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Performance Evaluation of Different Topologies of Z Source Inverter with Solar Input

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Abstract:

Nowadays, energy prices are much more volatile due to rising in the use. It concerns us in terms of power supply security and climate crisis because 85% of worldwide energy usage is generated with non-renewable energy which creates pollution in the air and is one of the main sources of climate change issue. Thus, One of the most possible alternatives for energy supply in every sector is solar-based energy. Advanced technologies based on solar panels such as concentrated PV cells (CVP and HCVP) are used in power generation which has an efficiency rate of up to 41%. There are also many other sly-SI) which is largely used by us for power generation at home and many more types of solar panels for various purposes. The solar panels convert the energy from the sun and store it in the battery from which inverters are used to supply to the home,grid, electrical appliances, etc. Thus, my project efforts have been focused on studying and reviewing different topologies of Z-source inverters mainly four, and have a conclusion about which is most suitable for solar energy applications.

At first, based on the system a Simulink model was created and the performance evaluation of different topologies of the Z source inverter was implemented successfully.With this successful design of the overall Z source inverter and topologies. The same model is used for the Z source inverter with PV array at the input. The use of PV array introduces a problem of the algebraic loop. This problem is overcome by using a Switch to auto algebraic loop solver algorithm. The work presented here has strong implications for Z-source inverters and their topologies and help solve the problem of power conversion.Topologies we analyzed in terms of line voltages, phase voltages,capacitance stress, and economically.

Keywords — **Z Source Inverter, Impedance Source Inverter, Z Source Inverter With Solar Input**

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I. INTRODUCTION

An inverter is a device that converts dc power into ac power to the desired frequency voltage. It is designed for the backup of energy from the separately charged batteries such as solar energy which we store in the battery and use with the help of an inverter.[1] It provides ac power by converting the dc power which is stored in the batteries. An inverter is a useful electrical device that is used in powering the electronic equipment which is rated or used at the ac mains voltage. They are also indiscreetly used in the conversion of power supply. [2]

One of the optimistic inverters in today world of power electronics is the z source inverter and its topologies. ZSI utilizes the shoot-through the state to boost the incoming voltage which improves the inverter credibility & increases its field of application.[3] Meanwhile, in correlation with other PE (power electronics) devices or converters, it gives buck-boost capability with single-stage DC/AC conversion with less capacitor volume, low cost & high efficiency due to the fewer components.

Thus, It the makes z source inverter very competitive and favorable topology for general and solar applications also.[4]

It consists of two inductors, one diode, two capacitors, & six semi-conductor switches. The ZSI is a two-port circuit which is an X shape where the paired network LC, e.g. Impedance placed between the input DC voltage source & the inverter switches is shown in figure 1.[5]

Z-source inverter uses the shoot-through states to boost the DC link voltage of the inverter which can not be done in traditional or conventional voltage sources of inverters. This single-stage boosting literally decrease the size, lower the system cost, and increases the efficiency & credibility of the power electronic converters. Thus, It makes the z source inverter performance better than the boost converter with a voltage or current source inverters in a comparison of the cost, size, efficiency, and credibility. [7]

A. *Classical Zsi Drawbacks*

Despite the specified qualities, the classical voltage-feed ZSI also suffers from downsides :

- Large start-up current
- Non-Continuous input current
- Less boost factor
- Stress of semi-conductor switches & higher capacitor voltage

Thus, These factors drive the researchers to outstretch the extent to bring the additional fundamental developments of the z source inverters and its came up with their different types of its topologies. [8]

B. Topologies

A range of different types of z source inverters are derived in this project mainly with the help of traditional type, quasi-types z source inverter, switching and coupled types source inverter.[9] The improvement in the z source inverter is basically done by re-arranging the present or adding additional elements in the basics architecture. Different topology of z source inverter provides a distinct characteristic & needs respective to its applications.[10]

The topologies of zsi networks have developed these purposes :

- To obtain the large-density power conversion
- To extend the range of voltage gain inverter
- To obtain the application-oriented adaption and correction
- To lower the elements cost & count [11]

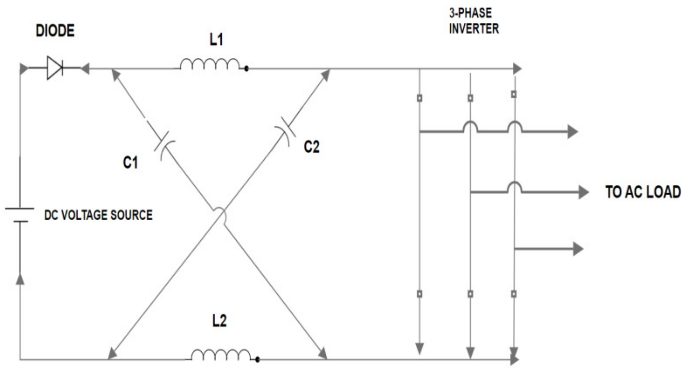

Figure 1 : Classical Z-source inverter

C. PV SOURCE ZSI

Renewable or sustainable energy is easily accessible and easily reachable everywhere. It is the most un-costly technology in which infrastructure is revamping very fast. There are many sustainable energy sources such as wind energy, hydro energy, geothermal energy, solar energy, etc. All are very important & useful in power generation but solar energy is the most popular among them because it is noiseless and can be obtained in a substantial amount and also it has a long life, more portable than other sources of power generation with small adjustments.[12]

Thus recently, The task for a renewable & reliable energy system majorly increasing & the use of this as alternative energy especially the solar to lower the dependence on the non-renewable energy is becoming essential & important.[13] The renewable energy power generation in the electrical grid causes several issues to the management capability & stability of the system.[14]Mostly the production of renewable energy needs the broad uses of the power electronics converters to obtain the necessary electrical conversions for efficiency enhancement & grid unification.[15]

