Midterm Report

Project #17: Shuttle Valve

Deliverable #3

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Abstract

Renewable energy, also known as “green” energy, has been the focal point for many present day industries. There are many ways of achieving this goal, including modifying existing technologies in order to improve their efficiency. Verdicorp Inc. is one such company that is at the forefront of developing next generation clean technologies for existing systems [1]. The objective of this project is to increase the efficiency of the Organic Rankine Cycle (ORC) system developed by Verdicorp Inc. This will be achieved by decreasing the parasitic losses within the system by removing the pump and replacing it with a shuttle valve system.

Therefore, the purpose of this project is to design a shuttle valve to be used in ORC systems. These systems are used for producing electrical energy from waste and low grade heat. The concept for the shuttle valve is to transfer liquid from the low pressure side of an ORC to the high pressure side without the aid of a pump. The end goal will be to design a simple, inexpensive system that can be incorporated into existing ORC’s. The benefit of a successful outcome will be to decrease the energy consumption of the existing systems and increase the efficiency and overall profit for the consumer.

Project Overview

Project Scope and Sponsor Requirements

Verdicorp Inc. has improved a revolutionary power generation system (Figure 1) that converts low grade waste heat into electrical energy. Organic Rankine Cycle systems can best be described as a refrigeration cycle running backwards. Instead of using electrical energy to produce cooling, this system takes heat from a low grade source and turns it into electrical energy. The power is then phase matched to meet the local electrical grids.

Figure 1. Picture of one of Verdicorp’s Organic Rankine Cycles.

Verdicorp Inc. uses the environmentally friendly refrigerant 245fa. The refrigerant is heated from the waste heat in a series of heat exchangers and sent into a turbo generator. The refrigerant spins a turbine blade which turns an electrical generator, producing electrical power. Once the fluid passes through the turbine it then goes through a condenser and back to the pump to be recirculated through the system. The pump is a parasitic loss which consumes electrical energy and lowers the overall efficiency of the ORC. Our sponsor has tasked our design team with the requirement to mitigate this effect with the insertion of the shuttle valve system.

Project Goal

The final prototype must be incorporated into the existing ORC system in place of the original pump. The ORC is capable of producing ~125 kW of power, but due to parasitic losses in the system that consume ~20 kW of the power produced, it is limited to a surplus of ~105 kW of useful power. The pump accounts for half of these parasitic losses, ~10kW, so replacing the pump with our team's shuttle valve design should basically eliminate half of the parasitic losses, thus increasing the overall efficiency of the system. The prototype must also maintain a constant flow rate of 3 gallons per minute through the use of multiple storage vessels. It should sufficiently decrease the amount of electrical waste compared to the original pump. The physical model will use water, but future calculations will be based on both water and refrigerant 245fa since the ORC system will use the refrigerant. The overall expectation of the end product is to increase the efficiency of the existing ORC system.

Project Objectives

- Design a shuttle valve system to replace the pump within the ORC.
- Maintain the continuous flow of liquid within the ORC.
- With the use of control valves and the aid of gravity, adjust the pressure inside the vessels up and down by balancing the gas pressure.
- Transfer the liquid from the low pressure side of the system to the high pressure side.
- Minimize parasitic losses in the system, i.e. use a very small pump or no pump at all, effectively minimizing the electrical consumption of the system.
- Confirm on a final design concept by late October 2013.

Project Constraints

- The overall design budget is limited to $2000.
- The prototype developed by the senior design team must use water in place of refrigerant 245fa, which is the fluid used in the actual system. Our design team is prohibited to use this product by the FAMU-FSU College of Engineering because of its possible health hazards.
- The fluid within the system must maintain a constant flow rate, with an approximated flow rate of 3 gallons per minute.

- The design must be as small as possible, with a 2 meter height restriction in place.
- The system must contain numerous vessels which contribute to the constant flow rate. A system containing only one vessel would be considered a failed prototype to the sponsor company.
- The modified system must use minimal, to preferably no, electricity.
- The system must be completely closed to prevent any losses in the amount of refrigerant 245fa used in the system.
- The system must contain pressure gages to indicate the changes in pressure within the system; when and where the pressure is changing.
- The overall change in pressure within the system is restricted to a total of 50 psi.

