ANALYSIS AND SIMULATION OF Z SOURCE INVERTYER USING PM SYNCHRONOUS MOTOR DRIVE

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ABSTRACT

In the PM Synchronous Motor (PMSM) the excitation is provided owing to permanent magnet instead of the field windings. Special construction causes that the PMSM Motor has sinusoidal back EMF. The motor requires sinusoidal stator currents to produce constant torque. PMSM is simple in construction due to its robustness PMSM used in the many industrial application and control to Adjustable Speed Drives. In this paper analysis of the z source inverter using PMSM is proposed. The z source network is a DC link Energy storage sub circuit was proposed in the paper z source network is used for AC-DC /DC-AC power conversion circuit due its advantages compare to the traditional LC, DC links. In the paper analysis of z source inverter and operating principle of the ZSI and the advantage of ZSI using the Adjustable Speed Drives is proposed. The proposed system topologies are validated by using the MATLAB/SIMULATION ,SIMULINK environment.

Keywords:PM Synchronous Motor Drives, Z Source Inverter, Inverter Topology

I.INTRODUCTION

For the environmental protection and energy saving, Fuel cell, photovoltaic cell and super capacitor can be employed to supply electric energy in the Electric vehicle, due to their environmental friendly nature the PMSM offers a potential candidate for used in the electric drive applications, where the portability and efficiency required. Especially Fuel cell is regarded as the future clean energy source. It is well known that the output voltage of fuel cell is decrease with increase in the output current. To overcome this problem, at present there are two main solutions are present, the traditional dc-dc boosted PWM Inverter and the original Z Source inverter proposed in the reference[1]

Fig 1 represent the Equivalent structure of Z source inverter

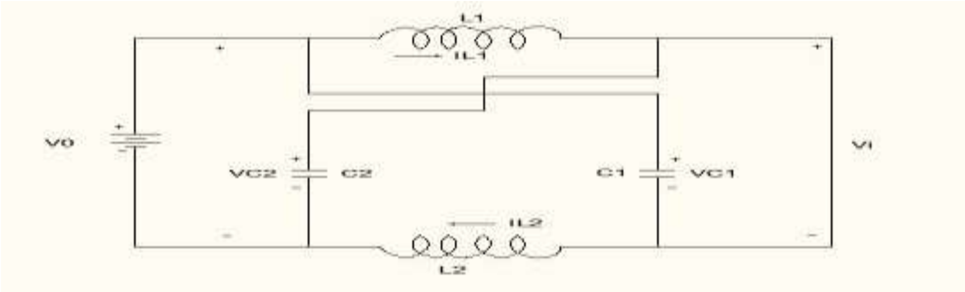


Fig. 1 Equivalent circuit of Z source inverter

One of the major problem the voltage source inverters, having in the input stage batteries, photovoltaic systems, and fuel cells or a diode rectifier fed by the 230 V ac line, is the DC link voltage level, which could be smaller than the desired level, imposed by applications. The VSI are used in photovoltaic systems as well as inverter based motor drives system. A growing interest also shown in the field of electric vehicles. The main reason why the Z-Source Inverter network seems to be god choice for the intermediate connection between the DC link voltage and inverter are the following, it provides greater voltage than the desired voltage level if it is necessary, it makes inverter immune to short circuits produced by the conduction of both transistor on the same phase leg, it reduce the inrush current and harmonics in the current this can be done by the inductors in the Z-Source network, and it forms a second order filter and handle the undesirable voltage sags of the DC voltage source[1-7]

Fig. 2 presents the electric circuit of the Z-Source Network connected to a Three phase inverter, the diode D at the front end of the Z Source network makes circuit unidirectional. The electrical energy flows from the DC voltage source to Load.

