

# A Simulation Overview of Magnetically Coupled Z-Source Inverters

D.Chandhrasekhara Reddy<sup>1</sup>, L.Sagar<sup>2</sup>, Reddy Prasad Reddivari<sup>3</sup>PG Student [PE], Dept. of EEE, SITAMS, Andhra Pradesh, India<sup>1</sup>,Associate Professor, Dept. of EEE, SITAMS, Andhra Pradesh, India<sup>2</sup>,Assistant Professor, Dept. of EEE, Sri Venkateshwara College of Engineering, Karnataka, India<sup>3</sup>

**ABSTRACT:** Z-source inverters are a new class of inverters proposed with output voltage or current buck–boost ability. And also its having limitations as mainly two. one is not flexible to provide continuity to inductor current, and second was there is coupling effect between modulation index and duty ratio. Its effects property of inverter. To minimize these concerns, an motivating methodology is to use magnetically coupled transformers or inductors to raise the gain and modulation ratio simultaneously, with reduced components. In this paper I proposed the magnetically coupled type inverters by developing with help of genetic methodology.

By comparing all magnetically coupled topologies the gamma source inverter shows matured characteristics. i.e the proposed topology use lesser turns ratio to produce same level of output. Other than gamma source inverter other topologies need infinite turn's ratio to produce infinite gains. But proposed topology need 1:1 transformer enough to produce infinite gains.

**KEYWORDS:** z-source inverter, Trapped inductor ZSI, Cascaded ZSI, Trans z-source inverter,  $\Gamma$ -SI, flipped  $\Gamma$ SI

## I. INTRODUCTION

THE application of power converters has grown rapidly, particularly with the recent proliferation of renewable energy, distributed generation, and more electric vehicles[9]. This trend is expected to continue and would therefore demand more challenging converters to be developed. Now a day's renewables play a vital role and that to PV Cells and Fuel Cells and MHD's in the case of thermal power stations to increase conversion efficiency. Solar cells and fuels still going to increase their generating capability. Output power of renewable not but all constant because input available energy is unpredictable in nature. In order to meet grid requirements we need a powerful converter (shown in fig. to interface 1) renewables and grid system with boosting flexibilities. Prior to Z-source[2-6] the boost inverter, buckboost inverter, chuk[1] type topologies are very popular. Z\_source[2-6] are invited by F.Z.Feng at 2002, with voltage and current buck boost availability. And also those topologies have inherent short-circuits protection and also open-circuit protection which was drawbacks of VSI, CSI, respectively.

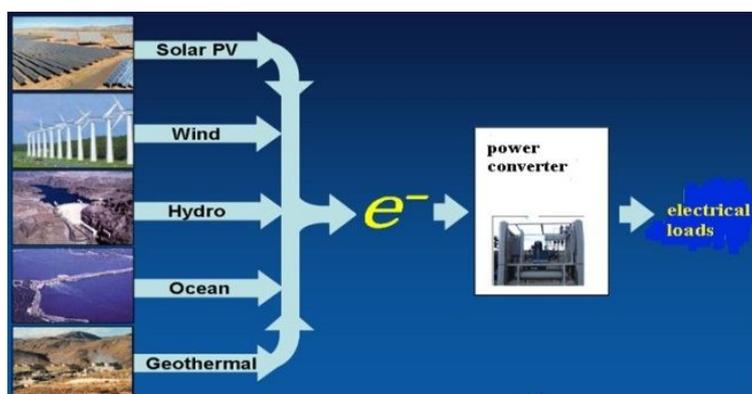


Figure1.alternatives for electrical energy generation

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The development impedance-source inverters says mainly two ways

1. Primary revolution
2. Secondary revolution

The traditional Z-source inverter and its modifications.(quasi-ZSI, embedded ZSI, embedded dc bus ZSI)[11-12]& trapped inductor based models, hybrid models(cascaded types)[15] coming under primary revolution.

The magnetically coupled ZSI[19-21] makes secondary revolution. And this type of topologies shows matured characteristics compared to primary stage ZSI's.is Clearly mentioned in fig.2.

