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The Implementation Of Voltage Inverse Control Scheme For Micro Grid Energy Storage Inverter Based On FPGA

Lin Yongjun[1], Zhou Honbo[2], Guo Lei[3], Liu Weiliang[4]

[1,2,3,4]**Department, North China Electric Power University, City, Baoding, China**

Abstract

When the micro grid is in a state of off grid operation, the voltage stability is maintained by the energy storage inverter. Due to the small capacity of the micro grid, energy storage level and load changes can easily lead to the deterioration of the quality of the system voltage waveform.In order to solve this problem, a new energy storage inverter voltage inverse control scheme is proposed, which is based on the neural network. In order to guarantee the real-time performance, the design of the neural network special arithmetic unit is carried out by using FPGA and comparise of the implementation scheme of the excitation function and float point operation. Simulation results show that the proposed scheme is feasible and effective.

Keywords: *Energy storage inverter; Micro grid; FPGA; Inverse control*

1. Introduction

In recent years, with the increasing depletion of fossil energy, the micro grid composed of photovoltaic power generation, wind power and other new energy power generation, such as storage battery, super capacitor, etc., has become a research hotspot [1-2].Micro grid can work in grid connected mode and off grid operation mode. In grid connected mode, the large power grid can provide voltage support for the micro grid, and it is generally provided by the energy storage inverter under the condition of off grid operation mode. Because of the smaller capacity, the change of the energy storage level and load can affect the waveform quality of the system voltage, and even lead to instability of the system. With the continuous improvement of the quality requirements of the user, the problem is to be solved urgently.In order to improve the energy storage inverter output voltage waveform quality of micro grid. In this paper, an inverse control scheme based on artificial neural network is proposed.

Because of the Large computation of artificial neural network and the control period of energy storage inverter is usually only a few dozen us, the conventional single chip microcomputer controller is difficult to complete the operation of neural network in one control cycle. Field Programmable Gate Arrays(FPGA) based on Parallel Computing. Compared with the traditional single chip microcomputer and PC machine, FPGA has the characteristics of fast operation speed .Therefore, this paper will use FPGA to design a neural network, and the emphasis of the paper is to evaluate the implementation scheme of the excitation function and floating point number. Experimental results show that the proposed control scheme is feasible and effective.

2. Neural network inverse model structure

According to the working principle of energy storage inverter, the main factor affecting the output voltage of u_o including the port voltage of energy storage unit u_{dc}, load current i_o, filter capacitor voltage u_c, PWM control signal duty cycle *d* should be taken when building an inverse model. In the *k* control cycle, *d (k)* for the period of the PWM control signal duty ration, and Sampling the u_{dc}, u_c, i_o, u_o when this cycle is coming to an end, remembering as *udc(k), uc(k), io(k), uo(k)*. In

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order to reflect the dynamic characteristics of the system better, sampling the u_o, i_o in the current cycle and previous cycle, and sampling the u_{dc}, u_c in the previous cycle, and sampling the PWM duty ration in the previous cycle, We can get $u_o(k)$, $i_o(k)$, $u_o(k-1)$, $i_o(k-1)$, $u_{dc}(k-1)$, $u_c(k-1)$, $d(k-1)$. Using these seven signals as input, a BP network inverse model with 7 inputs and 1 outputs is constructed. Selectting the number of hidden layer neurons is 9,and using the sigmoid function as the hidden layer neuron transfer function, and using the purlin function as the output layer transfer function we can construct the BP network inverse model. The structure of the BP neural network inverse model is shown in Figure 1.

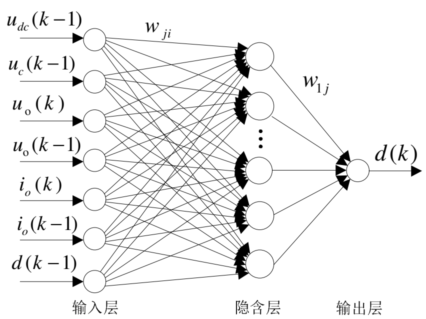


Fig. 1 Topology of BP neural network inverse model.