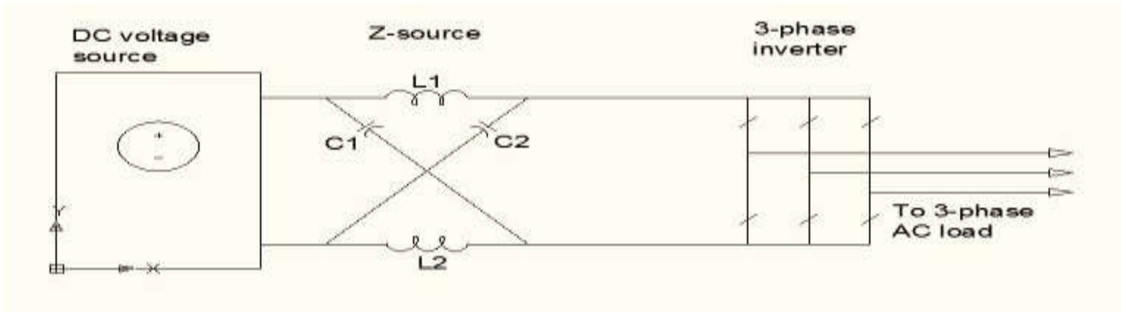


Fig 2: Z source network connected to Three phase Inverter

Compare with the former, the Z source inverter has more advantages such has higher efficiency and lower cost, which is very promising for FC systems due to its novel voltage buck/boost ability [2]. The interrelated literatures [1-6] demonstrated the unique features of Z source network and its feasibility for the adjustable speed drives (ASD) systems with induction machines.

PMSM Drives fed by the Z source inverter may have the advantages of both of them, and be suitable for the FC based electric drive systems. This paper investigates the PMSM drive system fed by Z source inverter. Firstly, the configuration, operation principle and control method of electric drive system are described. Then the state space method is used for mathematical modeling. Finally, simulation results are carried out to verify the desired performance of the proposed system

Fig 3 represents the Block Diagram of PMSM drive system.

From the below Block Diagram explained as when ever given the AC Supply to the system it will be converted to DC using the rectifier unit which present in the system and then the next block is the impedance source network the output of the rectifier is given to the Z source network and then the output of the Z source network will be given to the inverter by using inverter convert DC-AC and the output of the inverter will be given to the Load

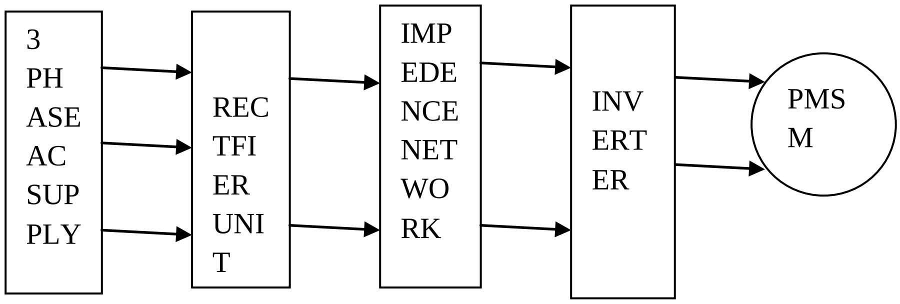


Fig 3 Block Diagram of the Z source inverter

II. EXISTING SYSTEM

Inverters are the dc to ac converters. The input dc supply is either in the form of voltage or current is converted in to variable output ac voltage. The output ac voltage can be controlled by varying input dc supplier by varying the gain of the inverter. There are two types of traditional inverters based on input source used in industries for variable speed drive and many other applications; those are

A) voltage-source inverter

B) current-source inverter

Inverter in traditional voltage source inverter (vsi), the dc voltage source connected at the input capacitor. Dc link voltage produced across this capacitor feeds the main bridge. The input dc supply can be a battery or fuel cell stack or diode rectifier, and/or capacitor. The bridge inverter circuit consists of four switches; each is composed of a power transistor and an anti- parallel diode to provide bidirectional current flow and reverse voltage blocking capability. In traditional current reversible voltage blocking capability. in traditional voltage source inverter (csi), the dc current source is formed by a large dc inductor fed by a voltage source such as a battery or fuel-cell stack or diode rectifier or converter etc. Like Vsi Bridge inverter circuit consists of four switches; each is composed of a switching device with reverse block capability such as a thyristor and scr or a power transistor with a series diode to provide unidirectional current flow and bidirectional voltage blocking. For voltage source Inverter and current source inverter the on/off time the switching devices is controlled by applying control voltage (PWM) to the control terminal i.e. Gate of the device.

Fig 4 represent the circuit diagram of Existing system Voltage Source Inverter

The operation of the traditional voltage source inverter is like normal three phase voltage source inverter. It will be conduct in 120^0 and 180^0 in the 120^0 conduction at a time 2 switches will be conduct where vas in 180^0 conduction at a time 3 switches will be on, whenever the two switches will be on in the same leg it will be causes a short circuit in the system, this is the disadvantage of the traditional Voltage Source Inverter. Some of the disadvantages of traditional VSI can be given below

Typical inverters (VSI and CSI) have few disadvantages. They are listed as,

- Behave in a boost or buck operation only. Thus the obtainable output voltage range is limited, either smaller or greater than the input voltage.
- Vulnerable to EMI noise and the devices gets damaged in either open or short circuit conditions.
- The combined system of DC-DC boost converter and the inverter has lower reliability.
- The main switching device of VSI and CSI are not interchangeable.

