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A Cascaded Quasi Z-Source Scheme Step up DC-DC Converter Using ANN Based Control

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Abstract

Modern renewable generation systems need smart and integrated power converters ensure for high efficiency of power conversion .This project intends to the Artificial Neural Network (ANN) based control step up DC-DC converter family with a cascaded Quasi Z-source network (qZS-scheme).The cascaded (two-stage) qZS-network could be derived by the adding of one diode, one inductor, and two capacitors to the traditional single stage quasi-Z-source inverter (qZSI). The proposed cascaded qZSI giving as same all the advantages of the traditional solution (voltage boost and buck functions in a single stage, continuous input current ,and improved reliability).As compared to the conventional qZSI, the proposed solution reduces the shoot-through duty cycle at the same voltage boost factor ,and without adding additional switches. The ANN based controller ensuring the better result compare to the conventional PI controller .The two-stage qZSI in the shoot-through and non-shoot-through operating modes are described. The proposed and conventional closed loop results are compared.

Keywords : Quasi Z-Source Inverter, VDR, DC-DC conversion, Artificial Neural Network.

Introduction

The voltage-fed (DC-link) Quasi Z-source Inverter (qZSI) has been mainly suitable for different renewable wide varying source (DC-link) applications (Fuel Cells (FC), Solar panels, wind power generators, etc.) because of its unique capability of voltage boost and buck functions in a single stage.

This switching state is forbidden for the traditional voltage-source inverters (VSI) because it causes the short circuit of the DC-link capacitors. If the input voltage is high enough voltage, the shoot-through states to be eliminated, and the qZSI begins to operate as a normal VSI. To improve the performance of voltage-fed qZSI with continuous input current gained by the introducing cascaded quasi Z-source network (qZS-network).The cascaded (two-stage) qZS-network is derived by the adding of one diode (D_3), one inductor(L_3), and two capacitors (C_3), and (C_4) to the traditional single stage qZSI system. Quasi Z-source inverter (qZSI) is a new promising power conversion technology perfectly suitable for interfacing of renewable (i.e., photovoltaic, wind turbines) and alternative (i.e., fuel cells) energy sources.

- Boost-buck function by the one-stage conversion.
- Continuous input current (input current never drops to zero, thus featuring the reduced stress of the input voltage source, which is especially topical in such demanding applications as power conditioners for fuel cells and solar panels).
- Excellent reliability due to the shoot-through withstanding capability.
- Low or no in-rush current during start up.
- Low common-mode noise.

The qZSI are used in a vital role in a DC-DC converter system for continuous and better output shown in Figure 1.

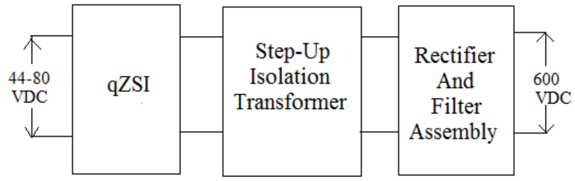

Fig 1: Single stage qZSI Step up DC-DC converter system

However, the efficiency and voltage gain of the qZSI are limited and comparable with the conventional system of a voltage source inverter with the auxiliary step-up DC/DC converter in the input stage. The concept of extending the qZSI gain without increasing the number of active switches. These new converter topologies are commonly referred to cascaded qZSI and could be generally classified as capacitor assisted and diode assisted topologies. In this paper cascaded qZSI with continuous input current will be presented with the ANN (Artificial Neural Network) based controlled step up DC-DC converter system.

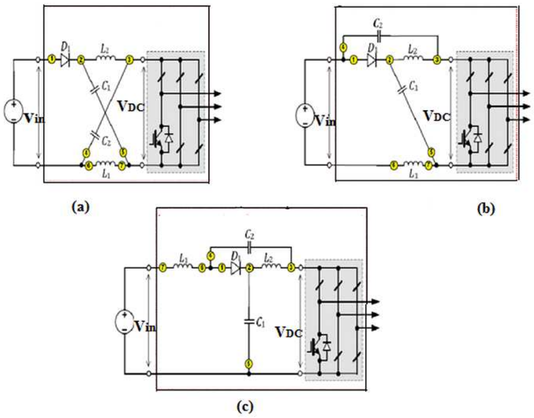

Fig 2: Derivation of qZ-inverter: basic Z-source inverter ((a) and qZ-source inverter (b) (c).

