DESIGN AND IMPLEMENTATION OF FPGA BASED MULTIPURPOSE REAL-TIME CONTROLLER FOR HYBRID STEPPER MOTOR

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Abstract – Stepper motors are one of the most widely used special electrical machine where controlled movement is mandatory. Hybrid stepper motors (HSM) exhibit high static and dynamic torque and run at very small step angles. They are also used in extensive industrial applications. Due to the development of digital control systems, HSM became more attractive to be used in robotics applications, nuclear reactors and computer numerical control machines where they have to perform high-precision positioning operations without any feedback sensor. The conventional HSM control using microprocessors and microcontrollers have limitations like sequential program processing, increased delay etc. which makes real time control a burden. The objective of this paper is to design and implement a cost effective multipurpose real-time controller using a single Field Programmable Gate Array (FPGA) platform for HSM. The Parallel processing power of FPGA is utilized here to implement multiple stepper motor controls. Hence, this work focuses on the hardware design and implementation of a high performance FPGA based algorithm developed using Very High Speed Integrated Circuit Hardware Description Language (VHDL) coded in Xilinx ISE, simulated and verified in ModelSim software which controls the HSM through driver circuit with dual H-bridges which provides simultaneous real-time control over speed, position, no of steps, switching modes and direction of the stepper motor within the motor constraints according to the input control logic given by the user.

Keywords- Stepper motor, Hybrid stepper motor, FPGA, VHDL,

1. INTRODUCTION

Stepper motors are electromechanical incremental devices that convert electric pulses to shaft motion. The basic operation of the stepper motor allows the shaft to move a precise number of degrees each time a control pulse is sent to the motor. Stepper motor can be a good choice whenever controlled movement is required. It is highly effective in motion control application for high precision and high performance of torque control. Instead, it is low cost, simple and offers better torque performance over wider speed ranges [1]. The stepper motors are mainly divided into three the permanent magnet stepper motor, variable reluctance stepper motor and hybrid stepper motor for industrial applications HSM is used widely because of its precise motions [2]. HSM is operated with the combined principles of the permanent magnet and variable reluctance stepper motors in order to achieve high torque in spite of small motor size. Hybrid stepper motors exhibit high static and dynamic torque and run at very small step lengths, so they are used in a wide variety of industrial applications.

The control of Stepper motors has always been the field of interest of many researchers and scientists. The need to control the speed and/or the position of stepper motors has countless applications in our daily life. The conventional stepper motor controls using microprocessor and microcontrollers are used for many applications. But the problems with these controllers are they fails to do multiple controls of HSM motor in real time due to the limitations like sequential processing and increased delay. In this aspect the stepper motor control using much efficient and cost effective FPGA platform will be an improvement. FPGAs have higher processing speed, offer fast time to market, low design/manufacturing cost and risk, extremely high processing performance and
In this paper a FPGA based prototype controller is instigated which are controlled by external control switches and results in simultaneous real-time control of speed, direction, position, switching modes (angle) and number of steps of Hybrid stepper motor. The implementation of this controller increase multipurpose dynamic applications of hybrid stepper motor in many areas like robotics, industry’s, machine tools etc. where precise position control is required.

II. HYBRID STEPPER MOTOR

Hybrid motors are a combination of both permanent magnet and variable reluctance stepping motors. The rotor for a hybrid stepping motor is multi toothed, like the variable reluctance motor, and contains an axially magnetized concentric magnet around its shaft. They generally can step at rates higher than permanent magnet motors, so the hybrid stepper motor is better than the other two types of the stepper motor. Hybrid stepper motor (HSM) can be easily operated with the use of the digital and open loop control techniques so HSM is used extensively throughout the world for the precise motions. Moreover, stepper motors are easily used with modern digital equipment [4] because of those advantages different kinds of stepper motors have been widely used in the computer peripheral, automated machinery, robotics application, belt conveyers etc.