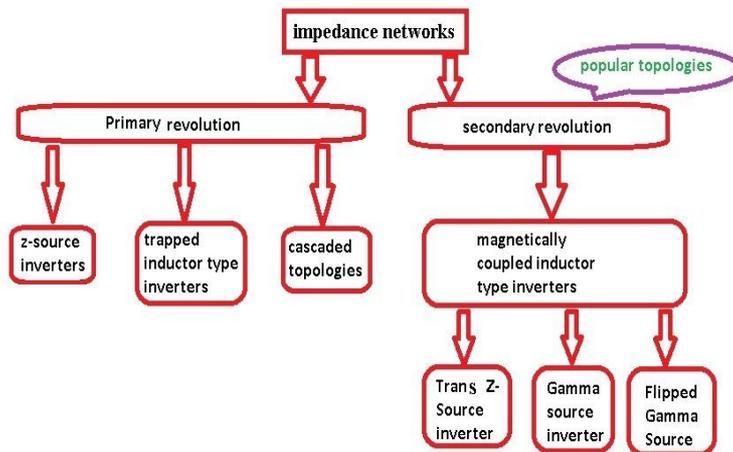


Figure2.impedance-source inverters

## II.TRADITIONAL Z-SOURCE INVERTERS

### 1. Traditional Z-source inverters

These types of topologies are primary models in impedance networks.by placing X-shaped LC components in between source and inverters

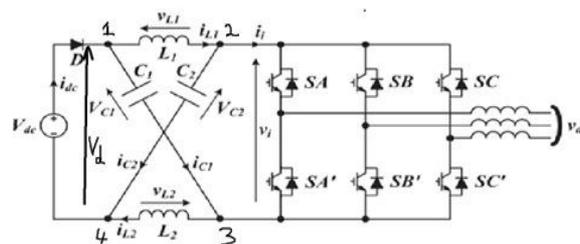


Figure3.Z-source inverters

### Genetic derivation methodology

The equation analysis is clearly discussed below

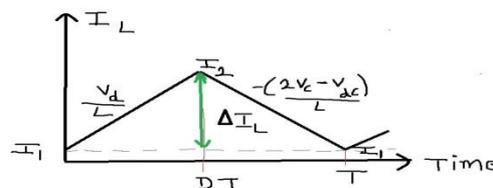


Figure4.inductor current in ZSI

RMS value of ac voltage

$$V_{ac} = M * \frac{V_{dc}}{2} \quad (\text{In case of normal inverter})$$

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$$V_{ac} = M * B * \frac{V_{dc}}{2} \quad (\text{In case of Z- Source inverter})$$

Major disadvantages of ZSI

1. Not flexible to provide continuity to inductor currents
- It effects on inductor size and max frequency limit
2. Coupling effect between modulation index and shoot through duty ratio

$$\text{Boost factor } \uparrow B = \frac{V_i}{V_{dc}} = \frac{1}{1-2D\uparrow}$$

$$\text{gain } \uparrow G = \frac{v_{ac}}{V_{dc}} = \frac{M\downarrow}{1-2D\uparrow} = M * B$$

$$\text{Where } \uparrow D = 1 - M\downarrow = 1 - \frac{V_{r\downarrow}}{V_c}$$

## 2. Trapped inductor type ZSI

The inductors going into modify such way that the high gain requirements. Here energy can transfer in both modes

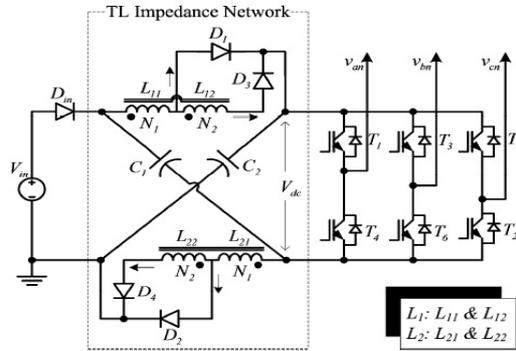


Figure5.trapped inductor Z-source inverters

It's really show improvement to provide continuity to inductor currents so inductor size come down further by this topology. But the coupling effect still persists in network.

## 3. Hybrid ZSI(cascaded ZSI)

In this type of topologies we can increase boost factor and gain but still the drawbacks is following along this model.

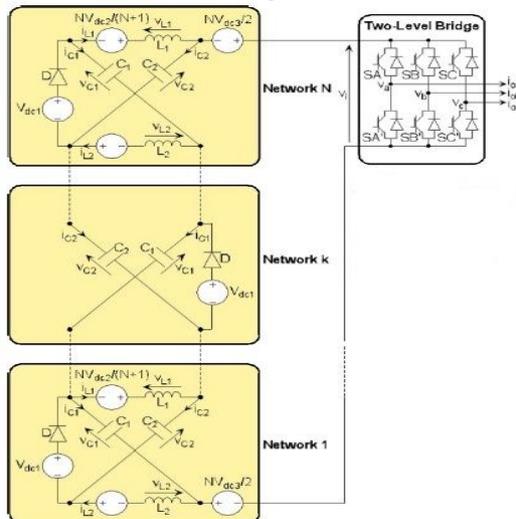


Figure6.trapped inductor Z-source inverters

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## III.IMPROVED Z-SOURCE INVERTERS

