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Review Article

Integration of Home Automation and Security System Controller with FPGA Implementation

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Abstract: A home automation system is essential for promoting a safe and comfortable living environment and notable energy conservation for the user. However, the system's favour had been obstructed by cost, power usage, inadequate security, complexity, and no emergency backup power. Current home automation systems with controllers were limited by their number of ports, fixed architecture, non-durable and non-parallel executions. Keeping this in view, integration of home comfort system, security system, and the automatic load transfer switch features are proposed using the base of Cyclone IV E: EP4CE115F29C7 FPGA Board (DE2-115). The top-level module is developed via Verilog Hardware Descriptive Language (HDL) with the bottom-up technique and used test bench for functional verification via ModelSim-Altera. The PWM method was applied to the lighting system to control the dimming of light through its digital signals via a maximum 500000 counter to improve energy efficiency for the proposed design. In this project, 200Hz pulses are successfully simulated to prevent visible flickering of lights in duty cycle generation. The light intensity of 40% and 100% are verified and successfully generated according to the inputs provided by the status of the LDR sensor and IR sensor. The proposed controller gives correct corresponding outputs to the 13 actuators based on the detected input stimuli. The proposed design utilized a total of 162 (<1%) logic elements, 32 registers, and total pins of 74 (14%). The proposed design successfully integrated the three-sub module and provided control on comfort and security system operations to prevent service failure during power blackout conditions at the top-level and utilized a low ratio of the FPGA.

Keywords: ***FPGA; Home Automation; PWM; Security***

1. Introduction

Home automation technologies significantly improve the human lifestyle through the mechanized monitoring and control of home devices. Home automation is sometimes referred to as a 'smart home' as it comprises one or more automated systems that control the basic home appliances spontaneously or remotely. The scheduling and automatic operation of these home devices such as the curtains, water sprinklers, security systems, and more can be implemented into the entire home automation network [1]. Energy efficiency has increased via implementing automation in the home system [2]. Benefits of adopting a home automation system is further explained in [3] such that convenience, comfort, flexibility, security, and electricity usage optimization can be achieved. Obadan *et al.* [4] defined the typical home automation system control the operation of various home actuators simultaneously through the central control unit where these home devices must be specifically developed to work together and with the majority of

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commercially available home automation control systems. In [5], components in the home automation system had divided into three categories which is sensors, controllers, and actuators. In [6], Malaysia's home automation system adoption rate in 2017 only has 1.4% compared to 50 of the world's leading digital economies such that United States consumed 26.5%. However, the penetration of the system hit up 10.7% in 2020 and expected to increase 9.5 % in the next five years.[1] System disadvantages, such as complexity, cost, power consumption, insufficient security system and emergency backup power, can be the cause of poor home automation deployments.

The current home automation system with microcontroller consists of several constraints such as less speed, does not operate in parallel, and is difficult to introduce to the market. FPGA. Suresh and Mastani [7] proposed a cost-effective home automation system with an FPGA controller to resolve the limited number of ports, fixed architecture, non-durable, less speed, and not expandable for the new devices brought by the microcontroller. The system proposed is eased to use for expanding the system by using the same FPGA. In [8], FPGA had been replaced Arduino or other microcontrollers as the home automation system control unit due to it able resolve the constraints such as lower speed and non-parallel operation. Moreover, FPGA was used as the control unit for the home automation system, which worked in two ways (manual and mechanized) to offer a simple and low-cost solution with the ability to be rewired in electronic format compared to the other microcontrollers [9]. Sharma *et al.* [10] had also proposed a method for replacing microcontroller with FPGA in home mechanization due to FPGA had more I/O ports, which enable many sensors to be connected and monitored at once while it was able to act as a microprocessor or microcontroller. In [11], FPGA was adopted as control unit for the security and home automation system due to its ability to perform all the parallel task and user programmable coordination functions. This showed that FPGA is effectively replaced the microcontroller in the current home automation system.

Bawiskar and Agrawal [12] proposed a cost-effective home security system using FPGA with various sensors (active infrared motion detector, smoke sensors, magnetic sensors, etc.), which only provided a narrow range of intrusion detection and lack of user verification for the home entry. In contrast, a system that combined comfort and security aspects by employing FPGA was proposed by Parvin et al. [13]. Their security system is an advancement from [12], whereas it consists of a complete user verification system and an automatic door locking system. However, the system proposed in their study only focused on the air conditioner's temperature management by using the LM35 (temperature sensor), and the door will only remain unlocked for a short while. To create an automated home, a system with automatic door-opening, a lighting system, and an air conditioner had been suggested in [10], but there was no security system. An automation system restricted for room condition is proposed by Sudiro *et al*. [14]. They had developed a cost-effective FPGA controller capable of instructing the relay in controlling the switching of light and fan. However, the indoor light is unable to switch off automatically during the day.