The purpose of DC-DC converters is to supply a regulated DC output voltage to a variable-load resistance from a fluctuating DC input voltage. In many cases the DC input voltage is obtained by rectifying a line voltage that is changing in magnitude. The DC-DC converters are commonly used in applications requiring regulated DC supply, such as computers, medical instrumentation, communication devices, television receivers, and battery chargers.

The voltage-fed Z-source inverter (ZSI, Fig. 2(a) has been reported to be suitable for different renewable power applications (solar panels, wind power generators and more because of the unique capability of voltage boost and buck functions in a single stage. If necessary, the ZSI can boost the input voltage by introduce a special shoot-through switching state, which is the simultaneous conduction (cross conduction) of both switches of the same phase leg of the inverter.

This switching state is forbidden for the traditional voltage source converters (VSI) because it causes the short circuit of the DC-link capacitors. It the ZSI, the shoot-through states are used to boost the magnetic energy stored in the DC side inductors *L1* and *L2* without short-circuiting the DC capacitors *C1* and *C2*. This increase in inductive energy in turn provides the boost of voltage seen on the inverter output during the traditional operating states of the inverter. If the input voltage is high enough states of the inverter. If the input voltage is high enough the shoot-through states are eliminated and ZSI begins to operate as traditional VSI.

A drawback of the voltage-fed ZSI is a discontinuous input current during the shoot-through (boost conversion) mode. In additional the problem the voltage-fed quasi-Z-source inverter (qZSI) with a continuous input current to be introduced as a modification of a currently popular voltage-fed ZSI . This qZSI could be derived from ZSI simply by the transformation presented in Fig. 2. The voltage-fed qZSI features a main advantage of the normal ZSI – the single stage boost-buck conversion. Based on presented transformation one should notice the presence of input inductor *L1* in the qZSI. This inductor buffers source current. Moreover, voltage of the capacitor *C2* is lower than in case of basic ZSI system.

Operation Principles of Converter

The desired DC-link voltage level of proposed converter in Fig: 3 could be selected in accordance with the characteristics of the voltage source implemented .Based on the input voltage, the operating modes of the proposed DC-DC converter could be broadly categorized as non-shoot-through and shoot-through operating modes.

The input voltage is equal or higher than the desired DC-link voltage, the converter works in the non-shoot-through mode. In this mode, the qZSI operates as a normal VSI performing only the buck function of the input voltage. The operating period of the qZSI in the non-shoot-through operating mode consists of the combination of active and zero states and is explained in more detail in .If the input voltage drops below the predefined DC link voltage level, the converter starts to operate in the shoot-through mode.

During the shoot-through states the primary winding of the isolation transformer is shorted through both the upper and lower switches of any one phase leg (i.e., both devices are gated on) or all two phase legs of the inverter.

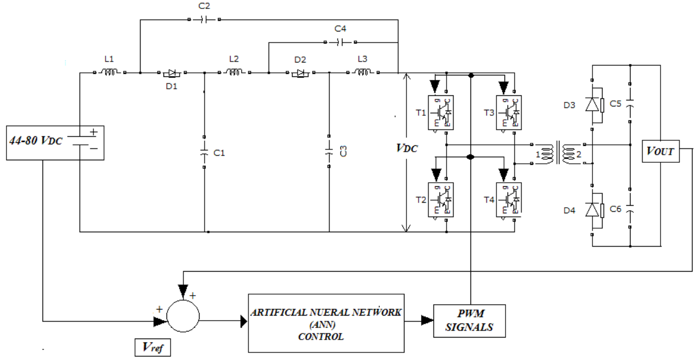

Fig: 3 Proposed cascaded qZSI step up DC-DC converter.

Modes of Operations

(a)Mode-I Non Shoot Through Mode

In the non-shoot through mode Fig:4, the qZSI performs only the voltage buck function. This operation mode is typically used during light-load conditions, when the DC-link voltage reaches its maximum.