The use of sustainable energy in inverters is now becoming common, efficient & compact use. Thus, to use renewable energy especially solar in the z source inverter we replace the dc input voltage source with a solar input source (PV Array) shown in *figure 2*. Solar energy is, noiseless, environment helpful, longer life with little maintenance, highly mobile, compact, and transferable in a comparison to other sources of power generation.[16] The Z-Source Inverter has been also classified as appropriate for household PV systems because of the single-stage inversion and voltage boost capability. we will use the solar as an input (PV Array) on the above-mentioned different topologies and also gets the conclusion from it.[17]

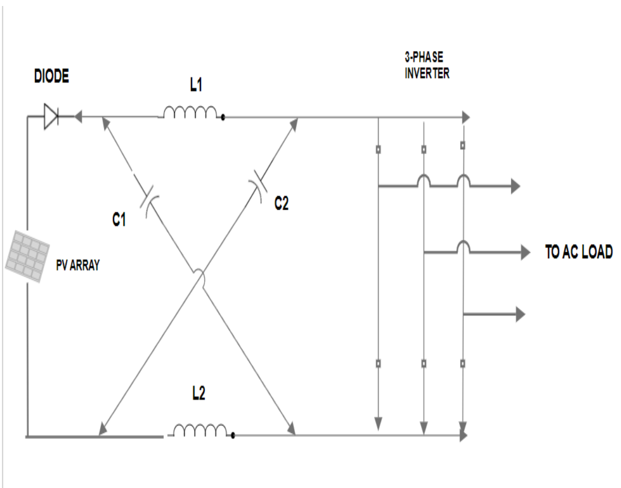

Figure 2 : PV Source Z-source inverter

II. VOLTAGE CONTROL

We use phase-controlled rectifiers, chopper, ac voltage regulators, etc. in the circuit and cascade, and this control to control the voltage technique It is also known as the 'External control technique'. But this technique will increase the size of the circuit, power stages, loss, and cost. Hence, we should prefer the internal control technique, for example, the PWM control technique inverter.[18]

A. PWM Control Technique

Pulse-width modulation, or pulse duration modulation, is a way of reducing the power of an electrical signal, by efficiently chopping it into discrete parts. With the help of the pulse wide modulation (PWM) control system, we can get the variable ac as a response and by selecting the appropriate pulse width range we can eliminate the harmonics, which represents the improvement of the load voltage waveform.[19]

Sinusoidal PWM -

SPWM shown in figure 5 is the most commonly used method, In carrier-based PWM techniques where the desired output is obtained by comparing the desired waveform with a higher frequency wave usually a triangular wave circuit shown in figure 3.[20]SPWM is used to control the voltage and the modulating signal is sinusoidal voltage with the following impedance present-

1. The instantaneous value of the modulating signal should not exceed the peak of the carrier signal.
2. The frequency of the carrier signal should be much larger than that of the modulating or reference signal.ie.integral multiple of the reference signal frequency.

The intersection of the reference wave and the carrier wave determines the switching instant and commutation of the modulated pulse.[21]In SPWM, both waveforms are compared, when the sinusoidal wave circuit shown in figure 4 has a higher magnitude than the carrier wave, the comparator output is high. The output of the comparator is progressed in a trigger pulse generator, which makes the inverter output voltage such that its pulse width is proportional to the comparator pulse width.[22]

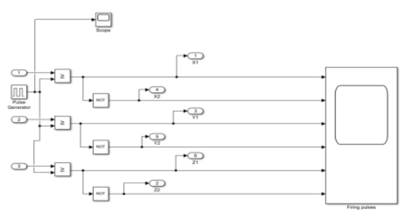

Figure 3 : Pulse Generator

Figure 4 : Sinusoidal wave circuit

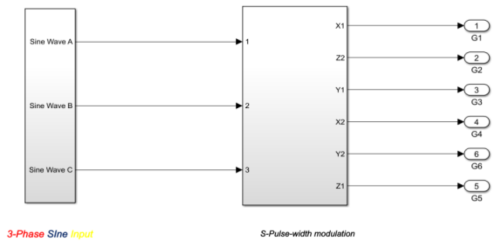

Figure 5a : SPWM

B. Modulation Index:

The ratio of the reference peak and the carrier wave is called the modulation index (MI). The Mi output voltage controls the harmonic content in the waveform. The magnitude of the output voltage fundamental component is proportional to Modulation Index. The maximum value of the Modulation Index is unity.[23]If we increase the number of pulses per half cycle then the order of the major harmonic frequency increases. And the high-frequency harmonics are easy to eliminate and the filtering cost is also low. But higher frequencies lead to higher switching losses, so a balance needs to be maintained between filtering requirement and inverter efficiency.[24]If the Modulation Index is greater than 1 then lower-order harmonics appear in the pulse width and the output is no longer a sinusoidal function of the pulse's angular position.

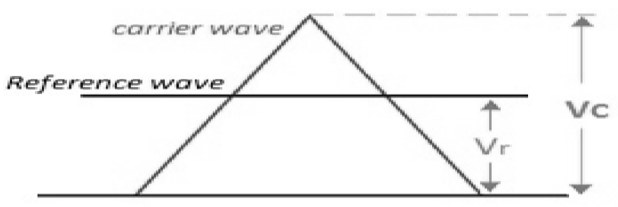

Figure 5b : Reference & Carrier Wave

Let be the modulating signal be a sinusoidal amplitude Vr(reference wave),And the amplitude of a triangular wave is Vc(Carrier wave)(Figure 5b).[26]

Then the ratio :

MI =Vr/Vc is known as modulation index.

