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SIMULATION STUDY OF QZSI Z-SOURCE INVERTER FOR RESISTIVE AND INDUCTIVE LOAD

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ABSTRACT

This paper involves design and simulation of a step up dc/dc converter topology connected with the chopper circuit intended for resistive and inductive load. The topology contains voltage fed qzsi Z Source Inverter (qzsi), a high frequency isolation transformer with reduced turn's ratio, a Voltage Doubler Rectifier (VDR). A carrier based Pulse-Width Modulation (PWM) which employs shoot through state strategy for qzsi is implemented which gives significantly high voltage gain compared to traditional PWM techniques. To improve the power density of converter, three phase ac-link and three-phase VDR is implemented. The designed step up dc/dc converter is tested for various kinds of resistive and inductive load in MATLAB/SIMULIKN platform.

INDEX TERMS: DC to DC converter, qzsi, Shoot through state, Voltage Doubler-Rectifier, Isolation Transformer

INTRODUCTION

Literature Survey

Traditionally, power inverters can be broadly classified as either the voltage-source inverter (VSI) or current- source inverter (CSI) type, For a VSI, the inverter is fed from a dc voltage source usually with a relatively large capacitor connected in parallel. It is well known that the maximum ac voltage output of a VSI is limited to 1.15 times half the dc source voltage (using modulation strategies with triplen offsets added) before being over-modulated. The VSI can therefore only be used for buck (step-down) dc–ac power conversion or boost (step-up) ac–dc power rectification, assuming that no additional dc–dc converter is used to buck/boost the dc link voltage. On the other hand, a CSI is fed from a dc current source, which is usually implemented by connecting a dc source in series with a relatively large inductor and its ac voltage output is always greater than the dc source voltage that feeds the dc-side inductor. The CSI is therefore only suitable for boost dc–ac power conversion or buck ac–dc power rectification. For applications requiring both buck and boost power conversions, -source inverters have recently been proposed as a possible solution with many performance benefits summarized , where a unique impedance network is coupled between a power source and an inverter circuit. The power source and inverter circuit can be of either the voltage-source or current source type, and the impedance network is implemented using a split-inductor (and) and capacitors (and) connected in Z shape. This unique impedance network allows the Z-source inverter to buck and boost its output voltage, and also provides it with unique features that cannot be achieved with conventional VSIs and CSIs. Given its many benefits, [1] presents a detailed analysis on the modulation of voltage-type Z-source inverters.

Z-Source inverters are new single-stage electronic power converters with both voltage-buck and boost capabilities that have been proposed for use in fuel cell energy conversion systems and motor drives with a front-end diode rectifier. As an extension to Z-source inverter investigation, [2] has presented transient modeling and analysis of a VS-type Z-source inverter to show its non-minimum-phase response caused by a dc-side and an ac-side phenomenon.

Fuel cell vehicles (FCVs) are being developed by auto manufacturers and have generated interest among industry, environmentalists, and consumers. A FCV promises the air quality benefits of a battery-powered electric vehicle, with the driving range and convenience of a conventional internal combustion engine vehicle. Because of its nature, a FC prefers to be operated under constant power to prolong its lifetime and it is also more efficient in this way. However, the traction power the vehicle demands is ever changing. To balance the difference of these two and also to handle the regenerative energy, a battery is often used as an energy storage device in FCVs, which forms a FC-Battery Hybrid Electric Vehicle (FCHEV). A Z-source inverter control strategy used to control power from the fuel cell, power to the motor, and State of Charge (SOC) of the battery for fuel cell (FC)—battery hybrid electric vehicles (FCHEV) in [3]. Traditional pulse width modulation inverter always requires an extra dc/dc converter to interface the battery in FCHEVs. The Z-source inverter utilizes an exclusive Z-source network to link the main inverter circuit to the FC (or any dc power source). By substituting one of the capacitors in the Z-source with a battery and controlling the shoot through duty ratio and modulation index independently, one is able to control the FC power, output power, and SOC of the battery at the same time. These facts make the Z-source inverter highly desirable for use in FCHEVs, as the cost and complexity is greatly reduced when compared to traditional inverters.