Design and Analysis

Function Analysis

Components within the system:

- Pressure vessels (4 - 6) (evaporator and holding tanks)
    - Preferably transparent material (clear acrylic)
    - Must withstand 50 psi internal pressure
- Atmospheric Vessel (1) (condenser: open to atmosphere)
- PVC piping (~20 ft)
- PVC 90° elbows (~6)
- Pneumatic control valves (~6)
- PVC Check Valves (~6)
- Sensors for fluid level (3) (type of sensor to be determined)
- Air compressor
    - Must supply a constant pressure of 50 psi (appropriate cfm)
    - Sound must be damped to an acceptable level for indoor use
- Tubing for air pressure lines (~10 ft) (1/4" stainless steel tubing)
- Controller to control all valves throughout the system

Specifications:

- The overall height of system must not exceed 2 meters.
- The length and width of the system are to be reasonable compared to the height but their exact dimensions are not critical.
- All system components must be able to withstand an internal pressure of 75 psi (the design pressure with a safety factor of 1.5).
- Power required should be minimal (enough to run a small circulation pump and compressor).

Design Concepts

During the previous weeks (Weeks 7 - 8) our team focused on generating design concepts individually with the goal of briefly evaluating these designs as a team during the later end of last week (Week 8). The team was able to compose 4 designs, but upon brief analysis, three of the designs were extremely similar, therefore, as a team we combined design concepts 1, 2, and 3 into one concept deemed the title Combined Design Concept. A not-to-scale CAD layout of this design concept can be seen in the following figure (Figure 2).

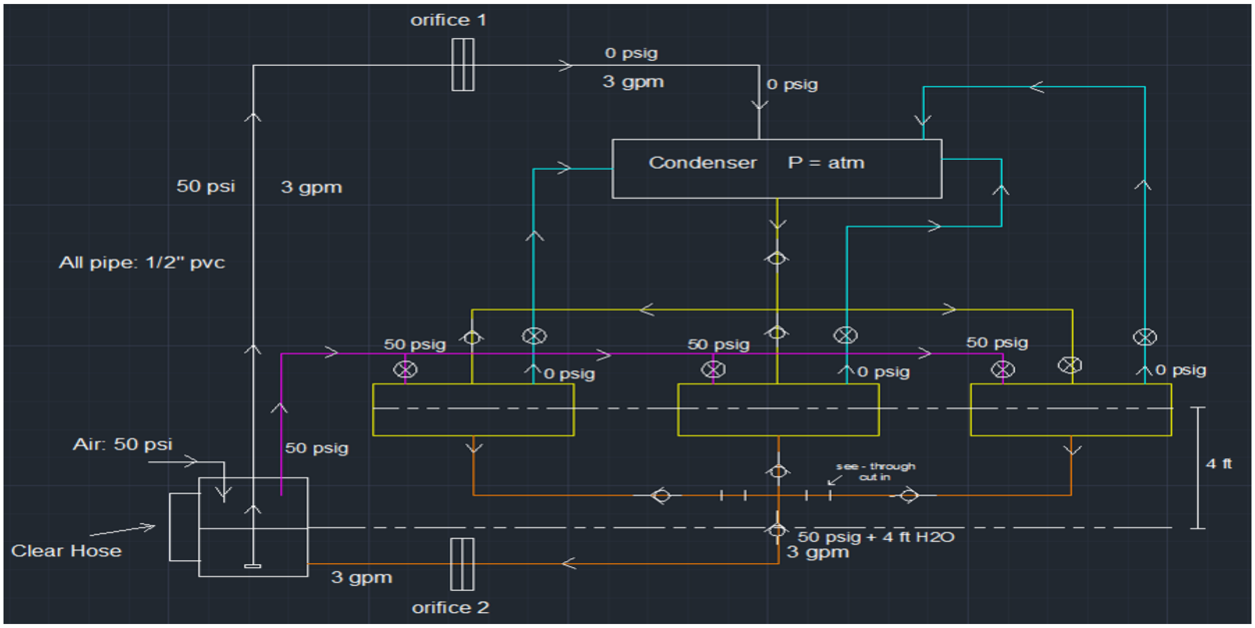


Figure 2. Combined Design Concept: Design concepts 1, 2, and 3.