Based on previous research, home automation and security system controller have been designed and implemented using FPGA based on Verilog code is proposed in this research on simulation level. FPGA had been chosen to replace the microcontroller as it does not have fixed architecture, more I/O ports, and lower power consumption during simultaneous operations for the proposed system [15-16]. The proposed project consists of integrating home automation and security system as well as the automatic load transfer switch features to prevent power blackout via mechanized switching between main and auxiliary power sources to load. Pulse width modulation (PWM) approach was used in the proposed project for boosting the system's efficiency in lighting control wise.

2. Home Automation and Security System Controller Design

A bottom-up technique was used to design the lower-unit block separately then integrated into a single top-level unit via Verilog code implementation. A testbench is written for each module and compiled using the EDA tool (ModelSim-Altera) for functionality verification. This proposed design is developed in the base of Cyclone IV E: EP4CE115F29C7 FPGA Board. This Cyclone IV E variant was chosen in the Cyclone IV devices as it enabled the system design in to be designed with the least amount of power and the most functionality for the least amount of money [17].

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[1] Statista. (2021, May). *Smart Home (Malaysia)*. Available: https://www.statista.com/outlook/279/122/smart-home/malaysia#market-globalRevenue.

The system design is divided into three main systems: security system control, environment and comfort system control, and automatic load transfer switching control. The sub-systems for the security system control were the alarms which have classified into three categories (Window, Fire, and Door). The sub-systems for the environment and comfort system control are lighting system control and heating, ventilation, and air conditioning (HAVC) system.

The proposed integrated design was depicted by the dotted line in Fig. 1. At the same time, sensors will act as the inputs for the comfort and security main control system. The overall proposed system consists of 13 outputs, whereas the first seven outputs were the outputs for the security system control and the last six outputs were categorized into the environment and comfort system control. Fig.2 described the hierarchical design for the proposed system in the register transfer level (RTL).

