Solar Powered Aquaponics: Modeling Real World Solutions through Engineering Technology

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I. Introduction

One of the challenges we face as the word population expands is that our needs for food water and energy also expand. The central questions is how to balance all of these needs. This is sometimes called the energy-water-food nexus and it has enormous implications for food policy and the future technology needs [1]. How can we grow more food for a growing population using less water or energy? How can we feed more people in urban centers and therefore reduce the carbon footprint for food production and transport? How can we feed more people and produce less carbon dioxide waste, while reducing our risk of global warming? These are questions we pose to our students in both biology and engineering technology. We also try to embrace projects that force them to work together to solve a problem through collaboration and technology.

This paper describes the technologies used to implement a senior capstone project which focuses on sustainable development. The overall goal of the senior capstone project was to bring together students from different disciplines to address a problem related to sustainability which was the design of an aquaponics system using renewable energy sources. Such a project helped students practice and further improve skills related to teamwork, communication, and work planning & management when working with others who do not necessarily “speak” the same technical/scientific language.

Engineering technology and biology students from the University of Houston-Downtown (UHD) worked together to design and build the fully instrumented and automated aquaponics system at our university’s sustainability garden. From a team leading viewpoint, biology students defined the requirements for the aquaponics system while engineering led the activities to design and build the system. The developed system allows interested students to study the growth and optimize the production of vegetables. In addition, this student-driven project revitalized and optimized the sustainability garden of the university from a controls and instrumentation viewpoint. This garden was destroyed during hurricane Harvey, a year ago and this project was a pivotal piece in rebuilding its functionality.

The paper is organized as follows. Section II presents the as built aquaponics system and provides technical details on the methods and materials used to build the garden with its renewable energy technologies. Section III summarizes student lessons learned while section V outlines main conclusions followed by Acknowledgements and References.

II. The Aquaponics system

An aquaponics system is a combination of hydroponics and aquatic life, working in a symbiotic environment. The system recycles the waste that the fish produce as nutrients for the plants. There are different types of aquaponics systems. The deep-water culture hydroponics system is the easiest method to implement. In a deep-water system, the roots of the plants are suspended in a reservoir that contains a nutrient solution. An air pump will pump bubbles in the reservoir to oxygenate the plants. This means that the plants receive a constant supply of water, nutrients, and oxygen.

Another type is the ebb and flow system (Figure 1). This system periodically brings in contact the roots of the plants with water to absorb nutrients in it. The frequency of these periodic contacts between water and plants roots can be controlled using a timer. The timer is set to water or flood the growing bed several times a day. However, there are is a disadvantage in using a timer. The roots can easily dry out if there is a failure in the electrical components.

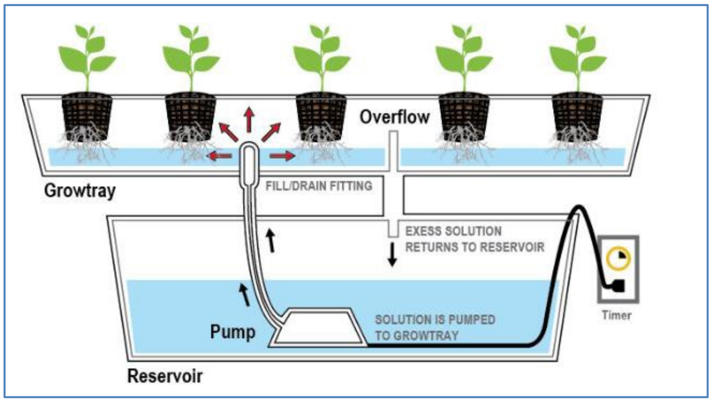

Figure 1: Schematic of an Ebb & Flow System [2]

Another way to control the ebb and flow type system is with a bell siphon. The bell siphon creates the ebb and flow dynamics by allowing the water to rise until the level reaches an overflow point. This creates a vacuum at the top of the standpipe and will pull the water from the grow bed to the next tank. It is a simple, inexpensive, and easy to maintain mechanism that does not require any automation. The system built as part of this work is of the ebb & flow type.

a. <u>The as Built System</u>

This project has been integrated with prior projects in the university's sustainability garden (Figure 2). A close up picture of the as built aquaponics system is shown in Figure 3.