An in-depth explanation of how the Combined Design Concept (Figure 2) operates has been provided below:

1) To model our heat exchanger (lower-left) a pressure vessel will be filled with water and an air compressor will supply a constant pressure of 50 psi to the vessel. The pressure will push the water up the pipe until it reaches orifice 1.
2) Orifice 1 (upper-left) will represent the turbo expander in our prototypes design. The purpose of this orifice is to resemble the pressure drop from 50 psi to 0 psi (atmospheric pressure) that would occur in the actual system. After the pressure is relieved from the system the water will flow into our model condenser which is at atmospheric pressure.
3) Our model condenser (upper-right) will just be a vessel that is held at atmospheric pressure. The condenser is what supplies water to the pressure vessels below it (yellow lines). The condenser also acts as a place for the pressure vessels to relieve their pressure back to 0 psi (blue lines).
4) The pressure vessels (yellow squares) are the most complex segment in this design due to the fact that they are solely responsible for maintaining the appropriate flow rate previously supplied by the pump. Analyzing one pressure vessel allows for an easier explanation. A pressure vessel, filled with water, is pressurized from opening its control valve to a pressure line from the heat exchanger, supplying a constant pressure of 50 psi. Once the pressure of the vessel is equal to the pressure within the heat exchanger (an instantaneous occurrence) the vessel will be able to drain the water by gravitational force

due to the elevation difference between the vessel and the heat exchanger. When the vessel needs to refill the control valve for the pressure line will close and the control valve for the condenser, at atmospheric pressure, will open. This will result in the flow of water from the condenser into the vessel with the aid of gravity and elevation difference.

5) One might have noticed that one vessel is not capable of maintaining a constant flow rate within the system because it needs to refill itself. That is why a second vessel is added to switch on and off with the first vessel and help establish a constant flow within the system since one vessel will always be draining while the other is filling. This sequence of phases can be visualized better with the schematic below (Figure 3).

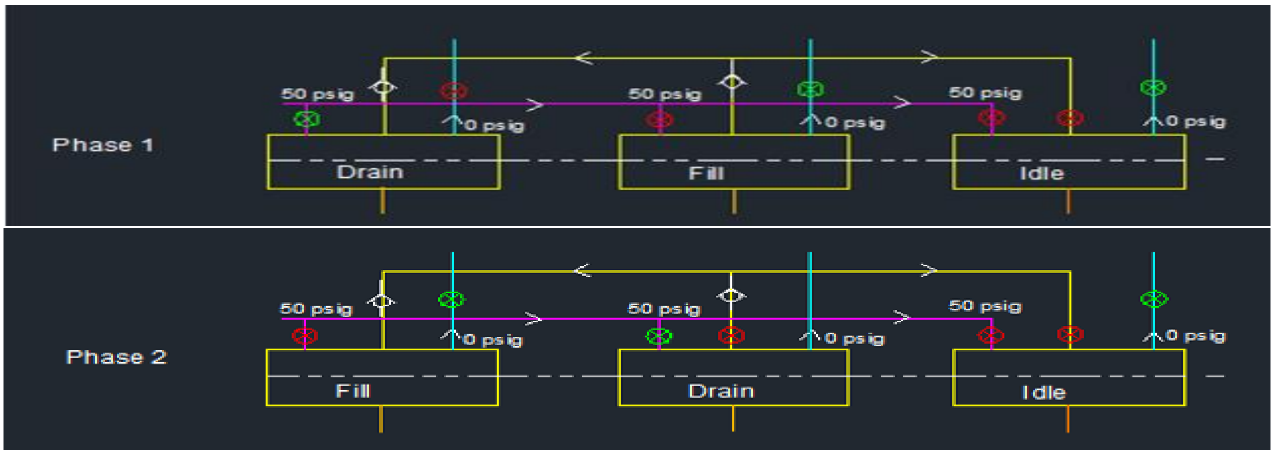
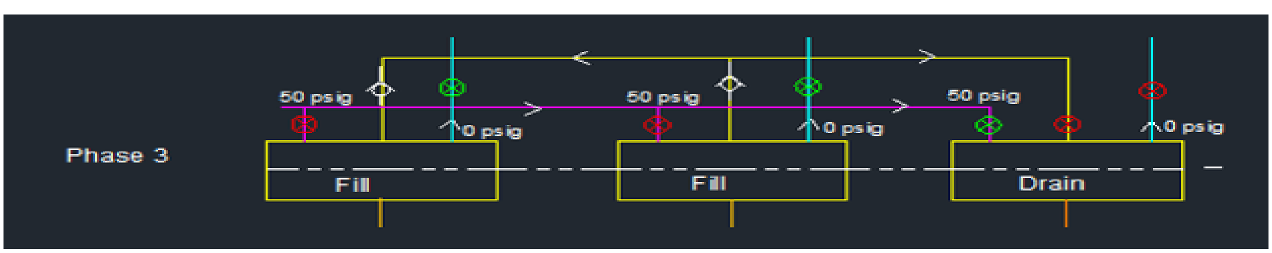