The connection of two traditional Voltage-Source Inverters (VSIs) to form a three-level inverter has been reported for use in either open-end-winding or dual-voltage induction motor drives. Compared with the popular Neutral-Point-Clamped (NPC) inverter a dual inverter does not suffer from neutral-point voltage unbalance, does not require any clamping diodes, and has more redundant states that can be used for equalizing the switching losses among the numerous controlled switches. It therefore offers an attractive topological alternative for implementing a three-level inverter, and a number of Pulse Width Modulation (PWM) algorithms have been reported since then. As for other three-level inverters (or VSIs in general), the dual inverter is expected to suffer from some performance limitations. First, it generates a significantly large common-mode voltage when controlled using traditional carrier disposition or Space Vector Modulation (SVM) schemes. This generated common-mode voltage is known to cause premature motor bearing failure in variable-speed ac drives, and its induced leakage current to ground can cause electromagnetic interference and false tripping of ground current protection relays. The design of a dual Z-source inverter that can be used with either a single dc source or two isolated dc sources is presented in [4].

The traditional Z-source inverter topology shows the following drawbacks: 1) the voltage across Z-source capacitors is no less than input voltage, thus high-voltage capacitors should be used, which may result in larger volume and prove to be cost expensive to the system; 2) it cannot suppress the inrush current and the resonance introduced by Z-source capacitors and inductors at startup, thus causing the voltage and current surge, which, in turn, may destroy the devices. To solve the a foresaid drawbacks in traditional Z-source inverter, a new Z-source inverter topology is presented with reduced Z-source capacitor voltage stress and inherent inrush current limitation at startup. It can suppress the resonance well by adopting a proper soft-start strategy. A soft-start strategy is proposed in [5] to suppress the inrush surge and the resonance of Z-source capacitors and inductors.

High-performance voltage- and current-source inverters (VSI and CSI) are widely required in various industrial applications. However, the traditional VSI and CSI have been seriously restricted due to their narrow obtainable output voltage range, shoot-through problems caused by misgating and some other theoretical difficulties due to their bridge-type structures. In 2002, the topology of the Z-source inverter was proposed to overcome the problems in the traditional inverters in which the functions of the traditional dc–dc boost converter and the bridge-type inverter have been successfully combined. As a research hotspot in power electronics, the Z-source topology has been greatly explored from various aspects, but the related research on its improvement techniques of boost inversion ability and impedance

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network are seldom reported in open literatures. On the basis of the classical Z-source inverter, [6] presents a developed impedance-type power inverter that is termed the switched inductor (SL) Z-source inverter. To enlarge voltage adjustability, the proposed inverter employs a unique SL impedance network to couple the main circuit and the power source. Compared with the classical Z-source inverter, the proposed inverter increases the voltage boost inversion ability significantly. Only a very short shoot-through zero state is required to obtain high voltage conversion ratios, which is beneficial for improving the output power quality of the main circuit. In addition, the voltage buck inversion ability is also provided in the proposed inverter for those applications that need low ac voltages.
Traditional voltage-source inverters (VSIs) and current-source inverters (CSIs) have similar limitations and problems. For VSIs: 1) the obtainable ac output voltage cannot exceed the dc source voltage. So a dc–dc boost converter is needed in the applications, for instance, with limited available dc voltage or with the demand of higher output voltage. 2) Dead time is required to prevent the shoot-through of the upper and lower switching devices of each phase leg. However, it induces waveform distortion. For CSIs: 1) their output voltage cannot be lower than the dc input voltage; and. 2) overlap time between phase legs is required to avoid the open circuit of all the upper switching devices or all the lower devices. The Z-source inverter (ZSI), as well as the derived quasi-Z-source inverters (qzsi), can overcome the aforementioned problems.. The voltage-fed Z-source inverter can have theoretically infinite voltage boost gain. A class of trans-Z-source inverters has been presented in [7] for voltage-fed and current-fed dc–ac inversion systems. When the turns ratio of the two windings is over 1, the voltage-fed trans- Z-source inverter can obtain a higher boost gain with the same shoot-through duty ratio and modulation index, compared with the original Z-source inverter; the current-fed trans-Z-source inverter can extend the motoring operation range to more than that can be achieved in the original Z-source and quasi-Z-source inverters. In this paper the output of the designed dc/dc converter is observed for various kinds of resistive and inductive loads in MATLAB/SIMULINK platform.

