121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014

Paper ID #9952

Design and Automation of a Zero Energy Model House (ZEH)

Mr. Jimmy Antoine Chahine
Minh Nguyen Ha, Forum Energy Technology

Graduated from UHD in 2011. Currently working as Electrical Engineer at Forum Energy Technology. Office number: (713)329-8234.

Mr. Vong Hem, Lectrus - Applications Engineer

Vong Hem is currently an Applications Engineer at Lectrus Corporation an electrical manufacturing company. His roles include developing electrical solutions for MV/LV electrical equipment and account management. He earned his BS degree in Engineering Technology from the University of Houston-Downtown.

Dr. Vassilios Tzouanas, University of Houston, Downtown

Vassilios Tzouanas is an Assistant Professor of Control and Instrumentation in the Engineering Technology Department at the University of Houston-Downtown. Dr. Tzouanas earned a Diploma in Chemical Engineering from Aristotle University, the Master of Science degree in Chemical Engineering/Process Control from the University of Alberta, and the Doctor of Philosophy degree in Chemical Engineering/Process Control from Lehigh University. His research interests focus on process control systems, process modeling and simulation, and renewable energy systems. His professional experience includes management and technical positions with chemicals, refining, and consulting companies. He is a member of AIChE and ASEE.

Design and Automation of a Zero Energy Model House (ZEH)

Abstract

Because of the rising energy prices, green-house effects, and environmental concerns, there has been a lot of emphasis on using alternative, renewable energy sources. This paper is concerned with the use of solar energy to meet the energy needs of a scaled model house. Photovoltaic (PV) panels are used to collect solar energy and convert it to electrical energy. In this experimental study, the design of a photovoltaic system is presented for a small model house along with its associated instrumentation, real time data acquisition and automation using NI® LabVIEW. The study clearly shows that energy requirements can be met using renewable energy sources and that the goal of a zero energy house is attainable in many locations.

This work was performed in partial fulfillment of the requirements of the Senior Capstone Project course in controls and instrumentation of the Engineering Technology department at the University of Houston - Downtown and then was continued as research project as part of continuing education. Student experiences are summarized and the need for teamwork and effective project management methods is emphasized.

I. Introduction

Solar energy offers consumers the ability to generate electricity in a clean, quiet, and reliable manner. In the United States, solar usage is growing at the industrial level but residential usage is still staggering behind other countries in Europe and Asia. This can be attributed to the cost of producing solar energy. The initial cost for a solar energy system is usually what discourages consumers from choosing it. Because of it, the residential usage in the United States is only account for 1 percent of the world's use[1]. Countries in Europe have set incentives for residents who adopt the use of solar panels and have a fixed price for utility companies to buy back the excess electricity. The United States is gradually introducing such incentives. So in the future, the use of solar energy would be more attainable for the average American household.

A PV system[2] includes panels and hardware that are comprised of photovoltaic cells that convert solar energy directly into electrical energy. A well designed PV system allows the consumers to create and store their own reusable energy without going through big energy companies; in some cases even allow homeowners to resell this energy back to the electric provider company. Since the growth and demand for solar systems is increasing, it is believed that projects like the current one will encourage readers to consider owning a PV system.

The objective of this work is to design a photovoltaic system to meet the energy requirements of a small model house. It is also within the objectives to design and implement an automation system for the distribution and use of the collected energy. The collected energy is used to primarily meet the heating and cooling requirements of the house model. A team of senior students identified, designed and implemented this project.

The team collectively built the small model home that operates on solar energy. The energy collected from the PV panels goes through a charge controller to charge the system battery. LabVIEW[3] is used to monitor battery voltage, solar voltage and user's temperature setting along with actual house temperature. LabVIEW was programmed to control various components within the house such as lights and fans to maintain a desired temperature.

This paper is organized as follows. Section II describes the design of the model house and its PV system. Section III discusses PV System automation using LabVIEW. Section IV summarizes lessons learned through this project. Finally, Section V presents the main conclusions of this work.

II. Design of the Model House and PV System

Model House

A simple model house was constructed using commonly available building materials and was equipped with a number of speed adjustable fans, lights, and temperature sensors. Fig. 1 shows different views the model house with or without its roof. The objective is to meet the energy needs of this house using energy generated using a PV system.