3.Inverter voltage inverse control system structure

3.1 inverse control system structure.

The neural network inverse control system of energy storage inverter voltage is mainly composed of three parts, such as the inverter circuit, single chip computer and FPGA operation unit, as shown in Figure 2.

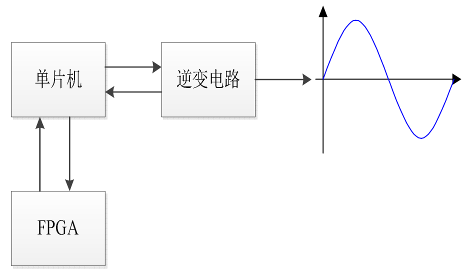


Fig. 2 Novel Control method of voltage.

Single chip microcomputer is the main controller of the neural network control system of micro grid energy storage inverter, and it is responsible for data acquisition. Using its 4 A/D acquisition port, the single chip microcomputer can collect the port voltage of the energy storage unit port voltage $u_{dc}(k)$, filter capacitor voltage $u_c(k)$, load current $i_o(k)$, inverter output voltage $u_o(k)$, the accuracy is ten, and then send it to the FPGA with $u_o^*(k+1)$, $\hat{i}_o(k+1)$, $d(k)$. The FPGA controller is a special operation for the neural network inverse model, and it receives the network input signal sent by the single chip microcomputer, and It will calculate the results sent to the microcontroller. Single chip microcomputer will complete control of the inverter circuit according to the results of the FPGA PWM control signal.

3.2 FPGA neural network arithmetic unit structure.

Determining the BP neural network structure (such as the number of hidden layer neurons) and the weights and threshold are based on a large number of training samples. With the continuous collection of samples, the BP neural network should be trained again to improve the accuracy of the model. Considering the structure, weight and threshold of the network will be changed after each new training, the design of the neural network control system using a modular design ideas in this paper. The overall structure is composed of six modules: the acquisition module, the normalized module, the input matrix operation module, the neuron module, the output matrix operation module and the anti normalization module.Its overall structure is shown in Figure 3.

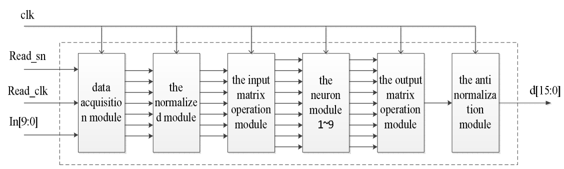


Fig. 3 FPGA neural network arithmetic unit structure.

3.3 excitation function implementation scheme

The excitation function is one of the important factors to determine the overall performance of artificial neural networks. In this paper, the Sigmoid function is chosen as the hidden layer of the neural network inverse model. How to achieve the high accuracy of the system has a significant impact on the quality of the control system. At present, the realization scheme of the excitation function mainly has two kinds of the Taylor series expansion method and the fitting approximation method, and then we will comparise the two schemes to achieve Sigmoid function.

3.3.1 Taylor series expansion method

The expression for the Sigmoid function is

$$y=\frac{1}{1+e^{-x}}=\frac{e^x}{e^x+1} \qquad (1)$$

With Taylor series expansion e^x

$$e^x=\lim_{N\to\infty}\sum_{n=0}^{N}\frac{x^n}{n!}=1+x+\frac{x^2}{2!}+\frac{x^3}{3!}+\dots\frac{x^N}{N!} \qquad (2)$$

Take N=9, That is expansing ex function to nine order, the error of the Sigmoid function approximation and the real value can be calculated by MATLAB. Results is shown in figure 4.

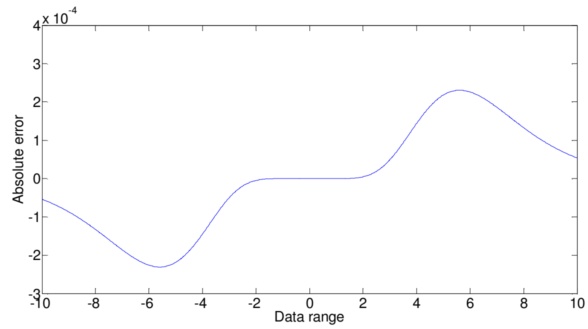


Fig. 4 Sigmoid function nine order expansion error chart.