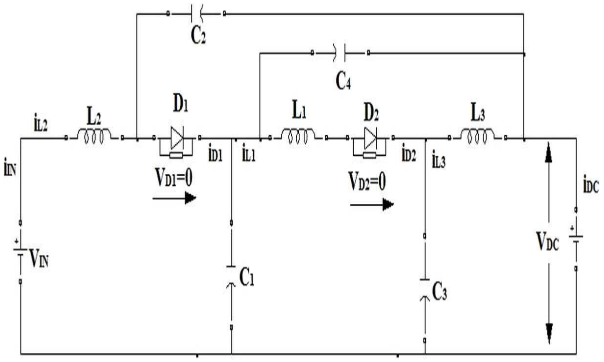

Fig: 4 Equivalent circuit for non shoot-through mode

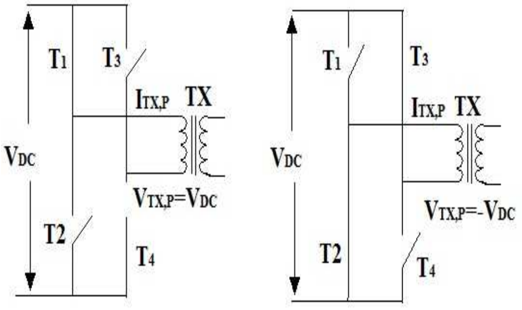

Fig: 5 (a) Inverter During positive half-cycle (b) Inverter during negative half-cycle.

The inverter is controlled in the same manner as with the normal VSI, utilizing only the active states when only one switch in each phase leg conducts.

(b)Mode -II Shoot Through State:

When the input voltage drops below some predefined value, the qZSI starts to operate in the shoot-through mode. In order to boost the input voltage during this mode, a special switching state the shoot-through state is implemented in the pulse width modulation (PWM) inverter control.

This shoot-through state is forbidden in the traditional VSIs because it would cause a short circuit of DC capacitors and destruction of power switches. The cascaded network makes the shoot-through states possible, effectively protecting the circuit from damage. Moreover, the shoot through states are used to boost the magnetic energy stored in the DC-side inductors L_1, L_2 and without short circuiting the dc capacitors C_1, . . ,. C_4.

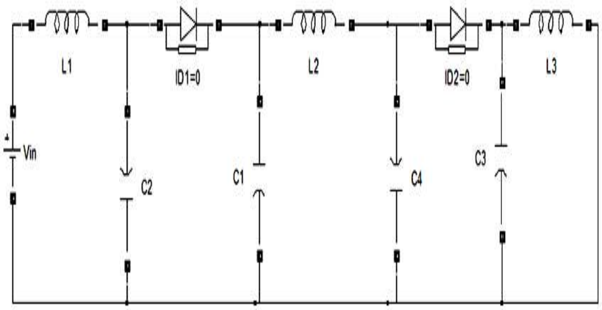

Fig: 6 Equivalent circuit for Shoot- through state.

This increase in the magnetic energy in turn provides the boost of the voltage seen on the Inverter output during the active states. The equivalent circuit of the two- stage qZSI during the shoot-through states is shown in Fig 6.

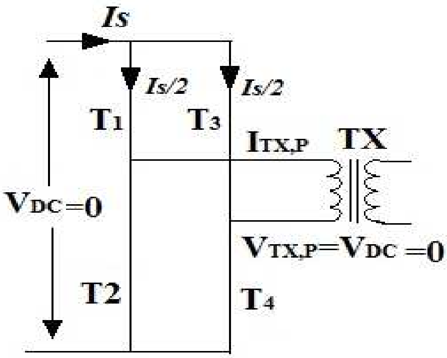

Fig: 7 Inverter During shoot shoot state

During the shoot-through states, the primary winding of the isolation transformer is shorted through all switches of both phase legs shown in Fig: 7.

PWM Control Method

The control principle of the single-phase qZSI in the shoot-through (voltage boost) operating mode are shown in Fig: 8 and The Fig: 8 (a) shows the switching pattern of the normal 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 (V_P and V_N) were introduced shown in Fig: 8(b).

According to the presented control methodology (Fig: 8), 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 (T_1 and T_3) or bottom (T_2 and T_4) inverter switches. To provide a sufficient regulation margin, the zero-state time t_Z should always exceed the maximum duration of the shoot-through states t_S , max per one switching period.

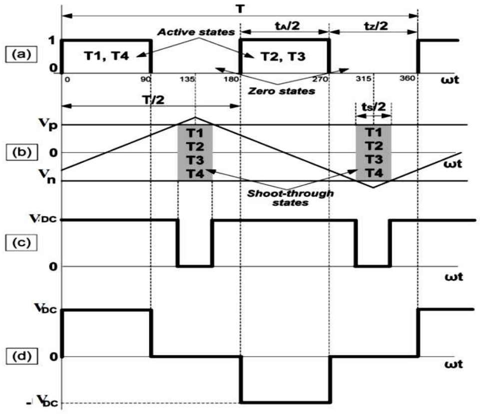

Fig :8 Basic PWM switching wave form for qZSI.

