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Design of Z Source Inverter based VSWECS with Improved PWM Control

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Abstract— ***With rapid development in Wind Energy Conversion Systems (WECS), various methods have been used to increase power generation from wind. In order to reach voltage gain as maximum in a variable speed WECS, an improved PWM method through varying shoot through time for Impedance source inverter is implemented in this paper. For a given modulation index, the correlation of voltage gain with capacitor voltage, and the device stress are analyzed in detail. For 'various shoot through time ,the simulation results of voltage across capacitor, current through inductor ,output current and output voltage are obtained by using Simpower system tool in MATLAB/ Simulink and compared. The results have been confirmed for the developed experimental model.***

Keywords: Z source inverter, wind Energy conversion systems, voltage Boost, Pulse width Modulations.

1. INTRODUCTION

Nowadays, renewable energy resources are being preferred to non-renewable energy sources due to its contribution to green environment. Hence, Wind Energy Conversion Systems play an significant role in generating high amount of electricity from wind. The wind energy can be converted using conventional systems, which consists of diode rectifier and three-phase inverter. Conventional systems possess some advantages such as simple design, less cost and maximum bus voltage[1]–[6].Due to liability voltage characteristics in Voltage Source Inverter(VSI), the bus voltage gets maximum, which effect on the working range of wind power turbine during constant frequency and change in speed conditions.

To overcome this drawback, the boost converter is coupled in the middle of three phase diode bridge rectifier and three phase inverter [2]–[10]. These types of converters reduce the system efficiency and increase the total cost. The WECS based on Impedance source inverter is an eye catching method for conversion of wind energy.[11]–[16].

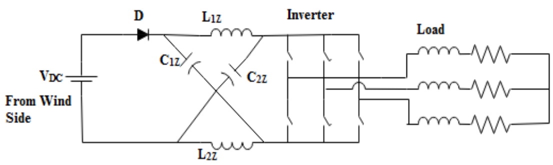

Figure 1.Impedance-source Inverter

Wind Energy Conversion System based on Impedance source inverter is depicted in figure 1.It increases or decreases the output voltage without connecting any additional switch. The reliability of the system does also increases due to the solicitation of 'shoot through state', .It is not conceivable in case of voltage source inverter [17].The set dead time is not needed ,which leads to reduction of voltage distortion in inverter. This feature of Z-source inverter makes it extensively used in wind generating as added Zero vectors that were not used in conventional voltage source inverter[18] systems and other system established on renewable energy. In the Impedance source inverter both devices of phase arm cannot be turned on instantaneously which results in short circuit and subsequently brings damage to the inverter [19]-[22].

However, the Impedance-source inverter uses this 'shoot through state' to increase the DC bus voltage by triggering both higher and lesser devices of a phase leg. Using Impedance -source inverter, it is conceivable to get the desired voltage output, higher than voltage DC.

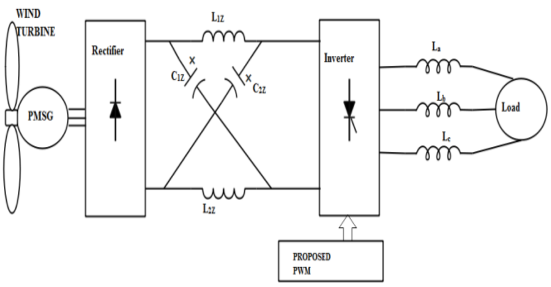

Figure 2.Simulation arrangement of the Z source inverter based WECS

In the proposed work, a new improved Pulse width Modulated scheme is implemented in the impedance-source inverter coupled with three-phase VSI. The relationship among voltage gain and 'Shoot through duty ratio' is evaluated. The voltage gain values, boost factor, modulation index, voltage across the capacitor and stress voltage are calculated. Characteristics between those parameters are also drawn and investigated. For variable wind speed, the buck–boost voltage at load side can be derived by changing modulation index value and 'shoot through duty ratio' which is further investigated in detail.

