DESIGN AND IMPLEMENTATION OF A MICROCONTROLLER-BASED PROTECTION SYSTEM FOR SOLAR WALLS

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Abstract

Solar energy, along with the other energy resources such as wind, tidal waves, hydroelectricity, and biomass, accounts for most of the available renewable energy on earth. Due to the growing use of solar and the other renewable energy technologies, many educational institutions are developing undergraduate and graduate courses and programs in renewable energy. The IUT Bethune in France is using a project-based instructional approach to allow the undergraduate electrical engineering students to develop skills in the use of solar energy technologies. This paper describes a renewable-energy based capstone design project conducted at the IUT Bethune.

Introduction

Renewable energy is becoming increasingly important as an energy resource [1]. The renewable energy sources are constantly replenished and will not run out. These sources include sunlight, wind, tides, biomass, and geothermal heat. Renewable energy serves as a replacement of fossil fuels in areas such as power generation, hot water/space heating, and transport fuels. New applications of renewable energy are being constantly developed. Thus, there is a clear need to educate engineering and engineering technology students regarding renewable energy technologies and their applications [2]

Due to the increasing importance of renewable energy, many educational institutions around the world are making significant efforts to integrate the renewable energy concepts into their engineering and technology curricula [3]. Examples of numerous educational institutions providing opportunities for renewable energy studies and research are described in [4, 5, 6, 7, 8].

As mentioned in [3], the IUT Bethune, located in France, is a prime example of an educational institution providing project-based renewable energy education and training. Through design and implementation of solar energy systems, the undergraduate electrical engineering students at IUT learn the renewable energy concepts and applications. The IUT Bethune electrical engineering students conduct capstone design projects which involve the integration of microcontrollers and power electronics with renewable energy systems. Conducting these design-based projects allows students to achieve the following objectives.

1. Students learn the basic concepts and applications of renewable energy.

2. Students are able to analyze characteristics and operational principles of various energy conversion mechanisms.

3. Students learn how to determine hardware and software requirements for solar energy systems design and implementation.
4. Students learn the effective use of hardware and software to develop their projects.

5. Students communicate design and test results in written reports and oral presentations.

This manuscript provides a detailed description of a renewable energy capstone design project conducted by an IUT Bethune electrical engineering student in 2011. The design project is titled "Implementation of an Automatic Protection for a Solar Wall". This protection system is based on the use of a PIC16F877 microcontroller.

Problem Statement

The Civil Engineering Department of the University of Artois maintains two prototypes of a solar wall capable of transferring solar energy into a special brick to store energy in the form of heat. The operation of this wall is depicted in Figure 1.

The bricks of solar wall get warmer upon receiving energy from the sun. As the system gets warmer, the hot air flows in an upward direction to warm up the house. To prevent the circulation of air in the opposite direction, an electrical gate is installed for the cold air intake. The gate is designed so that less air gets inside in one direction. The solar bricks which constitute the wall contain a plastic envelope which melts if the wall temperature is too high. To prevent this problem, an electric shutter is installed next to the wall. The goal of this project is to design and implement an automatic control for the shutter.

Solar Wall Protection Requirements

To protect the solar wall and make it work efficiently, the following variables must be taken into consideration:

1. Temperature – The temperature limits for an efficient operation of solar bricks must be determined to protect the wall from over-heating conditions.

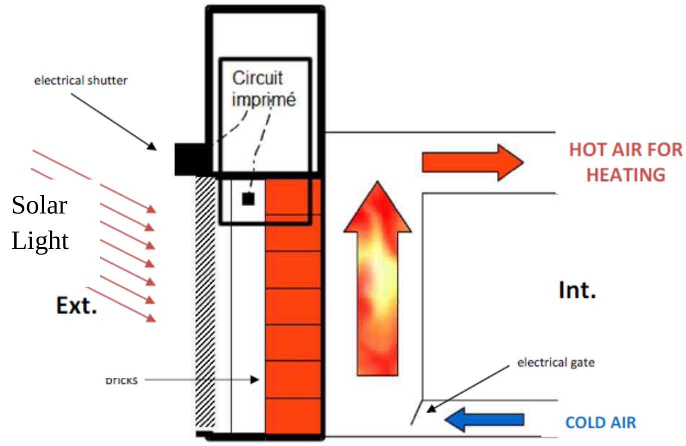


Figure 1: The operation of a solar wall.