Inverter
Traditionally, power inverters can be broadly classified as either the voltage-source inverter (VSI) or current-source inverter (CSI).

Half-Bridge VSI
Fig 1.1 shows the power topology of a half-bridge VSI, where two large capacitors are required to provide a neutral point N, such that each capacitor maintains a constant voltage (Vi)/2. Because the current harmonics injected by the operation of the inverter are low-order harmonics, a set of large capacitors (C+ and C-) is required. It is clear that both switches S+ and S- cannot be ON simultaneously because a short circuit across the dc link voltage source Vi would be produced. There are two defined (states 1 and 2) and one undefined (state 3) switch states. In order to avoid the short circuit across the dc bus and the undefined ac output voltage condition, the modulating technique should always ensure that at any instant either the top or the bottom switch of the inverter leg is on.

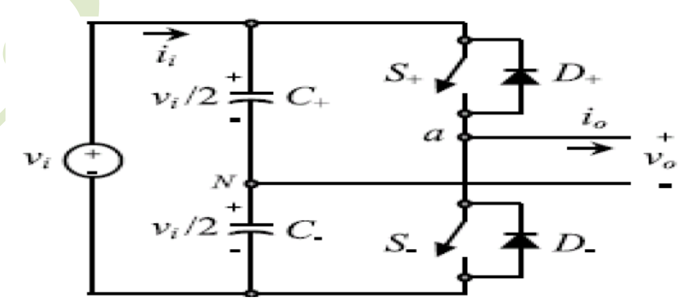

Fig 1.1 Half-Bridge VSI

Full-Bridge VSI

Fig. 1.2 shows the power topology of a full-bridge VSI. This inverter is similar to the half-bridge inverter; however, a second leg provides the neutral point to the load. As expected, both switches S1+ and S1- (or S2+ and S2-) cannot be on simultaneously because a short circuit across the dc link voltage source Vi would be produced. There are four defined (states 1, 2, 3, and 4) and one undefined (state 5) switch states. The undefined condition should be avoided so as to be always capable of defining the ac output voltage. It can be observed that the ac output voltage can take values up to the dc link value Vi, which is twice that obtained with half-bridge VSI topologies. Several modulating techniques have been developed that are applicable to full-bridge VSIs. Among them are the PWM (bipolar and unipolar) techniques.

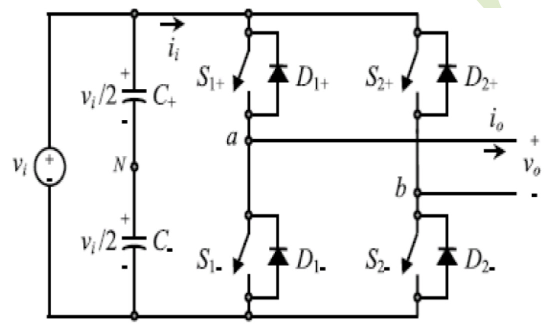

Fig1.2Full-Bridge VSI

Three Phase Voltage Source Inverters

Single-phase VSIs cover low-range power applications and three-phase VSIs cover the medium- to high-power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. Although most of the applications require sinusoidal voltage waveforms (e.g., ASDs, UPSs, FACTS, VAR compensators), arbitrary voltages are also required in some emerging applications (e.g., active filters, voltage compensators). The standard three-phase VSI topology is shown fig 1.3. As in single-phase VSIs, the switches of any leg of the inverter (S1 and S4, S3 and S6, or S5 and S2) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply. Similarly, in order to avoid undefined states in the VSI, and thus undefined ac output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity. Of the eight valid states, two of them produce zero ac line voltages. In this case, the ac line currents freewheel through either the upper or lower components. The remaining states produce non-zero ac output voltages. In order to generate a given voltage waveform, the inverter moves from one state to another. Thus the resulting ac output line voltages consist of discrete values of voltages that are Vi, 0, and -Vi for the topology. The selection of the states in order to generate the given waveform is done by the modulating technique that should ensure the use of only the valid states.