For SPWM, the modulation index (MI) should be less than 1.0.

$$MI = \frac{Vr}{Vc} < 1$$

III. ZSI OPERATION

The basic circuits include an SPWM unit,z source, switching device (inverter), three-phase load, a dc voltage source, and PV array(solar) for PV simulation.[27]The alteration of DC current to AC current is done by conversion of energy which is stored in the dc voltage source e.g cell or a battery, into an alternating voltage source. This is done by basically using the inverter switching devices in this case we take MOSFETs which consistently go on and off, and then they transfer to the three-phase load system, and the pulses that generate from the Sinusoidal Pulse Width Modulation (SPWM) go to the primary side of the switches in *Figure5c.*[28]

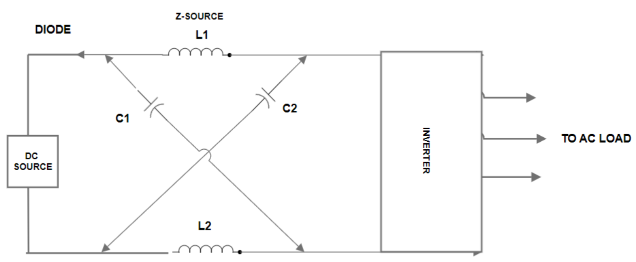

Figure 5c : Block diagram of ZSI

A. Mathematical Analysis of ZSI

As we know there are two types of shoot & non-shoot through the state. Let the C1 and C2 be the capacitors of the circuit & L1 and L2 are the inductors of the circuit which have the same capacitance & inductance values each. Thus the Z-source inverter circuit becomes symmetrical shown in figure 6.

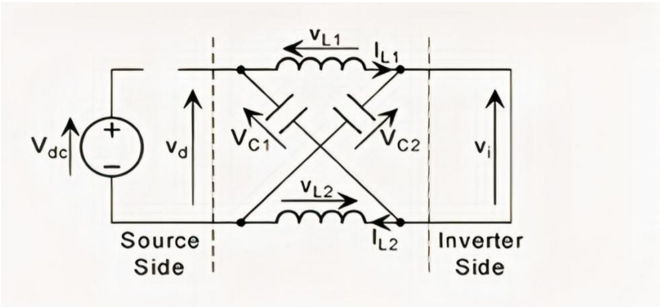

Figure 6 :An equivalent circuit when z source inverter in shoot through state

In the shoot-through state of the z source network inverter side is shorted during the interval of time T0.

Thus,C1=C2=C and L1=L2=L

Therefore;

VC1 = VC2=VL1=VL2 = VL=VC

Vd =VC + VL = VC + VC = 2*VC ….(I) [29]

Alternately,In non-shoot through active state current goes through z source network or its topologies across inverter to connect the alternating current load during the time interval of time T1.The Z-Source network of the inverter side can be represented by a circuit diagram as shown in figure 7.

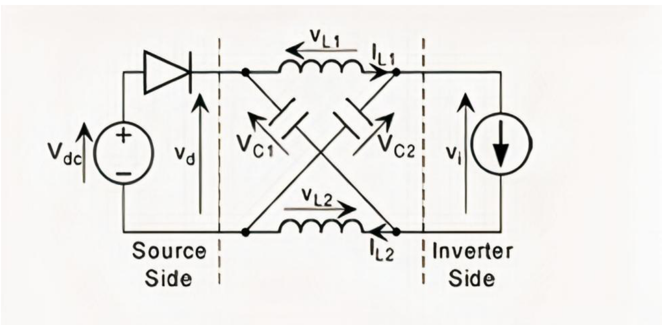

Figure 7 :An equivalent circuit when z source inverter

in non - shoot through state

Following equation can be written as now :

VL = Vdc - VC

Vd = Vdc

Vi = VC - VL

Now,By putting VL = Vdc - VC

Vi = VC-(Vdc - VC) =Vc - Vdc + VC = 2VC - Vdc ….(II)

Now,By average the voltage across z source inductor over 0 to T switching period

VC =T1/(T1-T0) Vdc….(III)

The peak voltage of the DC link across the inverter bridge is :

Vi = 2*VC-Vdc

= 2* [T1/(T1-T0)Vdc]-Vdc

1/(1-2T0/T)Vdc...(IV)

Vi = B*Vdc….(V)

Where,T=Switching Period of the inverter,B=Boost Factor of the inverter

The peak alternating current phase voltage of a Z-source network are :

Vac = M*Vi/2 = B*M.Vdc/2 ;Where M= Modulation Index.[30]

IV. SIMULATION

The output ac voltage of the Z-source inverter and their topologies will be Vac = M*Vi/2 = B*M*Vdc/2 (Theoretically); Where M= Modulation Index. Thus we will now obtain the output voltages result from the simulation and concludes their topologies.

Table 1: System parameters :

S_e	$40K_{hz}$	L_{zn}	10 mh
M_i	0.8	C_{zn}	10 uf
D_i	0.3	R_{ac}	10 ohm
V_{dc}	150 V	L_{ac}	15×10^{-3} H
I_r	40	C_{ac}	10×10^{-6} F
T_r	30^0C	Pv	412 V

A. Simulation of Z Source Inverter Topologies With Dc Source Input Voltage

In this project we mainly go through the four topologies of the Z-source inverter and they are :

1. Traditional Z-Source Inverter
2. Quasi Continuous Input Current Z-Source Inverter
3. Quasi Lower Capacitor Voltage Z-Source Inverter
4. Coupled Inductor Z-Source Inverter
5. Switching Inductor Z-Source Inverter

Thus we now go through the simulation :

A.1. Traditional Z -source Inverter

The traditional ZSI is shown in below figure 8.According to its working principle and its traditional topology :

$U_i = 1/1-2D_0*U_{dc} = BU_{dc}$

$U_C = 1-D_0/1-2D_0*U_d$

Where:

B = Boost factor.