2. Light – During the night time, the solar wall does not store energy. It provides energy to the receptor and the shutter has to be kept down to save the stored energy. During the day time, if the weather is cloudy and there is not enough sun light to efficiently warm up the solar wall, the shutter is to be kept down to save the stored energy.

The light and temperature effects on the shutter operation are shown in Figure 2. The shutter will only be open if the temperature and the light conditions are optimum. The upper and lower threshold values for light are represented by THLH and THLL respectively. The upper and lower threshold values for temperature are given as THTH and THTL respectively.

As shown in Figure 2, a hysteresis zone is defined to avoid the shutter moving up and down constantly in case of variable cloudiness. In this zone, the shutter does not move. This zone provides memory to the shutter system so that it can work in the imperfect light conditions.

Hardware Organization

A block diagram representing the hardware organization of the shutter system is shown in Figure 3.

The PIC16F877 microcontroller receives and processes the data from the temperature and the light sensors. The microcontroller outputs a control signal sent to the relay. The relay commands the electrical shutter to go up or down as needed. To protect the solar wall from overheating, a safety thermal contact system is installed to close the shutter if the temperature becomes too high.

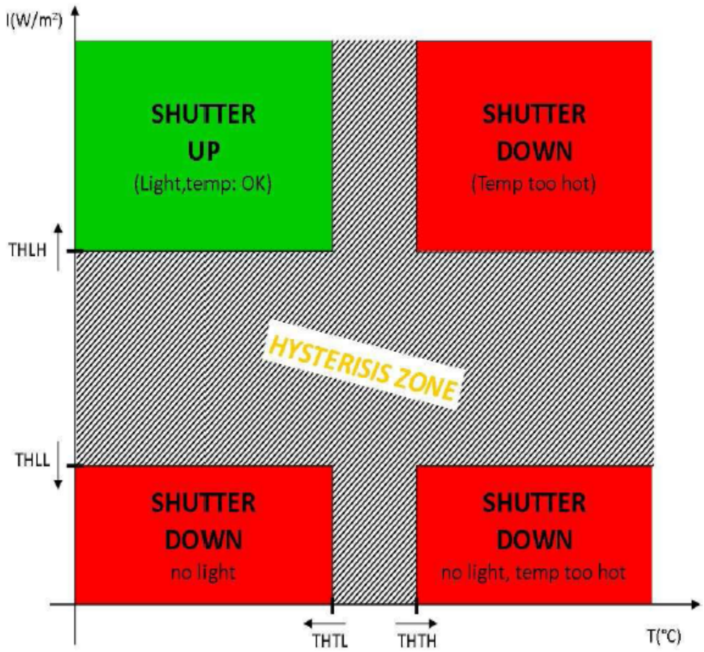


Figure 2: Operation zones for the shutter.

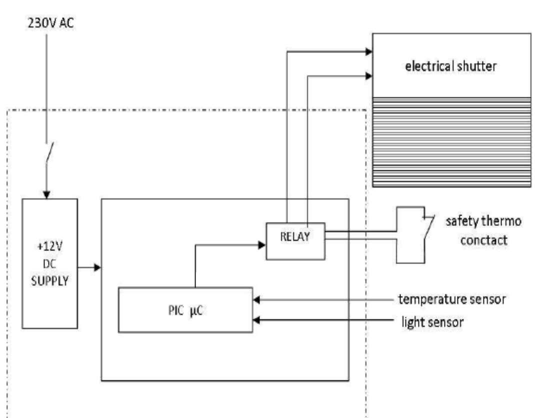


Figure 3: Protection system block diagram.

The light sensor consists of a photo-pile and a 22-ohm resistor. The value of output current from the photo-pile is proportional to the sun light that falls on it. The current value obtained for the standard value of irradiance (1000Watts/m^2) is 54 mA. The connection between the PIC microcontroller and the light sensor is shown in Figure 4.