Figure 3. Combined Design Concept: A schematic showing the phases of the pressurized vessels seen in the system in Figure 2.

In the figure above (Figure 3) a green control valve represents an open valve while a red control valve represents a closed valve. In phase 1, the first vessel is draining because it is being pressurized by the pressure line from the heat exchanger while the second vessel is filling because it is open to atmospheric pressure from the condenser. Phase 2 shows a switch in the roles between vessels 1 and 2. A third vessel is seen above, labeled "Idle" during both phases. This vessel is a reserve vessel in case the system faces any problems with its sensors or control valves. This vessel, being twice in volume as the others, will drain allowing vessels 1 and 2 to refill completely. Then phase 1 can restart for vessels 1 and 2 and the reserve vessel will refill itself from the condenser. This process is visually demonstrated in the schematic below (Figure 4) with phases 3 and 4.



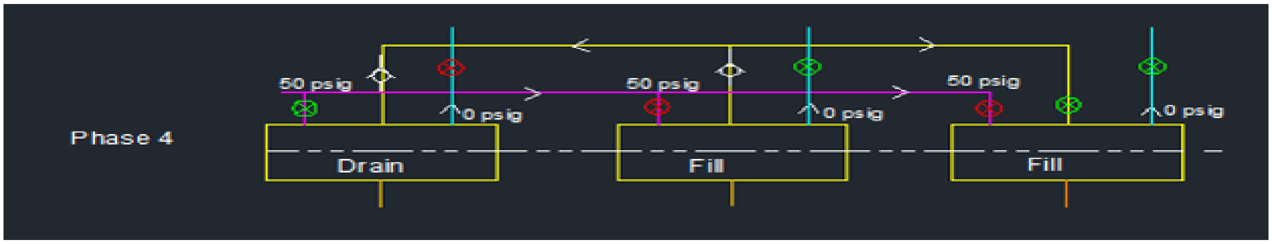


Figure 4. Combined Design Concept: A schematic showing the execution of the reserve vessel seen in the system in Figures 2 and 3.

6) After the water is drained from the pressure vessels it goes through orifice 2 before reconnecting with the heat exchanger and completing the entirely closed system. This second orifice is considered at this point to possibly minimize the flow rate back into the heat exchanger if it is not at a constant 3 gpm.

To create a difference between these designs for evaluation, each design concept will use a different type of sensor for monitoring the water level in its pressure vessels. Design 1A will consist of using magnetic sensors that will sense the height of the fluid in the holding tanks by tracking a magnetic float inside of the tank. This will require a magnetic material that can float in the refrigerant 245fa without having any negative side effects. Design 1B will use an old fashioned float valve as sees in many commodes. The float will rise and fall with the fluid level and cause a contact to be made on the other end of the lever. The contact will send a signal to the controller to tell the control valves to open and close accordingly. Design 1C will use an electro-optical sensor to detect the height of the fluid. This design will use no moving parts inside the holding tanks. It will simply thread into the top of the tank which means that it will also have no contact with the fluid.

There will also be three different types of control valves to choose from. The team will have to choose between using pneumatic, solenoid or mechanical control valves. The team is leaning more towards using either pneumatic or mechanical control valves because they will require no extra electric consumption, thus increasing overall efficiency. These are factors that, with the aid of a decision matrix, will be decided on and reported in the next presentation.