III. FIELD PROGRAMABLE GATE ARRAY

FPGA is a device that contains a matrix of reconfigurable gate array logic circuitry. When it is configured, the internal circuitry is connected in a way that creates a hardware implementation of the software application. A Field Programmable Gate Array (FPGA) offers significant advantage over the off shelf Application Specific Standard Product (ASSP) solutions in the areas of performance, flexibility and inventory control [5]. FPGA is superior to other control means due to its ability of doing parallel processing. That is ability to do much more tasks in parallel than sequential as in microprocessor so real time control of a stepper motor is a burden in case of microcontroller or microprocessor based controls. FPGA is a programmable logic device, so the advantage is that we can control the hardware resources by coding, while Micro-controller cannot do that because of it's fixed in hardware. For the tasks which are accomplishing multiple controls in this proposed HSM controller a single microcontroller of similar cost of Spartan 3A FPGA board is not sufficient or for implementing the same in a single microcontroller it have to use a more efficient microcontroller of higher cost which also results in complexity of driver circuits and software programing.

IV. FPGA BASED MULTIPURPOSE REAL-TIME CONTROLLER FOR HYBRID STEPPER MOTOR

This paper is meant to propose an FPGA based stepper motor control which over comes all the limitations of the conventional stepper motor controllers. This work starts with designing a driver and dual H bridge circuit which drives the hybrid stepper motor (HSM). The ability of parallel processing of FPGA is actually utilized to implement simultaneous real time controls of stepping modes, speed, position, direction of rotation, no of steps of HSM for achieving this FPGA is programmed using the control logics using VHDL (Very High Speed Integrated Circuit Hardware Description Language) in Xilinx ISE (Integrated Synthesis Environment) software and is simulated and verified using the ModelSim simulation software. The control signals from FPGA is used to drive the HSM through a driver circuit which uses TLP250 IC with optical coupling which is connected to the dual H bridge circuit designed using IRF840 MOSFET that facilitate the controller to control a wide range of stepper motor power rating which results in multiple applications of stepper motors. The control of the motor is done in real-time with external control switches which provide the logic for FPGA from the end user.
V. PROPOSED SYSTEM

The proposed system is shown in Figure 1 which consists of 7 externally connected switch assembly where the first two switches provide the speed control. The two switches provide 4 switching conditions \((2^2 = 4)\) and 4 speeds then the 3rd switch are to enable the motor means position control of the stepper motor. Then the 4th switch is to provide the direction control by switching the direction of stepper motor will be changed instantaneously. Then last three switches can provide 8 control logics in that five switching patterns are used for the switching mode control which results in angle control and no of steps control. That is three for switching 3 switching mode consisting 2 full stepping schemes and one half stepping scheme remaining 2 switching logics are used for number of steps control.

The switching assembly is connected to FPGA for providing the input control given by the user and the FPGA is coded in Xilinx ISE using VHDL program language thus the FPGA controls the stepper motor through dual H bridge circuit which is driven by a driver circuit which is designed to switch the H bridge circuits as per the control pulse from FPGA. For the proposed system a 4 phase 8 pole 12v HSM of 1.8° minimum step angle is used. The driver and dual H bridge circuits are implemented on board and they are assembled together with seven 230/15v transformers for power supplying the entire system, external switch assembly, and Spartan 3A XC3S50A FPGA board and hybrid stepper motor.

VI. FLOW CHART OF FPGA PROGRAM

The Figure. 2 shows the flow chart of the program logics used to program the FPGA. The code is developed in such a way that it must utilize the parallel processing power of FPGA to implement the real time control of hybrid stepper motor. The controls which are implemented with
the programs on FPGA are the 4 speed control, position control, direction control, 3 switch modes by that 3 switching modes two angles are controlled in this controller prototype, number steps control is also there here include 8 steps and 4 steps at a time with a certain delay to show the no of steps