II. Z SOURCE INVERTER

Simulation model of the suggested system is depicted in Figure. 2. The method has an impedance circuit, constructed

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using two capacitors and two inductors i.e., C_{1Z}, C_{2Z}, L_{1Z} and L_{2Z}.This impedance circuit appears nearby DC and it connects the DC source with inverter. The conventional VSI has two zero states and six active states. However, the impedance-source inverters have one extra zero state. It is also known as 'shoot through state' vector. Through this condition, the output ports are short circuited through together upper switch and lower switch of any one of the phase arm. Figure 3 depicts the equivalent circuit of the Impedance-source inverter.

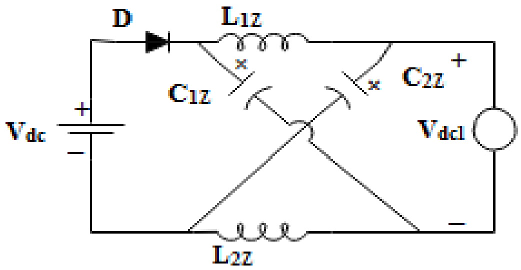

Figure 3.Equivalent Circuit of the Impedance source inverter

As described in the literature [1], the voltage at the DC link can be designed using the following equation,

$$V_i = B_f V_{dc} \tag{1}$$

Here V_{dc} is the input DC voltage , B_f is boost factor, which can be given by,

$$B_f = \frac{T}{T_1 - T_{on}} = \frac{1}{1-2\frac{T_{on}}{T}} \tag{2}$$

where T_{on} is the 'shoot through time'period over the switching period T. The peak output phase voltage V_o is given by

$$V_o = M_i B_f \frac{V_{dc}}{2} \tag{3}$$

Where M_i is the modulation index.

The capacitor voltage can be given by

$$V_C = V_{C1Z} = V_{C2Z} = \frac{1-\frac{T_{on}}{T}}{1-2\frac{T_{on}}{T}} V_{dc} \tag{4}$$

The DC link voltage Vi can be given in terms of voltage across capacitor as,

$$V_i = 2V_c - V_{dc} \tag{5}$$

Inductors ripple current can be expressed by

$$\Delta I = \frac{T_1 T_{on}}{T_1 - T_{on}} \frac{V_{dc}}{L} \tag{6}$$

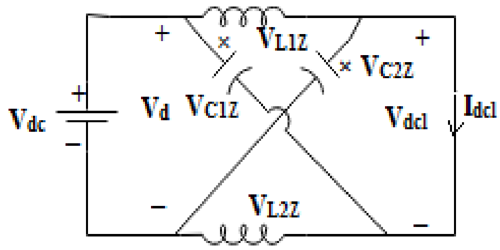

Figure 4.Equivalent circuit (Non-Shoot through Zero State)

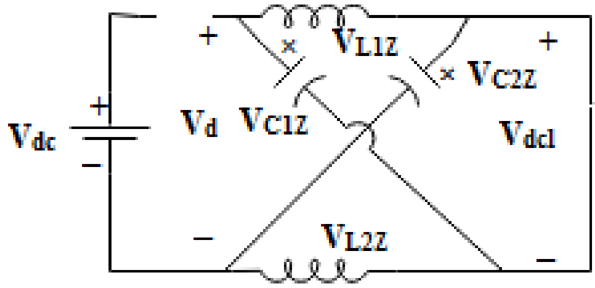

Figure 5.Equivalent circuit (Shoot through Zero State)

