Fall 12-2023

A Tessellation of Engineers

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By

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An undergraduate honors thesis submitted in partial fulfillment of the

requirements for the degree of

Bachelor of Science

in

University Honors

and

Electrical Engineering

Thesis Advisor

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Portland State University

2023

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Pursuing a degree of any type places students in many groups such as lab groups, study groups, societies, and teams. These groups are important to progressing and succeeding academically, and naturally the quality of these groups increases as the student approaches graduation. When I began the pursuit of an electrical engineering degree, more often than not, I would only work with a group when forced. A lab group rarely meant I did less work or produced better reports. I was a good student but not a good team member; I would just plow forward on my own. The further I got in my studies, the more I saw the benefit of a solid group of peers with similar ambition to my own.

As a senior in most areas of study, students participate in a large final project, known as a senior capstone project, with a team of people in a similar area of study. It is an opportunity to use knowledge and experience gained over years of schooling to do something one might then apply to a professional career. The senior capstone project was that big final project for me. I learned an incredible amount over the two terms our team of four worked on our capstone project. I expected to and did further my knowledge of power engineering and electrical power transmission and distribution systems. However, the most important thing I learned was the value of working with a team of highly dedicated and motivated engineers.

Background:

One of the first times I experienced working with a great group of solely future engineers was between my sophomore and junior year in two summer courses at Portland State University in courses called Introduction to Design Processes and Project Development, ECE 211 and 212. Participating in those courses was incredibly fun, beneficial, and rewarding. It was the first time I felt like I was working with a team and not just completing a list of preordained activities. The outcome was not decided for us; we chose our goals and determined the path to achieve them.

We learned about project management and used what we learned to design and create a semi-autonomous vertical hydroponic herb garden. We each used our interests and strengths, and we worked very well together! However, that was nothing compared to what I was in for with the senior capstone project.

The team I was on for the 2023 Winter and Spring capstone terms was exceptional! The project brought all of the experiences in various groups and classes together. I had all the puzzle pieces, but the process made me see the whole picture.

Purpose:

Seeking a degree is a scary thing. We often wish we could have a crystal ball to see if we are making the right choices. Will I like the career path I have chosen? What will my job be at the end of all of this? Can I succeed? I am not sure these worries will ever go away. I was a senior, mere months away from graduating and working as an intern in a job I wanted to continue after graduation when I completed my capstone project. I was still worried! The capstone project was grueling and difficult work, but it confirmed for me that I did choose the right path. The insights I gained over the process, could be helpful to other students with the same questions.

Our capstone project was to design the auxiliary power and protection systems for a planned substation. We were given details about the kind of equipment and requirements for the design. The rest was entirely up to us. The team consisted of four students, a professional sponsor, and an academic advisor. In the following sections, I will detail the project and technical aspects and address our successes and difficulties. Ultimately, I aim to fully explore how the team performed each step of the way.

Project:

In December of 2022, after completing the introductory course of Industry Design Processes, I was placed in a group of four students to prepare for our capstone project over the Winter and Spring terms of 2023. The team was introduced to the project and completed a preliminary planning memo. We met and discussed our probable project management, timelines, and individual roles. This allowed us to spend our winter break familiarizing ourselves with the expectations and technical aspects of the project. We were ready to hit the ground running with research and questions prepared for our professional advisor as soon as the winter term began.

The project was sponsored by HDR, an engineering and design firm. We were, of course, working with the electrical engineering department. Our capstone project was overseen by a professional advisor, an academic advisor, and the professor of the courses. The professional sponsor was an electrical engineer for HDR who specialized in substation design. He met with us regularly to guide us through the project, answer questions, and explain parts of the design criteria using his professional experience. Our academic sponsor oversaw our progress in the project and attended meetings to provide guidance to us throughout the reporting and learning process. The professor required regular reports, memos, and updates. Our professor had worked with us all in the introductory course to the capstone process, ECE 411, so we knew what was expected of us and had the tools to move forward when we were assigned the capstone project for subsequent terms ECE 412 and 413.

Our team was tasked with designing the auxiliary power systems for a planned 230/35.5 kV substation. This meant we needed to design a protection scheme for high voltage equipment as well as specify low voltage power and protection equipment necessary to operate and maintain the substation. We were given a preliminary circuit diagram, which included the two 230-34.5 kV transformers feeding eight 34.5 kV lines and one 34.5-12.5/7.2 kV transformer to provide power to the substation processes. Each line had to be protected with circuit breakers

and switches, and design choices had to be made to choose the correct components and wires. The layout of the substation was outside of the scope of our project.

The team:

We decided Scrum (“What is Scrum?”, n.d.) management style would benefit us. Scrum is an approach that involves breaking a project timeline into blocks called sprints where goals are set, worked on, reviewed, and adapted. It was important to meet nearly daily for quick five-minute breakdowns of the work we did, are doing, and will do. Fortunately, we had resources such as Zoom for remote, in-person meetings and Discord for regular discussion and collaboration. We set a timeline of meeting for longer, collaborative work sessions twice a week and a once a week meeting with our professional and academic advisors to fill them in on our progress and ask questions or get advice as we progressed through the project.

