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Design and Analysis of Closed Loop PI Regulator for a Z-Source Inverter-Fuel Cell Applications

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ABSTRACT
This research work presents a novel control structure of Z-source inverter (ZSI) for fuel cell (FC) Applications with the help of closed loop PI regulator. The Z-source concept is applicable to AC-DC-AC-AC conversions. So, the ZSI have more advantages compared to traditional voltage source and current source topologies. Here the Z-source topology employed for DC-AC conversion for fuel cell application. The fuel cell energy connected to Z-source inverter topology, the output of inverter connected to linear R-load. The entire proposed closed loop PI -ZSI system implemented and tested in MATLAB-SIMULINK software. And also provided comparison between conventional open loop ZSI systems with closed loop PI-ZSI system. By verifying these results, PI-ZSI system provides good response and improves system stability.

Keywords: ZSI, FC, DC-AC, closed loop, PI controller

I. INTRODUCTION

Conventional voltage source and current source inverters use pulse width modulation (PWM), which can occur under a variety of circumstances. Utilizing voltage source inverters in buck mode to produce output AC voltage below the DC bus voltage's maximum capacity. Instead, the load regulates the output AC voltage of current source inverters. The inability of any of them to provide an AC output voltage that is both smaller than and greater than the DC bus voltage is explained by this. When an impedance network is linked to the input DC bus, a Z-source inverter can operate in boost and buck modes to generate electricity. AC voltages that are lower or higher than the DC bus's maximum capacity. Since it may be used to alter the output AC voltage to increase it when the input DC supply is low and to reduce it when the input DC supply is high, this type of inverter can be especially useful in systems for converting renewable energy sources [1].

A number of applications, including solar photovoltaic systems, wind energy/fuel cell systems, electric cars, UPS systems, and others, have suggested the usage of Z source inverters (ZSI), single stage power converters with voltage buck boost capabilities. The Z (impedance) source network raises the DC voltage between the dc voltage source and the inverter. Researchers investigate the voltage enhancement capability of the Z source network using a signal flow graph approach [2].

It was suggested to use a ZSI. ZSI's are used for single-stage power conversion with buck and boost capabilities. Numerous Z-source topologies have been created in various research that concentrate on their pulse width modulation techniques. A group of inverters known as quasi-ZSI was developed to address some of the drawbacks of ZSI. These inverters have advantages such as improved input current profile and lower ratings for passive components. Later, in order to enhance the factor and get higher boost inversion capability, various authors created topologies by including additional inductors, capacitors, and diodes. In the impedance network of the traditional ZSI, a transformer is used in place of two inductors to increase the boost factor and voltage gain [3].

The ZSI unique impedance network, which also enables it to buck or improve its output voltage, gives it access to special functions that are not possible with conventional power inverters. For the standard 3phase VSI, numerous pulse-width modulation (PWM) control strategies have been created and are currently in use. When the load terminals are shorted through either the bottom three devices or the top three devices, the typical VSI has two zero vectors and six active vectors when the dc voltage is impressed across the load. These eight switching states altogether, as well as their combinations, have given rise to a large number of PWM control techniques. A short circuit (shoot through) could result from the standard VSI gating on both switches of any phase leg at once, which would destroy the inverter. Z source inverters, on the other side, have extra zero vectors or shoot-through switching states. By gating on both the upper and lower switches of a phase leg, the new Z-source inverter (ZSI) efficiently uses the shoot through condition to boost the dc bus voltage and provide a desired output voltage that is higher than the available dc bus voltage. The circuit can no longer be fully destroyed by the shoot-through brought on by misgating, thus enhancing the inverter's reliability. For buck and boost power conversion, it thus offers a low-cost, dependable, and high-efficiency single stage structure [4].

Multilevel inverters are becoming more and more common for high-voltage and high-power applications because of their inherent capacity to transfer the entire dc voltage through cascaded power semiconductors. By increasing the quantity of inverter dc levels, it is possible to generate high-voltage, low-distortion ac waveforms and reduce the blocking voltage requirement of individual switching devices. Integration solutions between the Z-source network and various multilevel inverters have been developed to combine the advantages of both Z-source and multilevel inverters. Additionally, configurations for the three-level Z-source neural point-clamped inverter with one LC impedance network and the five-level Z-source diode clamped inverter with two Z-source networks are suggested. These topologies can reduce system costs since they have fewer unique dc sources and impedance networks [5].