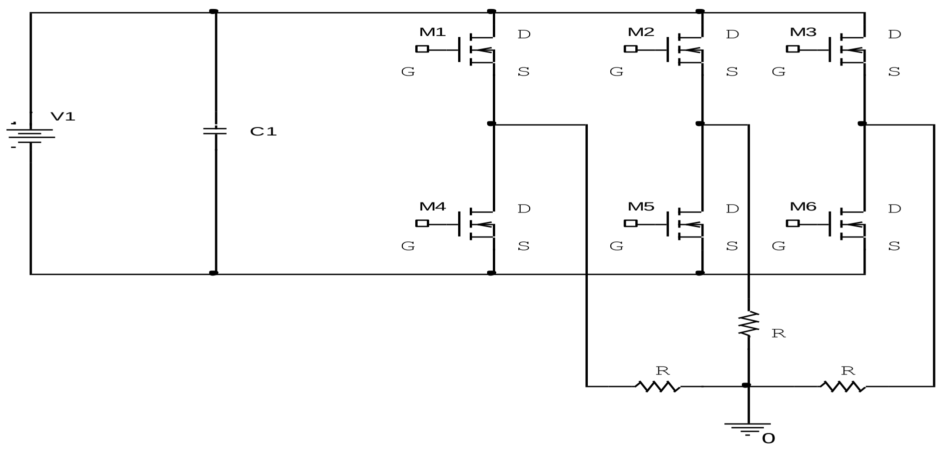


Fig 4: Traditional Voltage source Inverter

To overcome these disadvantages a new concept was developed in year 2002 by Dr. F.Z. Peng. This involves combination of VSI and CSI to form a cross coupled network of two inductors and two capacitors, known as Impedance Network..

III. OPERATING PRINCIPLE AND MATHEMATICAL MODELING OF PROPOSED SYSTEM

3.1 Operation of Z Source Inverter

The Z-source inverter is a buck–boost inverter that has a wide range of obtainable not (vectors) unlike the traditional inverter bridge that has six switching states. When the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on) or two phase legs shoot through zero state occurs. This shoot-through zero state (or vector) is forbidden in the traditional V-source inverter, because it would cause a shoot-through. The Z-source network makes the shoot through shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter. The inverter bridge is equivalent to a short circuit when the inverter bridge is in the shoot through zero states, where as the Inverter bridge becomes an equivalent current source where in one of four active states. These shoots through states are provided by simple boost controlled PWM technique.

Normally, three phase inverters have 8 vector states (6 active states and 2 zero states). But ZSI along with these 8 normal vectors has an additional state known as the shoot through state, during which the switches of one leg are short circuited. In this state, energy is stored in the impedance network and when the inverter is in its active state, the stored energy is transferred to the load, thus providing boost operation. Whereas, this shoot through state is prohibited in VSI.

To achieve the buck-boost facility in ZSI, required PWM is as shown in figure. The normal Sinusoidal PWM (SPWM) is generated by comparing carrier triangular wave with reference sine wave. For shoot through pulses, the carrier wave is compared with two complementary DC reference levels. These pulses are added in the SPWM, highlighted in figure. ZSI has two control freedoms modulation index of the reference wave which is the ratio of amplitude of reference wave to amplitude of carrier wave and shoot through duty ratio which can be controlled by DC level.

The Z-source inverter is analyzed using voltage source inverter. The unique feature of the Z-source inverter is that the output ac voltage can be any value between zero and infinity regardless of the input DC voltage. That is, the Z-source inverter is a buck–boost inverter that has a wide range of obtainable voltage. The traditional V- and I-source inverters cannot provide such feature.

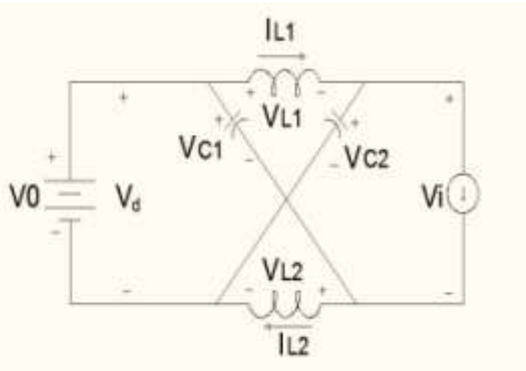
The main feature of the Z-source is implemented by providing gate pulses including the shoot-through pulses. Here how to insert this shoot- through state becomes the key point of the control methods. It is obvious that during the shoot-through state, the output terminals of the inverter are shorted and the output voltage to the load is zero. The output voltage of the shoot- through state is zero, which is the same as the traditional zero states, therefore the duty ratio of the active states has to be maintained to output a sinusoidal voltage, which means shoot-through only replaces some or all of the traditional zero states.