Fig. 1: Model House

PV System requirements

The main requirements for the system are as follows:

1. provide sufficient energy to power the model house during the day
2. store enough energy to meet the demands during the night

Based on the above requirements, consideration must be given to:

1. sizing of the solar panel system based on household needs
2. sizing battery to store enough energy for night-time consumption

In light of this, the household daily consumption must be known or assumed. Typically, for a household of four people, the average energy consumption is 18KWh per day[4]. For the model house with dimensions of 1/200 relative to a typical house, the energy consumption is 90Wh (assuming linear energy consumption.)

Based on the information above, the solar panel should produce no less than 90Wh, and the total electronics consumption should not exceed that same amount. Also the battery should have a power rating of 7.5 Ah.

The main energy consumers in a house are heating and cooling elements such as air-conditioning, water heaters and electric stoves. The heating element for this model will not exceed the 60% of 90Wh to ensure enough energy is supplied to the other electronics and sufficient energy is stored for later use.

PV System

The main components of the PV system are the panels, storage battery, charge controller, heating element, ducted fan, thermocouple, signal conditioners, and the controller. Each of these components is discussed next.

Photovoltaic Modules

Such modules are comprised of a number of smaller units, called cells, arranged in series and parallel configurations, depending on the energy requirements. For the purposes of this project and in order to keep the construction cost low, individual cells were purchased and used to construct two PV modules with 36 solar cells each. Fig. 2 shows one of the two PV modules.

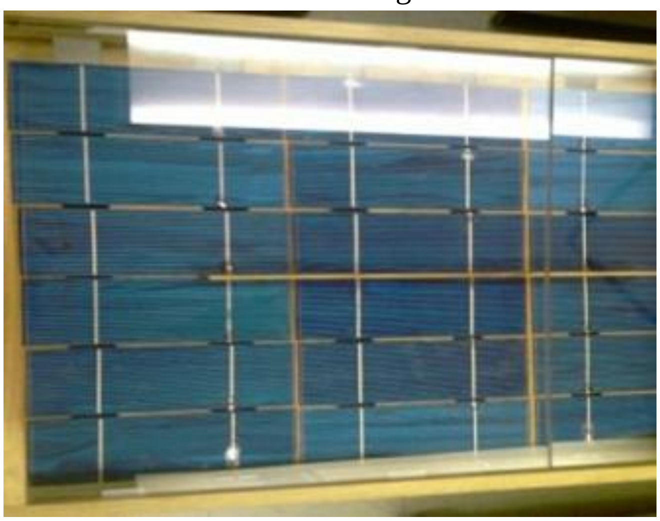

Fig. 2: PV Panel.

Evergreen Polycrystalline Class A cells were used in this work with the following specifications: 1.8Wp watts each, 3.6 max amps, rated at 0.5 volts each, thickness 0.2mm, dimensions 3.25"x6". The PV module open circuit voltage was 18V (36 cells in series).

Fig. 3 shows the PV system wiring diagram. Solar energy is harnessed by the two photovoltaic panels and is regulated by a charge controller to charge the battery. The collected energy powers the thermocouple, and the pulse width modulation (PWM) circuit which adjusts the speed of the fan and the duty of the heating element. A NI® USB-6009 system is used for data acquisition, monitoring, and control.