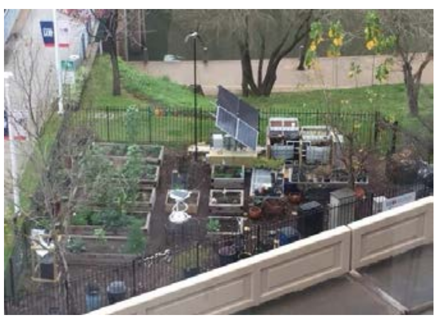

Fig. 2: The Aquaponics System in the UHD Sustainability Garden

Fig. 3: The Aquaponics System

The structure of the system was designed with stability and longevity in mind. The structure was built with exterior treated wood and made to hold the weight of the water in the system. The system will always house almost 700 gallons of water, with about 250 gallons each in the fish tank and sump tank, and about 100 gallons in each grow bed. The pumps for the system were selected to cycle the water in each tank at least once per hour.

The scope of the project also included revitalizing and optimizing the power system for the garden. This was achieved by providing enough power for current and future systems in the garden. The system currently makes use of four 250-watt photovoltaic solar panels that provide 1000 watts of power to the garden. The photovoltaic array charges a battery bank that has the capacity to consist of ten, 100-amp hour, 12 VDC batteries. The battery bank ensures that the garden maintains sufficient power to run all of the systems in the absence of solar energy. The system also consists of a power distribution panel that houses the charge controller and all breakers for the systems in the garden. This ensures that the garden systems can be easily turned off individually for any reason.

b. Project Timeline

This capstone project was executed in one academic semester. The timeline consisted of three major phases (see Figure 4). The first phase took place in the first three weeks of August. This phase focused on redesigning the aquaponics system and the irrigation system to run more efficiently. All initial calculations, valve sizing, instrument selection, structural designs, and controller designs were completed in this phase. Many of the parts were available already due to the efforts made over the last year to revitalize the systems. Parts that were not available were selected and ordered during this phase. The research into how to achieve reliable pH, temperature, and level control was conducted early in this phase. Any mathematical dynamic models required for the system were completed during this phase. The construction and positioning of instruments began late in phase one. The second phase of this project began in September and proceeded until October. This phase focused on completing any construction and installing any instruments that had not been installed yet. Initial startup of the system was done in this phase. Phase three commenced in October and ended with the end of the semester in November. This phase primarily consisted of troubleshooting and tuning the controllers. Documentation for the operation of the systems was written in phase four.

