International Journal of Scientific & Engineering Research, Volume 5, Issue 2, February-2014
ISSN 2229-5518

FPGA Based Point Kinetic Equation Simulator

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Abstract— : This paper presents the PKE Simulator system design and implementation project based on FPGA. In Nuclear Power Plant, Nuclear Reactors are essential to generate the energy through, the heat generating process called fission. The point kinetic equation(PKE) describes, the time dependent behaviour of the nuclear reactor. The computational solution of this equation provides ,the neutron population during withdrawal and insertion of the control rods in the nuclear reactor. Since the PKE simulator system is designed for purposes of optimizing the performance and regulating the safety of a nuclear reactor. The Nuclear Reactor run at a critical state. The Preserving of the critical state is vital both for the maximum power output of the nuclear reactor and minimizing radiation (heat) given out by the reactor. Cyclone-III operates more efficiently in thermally challenged environments. Hence the Cyclone-III FPGA is utilized for de- signing the PKE Simulator system. The PKE Simulator system is designed using HDL and implemented on Altera Cair board. The system is designed in such a way that, the user enters the initial parameters through the membrane Keypad and simulated results will be displayed on LCD.

1. INTRODUCTION

The point-kinetics equations model the time-dependent behaviour of a nuclear reactor. Computational solutions of the point-kinetics equations provide insight into the dynamics of nuclear reactor operation and are useful in understanding the power fluctuations experienced during start-up or shutdown, when the control rods are adjusted. The point-kinetics equations are a system of differential equations for the neutron density and for the delayed neutron precursor concentrations. The neutron density and delayed neutron precursor concentrations determine the time-dependent behaviour of the power level of a nuclear reactor and are influenced by control rod position [1]. The point-kinetics equations are deterministic and can only be used to estimate average values of the neutron density, the delayed neutron precursor concentrations, and power level. However, the actual dynamical process is stochastic in nature and the neutron density and delayed neutron precursor concentrations vary randomly with time. At high power levels, the random behaviour is negligible but at low power levels, such as at start-up, random fluctuations in the neutron density and neutron precursor concentrations can be significant. The PKE Simulator is widely used in nuclear power plant. The PKE simulator uses the Altera-Cair Board for implementing the PKE Simulator system.

2.1 OBJECTIVE OF THE STUDY:

- The basics of Point Kinetic Equations (PKE) and its computations are studied.
- Analyze the requirements of the PKE Simulator System. PKE simulator is designed using VHDL.
- Design is validated using Modelsim in Xilinx Software. Implementation Of the PKE Simulator is carried out using Altera Cair board.

2.2 METHODOLOGY:

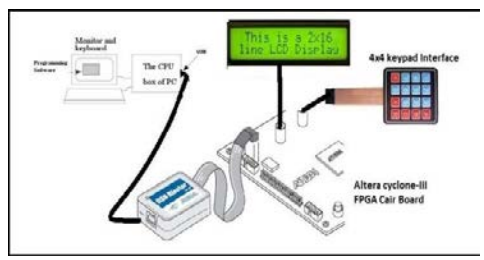

Figure 1. Methodology

Figure 1 shows the implementation methodology. The USB-Blaster download cable interfaces a USB port on a host computer to an Altera CAIR board. The membrane Keypad interface and LCD interface are connected to the Altera CAIR Board.

2.3 POINT KINETIC EQUATIONS COMPUTATION

In nuclear plant, for purposes of optimizing the performance and regulating the safety of a nuclear reactor, it is important that the nuclear reactor run at a level that is described as critical. The maintaining of this criticality is vital both for the maximum power output of the nuclear reactor, and the minimizing of the radiation given out by the reactor. To describe the state of criticality, we must first understand the nature of nuclear power. Nuclear power is based upon a process called fission, a process in which a neutron approaches a fissile isotope, and its very proximity, as the neutron slows

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near the atom, causes it to split into two or more pieces, generating fission products and generating even more neutrons called prompt and delayed neutrons, named aptly for the time interval between the initial split and their appearance. These neutrons collide with hydrogen in the water surrounding the fuel pins, depositing their energy and increasing the temperature of the water causing it to boil. The heat of the water, or rather the steam, is then used to power turbines and generate power[5]