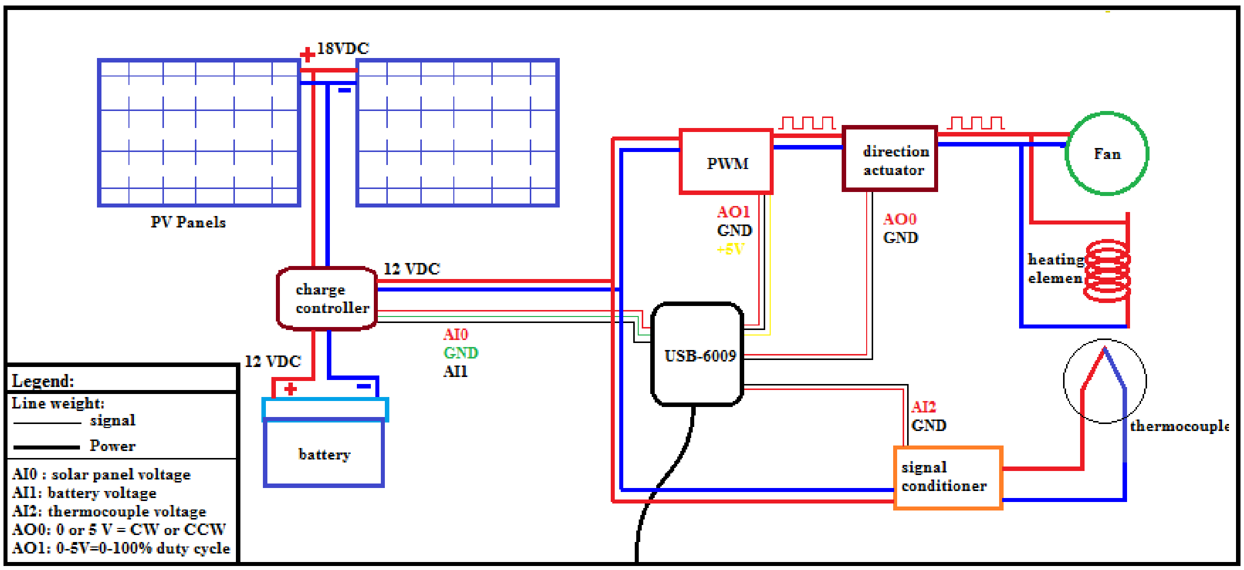

Fig 3: PV System Wiring Diagram.

Controller

The NI USB-6009 is a data acquisition system, commonly used in academia, allows for real time control monitoring through it I/O channels (Fig. 4). It can read/write both analog and digital signals.

Fig 4: Data Acquisition System [3].

Heating element:

The power source to control the model house temperature is the heating element shown in Fig. 5.

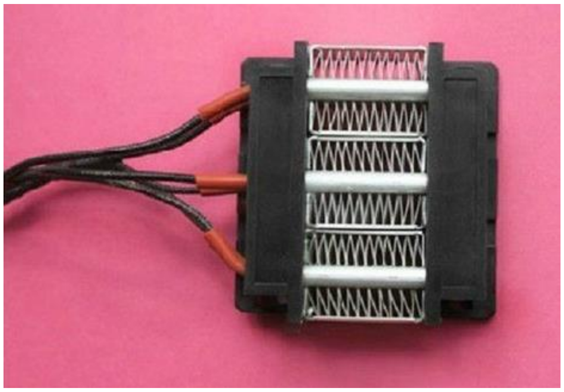

Fig 5: Heating element.

The above heating element is a PTC electric, ceramic, thermostatic heater that is safe for indoor use. It's a 12 V 150 W heater that consists of 3 small elements; it is capable of reaching temperatures up to 300 ° C (572 F).

Air Blower

A fan is used to circulate air into and out of the house (Fig. 6).

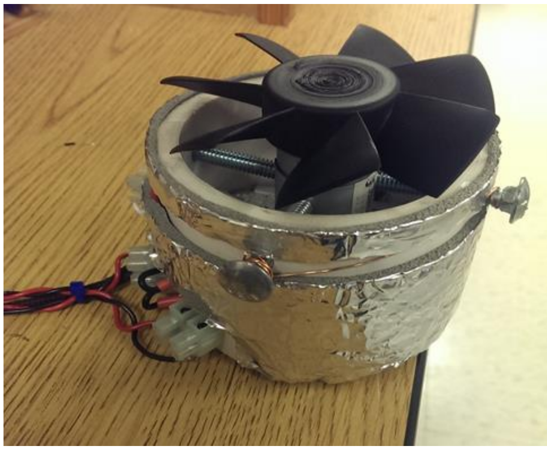

Fig 6: Air Blower.

The fan is a 12 V 400 mA ducted blower, it's responsible for both cooling and heating the house, based on the PWM duty cycle and the rotation direction. Enclosed in the duct is the heating element so that the air can only go through them. The fan rotates clockwise (CW) for cooling action and counter clockwise (CCW) for heating action. The air is either pulled from the outside through the heating element to increase the inside temperature, or from the inside to decrease the inside temperature.

Fan Direction Actuator Circuit Board

Fig. 7 and 8 show the circuit and corresponding wiring diagram to adjust the fan direction (clockwise (CW) or counter clockwise (CCW)).