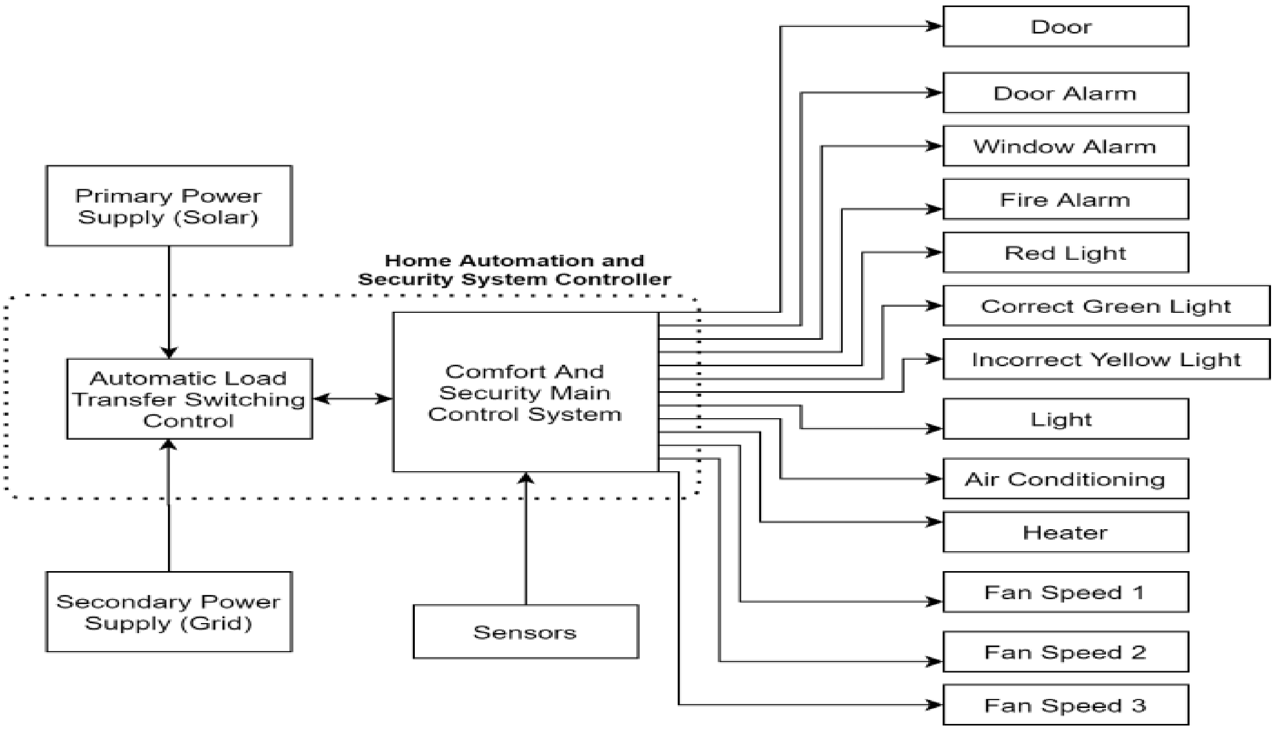

Figure 1. Block diagram of the proposed integrated design

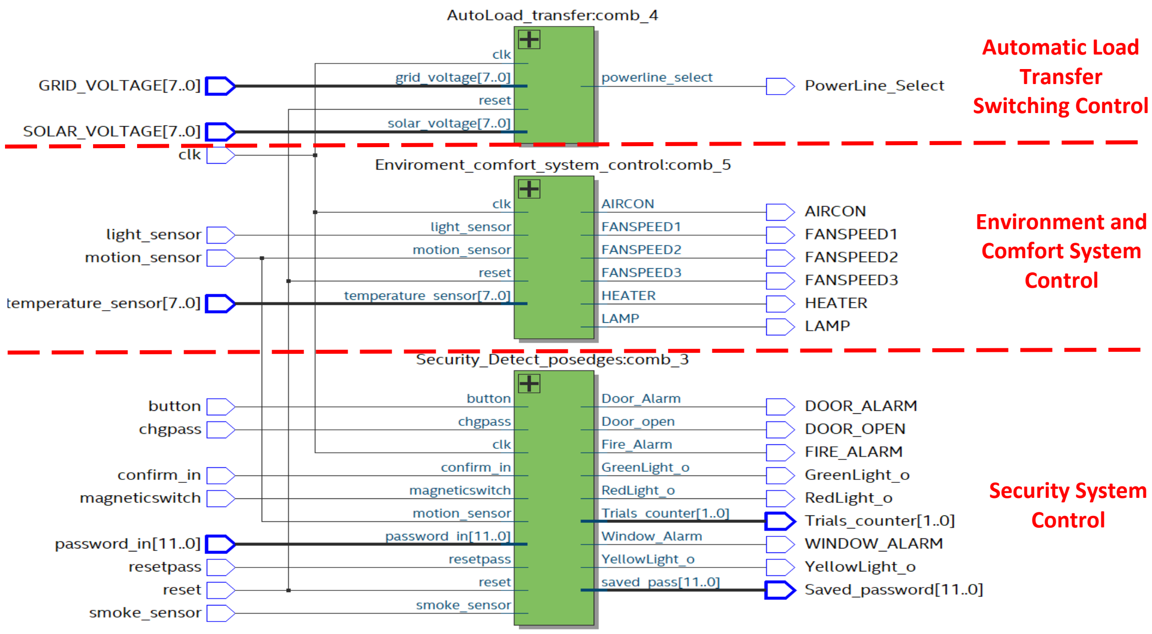

Figure 2. RTL schematic diagram for top-level module of home automation and security system controller

2.1. Security System Control

Three subsystems (window alarm, fire alarm, and door alarm) were well integrated to the system which providing security control. Its system operation flow had been shown in Fig. 3. Active IR sensor and magnetic switch sensor were chosen as the input for the window alarm system. The active IR sensor consists of an infrared emitter and a receiver. The emitter will emit infrared at a certain frequency, and the receiver will capture the reflected infrared (meets obstacle). The magnetic switch sensor operation is magnetic-dependent. In other words, the magnet had to be the close circumference of the metallic reeds to ensure a continuous current flow; else, it will give a binary 0. The smoke sensor (MQ2 gas sensor) was referred to as the fire alarm system's input. This smoke sensor had a fast response time and cost-effectiveness while preventing false alarms due to the temperature changes in the home environment [18]. For the user verification stage, a 12-bit hexadecimal passcode door lock acted as the input for the door alarm system. It consists of a passcode checker for verifying the input passcode and the saved passcode.

Once the verification failed, the password verification stage would only trigger the alarm system. The fire alarm system would continue checking for the smoke sensor's status, and it is designed to be independent of other alarm systems. This system continues to check the status of the IR sensor and magnetic switch sensor for the window alarm system.