Let us briefly examine the Z-source inverter structure. In Fig. 3, the three-phase Z-source inverter bridge has nine permissible switching states (vectors) unlike the traditional three-phase V-source inverter that has eight. The traditional three-phase V-source inverter has six active vectors when the DC voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices, respectively. However, three-phase Z-source inverter bridge has one extra zero state (or vector) when the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs. This shoot-through zero state (or vector) is forbidden in the traditional V-source inverter, because it would cause a shoot-through. We call this third zero state (vector) the shoot-through zero state (or vector), which can be generated by seven different ways: shoot- through via any one phase leg, combinations of any two phase legs, and all three phase legs.

The Z-source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter. The Z-source inverter can be operated in three modes which are explained in below.

(i)Mode I:

In this mode, the inverter bridge is operating in one of the six traditional active vectors; the equivalent circuit is as shown in figure 5



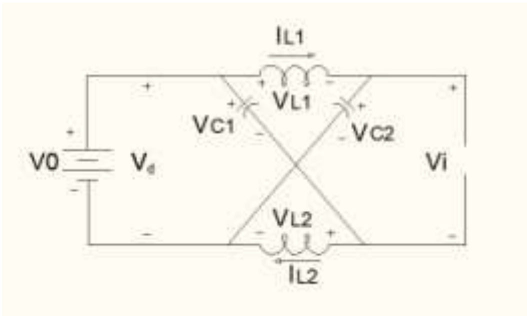


Fig.5: Equivalent Circuit of the ZSI in one of the Six Active States

Fig. 6: Equivalent Circuit of the ZSI in one of the two traditional zero states

The inverter bridge acts as a current source viewed from the DC link. Both the inductors have an identical current value because of the circuit symmetry. This unique feature widens the line current conducting intervals, thus reducing harmonic current.

(ii)Mode II:

The equivalent circuit of the bridge in this mode is as shown in the fig. 6

The inverter bridge is operating in one of the two traditional zero vectors and shorting through either the upper or lower three device, thus acting as an open circuit viewed from the Z-source circuit. Again, under this mode, the inductor carry current, which contributes to the line current's harmonic reduction as shown in below fig 7.

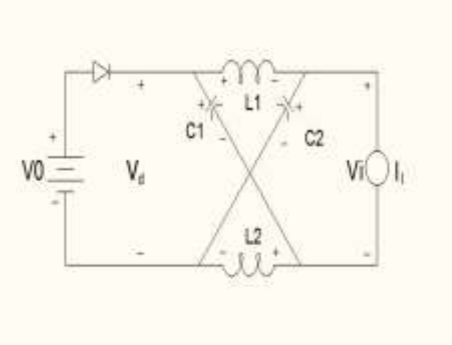


Fig 7: Equivalent Circuit of the ZSI in the Non Shoot-Through States.

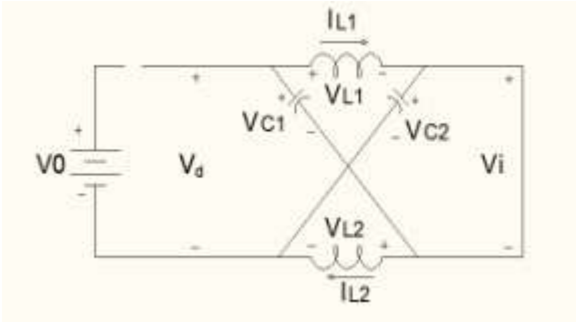


Fig. 8: Equivalent Circuit of the ZSI in the Shoot through states

(iii)Mode III:

The inverter bridge is operating in one of the seven shoot-through states. The equivalent circuit of the inverter bridge in this mode is as shown in the below figure 8. In this mode, separating the dc link from the ac line. This shoot-through mode to be used in every switching cycle during the traditional zero vector period generated by the PWM control. Depending on how much a voltage boost is needed, the shoot-through interval (T_0) or its duty cycle (T_0/T) is determined. It can be seen that the shoot-through interval is only a fraction of the switching cycle.