The fourth design concept, Design Concept 4 (Figure 5), was the only design that showed significant difference in the components required for the design. These significant differences included the use of 4 pressure vessels in constant operation and collection of the liquid from the 4 vessels by a pressurized storage tank below them. Otherwise, the entire system operates in the same exact manner as the Combined Design Concept (Figure 2), explained previously. This design integrates 4 pressure vessels into the same sequence of phases 1 and 2 previously mentioned in the last design. Pressures vessels 1 and 2 and pressure vessels 3 and 4, undergo the same phases of 1 and 2, demonstrated (Figure 3) and explained previously. This design also uses a pressurized storage tank below the pressure vessels, collecting the water from the vessels draining two at a time. This storage tank is constantly pressurized at 50 psi due to the pressure being supplied by the pressure vessels above which drain into it. This constant pressure is equal to the pressure of the heat exchanger, allowing for continuous drainage of the storage tank at the appropriate flow rate (3 gpm) back to the heat exchanger.

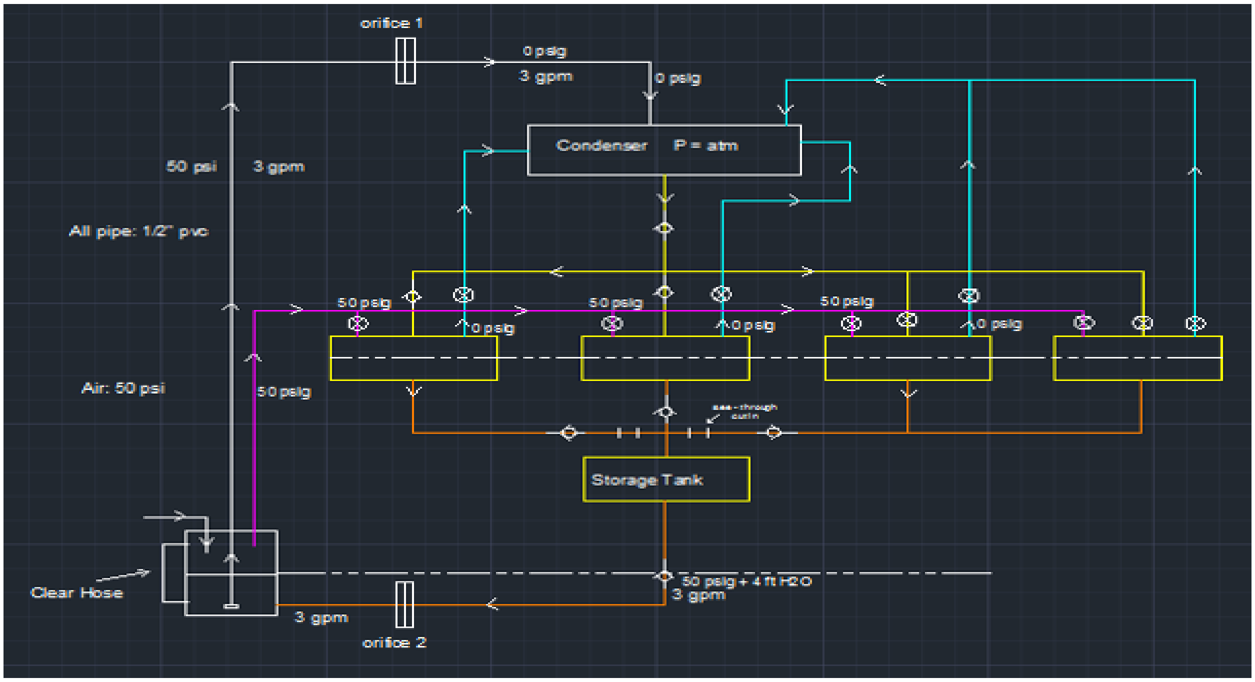


Figure 5. Design Concept 4

Evaluation of Design Concepts

As of this week (Week 9), the design team has produced 4 individual designs that still need official evaluation. Of the four designs, three of the designs were extremely similar; therefore, the team combined these designs into one combined design concept. The only difference in these designs is the type of sensor used to monitor the liquid levels in the vessels, allowing for evaluation of one design concept on three different criteria. The design team and our sponsor have both agreed upon this one combined design concept and, upon further evaluation, it will most likely be our final selection with the possibility of slight variations in the components. The fourth design was the only design that showed significant differences from the others. This design used a storage tank to collect water from 4 vessels that are all in continuous usage. This design will still be evaluated but because of its extra materials and components to accomplish the same goal as the previous combined design concept it will most likely be discarded.