If the triangle waveform is greater than V_P or lower than V_N, the inverter switches turn into the shoot-through state shown in Fig: 8(b). 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 Fig:8 (c) and (d), respectively.

$$t_Z > t_S, \text{max}$$
(1)

Thus, each operating period of the qZSI during the shoot through always consists of an active state t_A , shoot-through state t_S, and zero state t_Z

$$T = t_A + t_S + t_Z$$
(2)

Equation (ii) could also be represented as,

$$\frac{t_A}{T} + \frac{t_S}{T} + \frac{t_Z}{T} = D_A + D_S + D_Z$$
(3)

$$\frac{t_A}{T} + \frac{t_S}{T} + \frac{t_Z}{T} = D_A + D_S + D_Z = 1$$
(4)

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 from the Fig: 9.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 qZS scheme 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 normal VSI. Thus, the qZSI discussed could provide both the voltage boost and buck functions by the single stage energy conversion.

The proposed cascaded qZS-network enables the duty cycle of the shoot-through state to be sufficiently decreased at the same voltage boost factor and component stresses as those of the traditional qZSI. Due to the decreased shoot through duty cycle, the values of the inductors and capacitors of the qZS-network could also be decreased. On the other hand, for the same component ratings and voltage and current stresses, the qZSI with the proposed cascaded qZS-network will ensure a higher voltage boost factor than with traditional solutions.

$$v_{L1} = V_{IN} - V_{C1}$$
(5)

(a)Boost Factor In Cascaded Model:

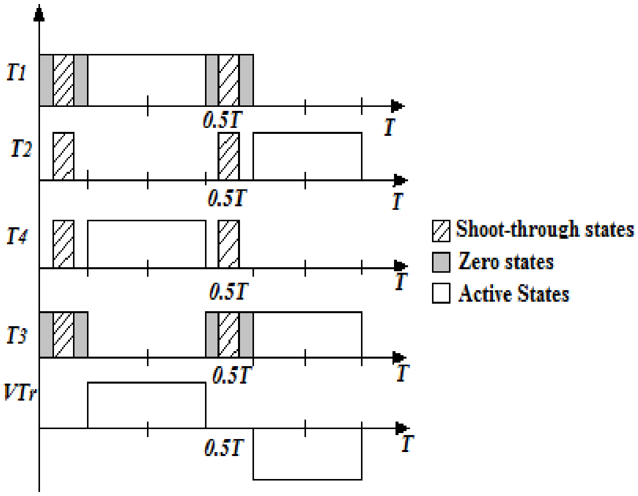

Fig: 9 PWM switching wave form for cascaded qZSI

$$v_{L2} = V_{C4} - V_{C2} = V_{C1} - V_{C3}$$
(6)

$$v_{L3} = V_{IN} - V_{C1}$$
(7)

From the equivalent circuit of the two-stage qZSI during the shoot-through state Fig: 6, the voltages of the inductors can be represented as,

$$v_{L1} = V_{IN} - V_{C2}$$
(8)

$$v_{L2} = V_{C4} + V_{C1}$$
(9)

$$v_{L3} = V_{IN} - V_{C2}$$
(10)

Let us consider that the duty cycles of the shoot-through and non-shoot-through states are D_S and (1 − D_S), correspondingly. At steady state, the average voltages of the inductors over one switching period are zero.

$$V_{L1} = \int_t^{t+T} v_{L1} dt = 0$$
(11)

$$V_{L2} = \int_t^{t+T} v_{L2} dt = 0$$
(12)

$$V_{L3} = \int_t^{t+T} v_{L3} dt = 0$$
(13)

From equation (5)-(13)

$$V_{L1} = D_s(V_{IN} + V_{C2}) + (1 - D_S)(V_{IN} - V_{C1)} = 0$$
(14)

$$V_{L2} = D_s(V_{C4} + V_{C1}) + (1 - D_S)(V_{C4} - V_{C2)} = 0$$
(15)

$$V_{L2} = D_s(V_{C4} + V_{C1}) + (1 - D_S)(V_{C1} - V_{C3)} = 0$$
(16)

$$V_{L3} = D_s(V_{C3}) + (1 - D_S)(V_{C4)} = 0$$
(17)

Solving (14)-(17) the voltages of capacitors *C*1, . . ,*C*4 could be found as

$$V_{C1} = V_{IN} \frac{1-2D_S}{1-3D_S}$$
(18)

$$V_{C2} = V_{IN} \frac{2D_S}{1-3D_S}$$
(19)

$$V_{C3} = V_{IN} \frac{1-D_S}{1-3D_S}$$
(20)