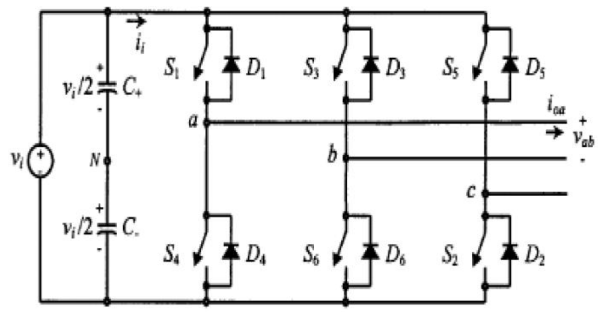

Fig: 1.3Three Phase Voltage Source Inverters

Applications of Inverters

Voltage source inverters (VSI) have been widely used in uninterruptible power supplies, unified power flow controllers or unified power quality conditioners, and distributed generation systems (DGS). VSIs are inherently efficient, compact, and economical devices used to control power flow and provide quality supply

qzsi z- source inverter

Shoot Through State in qzsi:

The voltage-fed qzsi with continuous input current implemented at the converter input side has a unique feature: The input voltage is boosted by utilizing extra switching state—the shoot-through state. The shoot-though state here is the simultaneous conduction of both switches of the same phase leg of the inverter. In the traditional voltage source inverter (VSI) this state of operation is forbidden because it causes the short circuit of the dc-link capacitors. The shoot-through state is used to boost the magnetic energy stored in the dc-side inductorL_1 and L_2 without short-circuiting the dc capacitors. This increase in inductive energy,in turn, provides the boost of voltage seen on the transformer primary winding during the traditional operating states (active state) of the inverter, thus the varying input voltage is first pre-regulated by adjusting the shoot-through duty cycle; afterward, the isolation transformer is being supplied with a voltage of constant amplitude value. Although the control principle of the qszi is more complicated than that of a traditional VSI, it provides a potentially cheaper, more powerful, reliable, and efficient approach to be used for varying-input-low-powered systems.

The voltage-fed qzsi with continuous input current was first presented & modified of a currently popular voltage-fed z-source inverter (zsi). The drawback associated with the conventional zsi is substantial—discontinuous input current during the boost mode that could have a negative influence on the input source. The qzsi shown in Fig. 2.1 features continuous current drawn from the input as well as lower operating voltage of the capacitorC_1, as Compared to the qzsi topology. The operating dc voltages of the capacitorsC_1 andC_2 could be estimated as

$$U_{C1} = \frac{1-D_S}{1-2D_S} U_{IN}$$

$$U_{C2} = \frac{D_S}{1-2D_S} U_{IN}$$

Where $D_S$is the duty cycle of the shoot-through state,

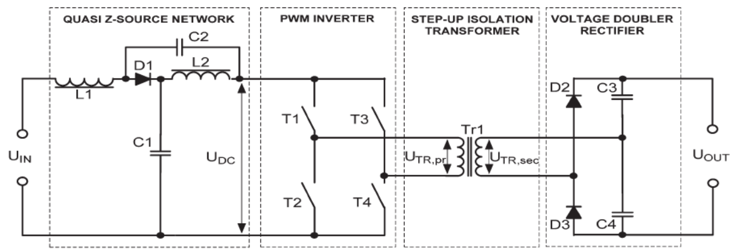

Fig.2.1Simplified power circuit diagram of the converter

$$D_S = \frac{T_S}{T}$$

Where theT_S duration of the shoot-through state and T is the operating period

When the input voltage is high enough, the shoot-through states are eliminated, and the qzsi starts to operate as a traditional VSI, thus performing only the buck function of the input voltage. Thus, the qzsi could realize both the voltage boost and the buck functions without any additional switches using a special control algorithm only.

2.2Voltage Boost Control Method of qzsi-based Single-Phase DC/DC Converter

Fig.2.2shows the control principle of the single-phase qzsi in the shoot-through (voltage boost) operating mode. Fig 2.2(a) shows the switching pattern of the traditional single-phase VSI. These switching states are known as active states when one and only one switch in each phase leg conducts. To generate the shoot-through states, two reference signals (UpandUn) were introduced [Fig. 2.2(b)].