This model is also called as magnetically coupled models. by eliminating all drawbacks in primary models eliminated by these models. See given table and fig.7 for further details. in that table we can observe that there is

TABLE I

	<i>Boost converter</i>	<i>Z-Source Inverter</i>	<i>Magnetically Coupled Z-Source Inverter</i>
<i>Boost factor(B)</i> ↑	$\frac{1}{1-d}$ ↑	$\frac{1}{1-2d}$ ↑	$\frac{1}{1-(\gamma+1)*d}$
<i>Input to output gain(G)</i> ↑	No ac conversion	$\frac{0.5 * M}{1-2d}$ ↓	$\frac{0.5 * M}{1-(\gamma+1)*d}$

alternative for gain increment is turns ratio in magnetically coupled converters. Its eliminates coupling effect because doesn't vary the modulation inductor and so duty ratio

$$D(\text{constant}) = 1 - M(\text{constant})$$

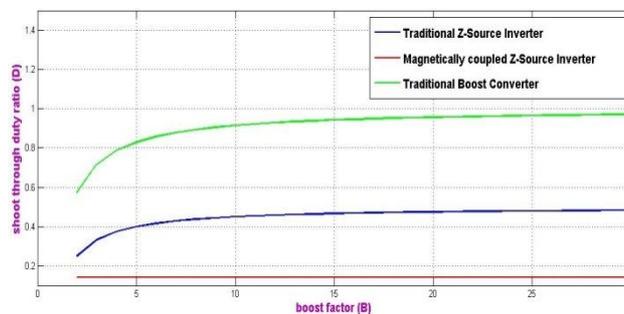


Figure7.duty ratio relationship among impedance source inverters

Above figure clearly explains how the magnetically coupled ZSI are going to eliminates the coupling effect called  $D=1-M$  by making  $M$  as constant.