VII. CONTROL LOGIC FOR HSM CONTROL

The hybrid stepper motor is controlled in this work according to the control given by the user. For providing the input control 7 switches are set upped externally. The switch provides the input logic such that when it is on down position (ON) the logic is 1 and when it is in up position (OFF) the logic is 0 and these logics from the switch are taken in combination for controlling the HSM. The speed control is done by using the 12MHz primary clock of FPGA where this clock used by program defined clock to generate different speeds, for this the switches S1 and S2 are used. During FPGA coding this control is given using an “if” condition that is “if (EN=’1’) then” means the motor will only run if the logic from the switch S3 is 1 and its stops when the switch S3 is 0 is used for position control. By changing the sequence of phase switching as the input from S4 switch the direction is controlled. For implementing the switching mode control and there by achieving the angle control 3 switches S5, S6, S7 are used by this 3 switches 2^3=8 controls can be obtained but here only five switching logic are used. Of these five controls 3 control inputs from the 3 switch combinations 000, 001, 010 are used. The three schemes implemented are 2 full stepping schemes and one half stepping scheme which results in two angle controls 1.8°, 3.6°. The number of step control is also important in terms of industrial, robotics or any application based controls like belt conveyers, robotics arm, control of control rod movement in nuclear reactor, etc. so in these aspect the FPGA is programmed in a such a way that this prototype stepper motor controller will using two inputs from the external switches S5, S6, and S7 in order to provide 8 steps at a time and 4 steps at a time.

VII. FPGA PROGRAMMING AND SIMULATION RESULTS

The coding software used to implement the control logics for this FPGA based multipurpose real-time controller for hybrid stepper motor is done using Xilinx ISE design suite 14.1 in Very High Speed Integrated Circuit Hardware Description Language (VHDL) and by using the behavioral model for programing. After coding the program is converted into bit file is transferred from the PC directly to the FPGA using the USB-JTAG port and flashed to the integrated flash memory of Spartan 3A. The program is simulated using Modelsim simulation software for understanding the multiple control schemes of stepper motor and the simulation results for each controls are given below,
VIII. DRIVER CIRCUIT WITH DUAL H BRIDGE

The driver circuit with power supply is shown in Figure 9 The 230/15 is step down by the transformer and it is fed to the rectifier which converts ac to dc and there a capacitor of 1000uF is provides as the filter capacitor and then it is connected to the regulator IC 7815 which regulates the power to 15V regulated DC the next component in the circuit is 100uF which acts as DC stabilization and filter capacitor also a LED is connected with a 1K resistor to indicate the voltage in the circuit. For controlling the MOSFET’s used in the dual H bridge circuit TLP250 MOSFET driver is used. The TLP250, like any driver, has an input stage, an output stage and a power supply connection. What’s special about the TLP250 is that the TLP250 is an optically isolated driver, meaning that the input and output are “optically isolated”. The isolation is optical, the input stage is an LED and the receiving output stage is light sensitive. The H bridge circuit used here is constructed using MOSFET’s of IRF840 as switch which has the ability to control motor up to 8 Amps rating so it facilitates steppers motor control of wide power range

IX. FINAL HARDWARE SETUP

Figure 9. Driver circuit with power supply

Figure 10. Final hardware setup
X. CONCLUSION

The design and implementation of the proposed hybrid stepper motor controller was done. The hardware setup succeeded to achieve the objectives of the work and it outperforms the conventional stepper motor controllers using microcontrollers and microprocessors with the excellent parallel processing power, flexibility in control, speed and multiple controls with feeble delays using cost effective FPGA platform. The control logics were created and incorporated in Spartan 3A XC3S50A FPGA board programed using VHDL language on Xilinx ISE and the programs was successfully simulated and verified in ModelSim simulation software. Hardware implementation of Driver circuit and dual H bridges with external control switches for user controls are instigated. The controller has an added advantage that it can control stepper motors of wide power ratings without any modification in the hardware setup. The prototype controller has accomplished simultaneous real time control of HSM with multiple controls according to control switches inputs. This FPGA based control will results in more dynamic multipurpose applications of hybrid stepper motor.

REFERENCES