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Efficient VLSI Design & Implementation of Digital PID controller for Classic Temperature Controller

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***Abstract*— This paper explains a method for the design and implementation of digital PID controller for classic temperature controller based on Complex Programmable Logic Device (CPLD) device. It is more compact, power efficient, EEPROM based, cheaper and provides high speed capabilities as compared to software based PID controllers. The proposed work is based on the implementation of digital PID controller for the Classic temperature controller. The PID controller is designed using QUARTUS and Simulink to generate a set of parameters associated with the desired controller. The architecture was implemented on hardware to give flexibility and compatibility with the Simulink design of a controller. The controller parameters are then included in VHDL that implements the PID controller for temperature control on to CPLD. QUARTUS program is used to design PID controller to calculate and plot the time response of the control system as per temperature variation.**

***Keywords*— Architecture on Hardware, VHDL Programming, Digital PID controller, Temperature sensor, CPLD, QUARTUS.**

I. Introduction

The objective of our project is maintaining the temperature of a heater using digital PID controller. Generally, an implementation of temperature controller includes the use of ON/OFF controller. This ON/OFF controller has been used where Precision doesn't matter. This method has a disadvantage in switching and overshoot because the operation of heater will off after desired set point that makes heater still hot which further raise temperature and simultaneously overshoot changes. Therefore, FPGA-based digital PID controller is proposed but the FPGA is expensive and requires external memory and uses larger area. Thus implemented on CPLD-based digital PID controller is proposed because the operations on CPLD are hardware compatible operations and digital PID controller has precision control over temperature of heater [1].
More flexible and compatible architecture implemented on hardware for the given temperature control application.
Finally, system functionality verification using CPLD and comparisons of implementation was done. Today's high-speed and high-density CPLD's provide practical design alternatives to ASIC based implementations [3].

II. Digital PID Controllers

A proportional integral derivative controller (PID controller) is a control loop feedback mechanism broadly used in commercial control systems – a PID is the most commonly used feedback controller. A PID controller computes an "error" value as the difference between a measured process variable and a desired setpoint. The controller needs to minimize the error by adjusting the process control inputs [2].

The PID control technique is named after its three correcting terms, whose sum consists the manipulated variable (MV). The derivatives, proportional and integral terms are added to calculate the outcome of the PID controller. Defining as the controller outcome, the final form of the PID algorithm is given as:

$$u(t) = MV(t) = K_p\, e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t)$$

Where K_p: Proportional gain, a tuning parameter
K_i: Integral gain, a tuning parameter
K_d: Derivative gain, a tuning parameter
e : Error
t: Time or instantaneous time (the present)

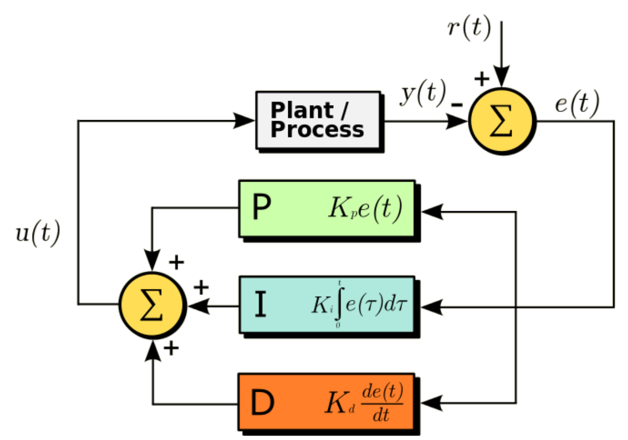

Fig.1 Digital PID controller

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Thus, in order to design digital PID controller we use the above architecture as the base which will improve hardware efficiency [10].

III. Principle Of Operation

Consider the block diagram of digital PID controller for temperature controller as shown below:

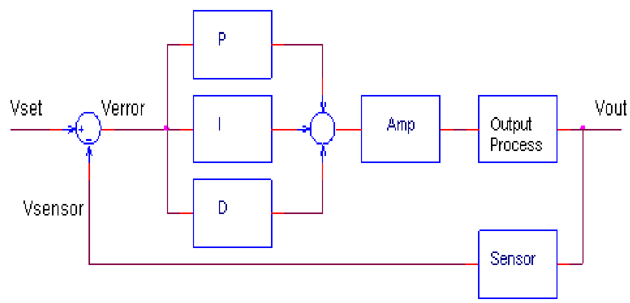

Fig.2 Block diagram of Digital Control System

The PID controller would receive input as the actual temperature and controls a switch that regulates the temperature of heater. The PID controller automatically finds the correct (constant) temperature to the heater that holds the temperature steady at the setpoint. In spite of the temperature bouncing back and forth among two points, the temperature is held constant. If the setpoint is lowered, then the PID controller automatically decreases the amount of current flowing to the heater. If the setpoint is increased, then the PID controller automatically raises the amount of current flowing to the heater.

A PID controller is a process control with the following characteristics:

- Continuous process controls the Analog input (also known as "measurement" or "Process Variable" or "PV")
- Analog output (referred to simply as "output")
- Setpoint (SP)
- Integral (I), Proportional (P), and / or Derivative (D) constants.

Once the PID controller has the process variable equal to the setpoint, a good PID controller will not change the outcome. It is desired to maintain the outcome very steady (not changing). If the temperature (temperature sensor through heating element) is constantly changing, in spite of maintaining a constant value, this case could more wear on the control element [2].

