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Fuzzy Logic Based Z-Source Inverter for Hybrid Energy Resources

S.Sathya[1], C.karthikeyan2
PG/Applied Electronics[1], Associate Professor[2], K.S.R. College of Engineering, Tiruchengode

Abstract* - *This paper proposes a fuzzy logic based voltage controller for hybrid energy resources using Z-source inverter. Among renewable energy sources, the wind and photovoltaic energy is being widely utilized because of their abundance and sustainability to generate electricity. In wind and PV based power conditioning systems, the interface converter system acts as the major key components. The proposed system can boost and generate the desired output voltage efficiently when a low voltage is introduced. Z–source inverters have been recently proposed for alternative power conversion concept as they have both voltage buck and boost capabilities. These inverters use a unique impedance network coupled between the power source and inverter circuit, to provide both voltage buck and boost properties, which cannot be achieved with conventional voltage source and current source inverters. It has single stage power conversion, high performance, minimal component count, increased efficiency, improved power factor and reduced cost. The obtained AC voltage must be pure sinusoidal but it can't obtained because the harmonic content are highly present. Higher order harmonics are eliminated by with the help of filters. Here impedance network act as a filter to reduce the lower order harmonics. This paper describes the design of Fuzzy logic controller for Z-source inverter.

Index terms–**Wind power generation, Photovoltaic cell, Z-source inverter and Fuzzy logic controller.**

I. INTRODUCTION

The electricity requirements of the world including India are increasing at alarming rate and the power demand has been running ahead of supply. Renewable energy is the energy which comes from natural resources such as sunlight, wind, rain, tides and geothermal heat. A Hybrid Renewable Energy System uses several kinds of sources, including wind and solar, to make better use of the natural resources in standalone and microgrid applications. Generally, PV power and wind power are matching since sunny days are usually calm and strong winds often occur on cloudy days or in night time. A common application of HRES is in remote communities, where interconnected electrical grid is unreachable due to economics and physical reasons. Due to the long distance and difficult access to these isolated areas, electrical generation systems used in these applications must be reliable. And the reliability of the system, especially the inverter used to regulate the AC voltage is one of the main problems associated with these systems, and it is responsible for the lack of confidence in renewable systems. Also the desired output of the inverter must be pure sinusoidal but it cannot be obtained, which means harmonic content are present. For controlling and eliminating the harmonic values various techniques and controllers are used. Recently, fuzzy logic controllers are proposed in many applications. It is quite easy to handle due to quick maintenance and explores the potential and feasibility of fuzzy logic control schemes that are suitable for eliminating the harmonic contents and also for controlling the inverter voltage.

Fig.1 shows the schematic diagram of wind and PV energy resources. The main energy sources wind and solar radiation are transformed in a wind generator and PV modules. In order to combine these energy sources, a multiple input dc-dc converter is used because it is more effective for maximum power tracking (MPP) in PV and also used for the input current control method [1]. It is capable of converting power from multiple power sources to a common load. The MIC is often selected due to its reduced component count and cost of the system.

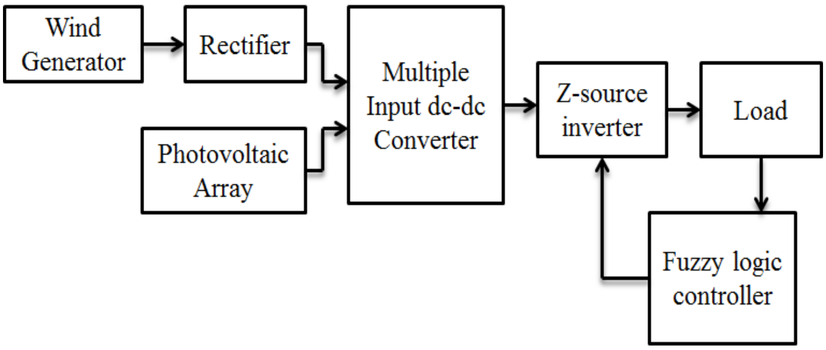

Fig. 1 Schematic diagram of wind-solar hybrid energy resources using Z-source inverter