However, the majority of the circuit designs that academics have suggested are not isolated and do not separate the electrical properties of the input and output. Because of this, Professor Peng Fangzheng's high-frequency isolated Z-source/quasi-.ZSI (also known as HI-q-ZSI) circuit design significantly enhanced the series of Z-source/quasi-Z-source counter variation topologies. The input and output isolation circuits of the HI-q-circuit ZSI have uniform coupling at the front and rear levels of the control scheme. It is based on a quasi-ZSI. By utilising a high-frequency coupling inductor, this is accomplished. As a result, the circuit has electrical isolation properties, which opens up a wider range of application possibilities. The new high-frequency isolation quasi-ZSI (abbreviated NHI-q-ZSI for short) described in this study may significantly increase the boosting capacity of the inverter on the basis of this to further enhance the performance of the inverter [6].

Adding more cascaded networks can further increase the boost capability. ZSI topologies for extended-boost are referred to as capacitor- or diode-assisted converters for high boost ratios. A brand-new family of switching impedance, high-boost ZSIs is demonstrated. A switched impedance network design (EB-ZSI), as shown in Fig. 3, was specifically created. Since the shoot-through length is shorter and the modulation index is higher, this architecture can achieve an even higher boost ratio. The inverter volume does, however, also rise as a result of the extra inductors and/or capacitors [7].

There are many different structures for ZSI with voltage sources. Inductor cells in the ZSI are switched. Several other works have introduced switched ZSI, which use a power switch in the Z-source network. Despite the presence of ZSI using voltage sources, few layouts for current-fed ZSI have been developed. A few references have discussed PWM control approaches for CZSI and their frequency response. In this study, two new CSZSI structures for current-fed ZSI's are proposed. The recommended inverters can provide full CZSI characteristics and address CSI concerns. The suggested topologies' operations are displayed below [8].

To overcome the drawbacks which are mentioned above this paper introduced Design and analysis of closed loop PI regulator for a Z-source inverter-Fuel cell. Hydrogen technology is one of the renewable sources that is dominating the market despite its limited power output. Hydrogen is a fuel that fuel cells use to generate electricity. Fuel cells generate electricity in the external circuit that is connected to them through chemical reactions. The fuel cell is utilised in this study due to its advantages, which include its capacity to run at a relatively low temperature, high power density, and instantaneous output change to match changes in load needs. Because the fuel cells' output ranges from a few watts to a few kilowatts, large-scale applications are feasible. In order to look at dynamic modelling, research has been done concentrating more on the electrical terminal properties of the fuel cell. When compared to other distributed generating sources like solar and wind, fuel cell has no geographical limits. It may therefore be moved and installed wherever the best performance can be attained. Fuel cells are a good, dependable source of energy when used in steady state. Due to its sluggish internal mechanism, fuel cells are not found to be capable of responding to transients. In order to assure efficient functioning, numerous research on the fuel cell's steady-state and dynamic modelling have been carried out [9]. Section II provides an explanation of the system description, Section III provides an explanation of the suggested closed-loop PI regulator for a ZSI-fuel cell, Section IV explains the results and discussion, and Section V presents the conclusion.

II. SYSTEM DESCRIPTION

Figure 1 depicts the general layout of a ZSI. The two-port network that connects the inverter to the DC source is made up of split-inductors L1 and L2, capacitors C1 and C2, and connections made in the shape of an X. Z-source inverters employ an impedance source that is distinct from that used by ordinary inverters and has a variety of advantageous characteristics. A three-phase voltage-source inverter has eight permitted switching states, as shown in Fig. 1. Two of these states—referred to as the zero system—occur when the load terminals are shorted through either the lower or top three devices. When the DC voltage is impressed over the load, there are a total of six active states.

The operational states coupled with shorted load terminals are not possible for the conventional three-phase voltage-source inverter depicted in Figure 1 because doing so would result in a shoot-through, an overheated switch, and a shoot-through. The shoot-through zero state, also known as the zero state provided by the three-phase voltage-fed Z-source inverter, is enabled by the inverter's unique structural design.