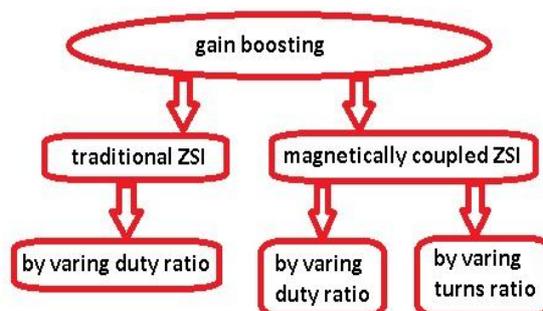


Figure8.alternatives to boost gains

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## IV.CONCEPT OF MAGNETICALLY COUPLED z-SOURCE INVERTERS

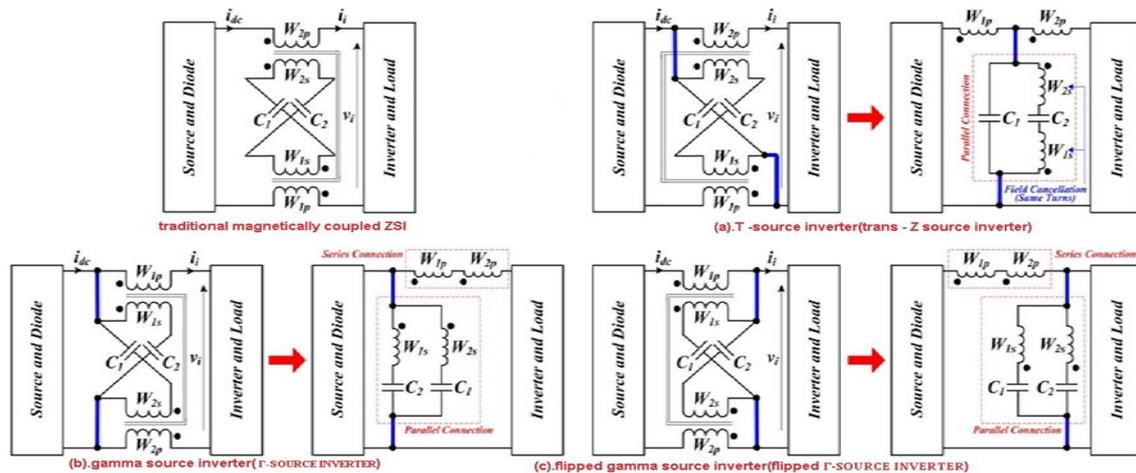


Fig 9. basic block diagram of developments of impedance networks

TABLE -II DERIVATIVE EXPLORATION OF MAGNETICALLY COUPLED ZSI

Feature	Traditional Z-source	Mutually coupled inductor type			comments
		Trans Z-Source (TZ)	$\Gamma$ – Source ( $\Gamma$ )	Flipped $\Gamma$ – Source ( $f\Gamma$ )	
Turns ratio relationship for gain equalization	Not applicable	$\gamma_{TZ} = \frac{1}{\gamma_r - 1} = \gamma_{f\Gamma} - 1 = \frac{W_1}{W_2}$ 5.1(a)			-when 5.1 (a)=1, response of traditional and mutually coupled inverters are same
Turns ratio trend & range	Not applicable	Increasing $1 \leq \gamma_{TZ}$	Decreasing $2 \geq \gamma_r > 1$	Increasing $2 \leq \gamma_{f\Gamma}$	- $\gamma_{TZ}$ and $\gamma_{f\Gamma}$ can become excessive at high gain - $\gamma_r$ approaches 1 at high gain - $\gamma_{f\Gamma}$ demands the most turns
Range of modulation ratio M		$0 \leq M_x \leq 1.15 * (1 - d_x)$			-Upper limit $d_x$ required can be made smaller than 0.5 by adjusting $\gamma_x$ -upper limit of $M_x$ can be high even at high gain
Range of shoot-through duty ratio	$0 \leq d_t < 0.5$	$0 \leq d_{TZ} < \frac{1}{\gamma_{TZ} + 1}$	$0 \leq d_r < \frac{1}{1 + \frac{1}{\gamma_r - 1}}$	$0 \leq d_{f\Gamma} < \frac{1}{\gamma_{f\Gamma}}$	
Capacitor voltage Vc	$\frac{(1 - d_t) * Vdc}{1 - 2 * d_t}$	$\frac{(1 - d_{TZ}) * Vdc}{1 - (\gamma_{TZ} + 1) * d_{TZ}}$	$\frac{(1 - d_r) * Vdc}{1 - (1 + \frac{1}{\gamma_r - 1}) * d_r}$	$\frac{(1 - d_{f\Gamma}) * Vdc}{1 - \gamma_{f\Gamma} * d_{f\Gamma}}$	-same for all mutually coupled inverters if (a) satisfied
DC link Voltage Vi	$\frac{Vdc}{1 - 2 * d_t}$	$\frac{Vdc}{1 - (\gamma_{TZ} + 1) * d_{TZ}}$	$\frac{Vdc}{1 - (1 + \frac{1}{\gamma_r - 1}) * d_r}$	$\frac{Vdc}{1 - \gamma_{f\Gamma} * d_{f\Gamma}}$	
Peak output voltage Vac	$\frac{0.5 * M_t * Vdc}{1 - 2 * d_t}$	$\frac{0.5 * M_{TZ} * Vdc}{1 - (\gamma_{TZ} + 1) * d_{TZ}}$	$\frac{0.5 * M_r * Vdc}{1 - (1 + \frac{1}{\gamma_r - 1}) * d_r}$	$\frac{0.5 * M_{f\Gamma} * Vdc}{1 - \gamma_{f\Gamma} * d_{f\Gamma}}$	
Shoot-through current $i_i$	$2 * i_{dc}$	$(\gamma_{TZ} + 1) * i_{dc}$	$\frac{\gamma_r * i_{dc}}{\gamma_r - 1}$	$\gamma_{f\Gamma} * i_{dc}$	-shoot-through currents generally high
Magnetizing current $i_m$ at low voltage winding	$2 * i_{dc}$ (2*current $i_L$ )	$(\gamma_{TZ} + 1) * i_{dc}$	$\gamma_r * i_{dc}$	$\gamma_{f\Gamma} * i_{dc}$	-value of TZ & $f\Gamma$ are the same if (a) satisfied -value for $\Gamma$ is smaller

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## 1. Trans Z-Source Inverters

By replacing traditional inductors by coupled transformer and simplified such a way that two form trans z-source network. Generally the name trans Z-source called T- source is mainly due to the shape of impedance circuit is clearly showed in fig.9 (a).

