ELEC 399: Design Project I
Progress Report #2

Design and Build a DC-DC Convertor for Charging Electric Vehicle Batteries

Group: 14

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Supervisor: Ashoka Bhat

Due: July 6, 2012

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Chapter 1: Designing and Building of a DC-DC Converter for Charging Electric Vehicle Batteries

Revision of Progress Report 1 Chapter 1

Supervisor: Ashoka Bhat

The project selected will be to design a charging system for electric vehicle battery packs. Motivation for selecting this project stems from its obvious real-world applications and its commercial potential. With environmental consciousness becoming more and more prevalent in the world many of the companies producing new technologies are steering there designs towards "greener" solutions. All members of this group are very environmentally conscious and hope to apply our education and experience in the electrical engineering field to design a system that supports the "green energy" initiative.

In addition to its environmental applications the rising popularity of hybrid and plug-in Electric Vehicles (EV's) presents a rapidly expanding market for EV chargers. According to Alec Tsang, a representative from BC Hydro at the 2009 EMC Conference, electric vehicle adoption within BC is expected to eclipse 1 million vehicles by 2030, as advancements in charging technology make EV's more accessible to average consumers this number will likely rise even higher.

DC charging stations allow for much faster charging than would otherwise be possible using the vehicles on-board system. This is because weight and size restrictions prevent the bulky transformers and rectifiers from being permanently installed on the vehicle so smaller slower chargers are used to ensure consumers are never left stranded with no way of charging their vehicle. An external DC charging station bypasses the internal charger, flowing much higher currents and voltages allowing the batteries to be charged at a greater rate.

The aim of the project will be to develop a fast and efficient method for charging electric vehicles using an LCL type resonant converter configuration with a clamping type high-frequency transformer that will be magnetically coupled to the vehicle for added safety. An intuitive and easy to use charging process will be accomplished by using a microcontroller, which controls the power output of the charger and monitors the charging state of the battery.

Scope

Before commencing the design process it is important to research any existing technologies of a similar nature in order to learn from their strengths and weaknesses. By researching current technologies incite can also be gained into exactly what the market is for a DC-DC converter of this type. The background research will also include identifying the major components needed for the converter and how they work individually as well as how they interface with one another.

Once the preliminary research is completed and a strong understanding is gained regarding the components needed and how they will interface, the design process can begin. The conceptual design will lay out the major components previously researched and outline how they will interface in general using a single line diagram and average size measurements taken from manufacturer specifications. The conceptual design will also outline how the converter will interact with the vehicle and what voltages and currents are required.

The completed conceptual design will clearly layout what parameters are most critical when selecting the major components for the converter and also what specifications the microcontroller will need to meet. By comparing different components and different manufacturers of those components the design can be optimized to meet not only the requirements of the vehicle, but also ensure as compact of a design as possible while maintaining a reasonable overall materials cost.

After the parts have been selected to meet the parameter criteria they will be added into the design to confirm proper theoretical operation of the system and a draft of the final design will be produced for the DC-DC converter to clearly layout the component interaction and demonstrate the expected output of the system when interfacing with the vehicle.

An Arduino microcontroller will be used to interface with the DC-DC converter to maintain coherent operation and to ensure maximum operation efficiency [1]. Pseudo code will be created to outline how the controller will interface with the DC-DC converter and then expanding that into the required language it will ensure that all required aspects are accounted for in a logical order.

Lastly, once the Arduino microcontroller has been programmed and the design has been finalized the final report will be written. The final report will include all design specifications and parameters along with all necessary wiring diagrams and the size expectation of the design, along with the code for the microcontroller. The report will also include a summary of the project with a conclusion outlining the theoretical output of the system when interfacing with an electric vehicle and lastly any recommendations for how to further optimize the project.