When we met in December to plan, we decided on our main jobs for the coming months. I was the database lead. My main focus was to create calculators and spreadsheets for keeping track of the calculations used in determining components and maintaining our data for use and access in the design. Team member A was our design engineer. They made a majority of the design choices and created documentation including descriptions of components and drawings using CAD of circuit diagrams and layouts. Team member B was our archive manager. They studied, documented, and made recommendations for design practices and requirements to include NEC/NFPA (“Draft of Proposed NFPA”, 2014) standards, IEEE (“Electrical Engineering”, n.d.), and RUS guidelines (“Design Guide for Rural Substations”, n.d.). Team member C was our Scrum master. They led the team in meetings and kept the schedule of reports and assignments.

While these were our designated jobs, of course each team member had to rely on each other, and our jobs evolved throughout the process. It was a great starting point, however, and this team management framework was integral to being successful and maintaining our sanity

with the heavy workloads we each carried. No job could be performed alone or without consistent communication with the entire team, and every team needs an effective project management system in place to manage tasks and facilitate communication.

Method:

We began each sprint by reviewing our last sprint. What did we accomplish? What worked well? How can we improve? What do we need to focus on next? These meetings were how we assessed our progress and moved forward. We gained confidence and knowledge each sprint. We kept track of these goals and achievements using a virtual board of columns of sticky notes. Each sticky note would describe a small task needing to be completed. We would claim sticky notes from a “planned” column as our intended work for the sprint and move them to an “in progress” or “completed” column as the work on the task proceeded. During our reviews, it was clearly laid out what each team member did and what was left to be done. This process created a sense of accomplishment and ownership, and it made us aware of the progress that everyone on the team was making. We would identify areas where tasks were not necessary or add tasks we had not foreseen.

Early in our project we were sifting through mountains of technical documents. Our design engineer studied the cut sheets to determine the power needs for each of the components. For example, a transformer is an incredibly expensive and important piece of equipment. It must be protected from surges or faults that may occur in the electrical system. It also has to be protected from weather such as extreme heat or cold. In the event that there is an issue with this equipment, it must be assessed and serviced. There is a thermostat, heating and cooling systems, oil level and pressure indicators and alarms, and cabinet lighting for maintenance to name some of these processes which need power. The design engineer created a detailed load analysis of each component to begin deciding how to design the support for the system. Our archive manager was collecting and organizing NEC/NFPA, IEEE, and RUS

documentation, standards, articles, and guides: There were many we had to study, and it was quite a task to pick out the ones relevant to our work. The Scrum master was organizing templates, updating our boards, and maintaining the schedule of meetings and notices to advisors. As the database lead, I was setting up our spreadsheets to keep track of components and calculators for impedance, wire selection, breakers, and short circuit analysis. Many of the equations needed for these calculators would be found within the documents provided by the archive manager, and the variables for calculation were found in the load analysis.

Most of the work described above took several sprints to iron out the details. Each sprint, we saw the work coming together more and more until we had what was looking like a real design! A typical sprint review during this phase would begin with each team member discussing in detail what they were working on, what they accomplished, and what they were needing to accomplish in the next sprint. For example, I had created a working calculator to determine wire or conductor size required according to NEC standards. The load and voltage taken from the load analysis determined the current capacity which led to a recommended wire size. The calculator then reported the impedance in the wire which determined the voltage drop expected in the wire. There is an acceptable amount of loss in a wire, and if the voltage at the end is too high or too low, insufficient power or damage to wires and components may occur. The calculator was working great, but as a group we realized our next steps would involve grouping our equipment and components. Each item did not necessarily have its own conductor. This realization gave us each a new goal to add to our list for the next sprint. It also gave us questions for the professional advisor as he had experience in what would typically be acceptable as a grouping in substation design. We planned our next advisor meeting and prepared our questions.

Results:

Our team completed the substation auxiliary power design by the end of the two-term capstone period. We produced a package of documents and made a presentation for our professional and academic sponsors. We included the working calculators for conductor sizing and transformer impedance, short circuit analysis, AC and DC one-line diagrams with switches and protection, three panelboard schedules with conductor and breaker sizes, and a bill of materials for components we deemed necessary for a resilient system. We included future upgrade plans within the documents described above as well as a plan for maintenance should any equipment need to be taken offline.

Conclusion:

Animals are often described with clever words or phrases when grouped together: A murder of crows, a conspiracy of lemurs, a dazzle of Zebras. In the end, I thought of our team as a tessellation of engineers. A tessellation is a grouping of objects or shapes which fit together without gaps or overlapping parts. We often picture a work by MC Escher where the shapes flow together to cover an area completely. We did not have time to complete redundant work, and everything we did had to have a purpose. We were all soon-to-be engineers, but we each brought a different piece to the puzzle.

Completing the design was a lot of hard work, and we were proud of what we produced. We worked very well together. Each team member had a job to do, but no one's job was possible without the work of the other team members. Our professional advisor became our mentor; they spent time every week speaking with us about any questions we had. Much of what we were designing was not expressly described in our classes and studies. We had to take the time to learn on our own and with the support of the rest of the team and advisors.

As I approached my senior year and the capstone project, I was still worried I was a fraud and not ready. I had gained an incredible amount of knowledge, but I was unsure how that

would translate into a career. Completing the project with an amazing team and encouraging advisors made me feel accomplished, confident, prepared, and excited to enter the engineering field.

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