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Implementation of Three Level Inverter with Single Z-Source Network in MATLAB

P.Salman Khurshid[1], S.Manohar[2], P.Ravi Kiran[3]

[1, 2, 3] Electrical Engineering, K l University, Guntur, India

Abstract- The Z-Source concept has many advantages and can be applied for any type of power conversion. Both boosting and modulation index can be controlled in inverter operation itself, by inserting proper shoot through states. This paper presents procedure for implementing, space vector modulated REC Z-source inverter in MATLAB SIMULINK by inserting shoot through states. It also explains a clear procedure of selection of shoot through states at required time and presents an overall tabular column of the sequence of switching states for three level space vector modulation. The proposed techniques are demonstrated in MATLAB and have achieved good performance results.

Index Terms- MATLAB SIMULINK, REC Z-Source inverter, Space vector modulation (SVM)

I. Introduction

Multi-level inverters have many advantages which include synthesizing voltage waveforms with low harmonic content. Three common topologies in multilevel inverter are Cascaded inverter, the diode clamped, capacitor clamped inverter. Diode clamped inverter is also known as neutral point clamped (NPC) inverter. This type of inverter will not have possibility to get output voltage greater than supply dc source, there is a need to boost the output voltage for high voltage applications this increases complexity. Z-Source concept has good flexibility and can be applied for all types of power conversions like ac-to-dc, dc-to-ac, dc-to-dc, ac-to-ac Power conversions .When z-source concept is applied to neutral point clamped inverter the circuit become bulky, complex and require two z-sources. Moreover it is expensive and requires complex modulator. For low complexity NPC inverter is designed with single z source network and is called as reduced element count (REC) Z-Source NPC inverter. It has many applications in grid connected distributed generation.

II. Operation OF REC Z-source NPC INVERTER

The operation of the single z source NPC inverter is represented by P, O, N states. P denotes upper two switches are ON in a phase leg. N denotes lower two switches are ON in a phase leg. And O denotes middle two switches are ON. These are the active states .Along with these states zero states are also present .These zero states are called as shoot through states they are

1. UST (upper shoot through)
2. LST (lower shoot through)
3. FST (full shoot through)

FST state occurs when all four switches are ON in a phase leg. UST state occurs when all upper three switches in a leg are ON. LST occur when all lower three switches are ON. These states will do the short circuit in such a way that the inductor gets charged, and the voltage is added to the supply voltage in this way the boosting is achieved. The amount of boosting depends upon the time for which shoot through states are implemented in the inverter operation.

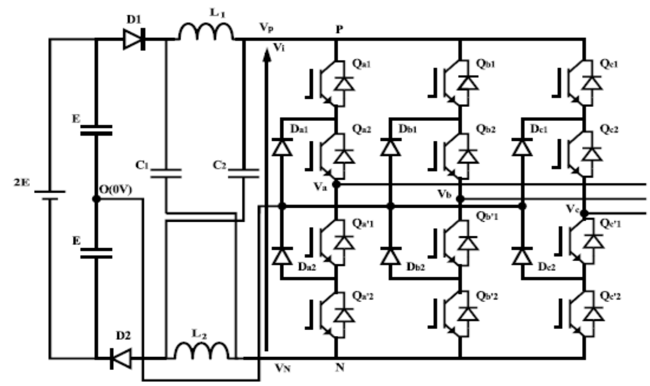

Fig1: REC Z-source NPC inverter

State type	ON switches	ON Diodes	Vo	Switching states
NST	Qx1,Qx2	D1,D2	+Vi/2	P
NST	Qx2,Qx1	D1,D2,{Dx1 or Dx2}	0	O
NST	Qx’1,Qx’2	D1,D2	-Vi/2	N
FST	Qx1,Qx2,Qx’1,Qx’2	------	0	FST
UST	Qx1,Qx2,Qx’1	Dx2,D1	0	UST
LST	Qx2,Qx’1,Qx’2	Dx2,D2	0	LST

Table 1: Behavior of Switches for different shoot through states

A.Insertion of Shoot through States

In traditional three levels NPC inverter only switching transitions are made from P state to O state, N state to O state, O state to N state, and O state to P state. But P state to N state, N states to P state are to be avoided because of more switching Transitions occurring and consequently losses.

