Abstract
Objectives: Proposed impedance network also has more degrees of freedom for varying its voltage gain, and hence, improving the versatility of the inverter. A switching algorithm is applied to this topology to control the charging time and discharging interval of inverter inductor. Methods/Statistical Analysis: On the basis of the conventional Z-source inverter [ZSI], this paper offers a novel on new type impedance source inverter which only contains one capacitor with tightly coupled three winding transformer, whose obtained voltage gain is presently not matched by existing networks operated at small duty ratio. The inverter can increase the boost factor through adjusting shoot-through duty ratio and varying the number of turns in the three winding transformer. Findings: The proposed impedance network also has more degrees of freedom for varying its voltage gain, and hence, improving the versatility of the inverter. A switching algorithm is applied to this topology to control the charging time and discharging interval of inverter inductor. A simple control strategy is applied to this configuration which is responsible for regulating the transfer power to the maximum amount and also to justify the amount of Total Harmonic Dissortion (THD) in minimum point. The working principle of the proposed Y-Source Inverter has been demonstrated by mathematical analysis in detail. The MATLAB/Simulink Simulation results are conducted to validate the analysis. Application/Improvements: For regulating the transfer power to the maximum amount in PV applications.

Keywords: MATLAB/Simulink, Switching Algorithm, Z-Source Inverter

1. Introduction
Voltage Source Inverters (VSI) and Current Source Inverters (CSI) are two traditional converters which are used conventionally. These traditional converters comprises of six switches fed by source consisting of a battery, fuel cell, solar or any other renewable energy resources. However in the past decade use of a impedance network proven to provide an effective and efficient power conversion between the source and load over a wide range of electric power applications. An impedance network is a combination of inductors and capacitors which acts as a buffer between the converter switches and source.

This use of impedance network allows overcoming their common problems like-

- Main circuits are not interchangeable.
- Vulnerable to the EMI noise in the system.

Various impedance networks are proposed over the past decade, out of which Z-Source impedance is the pioneer and prominent network. It has been used in various DC-DC, DC-AC, AC-AC power conversion converters. The voltage fed Z-Source inverter can have high gain theoretically. However, the higher the voltage gain, smaller modulation index has to be used. In applications like fuel cell power conversion, grid integrated Photovoltaic (PV) generation, where a low voltage DC input has to boosted to a higher level AC voltage, smaller modulation index, M will increase the stress on the switches. Thus, networks which can produce higher voltage boost gain at high modulation index are focused. The similar affability has further shown by other impedance networks like quasi-Z, Embedded Z, and...
series $Z_7$, switched inductor $S_9$, tapped inductor $S_8$, cascaded $S_{10}$. However, they add passive components like diode, inductor and capacitor for raising the gain. Increase in components, increases the size of the inverter and is not economically justifiable. Thus the investigation continues with networks using coupled inductors and transformers for boosting the gain. T-Source, Trans-Z-Source, Γ-Source use coupled inductors or two winding transformer to achieve a higher voltage gain. These networks provide a higher voltage gain while keeping the component count low. These networks have their own characteristic features which might occur depending on the application. It is appropriate to look for an alternative which can combine all the advantages in a single network.

To experience all the preferred characteristics of the various impedance networks (shown in Table 1) in a single network, a Y-Source impedance network with a three phase PWM controlled converter is presented in this paper as shown in Figure 1, which can provide a very high voltage gain while using a small duty ratio with improved flexibility of the network. Proposed Y-source by inverter consists of a DC source, Y-impedance network and a three phase Pulse Width Modulation (PWM) controlled bridge inverter. Proposed Y-source network comprises a passive diode D1, a capacitor C1 and a three winding transformer (N1, N2, N3). Since the transformer is directly connected to the Inverter Bridge and diode, effectiveness of the proposed network is ensured by tightening the magnetic coupling between the coupled inductors to avoid the losses through leakage inductances. Bifilar coils may be used to minimize the leakage inductances in the transformer or coupled inductors. Proposed Y-source inverter can realize a very high voltage gain with different winding factor, k, which can be varied by varying the turns ratio (N1:N2:N3) of the three winding transformer. Higher voltage gain is experienced also while using a range of shoot through duty cycle, $d_{ST}$, at higher modulation index. Thus the proposed network allows a higher voltage gain with different winding factors, turns ratio and shoot through duty cycle at higher modulation index, which makes the network more versatile and even more flexible than any other present impedance source networks.