After further analysis during the following week (Week 10) the team will evaluate all design concepts with a decision matrix. The decision matrix will evaluate each design based on important factors selected by the design team or specified by the sponsor. This method will help the team conclude on the best final design and proceed with the analysis and development of the prototype.

Programming Needs/Controls

The programming needs and controls for the prototype will be simple. There will be a demand for a simple programmable logic controller (PLC). The PLC will require a sensor to be placed in each holding tank. These sensors will detect the height of the fluid in the tank and feedback to the controller to tell the control valves when to open and close. This is how the system will maintain its constant flow rate. The programming language to be used in the prototype has not yet been determined but it will probably be the language that is preferable by the sponsor, Verdicorp.

Procurement

All purchasing and machining will be done through our sponsor, Verdicorp. They have allotted us with a $2000 budget. We must present them with a purchase order form prior to purchasing any supplies. Upon their approval we will purchase what is necessary to begin building and testing of the prototype. Verdicorp also has an on-site machine shop. Any parts that must be designed by the group will be built and/or machined here. The team will submit valid engineering drawings to the machine shop at Verdicorp and the part will be constructed there.

Conclusions

The design is progressing at an acceptable rate. The sponsor has been pleased with the team's work so far and there is confidence within the team and sponsor that the overall design will accomplish the project goals. There are only a few minor details that need to be refined before the final design will be selected and ready for building and testing. Some of these details will include selecting the sensors to be used inside the holding tanks. These sensors must be simple in their operation and must be affordable, keeping in mind the project budget of $2000. The sensors must also be non-corrosive in an environment containing 245fa refrigerant. Verdicorp has many PLC's available on-site and they will provide the controller for the project. The control valves must also be selected. They must be fast activating control valves with minimal pressure loss across them. Once these items have been selected and implemented into the prototype the team will be ready to build and run tests for the overall system.

Future Work

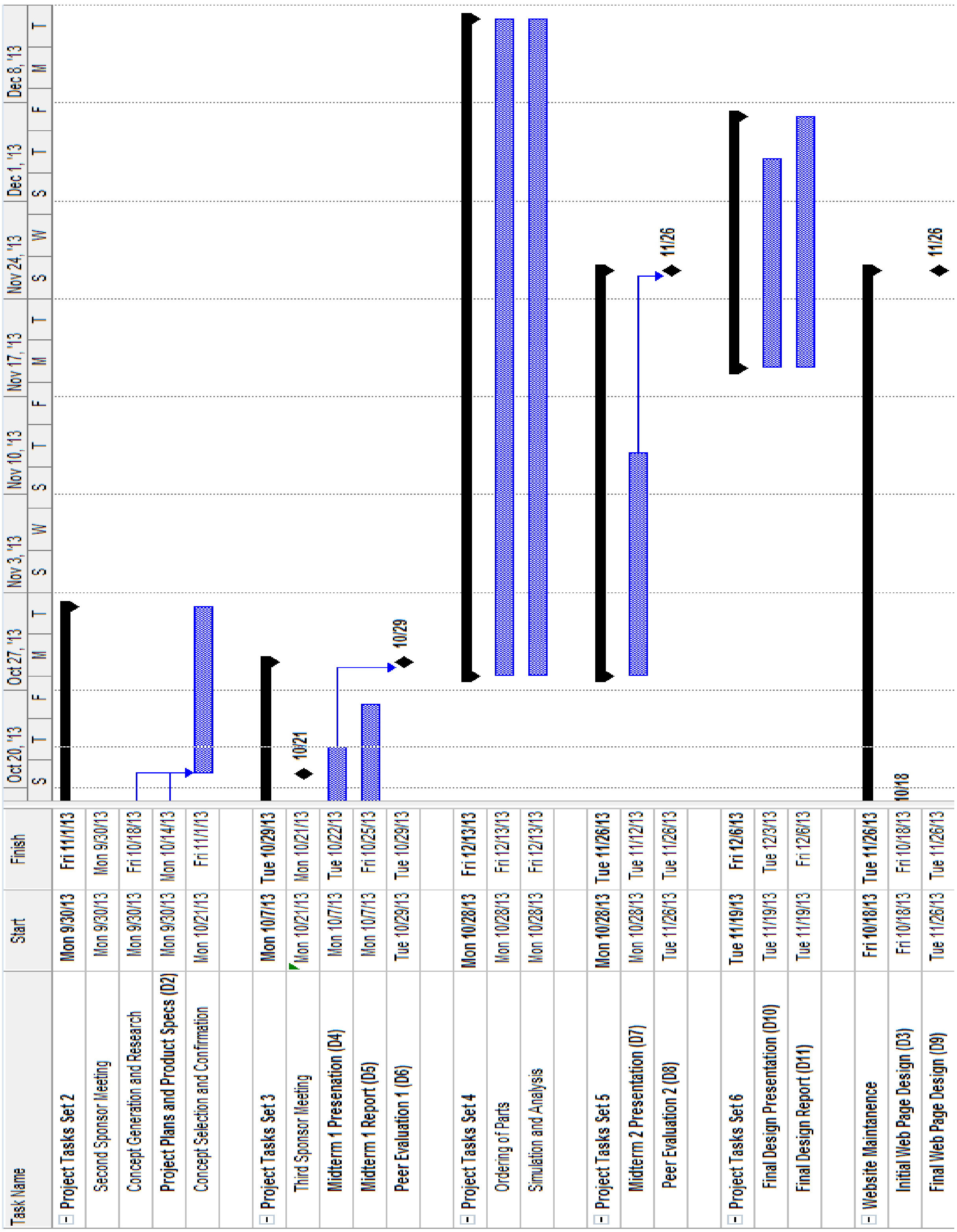
A work breakdown structure (WBS) has been provided below; detailing all deliverables, tasks, and courses of action that are needed to ensure the success of the project in a time efficient manner for the remainder of the semester.