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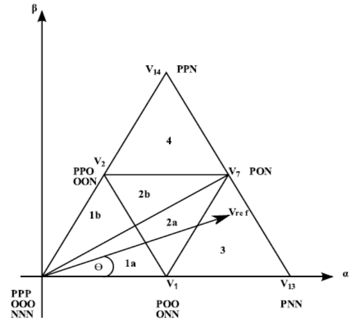

Fig2: space vector diagram for sector-1

From the fig.2 it can be observed that the reference vector rotates in all the sectors In the modified space vector modulation technique main aim is to control both boosting, modulation in the inverter operation itself by inserting shoot through states in between active states .The insertion of shoot through states for triangle3, triangle4 f or sector1 are explained and other states are tabulated in Table 7

UST states	LST States
UNN	PLO
UON	POL
OUN	PPL
NUN	LPO
NUO	OPL
NOU	LPP
NNU	LOP
UNO	OLP
ONU	PLP

Table 2: Possible shoot through states

B. Switching Sequence and Insertion of Shoot-Through States

To insert shoot through its important to know when and where UST, LST are implemented. Upper shoot through state is implemented in between P state to O state or O state to P state. If LST is implemented, more switching losses occur by more transitions. Likewise lower shoot through state is inserted in between O to N transition or N to O transition.

In triangle 3 The first state is ONN (V_1), and the next state is PNN (V_{13}) but the boosting can be done in between zero state and P state in first leg by inserting UST. After PON (V_7) the POO (V_1) state should be implemented, but the boosting can be done in third leg by inserting LST shoot through state in third leg. Next the same states are operated reverse and finally end in ONN state it is clearly shown in Table 3

ONN		PNN	PON	POO			PON	PNN	ONN	
ONN	**UNN**	PNN	PON	**POL**	POO	**POL**	PON	PNN	**UNN**	ONN

Table 3: Modified switching sequence for triangle 3

In triangle 4 The first state is OON (V_2), and the next state is PON (V_7), but the boosting can be done in first leg by inserting UST. Then again after PPN the next state is PPO, there is a chance to boost in third leg by inserting LST .After implementing PPO the same states must be operated in reverse manner it is clearly shown in Table4.

OON		PON	PPN	PPO			PPN	PON	OON	
OON	**UON**	PON	PPN	**PPL**	PPO	**PPL**	PPN	PON	**UNN**	ONN

Table 4: Modified switching Sequence for triangle4

III.MATLAB SIMULATION PROCEDURE

A. Determining the sector:

Angle is calculated by converting Three phase voltages to Two phase voltages (magnitude and angle)and then the sector in which the command vector V* is located, is determined as shown in the Table5;

ANGLE	0 to 60	60 to 120	120 to 180	-180 to 120	-120 to 60	-60 to 0
SECTOR	1	2	3	4	5	6

Table5: Sector determination

B. Determining the region in the sector:

As shown in Fig 3 by calculating m_1 and m_2 vectors from the below given equations, the resultant m_n vector can be found**.**

$$a = m_2 = \frac{b}{\sin(\frac{\pi}{3})} = \frac{2}{\sqrt{3}}b = \frac{2}{\sqrt{3}} m_n.\sin\alpha$$

$$m_1 = m_n.\cos\alpha - \left[\frac{2}{\sqrt{3}}.m_n.\sin\alpha\right]\cos(\pi/3)$$

$$m_1 = m_n\left(\cos\alpha - \frac{\sin\alpha}{\sqrt{3}}\right)$$

If m1, m2 and (m1+m2) < 0.5, then V* is in Region 1,
If m1 > 0.5, then V* is in Region 2,
If m2 > 0.5, then V* is in Region 3,
If m1 and m2< 0.5 and (m1+m2) > 0.5, then V* is in Region 4

Based on the region the voltage vector are classified as
1. Zero Voltage Vectors (ZVV): V=0
2. Small Voltage Vectors (SVV): V1, 4, 7,10,13,16
3. Medium Voltage Vectors (MVV): V3, 6, 9,12,15,18
4. Large Voltage Vectors (LVV): V2, 5, 8,11,14,17

In similar way the calculations for every sector and region should be calculated. Having the duration time for the vectors will give information about the duty cycle for each switch.

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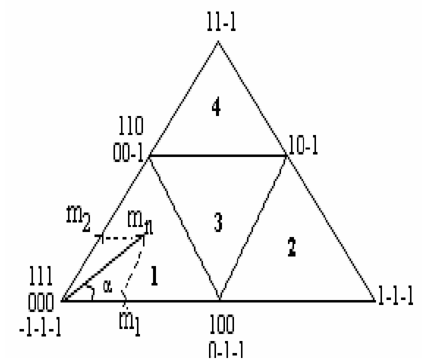