The peak dc-link voltage across the inverter bridge is,

$$V_{DC} = V_{C1} + V_{C2} = V_{C3} + V_{C4} = V_{IN} \frac{1}{1-3D_S}$$
(21)

The resulting boost factor B of the input voltage is,

$$B = \frac{V_{DC}}{V_{IN}} = \frac{1}{1-3D_S}$$
(22)

For the desired input voltage boost factor *B*, the duty cycle $D_S$of the shoot-through state is calculated as,

$$D_S = \frac{1-B^{-1}}{3}$$
(23)

Higher stage qZS-networks can be designed by just multiple repeating of the parts $D_2 - C_3 - L_3 - C_4$ .For the nth stage qZS-network, the boost factor B_n of the input voltage is calculated

$$B_n = \frac{1}{1-D_S*(1+n)}$$
(24)

From the equation (24) calculate n number added stages of qZS to be finding out in this system.

Isolation Transformer And Voltage Doubler Rectifier VDR

In this system transformer will "step-up" the voltage from the primary side ($V_{TX}P$) of the transformer to the secondary side ($V_{TX}S$) of the transformer. The second purpose of the transformer is to provide galvanic isolation between the primary and secondary. The galvanic isolation achieved by using the transformer is the greatest benefit of using a DC-DC converter schemes. The operation and working principle are detailed in this converter system.

A Voltage Doubler Rectifier (VDR) is an electronic circuit which charges capacitors from the input voltage and switches these charges in such a way that, in the ideal case, exactly twice the voltage is produced at the output as at its input as well as rectify the DC voltage to AC voltage.

The VDR improves the rectification efficiency due to minimized voltage drops in the components (twice reduced number of rectifying diodes and full elimination of a smoothing inductor). Moreover, the VDR provides the demanded voltage doubling effect of the peak voltage of the secondary winding of the isolation transformer, thus ensuring the ripple free output voltage of 600 V at the rated power.

To reduce the turns ratio of Isolation transformer VDR could be implemented on the secondary side of the converter. In contrast to the traditional full-bridge rectifier, two diodes of one leg in the VDR topology are replaced by the capacitors. Since each capacitor charges to the peak secondary voltage ($V_{TX}S$) the output voltage from this circuit will be the sum of the two capacitor voltages or twice the peak voltage of the secondary winding.

Artificial Nueral Network Control

Artificial Neural Networks (ANN) is one of the soft computing technique inspired by the structure and function of the human nervous system. There are many different types of ANN. Includes Hopfield, back propagation, linear vector quantization, artmap and many others.

ANN act similar to the biological nueron system. Artificial neurons receive input from other neurons through a weighting function. This is usually an amplification or suppression of the signal. All of such signals connected to the neuron are added together. If this sum is higher than some threshold the neuron will fire and send out its own signal to other neurons. The output of the neuron is often determined by a sigmoid function of its input rather than the threshold function. This gives the neuron a non-linear input to output relationship. It should be noted that the knowledge is stored in the input weights of the neuron. Adjusting these weights give the neurons the ability to store different information. One neuron can't store much information, but many neurons, interconnected in several layers can store much information.

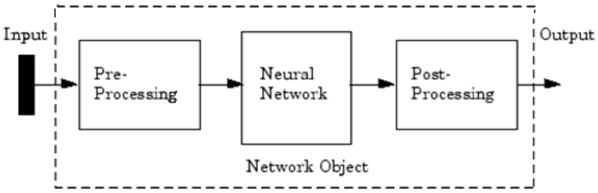

Fig 10: Block diagram of ANN controller

Artificial neural network (ANN)-based techniques have the potential advantage over conventional techniques in significantly improving the performance of the other techniques. This is so by virtue of the fact that ANNs have the capability of non-linear mapping, parallel processing and learning; these attributes make them ideally suited for power system control application. The block diagram of ANN-based algorithm for voltage and reactive power control in power systems is shown in Fig: 10. The method is based on using linear programming technique to generate different training patterns and obtain the input data to ANN.

(a)Implementation Of ANN Controller

The soft computing techniques (ANN, Fuzzy Logic, Genetic Algorithms) are widely used for the controllers action instead of conventional control (P, PI, PID) controllers for better, exact results from the Linear, Non-Linear systems.

