upper and lower devices of any one phase leg (three ways), by combination of any two phase legs (three ways), by all the three phase legs (one way).

The important mathematical expressions are as follows:

$$\text{Shoot through Duty ratio (D)} = 1 - M = \frac{T_o}{T} \qquad (1)$$

Where M = modulation Index
T_o = Shoot through time interval

So the peak value of fundamental component of phase voltage is given as:

$$\hat{V}_{ac} = M \bullet B \bullet \frac{V_{dc}}{2} \qquad (2)$$

$$\text{Where B = Boost Factor} = \frac{1}{2M-1} \qquad (3)$$

Voltage across capacitors:

$$V_{c1} = V_{c2} = \frac{1-\frac{T_0}{T}}{1-2\frac{T_0}{T}} V_{dc} \qquad (4)$$

Where V_{ac} is the output ac voltage value of inverter. Vc1 and Vc2 are voltages across capacitors, V_{dc} is dc voltage applied to bridge, and To and T are on time and total time.

II. T-Shaped Z- Source Inverter

Fig.3 shows the T-Shaped Z-Source inverter. It has three main parts: a dc power supply, a dc link circuit and a inverter circuit. The dc link circuit is made of two coupled inductors and a capacitor. The purpose of dc link circuit is to boost up the voltage and then the inverter circuit converts it into AC. The advantage of using coupled inductors is that we can control the voltage L2 by controlling the voltage across L1 by changing the turn ratio $n=n_1/n_2$

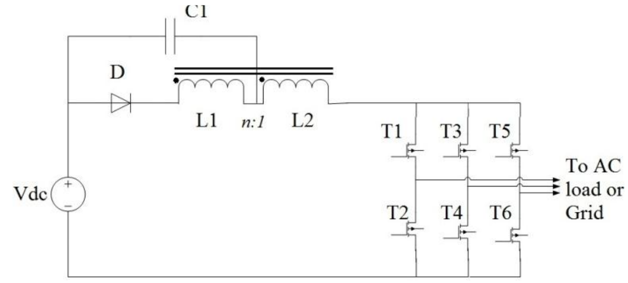

Figure 3. Voltage fed T-Shaped Z-Source Inverter.

Equations that govern the behavior of T- Shaped Z-Source inverter are as follows:

From the equation it is clear that if the turn ratio is 1 the boost factor (B) become same as that for ZSI means we can get the ZSI with one capacitor save. On the other hand if the turn ratio is greater than one, we can get the higher boost factor with same modulation index or with the smaller shoot through duty ratio (D).

The Voltage across capacitor C_1 is calculated as:

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

Where turn ratio n = $\frac{n1}{n2} \geq 1$, and D= duty cycle, n_1= number of turn on primary side and n_2= number of turn on secondary side.

Peak value of fundamental component of phase voltage is given as:

$$\hat{V}_{ac} = M \bullet B \bullet \frac{V_{dc}}{2} \qquad (6)$$

Where $$B = \frac{1}{1-(1+n)D} \qquad (7)$$

Here we are taking voltage signal as a feedback signal to feed voltage controller block.

III. Maximum Constant boost switching methods

Fig.4 defines the maximum constant boost control scheme, that is used to achieve maximum voltage gain keeping shoot through duty ratio constant always. Here we have total five signals, three of them V_a , V_b , and V_c, as three phase supply and V_p and V_n as envelope signals. When the triangular carrier wave is greater than the upper shoot-through envelope Vp or lower than lower shoot through envelope V_n, the inverter is turned to a shoot through state. For all mean stages inverter works same way as in tradition carrier based PWM control.

As the boost factor (B) is determined by the shoot through duty cycle, the shoot through duty cycle must kept the same in order to maintain a constant boost.

