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Neuro-Fuzzy based Inverter Implement with FPGA

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Abstract: In power-electronics the word 'inverter' denotes a class of power conversion (or power conditioning) circuits that operates from a dc voltage source or a dc current source and converts it into ac voltage or current. This article presents the benefits of using field-programmable gate array (FPGA) & Neuro-Fuzzy controllers based Inverter for power electronics and ac drive applications.

In this paper, a neural fuzzy system (NFS) for single-phase full-bridge voltage source Inverter based on the technology of FPGA need to design. Firstly, a model of the Inverter is designed; then to increase the performance of the Inverter system, a fuzzy controller (FC) which its parameters are adjusted by a basis neural network (NN) function. Secondly, the Xilinx ISE program is employed to synthesis the VHDL codes that describe the operation of the Neuro-fuzzy system and generate the configuration file used to program the FPGA. Thirdly, the ModelSim program is used to simulate the operation of the VHDL codes and to obtain the expected output data of the FPGA board.

Keywords: PWM, Inverter, Neuro-Fuzzy Control, VHDL, FPGA.

I. INTRODUCTION

Power conversion (DC-AC) has been increasingly used in many fields, due to its properties regarding high voltage capability and high power quality. But in industrial applications, there are many uncertainties, such as system parameter uncertainty, external load disturbance etc. which always diminish the performance quality of the design system. To cope with this problem, in recent years, many intelligent control techniques [3,4,5,6,7,8], such as fuzzy control, Proportional-Integral-Derivative (PID) control, neural networks control, DSP or microprocessor and other control method, have been developed to obtain high operating performance. Lately, the FPGA (Field Programmable Gate Array) has drawn much attention in the development of electronics circuit control scheme due to its shorter design cycle, lower cost and higher density.

Some of intelligent control techniques based on FPGA for PWM (Pulse Width modulation) Inverter are discussed: A FPGA based control IC (Integrated Circuits) for controlling the PWM inverters has been realized using a single FPGA XC4005 from Xilinx, Inc. which can be used as a coprocessor with a general-purpose DSP (Digital Signal Processor) or microprocessor in application of ac-voltage regulation [3]. The hardware implementation of a NN (Neural Network) based SVM (Space Vector Modulation) technique for a VSI is designed which is independent of inverter switching frequency [4]. A sinusoidal PWM generator for a single-phase hybrid power filter was developed in an Altera® Flex 10 K FPGA and the modulation index was selected by calculating the DC bus voltage of the active filter through a digital controller, by PID technique. The implemented PWM generator using an FPGA required less memory usage while providing flexible PWM patterns whether same phase, lagging, or leading, the reference voltage signal [5]. The implementation of PI and fuzzy control strategies for single phase PWM Multil Level Inverter (MLI) has been carried out and the results are presented for both linear and non-linear loads. It is observed that FLC (Fuzzy Logic Controller) performs better than PI (Proportional-Integral) controller in view of harmonic content of the steady-state output voltage with linear loads whereas better output voltage is observed with PI control under loads with less non-linearity. FLC is found to perform better in FPGA based control [6]. An FPGA-based NFC controller for PMSM drives was presented and successfully demonstrated its performance through co-simulation by using Simulink and ModelSim [7]. In power converter control, PWM control is the most powerful technique that offers a simple method for controlling of analog systems with processors digital output. The development of high-frequency PWM generator architecture for power converter control, using FPGA and CPLD (Complex Programmable Logic Devices) ICs, based on a special design synchronous binary counter can be easily interfaced to a microcontroller or DSP system [8].

Although FC (Fuzzy Control) has been successfully applied in several industries, however, it is not an easy task to obtain an optimal set of fuzzy membership functions and rules in FC. A lot of research is devoted to improve the ability of fuzzy systems, such as evolutionary strategy and neural networks. The combination of fuzzy logic and neural networks is called neuro-fuzzy system. This paper presents an FPGA-based neuro-fuzzy control scheme for the regulation of a PWM inverter used for ac power conditioning. The proposed digital controller has been realized by an FPGA from Xilinx, Inc.

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An inverter can produce square wave, modified sine wave, pulsed sine wave, or sine wave depending on circuit design. The two dominant commercialized waveform types of inverters as of 2007 are modified sine wave and sine wave. Static inverters use switching devices and do not use moving parts in the conversion process. Some applications for inverters include converting high-voltage direct current electric utility line power to AC, and deriving AC from DC power sources such as batteries. There are two basic designs for producing household plug-in voltage from a lower-voltage DC source, the first of which uses a switching boost converter to produce a higher-voltage DC and then converts to AC. The second method converts DC to AC at battery level and uses a line-frequency transformer to create the output voltage. This static inverter can be implemented using FPGA [1].