In the conventional single stage model system of qZS step up DC-DC converter system PI controller for the closed loop voltage control from that system data has been collect for the ANN control system for train the neuron model.

(b)Transfer Functions

Transfer functions are the important constrain in the ANN controller design. Many transfer functions are included in the Neural Network. A complete list of them can be found in "Transfer Function Graphs" in the Neural Network. Two of the most commonly used functions are pure linear transfer function and sigmoid transfer function.

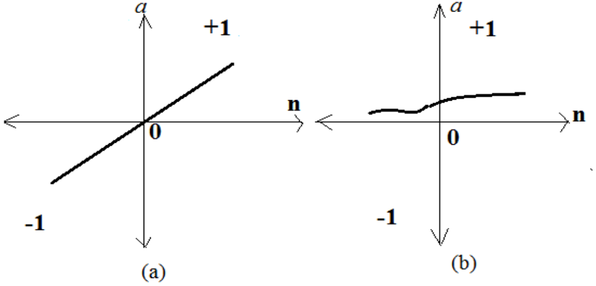

Fig: 11 Transfer functions (a) Linear Function (b) Sigmoid Function

The Fig: 11(a) Illustrates the pure linear transfer function Neurons of this type are used in the final layer of multilayer networks that are used as function approximation (*a*=Pure linear of n) .It is widely used transfer function (-1 to +1) hard limit variations.

Fig: 11(b) Illustrates the Sigmoid Function. The sigmoid transfer function takes the input, which can have any value between plus and minus infinity, and squashes the output into the range 0 to 1.

The transfer functions are leads to develop the neuron by taking boundary of hard limits of output in the system. It's obtained by means of classical control result analysis, or taking from the probability of result obtained from the system.

(c)*PI Controller Result*

From the resulting waveform (Figure: 5.4) of PI controller input, output variation in the closed loop voltage control to be calculated.

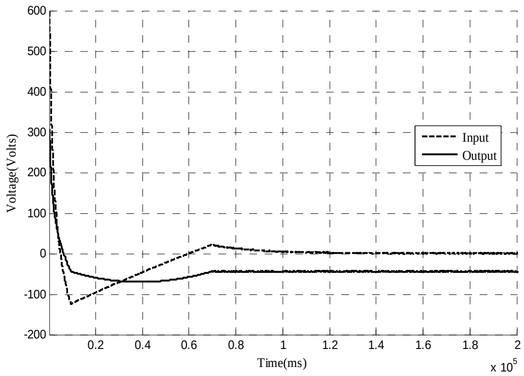

Fig: 12 PI controller Input , Output comparison

The input and output values are saturated at the point of (0,-44) and its saturation to be linear in the system. The most expected various values of voltages are to be taken for train the neural network and obtaining the result from the system.

There are three distinct functional operations that take place in this simple neuron model (single perceptron) shown in Fig: 13. First, the scalar input *p* is multiplied by the scalar weight *w* to form the product *wp*, again a scalar. Second, the weighted input *wp* is added to the scalar bias *b* to form the net input *n*. (In this case, you can view the bias as shifting the function *f* to the left by an amount *b*. The bias is much like a weight, except that it has a constant input of 1.) Finally, the net input is passed through the transfer function *f*, which produces the scalar output *a*. The names given to these three processes are: the weight function, the net input function and the transfer function.

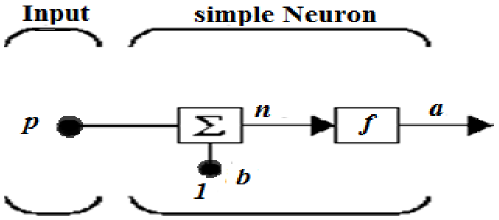

Fig: 13 simple neuron model

$$a = f(wp + b$$

(25)

From the equation (25) the expected results could be derived by varying weight(w) and bias(b) values of the neuron. The set of expected and actual values (voltages) from PI controllers are shown in the table (1).