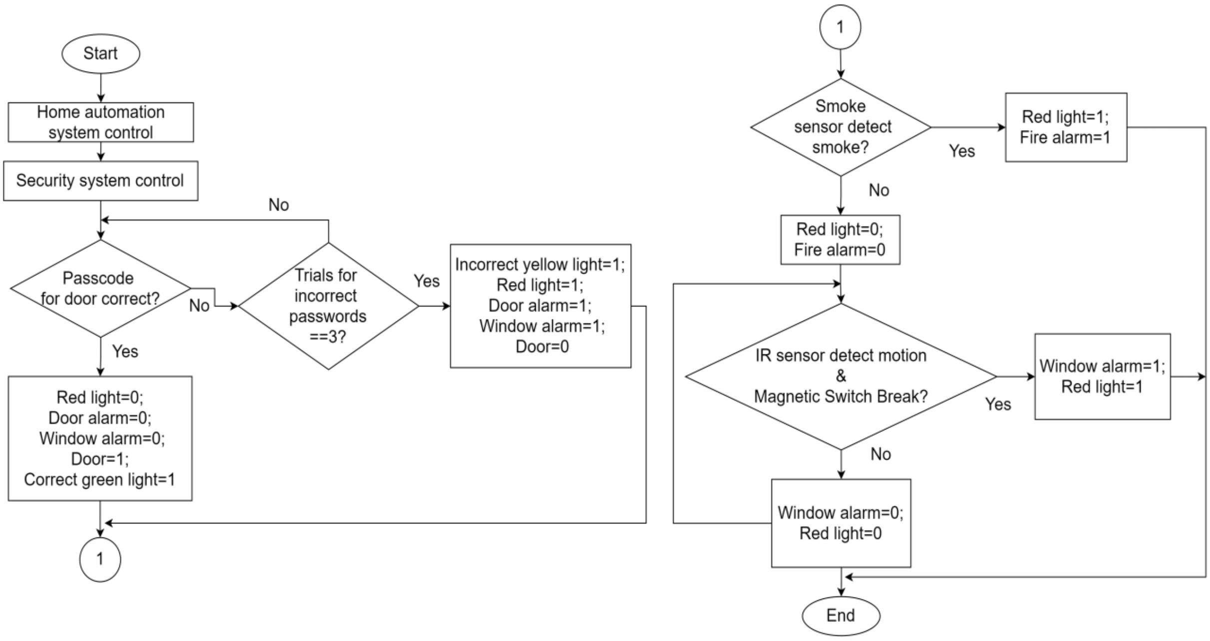

Figure 3. Flowchart for the security system control operation

2.2. Environment and Comfort System Control

Two-sub system (HAVC and lighting system control) were well fused into the system which providing the control for the house environment and its surroundings temperature. Its system operation flow had been shown in Fig. 4. This system was designed to monitor the status of the LDR sensor and IR sensor in the lighting system control module and then enter the temperature management of each actuator like air conditioner, heater, and fan once there was a motion. The LDR sensor controls the mechanized lighting system to switch on and off during the day or night. Temperature management for the rest of the actuators was implemented using an 8-bit temperature sensor (LM35). It is an integrated-circuit (IC) temperature sensor which had high precision and able to provide a linearly proportional output voltage to Celsius. It had high accuracy compared to the thermistor, and it is prone to oxidation [19]. These actuators will turn on according to the specific temperatures, and the fan will turn on with the corresponding speed based on the home environment temperature.