Fig 3: m_n vector in sector1

	Region I	Region II
T_a	$1.1*m*T_s*\sin((\pi/3)-\alpha)$	$T_s(1-1.1*m*\sin(\alpha+\pi/3))$
T_b	$T_s/2(1-(2*1.1*\sin(\alpha+\pi/3))$	$1.1*T_s*m*\sin\alpha$
T_c	$1.1*T_s*\sin\alpha$	$T_s/2((2*1.1*m*\sin(\pi/3-\alpha))-1)$
	Region III	**Region IV**
T_a	$T_s/2(1-2*1.1*m*\sin\alpha)$	$T_s/2(2*1.1*m*\sin(\alpha)-1)$
T_b	$T_s/2(2*1.1*m*\sin(\pi/3+\alpha)-1)$	$1.1*m*T_s*\sin((\pi/3)-\alpha)$
T_c	$T_s/2(1+2*1.1*m*\sin(\alpha-\pi/3))$	$T_s(1-(1.1*m*\sin(\alpha+\pi/3))$

Table 6: Switching times for each sub region

This is to achieve minimum switching transitions, low power loss and smooth controlling. After getting the timings based on the boosting factor required, insert shoot through states between the voltage vectors and divide timings among them.

C. Calculating the switching times, Ta, Tb, and Tc:

Ta, Tb, and Tc switching times for Sector 1 is given in Table6 The duration time for the vectors will give information about the duty cycle for each switch in every sub region of the sectors. The switching states in every sub region are operated in clock wise and anti-clock wise directions

D. Finding the switching states:

By considering the switching transition of only one device at any time; the switching orders with shoot through states are tabulated for all sectors

Region 2(A)

SECTOR1	ONN	**UNN**	OON	PON	**POL**	POO	**POL**	PON	OON	**UNN**	ONN
SECTOR2	PPO	**PPL**	OPO	OPN	**OUN**	OON	**OUN**	OPN	OPO	**PPL**	PPO
SECTOR3	NON	**NUN**	NOO	NPO	**LPO**	OPO	**LPO**	NOP	NOO	**NUN**	NON
SECTOR4	OPP	**LPP**	OOP	NOP	**NOU**	NOO	**NOU**	NOP	OOP	**LPP**	OPP
SECTOR5	NNO	**NNU**	ONO	ONP	**OLP**	OOP	**OLP**	ONP	ONO	**NNU**	NNO
SECTOR6	POP	**PLP**	POU	PNO	**UNO**	ONO	**UNO**	PNO	POO	**PLP**	POP

Region 2(B)

SECTOR1	PPO	**PPL**	POO	PON	**UON**	OON	**UON**	PON	POO	**PPL**	PPO
SECTOR2	NON	**NUN**	OON	OPN	**OPL**	OPO	**OPL**	OPN	OON	**NUN**	NON
SECTOR3	OPP	**LPP**	OPO	NPO	**NUO**	NOO	**NUO**	NPO	OPO	**LPT**	OPP
SECTOR4	NNO	**NNU**	NOO	**NOP**	**LOP**	OOP	**LOP**	NOP	NOO	**NNU**	NNO
SECTOR5	POP	**PLP**	OOP	ONP	**ONU**	ONO	**ONU**	ONP	OOP	**PLP**	POP
SECTOR6	ONN	**UNN**	ONO	PNO	**PLO**	POO	**PLO**	PNO	ONO	**UNN**	ONN

Region 3

SECTOR1	ONN	**UNN**	PNN	PON	**POL**	POO	**POL**	PON	PNN	**UNN**	ONN
SECTOR2	PPO	**PPL**	PPN	OPN	**OUN**	OON	**OUN**	OPN	PPN	**PPL**	PPO
SECTOR3	NON	**NUN**	NPN	NPO	**LPO**	OPO	**LPO**	NPO	NPN	**NUN**	NON
SECTOR4	OPP	**LPP**	NPP	NOP	**NOU**	OPO	**NOU**	NOP	NPP	**LPP**	OPP
SECTOR5	NNP	**NNU**	NNP	ONP	**OLP**	OOP	**OLP**	ONP	NNP	**NNU**	NNO
SECTOR6	POP	**PLP**	PNP	PNO	**UNO**	ONO	**UNO**	PON	PNP	**PLP**	POP