In the late nineties, Fang Zhang Peng popularised the concept of the Z-source inverter [6].It employ a unique impedance network to couple the converter with the main circuit and then fed to the power source. The conceptual and theoretical barriers and limitations of the traditional voltage-source inverter and current-source inverter are overcome by the Z-source inverter. This inverter enables voltage boost capability with the turning on of both switches in the same inverter phase leg (shoot-through state). Additionally, reliability of the system is greatly improved because the short circuit across any phase leg of inverter is allowed and does not destroy the inverter.

II. Z-SOURCE INVERTER

The main objective of static power converters is to produce an AC output waveform from a dc power supply. Impedance source inverter is an inverter which employs a unique impedance network coupled with the inverter main circuit to the power source. This inverter has unique features in terms of voltage (both buck & boost) compared with the traditional inverters. A two port network that consists of a split-inductor and capacitors that are connected in X shape is employed to provide an impedance source (Z-source) coupling the inverter to the dc source, or another converter. The DC source/load can be either a voltage or a current source/load. Therefore, the DC source can be a battery, diode rectifier, thyristor converter, fuel cell, PV cell, an inductor, a capacitor, or a combination of those [6]. Switches used in the converter can be a combination of switching devices and anti-parallel diodes as shown in Fig. 2.

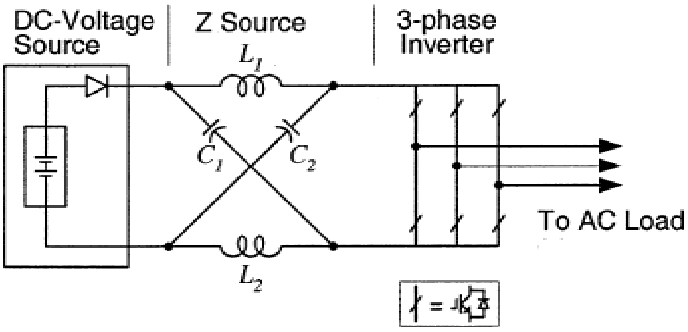

Fig.2 ZSI Using the Antiparallel Combination of Switch and Diode

Six switches are used in the circuit; each is traditionally composed of a power transistor and an antiparallel (or freewheeling) diode to provide bidirectional current flow and unidirectional voltage blocking capability. The commonly used switches are Metal Oxide Semi-Conductor Field Effect Transistor (MOSFET), Insulated Gate Bipolar Transistor (IGBT), Bipolar Junction Transistor (BJT), Silicon Controlled Rectifier (SCR), and Gate Turn off Thyristors (GTO) etc. Here IGBT is employed as the switch as it combines the advantages of both BJT and MOSFET.

A. Impedance Network

The Z-source concept can be applied to all DC-to-AC, AC-to- DC, AC-to-AC and DC-to-DC power conversion. The output DC voltage fed to the Impedance source network which consists of two equal inductors (L_1, L_2) and two equal capacitors (C_1, C_2).The network inductors are connected in series arms and capacitors are connected in diagonal arms .The impedance network, used to buck or boost the input voltage depends upon the boosting factor. This network also acts as a second order filter. This network should require less inductance and be smaller in size. Similarly capacitors required should be of low capacitance and smaller in size. This impedance network feeds constant impedance output voltage to the three phase inverter main circuit. Depending upon the gating signal, the inverter operates and this output is fed to the 3-phase ACload.

B. Equivalent Circuit and Operating Principle

The Z-source inverter is analysed using voltage source inverter. The unique feature of the Z-source inverter is that the output ac voltage can be of any value between zero and infinity regardless of the input DC voltage. That is, the Z-source inverter is a buck–boost inverter that has a wide range of obtainable voltage. The traditional voltage source and current source inverters cannot provide such features. The main feature of the Z-source inverter is implemented by providing gate pulses including the shoot-through pulses. Here to insert this shoot through state becomes the key point of the control methods. It is obvious that during the shoot-through state, the output terminals of the inverter are shorted and the output voltage to the load is zero. The output voltage of the shoot through state is zero, which is the same as the traditional zero states, therefore the duty ratio of the active states has to be maintained to output a sinusoidal voltage, which means shoot-through only replaces some or all of the traditional zero states.