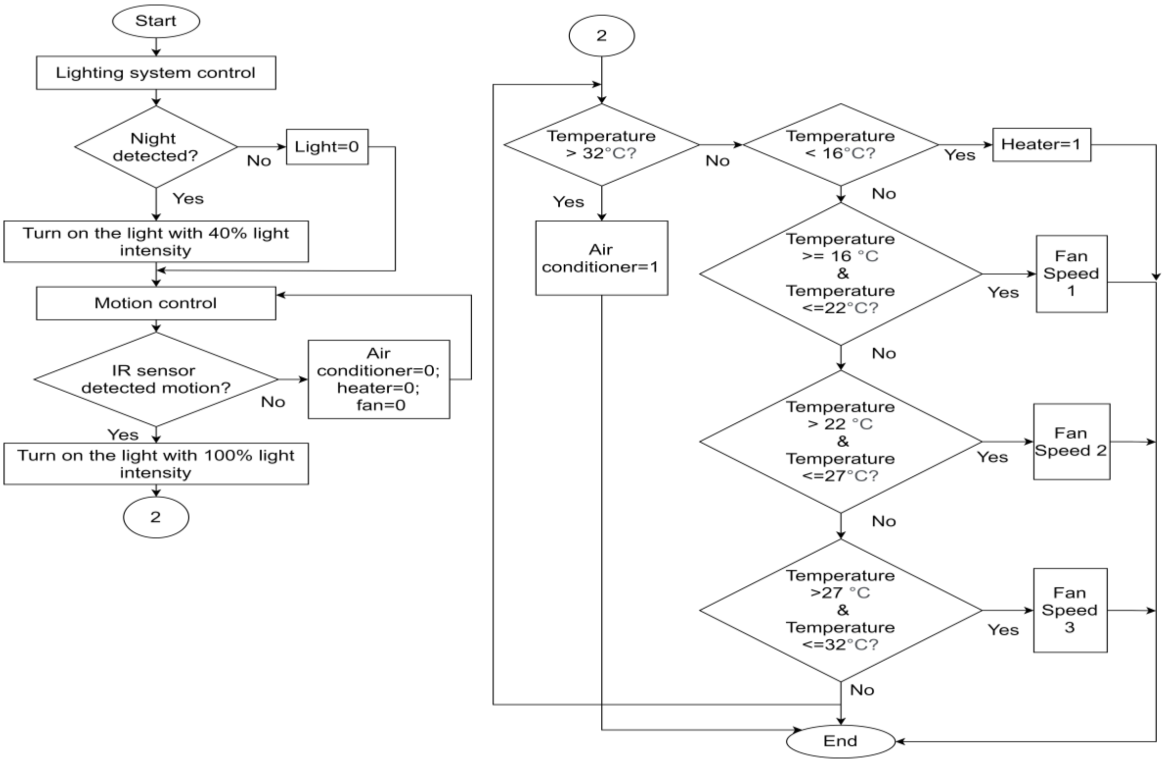

Figure 4. Flowchart for the environment and comfort system control operation

2.3. Automatic Load Transfer Switching Control

This system is designed based on automatic load transfer switch features, capable of blackout prevention. The home automation and security system would not be interrupted during no power conditions, especially for the internet router-dependent system. The Solar PV system was chosen as the primary source, while the grid was chosen as the secondary source. The suppliable voltage range for each power source is between 200V to 240V. Mechanized switching event will happen when the solar battery indicator is not within the range of the primary source. Its operation is described in Fig. 5. 8-bit voltage level for each primary and secondary source had been designed.

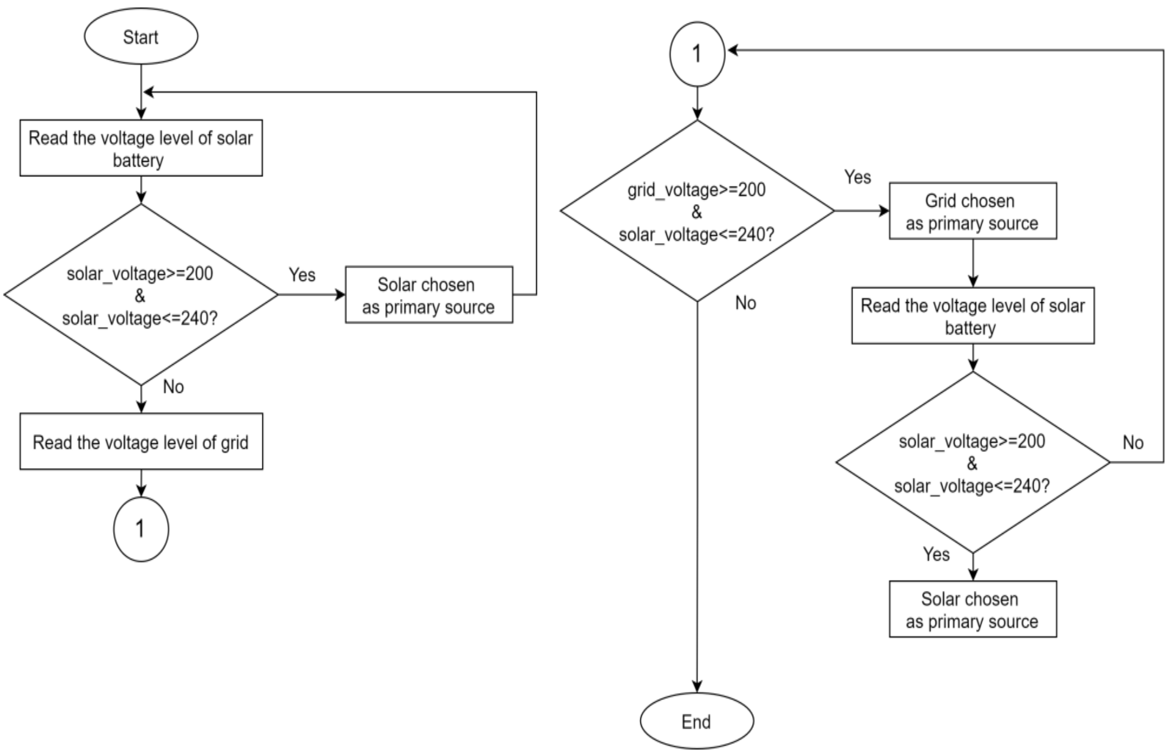

Figure 5. Flowchart for the environment and comfort system control operation

2.4. Pulse Width Modulation

The lighting system consists of light dimming features such that the light intensity will be reduced to 40% in no presence of a human. In comparison, it gives maximum (100%) light intensity when detected a human's presence. According to Hamza *et al.* [20], the light dimming features controlled by the width of pulses need to be provided with enough pulses rate so that the eyes do not perceive the pulsing but the average amount of light in the pulses. In their study, approximate 200Hz pulses were enough to archive the objective. Thus, pulses generated using the pulse width modulation (PWM) technique for this project are set to approximately 200Hz to obtain a period of 5ms. The simulation period is set to 10ns, whereby a maximum counter of 500000 is needed for the on-time is set for the 100% duty cycle configuration. In comparison, a maximum counter of 200000 for the on-time is set for the 40% duty cycle configuration by referring to "(1)".

$$Duty\ Cycle = \left(\frac{On\ Time}{Period}\right) \times 100\% \quad (1)$$

3. Results

ModelSim-Altera does the verification of the 40% duty cycle design and the 100% duty cycle design. Fig. 6. proved that the simulated pulses for the output were 200Hz which is equivalent to the study in [14]. 40% duty cycle on time is 2ms as shown in Fig. 7 and followed by Fig. 8 which shows the 3ms of simulated-off time for 40% duty cycle. Referring to "(1)", the simulated waveform turned into discovered to correspond to a 40% cycle configuration.