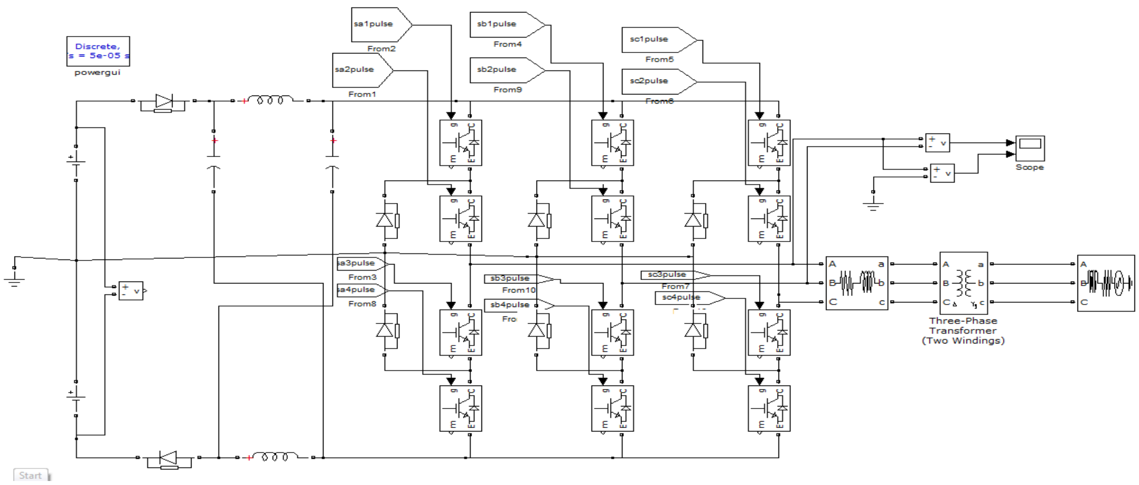
Region 4

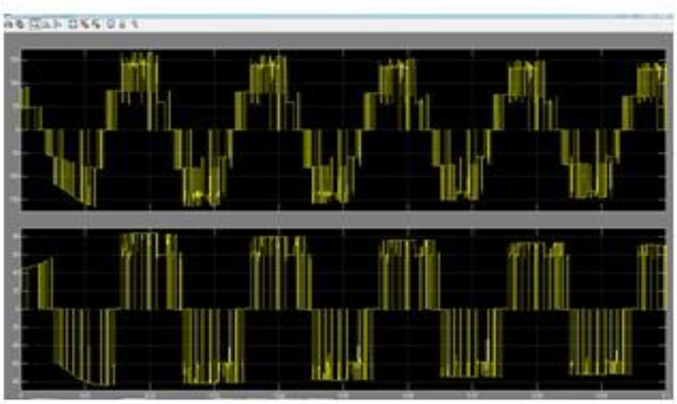
SECTOR1	OON	**UON**	PON	PPN	**PPL**	PPO	**PPL**	PPN	PON	**UON**	OON
SECTOR2	OPO	**OPL**	OPN	NPN	**OUN**	NON	**OUN**	NPN	OPN	**OPL**	OPO
SECTOR3	NOO	**NUO**	NPO	NPP	**LPP**	OPP	**LPP**	NPP	NPO	**NUO**	NOO
SECTOR4	OOP	**LOP**	NOP	NNP	**NNU**	NNO	**NNU**	NNP	NOP	**LOP**	OOP
SECTOR5	ONO	**ONU**	ONP	PNP	**PLP**	POP	**PLP**	PNP	ONP	**ONU**	ONO
SECTOR6	ONO	**ONU**	ONP	PNP	**PLP**	POP	**PLP**	PNP	ONP	**ONU**	ONO

Table 7: Sequence of switching states in all the sectors

IV. MATLAB RESULTS

Simulation block diagram for REC Z-source inverter





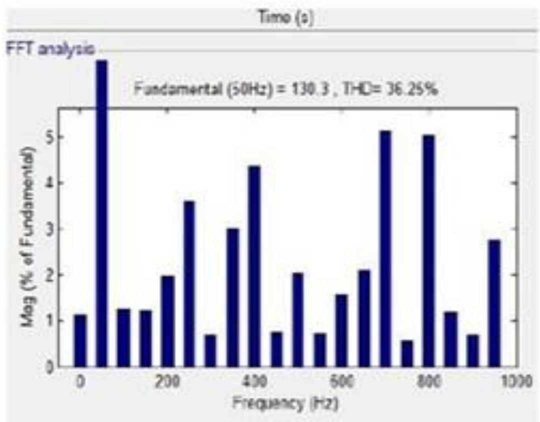


Fig4: Output voltages (L-L)

Fig5: FFT analysis

As per the mat lab simulation done on REC Z-Source inverter, good performance results are obtained .The output voltages are not affected by low frequency harmonics and a Total Harmonic Distortion of 36.25% is observed from Fig5

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V .CONCLUSION

In this paper, a Matlab Procedure for modified SVM for an REC Z-source NPC inverter is presented. Using carefully inserting UST and LST states to the traditional NPC inverter switching sequence, the REC Z-Source NPC inverter functions with the correct volt–second average and voltage boosting capability regardless of the angular position of the reference vector. The insertion of the shoot through states was such that the number of device commutations was kept at a minimum of six per sampling period, similar to that needed by a traditional NPC inverter. The presented concepts have been verified in simulations.

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AUTHORS

First Author – P. Salman Khurshid, Electrical Engineering, and p.salmankhurshid@gmail.com.
Second Author – S. Manohar, Electrical Engineering and manoharsriram@hotmail.com.
Third Author – P. Ravi kiran, Electrical Engineering and ravikiran.polani@gmail.com.

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