For simplicity, assuming that the inductors L_1 and L_2 and capacitors C_1 and C_2 have the same inductance and capacitance respectively, the Z-source network become symmetrical.

3.2 Shoot Through PWM Control

There are several control methods such as: simple boost control, maximum boost control, and maximum constant boost control[9].

In traditional PWM switching sequence based on the triangular carrier method. In every switching cycle, the two non-shoot-through zero states are used along with two adjacent active states to synthesize the desired voltage. When the dc voltage is high enough to generate the desired ac voltage, the traditional PWM is used.

The shoot-through period is generated by comparing the same triangular wave with straight lines or envelopes of the modulating signal or sinusoidal signal depending upon the technique used and inserted in the switching waveform with the help of OR gate.

The working principle is almost the same as the one that traditional carrier based PWM has. In addition to six working states and two zero states the shoot through states will be added.

The shoot-through impulses will be generated when the triangular carrier signal is greater than the upper shoot- through signal or lower than the lower shoot-through signal shown in fig-4.6

While the dc voltage is not enough to directly generate a desired output voltage, a modified PWM with shoot-through zero states will be used as shown in Fig. 5 to boost voltage. It should be noted that each phase leg still switches on and off once per switching cycle. Without change the total zero-state time interval, shoot-through zero states are evenly allocated into each phase. That is, the active states are unchanged. However, the equivalent dc-link voltage to the inverter is boosted because of the shoot-through states. The maximum shoot-through duty ratio is limited to Ds=1-Ma

Where. M_a is modulation index which indicates the ratio of modulating signal to amplitude of carrier signal. And duty ratio is defined as total time period taken in shoot during one cycle to total time period.

The maximum shoot-through duty ratio reaches to zero when the modulation index one is. When the modulation index increases, the switching frequency of the inverter will also increase, as well as switching losses.

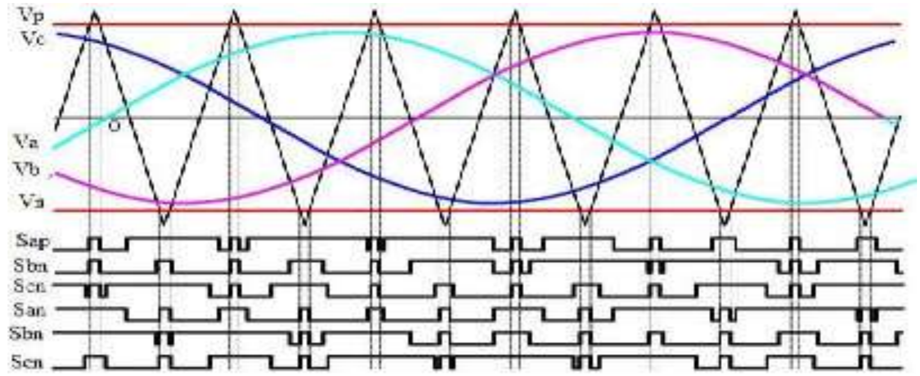


Fig. 9 Control Method of Simple Control

3.3 Mathematical Modeling of ZSI

Assuming that the inductors L_1 and L_1 capacitors C_1 and C_2 have the same inductance & capacitance, respectively, the Z-source network becomes symmetrical. From the symmetry and the equivalent circuit, voltages across capacitors and inductors are as follows:

$$V_{C1}=V_{C2}=V_C \qquad V_{L1}=V_{L2}=V_L \qquad (1)$$

Given that the inverter bridge is in the shoot - through zero state for an interval of T_0, during a switching cycle, T and from the equivalent circuit as shown in Fig.

$$V_L=V_C, \qquad V_d=2V_C, \qquad V_i=0 \qquad (2)$$

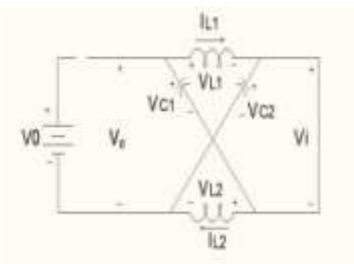


Fig.10. Z-source Inverter Bridge in the shoot-through zero state

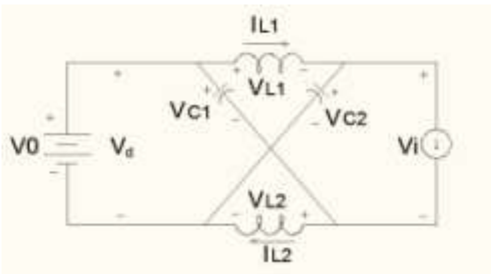


Fig.11. Z-source Inverter Bridge in one of the eight non shoot through state

Now consider that the inverter bridge is in one of the eight non-shoot-through states for an interval of T_1, during the switching cycle, T. From the equivalent circuit, Fig.7, one has-