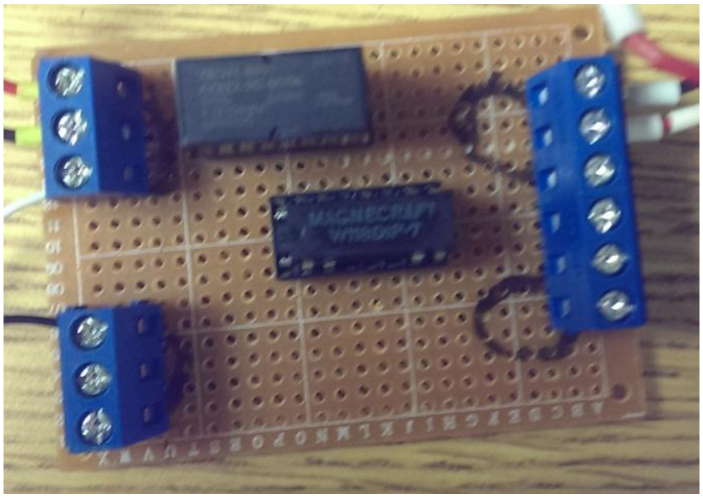

Fig 7: Direction Actuator Circuit

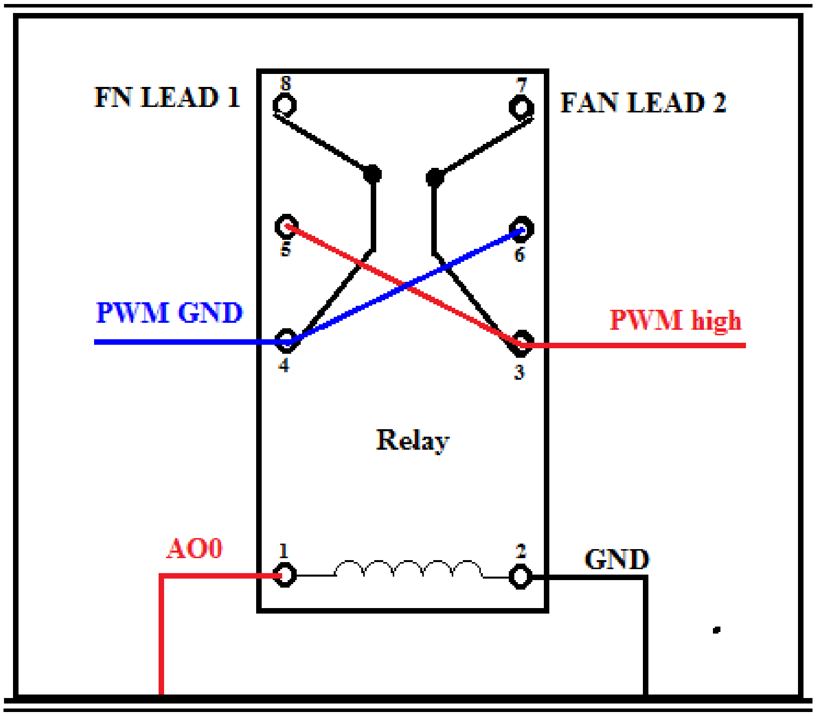

Fig 8: Relay Wiring Diagram CW and CCW Fan Action.

The above circuit consists of two relays that switch the fan from CW to CCW and the heating element on or off. The relay used is a 5 V trig, 0-120VDC mechanical relay. Model number is AZ822-2G-5DSE.

PWM:

The pulse width modulation circuit is shown in Fig. 9.

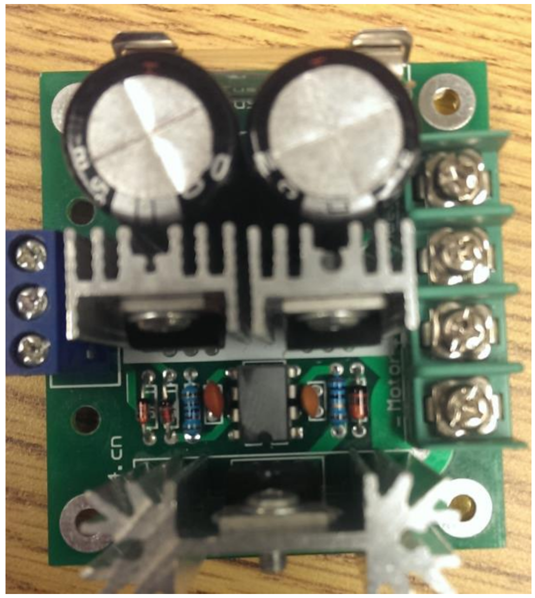

Fig 9: PWM circuit.

The above PWM is a 12-60 V, 0-100% duty cycle, 13.5 KHz module with a maximum discharge load of 10A. This PWM allows for garter energy savings for both the fan and the heating element. It is controlled by the NI USB-6009 with a signal of 0 to 5V corresponding to 100-0% duty cycle.