Expected values (p)	[1100 1075 1050 1025 1000 975 950 925 900 875 850 825 800 775 750 725 700 675 650 625 600 575 550 525 500 475 450 425 400 375 350 325 300 275 250 225 200 175 150 125 100 75 50 25 0]
Actual values (q)	[1056 1031 1006 981 956 931 906 881 856 831 806 781 756 731 706 681 656 631 606 581 556 531 506 481 456 431 406 381 356 331 306 281 256 231 206 181 156 131 106 81 56 31 6 -19 -44]

Table 1 PI controller result comparison

To implement each of these values to the equation (25) with weight $(w = 1)$ and bias $(b = -44$) for the train the resulting voltages of the ANN controller. For example at value of $p = 700$ (expected value at the table) means the actual could be trained by,

$$q = pw + b$$

(26)

$$q = 700 \times (1) + (-44)$$

(27)

$$q = 656$$ (actual value in the table)

(d)Program coding for ANN Controller

```
p=[1100 1075 1050 1025 1000 975 950 925 900 875
850 825 800 775 750 725 700 675 650 625 600 575
550 525 500 475 450 425 400 375 350 325 300 275
250 225 200 175 150 125 100 75 50 25 0];
q=[  1056 1031 1006 981 956 931 906 881 856 831
806 781 756 731 706 681 656 631 606 581 556 531
506 481 456 431 406 381 356 331 306 281 256 231
206 181 156 131 106 81 56  31 6 -19 -44];
net=newlin(p,t)
net.iw{1}=1;
net.b{1}=-44;
net=train(net,p,t)
gensim(net)
```

Simulation Results

MATLAB is an efficient way for designer to learn how a circuit and its control are working. It is normally much cheaper to do a thorough analysis than to build the actual circuit in which component stresses are measured. A simulation can discover the possible problems and determine optimal parameters, increasing the possibility of getting the prototype. New circuit concepts and parameter variations are easily tested. Destructive tests that cannot be done in the lab, either because of safety or because of costs involved, can easily be simulated.

Matlab is the tool of choice for high-productivity research, development and analysis. Matlab features a family of add-on applicationspecific solutions called toolboxes. Toolboxes are comprehensive collections of Matlab functions that extend the Matlab environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation and many others. The Matlab version used here is 11.5.0.

(a)Simulation Parameters

The key parameters of the proposed converter are listed in the Table 2

Table: 2 Key Parameters of the Proposed Converter

Parameter	Symbol	Value
Input voltage	V_{IN}	(44-80)V
Output voltage	V_0	600V
Inductors in qZS scheme	L_1, L_2, L_3, L_4	33.5µH
Capacitors in qZS scheme	C_1, C_2, C_3, C_4	180µF
Output resistor	R_0	10Ω
Operating frequency of qZSI	F_n	10kHz
Isolation Transformer	TF	1:3.75; 5 kHz
Capacitor in VDR	C_5, C_6	1200 µF
Diodes of qZS-Schemes	C_3	200V/71A
Nominal frequency at Grid.	F_u	50HZ

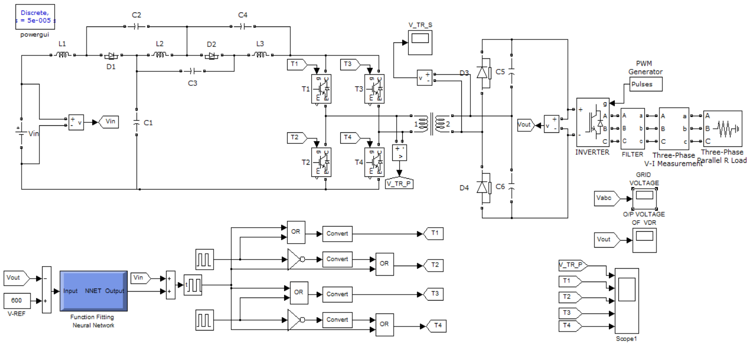

Fig: 14 Simulation circuit for proposed Cascaded qZS scheme step up DC-DC Converter

The proposed Cascaded qZS scheme step up DC-Dc converter modeled in Matlab-Simulink environment shown in Fig: 14 and its parameters to be modified for obtaining the continuous output (600V) DC voltage from the wide varying source voltage (44V-80V). The variation of the source (DC-link) voltage with the load, the output voltage of the step-up dc/dc converter could be kept constant simply by the variation of a shoot-through duty cycle For the control of the input voltage gain, a special shoot-through generation method by phase-shift modulation (PSM) to be implemented.

The closed loop voltage control made by ANN controller it designed from the classical PI controller (For training the values).The converter simulated by the various conditions and obtaining the following simulation results.