$V_L = V_0 - V_C$, $V_d = V_0$,

$V_i = V_C - V_L = 2V_C - V_0$ (3)

Where V_0 is the DC source voltage and $T = T_0 + T_1$

The average voltage of the inductors over one switching period T should be zero in steady state. From Eq. 2 and Eq (3) Voltage across Inductor and capacitor are Obtained as:

$V_L = [T_0\ V_C + T_1\ (V_0 - V_C]/T = 0$ (4)

Similarly, the average DC-link voltage across the inverter bridge can be found as follows:

$V_i = [T_0 * 0 + T_1\ (2V_C - V_0)] / T = [T_1 / (T_1 - T_0)]\ V_0$ (5)

The peak DC-link voltage across the inverter bridge is expressed in Eq. 3 can be rewritten as:

$V_i = V_C - V_L = 2V_C - V_0 = [T / (T_1 - T_0)] = BV_0$ (6)

Where,

$B = T / (T_1 - T_0) = 1 / (1 - 2T_0 / T) \geq 1$ (7)

The DC-link voltage is the boost factor resulting from the shoot-through zero state. The peakDC-link voltage V_i is the equivalent DC-link voltage of the inverter. On the other side, the output peak phase voltage from the inverter can be expressed as:

$Vac = M\ V_i/2$ (8)

where M is the modulation Index. Using Eq. 6 and Eq. 8 can be further expressed as:

$V_{ac} = M*B*V_0/2$ (9)

For the traditional V-source PWM inverter, we have the well known relationship: $Vac = M*\ V_0\ /2$. Eq. 10 shows that the output voltage can be stepped up and down by choosing an appropriate buck–boost factor BB,

$BB = M*B(0 \approx \infty)$ (10)

From Eq. 1, Eq. 5 and Eq. 7, the capacitor voltage can expressed as

$V_{C1} = V_{C2} = V_C = [1 - (T_0 / T)] / [1 - (2T/T)]V_0$ (11)

The buck–boost factor BB is determined by the modulation index M and boost factor B. The boost factor B as expressed in Eq. 7 can be controlled by duty cycle (i.e., interval ratio) of the shoot-through zero state over then on shoot-through states of the inverter. One note that the shoot-through zero state does not affect the PWM control of the inverter, because it equivalently produce the same zero voltage to the load terminal. The available shoot-through period is limited by the zero- state period that is determined by the modulation index.

IV. MATLAB/SIMULINK MODELLING AND SIMULATION RESULTS

In order to verify the results of z source inverter using PMSM proposed system the system will be modeled in the MATLAB/SIMULINK by using this circuit verify the results of proposed system Fig 9 shows the matlab/simulink model of z source inverter using PMSM.

The simulink diagram of the z source inverter using PMSM can be as shown in the above figure 12. In the above simulation diagram we are using PI speed controller and hysteresis current regulator. The PM synchronous machine was modeled as a series connection of the following elements: the stator resistance R, the stator inductance L and a programmable voltage source which is the EMF, calculated in “Simulink” based on the motor equations at every sample time. We used three sensors in total: one load current sensor, one motor speed transducer and one voltage sensor for the measurement of C1 capacitor voltage (which is the average DC link voltage in steady state). So we have three control loops. For speed regulation a PI controller was used, for the load current control a hysteresis current controller. The hysteresis current controller commands one of the two transistors all the time. This means that there are no “inactive states” (e.g. the time duration for zero state vectors in case of a three phase inverter) during which the shoot-through states could be generated. In conclusion the shoot through states will take place during the active states. By connecting the motor between the common node of the two transistors T1 and T2 and the common node of the capacitors C2 and C3 the maximum voltage which can be delivered to the motor in our case study is 150 V if the voltages on the two capacitors C2 and C3 are equal to each other. In order to be able to supply the motor from 300 V with the block V* we prescribe 600 V average DC link voltage..