It is known that the maximum absolute error between [-10, 10] is about $2.49*10^{-4}$, and the accuracy is satisfied.

3.3.2 least squares fitting approximation method

The least square method often use a basis function to realize curve fitting, such as polynomial, exponential function, trigonometric function and so on. Taking into account the use of FPGA to achieve the above basis functions need to consume a lot of logic and a long time, this paper uses linear function as the basis function, and piecewise fitting the Sigmoid function. Each fitted section of the slope, intercept the data stored in the ROM table to call. This can reduce the number of operations per cycle and improve the utilization of the FPGA storage unit. Through the MATLAB simulation, the error of the Sigmoid function is approximated by piecewise linear approximation of the Sigmoid function. The simulation results are shown in Figure 5.

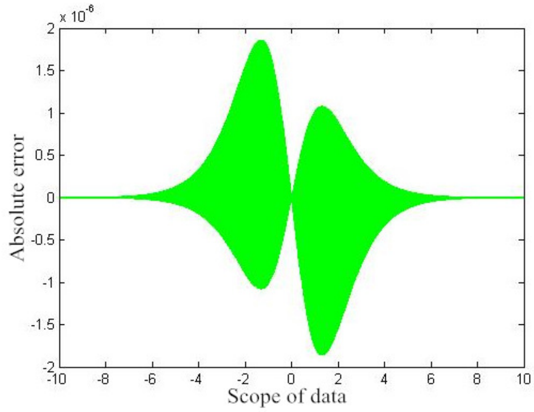


Fig. 5 Sigmoid function piecewise linear approximation error.

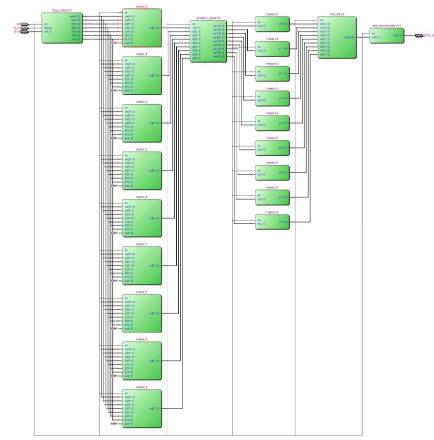


Fig. 6 schematic diagram of inverse model structure.

To sum up, when using a piecewise linear approximation of Sigmoid function in the [-10,10] between the absolute maximum error is about $1.87*10^{-6}$, and comparing with the nine bands Taylor series expansion the error is greatly reduced.

4.Simulation of neural network inverse model

With the above design, we can build a storage inverter neural network inverse model in Quartus ii which use Verilog HDL hardware description language, as shown in Figure 6. In Modelsim-altera simulation software simulation of its basic functions and fast operation. Finally, we chose the EP4CE115F FPGA which is made in altera company. It has 114,480 logic gates, 3.9M of storage space and 529 I / O port, and the crystal is 50Mhz.

Neural network inverse model operation time sequence is shown in Figure seven, and We can see that at each clock rising edge a data is collected, the seven sets of data acquisition time for 7 machine cycles. After 1 cycles, the result of the input matrix is obtained, and the result of the calculation of the neuron in the next clock is the duty cycle. The whole computing process is ten clock cycles, each clock cycle is 20ns, so the whole calculation process is 200ns, far lower than the control period of the energy storage inverter 50us.