If the triangle waveform is greater than Up or lower than Un, the inverter switches turn into the shoot-through state. During this operating mode, the current through the inverter switches reaches its maximum. Depending on the control algorithm, the shoot-through current could be distributed between one or both inverter legs. The dc-link voltage and the primary winding voltage waveforms of the isolation transformer during shoot-through are shown in Fig2.2(c), (d) respectively.

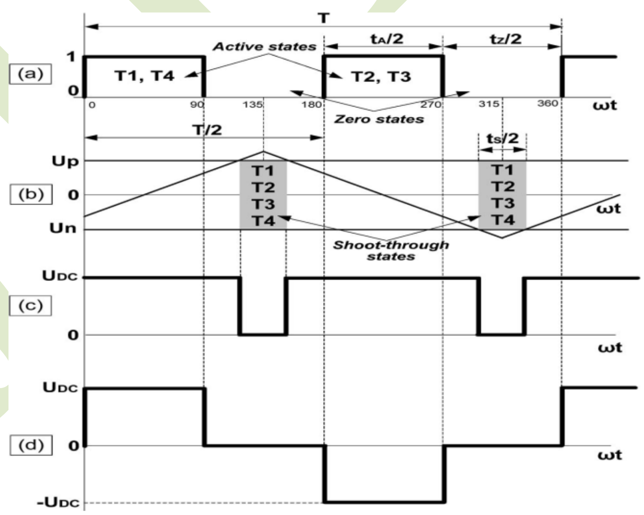

Fig2.2operating principle and resulting voltages of the single-phase Qzsi in the shoot-through (Voltage boost) mode

According to the presented control methodology, the shoot-through states are created during the zero states of the full-bridge inverter, where the primary winding of the isolation transformer is shorted through either the top (T1 andT3) or bottom (T2 andT4) inverter switches. To provide a sufficient regulation margin, the zero-state time $t_z$should always exceed the maximum duration of the shoot-through state ts , max   per one switching period

$$t_z > t_s \text{ max}$$

Thus, each operating period of the qzsi during the shoot-through always consists of an active statet_A, shoot-through statet_s, and zero state t_z

$$T = t_A + t_s + t_z$$

Equation could be represented as

$$\frac{t_Z}{T} + \frac{t_S}{T} + \frac{t_A}{T} = D_A + D_S + D_Z = 1$$

Where $D_A$is the duty cycle of an active state, $D_S$is the duty cycle of a shoot-through state, and $D_Z$is the duty cycle of a zero state. It should be noted that the duty cycle of the shoot-through state must never exceed 0.5. It should be noted here that, in the presented control scheme, the shoot-through time interval is evenly split into two intervals of half the duration. In that case, the operating frequency of the qszi network will be two times higher, and the resulting switching frequency of the power transistors will be up to three times higher than the fundamental harmonic frequency of the isolation transformer. That fact is very relevant for proper component and operating frequency selection. In the operating points, when the input voltage is high enough, the shoot-through states are eliminated, and the qzsi operates as a traditional VSI. Thus, the qzsi discussed could provide both the voltage boost and buck functions by the single-stage energy conversion.

2.3. Applications of Quasi z source inverter:

The proposed qzsi based dc/dc converter for dc motor drives with a high frequency step up transformer & a VDR could be positioned as a new alternative for the front end dc/dc converter for residential power system. The proposed converter could be extended to photovoltaic & regenerative Fuel cell application as well as to

1. Traction system,
2. Mobile equipment such as golf carts & mining application
3. For dc drives application
4. Telecommunication
5 Aerospace fields
6 Isolated distribution systems

PROPOSED DC/DC CONVERTER

Block diagram:

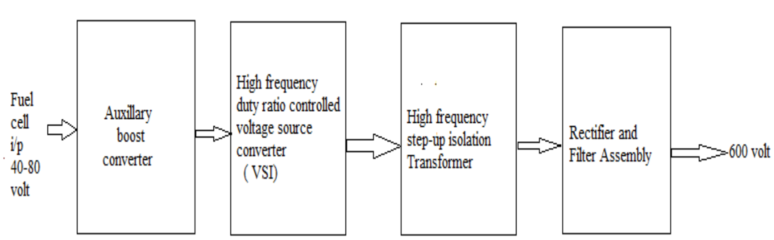

Fig : block diagram of model

The block diagram in fig 3.1 shows the conversation of low dc voltage to high dc voltage, the low dc voltage (40-80 volt) from fuel cell is applied to auxiliary boost converter which boost the low dc voltage and reduce the current. Due to the reduction in the current, the loss in the converter switches is reduced. The output of the auxiliary boost converter is applied to high frequency duty ratio voltage source inverter (VSI). The PWM fed VSI convert the dc voltage into ac voltage. The output of VSI is connected to high frequency step isolation transformer. The output of the isolation transformer is applied to rectifier and filter circuit. The rectifier circuit converter the ac voltage into dc voltage, which is further applied to voltage doubler circuit and the output is 600 volt. The function of each block is explained in detail below.

Auxiliary boost converter:

Auxiliary boost converter steps-up the varying FC voltage to a certain constant voltage level (80–100 Vdc). This voltage is then applied to the input terminals of High frequency duty ratio controlled voltage source inverter. A Boost converter is a switch mode DC to DC converter in which the output voltage is greater than the input voltage. It is also called as step up converter. The name step up converter comes from the fact that analogous to step up transformer the input voltage is stepped up to a level greater than the input voltage. By law of conservation of energy the input power has to be equal to output power.

High frequency duty ratio controlled voltage source inverter:

An inverter is basically a device that converts electrical energy of DC form into that of AC. The DC-AC inverters usually operate on Pulse Width Modulation (PWM) technique. The PWM is a very advance and useful technique in which width of the Gate pulses are controlled by various mechanisms. PWM inverter is used to keep the output voltage of the inverter at the rated voltage (depending on the user's choice) irrespective of the output load. To nullify this effect of the changing loads, the PWM inverter correct the output voltage by changing the width of the pulses and the output AC output of the inverter depends on the switching frequency and pulse width which is adjusted according to the value of the load connected at the output so as to provide constant rated output. The inverters usually operate in a pulse width modulated (PWM) way and switch between different circuit topologies, which means that the inverter is a nonlinear, specifically piecewise smooth system.

High frequency step up isolation transformer:

An isolation transformer is a transformer, often with symmetrical windings, which is used to decouple two circuits. An isolation transformer allows an AC signal or power to be taken from one device and fed into another without electrically connecting the two circuits. Isolation transformers block transmission of DC signals from one circuit to the other, but allow AC signals to pass. They also block interference caused by ground loops.

Rectifier & filter circuit:

It rectifies the ac voltage into dc voltage which required for load. The ZRF comprises a coupled inductor based filter for minimizing the high-frequency switching ripple and an active power filter for mitigating the low-frequency ripple.

3.2Simulation diagram

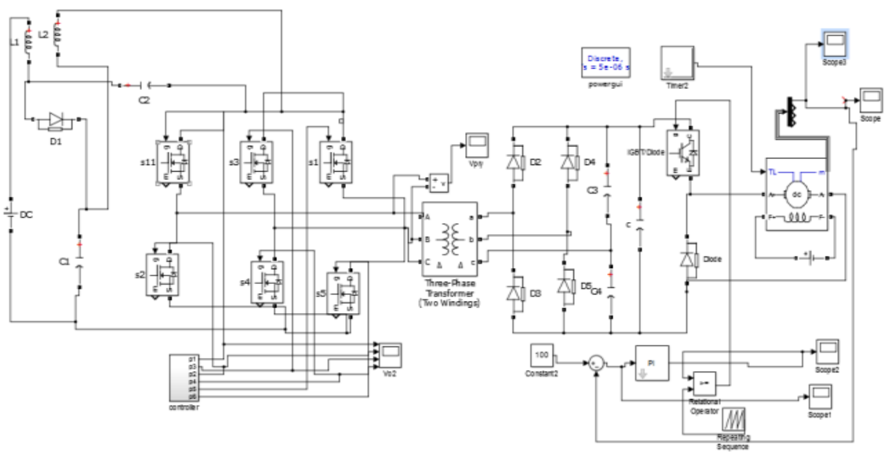

Fig: quasi z source isolated dc / dc converter closed loop system with dc motor load