Like any other impedance source inverter, Y-source network has a shoot through state, six non-shoot through active states and two zero states. Shoot through operation of the proposed Y-source inverter is discussed in the Section 2. Mathematical analysis of the network is documented in Section 3, control techniques of the inverter is discussed in Section 4, which is validated through simulation in Section 5 and concluded with results.

### Table 1. Comparison of passive components count between different network topologies

| Topology            | Diode count | Capacitors count | Inductors count |
|---------------------|-------------|------------------|-----------------|
| Z-Source [1]        | 1 Diode     | 2 Capacitors     | 2 Inductors     |
| QuasiZ-Source [5]   | 1 Diode     | 2 Capacitors     | 2 Inductors     |
| Γ-Source [13]       | 1 Diode     | 2 Capacitors     | 1 Inductor, 2 winding |
| TransZ-Source [12]  | 1 Diode     | 2 Capacitors     | 2 integrated 2 winding |
| Y-source [15]       | 1 Diode     | 1 Capacitor      | 1 integrated winding |

![Figure 1. Y-source impedance network.](image-url)
advanced core and windings. Thus effects caused by the
leakage inductances must be studied thoroughly.

2.1 Modes of Operation
The proposed Y-source network has a shoot-through
and non-shoot-through operation like any other imped-
ance source inverter\footnote{19}. However, the network undergoes a
intermediate third state as explained in this chapter.

2.1.1 Non-Shoot Through to Shoot through Transition
A new intermediate equivalent circuit is introduced
when the impedance source transits from non-shoot-
through state to shoot through state as shown in Figure
2(a). During non-shoot-through state inductances are all
discharging energies and current is thus decreasing. The
shunt switch SW in the Figure is next shorted, which ide-
ally, will lead to the shoot-through circuit shown in Figure
2(c). However, for the non-ideal case, an intermediate cir-
cuit shown Figure 2(b) will be inserted for a short time
interval, caused by the rapid fall of the current through
leakage inductance in N1, and rapid rises of currents
through leakage inductances N2 and N3. The intermedi-
ate state ends only when the leakage current through N1
and diode D falls to zero.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{fig2.png}
\caption{Operation during. (a) Non-shoot through. (b) Intermediate state. (c) Shoot through state.}
\end{figure}

2.1.2 Shoot through to Non-Shoot through Transition
For shoot through to non-shoot through transition, the
network is in its shoot-through state, when the switch
SW is turned OFF, the network connects the source to the
load and transits to non-shoot through state. Unlike
the forward transition, there is no intermediate state and
the network enters its non-shoot-through state directly
with diode D conducting, even though its current might
increase rapidly over a short duration rather than step-
increased. No reduction of the shoot-through duration
is therefore introduced by the reverse transition. The
concern in reverse transition is concentrated on loads,
categorized as capacitive and inductive loads, rather than
leakage currents.

The first possibility involves the commutation of the
network output to a capacitive load. The current drawn
by this capacitive load can not adapt to leakage current
at instant of commutation, thus voltage spikes\footnote{20} nor are
constraints experienced with capacitive loads. Second
possibility involves an inductive load, which may not be
as smooth as capacitive load. Being less inductive,
during the commutation from shoot through state to
non-shoot through state, leakage currents caused by
leakage inductance in N3 will be pulled down to output
current instantaneously, resulting in high voltage
spikes in the circuit. If this transient is not mitigated,
it may affect the leakage currents of N1 and N2 as well.
Thus a capacitive snubber may be added in order to
bring down the difference between the load and leakage
currents.
3. Mathematical Analysis

During the shoot through state interval $d_{ST}$, while the switch SW is ON and diode D1 is reverse biased, the expression for the equivalent circuit is arrived as,

$$V_{CI} + \frac{V_L}{n_{12}} - \frac{V_L}{n_{13}} = 0$$  

(1)