IV. Architecture On Hardware

The temperature sensor ranges from 0 to 100℃ and convert it into equivalent 10mV/℃. This analog voltage gets converted into equivalent 8-bit digital voltage through ADC. These 8-bit inputs are applied to VLSI kit where PID controller controls a switch that regulates the temperature of heater corresponding to desired set point [5].

The programming in VLSI kit is done by VHDL language and that builds PID controller on kit.

The block diagram for hardware of digital PID controller for classic temperature controller:

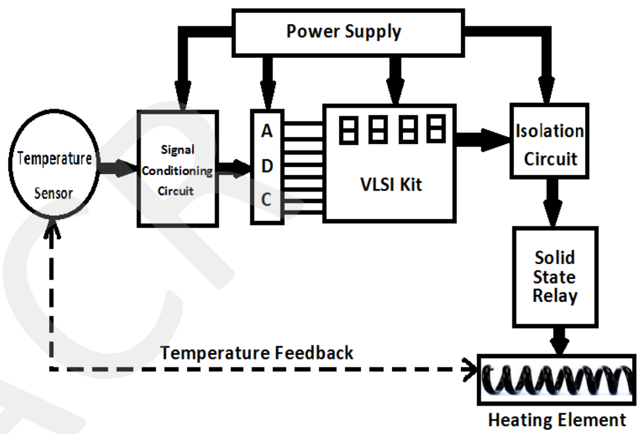

Fig.3 Block diagram of architecture on hardware

The power supply is to convert AC voltage into DC voltage since all ICs and components operate on positive 3 to 5V. The isolation circuit is to isolate DC circuit from heater which operates on AC voltage [5].

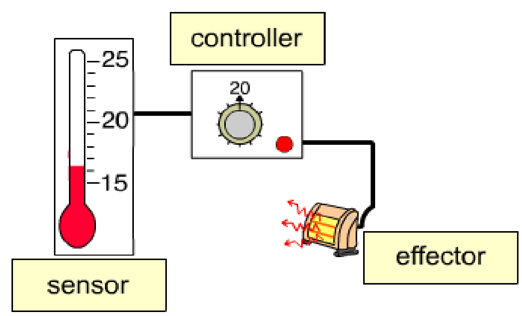

Fig.4 Controlled Variables of Temperature Control

V. CPLD Implementation

QUARTUS implements the design by VHDL programming and also takes care of the synchronization and interfacing problems. Outputs from the digital controller are functions of current and past input samples, as well as past output samples - this can be implemented by storing relevant values of input and output in registers. The output can then be formed as per VHDL coding [9].

The VHDL program burn in the ALTERA chip on hardware (CPLD). CPLD is a combination of a fully

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programmable AND/OR array and a bank of macrocells. The AND/OR array is reprogrammable and can exhibit a multiple logic functions. Macrocells are the functional building blocks that exhibit sequential or combinatorial logic functions, and also have the attached ductility for complement or true, along with changed feedback paths [7].

VI. Results

In fig.5 the simulation results of CPLD based Digital PID controller for classic temperature controller.

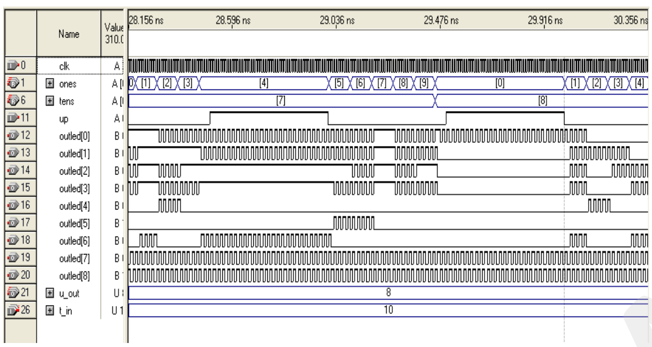

Fig.5 Results of simulator waveform

The QUARTUS software generates the output waveform corresponding to input change of temperature on simulation. This simulation is executed by random values chosen in inputs. RTL level synthesis of simulation is generated by QUARTUS software after code is compiled. The RTL level synthesis is the lowest level representation of circuitry from QUARTUS software.

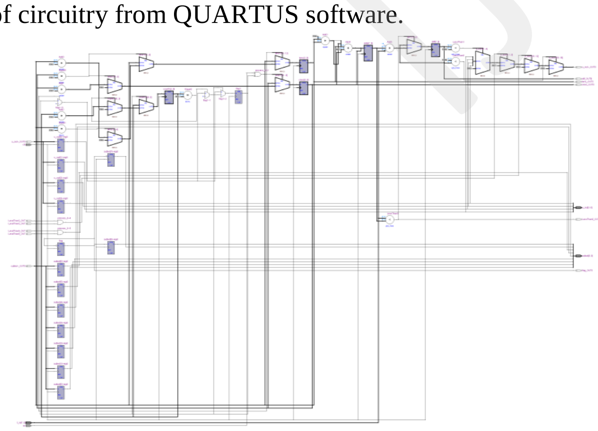

Fig.6 RTL level synthesis of a simulation

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VII. Conclusions

Implementing the digital PID controller for temperature controller on CPLD gives an opportunity for bulk production of ASIC since VLSI technology is used. In designing and implementing the digital PID controller for temperature controller one major thing which affects the performance of controller and its effects on plant is the effective hardware utilization. Also implementing PID controller on CPLD improves features accuracy, speed, compactness, power, and cost. In future work, many PID controllers for temperature controller can be implemented on a CPLD chip higher rating that reduces the hardware design.

The advantages are high processing speed, reduced power consumption and hardware compatibility for implementing on CPLD.

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