Battery

The battery used in this work (Fig. 10) is a deep cycle, solar panel purposed, 35 Ah 12 V Power Sonic. It is capable of providing sufficient energy to power all electronic components at full load.

Fig 10: Energy Storage Battery.

Charge Controller

When connecting a solar panel to a rechargeable battery it is usually necessary to use a charge controller circuit to prevent the battery from overcharging. Charge control can be performed with a number of different circuit types. Fig. 11 shows the charge controller built for this work while Fig. 12 shows the wiring diagram.

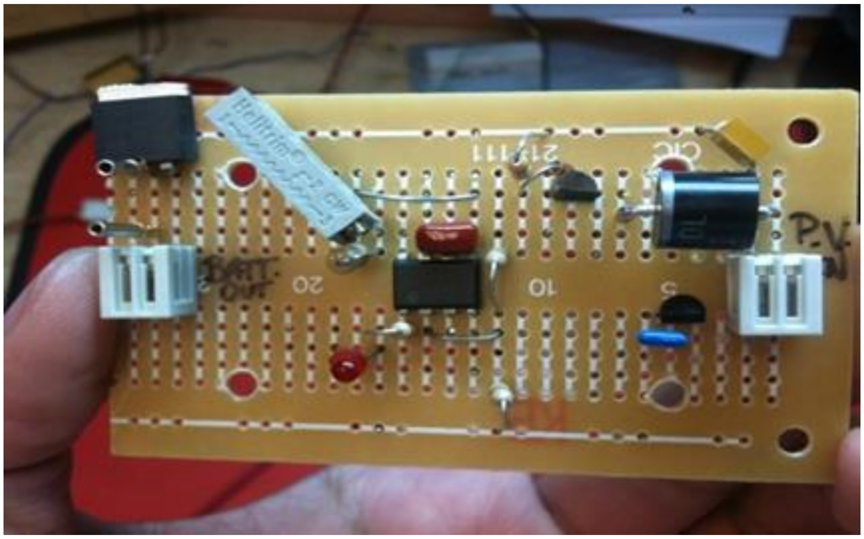

Fig. 11: PV System Charge Controller

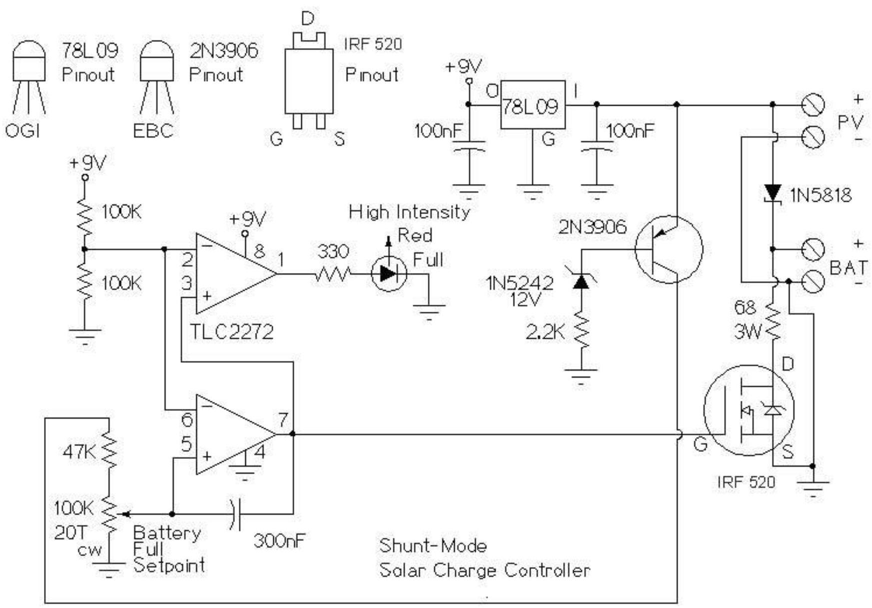

Fig 12: Charge Controller Wiring Diagram.

Other Instrumentation

As mentioned earlier, several other instruments have been included in this project. Thermocouples are used to measure house temperature. Thus, thermocouple signal conditioning must be addressed. The thermocouple signal conditioning circuit AD595 is used. Since the AD595 circuit needs an external power source of 5V DC at pin11 to operate, it was decided to use a 0-30V DC to 5V DC voltage regulator to power the AD595. This on board voltage regulator draws its power from the battery and converts it to a constant 5V DC output. This design eliminates the need for a dedicated 5V DC power supply and saves precious space in the junction box. Both the V DC Power and the thermocouple are installed on quick disconnect WAGO connectors for ease of installation and removal.