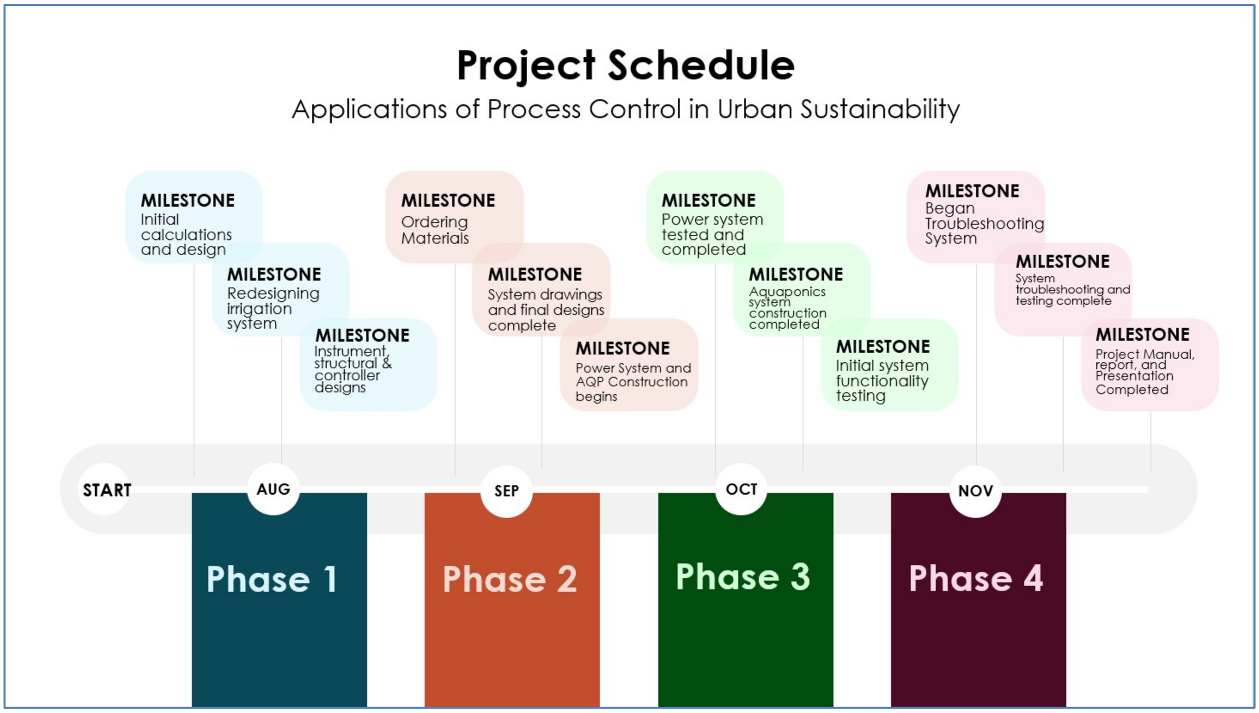

Figure 4: Project Schedule

The project was considered complete from a technological viewpoint after the following conditions were satisfied:

1. The frequency at which the first grow bed ebbs and flows can be controlled around a set point and the aquaponics system bell siphon reliably forces the first grow bed to ebb and flow.
2. The level in the fish tank is controlled with at least 5% accuracy.
3. The system successfully dechlorinates automatically any water added to the process.
4. The pH and temperature monitoring system successfully trends data over time.
5. The irrigation system reliably waters the plant plots.
6. The PV panel power system meets the power requirements of the garden systems with some to spare for future projects.

c. <u>Automation</u>

A schematic of the aquaponics system is shown in Figure 5. From a controls and instrumentation viewpoint, the aquaponics system has four objectives. The first is to control the frequency in which the water in the first grow bed ebbs and flows. This was achieved by using a proportional integral controller [3] to adjust the duty cycle of pump M1 around a set point that is user specified. The system measures the flow rate to the first grow bed by using a flow transmitter.

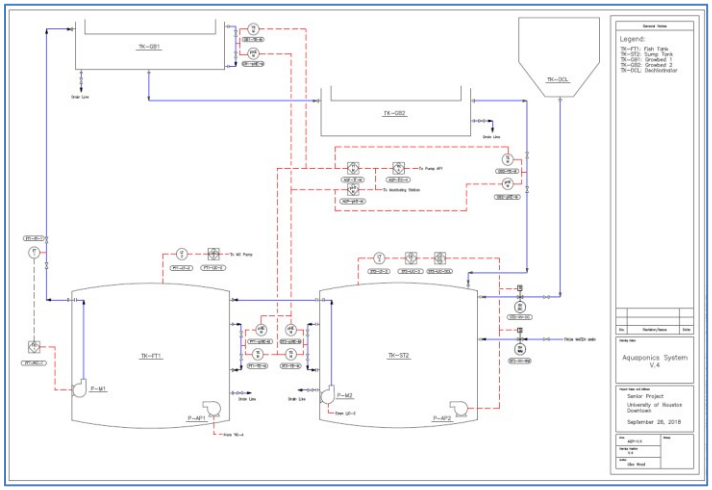

Figure 5: Aquaponics System P&ID

The second objective is to control the level in the fish tank to ensure that the tank will never overfill. This was achieved by using a proportional controller to adjust the duty cycle of pump M2 around a user specified set point. The system measures the level in the tank by using an ultrasonic level transmitter. The proportional controller determines the duty cycle of the pump. The proportional controller is tuned using empirical methods. The system controls the level within +/- 5% accuracy.

Third, the system combats water loss due to evaporation automatically. This is achieved by using a proportional controller to open a normally closed valve that is connected to the water main. The level in the sump tank (SP2) is continuously measured by a second ultrasonic level transmitter. Once the level in the sump tank reaches a certain low level of 8 inches of water, the controller opens the valve to refill the sump tank with water from the city and then run a de-chlorinating process on the water before it is pumped into the aquaponics system. This process is executed using the principles of sequential control.

The system also monitors the pH and temperature of the fish tank, sump tank, and both grow beds over time and sends alerts to key personnel responsible with the maintenance and operation of the university garden. The system makes use of four differential pH probes with RTD sensors that output a signal to two Hach pH transmitters. The transmitters output signals to a wireless monitoring system that trends the pH and temperature data over time on a computer in the lab.

All data acquisition and control tasks are accomplished using an Allen Bradley CompactLogix [4] programmable logic controller (PLC) which is located in the garden. The PLC is wirelessly connected to a lab computer that runs LabVIEW for trending purposes. All of the components have been placed and secured to the panel (Figure 6). The power distribution for the control panel is completely wired.