This process would seem hap hazardous at first. With the flurry of neutrons scattering everywhere and splitting atoms at all points, it is very easy to attain a state that is called supercritical, or an out of control reactor (an event that occurred at Chernobyl). Thus said, it is important to maintain the critical state, which can now be defined as a steady state system, or, one where the average number of neutrons remains constant in time. The base of a reactor model is a set of ordinary differential equations known as the point reactor kinetics equations. These equations which expresses the time dependence of the neutron population and the decay of the delayed neutron precursors within a reactor are first order and linear, and essentially describe the change in neutron population within the reactor due to a change in reactivity. One of the important properties in a nuclear reactor is the reactivity, due to the fact that it is directly related to the control of the reactor. For safety analysis and transient behaviour of the reactor, the neutron population and the delayed neutron precursor concentration are important parameters to be studied. An important property of the kinetics equations is the stiffness of the system. The stiffness is a severe problem in a numerical solution of the point kinetics equations and results in the need for small time steps in a computational scheme[6].

The understanding of the time-dependent behaviour of the neutron population in a nuclear reactor in response to either a planned or unplanned change in the reactor conditions is of great importance to the safe and reliable operation of the reactor. the population of the neutrons in the system is, therefore, quite important knowledge when analysing this factor. likewise is the precursor density, or the population fission products that result in delayed neutrons. these equations have been found. The numerical Integration method is used to solve these equations.

The Point Kinetic Equation is given by

$$n(t) = \left\{\left(\frac{\rho - \beta}{tn}\right) no + \lambda co\right\} - - - (1)$$

To solve this Equation(1), First find the value of Co by using Equation(2)

$$co = \left\{\left(\frac{\beta}{\lambda tn}\right) no\right\} \quad - - - (2)$$

- $$n(t) = [no + f(no, co)h] - - - (3)$$

$$h = \left\{\frac{tf - tn}{N}\right\} - - - (4)$$

- Where
- ρ = Reactiviy.
- β = Delayed Neutron fraction.
- λ = Decay Constant.
- n0= Neutron Population.
- tn= mean generation time
- h = time step
- N = Number of Intervals
- ti = Initial Time
- tf = Final time
-

3. SYSTEM DESIGN

3.1 PKE Simulator system

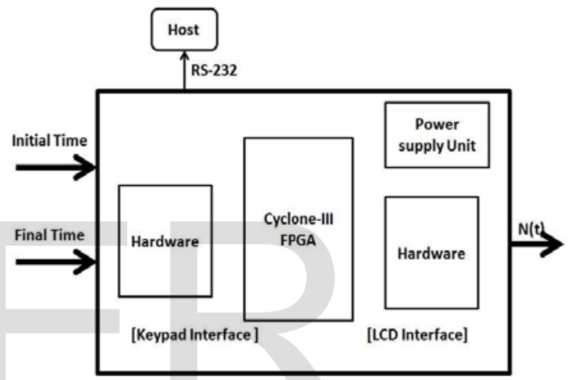

Figure. 2. PKE Simulator System

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The figure 2 shows the PKE simulator system. The initial time and Final time are the two parameters to be given by user through 4x4 keypad interface. The PKE simulator system will find the neutron population in nuclear reactor. The simulated results are displayed on 4x20 line LCD display.

3.2 Block Diagram:

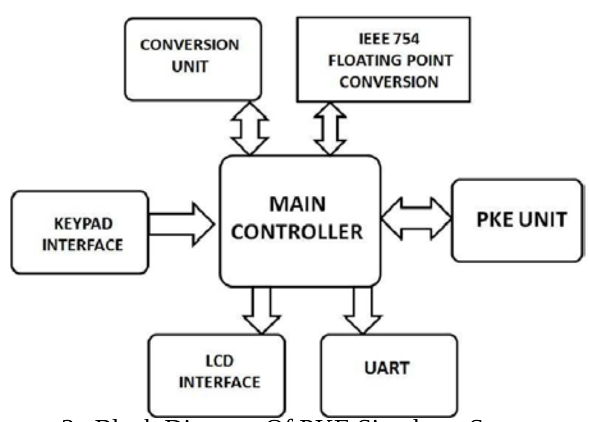

Figure. 3. Block Diagram Of PKE Simulator System

Figure 3 shows the overall block diagram of the PKE simulator system. The system consists of different modules are designed

in FPGA.
Keypad Interface: This module will be having debounce logic and decoder. This interface used to receive initial and final time inputs from user[18].