Background Research	Conceptual Design	Parameter Specification	Final Design Draft	Controller Interfacing	Final Report
June 1	June 15	July 1	July 15	July 25	Aug. 2

Table 1: Project Mile Stones

Deliverables

1. Progress Report 1 - COMPLETE
2. Progress Report 2 - Due July 6
3. Demonstration - Due July 31
4. Project Website - Due Aug 3
5. Final Report - Due Aug 3

Biographies

Allen Houle

I am a 4th year Electrical Engineering student at the University of Victoria. My first passion in life has been cars; building, racing and anything 12V related. I purchased my first vehicle when I was 14 and spent the next 2 years fixing it before obtaining my license. That car has undergone extensive modifications under my hand, starting with the restoration of the rusted body, and then an engine swap where I became intimately familiar with vehicle electrical systems as I wired it myself. I have since rebuilt that engine from the ground up and improved the drive train.

During My first Coop through UVic I was employed by Canadian Electric Vehicles where under the tutelage of my supervisor I learned a great deal about electric drive systems and AC drive motors.

I have also applied my passion for music to a more technical pursuit. For a final project in my electronics class in high school I designed and built an Electrostatic Loud Speaker. Electrostatic speakers use potential across a small air gap to vibrate a thin membrane instead on the conventional current carrying coil of wire/magnetic field employed in a conventional speaker.

Currently I am pursuing my passion for electronics with Arduino microcontrollers, constructing programmable light arrays and looking into using the microcontrollers to accomplish home automation tasks.

Brayden MacDonald

I am a fourth year electrical engineering student at the University of Victoria. I am currently working on specializing in electrical energy systems and electronics. My career interests lie in the field of power systems and utilities. My previous BC Hydro job experience in the Generation Protection and Controls department confirmed this as I really enjoyed programming PLCs and learning about Protection and Control design. My favorite day at work was the field trip to Stave Lake Generating Station. It was thrilling to go inside of a dam, and I look forward to going to some of the larger, more impressive generating stations.

I also learnt a lot from my first work term at Stantec Consulting about cabling and voltage drops for various pieces of industrial equipment as well. I learnt about oil-sands pipeline pumping stations and the many components required to power and run the pumping station safely and efficiently. My most recent work term at Alcatel-Lucent provided me with lots of hands on electronics experience. I developed my soldering skills and my circuit debugging skills in addition to learning much more about the telecommunication industry.

Assembling service router line cards at my last job inspired me to build my own desktop PC with parts I bought on the internet. I do enjoy working on electronic project for school and on my free time, and I look forward to further developing my soldering skills.

Jason Small

I am Jason Small currently in my fourth year of electrical engineering at the University of Victoria, my interest in engineering and sciences started at an early age. My parents believed it started with my love for Lego. I would often play for hours each day constantly building and creating new things, this naturally progressed to being interested in building/designing things at an older age like forts outside and wood working and shop classes in high school. Along with those hands on skills in school I also took a wide range of sciences. I enjoyed my classes in math physics and calculus. However I was undecided as I graduated and took general sciences for 2 years before deciding to apply to the electrical engineering program at UVic.

I was drawn to UVic for its coop program as it is a true advantage after graduation, already having relevant work experience is a huge asset. The smaller school size was also a bonus.

My two coops were at Gibraltar Mine in Williams Lake BC. It is the second largest open pit mine in BC. There on my first coop I worked under the Electrical superintendent of the entire mine, there I focused on the maintenance of the AC motors of the 240 ton haul trucks on site, the maintenance of the motors was extremely important to the through put of the mine and downtime could not be tolerated. I learnt much about the design and construction the AC drives used to power the trucks.

On my second work term I worked under the electrical planner, who was in charge of power distribution to the pit and mine site. I learned about power transformation on site. Power must be stepped down on the main site substation, then as it is directed to different mine equipment, such as shovels and drills, at has to be stepped down again to their respective voltages. This was important again to the throughput of the mine. Safety was also a primary concern on the site, and we developed safe procedures for unit substation and cut off house maintenance.

My goal is to work in a setting similar to Gibraltar, I enjoyed learning about the high energy systems on site, and that is why I chose a specialization in electrical energy systems.

Nathan Bellmore

I am currently in my last semester at UVic and will be getting my bachelors in Electrical Engineering in December 2012 after completing my last work term. I have always had a strong interest in computers and other electronics, which has helped motivate me for many of my undergraduate classes. I chose not to specialize in a specific field in electrical engineering, but after doing 3 sequential work terms in the power distribution field I decided to take all the power courses offered at UVic.