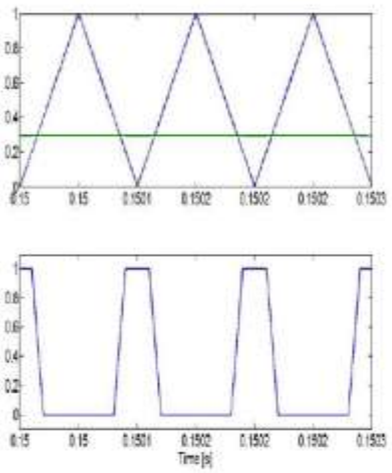


Fig 13. Shoot-through pulse generation

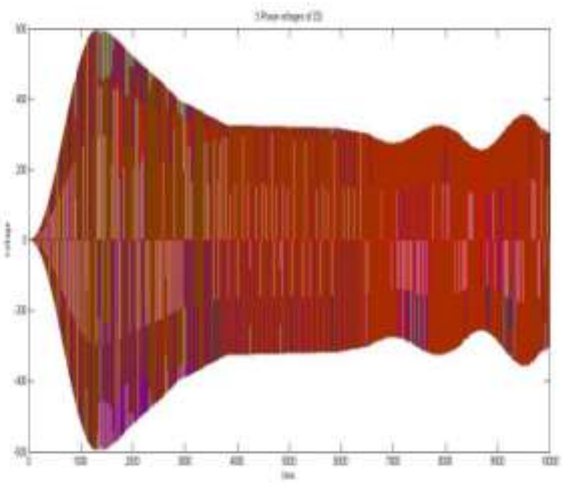
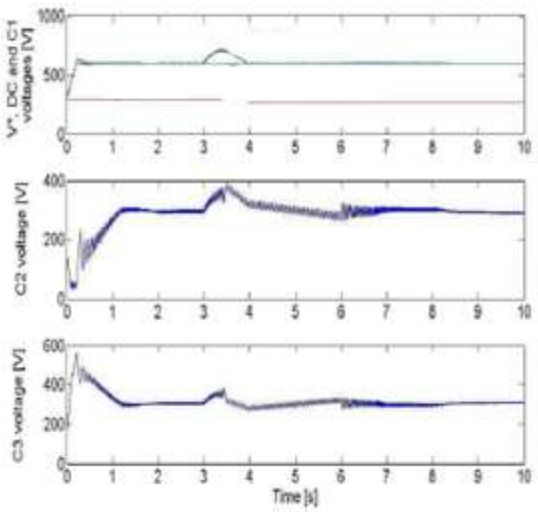


Fig 14(a). 3-φ inverter voltages

To reduce the inrush current spikes in the inductors the V* voltage was increased from 300 V to 600 V in 300 ms. The output of the PI regulator in the DC link voltage control loop in Fig gives the ratio of the input DC voltage and the average DC link voltage. Based on equation (3) the block after the PI regulator calculates the shoot through time.The shoot through time generation can be seen in Fig.6. It should be noticed that the shoot through time is calculated with a 10 kHz sampling rate and the shoot through pulses are distributed equally over the 100 μs period at the beginning and at the end of the sampling period. The shoot-through pulses override the pulses generated by the hysteresis current controller thanks to the two or gates at the gate of each transistor.

The above figure can be shows the generation of shoot through pulses. The Shoot Through Pulses Can be generated in the Z Source Inverter only, how the shoot through pulses can be generated in z source inverter can be given as whenever the same switches will be on in the same leg of the inverter then it will be short circuited then the Z source will be done the shoot through state operation at this time. The shoot through pulses generation of the Z source Inverter can be given above , from the above wave we can explain that the generated pulse will be given in triangular wave and figure 6.1 can be shows that the pulse will be start from 1 and it will be decreasing and come to zero when the triangular wave will be one and the another wave will be at zero, and the triangular wave will be zero and the another wave will be one as shown in above figure.