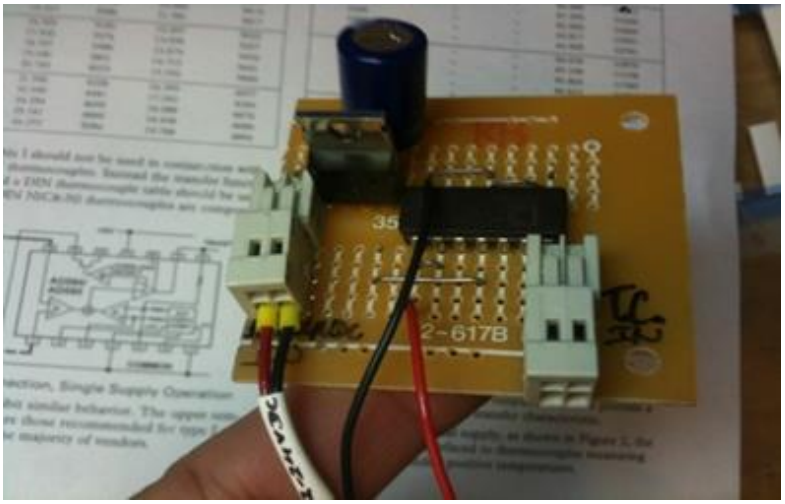

Fig. 13: Thermocouple Signal Conditioning Board.

Fig. 13 shows the thermocouple signal conditioning board. This board contains the AD 595 thermocouple signal conditioner with ice point compensation. it also has a built in 0-30V DC Input to 5 V DC Regulated Output. Fig. 14 shows the wiring diagram and pin outs of the AD 595 conditioner.

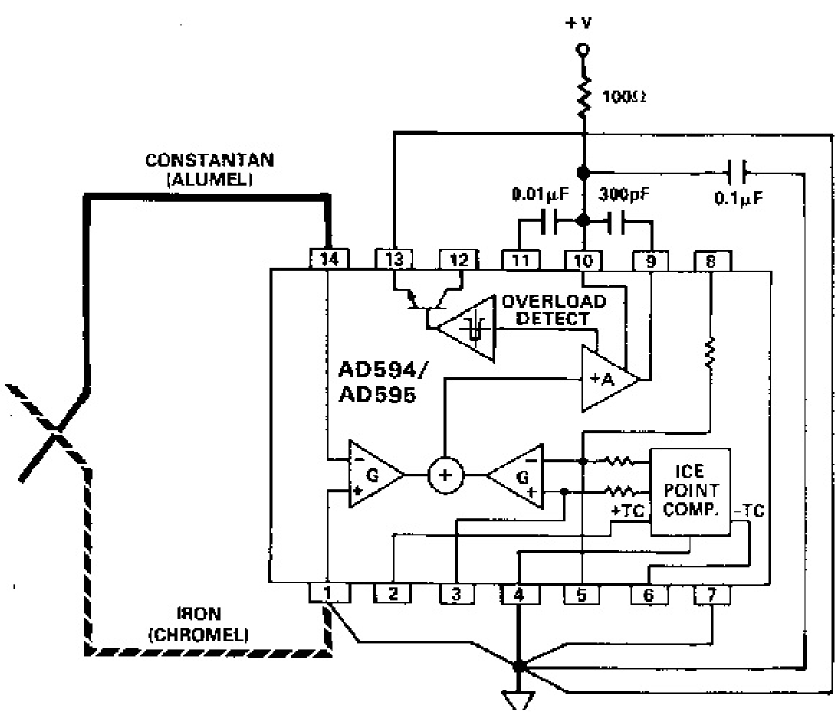

Fig 14: AD595 Thermocouple Signal Conditioner Wiring Diagram[5].

III. PV System Automation Using LabVIEW

LabVIEW provides an easy to use platform for real time data acquisition and control. It extensively has been used in academia and has been available for this work. Programming of the different control functions proved a time consuming process. However, online references such as the National Instrument[3] forum proved very useful.

Data Acquisition, Control and Programming

Temperature control is achieved using a PI control algorithm. The manipulated variable is the fan speed (i.e. air flow to and from the house.) The block diagram shown in Fig. 15 displays the block diagram of the temperature control loop. Data acquisition, signal conversion, control, and display functions are included in the programming shown in Fig. 15.