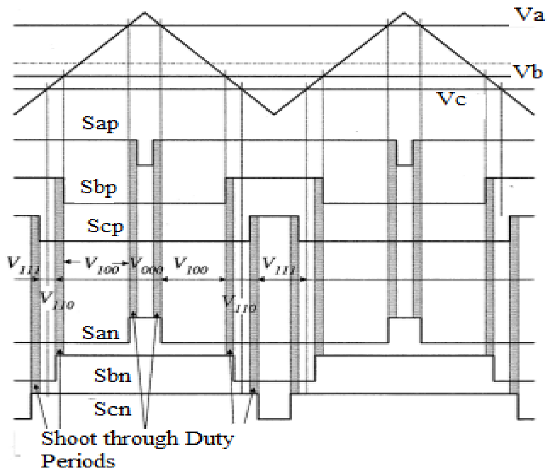

Figure 6.Improved PWM Method Waveform

III.IMPROVED PWM METHOD

Nowadays, it is being given importance to reduce the voltage stress for a necessary voltage gain in the Impedance-source inverter. As described above, the voltage gain is given as the product of Modulation index and Boost factor . The figures 4 and 5 show 'Non shoot through state' and 'shoot through state' circuits of the Z-source inverter respectively. Voltage stress of the switch can be calculated using the equation $B_f V_{dc}$. Therefore, the Bf should be minimized and M_i should be increased so as to decrease the stress voltage for a particular voltage gain. Otherwise, Bf may be increased for a particular modulation index to obtain high voltage gain. Accordingly, from the equation (2),it is conceivable to set the 'shoot through duty ratio' as high as conceivable. The Fig 6 shows the improved pulse width modulation method, which is similar to traditional carrier-based PWM. The important point is that this novel and improved pulse width modulation method keeps active vectors remain unaffected and turn all zero to 'shoot through zero states'. Thus, the peak'shoot through time' T_{on} and Boost factor can attained for any Mi without affecting output waveforms.

As given in Figure 6, the circuit works in 'shoot through state', if the triangular carrier wave is higher than extreme reference curves(V_a, V_b ,V_c) or lower than smallest reference curves. The shoot through duty cycle ratio' changes for each cycle. Thus, the voltage gain depends on the mean 'shoot through duty cycle'.

One switching cycle in the period (π/6,π/2) can be written by.

$$\frac{T_{on}(\theta)}{T} = 1 - \frac{(M_i \sin\theta - M_i \sin(\theta - 2\pi/3)}{2} \quad (7)$$

The mean 'shoot through state duty cycle ratio can considered using the following expression

$$\frac{T_{on}}{T} = \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} [1 - \frac{(M_i \sin\theta - M_i \sin(\theta - \frac{2\pi}{3})}{2}] d\theta$$

$$= \frac{2\pi - 5.196 M_i}{2\pi}$$

$$= 1 - 0.83 M_i \quad (8)$$

From equation (2), the Boost factor (Bf) is expressed by

$$B_f = \frac{1}{1 - \frac{T_{on}}{T}} = \frac{\pi}{5.196 M_i - \pi} \quad (9)$$

In this method, the voltage gain is calculated using M_i as

$$G = M_i B_f = \frac{\pi . M_i}{5.196 M_i - \pi} \quad (10)$$

The inverter output voltage Vo determines voltage in the capacitor. For the desired modulation index, if we get more inverter output voltage, then it results in increasing capacitor voltage Vc which leads to increased stress on the device. This analysis is shown in the Fig 7.

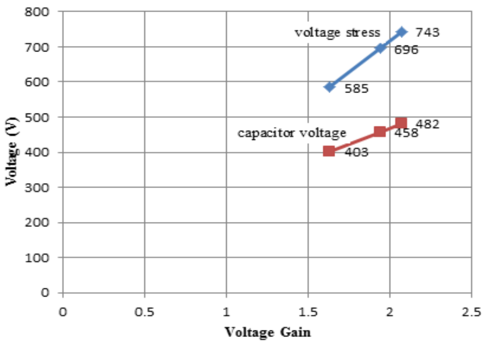

Figure 7.Voltage gain (G) vs Vc, Vst

Figure 8 shows the correlation of boost factor with stress voltage, voltage across the capacitor and the AC output voltage. From this plot, there is a clear understanding that the increasing boost factor increases the output ac voltage. Further, when the boost factor increases, the voltage across the capacitorsVC1Z and VC2Z increases gradually which produce great voltage stress in the devices.