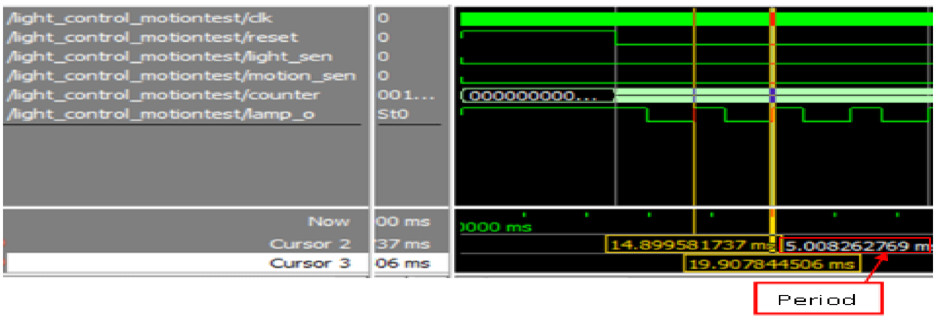

Figure 6. Output waveform with period of 5ms (200Hz)

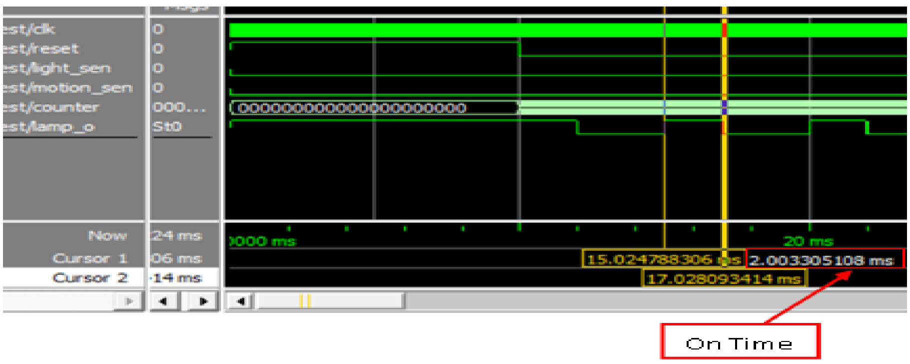

Figure 7. 40% duty cycle (on-time) is 2ms

Fig. 10 shows the overall simulation result for the integration of the three systems. As for the security system control, a button had been integrated for users to ensure the alarm system's deactivation except for the fire alarm system when the user enters the house once the verification is successful. All the systems in this module can be reset except the fire alarm system to keep a house's fire status in monitoring. The smoke sensor gives a high input in the fire alarm system once the combustible gas environment is above the threshold value and activates the fire alarm and red light (warning light). In the window alarm system, the magnetic switch breaks contact (magneticswitch=0), and motion detected (motion_sensor=1) will result in the window alarm and the red light being turned on. As for the door alarm system, the user can reset their password (resetpass=1), and it will clear the saved password. (saved_pass=0). The user only can save and verified the password once they confirm the input password (confirm_in=1). The trails counter will clear the number of attempts for incorrect passwords once the user verification was successful. This results in the green light will be turned on, and the door will automatically open. In contrast, the yellow light will be turned on once the verification failed. The system will enter a freeze state once the counter counted to 3 (Trails_counter=3) and activated the alarm system until a reset is given to the system.