Main objective to get maximum B while keeping it constant all the time. The upper and lower envelope curves are periodical and are three times the output frequency. There are two half-periods for both the envelope curve in a cycle. For the first half period (i.e 0, π/3) in fig 4 the upper and lower envelopes curves can be expressed mathematically by (8) and (9) respectively

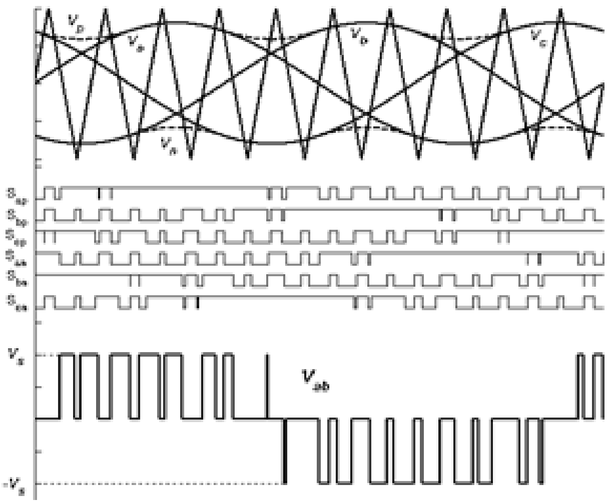

Figure4. Maximum constant boost control method

A. $V_{p1} = \sqrt{3} + M\sin(\theta - \frac{2\pi}{3})$, For $0 < \theta < \frac{\pi}{3}$ (8)

B. $v_{n1} = M\sin(\theta - \frac{2\pi}{3})$, For $0 < \theta < \frac{\pi}{3}$ (9)

For the second half-period (π/3, 2π/3), the envelope curves are expressed by (10) and (11), respectively

C. $V_{p2} = M\sin(\theta)$ For $\frac{\pi}{3} < \theta < \frac{2\pi}{3}$ (10)

D. $V_{n2} = M\sin(\theta) - \sqrt{3}M$ For $\frac{\pi}{3} < \theta < \frac{2\pi}{3}$ (11)

IV. WIND TURBINE AS THREE PHASE ELECTRICITY GENERATOR

The mechanical power expression of wind turbine is given as:

$$P_t = \frac{1}{2}\rho A u^3 c_p \tag{12}$$

Where P_t is the mechanical power of the wind turbine, ρ is the air density, A is the area covered by the rotor blades, u is the wind speed upstream of the rotor, and C_p is the power coefficient.

The power coefficient Cp is a function of pitch angle θ of rotor blade and tip speed ratio λ, which is the ratio between blade tip speed and wind speed upstream of the rotor. Various computation and optimization requires get optimized value of θ and C_p.

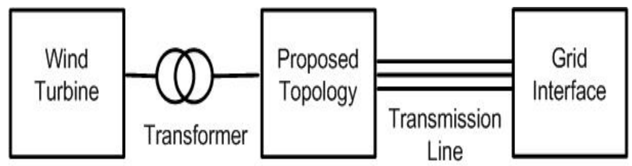

Figure5. Schematic grid connected wind turbine with proposed topology module.

On electrical end of wind generator we use a asynchronous machine as a three phase supply generator fed from torque generated by wind turbine. A power factor correction capacitor bank and a ripple filter are also added in parallel in this module.

V. SIMULATION RESULT

Simulating circuit with following run time parameters with pitch angle (θ) = 0, wind speed = 12m/sec, PI controller gain constant K_p= 0.4, K_i= 500,provided with voltage feedback to voltage regulator to further generate

Active and reactive power has been estimated respectively (13) and (14).

$$P = V_a * I_a + V_b * I_b + V_c * I_c \tag{13}$$

$$Q = \frac{1}{\sqrt{3}} * (V_{bc} * I_a + V_{ca} * I_b + V_{ab} * I_c) \tag{14}$$

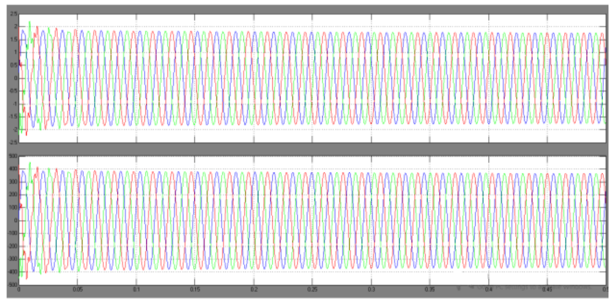

Figure 6. Current and Voltage output waveforms respectively, of wind generator with respect to time.