Let us briefly examine the Z-source inverter structure. In Fig. 2, the three-phase Z-source inverter bridge has nine permissible switching states unlike the traditional three-phase voltage source inverter that has eight. The traditional three-phase V-source inverter has six active vectors when the DC voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices, respectively.

However, three-phase Z-source inverter bridge has one extra zero state when the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on),any two phase legs, or all three phase legs. This shoot-through zero state is forbidden in the traditional V-source inverter, because it would cause a shoot-through. We call this third zero state the shoot-through zero state, which can be generated by seven different ways: shoot through via any one phase leg, combinations of any two phase legs, and all three phase legs. The Z-source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter. The Z-source inverter can be operated in three modes which are explained below.

Mode I:

In this mode, the inverter bridge is operating in one of the six traditional active vectors; the equivalent circuit is as shown in Fig.3.

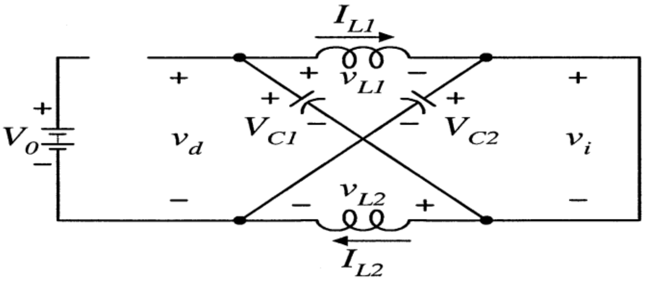

Fig. 3 Equivalent Circuit of the ZSI in one of the Six Active States

The inverter bridge acts as a current source viewed from the DC link. Both the inductors have an identical current value because of the circuit symmetry. This unique feature widens conducting intervals of the line current, thus reducing harmonic current.

Mode II:

The equivalent circuit of the bridge in this mode is shown in the Fig.4.

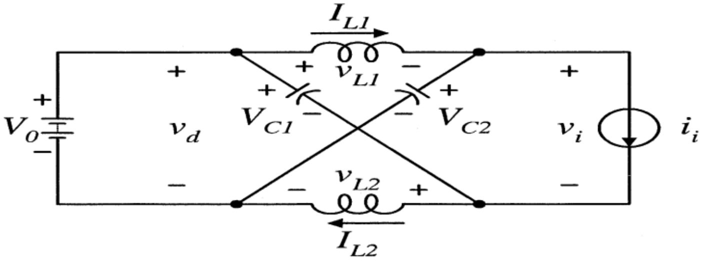

Fig.4 Equivalent Circuit of the ZSI in one of the Two Traditional Zero States

The inverter bridge is operating in one of the two traditional zero vectors and shorting through either the upper or lower three devices, thus acting as an open circuit viewed from the Z-source circuit. Again, under this mode, the inductor carries current, which contributes reduction of harmonics in line current as shown below in Fig. 5.

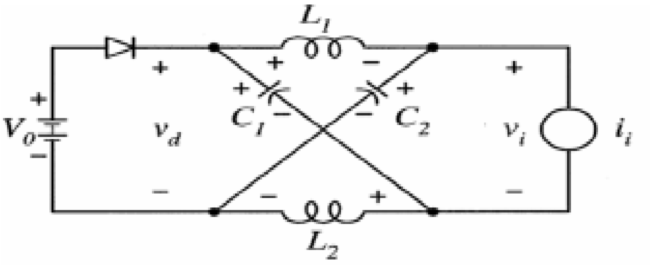

Fig. 5 Equivalent Circuit of the ZSI in the non -Shoot- through States

Mode III:

The inverter bridge is operating in one of the seven shoot-through states. The equivalent circuit of the inverter bridge in this mode is as shown in below Fig.6. In this mode, the dc link is separated from the ac line. This shoot-through mode to be used in every switching cycle during the traditional zero vector period generated by the PWM control.