Shoot through duty ratio is an significant factor in determining the inverter output voltage and voltage gain of the impedance source inverter system. By increasing the shoot through state time (Ton), possible to achieve high voltage gain. This concept is examined in Figure 9.

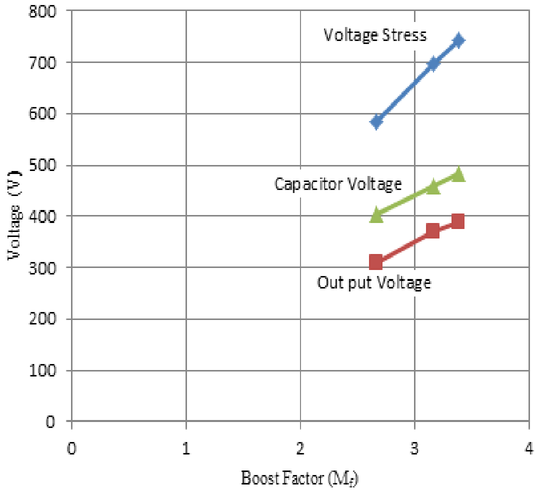

Figure 8.Boost factor vs V0,Vc and Vst

IV. SIMULATION RESULTS

The above analysis can be confirmed through simulation using MATLAB/ Simulink. To simulate the circuit, the designated parameters are Input DC voltage V_{dc}=220Vand the values of Z source circuit parameters are $L_{1Z}=L_{2Z}$=112μH and $C_{1Z}=C_{2Z}$=1200μF. Figure 10 shows the simulation results of PMSG. This voltage is converted into DC using uncontrolled rectifier as shown in figure14.Simulation was performed in PMSG at variable speed conditions from which various parameters such as rotor speed, torque and stator current wave forms are depicted in fig 15.The key purpose of the proposed work is to produce three phase ac voltage from variable speed wind. In this analysis, the modulation index M_i is equal to .612 and the shoot through state duty ratio Ton/T=0.312. The switching frequency was fixed as 12KHz.The shoot through state was spread consistently between all the three-phase arm to achieve corresponding frequency of 8 KHz as seen from Impedance-source circuit. Soon occasion of DC inductor L is decreased. As per the mentioned impedance source parameters assigned, the following theoretical calculations are performed.

Boost Factor

$$B_f = \frac{1}{1 - 2\frac{T_{on}}{T}} = 2.659 \quad (11)$$

Capacitor voltage

$$V_{c1} = V_{c2} = V_c = \frac{1 - \frac{T_{on}}{T}}{1 - 2\frac{T_{on}}{T}} V_{dc} = 409V \quad (12)$$

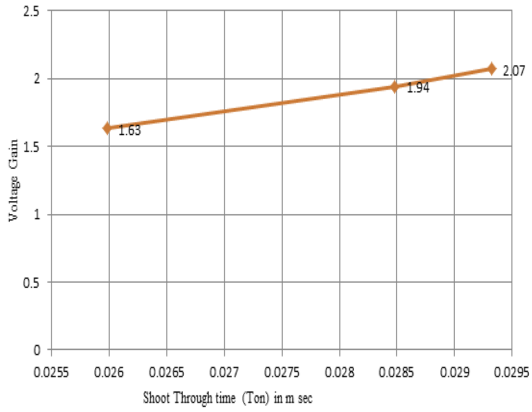

Figure 9.Shoot through Time(Ton) vs Voltage Gain (G)

Output AC voltage

$$V_0 = M_i B_f \cdot \frac{V_{dc}}{2} = 0.612 X 2.659 X 220 / 2 = 179V \quad (13)$$

Voltage gain

$$G = \frac{V_0}{Vdc/2} = \frac{179}{110} = 1.63 \quad (14)$$

In the current paper, 179 V line voltages and 409 V Peak-to-Peak voltage were calculated. The above theoretical results resemble the obtained simulation results.From the above analysis, the theoretical boost factor, voltage stress, capacitor voltage, the inverter output voltage and gain for the various shoot through time are tabulated (Refer Table 1).