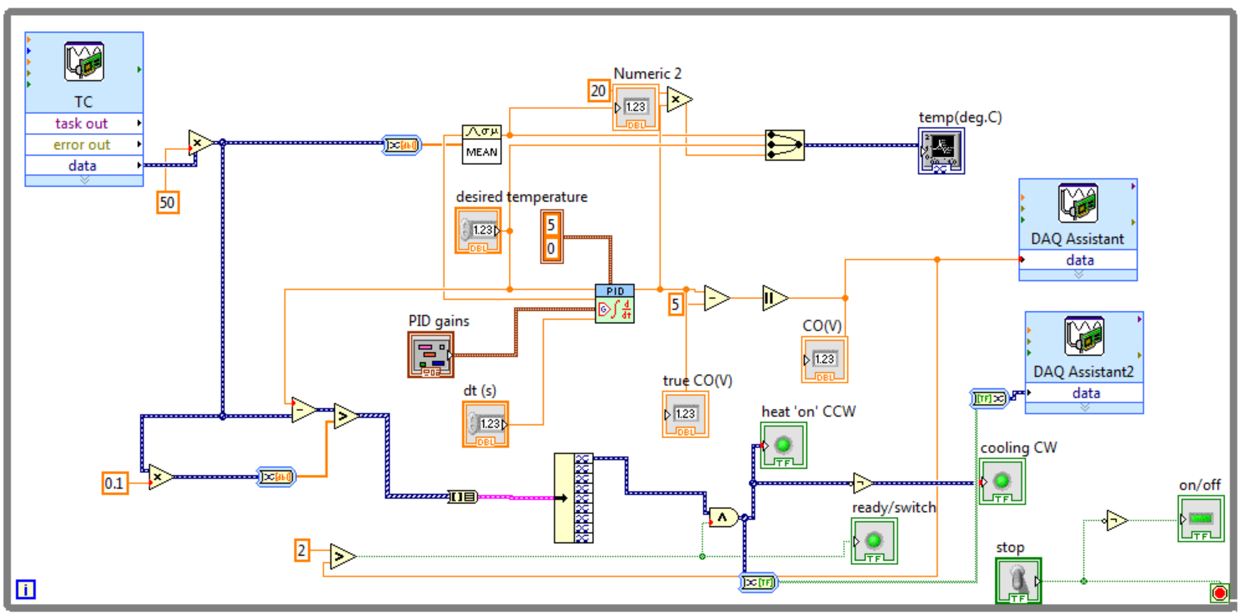

Fig. 15: Temperature Control Using LabVIEW

Human Machine Interface (HMI)

Fig. 16 shows the LabVIEW HMI for power monitoring and house temperature control. The charts show the system variables on the top chart, the PV voltage level on the middle chart, and the battery charge level on the bottom chart. Also two indicators on the mid-right section indicate the status of the fan and lights.