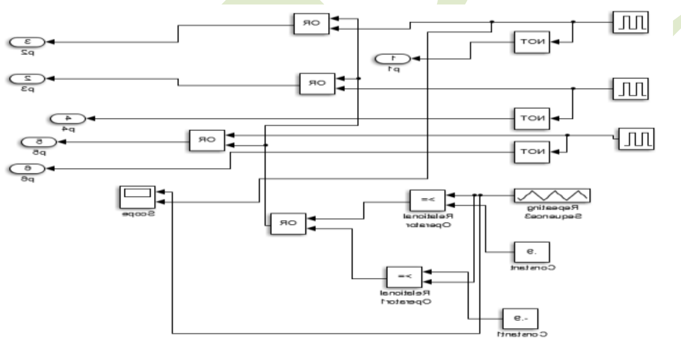

Fig 3.3 block diagram of gating signal generator

RESULT

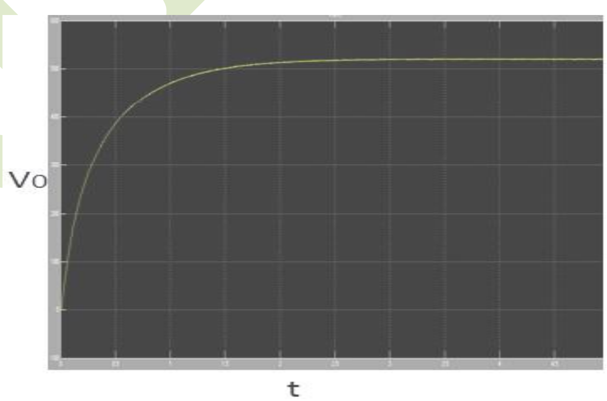

Fig. A) For input voltage = 40 volt

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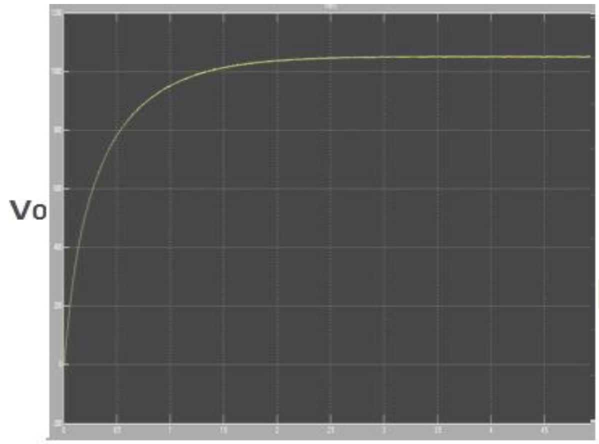

Fig. B) input voltage = 80 volt

Fig (A&B) waveform shows the output voltage of qzsi for various input voltages 40, 80 for resistive load

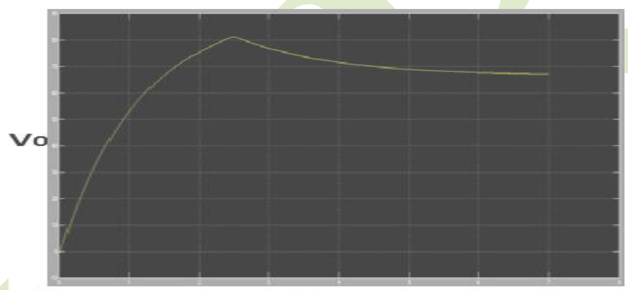

Fig. A) for input voltage =40 volt

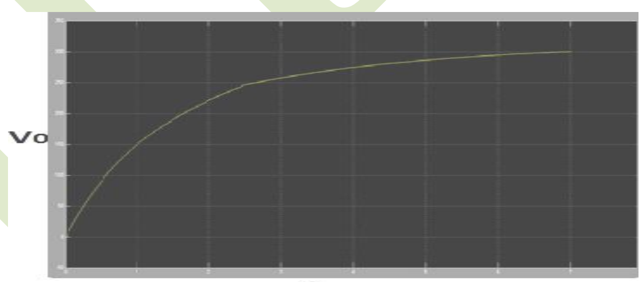

Fig. B) for input voltage =80 volt

Fig 4.2 (A&B) waveform shows the output voltage of qzsi with open loop system for various input voltages 40V, 80V for DC Motor load.