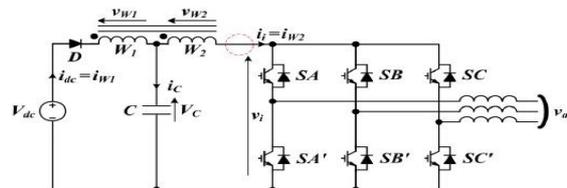


Fig10.circuit diagram of Trans Z-source inverter

Circuit analysis

a) **shoot trough:** diode is OFF and two switches in same leg ON at the same time to form shoot trough

$$V_{w1} = \gamma T Z * V_{w2} ; V_{w2} = V_c.$$

b) **non shoot trough:** diode is ON and inverter acts they own work to form active state

$$V_{w2} = V_{dc} - V_c ; V_{w1} = V_{dc}$$

$$\text{Capacitor voltage: } V_c = \frac{(1-D_r) * V_{dc}}{1-(1+\gamma T) D_r}$$

$$\text{DC link voltage: } V_i = \frac{V_{dc}}{1-(1+\gamma T) D_r}$$

$$\text{AC RMS voltage: } V_{ac} = \frac{0.5 * M * V_{dc}}{1-(1+\gamma T) D_r}$$

## 2. gamma( $\Gamma$ ) source inverters

By replacing inductors by coupled parameters and is shown clearly in the fig.9(b).it was the best and matured topology among all magnetically coupled models and that discussed later

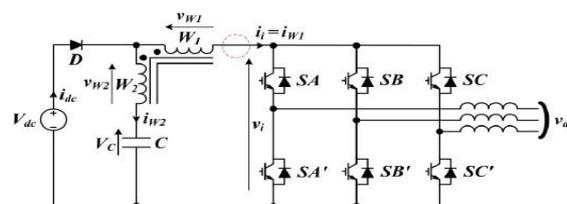


Fig11.circuit diagram of gamma-source inverter

Circuit analysis

a) **shoot trough:** diode is OFF and two switches in same leg ON at the same time to form shoot trough

$$V_{w1} = V_{w2} + V_c ; V_{w2} = V_c / (\gamma T Z - 1) .$$

c) **non shoot trough:** diode is ON and inverter acts they own work to form active state

$$V_{w2} = V_{dc} - V_c ; V_{w1} = \gamma \Gamma Z * V_{w2}$$

$$\text{Capacitor voltage: } V_c = \frac{(1-D_r) * V_{dc}}{1-(1+\frac{1}{\gamma \Gamma - 1}) D_r}$$

$$\text{DC link voltage: } V_i = \frac{V_{dc}}{1-(1+\frac{1}{\gamma \Gamma - 1}) D_r}$$

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AC RMS voltage: 
$$V_{ac} = \frac{0.5 * M * V_{dc}}{1 - (1 + \frac{1}{\gamma r - 1}) D r}$$

### 3. Flipped Gamma(7) source inverter

By replacing inductors by coupled parameters and is showed clearly in the fig 9(c).this topology impedance source is flipped impedance of gamma source

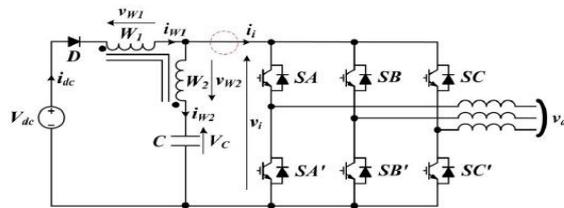


Fig11.circuit diagram of flipped gamma-source inverter

### Circuit analysis

a) **shoot trough:** diode is OFF and two switches in same leg ON at the same time to form shoot trough

$$V_{w1} = \gamma T Z * V_{w2} ; V_{w2} = V_c.$$

b) **non shoot trough:** diode is ON and inverter acts they own work to form active state

$$V_{w2} = V_{dc} - V_c - (\gamma - 1) V_{w1} ; V_{w1} = V_{dc}$$

Capacitor voltage: 
$$V_c = \frac{(1 - D r) * V_{dc}}{1 - (\gamma f r) D r}$$

## V.COMPARITIVE OVERVIEW

### A. Gain Equalization

Input to output gain 
$$\frac{V_i}{V_{dc}} = \frac{0.5 * M}{1 - 2 * D 0} = \frac{0.5 * M}{1 - (\gamma T Z + 1) * D T Z} = \frac{0.5 * M}{1 - (1 + \frac{1}{\gamma r - 1}) D r} = \frac{0.5 * M}{1 - \gamma f r * D r}$$