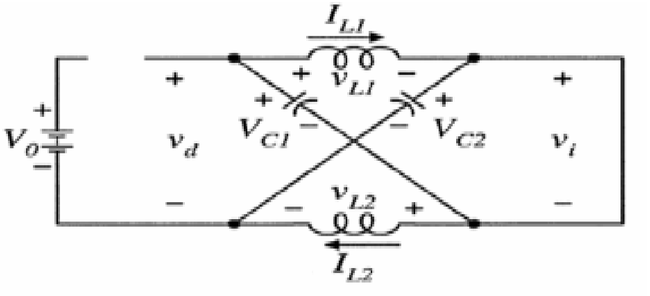

Fig.6 Equivalent Circuit of the ZSI in the Shoot-through State

III. PWM TECHNIQUES

There are a number of control methods to control Z-source inverter including sinusoidal PWM techniques, three types of PWM control algorithms: Simple Boost Control (SBC), Maximum Boost Control (MBC), and Constant Boost Control (CBC).

A. Simple Boost Control

Actually, this control strategy inserts shoot through in all the PWM traditional zero states during one switching period. This maintains the six active states unchanged as in the traditional carrier- based PWM. Two straight lines are employed .The first one is equal to the peak value of the three-phase sinusoidal reference voltages while the other one is the negative of the first one. When the triangular carrier waveforms is greater than the upper enveloper lower than the bottom envelope the circuit turns into shoot-through state. Otherwise it operates as traditional carrier-based PWM.Fig. 7 show the pulse generation of the three phase leg switches (S1, S3 and S5-positive upper switches and S2, S4 and S6-negative lower switches).

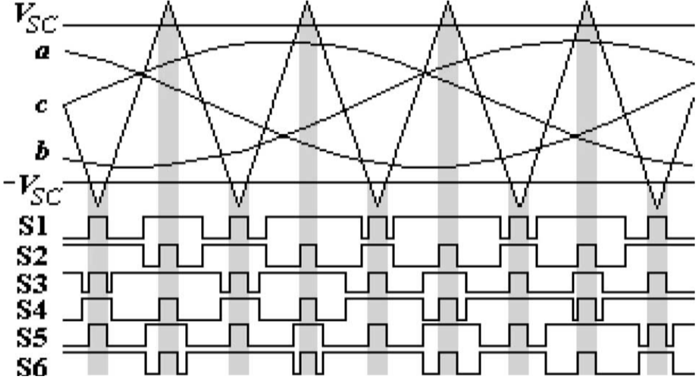

Fig. 7 PWM Signals from Simple Boost Control

IV. FUZZY LOGIC CONTROLLER

The Fuzzy Logic Controller (FLC) requires that each control variables which define the control surface be expressed in fuzzy set notations using linguistic labels. The fuzzy logic controller is appropriate for nonlinear control because it does not use complex mathematical equation. Fuzzy controller is a non-linear controller that does not require a precise mathematical model for its design [9]. In essence, fuzzy controller is a linguistic-based controller that tries to emulate the way a human thinks in solving a particular problem. The basic fuzzy logic control system is composed of a set of input membership functions, a rule-based controller, and a defuzzification process.

The fuzzy logic input uses member functions to determine the fuzzy value of the input. There can be any number of inputs to a fuzzy system and each one of these inputs can have several membership functions. The set of membership functions for each input can be manipulated to add weight to different inputs. The output also has a set of membership functions. These membership functions define the possible responses and outputs of the system [12]. The fuzzy inference engine is the heart of the fuzzy logic control system. It is a rule based controller that uses If-Then statements to relate the input to the desired output [10].