D_0 = Duty ratio (Shoot Through)

U_C = Capacitor voltage

U_i = Boost side voltage

U_{dc} = DC supply voltage

Simulink Model :

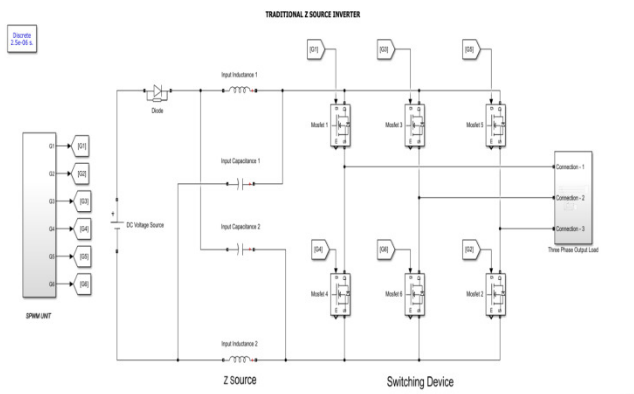

Figure 8 :Traditional z Source inverter

Graphs :

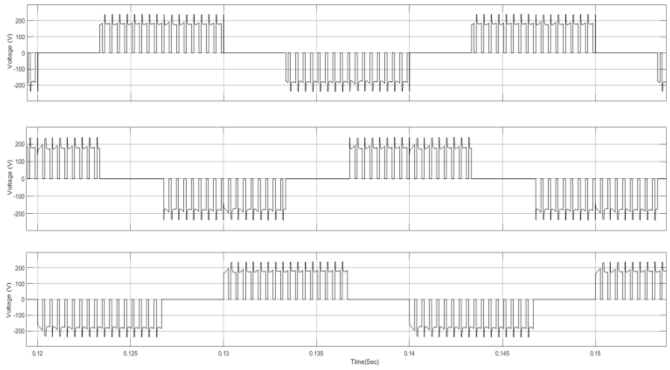

Figure 9 : Line voltage graph of traditional z source inverter

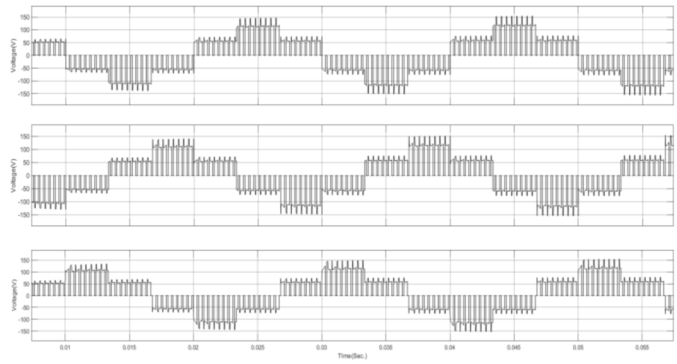

Figure 10 : Phase voltage graph of traditional z source inverter

A.2. Quasi Continuous Input Current Z-Source Inverter

In figure 11 is the continuous input current z source topology. It is an asymmetric structure, The inductor is connected with the dc source power supply in series to make the input current of Z-source inverter continuous. This topology effectively simplifies the filter circuit & reduces the system cost.

Simulink Model :

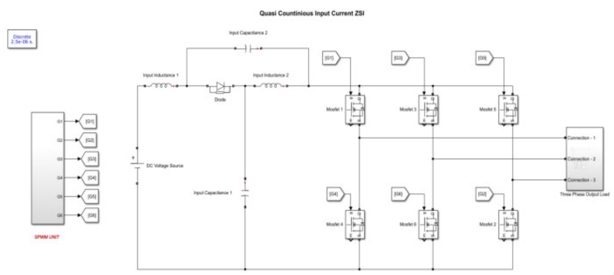

Figure 11 :Quasi continuous input current z source inverter

Graphs :

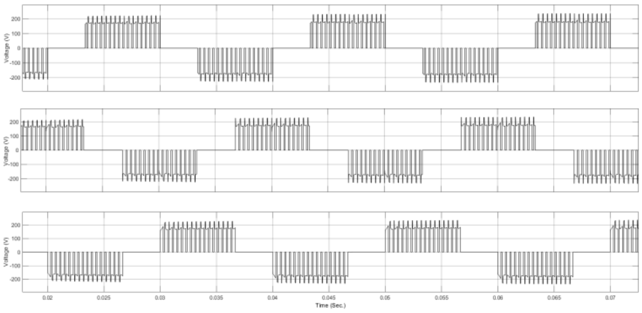

Figure 12 : Line voltage of quasi continuous input current z source inverter

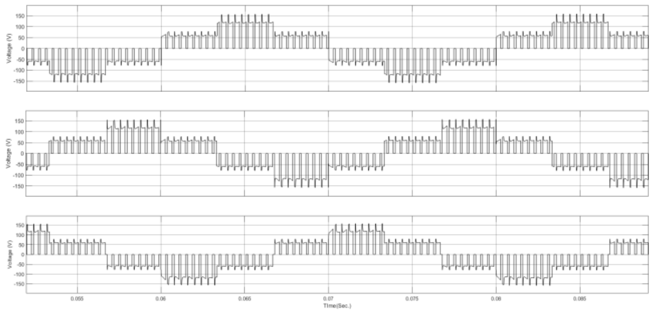

Figure 13 : Phase voltage of quasi continuous input current z source inverter

A.3. Quasi Lower Capacitor Voltage Z-Source Inverter

Lower Capacitor Voltage Z-Source Inverter in figure 14 .The cathode position of the capacitor is adjusted on the grounds of the above topology figure 11.With the dc power supply it makes the capacitor voltage continuous, in the meantime it reduces the capacitor voltage because of it.