My first work term was at Teck Coal Ltd. working with an Electrical Engineer in the engineering maintenance department. I began mostly updating and creating single line and 3 wire CAD drawings, but ended up assisting in many new installations by researching and selecting components that met the required specifications and were in accordance with the Canadian Electrical Code. Next I did a second work term at the same job, but primarily worked with various programmable logic controllers and HMI screens around the mine site. In September of 2011 I worked at the Canadian Forces Base in Esquimalt in the Engineering Project management department shadowing one of the electrical PMs and began managing a backup power upgrade in one of the older buildings. This included working with consultants to get a power quality analysis done as well as a full options analysis. Due to the time constraints I was only able to see the project through the initial phases and passed it off to one of the PMs when I left.

I look forward to working on a project that supports “green” energy and I am excited to expand my knowledge of how electric vehicles operate. My education and experience in the power distribution field will be a strong asset to the team and will hopefully prove useful for a project relating to power electronics.

Neil Hindle

I began my post secondary schooling enrolled in the Physics Department where I spent two years. During my second year I had taken Physics 220 – Electrical Properties on Materials, which is the same course offered by the Electrical Engineering department ELEC 220. After completion of this course and an utter love of the material I decided that my studies should be focused towards my interests and my strengths, thus the logic solution was to transfer into Electrical Engineering Program to finish out my post secondary career.

My specialization fields are Communications and also Electromagnetism and Photonics. My career goal has been directed towards communications ever since my first cell phone and was further inspired by my two work terms at Capital Region Emergency Service Telecommunications.

I was born in Kindersley, Saskatchewan and was raised in Duncan, British Columbia. My youth was spent outdoors doing activities such as hiking, biking, fishing, and skateboarding. Electronics was a large part of my child hood as I had child starter electronics kits and also many video game systems. I had an older brother that always had an intense interest in computers which allowed me to learn and work with computers at an early age, during my high school years he completed his doctorate in Computer Science jointly at UVic and at Waterloo. Having a role model such as my brother I have always strive to contribute to the technical industry and with graduation coming in a year's time I believe I will.

Chapter 2: Progress Review for Design Project I

Introduction

The last month has been spent thoroughly researching LCL type resonant DC-to-DC converter configurations. In order to accurately select the best possible design for the electric vehicle charger, all aspects were examined and the findings are outlined below. Another important task is developing a detailed timeline for the completion of our project. The future steps to be taken in order to accomplish our objectives are listed below in the recommendations section.

Research

The LCL converter configuration has a number of advantages such as the ability to accommodate a wide range of input and output voltages, can operate both in step up and step down modes, soft switching and can be accomplished over an entire operating range.

An LCL circuit is used to minimize the output current ripples present in DC-to-DC converters. Another advantage to this converter is the reduced Electromagnetic Interference (EMI) and stresses while also having a high power density [2]. The LCL circuit that is contained in the charging structure will be magnetically coupled with a full bridge rectifying circuit typically found in electric vehicle battery charging circuits as seen in Figure 1: DC-DC LCL Circuit. The process of magnetically coupling the two circuits and transferring power between them is detailed in the next paragraph. The full bridge rectifier will be chosen for the implementation of our design. Advantages of the full bridge system include:

- No requirements of center-tap transformer.
- For the same secondary winding voltage output this circuit will produce twice that of center-tap full wave rectifier circuit.
- For the same DC output the PIV is one-half of that of center tap full wave rectifier.