Conversion Unit: This module will be having BCD to fixed point conversion unit, which converts the keypad output value into Fixed point format.

IEEE 754 Floating Point Format: This module will have floating point conversion module, which converts fixed value into IEEE-754 Floating format this value will be sent to PKE Unit[9] .

PKE Unit: This module will have Floating Point arithmetic Unit in order to simulate the point kinetic equation it will be interfaced with keypad, IEEE-754 floating point format, LCD,UART modules[3].

Main control Engine: This module will have state machine which controls all the modules.

LCD Interface: This module will be having LCD initialization LCD write functions. It will display the simulation results[7] .

UART: This module used for communicating with host PC through the RS-232 port. This is used to send the simulated results to the host PC. In FPGA UART-Tx module will be designed using HDL[15].

3.3 Main Controller State Machine

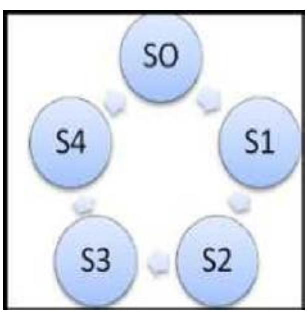

Figure. 4. Main Controller State Machine.

Figure 4 shows the main controller state machine. The main control engine consists of five states s0,s1,s2,s3,s4.

S0: In this state, it receives the input parameters through Keypad interface it immediately enters the S1 state.

S1: In this state, it converts BCD to Fixed format enters the S2 state.

S2: In this state, it converts fixed to IEEE-754 floating point format and enters the S3 state.

S3: In this state, PKE Unit computes the point kinetic equation and enters the S4 state.

S4 : In this state PKE simulated results are displayed on LCD and transmitted to the host PC using RS232 port.

4. SIMULATION RESULTS

Initial testing and verification of the Register Transfer Level (RTL) VHDL code is performed through wave signal analysis using the Model-Sim RTL systems simulation CAD tool. For independent module based testing, custom Verilog test-benches are written to test all possible input combinations to the RTL circuits. These test- benches are then run on the ModelSim Simulator and their outputs are visually verified. The PKE simulator system takes the inputs ti and tf from the user, simulates the PKE and gives the output n (t).

4.1. Timing Summary

Minimum Period =2.989ns.

Minimum Input Arrival Time Before Clock=3.035ns Maximum Output Required Time After Clock=3.718ns Maximum Combinational Path Delay=3.108ns.

Pad to Pad Delay:

Source Pad	Destination Pad	Delay
RESET	LCDRESET	4.292ns

Table.1 Timing Analysis

4.2 Implementation Results

The PKE Simulator can be implemented on Altera Cair Board. A screenshot example is shown in Figure 5.

Figure.5. PKE Simulator System.

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V. CONCLUSION AND FUTURESCOPE

Based on Survey of the present FPGA Based PKE Simulator described is widely used in Nuclear power plant. The PKE simulator system is designed and implemented on Altera Cair board .It is found that the system is able to operate in thermally challenged environment .The PKE Simulator finds the neutron population in the nuclear reactor by simulating the equation. The design has been tested for verification and it is working according to the specifications.

The future scope of this work includes the followings.

10-Bit DAC can be designed and interfaced with FPGA .In this project, we have designed FPGA based PKE simulator for simulating the PKE, we get the neutron population. In future10-bit DAC can be designed for generating the neutron flux voltage and develop the hardware module for the PKE Simulator system.

The IEEE-754 double precision format would be used to increase the accuracy of the System.

UART Receiver can be designed and interfaced with FPGA for receiving the initial parameters from the user.

Design the alphanumeric Keypad Interface would be used to enter the start/stop of the simulation.

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ACKNOWLEDGMENT

We the authors of this paper would like to grateful acknowledge with thanks to SAIT management,Principal,HOD of ECE Bangalore & VVIET management,Principal,HOD of ECE Sholapur, for providing us the infrastructure and giving us an opportunity to carry out the work.

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