Simulink Model :

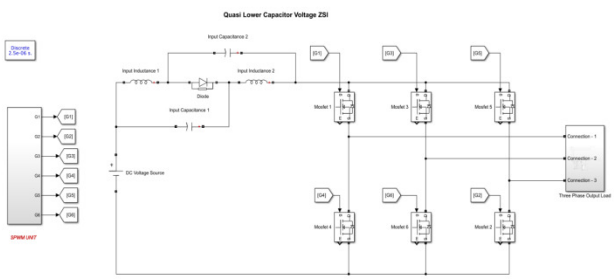

Figure 14 :Quasi lower capacitor voltage z source inverte

Graphs :

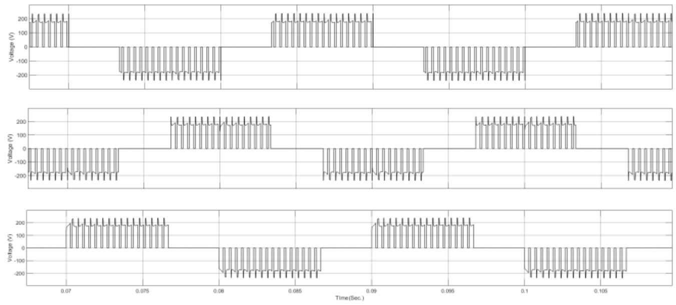

Figure 15 : Line voltage of quasi lower capacitor voltage z source inverter

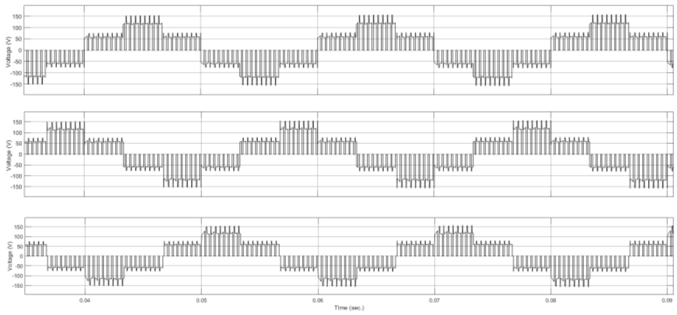

Figure 16 : Phase voltage of quasi lower capacitor voltage z source rinverter

A.4. Coupled Inductor Z-Source Inverter

Coupled-inductor Z-source inverter is in figure 17 which increases the number of quasi z source network which reduces the voltage stress of electrical elements.This topology of z source networks can't change the boost capability.

Simulink Model :

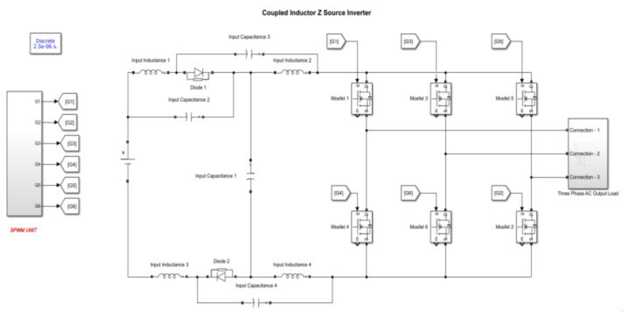

Figure 17 :Coupled inductor zsi

Graphs :

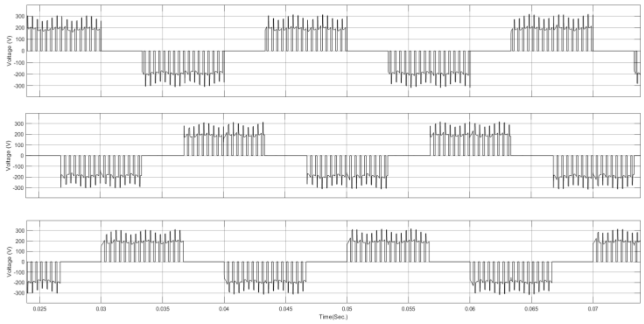

Figure 18 : Line voltage of coupled inductor zsi

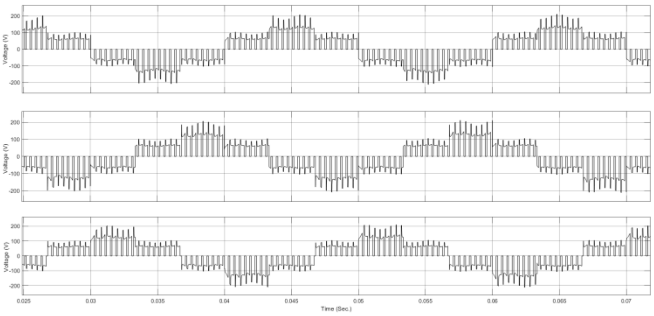

Figure 19 : Phase voltage of coupled inductor zsi

A.5. Switching Inductor Z-Source Inverter

Switching Inductor Z-Source Inverter topology is in figure 20 in which switch inductor use in place of the inductor.Different from the traditional topologies of z source inverter this topology adds three diodes and one inductor to each inductor circuit. This topology increases the boost capacity greatly but the cost increase also.

Simulink Model :

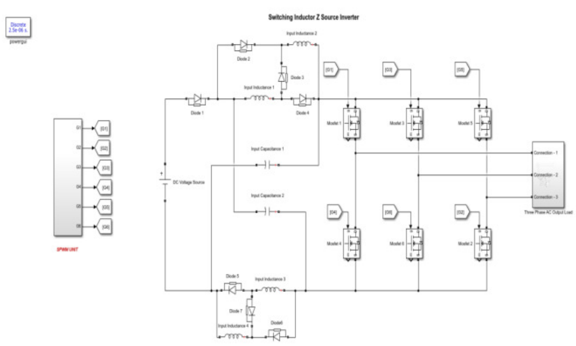

Figure 20 : Switching inductor zsi

Graphs :