Figure 6: Aquaponics System Control Panel

d. <u>Garden Power System</u>

The energy needs of the aquaponics systems and the garden are met using renewable energy sources. Figure 7 shows the final electrical diagram of the system. Tables 1 provides the current load list that the garden system will power with both maximum load and typical load. The difference is that not all devices in the garden require power on a continuous basis. The current from the solar panels during the day reaches a maximum of about 45 amps. This rating is used to size the gauge of the wire, the circuit breaker for the array, and the charge controller itself. The wires from the solar panels to the charge controller are 8 AWG, the wires from the battery bank are 10 AWG, the power wires to the aquaponics system are 10 AWG, and the wires to the irrigation system and the battery bank blowers are 14 AWG. Table 2 shows calculations to determine the number of batteries required to meet the energy needs of the system.

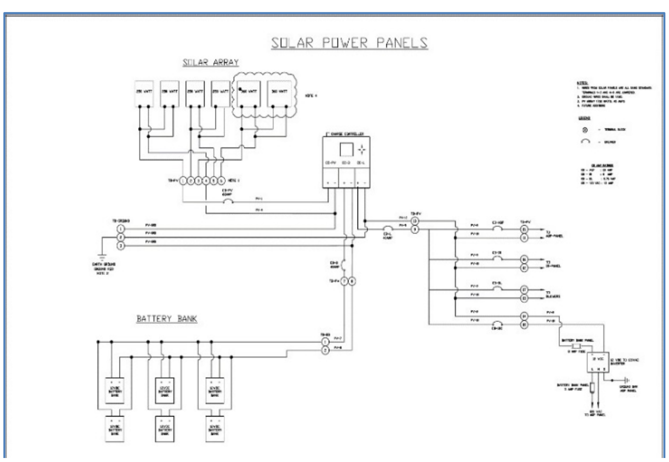

Figure 7: Electrical Diagram of PV System

Table 1: Typical Load Calculations

Load List: Typical Loads:				
Component:	**Continuous:**	**Current (A):**	**Power (Watts):**	**Watt-hrs/day:**
M1	Yes	5.5	66	1584
M2	Yes	4.200	50.4	1210
AP1	no	0.000	0	0
AP2	No	0.000	0	0
XV-WM	No	0.000	0	0
XV-DC	No	0.000	0	0
LT-1	Yes	0.021	0.5	12
LT-2	Yes	0.021	0.5	12
FT-1	Yes	0.035	0.84	20.16
phT-1 sc100 w/probes	Yes	0.208	25	600
pHT-2 sc200 w/probes	Yes	0.308	37	888
PLC Max Estimate	Yes	0.660	15.84	380.16

Table 2: Battery Amount at Typical Load

Battery Calculations at Typical Load :			
Total Watt-hrs/day	4345.9	W/day	
Hours of Autonomy	19	3440.52	W/hr
DOD (discharge amount):	0.5	6881	W/hr
Temperature Factor	1	6881	W/hr
System Voltage	12	573	Ah
Required Battery Size		6	100 Ah Batteries

Figure 8 shows the battery bank cabinet while Figure 9 shows the photovoltaic system power panel.

Figure 8: Battery Bank Cabinet

Figure 9: PV Power Panel

III. Lessons Learned

Students commented that the project was useful for a number of reasons. During this project they felt that they had one main goal: to demonstrate what they had learned throughout the program. Unlike the past semesters where they could ask questions to the professors to understand the projects, during this senior project the professors asked the team questions to prove their understanding of the project. They thought this approach was more representative of what happens in industry. Also, they learned that it's okay to rely on others team members for support and that a little research goes a long way. This is particularly important when cross-disciplinary teams are attempting to solve complex, real-world problems. Working effectively as team members is crucial for their professional careers while being able to conduct research helps them in life-long learning. Some of the students indicated that the senior project pushed them beyond their comfort zone. They took leadership in an aspect of the project and made individual contributions count with the very limited amount of time they had to complete the project. They had to manage their time effectively to meet tight project deadlines. They also commented that they would not have been able to complete this project unless they had to rely on the strengths of each team member and support one another. Finally, students felt that the weekly project status updates and various reports and presentations required by the class helped them improve their technical writing and presentation skills.

IV. Conclusion

Throughout this project students demonstrated the skills they have learned throughout their studies. By successfully completing the objectives of this project, students demonstrated competencies (technical as well as soft skills) in the field of instrumentation and control systems engineering. This senior capstone project demonstrated how renewable energy sources can be utilized to achieve sustainable development.

V. Acknowledgements

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VI. References

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