■ trans Z-source ■ gamma source ■ flipped gamma

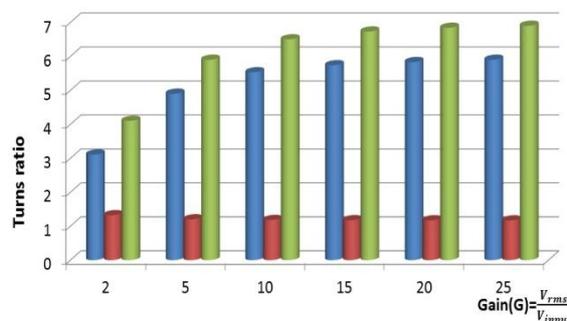


Fig12.gain variations in magnetically coupled topologies

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TABLE- III Turns ratio requirement to reach gain demands

gain	Z-source	Trans Z-source		Γ-source		Flipped Γ-source	
	D0	DTZ	$1 \leq \gamma_{TZ}$	DΓ	$2 \geq \gamma_{r} > 1$	D fl	$2 \leq \gamma_{fr}$
2	0.3937	0.14	3.107	0.14	1.3218	0.14	4.107
5	0.4575	0.14	4.92855	0.14	1.2029	0.14	5.928
10	0.47875	0.14	5.535	0.14	1.1806	0.14	6.535
20	0.4893	0.14	5.8392	0.14	1.171	0.14	6.839
50	0.49575	0.14	6.0214	0.14	1.1661	0.14	7.0214

The above table and figure.12 says that compare to other topologies the gamma source inverter needs lesser turns ratio transformer for producing higher gains. And not only single concern, the Trans Z-source and Flipped Gamma source needs almost turns ratio= infinity to produce infinity .i.  $e\gamma_{TZ}, \gamma_{fr} \rightarrow \infty$  at high gains. But the gamma source inverter needs turns ratio  $\gamma_{r} \rightarrow 1$ .so the gamma source inverters going to produce higher gains at 1:1 transformer as placed there.it makes the size and weight low.

### B. Coupled transformer parameters

Whenever we are using coupled parameters we must analyze how the magnetizing inductance and flux going to varies and what was the flux strength, those parameters must help to design transformers according to requirements.

$$\{L_m^1\}_{TZ} = \left\{ \frac{\gamma_{TZ}}{\gamma_{TZ} + 1} \right\}^2 * \{L_m^1\}_{\Gamma} = \left\{ \frac{\gamma_{TZ}}{\gamma_{TZ} + 1} \right\}^2 * \{L_m^1\}_{fr}$$

If we substitute the turns here means we got below equation.it says the gamma source and flipped gamma source must need higher magnetizing inductance to store energy

$$\{L_m^1\}_{TZ} = 0.489 * \{L_m^1\}_{\Gamma} = 0.489 * \{L_m^1\}_{fr}$$

By comparing all topologies we can says that gamma source inverter shows matured characteristics for voltage as a source.

TABLE –IV  
DESIGN ASPECTS OF SIMULATION OF VOLTAGE TYPE GAMMA SOURCE INVERTER

Components	Values					
Source	V <sub>dc</sub> = 100 V					
Magnetically coupled impedance parameters	Winding turns(w1)=66 Winding turns(w2)=46 Turns ratio( $\gamma_r$ )=1.43 Coefficient of coupling(k)=0.999 Mutual inductance(L <sub>m</sub> )=0.4145mH Total transformer resistance=0.091 Ω Z-source capacitance C=220μF					
Inverter	<table border="1" style="width: 100%;"> <tr> <td>f<sub>c</sub> =10 KHz</td> </tr> <tr> <td>f<sub>r</sub> =50 Hz</td> </tr> <tr> <td>M<sub>r</sub> = 0.85*1.15(3<sup>rd</sup> harmonic)</td> </tr> <tr> <td>d<sub>r</sub>=d<sub>rr</sub>=0.14 (boost)</td> </tr> <tr> <td>d<sub>r</sub>=d<sub>rr</sub>=0 (buck)</td> </tr> </table>	f <sub>c</sub> =10 KHz	f <sub>r</sub> =50 Hz	M <sub>r</sub> = 0.85*1.15(3 <sup>rd</sup> harmonic)	d <sub>r</sub> =d <sub>rr</sub> =0.14 (boost)	d <sub>r</sub> =d <sub>rr</sub> =0 (buck)
f <sub>c</sub> =10 KHz						
f <sub>r</sub> =50 Hz						
M <sub>r</sub> = 0.85*1.15(3 <sup>rd</sup> harmonic)						
d <sub>r</sub> =d <sub>rr</sub> =0.14 (boost)						
d <sub>r</sub> =d <sub>rr</sub> =0 (buck)						
Filter	L=6.3mH/phase					
Load	Resistive: R=25Ω/phase Motor: 4KW(5HP),400V,1450RPM					