Where, $n_{13} = N1/N2$, $n_{12} = N1/N3$ and $V_L$ is given as voltage across winding $N1$

i.e., $V_L = V_{CI} \left( \frac{n_{13} \cdot n_{12}}{n_{12} - n_{13}} \right)$  

(2)

On the other hand, during any non-shoot-through state interval $(1-d_{ST})$, diode D1 is conducting and the inverter bridge is conducting source to the load, the expression for the equivalent circuit is arrived as,

$$V_{CI} + \frac{V_L}{n_{12}} = V_{in}$$  

(3)

i.e., $V_L = [V_{in} - V_{CI}] \left( \frac{n_{12}}{1 + n_{12}} \right)$  

(4)

Where $V_{CI}$ is the capacitance voltage

Performing the state-space averaging for both the shoot through state interval and non-shoot through state interval, the voltage across the capacitor $C_1$ can be deduced to be,

$$V_{CI} \left( \frac{n_{13} \cdot n_{12}}{n_{12} - n_{13}} \right) (d_{ST}) + \left\{ V_{in} - V_{CI} \right\} \left( \frac{n_{12}}{n_{12} + 1} \right) (1 - d_{ST}) = 0$$  

(5)

From the above expression, the voltage across the capacitor is obtained as

$$V_{CI} = \frac{V_{in} (1 - d_{ST})}{1 - n_{13} d_{ST} (1 + n_{13}) (n_{12} - n_{13})}$$  

(6)

Referring now to the dc-link voltage across the inverter bridge ($V_{dc\_link}$), its peak value $V_{dc\_link}$ during the nonshoot through states can be written as

$$V_{dc\_link} = V_{in} - V_L + \frac{V_L}{n_{13}}$$  

(7)

$$V_{dc\_link} = \frac{V_{in}}{1 - K d_{ST}}$$  

(8)

Where

$$K = \left( \frac{N_3 + N_1}{N_3 - N_2} \right)$$  

(9)

N3 - N2 > 0, N1 + 2 N2 > N3, N2 < N3 and N3 > 1  

(10)

The Y-source inverter is therefore capable of producing a high gain at a small duty ratio.

$$0 < 1 - K d_{ST} \leq 1$$  

(11)

Thus,

$$0 \leq d_{ST} \leq d_{ST\_max} = 1/k$$  

(12)

And the corresponding modulation index is

$$M = 1.15 \left( 1 - d_{ST} \right)$$  

(13)

The Y-source inverter voltage gain varies with different winding factors $K$ and shoot-through duty cycles $d_{ST}$. The Equation (8) clearly shows that the Y-source inverter can produce the desired gain with many different combinations of $K$ and $d_{ST}$. Besides $K$ and $d_{ST}$, the winding turns of the transformer can also be flexibly chosen as long as they give the specified $K$, which is illustrated in Table 1. Equation (13) depicts that a higher modulation index can be achieved by varying the $d_{ST}$ in the specified range. From Table 1 it can be seen that, for each $K$ value chosen for a certain gain $G_v$ and range for $d_{ST}$, there are more than one combination of winding turns $(N_1: N_2: N_3)$ to select from. In the proposed Y-source inverter, a higher modulation index can be achieved at a small shoot through duty ratio as shown in the Table 1. In this paper, the Y-source network is designed for winding factor 4, which allows shoot through duty ratio between 0 and $1/4$, with turns ratio of 1:2:3 as shown in Figure 3. The gain produced by the Y-source network is thus a combination of those expected from the T - or trans-Z-source and Γ-source networks. This either creates a higher gain or allows merits of the other networks to be flexibly merged. The latter can be helpful when subject to size and type availabilities while choosing magnetic core, wire and coupling method for winding the transformer. The goal is to maximize coupling, and hence minimize leakage, which if not ensured, will lead to higher switching voltage