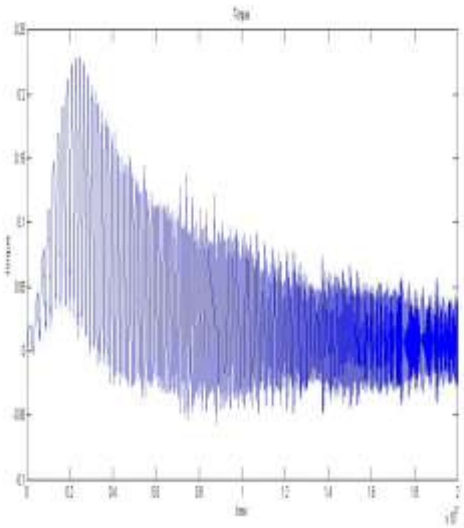
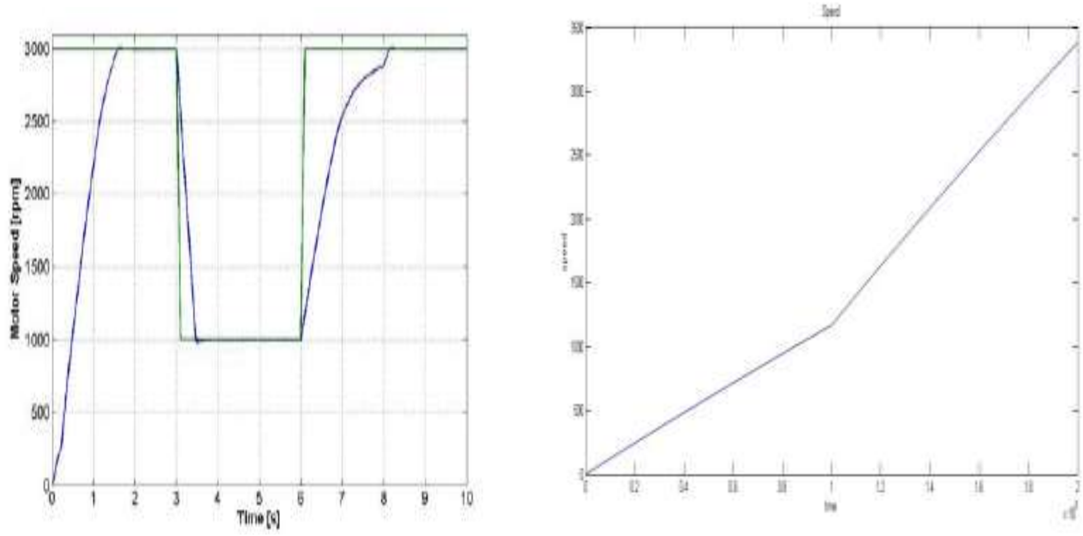


Fig 14(b) : Average Voltage across Capacitors **Fig. 15 Torque Characteristics of PMSM**

To demonstrate that the proposed Z Source inverter is suitable for motor drives with single phase PM synchronous machines, different perturbations on the drive were simulated. For example, it can be seen in Fig. 14(a) shows that the given voltage will be 300 and it will be shown in the above wave form the output voltage of 3 phase inverter is 600 v and from Fig 14(b) it explains that for a 10% voltage sag of the nominal DC voltage source (fall from 300V to 270V) the C1 capacitor voltage remains unchanged. At the start of the converter one of the two series capacitors (C2) is discharged and the second (C3) is charged with electrostatic energy. The C1 capacitor voltage smoothly follows the prescribed average DC link voltage; it has a very small overshoot. Even if the prescribed average DC link voltage is raised gradually from 300V to 600V in 300ms, we do have some inrush current spikes in the inductors L1 and L2 . A longer ramping time could reduce these inrush current spikes. In Fig. 14(b) can be seen that the instantaneous voltage across the load is asymmetrical, the positive part is two times greater than the negative part.



(a)

(b)

Fig 16(a) (b) The motor measured speed during acceleration.

The above Fig 15 can be shows the Torque characteristics of PMSM

Fig. 16(a)(b) shows the motor reference and measured speed while the motor accelerates to the nominal speed 3000 rpm in about 1.5 seconds. A breakpoint in the speed ramping is visible at 300 ms the moment when the C1 capacitor voltage reaches 600V. From this moment the motor has a steeper acceleration ramp, until it reaches 3000 rpm. A step load torque of 0.35 Nm is applied to the motor at t = 2 seconds until t = 8 seconds. This load torque is not reflected in the capacitor voltages and the speed does not suffer a speed drop, which indicates that the speed and current loops work well. At t = 3 seconds, the motor is decelerated to 33% of its nominal speed for 3 seconds. A voltage boost is visible in the capacitor voltages during the deceleration process. At t = 6 seconds the motor speed increases again to the nominal speed. This time the acceleration time duration is longer than the deceleration time duration because we have a torque load which goes to zero at t = 8 seconds and the acceleration ramp gets steeper, again.

VI. CONCLUSION

The proposed modified Z-source three phase inverter is a possible solution for motor drives with three phase permanent magnet synchronous machines. The converter is able to override the DC voltage sags. The inductors peak currents are approximately twice the load peak current. The voltage boost of the intermediate DC link it can be produced even if there are no “inactive states”. The results has been studied and observed in the SIMULINK/MATLAB.

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