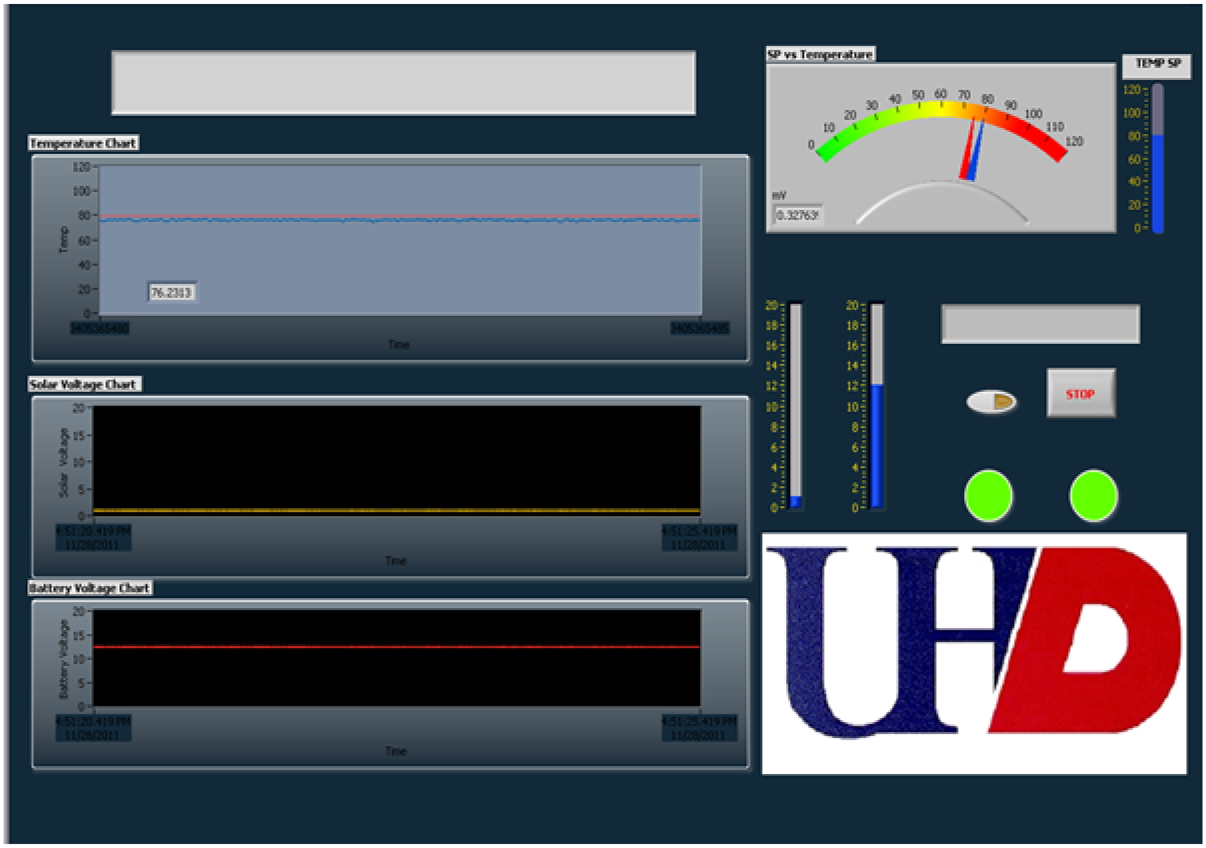

Fig. 16: PV System Human Machine Interface

IV. Lessons Learned

The four member team accomplished the task identified at the beginning of the semester. In the form of a project proposal, a couple of goals were set in the beginning of the Senior Capstone Project course. One was to design and develop a functional PV system that could be used to meet energy requirements of a model house. Another goal was to develop a LabVIEW program to control the house temperature to a desired level using the generated energy. It was also within the team's goals to meet all project deadlines while producing quality work.
In the end, these goals were met. All the work was completed in a semester's timeframe. To complete the project, each team member had to contribute to the overall success of the group. Even though each team had a specific job function, all members worked together as a team to accomplish the overall objectives. In this self-directed team, each member was responsible for the overall project success. Project deadlines set early on in the project proposal drove team's actions.

It was learned that working in teams can be rewarding, but at times it can be difficult and sometimes frustrating. But to create a successful team, each member learned to effectively communicate and come together as a group. Teamwork provided an opportunity to connect with fellow students and learn from them. While working on the project, each member learned from the others by openly sharing and debating ideas. Working in a team environment on this project, team members feel this experience allowed each one of them to gain valuable information that is directly applicable to a real working engineering environment.

By designing and building a PV system, this project has impacted students' learning in the energy field and increased their awareness of and responsibility to use renewable energy sources in their everyday life. This learning experience can be used to incorporate sustainability in engineering education and provide a good foundation in renewable energy systems for future undergraduate students.

V. Conclusions

This paper was concerned with the use of solar energy to meet the energy needs of a small model house and automation of the distribution and use of the collected electrical energy by using photovoltaic panels. This experimental study discussed the design of the photovoltaic system, for a small scale model house, along with its associated instrumentation, real time data acquisition and automation using LabVIEW. The study showed that house energy requirements can be met using renewable energy sources. This work was performed in partial fulfillment of the requirements of the Senior Capstone Project course in controls and instrumentation of the Engineering Technology department at the University of Houston – Downtown. Successful project completion required teamwork and effective project management skills.

References

1. National Academy for Engineering, "Make Solar Energy Economical", http://www.engineeringchallenges.org/cms/8996/9082.aspx
2. Home Solar Energy Systems-Residential Wind Power, www.solarpowerwindenergy.com
3. National Instruments Forum, www.ni.com
4. Carbon estimation: http://www.carbontrust.com/client-services/footprinting/footprint-measurement
5. AD595 datasheet: www.vishay.com