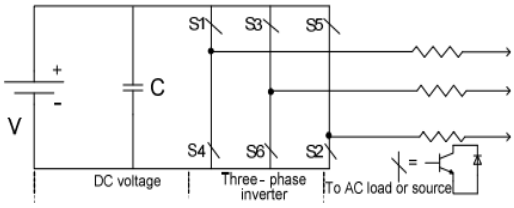


Figure 1. The topology of voltage-source inverter

The ZSI in Fig. 1 is guaranteed to be in the shoot-through zero condition, and because the dead time does not need to be included in the control signal, the inverter's control method can be significantly simplified.

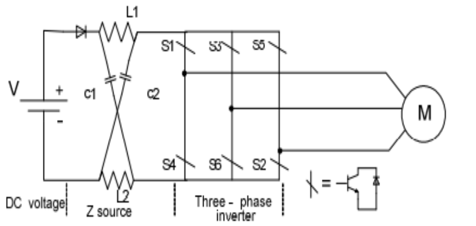
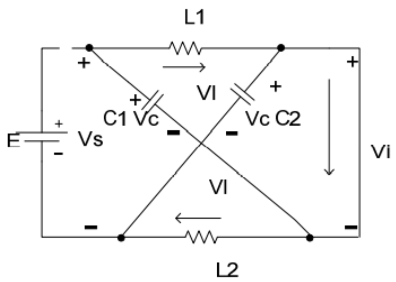


Figure 2. The voltage-fed ZSI's topology

Figure 1 depicts a similar ZSI circuit when the inverter bridge is seen from the dc link to be in the shoot-through switching condition. The non-shoot-through zero state of the inverter bridge, as shown in Fig. 2, enables us to construct a uniform equivalent circuit of the ZSI.



When the inverter bridge is in the shoot-through zero state, Figure 3 depicts the equivalent circuit of the Z-source inverter as seen from the DC link.

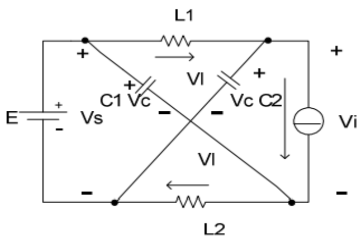


Figure 4 shows the ZSI's equivalent circuit when it is operating in the non-shoot-through state.

In the Z-source topology, the inductors L1 and L2 and the capacitors C1 and C2 have the same inductance and capacitance. As a result, we've arrived.

$Vc1=Vc2=Vc, VL1=VL2= VL$ (1)

If T0 is the shoot-through zero-state interval and T is chosen as the inverter's operational cycle, then in Fig. 1 at the time of T0, there had

$VL=VC, Vs=VL+VC =2VC$ (2)

T1 stands for the non-shoot-through zero state interval. When the time period is represented by T1 in Fig. 2, there have

$VL=E-VC, \quad Vs=E, \quad Vi=VC-VL=2Vc-E$ (3)

The average voltage of inductors must be zero during a switching cycle in order for them to be in a stable state.

$20TVLdt=0$ (4)

$0TVC dt+T0TE-VCdt=0$ (5)

We can get,

$VC=T1T1-T0E$ (6)

$VI'=2VC-E=BE$ (7)

$B=TT1-T0=11-2T0T1$ (8)

Where Vi' is the inverter bridge's highest possible input voltage. Figure 4 depicts the analogous circuit for a ZSI when it is in the non-shoot-through mode of operation.

$VX'=MVi'2=BME2$ (9)

Where M is the modulation index of the typical voltage source PWM inverter and B is the boost factor caused by the shoot-through switching condition. We can raise the output voltage by raising the boost factor B.

The ZSI in Fig. 4 uses the shoot-through zero-state period, or time T0, to boost output voltage. The inverter operates normally while in the shoot-through zero condition and charging inductors L1 and L2. The DC circuit's input has no effect on the AC circuit's output. The inductors L1 and L2 discharge when the inverter is in the non-shoot-through zero state. Voltage source E serves as the inductors' Voltage source E is the primary energy source for the inductors, which powers the inverter. As a result, the input voltage of the inverter bridge rises. When the ZSI is connected to a three-phase voltage-source inverter, the shoot-through zero condition is permitted, in which the load terminals are shorted across both the upper and lower devices of any one phase leg. Adjusting a PWM with shoot-through zero states raises the DC voltage even if it is insufficient to deliver the required output voltage directly. When the input DC voltage is sufficiently high, regular PWM is used.