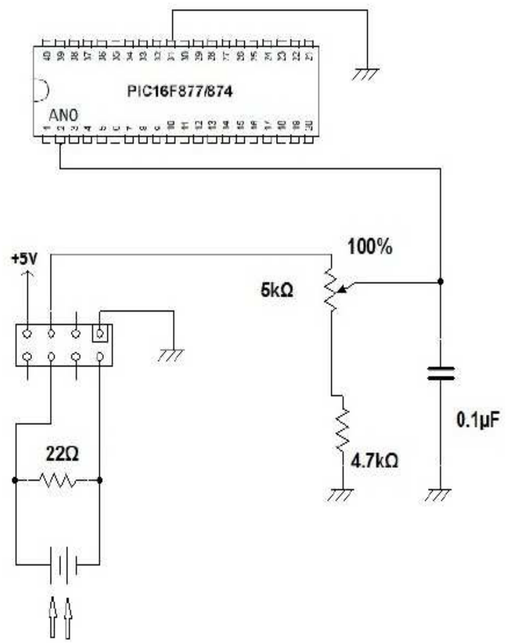


Figure 4: The connection between the PIC microcontroller and the light sensor.

The temperature sensor used for the shutter system consists of a serial digital thermal sensor chip TC74. The TC74 chip acquires and converts temperature from its on-board solid state sensor with a resolution of ±1°C. It stores the data in an internal register which is read through the serial port. The system interface is a slave SMBus/12C port through which temperature data can be read at any time. The temperature data can be made available as an 8-bit digital word.

In order to operate the shutter, a relay is used as a switch. A DPDT (Double Pole Double Throw) relay having two rows of change-over terminals is used. In addition, a MICROTHERM 05N1034 thermal switch is used to protect the system from the effects of overheating due to high temperatures. It is a simple on-off normally closed switch with a reset pin. When the temperature reaches 55° C, it opens up automatically. When the thermal switch is open, the shutter goes down to close the switch, the reset pin should be pressed. However, at that time the shutter is down and the only way to open it is to short circuit it. A push-button switch is installed which will produce a short circuit at the thermal switch. Using this push-button switch, the shutter can be opened and the thermal contact can be reset. The relay and safety thermal switch interface with the PIC microcontroller is shown in Figure 5.

The power supply needed by the solar wall protection system consists of a rectifier placed at the output of a transformer with a ratio of 230V/15V. Two capacitors are used to filter the signal. A voltage regulator provides a constant 12V dc voltage at the output.

The complete prototype of the solar wall system consists of a solar heater mounted on a frame with the electric shutter and the electronic board containing the shutter control system (consisting of a PIC microcontroller and the sensors), the block diagram of which is shown in Figure 3. The solar heater used in this project is described in [3]. The solar heater is mounted into the frame in a vertical position.

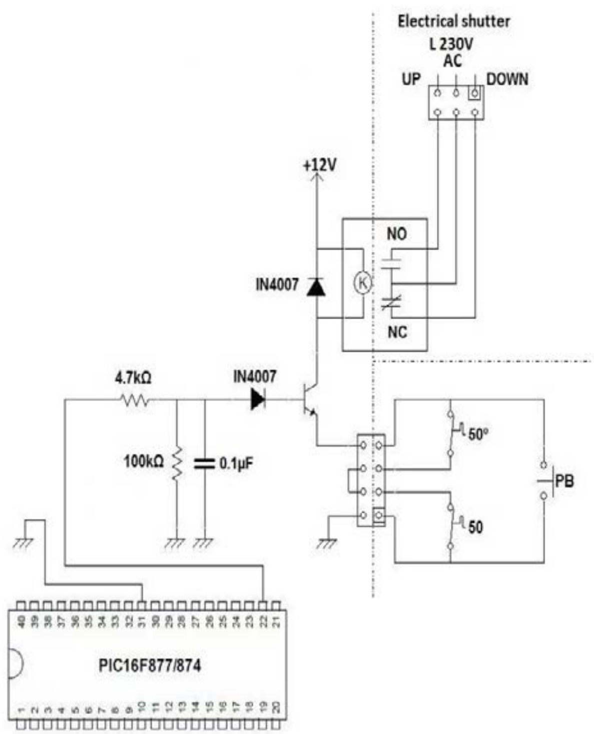


Figure 5: The relay and the safety thermal switch interface with the PIC microcontroller.

Software Organization

The software developed for the PIC microcontroller to control the system is structured as a set of subroutines. Two subroutines, *cadlum* and *actemp* are used to receive and process the data from the sensors. This information is then used to control the electric shutter.