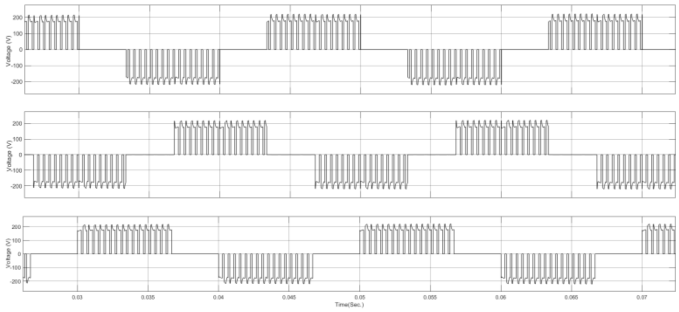

Figure 21 : Line voltage of switching inductor zsi

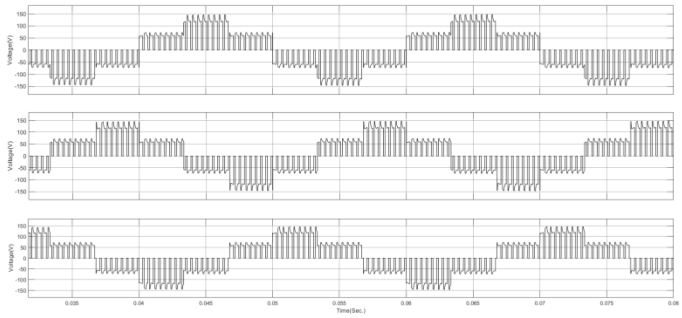

Figure 22 : Phase voltage of switching inductor zsi

B. Simulation of Z Source Inverter Topologies With Pv Array (Solar) Input Voltage

In this project simulation we again go through the same four topologies of the Z-source inverter and they are :

1.PV-Traditional Z-Source Inverter

2.PV-Quasi Continuous Input Current Z-Source Inverter

3.PV-Quasi Lower Capacitor Voltage Z-Source Inverter

4.PV-Coupled Inductor Z-Source Inverter

5.PV-Switching Inductor Z-Source Inverter

Thus, we now go through the same simulation components again but only DC voltage source will be replaced by PV array source which will have two constants which is irradiance and temperature. The, value and the working features of components beside source will be same.In this project simulation basically we focused on the voltage gain (Line & Phase Voltage) in the simulation by the inverter when connected to a solar or pv array source.

B.1. PV-Traditional Z-Source Inverter

Simulink Model :

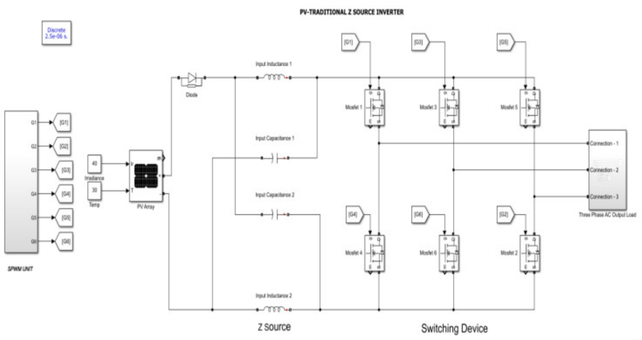

Figure 23 : PV-Traditional zsi

Graphs :

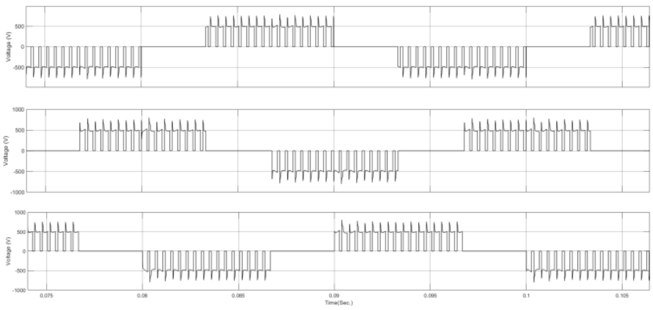

Figure 24 : Line voltage of pv-traditional zsi

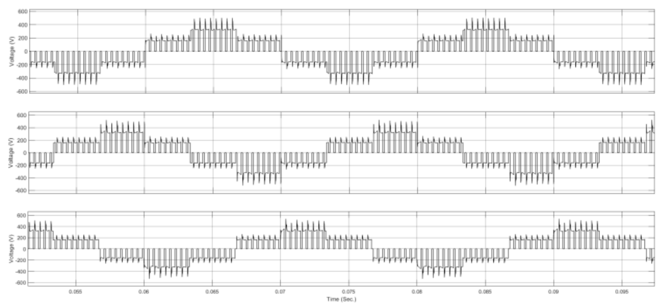

Figure 25 :Phase voltage pv-traditional zsi

B.2. PV-Quasi Continuous Input Current Z-Source Inverter

Simulink Model :

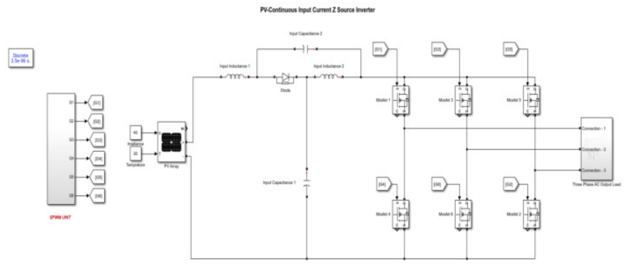

Figure 26 : PV-quasi continuous input current zsi

Graphs :