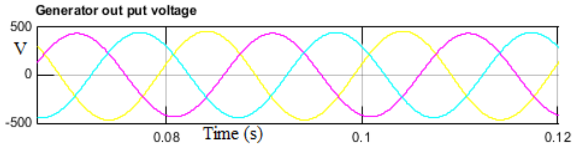

Figure 10. PMSG three phase output voltage

Table 1.Theoretical calculations of various parameters

Working Conditions	B	V_{st}	V_0	V_c	G
Ton//T=0.31 Mi=0.88 Vdc=180	2.63	474	361	379	2.31
Ton//T=0.32 Mi=0.98 Vdc=190	2.78	528	401	437	2.72
Ton//T=0.33 Mi=1.08 Vdc=200	2.94	588	551	654	3.18
Ton//T=0.34 Mi=1.18 Vdc=210	3.13	657	671	799	3.69
Ton//T=0.35 Mi=1.28 Vdc=220	3.33	733	814	1018	4.27

Case1:
Input DC voltage Vdc=220V,
Modulation Index Mi=0.612,
Shoot through duty time Period Ton=.02598msec,
Duty ratio=0.312.

With these parameters, the obtained simulation results are given below (refer fig. 11)

Boost factor (B_f)=2.659
Voltage stress of the device (V_{st})=585V
Voltage across the capacitors (V_c)=403V
Inverter output voltage(V_0)=310 V
Voltage gain (G)=1.63

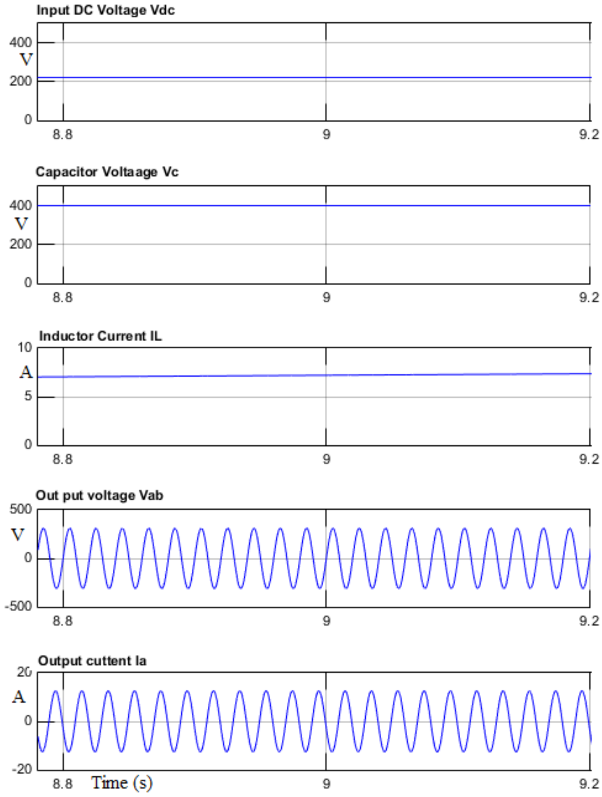

Figure 11.Simulation output for Shoot through time (Ton)=0.025m.sec

Case2:
Input DC voltage Vdc=220V,
Modulation Index Mi=0.612,
the shoot through duty time Period Ton=.02848msec,
Duty ratio=0.342.