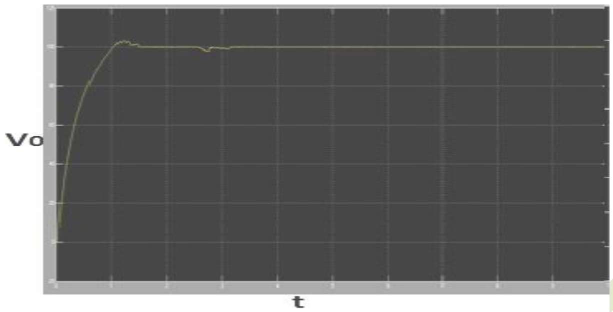

Fig. A) Input voltage = 40 volt

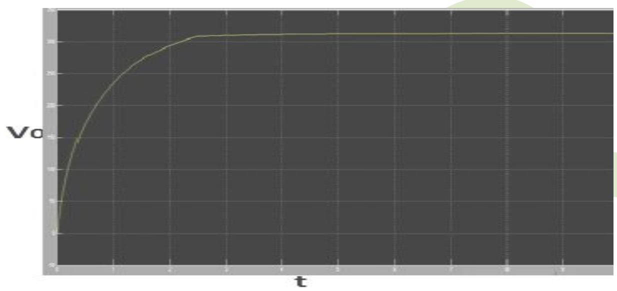

Fig. B) for input voltage = 80 volt

(A&B) waveform shows the output voltage of qzsi with closed loop system for various input voltages 40V, 80V for DC or load

When resistive load is connected to qzsi with open loop system, the output voltages for various input voltages are given in below table 1

Table 1

Sr.No	Input voltage (volt)	Output voltage (volt)
1	40	525
2	80	1050
3	160	2105
4	320	4210

When resistive load is connected to qzsi with open loop system, maximum voltage obtained is more as compared to inductive load connected to the system.
When DC motor (inductive load) is connected to qzsi with open loop system, the output voltages for various input voltages are given in below table 2:

Table 2

Sr.No	Input voltage (volt)	Output voltage (volt)
1	40	80
2	80	304
3	160	875
4	320	2250

From Table 2 it can be concluded that when inductive load is connected to system the maximum voltage obtained for same input is less as compared to resistive load. Due to inductive load large voltage drop occurs in qzsi.
When DC motor (inductive load) is connected to qzsi with close loop system, the output voltages for various input voltages are given in below table 3.

Table 3

Sr.No	Input voltage (volt)	Output voltage (volt)
1	40	100
2	80	313
3	160	895
4	320	2255

From Table 3 it can be concluded that when DC motor (inductive load) is connected to qzsi with closed loop system, constant maximum dc voltage is easily obtained as compare to open loop system.

CONCLUSION

This paper has presented an isolated step-up dc/dc converter topology with qzsi for resistive & inductive load. It has been analyzed, designed, simulated using MATLAB software .The topology is intended for applications with widely varying input voltage and to get stabilized output voltage and where the galvanic separation of input and output sides is required. The high-frequency transformer stack is responsible for providing the input/output galvanic isolation demanded in many applications. Moreover, to improve the power density and reliability, the updated converter topology with the three-phase auxiliary a clink and the three-phase VDR are proposed and verified. With the simulation, the following are the key features in comparison to traditional topologies.
1) The qzsi implemented on the primary side of the converter could provide both the voltage boost and buck functions with no additional switches, only by use of a special control algorithm.

2) The qzsi has excellent immunity against the cross conduction of the bottom-side inverter switches. Moreover, the qzsi implemented can boost the input voltage by introducing a shoot-through operation mode, which is forbidden in traditional VSIs.
3) The qzsi implemented has continuous input current (input current never drops to zero) during the shoot-through (voltage boost) mode.
4) The high-frequency step-up isolation transformer provides the required voltage gain as well as input–output galvanic isolation demanded in several applications.
5) The VDR implemented on the converter secondary side has the improved rectification efficiency due to the reduced voltage drop (twice reduced number of rectifying diodes and full elimination of the smoothing inductor).
6) For open loop feeding resistive load the output remains at set value
7) For open loop feeding inductive load voltage decreases
8) For closed loop system output voltage remains constant irrespective of load

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