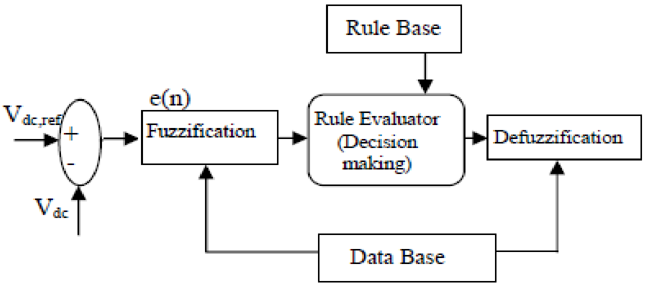

Fig. 8 Structure of fuzzy logic system

The fuzzy inputs are combined based on these rules and the degree of membership in each function set. The output membership functions are then manipulated based on the controller for each rule. All of the output member functions are then combined into one aggregate topology. The defuzzification process then chooses the desired finite output from this aggregate fuzzy set. There are several ways to do this such as weighted averages, centroids, or bisectors. This produces the desired result for the output. FLC is the combination of various different processes which are shown above in the Fig.8.It means a fuzzy logic controller comprises of numbers of methods [11] which are described below in stepwise form. Here the processes are explained in general format as explained above are described in detail below:

A. *Fuzzification*

Fuzzy logic uses linguistic variables instead of numerical variables. In a control system, error between reference signal and output signal can be assigned as (for example) Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive small (PS), Positive Medium (PM), Positive Big (PB). The triangular membership function is used for fuzzifications. The process of fuzzification converts numerical variable (real number) to a linguistic variable (fuzzy number).

B. *Rule Elevator*

Conventional controllers like PI and PID have control gains which are numerical values. Fuzzy logic controller uses linguistic variables instead of the numerical values. The linguistic variables of error signal taken as input (en) and output is represented as in the form of degree of membership functions.

C. *Defuzzification*

The rules of fuzzy logic generate demanded output in a linguistic variable, according to real world requirements. Linguistic variables have to be transformed to crisp output. The choices available for defuzzification are numerous. So far the choice of strategy is a compromise between accuracy and computational intensity.

V. SIMULATION & RESULTS

The simulations have been carried out. The wind speed variations and rapidly changing solar irradiance are measured with respect to time. For simulation, the impedance network elements are designed with the following values:L1=L2=3mH and C1=C2=1000µF. The switching frequency is 10 kHz and the fundamental frequency is 50Hz.

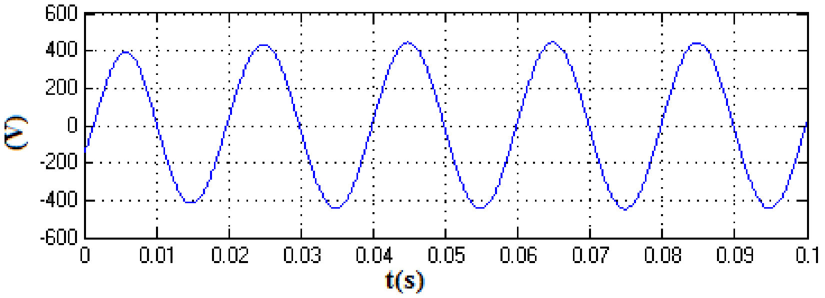

Fig. 9 Output Voltage in Volts

Fig.9 shows the output voltage waveform of Z-source inverter. The input dc voltage is boosted through Z-source inverter and to produce the output phase load voltage is around 440 V. The output voltage is dependent on the voltage across at the inverter bridge.

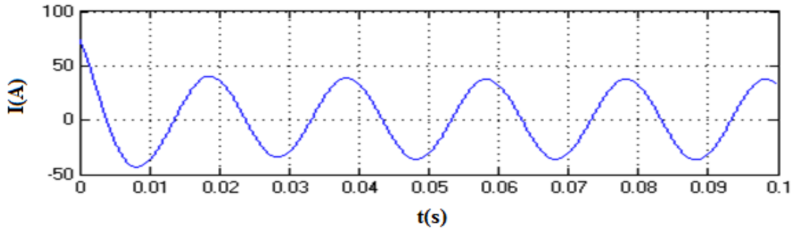

Fig. 10 Output Current in Amps

Fig. 10 shows the output current waveform of Z-source inverter. Z-source inverter naturally generates the output AC voltage always higher than the input DC voltage depending on the duty cycle produced.