(b)Transformer Primary Voltage & Switching Pulse Signals

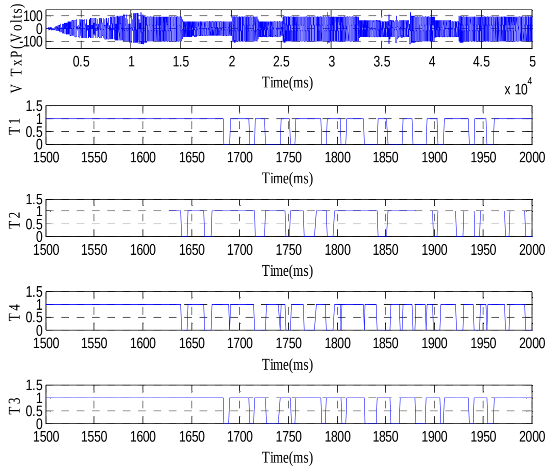

Fig: 15 Simulation wave form for $V_{TX}P$ & T_1, T_2, T_3, T_4 Pulse Signals

This waveforms are showing the primary voltage of the Isolation Transformer Primary$(V_{TX}P)$, and corresponding switching pulse signals for the qZSI. The reverse recovery time of the IGBTs and response (ON, OFF) are remarkable in this system.

When the all switches turned ON (cross conduction of the switches),the Transformer voltage is absent and also it does not allows DC voltage across the primary so the circuit will closed and gives galvanic protection between the source side (qZSI) and the output (VDR) it is the major advantage to using the Isolation.

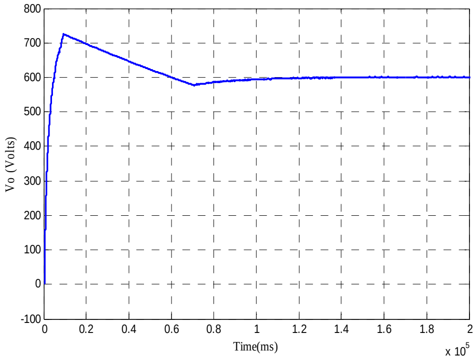

Fig: 16Simulation waveform for existing single stage qZSI

VDR output voltage using PI controller Simulation waveform for single stage qZSI VDR output voltage using PI controller Fig:16 .This indicating the voltage deviation at the staring time.

The simulation waveform of transformer secondary voltage ($V_{TX}S$) shown in the Fig: 17. It never drops to zero at any input (44V-80V) wide variations. Transformer secondary voltage directly fed to the input of VDR.

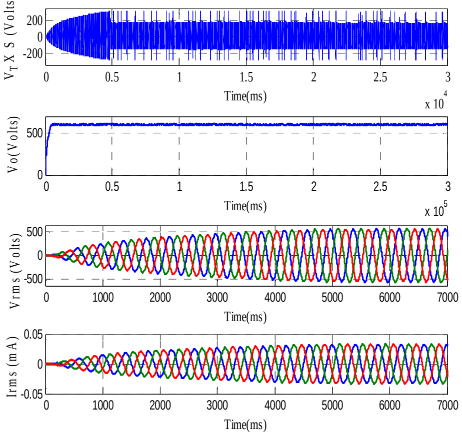

Fig: 17 $V_{TX}S$, V_o, V_{abc}, I_{abc} Waveforms.

The simulation wave form of output voltage $V_o$using ANN controller is shown in the Fig : 17 It achieves the maximum voltage at the instant of starting time itself.

Simulation waveform for V_{rms} of grid at 50W Nominal power Shown in the Fig: 17.The results indicating the useful power from the proposed system. Simulation waveform for I_{rms} of grid at 50W Nominal power Shown in the Fig: 17.The results indicating the useful power from the proposed system.

Conclusion

The cascaded qZSI offer a output voltage in a continuous and improved boost factor manner. This project has presented a implementation of a cascaded qZSI in order to the single stage model with same capacitor and inductor values and also same number of switches used in this system. Instead of PI controller ANN (Artificial Neural Network) has to be used for better closed loop performances avoids the time delay to reach the maximum output voltage. The proposed cascaded qZSI can be applied to almost all DC-DC, AC-DC, AC-AC, DC-DC power conversion schemes. The proposed configuration inherits all the advantages of traditional solutions (voltage boost and buck functions in a single stage, continuous input current, and improved reliability). Moreover, the voltage-fed qZSI with the cascaded qZS-network reduced the shoot-through duty cycle range at the same voltage boost factor and component stresses as the conventional qZSI. The proposed system ensures continuous input current of the converter during the shoot-through operating mode, thus featuring the reduced stress of the input voltage source, which is particularly used in such demanding applications as power conditioners for solar panels, fuel cell and wind power systems.

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