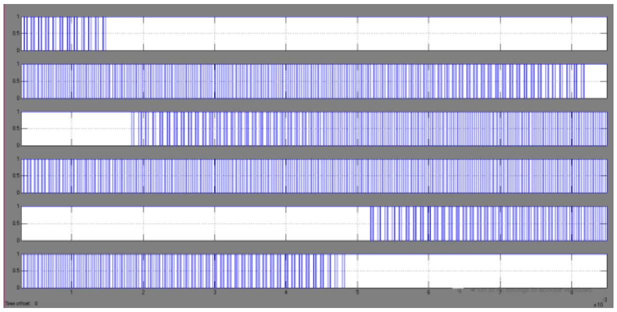

Figure 7. Shoot through pulse generation for ZSI Inverter Bridge by close loop maximum constant boost control

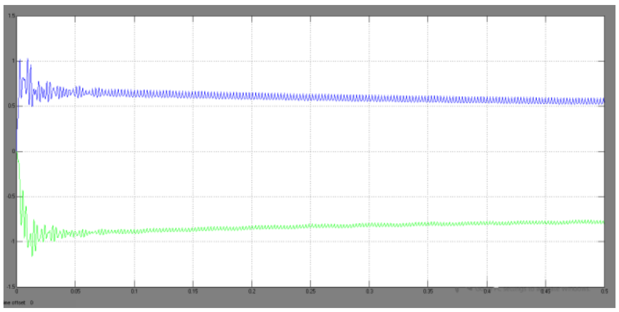

Figure 8. Active and reactive power waveform (uncompensated waveforms)

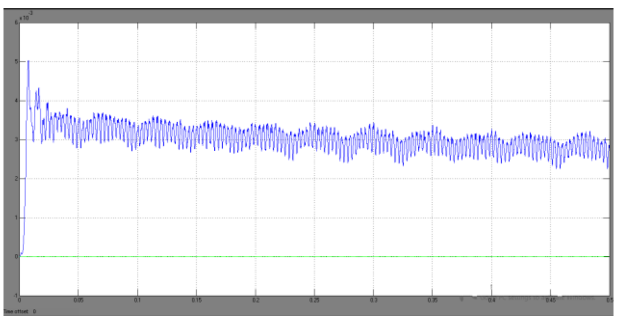

Figure 9. Active and reactive power waveform (compensated waveforms)

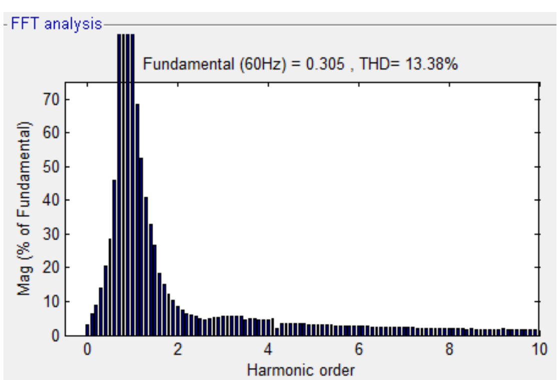

Figure 10. THD plot of T shape ZSI voltage waveform

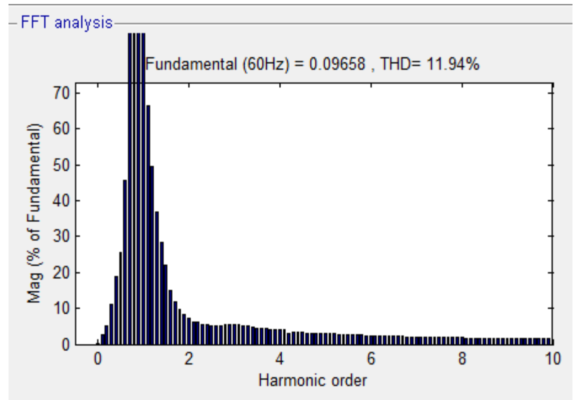

Figure 11 . THD spectrum of T shape ZSI current waveform

VI. CONCLUSION

This paper has used T shape ZSI working at maximum constant boost switching with feedback voltage signal to compensate reactive power. Power signal was generated with help of wind mill. Non-linear load added reactive power to flow in circuit, which is a loss. Compensator design has used a tracking PI controller cascaded with a T shape ZSI to compensate this reactive power. To reduce stress on switch and number of component we used T shape ZSI and maximum constant boost control method is demonstrated to achieve maximum gain value from T shape ZSI.

Future work can be done on improving its efficiency by removing DC source of T shape ZSI by a non-conventional energy source like photovoltaic array or fuel cell. Also asynchronous machine can be replaced by permanent magnet synchronous generator (PMSG) to get better enhanced three phase supply voltage.

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Biographies

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