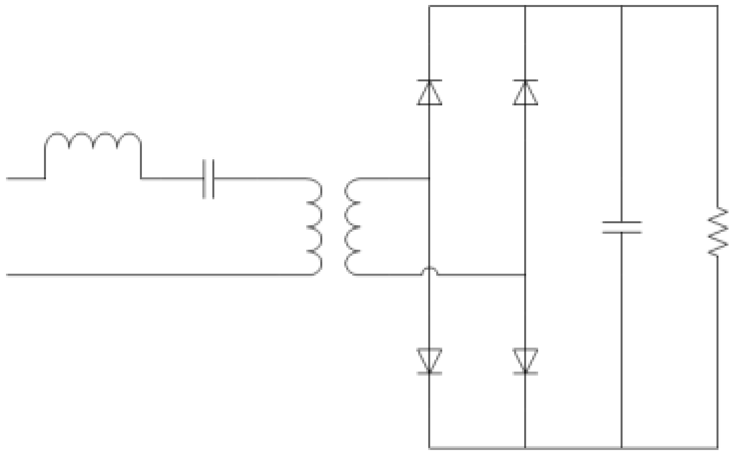

Figure 1: DC-DC LCL Circuit

The circuit will be designed to operate in Continuous Conduction Mode (CCM) as it allows for the lowest peak to average current ratio for the converter throughput power [3]. This provides a much more effective charging current for higher power applications like our Electric Vehicle charger.

Safety

An important aspect of the LCL converter design is the ability to magnetically couple to the vehicle using a clamping type-high frequency transformer. Although there will be no exposed metal connections on the interface between the car and charging station by magnetically coupling the two will prevent damage to anything or exposing conductors in the event the car is driven away without properly disconnecting the charging device. An issue may be encountered due to the United States Patent 7,311,526 held by Apple Inc., which covers techniques for coupling interfaces parts using moveable magnetic elements [4]. This patent states that when the plug and receptacle are brought into proximity the magnetic attraction between the magnet and its complement, whether another magnet or a ferromagnetic material, maintains the contacts in an electrically conductive relationship. Similar patents are also held for deep fryer power cables and Microsoft, who designed a magnetically coupled connector for data transfer to phones. To navigate these held patents for similar devices a patent lawyer may be consulted to avoid future issues for patent infringement.

Charging Control Unit

It was decided that an Arduino microcontroller would be used for the main component of the overall charging control unit. Arduino is an open-source electronics prototyping platform designed with the purpose of connecting multidisciplinary electronics with ease [1]. The board has a variety of sensors that are capable of controlling lights, motors, and other actuators making the input/output capabilities of the microcontroller very versatile. The Arduino programming language used for the microcontroller is very similar to C++ and Arduino has its own development environment.

For the purpose of this project it would be most efficient to order a pre-assembled board and wire it to a separate prototyping board that will accept any other parts required for the design. It has not been decided yet exactly how the battery voltage should be recorded and sent to an input of the microcontroller which will ensure proper shutoff at completion of the battery charge. The design needs to be non-intrusive and easy to use on any electric vehicle without requiring any major changes in the vehicle design itself.

One option explored is to include pin-outs directly in the charger plug that can communicate with the vehicles ECU to read the battery voltage. However, this would require a standardized receptacle in the each electric vehicle with ECU outputs directly wired it, and would require the vehicle to be turned on in order for the ECU to send the information to the microcontroller. Another potential option is including an instrument transformer in the design in order to measure the real time voltages which would allow software to calculate when the battery is fully charged. Other options will be explored in the future with the intent of finding the most feasible option.

Recommendations and Plan of Action

After handing in the second progress report, the following deliverables remain:

Demonstration:	10% Date: Tuesday, July 31
Web Presentation:	10% Due: Friday, Aug. 3
Final Report:	40% Due: Friday, Aug. 3

The demonstration will be completed by July 28th in order to provide adequate time for rehearsal. The web presentation will be uploaded onto the University of Victoria web space by August 3rd. The final report will follow the same structure that the previous project reports have had for the sake of conformity, and it will be completed by July 31st in order to provide adequate time to proofread and format the final result. The main item that needs to be completed for the final report is the calculations for the resistance, capacitance, and inductance values to provide the necessary power to the load. Also, the outstanding issues outlined in the Arduino section need to be resolved. If the aforementioned deadlines are reached, the team should have no issues delivering the project on time.

Chapter 3: Requirements Determination

Introduction

This chapter focuses on indentifying the analysis phase and its associated deliverables, mainly the system proposal. Requirements are also define to an extent with several categories of the requirements being explained and outlined. The purpose of the requirements definition statement is outlined, techniques of specific requirements will also be explained, and discussed; interviews, questionnaires, document analysis, and observation.

This chapter outlines five main concepts for analysis of the Systems Development Life Cycle (SDLC). These concepts are listed below.