WBS Remainder of Fall 2013 Semester

- **Midterm 1 Report**
  - Week 9
  - Prepare/complete fifth deliverable: Midterm 1 Report
  - Due: Friday, Oct. 25th, 2013
- **Concept Selection and Confirmation**
  - Week 9 - 10
  - With aid of a decision matrix, all individual design concepts will be analyzed by the team and selection of the best (or top choices) will then be presented to the sponsor for their critique and confirmation.
  - CAD drawings of the final selection(s) must be made.
- **Website (Construction/Maintenance/Completion)**
  - Weeks 9 – 16
  - The website must be updated and maintained with all major deliverables and goals of the project throughout the remaining semester.
  - Prepare/complete the ninth deliverable: Final Web Page Design
  - Due: Tuesday. Nov. 26th, 2013
- **Ordering of Parts/Components**
  - Weeks 10 – 16
  - With a selection of a final design and confirmation by the sponsor, the team can now order the necessary parts and components which will be needed to construct the prototype during the spring semester
- **Simulation and Analysis of Final Design**
  - Weeks 10 – 16
  - Simulation and analysis of the final design with the use of computer programs will be implemented in these weeks to make sure that the prototype will be ready for construction in the Spring semester without anything that could possibly delay the progress of the project
- **Midterm 2 Presentation**
  - Weeks 10 – 13
  - Prepare presentation of project progress up until Week 12 of the semester: Analysis of components/part needed for the final design; update on any information not presented during the Midterm 1 presentation
  - Prepare/complete seventh deliverable: Midterm 2 Presentation
  - Presentation will take place on Tuesday, Nov. 12th and Thursday Nov. 19th
- **Peer Evaluations**
  - Week 10 and Week 14
  - Prepare/complete sixth deliverable: Peer Evaluation 1
  - Due: Tuesday, Oct. 29th, 2013
  - Prepare/complete eighth deliverable: Peer Evaluation 2
  - Due: Tuesday, Nov. 26th, 2013

- **Final Design Presentation/Report**
  - Weeks 13 - 15
  - Prepare presentation of project progress up until Week 15 of the semester: final design analysis and explanation, actions to be taken next semester, and anything accomplished during the entire semester.
  - Prepare/complete tenth deliverable: Final Design Presentation
  - Presentations will take place on Tuesday, Dec. 3rd and Thursday, Dec. 5th
  - Prepare/complete eleventh deliverable: Final Design Report
  - Due: Friday, Dec. 6th, 2013
- **End:** December 13th, 2013

Gantt Chart (Remainder of Fall Semester)



References

[1] "Verdicorp Environmental Technologies," Verdicorp INC., [Online]. Available: http://verdicorp.com/. [Accessed 18 September 2013].