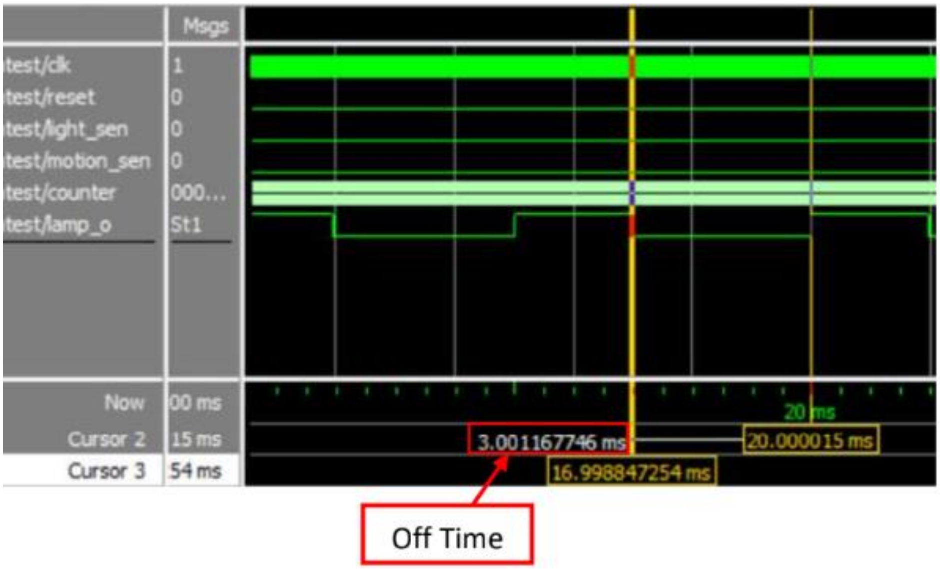

Figure 8. 40% duty cycle (off-time) is 3ms

The simulated waveform of 100% duty cycle is also proved by refer to "(1)" such that simulated on-time and off-time in Fig. 9 are 5ms and 0ms.

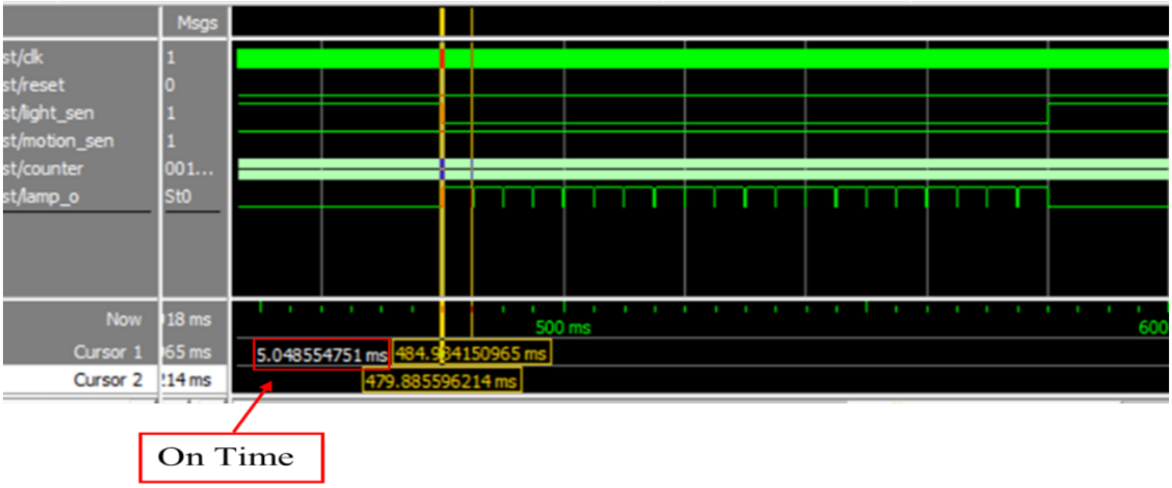

Figure 9. A 100% duty cycle with the on time which is 5ms and off time is 0ms

The light sensor (LDR) will give a low input once it senses darkness which in turn switch on the light with a 40% duty cycle when no motion is detected. In contrast, 100% duty cycle output waveform had been successfully obtained in two conditions: night time and motion detected. As for the HAVC system, the corresponding signal will be sent by this sub-module to the specific actuators after reading the 8-bit temperature sensor input.

When the whole reset is pressed, power line will be automatically switch back to the default (powerline_select=1), which is solar. If both primary and secondary power sources were in the stable or suppliable voltage range, this sub-module would instruct the relay to stay the default power line to reduce the household's electricity bills. However, the secondary power line (powerline_select=0), which is the grid, will be selected once the voltage level of the solar battery is not suppliable or both power sources were not in the voltage range. This design had the ability in preventing the over usage of the solar battery and allow the solar battery to be recharged.

Fig. 11 shows the utilization report of the proposed design (top-level module) via the base of Cyclone IV E: EP4CE115F29C7 FPGA Board (DE2-115). It had utilized a total of 162 (<1%) logic elements, 32 registers, and total pins of 74 (14%). This top-level module does not utilize the virtual pins, memory bits, embedded multiplier 9-bit elements, and PLLs of the FPGA.