II. SYSTEM ARCHITECTURE

2.1 Neuro-Fuzzy Systems:

❖ **Neural Networks:** The neural networks try to shape the biological functions of the human brain. This leads to the idealization of the neurons as discrete units of distributed processing. The main characteristic of the neural networks is the fact that these structures can learn with examples (training vectors, input and output samples of the system). The neural networks modifies its internal structure and the weights of the connections between its artificial neurons to make the mapping, with a level of acceptable error for the application, of the relation input/output that represent the behavior of the modeled system.

❖ **Fuzzy Systems:** Fuzzy systems propose a mathematic calculus to translate the subjective human knowledge of the real processes. This is a way to manipulate practical knowledge with some level of uncertainty.

❖ **Neuro-Fuzzy Systems:** The combination of fuzzy logic and neural networks is called neuro-fuzzy system.

Neuro-Fuzzy System (NFS) = Neural Network (NN) + Fuzzy Logic (FL)

A NFS is a fuzzy system that uses a learning algorithm derived from or inspired by neural network theory to determine its parameters (fuzzy sets and fuzzy rules) by processing data samples. Figure 2.1 shows the neuro-fuzzy system which attempts to present a fuzzy system in a form of neural network.

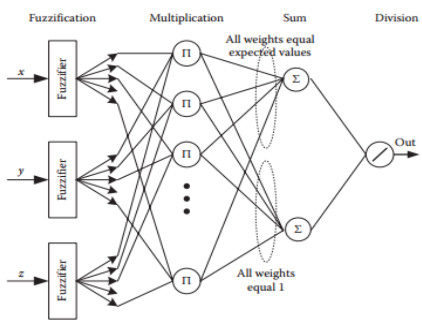

Figure 2.1: Neuro-Fuzzy System

The neuro-fuzzy system consists of four blocks: Fuzzification, Multiplication, Summation, and Division. Fuzzification block translates the input analog signals into fuzzy variables by membership functions. Then, instead of MIN operations in classic fuzzy systems, product operations (signals are multiplied) are performed among fuzzy variables. This neuro-fuzzy system with product encoding is more difficult to implement, but it can generate a slightly smoother control surface. The summation and division layers perform defuzzification translation. The weights on upper sum unit are designed as the expecting values (both Mamdani and TSK rules can be used); while the weights on the lower sum unit are all “1” [9].

2.2 Inverter & Its Types:

A power inverter, or inverter, is an electrical power converter that changes direct current (DC) to alternating current (AC). Inverters can be broadly classified into two types:

1. Voltage Source Inverters (VSI)/ Voltage–fed Inverter (VFI)

- A VFI/VSI is one in which the input dc is a voltage source with small or negligible impedance.
- The voltage at the input terminals is constant.
- The VSI circuit has direct control over ‘output (ac) voltage’.

2. Current Source Inverters (CSI)

- A CSI is one in which the input dc is a current source with high impedance.
- The current at the input terminals is adjustable.
- The CSI circuit has direct control over ‘output (ac) current’.

2.2.1 Voltage Control in Single - Phase Inverters:

The schematic of inverter system is as shown in Figure 2.2.1, in which the battery or rectifier provides the dc supply to the inverter. The inverter is used to control the fundamental voltage magnitude and the frequency of the ac output voltage. AC loads may require constant or adjustable voltage at their input terminals, when such loads are fed by inverters, it is essential that the output voltage of the inverters is so controlled as to fulfill the requirement of the loads.

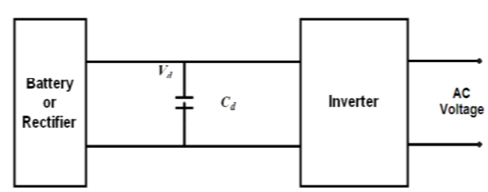

Figure 2.2.1: Schematic for Inverter System

The various methods for the control of output voltage of inverters can be classified as:

(a) External control of ac output voltage.

(b) External control of dc input voltage.

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(c) Internal control of the inverter.

The first two methods require the use of peripheral components whereas the third method requires no external components. Mostly the internal control of the inverters is dealt, and so the third method of control is discussed in the following section.

2.2.2 Pulse Width Modulation Control:

The fundamental magnitude of the output voltage from an inverter can be controlled to be constant by exercising control within the inverter itself that is no external control circuitry is required. The most efficient method of doing this is by PWM control used within the inverter. In this scheme the inverter is fed by a fixed input voltage and a controlled ac voltage is obtained by adjusting the on and the off periods of the inverter components. The advantages of the PWM control scheme are:

a) The output voltage control can be obtained without addition of any external components.

b) PWM minimizes the lower order harmonics, while the higher order harmonics can be eliminated using a filter.