With these parameters, the obtained simulation results are given below(Refer Fig. 12)

Boost factor (B_f)=3.165
Voltage stress of the device (V_{st})=696V
Voltage across the capacitors (V_c)=458V
Inverter output voltage(V_0)=369 V
Voltage gain (G)=1.94

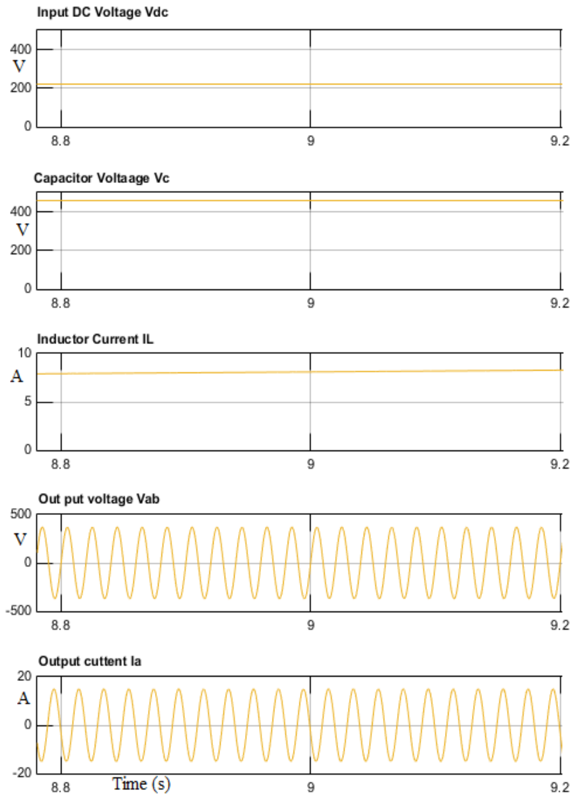

Figure 12.Simulation output for Shoot through time Ton)=0.028m.sec

Case 3:

Input DC voltage Vdc=220V,

Modulation Index Mi=0.612,

Shoot through duty time Period Ton=.02932 m sec,

Duty ratio=0.352.