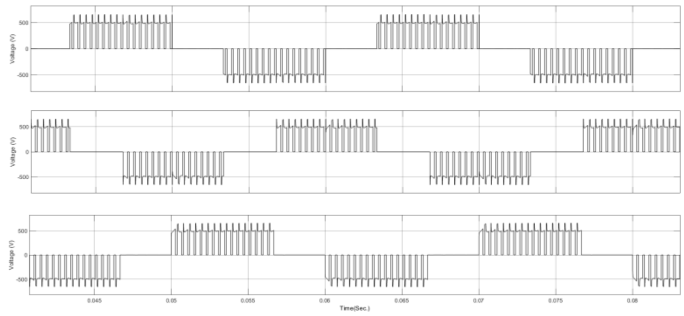

Figure 27 : Line voltage of pv-quasi continuous input current zsi

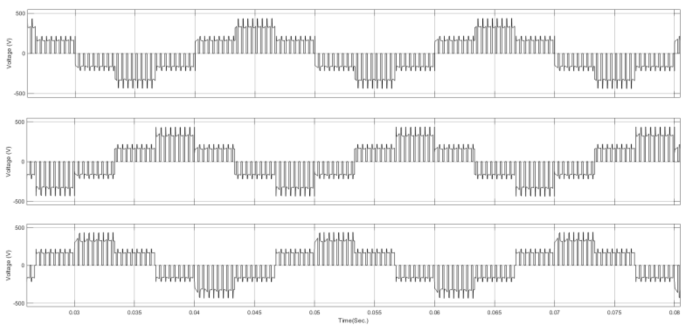

Figure 28 :Phase voltage of pv-quasi continuous input current zsi

B.3. PV-Quasi Lower Capacitor Voltage Z-Source Inverter

Simulink Model :

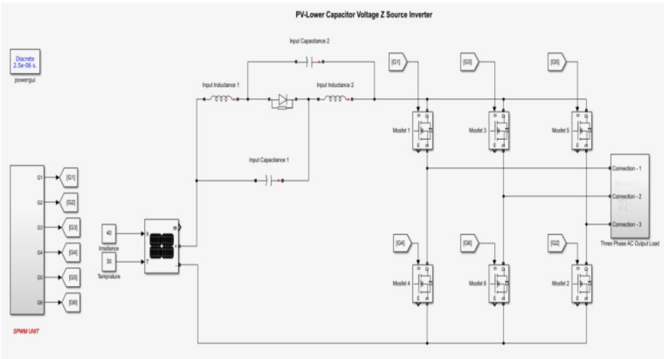

Figure 29 :PV-Quasi lower capacitor voltage zsi

Graphs :

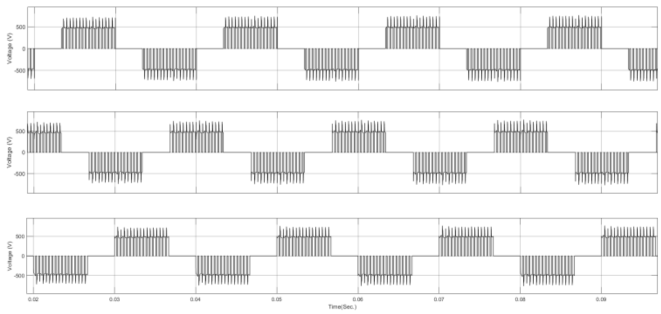

Figure 30 :Line voltage of pv-quasi *lower capacitor voltage zsi*

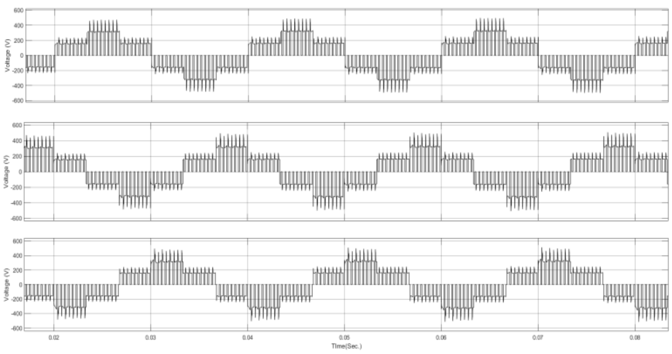

Figure 31 :Phase voltage of pv-quasi lower capacitor voltage zsi

B.4. PV-Coupled Inductor Z-Source Inverter

Simulink Model :

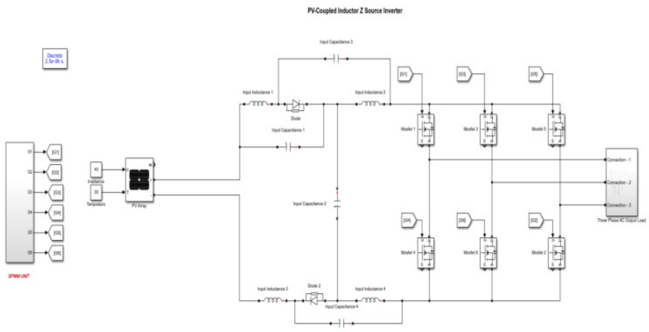

Figure 32 : PV-Coupled inductor zsi

Graphs :

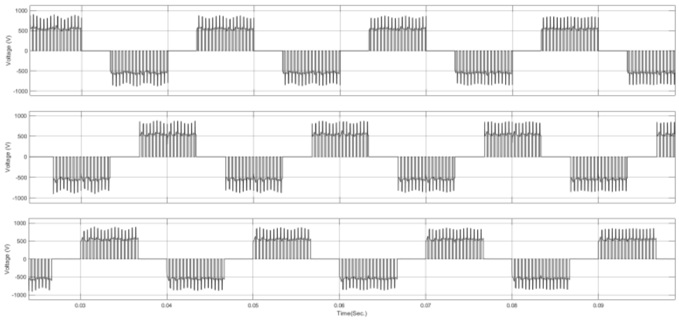

Figure 33 :Line voltage of pv-coupled inductor zsi

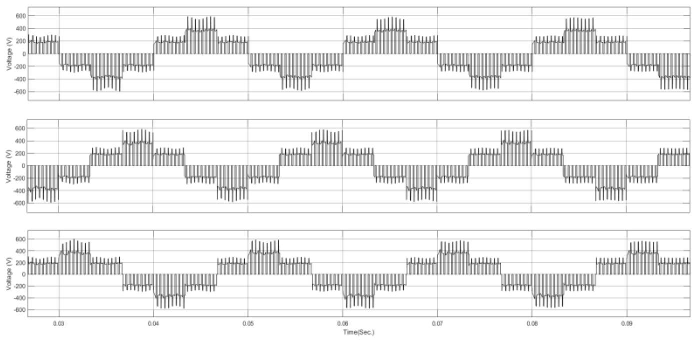

Figure 34 : Phase voltage of pv-coupled inductor zsi

B.5. PV-Switching Inductor Z-Source Inverter

Simulink Model :