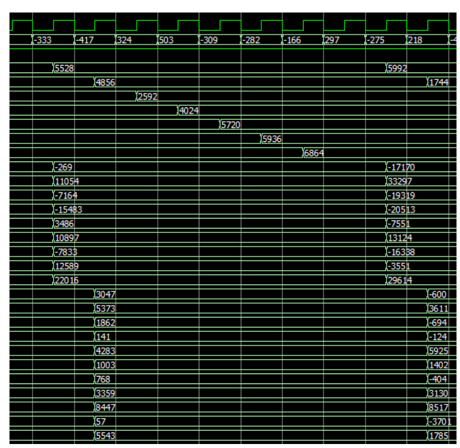


Fig. 7 the time sequence diagram of inverse model of neural network.

In order to verify the accuracy of the FPGA to the inverse model, the calculated results are compared with the calculation results of Matlab. Because the calculation result of Matlab can be considered as complete and accurate, the error curve of the result of FPGA is shown in Figure 8. In most of the cases, the absolute error is less than 0.005, the maximum absolute error is no more than 0.015, and the accuracy of the inverse model of the energy storage inverter is fully satisfied.

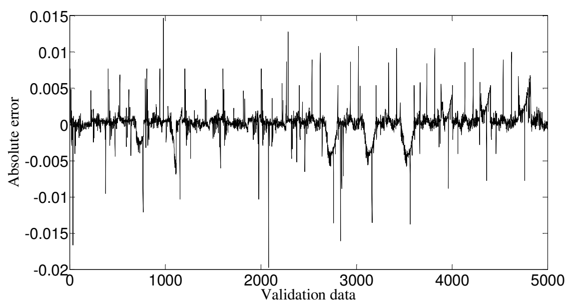
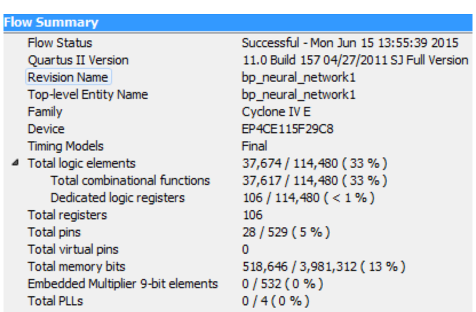


Fig.8 FPGA absolute error.

In the Quartus II environment, the inverse model is compiled and the results are shown in Figure 9. It is known that the whole inverse model need 37674 logic gate, accounting for 33% of the total logic gate; using 28 I/O ports, accounting for 5% of the total I/O ports; using the memory 518.6Kb, accounting for 13% of the total memory. The resource of EP4CE115F FPGA can satisfy the demand of the inverse model.



Flow Summary	
Flow Status	Successful - Mon Jun 15 13:55:39 2015
Quartus II Version	11.0 Build 157 04/27/2011 SJ Full Version
Revision Name	bp_neural_network1
Top-level Entity Name	bp_neural_network1
Family	Cyclone IV E
Device	EP4CE115F29C8
Timing Models	Final
Total logic elements	37,674 / 114,480 (33 %)
Total combinational functions	37,617 / 114,480 (33 %)
Dedicated logic registers	106 / 114,480 (< 1 %)
Total registers	106
Total pins	28 / 529 (5 %)
Total virtual pins	0
Total memory bits	518,646 / 3,981,312 (13 %)
Embedded Multiplier 9-bit elements	0 / 532 (0 %)
Total PLLs	0 / 4 (0 %)

Fig. 9 Compiled results of inverse model.

5.Conclusions

This paper introduces a method of neural network control system for micro grid energy storage inverter based on FPGA. The whole system is suitable for the application of the system, the operation speed is fast, the logic gates are few and the calculation precision is higher. The simulation results show that the system can be used to complete a neural network operation which has nine neurons as the hidden layer and seven set of data as the input in the 200ns. And the accuracy can be controlled within 2%. Therefore, this design has high practicability, which can be used for the control of the energy storage inverter and improve the quality of the output power of the energy storage inverter.

In this paper, a neural network based voltage inverse control scheme for energy storage inverter is proposed. In order to guarantee the real-time performance, the design of the neural network special operation is carried out by using FPGA technology. The comparison of the implementation scheme of the excitation function and the floating point number is carried out. Experimental results show that the proposed scheme is feasible and effective.

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