With these factors, the obtained results of simulation are given in Fig 13

Boost factor (B_f)=3.165

Voltage stress of the device (V_{st})=743V

Voltage across the capacitors (V_c)=482V

Inverter output voltage(V_0)=389 V

Voltage gain (G)=2.07

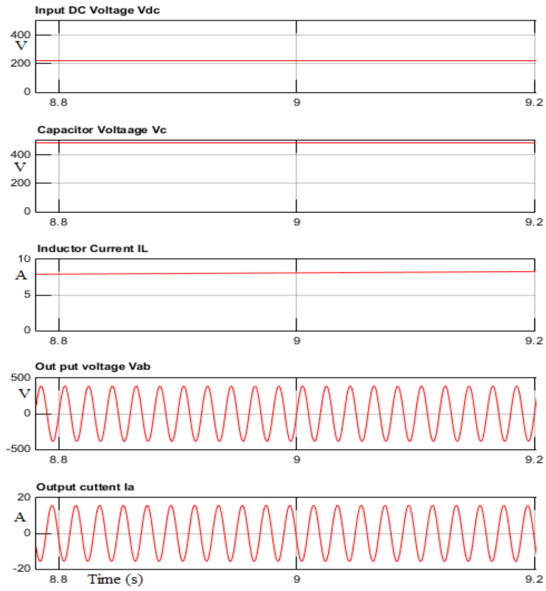

Figure 13.Simulation output for Shoot through time Ton =0.029m.sec

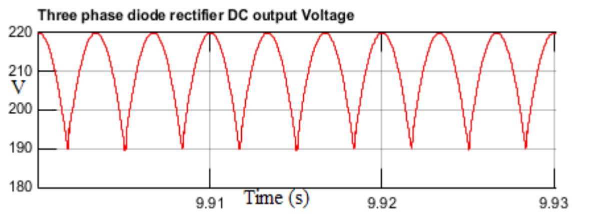

Figure 14.Simulation output of 3 phase diode rectifier

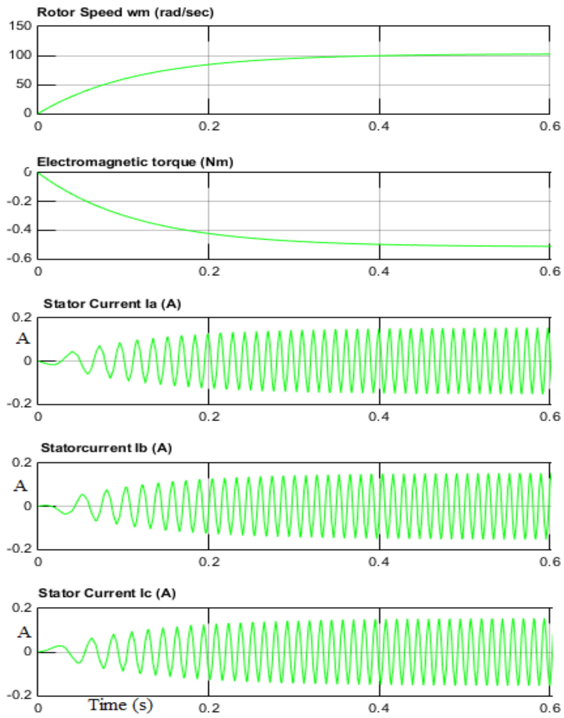

Figure 15.Simulation output of various Parameters of PMSG

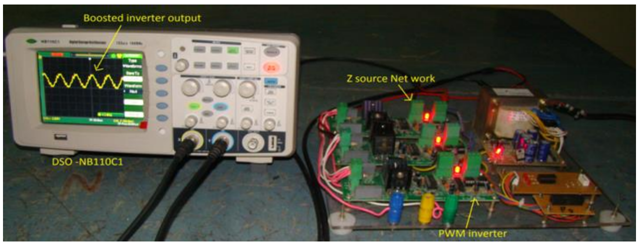

Figure 16.Experimental Arrangement

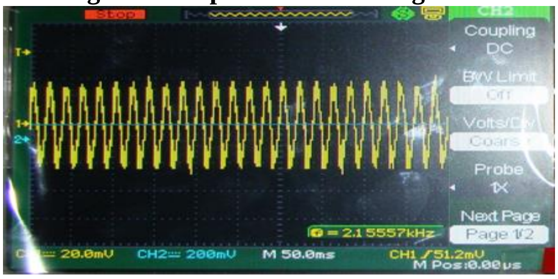

Figure 17.Experimental waveforms –

Ch:1 Inverter output voltage Ch 2: input DC voltage, when Ton=0.029 m.sec

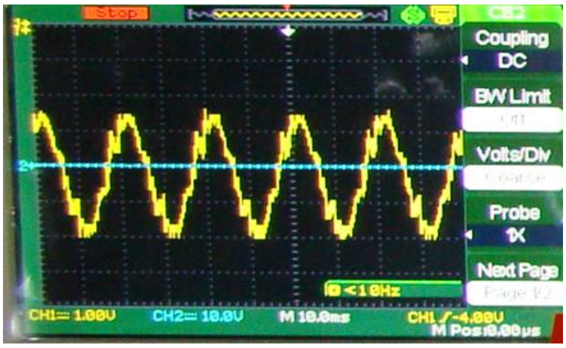

Figure 18.Experimental waveforms –Inverter output voltage when Ton=0.028 m.sec

V. CONCLUSION

An improved PWM Method has been implemented in the proposed Impedance-source inverter-based PMSG WECS, to generate maximum voltage. PMSG generates ac voltage. However, owing to the existence of Impedance-source network, it is conceivable to achieve the desired boosted AC voltage output. In this novel method of varying 'shoot through time', various parameters such as voltage across capacitor, device voltage stress and inverter voltage are analyzed in detail. The correlation between the Boost factor and 'shoot through duty ratio' is explained through graphical representation and necessary equations.

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