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## V.RESULTS & DISCUSSIONS

The gamma source inverters produces output voltages  $V_{rms}$ ,  $V_c$  and fundamental components as given below  
1.Capacitor voltage

$$V_c = \frac{(1-Dr)*V_{dc}}{1-(1+\frac{1}{\gamma r-1})Dr} = \frac{(1-0.14)*100}{1-(1+\frac{1}{1.43-1})*0.14} = 160.922 \text{ volts}$$

2.D.C Link voltage

$$V_i = \frac{V_{dc}}{1-(1+\frac{1}{\gamma r-1})Dr} = \frac{100}{1-(1+\frac{1}{1.43-1})*0.14} = 187.11 \text{ volts}$$

3.A.C RMS voltage

$$V_{ac} = \frac{0.5*M*V_{dc}}{1-(1+\frac{1}{\gamma r-1})Dr} = \frac{0.5*0.85*100}{1-(1+\frac{1}{1.43-1})*0.14} = 79.52 \text{ volts}$$

The same output voltage can produce by using Trans Z-source[18-19] and Flipped Gamma source also but the only change is orientation of connection and turns ratio requirement. That can be explaining clearly by using given equation and table.

$$\gamma TZ = \frac{1}{\gamma r - 1} = \gamma fr - 1$$

Where  $\gamma TZ$  = turns ratio in Trans Z-source

$\gamma \Gamma$  = turns ratio in gamma source

$\gamma f\Gamma$  = turns ratio in flipped gamma source

TABLE –V TURNS RATIO REQUIREMENT

Topology type	Turns ratio symbol	Turns ratio=W1/W2
Trans Z – source(T - Source)	$\gamma TZ$	2.3255 (medium)
$\Gamma$ -source inverters	$\gamma r$	1.43 (low)
Flipped $\Gamma$ -source inverters	$\gamma fr$	3.3255 (high)

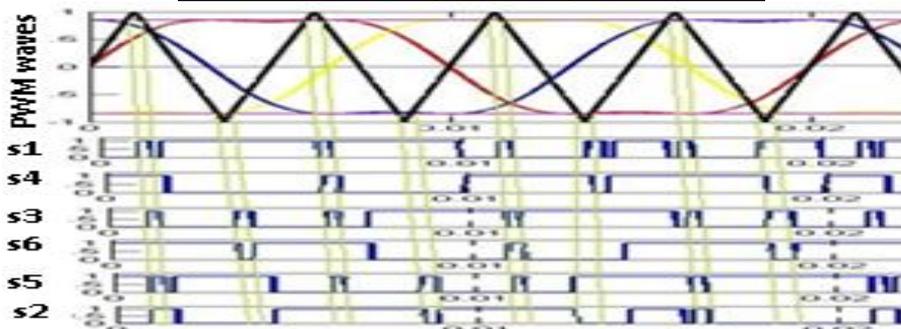


Fig8.maximum constant boost PWM techniques

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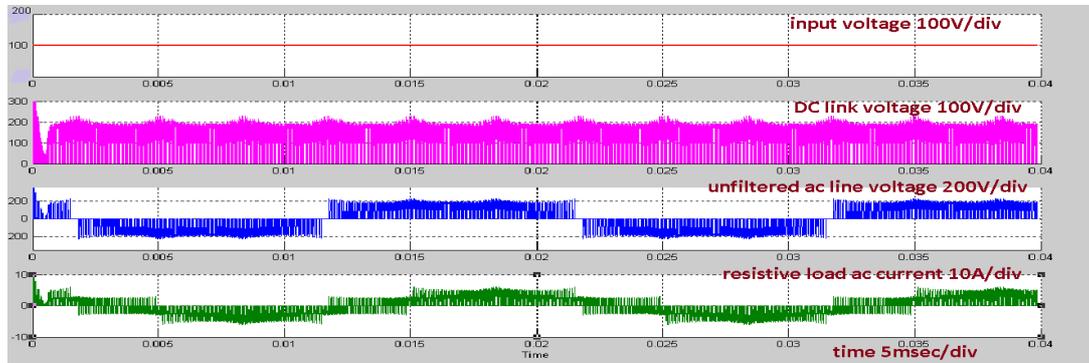


Fig.(9a) Simulink input, dc-link and output waveforms of  $\Gamma$ -Z-source inverter when in voltage-boost mode in R-LOAD