The subroutine titled *normal function* is used to make sure that upon arriving at a temperature or light threshold, the system will work according to the operation zones for the shutter as previously shown in Figure 2. The flowchart for the *normal function* subroutine is shown in Figure 6.

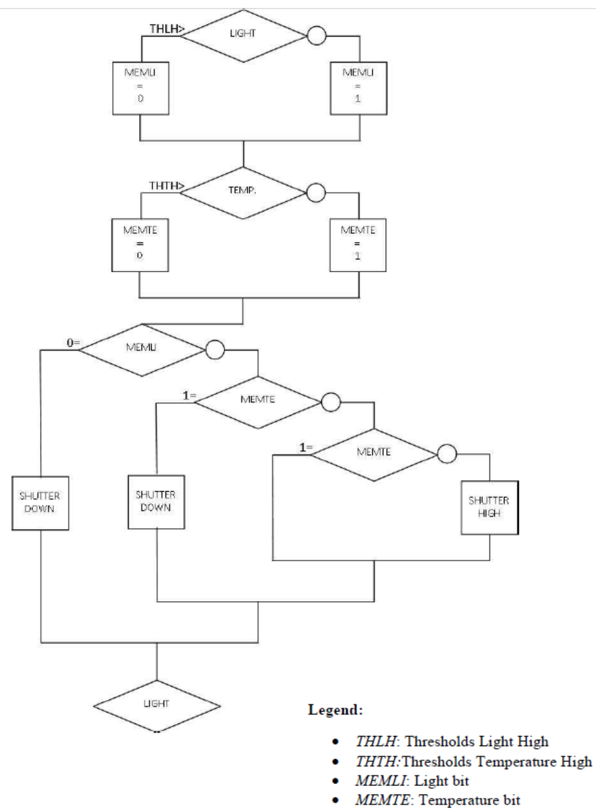
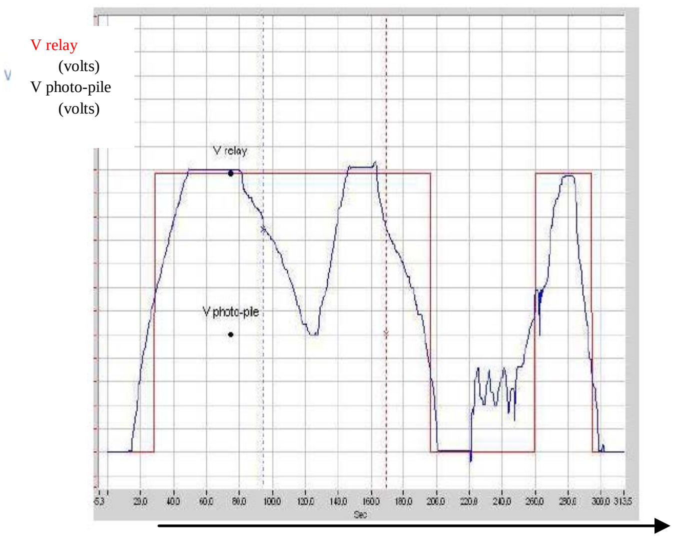


Figure 6: The flowchart for the *normal function* subroutine.

System Testing and Results

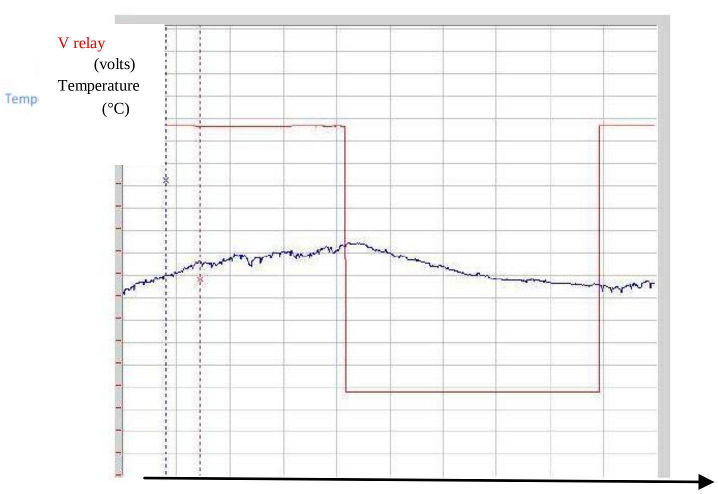
To test the light system, a potentiometer is used to simulate the sunlight variation. The test is started without light and then the light intensity is gradually increased until a radiation level of 1.2V which corresponds to 1000Watts/m^2 is attained. The hysteresis mode is also tested for the condition when the output high temperature level for the shutter is higher than the threshold level. The relay voltage is used to realize the up/down state of the electric shutter. The high voltage level indicates an open shutter. The low voltage level corresponds to the closed shutter. The above mentioned light test results are shown in Figure 7.