The disadvantage possessed by this scheme is that the switching devices used in the inverter are expensive as they must possess low turn on and turn off times, nevertheless PWM operated are very popular in all industrial equipments. PWM techniques are characterized by constant amplitude pulses with different duty cycles for each period. The width of these pulses are modulated to obtain inverter output voltage control and to reduce its harmonic content. There are different PWM techniques which essentially differ in the harmonic content of their respective output voltages, thus the choice of a particular PWM technique depends on the permissible harmonic content in the inverter output voltage.

2.2.3 Single-Phase Full Bridge Inverters:

A single-phase inverter in the full bridge consists of four switching devices, two of them on each leg. The full- bridge inverter can produce an output power twice that of the half-bridge inverter with the same input voltage. Three different PWM switching schemes are discussed below, which improve the characteristics of the inverter. The objective is to add a zero sequence voltage to the modulation signals in such a way to ensure the clamping of the devices to either the positive or negative dc rail; in the process of which the voltage gain is improved, leading to an increased load fundamental voltage, reduction in total current distortion and increased load power factor. Generally, the top devices are assigned to be S11 and S21 while the bottom devices as S12 and S22.

❖ **PWM with Bipolar Switching:** In this scheme the diagonally opposite transistors S_{11}, S_{22} and S_{21}, S_{12} are turned on or turned off at the same time. The output of leg A is equal and opposite to the output of leg B.

❖ **PWM with Unipolar Switching:** In this scheme, the devices in one leg are turned on or off based on the comparison of the modulation signal V_r with a high frequency triangular wave. The devices in the other leg are turned on or off by the comparison of the modulation signal $-V_r$ with the same high frequency triangular wave.

❖ **PWM with Modified Bipolar Switching (MBPWM):** In the inverter employing the bipolar switching scheme, switches are operated in such a way that during the positive half of the modulation signal one of the top devices in one of the switching leg is kept on and the two other switching devices in the other leg are PWM operated, and during the negative half of the modulation signal one of the bottom switching device is kept on continuously while the other two switching devices in the other leg are PWM operated. The output voltage is determined by comparing the control signal V_r and the triangular wave.

2.3 Proposed Block Diagram:

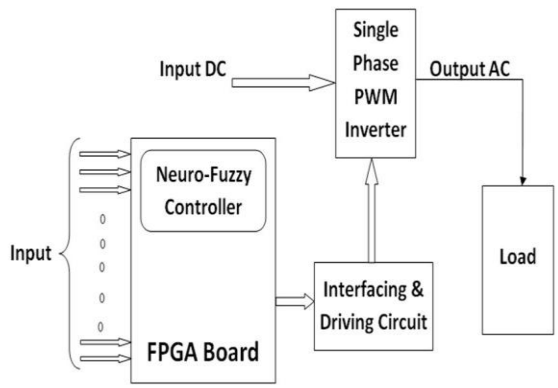

Figure 2.3: Diagrammatic representation of the proposed work

Figure 2.3 shows the proposed work behavior of Neuro-fuzzy logic control that will be design in VHDL language & implement on FPGA board. First, a VHDL codes are downloaded from the host computer into the FPGA chip using a USB cable. Then, edge connector is used to interface the board (NF controller) with model of the Inverter. The digital input with switches has been applied as input data to the FPGA boards. The FPGA board generates the digital inputs to the NF controller. The NF controller generates a suitable digital control signal based on the rules that were stored in the FPGA chip. The digital control signal generates pulse waveform (PWM) and pulse waveform will be applied as an input to the Inverter for controlling the gate trigger of the device. The width of the pulse waveform is under control. Thus based on the application, a pulse waveform of different duty cycles is able to produce. Finally, the output we get is an AC type which is used to drive multiple AC loads.

In addition to FPGA, Xilinx/Modelsim software was used for simulation and verification of the proposed circuit before implementation. Simulation results obtained will be compared with the experimental results.

2.3.1 Design Flow:

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Figure 2.3.1 shows the sequence of steps followed when implementing Inverter design on FPGA.

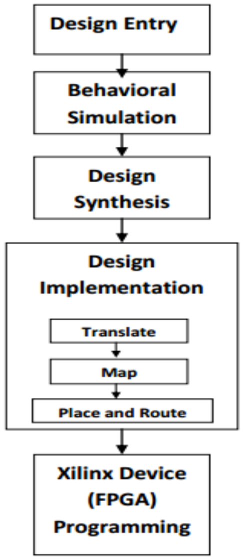

Figure 2.3.1: Design Flow

III. CONCLUSION

This project aims to develop efficient design methodologies for FPGA Implementation of Neuro-Fuzzy based Inverter for AC drive applications. This research represents one of pioneer efforts for applying intelligent control algorithms in control of AC drives based on the FPGA technology. Expected results will provide industry with viable solutions for drive applications and contribute to the emerging area of manufacturing ICs for drive applications using the novel FPGA technology.

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