III.PROPOSED TOPOLOGY

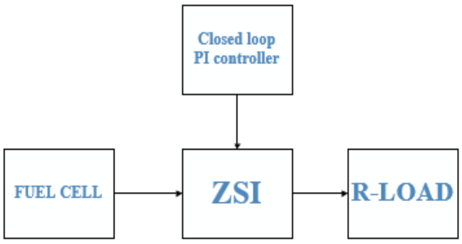


Fig. 5. Proposed block diagram

The above figure depicts the block diagram of proposed closed loop PI regulator for a fuel cell.

Here fuel cell taken as input, generates DC as output. This output connected to ZSI. It converts DC-AC, the output of ZSI connected to linear R-load. Here the ZSI is controlled by closed loop PI controller. In this PI controller operates on generated error signal from actual output voltage of ZSI and reference voltage to produce gate pulses for ZSI. The reference voltage in this project is 340V, this voltage is compared with actual output voltage of ZSI to produce error signal for PI controller.

PI-controller

In any open loop system more oscillations and steady state error. So, to overcome these drawbacks implemented different types of closed loop controllers. Here implemented closed loop PI controller for ZSI.

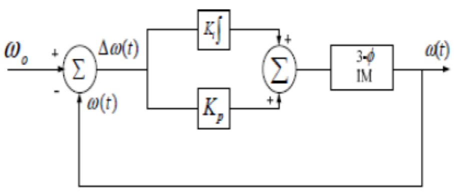


Fig 6. Internal structure of proposed controller

The output of PI controller:

$$U(t) = K_p . e(t) + K_i \int e(t)\, dt \quad (10)$$

In PI controller, the response time is quick and steady state error is less. There is no damping's in this controller. The accuracy of the PI controller is more compared to P and PD controllers. So, these controllers gain more popularity in process industries. The PI controllers are often used in industrial settings, especially when response time is unimportant. When: An alternative control is employed.

A) Quick system response is not necessary.
B) When the procedure is running, there are numerous disruptions and noise.
C) Only one energy storage is currently being used (capacitive or inductive).
D) The system has significant transportation delays.

IV. RESULTS & DISCUSSION

a) Open loop based controller:

In this project, the MATLAB/SIMULINK programme is used to compare the performance of an open loop controller and a closed loop controller with a ZSI. The performance of the suggested ZSI with a closed loop PI controller was evaluated using MATLAB/SIMULINK software. A closed loop pi controller was used to assess the performance of the suggested method, the ZSI. The results of the suggested method were compared to those of the existing method in terms of total harmonic distortion. In Z-source network, the zero state operates in three legs equally. In Z-source network, leads to leading to an equivalent switching frequency of 60 kHz. As a result, less DC inductance is required.