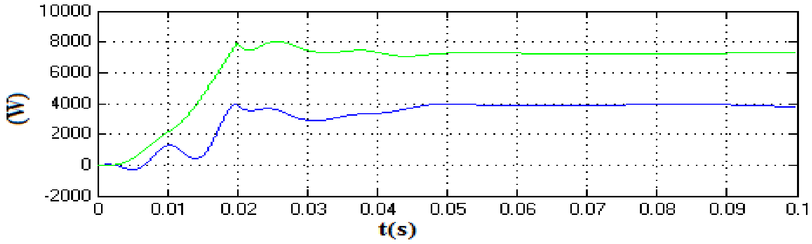

Fig. 11 Output power waveform for Z-source inverter

Fig. 11 shows the power flow of active and reactive power waveform for Z-source inverter. The active power of Z-source inverter is around 7 KW and the reactive power is around 4 KVAR.

The Total Harmonic Distortion (THD) is calculated using FFT analysis tool which is provided in Simulink model in the form of powergui. The nominal THD value is <5%.The simulation results are shown for Z-source inverter using RL loads. By using PI Controller, the THD is calculated as 12.64%. The Harmonic Distortion is higher in PI controller and hence it can be reduced.

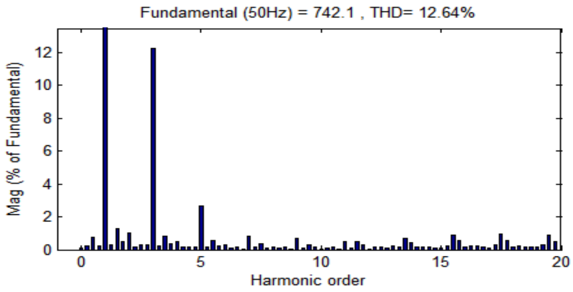

Fig. 13 THD Waveform using PI controller

The fuzzy logic controllers are suitable for reducing the THD value and also give sinusoidal voltage.

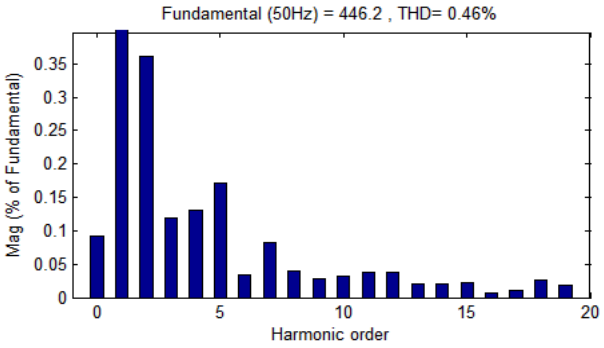

Fig. 14THD Waveform using Fuzzy logic controller

Harmonic analysis on the output voltage is performed and total harmonic distortion by using fuzzy logic controller's calculated as 0.46%.In this figure we observe that THD is reduced to 0.46% compared to traditional inverters. Harmonic spectrum of output phase voltage is shown in Fig. 14.Fuzzy logic controller is capable of providing sinusoidal voltage with low distortion.

VI. CONCULSION

In this paper, wind and PV system along with multiple input dc-dc converter and Z-source inverter with Fuzzy logic controller has been proposed and corresponding simulated waveforms are verified. The proposed wind generator and PV array to extract maximum power from the wind and solar energy sources. The Multiple input dc-dc converters are applied to the wind generator and PV cell system to obtain the DC voltage. The DC voltage is fed into the Z-source inverters has both buck and boost voltage capabilities to obtain the voltage level of 440V AC. By using FLC method, the harmonics are greatly reduced and to generate pure sinusoidal voltage waveform with low distortion. The MATLAB/SIMULINK software is used for modelling the entire system.

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