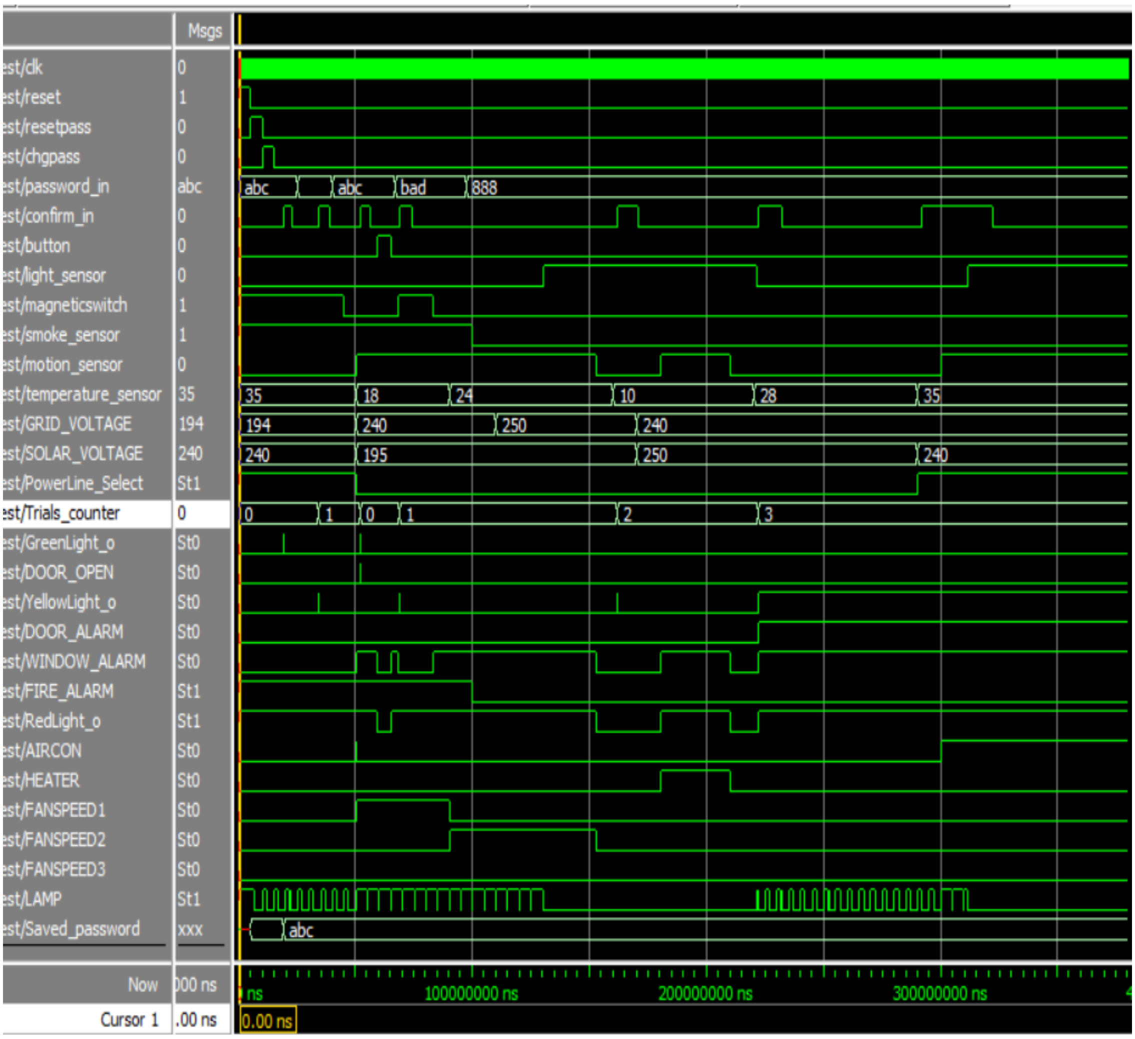

Figure 10. Output simulation waveform for the top-level module (Home Automation and Security System Controller)

Flow Status	Successful - Sun Jan 24 22:21:59 2021
Quartus Prime Version	18.1.0 Build 625 09/12/2018 SJ Lite Edition
Revision Name	HAS_Security_Controller
Top-level Entity Name	HAS_Security_Controller
Family	Cyclone IV E
Device	EP4CE115F29C7
Timing Models	Final
Total logic elements	162 / 114,480 (< 1 %)
Total registers	32
Total pins	74 / 529 (14 %)
Total virtual pins	0
Total memory bits	0 / 3,981,312 (0 %)
Embedded Multiplier 9-bit elements	0 / 532 (0 %)
Total PLLs	0 / 4 (0 %)

Figure 11. FPGA utilization report for the top-level module

4. Conclusion

In conclusion, an energy-efficient controller was proposed to integrate the comfort, security, and power outages prevention features. A total of 200Hz pulses of the duty cycle had been successfully designed and simulated to avoid the visible flickering of light during a dimming light event. The proposed design advances the previous proposed works in terms of additional user verification, automatic load switching, mechanized lighting system with dimming features, and increased home devices in temperature management. The proposed controller can be implemented as a control unit of the home automation system, which had low FPGA resource utilization and provided a safe and quality living environment to the user. It prevented the services, especially for the internet router or network-dependent devices that depending on grid from being interrupted by power blackout and improved the effectiveness of lighting control. It allows the further expansion of the automation system by using the same controller.

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