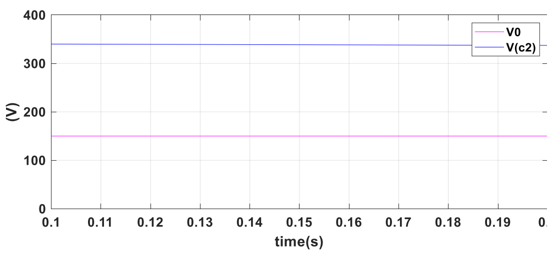


Fig 7. Vfc & Vc2

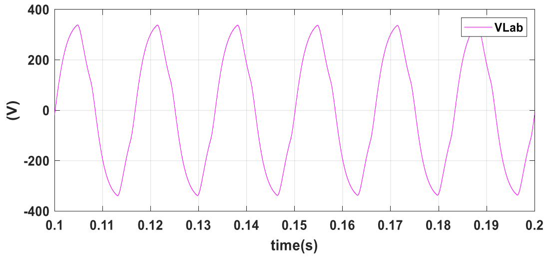


Fig 8. Va

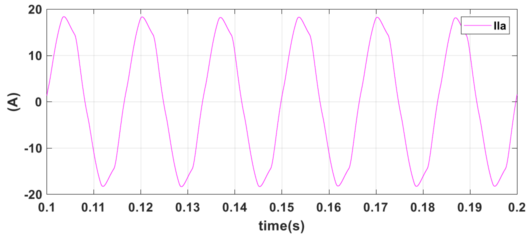


Fig 9. Ia

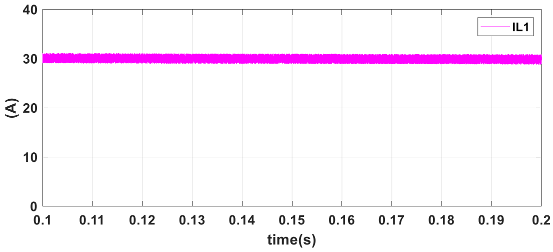


Fig 10. Il1

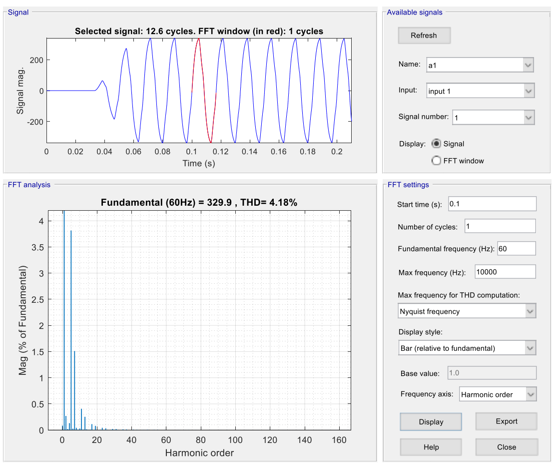


Fig 11. VA

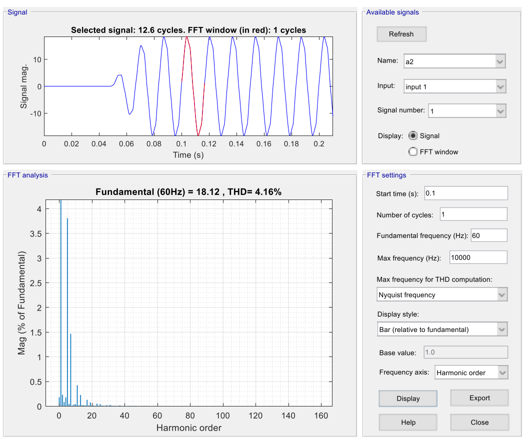
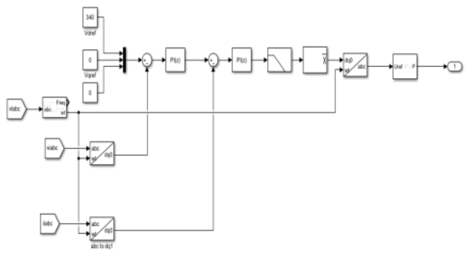


Fig 12. Ia

The fuel cell with z source converter based load configuration the system implemented in the Matlab/Simulink software. In the existing method to control the inverter open loop controller based pulse width modulation implemented. The obtained results are shown in fig-7-12 load voltage (Va), load current (Ia), fuel cell voltage (Vfc) and z-source converter voltage (Vc2) and z-source inductor current (Il1). The performance of the existing method evaluated in terms of THD in load voltage (Va).

Closed loop PI controller:



Closed loop based controller

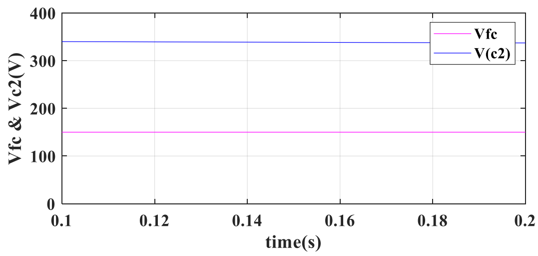


Fig 13. Vfc & Vc2

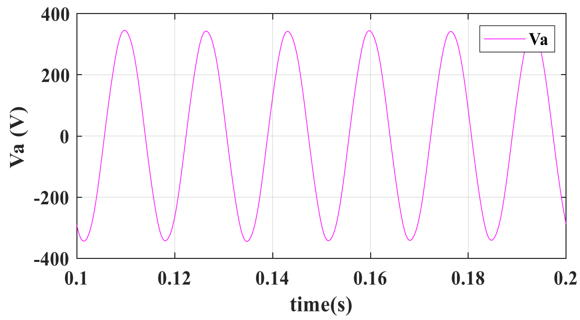


Fig 14. Va

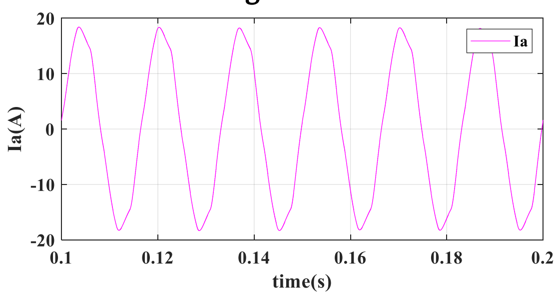


Fig 15. Ia

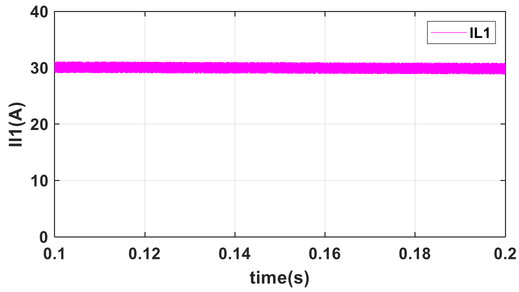


Fig 16. Il1

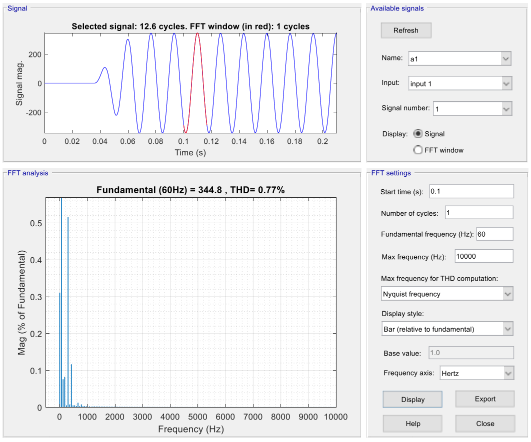


Fig 17. Va

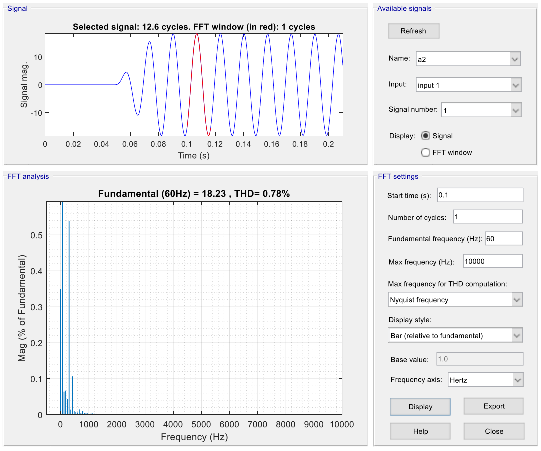


Fig 18. Ia

The fuel cell with z source converter based load configuration shown. The system implemented in the Matlab/Simulink software. In the proposed method to control the inverter closed loop-PI controller based pulse width modulation implemented. The obtained results are shown in fig-13-18load voltage (Va), load current (Ia), fuel cell voltage (Vfc) and z-source converter voltage (Vc2) and z-source inductor current (Il1). The performance of the proposed method evaluated in terms of THD in load voltage (Va).

The proposed method z source converter evaluated results by using a closed loop pi controller. The proposed method compared to the existing method evaluated the results in terms of total harmonic distortion.

V. CONCLUSION

A novel control structure of ZSI for FC Applications with the help of closed loop PI regulator is implemented in MATLAB-SIMULINK software. Here the Z-source topology designed for DC-AC conversion for fuel cell application. So, the closed loop PI-ZSI have more advantages compared to traditional voltage source and current source topologies is proved here. The fuel cell energy connected to ZSI topology, the output of inverter connected to linear R-load. And also provided simulation results comparison between conventional open loop ZSI systems with closed loop PI-ZSI system. By verifying these results, PI-ZSI system provides good response and improves system stability.

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