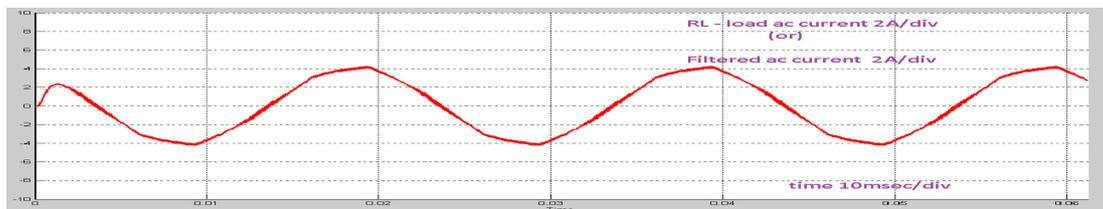


Fig (9b).output current waveforms of  $\Gamma$ -Z-source inverter when in voltage-boost mode in RL-LOAD

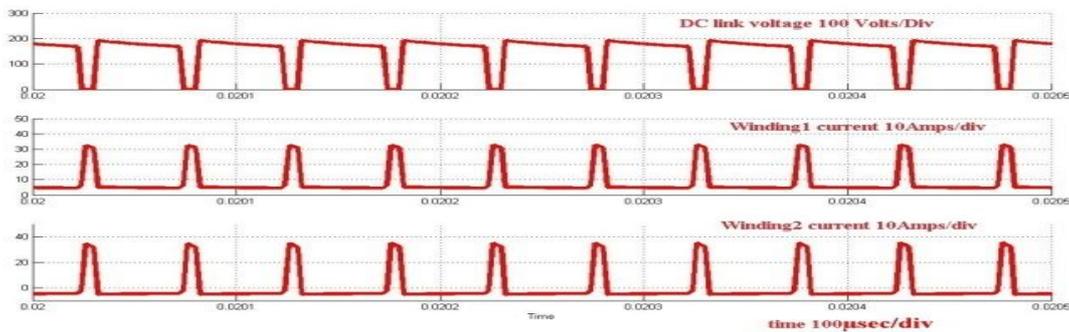


Fig.( 9c). Simulink dc-link and winding waveforms of  $\Gamma$ -Z-source inverter when in voltage-boost mode.

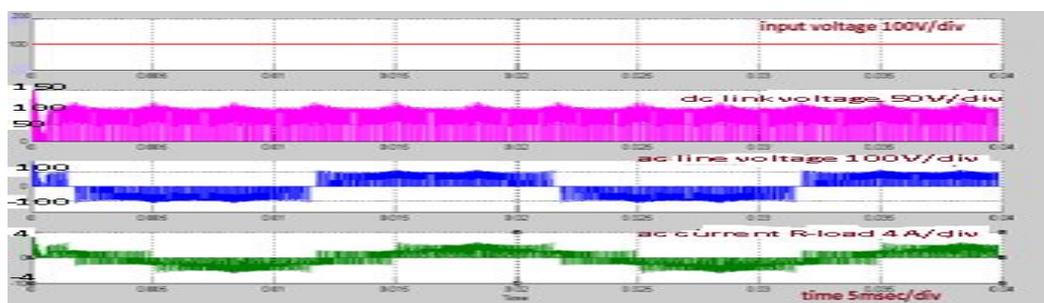


Fig. (10). Simulink input, dc-link and output waveforms of  $\Gamma$ -Z-source inverter when in voltage-buck mode.

## VI.CONCLUSION

This Paper concludes the magnetically coupled Z-source Inverters are shows matured characteristics compare to tractional Z-source inverters. The Gamma source Z-source inverter requires less number of turns to produce same amplitude of output. The simulation results and tabular columns concludes same.



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## BIOGRAPHY



**D. Chandrasekhara Reddy** was born in bubusanipalli, india in 1991. He received B.Tech(Electrical and Electronics Engineering) degree from JNT University, Ananthpur in 2012. And pursuing M.Tech (Power Electronics) in SITAMS, chittoor.



**L. Sagar** received his B.E Degree in 2000 and M.Tech(PE) from VIT,Vellore in 2005. He is working as Associate Professor in EEE Dept., Sreenivasa Institute of Technology and Management Studies(SITAMS),Chittoor. He is pursuing Ph.D in Electrical Engineering from JNTUA,Anatapur. His research interests are in the areas of Power Electronics & Drives, AI Techniques to Solid state drives.



**R. Reddy Prasad** was born in Chittoor, Andhrapradesh, India. He received B.Tech(Electrical and Electronics Engineering) degree from JNT university, Ananthpur in the year of 2011. And Received M.Tech (Power Electronics) Post graduation From RGM CET, Nandyala in the year of 2014. He currently working as Assistant Professor with Sri Venkateshwara College of Engineering, Bengaluru. His area of interests are Power electronics converters, high frequency DC-DC converters, and Z – Source inverters, Multilevel inverters and hybrid electric vehicles.