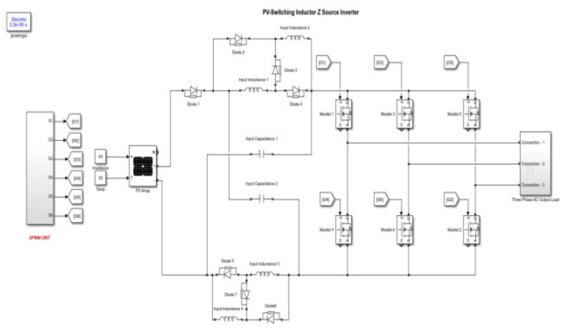

Figure 35 : PV-Switching inductor zsi

Graphs :

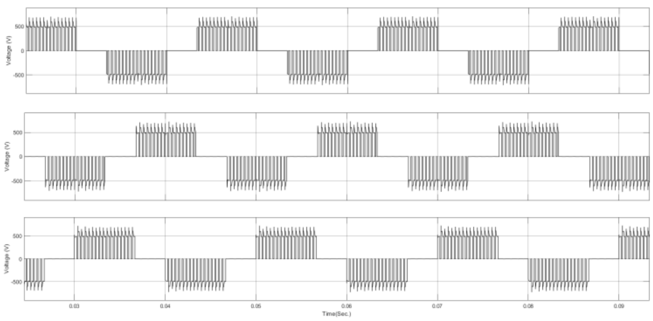

Figure 36 : Line voltage of pv-switching inductor zsi

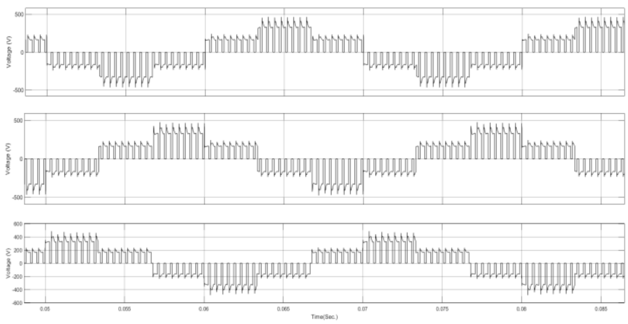

Figure 37 : Phase voltage of pv-switching inductor zsi

V. RESULTS

TABLE 1
Five Different Topologies of Z-source Inverters With Dc Source Input Voltage Performance Comparison

S.NO	TOPOLOGIES	BOOST CAPACITY	LINE VOLTAGE	PHASE VOLTAGE	CAPACITOR VOLTAGE	COST	EFFICIENCY
1.	TRADITIONAL	1/ $(1-2D_0)$	239	159	194	LOW	HIGH
2.	CONTINIOUS INPUT CURRENT	1/ $(1-2D_0)$	239	159	194	LOW	HIGH
3.	LOWER CAPACITOR VOLTAGE	1/ $(1-2D_0)$	239	159	44	LOW	HIGH
4.	COUPLED INDUCTOR	1/ $(1-2D_0)$	303	202	223	HIGH	HIGH
5.	SWITCHING INDUCTOR	$(1+D_0)$/ $(1-3D_0)$	218	145	184	HIGH	LOW

TABLE 2
Five Different Topologies of Z-source Inverters With Pv Array Input Voltage Performance Comparison

S.NO	TOPOLOGIES	BOOST CAPACITY	LINE VOLTAGE	PHASE VOLT.	CAPACITOR VOLT.	COST	EFFICIENCY
1.	PV TRADITIONAL	$1/(1-2D_0)$	697	464	529	LOW	HIGHER
2.	PV CONTINIOUS INPUT	$1/(1-2D_0)$	658	438	535	LOW	HIGHER
3.	PV LOWER CAPACITOR VOLTAGE	$1/(1-2D_0)$	705	470	118	LOW	HIGHER
4.	PV COUPLED INDUCTOR	$1/(1-2D_0)$	838	559	617	HIGHER	HIGH
5.	PV SWITCHING INDUCTOR	$(1+D_0)/(1-3D_0)$	617	411	507	HIGH	LOWER

VI. CONCLUSIONS

ZSI bears down the downside of the traditional sources of inverters e.g CSI & VSI. It improves the efficiency and the performance remarkably as it has the buck-boost operation of the inverter with less power loss, lower cost, and a rise in efficiency. Z Source inverter has more attractive power conversion than another inverter.

We discussed the Z-source inverter and its five topologies in this paper and it is simulated by the MATLAB software and its toolbox. The various topologies results can be analyzed from TABLE ONE & TABLE TWO. The two topologies in S.no 3 & 4, have a noticeable effect on the lowering of the capacitor voltage & boost capacity of both the topologies are equal, and other topologies S.no.5 has increased the boost capacity of the inverter but the input current & capacitor voltage are also increased and it directly increases the cost of the whole system. The quasi topologies with the power supply ensure the boost capability and also it has lower capacitor voltage. These improved and efficient topologies will be widely used in wind power, fuel-cell, and other new energy generations.Also, From the same topologies of ZSI but with a PV array source (solar power)it overcomes the limitation of traditional solar inverters. It increases efficiency and performance with low cost and less power loss.

A zsi is a remarkable achievement for the researcher as they deliver high boost output than input with an efficiency that comes up with a low-cost model too.The lower boost capacity high capacitor volume are yet an area to a work on for the researchers. Meanwhile, A z source inverter has remarkable power electronic device in conversion and it's the best replacement of traditional inverters in the coming days.

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