Time in seconds

Figure 7: Light test results.

The testing arrangement described above is used also to test the temperature variation. Figure 8 shows the temperature test results. The temperature is measured in °C and the relay voltage is expressed in volts. The hysteresis zone and the thermal inertia condition are also shown in Figure 8.



Time in seconds

Figure 8: Temperature test results.

Conclusion

A microcontroller based protection system for solar walls is described in this paper. This system uses an electric shutter, PIC 16F877 microcontroller, light and temperature sensors, and a safety thermal contact.

The system is implemented with the solar heater mounted into the frame along a vertical axis. The future work on this project will involve the automation of the solar heater movement to maximize the energy transfer.

The above mentioned capstone design project is a demonstration of the instructional approach being used by IUT Bethune to allow the electrical engineering students to develop a good understanding of the renewable energy concepts and applications.

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Biographical Information

Dr. Patrick Favier is an Associate Professor of Electrical Engineering at the University of Artois, France. His areas of expertise include electrical drives, power electronics, and renewable energy systems. He studied at University of Lille, France, during 1984-1988 and earned a Ph. D. in electrical engineering. His current research focus is renewable energy systems and technologies. Since 1984, he has been teaching electrical drives and power electronics at IUT, Bethune, France, where he served as the Head of Electrical Engineering Department from 1997 to 2004. Since 1992, he has been serving as the Director of the Teaching Laboratory in Electro-energetics at IUT, Bethune. Dr. Favier is actively involved in the international programs of the IUT, Bethune. At present, he is developing an international collaboration in engineering education with partner institutions from USA and several European Union (EU) countries.

Dr. Laurent Zalewski is an Associate Professor of Civil Engineering at the University of Artois (Applied Sciences Faculty), France. Since 2007, he has been responsible for the formation (third year of university) in the disciplinary area of "Sustainable buildings, home and urban environment". His research focuses on heat transfer mechanisms in buildings. His research activities are related to the thermal behavior of buildings, passive solar walls, and storage of energy. The passive solar walls are intended to heat the interior environment or to preheat new air (exterior air). The thermal characterization of these materials currently constitutes most of his research. He is currently participating in a project titled "Use of Identification Methods to characterize Phase Changes Materials", sponsored by the French National Research Academy.

Stéphane Lassue is University Professor at the Faculty of Applied Sciences at the University of Artois. He has served as the Director of "Mechanics, Thermics, and Instrumentation Laboratory" (LAMTI) from 2000 to 2003. He is currently the director of the "Habitat" research axis for the "Civil Engineering and geo-Environment" Laboratory (LGCgE) and Head of the Masters' Program in "Habitat, Environment and Quality" for the Civil Engineering Department. Since 1990 he has been developing experimental research related to the thermal behavior of buildings, passive solar walls, and instrumentation for the characterization and control of heat transfer and storage phenomena in complex systems for building envelopes. He works on the use of new windows for air pre-heating in an european program for energetics retrofit of houses.

Dr. Sohail Anwar is an Associate Professor of Engineering at the Altoona College of The Pennsylvania State University. In addition, he is a Professional Associate of the Management Development Programs and Services at The Pennsylvania State University, University Park. Dr. Anwar has served as the Editor-in-Chief of the *Journal of Engineering Technology*. He is currently serving as the Editor-in-Chief of the *International Journal of Modern Engineering* and the *Encyclopedia of Energy Engineering & Technology.* In addition, he is serving as the Series Editor of the *Nanotechnology and Energy Series*, Taylor and Francis Group/CRC Press.