| $K$ | $0 < d_{ST} \leq d_{ST\_max}$ | Voltage Gain,$G_v$ | $N_1$,$N_2$,$N_3$ |
|-----|-----------------------------|-------------------|------------------|
| 2   | $0 \leq d_{ST} \leq 1/2$   | $0.5M(1-2d_{ST})^{-1}$ | 1:1.3, 2:1.4, 1:2.5, 3:1.5 |
| 3   | $0 \leq d_{ST} \leq 1/3$   | $0.5M(1-2d_{ST})^{-1}$ | 1:1.2, 3:1.3, 2:2.4, 3:3.5 |
| 4   | $0 \leq d_{ST} \leq 1/4$   | $0.5M(1-2d_{ST})^{-1}$ | 2:1.2, 1:2.3, 5:1.3, 4:2.4 |
| 5   | $0 \leq d_{ST} \leq 1/5$   | $0.5M(1-2d_{ST})^{-1}$ | 3:1.2, 2:2.3, 1:3.4, 7:1.3 |
| 6   | $0 \leq d_{ST} \leq 1/6$   | $0.5M(1-2d_{ST})^{-1}$ | 4:1.2, 3:2.3, 2:3.4, 1:4.5 |
in addition to a reduction in gain (Table 2. and Table 3).

Voltage gain and turns ratio for different and Voltage gain of different impedance networks winding factor.

### 4. Control Techniques

Pulse Width Modulation (PWM) inversion is an effective technique for increasing power and reducing harmonics of ac waveforms. PWM control is a common control strategy used in many applications which is the heart of inverter control technique. PWM methods uses high switching frequency carrier waves in comparison to the reference waves to generate a sinusoidal output wave, much like in the two-level PWM case. To reduce harmonic distortions in the output signal phase-shifting techniques are used. Under PWM method, the most popular control technique is the Sinusoidal Pulse Width Modulation (SPWM). Since it has some disadvantages like production of less peak voltage, power transfer etc, it can be rectified with the help of advanced modulation control technique like sine PWM, 60 degree PWM, trapezoidal PWM, stepped wave modulation, switching frequency optimal PWM etc. Double peak PWM is the proposed control method for the Y-source three phase PWM controlled inverter but can be used with other topologies as well.

The double peak PWM technique is proposed to improve the inverter performance. The Double peak PWM is implemented in the same manner as the SPWM, that is, therefore waveforms are compared with a triangular waveform. As a result, the amplitude of the reference waveforms do not exceed the dc supply voltage Vdc/2, but the fundamental component is higher than the supply voltage Vdc. This is approximately 15.5% higher in amplitude than the normal sinusoidal PWM. Consequently it provides a better utilization of dc voltage. Consider a waveform consisting of a fundamental component with the addition of a triple-frequency term $y=\sin\theta+Asin3\theta$,

Where $\theta = \omega t$ and A is a parameter to be optimized while keeping the maximum amplitude of $y(t)$ under unity The maximum and minimum of the wave form the reforeoccur at $\cos \theta = (9A-1)/12A$ and $\cos \theta = (1+3A)/12A$.

Thus, the double peak sine wave can be obtained from

$$V_{an} = 2/3 (\sin wt + 1/6 \sin 3wt) \quad (14)$$
$$V_{bn} = 2/3 (\sin(wt - 2\pi/3) + 1/6 \sin 3wt) \quad (15)$$
$$V_{cn} = 2/3 (\sin (wt + 2\pi/3) + 1/6 \sin 3wt) \quad (16)$$

With the help of above equations, Double peak PWM waveform has been simulated which is shown in the Figure 4.

### 5. Results and Discussions

A three phase PWM controlled Y-source inverter is simulated in MATLAB/Simulink platform. The proposed Y-source inverter is simulated with a DC input voltage of 60V while keeping the winding factor, $k = 4$ with winding ratios $N1:N2:N3 = 1:2:3$ at a higher modulation index 0.9 while maintaining the shoot through duty ratio at 0.185 as
6. Conclusion

The proposed Y-source inverter can produce a very high voltage gain while operating at a higher modulation index. Voltage gain of different impedance networks in literature has been compared. The flexibility and performance of the proposed inverter are presently unmatched, as it is proved by the mathematical analysis and simulation results. The proposed Y-source inverter operation is better than other impedance source networks and can produce better results for the grid applications and Plug in Hybrid Electric Vehicle [PHEV] applications.

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