1. The Analysis Phase
2. Requirements Determination
   - 2.1. What is a requirement
   - 2.2. The process of determining requirements
   - 2.3. Requirements definition statements
3. Requirements Elicitation Techniques
   - 3.1. specific requirements explained, and discussed; interviews, questionnaires, document analysis, and observation
   - 3.2. also includes joint application development (JAD)
4. Requirements Analysis Strategies
   - 4.1. Analysis strategies for problems, roots causes, duration, technology, outcome, and activity elimination
5. Applying concepts at Tune source
   - 5.1. Eliciting and Analyzing requirements
   - 5.2. Requirements Definitions
   - 5.3. System Proposal

The Analysis Phase

The analysis phase is defined as the breaking down of whole parts into smaller manageable pieces used to better understand the whole. Analysis with respect to SDLC involves breaking down the outline, the business goals for the new system, outputs of the planning phase (the system request, feasibility study, and project plan), definition of the project's scope, assessment of project feasibility, and providing of the initial work plan, for a better understanding of the whole SDLC project. This develops the main process for analysis;

- Understanding the current situation
- Indentifying improvements
- Defining the requirements for the future system

In summary the analysis focuses on identifying and targeting the requirements for the system. This clarifies the deliverables for the project including the requirements definition. Along with the deliverables, revised planning and project management goals are amalgamated into the system proposal which is presented to the approval committee to determine if the will move forward with the project.

Requirements Determination

The part of the analysis where the project team makes a precise list of requirements based on the high level explanation of the business requirements from the system request. The definition of a requirement is simply a statement of what the system must do, based on business needs during the process of SDLC.

Business and IT services need to determine requirements for the analysis phase. A system analysis may not truly understand the needs of a user, that's why it must be the responsibility of the more specialized project team members. During the project development it should not be assumed that requirements can change, however, it is also a requirement can be added to the list.

The requirements definition statement is a straightforward report that lists the functional and non-functional requirements in a simple outlining form. It is important that the requirements be identified with unique numbers so that each requirement can be easily tracked through the entire development process. Requirements can also be prioritized on the requirement definition statement.

Requirements Elicitation Techniques

Requirements elicitation techniques involve five steps;

1. Interviews
   1.1. Meeting one or two people, involves selecting interviewees, designing questions, preparation, conducting the interview, and a post interview follow up.
2. Joint application development
   2.1. Allows the project team, users, and management to work together to identify requirements for the system. This can be done electronically to keep all team members on track i.e. Google groups.
3. Questionnaires
   3.1. A set of question laid out in order to gather information from individuals
4. Document analysis
   4.1. Examining of the system itself through documentation, reviewing existing files etc., this will provide insights into the project and its processes.
5. Observation
   5.1. Used for gathering information about the system in its current state

Requirements Analysis Strategies

Requirement analysis strategies are tools utilized to help business user think analytically about their system requirements. Problem analysis and root cause help business user understand the problems and issues with the current established system. Outcome analysis, technology analysis, and activity elimination are three strategies that can be used to make the business users to consider the business processes in new, original ways.

Chapter 4: Use Case Analysis

A use case is used to form an explanation and document the interaction required between a user and the system needed to accomplish the user's task. They will develop a team to understand the steps needed to accomplish the user's goals. This chapter goes on to describe Use causes, more specifically, the elements of a use case, alternative formats for cases, their functional requirements, testing, and building, along with applying the concepts at Tune Source, by identifying major use cases, and elaborating.

Use Cases

Use cases will depict a set of activities performed in order to produce a desired output result. The activities will be triggered by certain inputs to the system. Use cases can vary largely from each business. This is why they may be unique to each business, and based on the needs and goal of the system. However Use Cases are broken down and systemically designed with the same elements.

1. Basic information
    - 1.1. Each use case has a number and a name, the name is simple yet descriptive
    - 1.2. Priority relates the cases importance to the overall operation of the system
    - 1.3. The actor refers to the person place or thing interacting with the use case, giving it an input, giving it a trigger
2. Preconditions
    - 2.1. Preconditions define the state the system must be in before the use case starts. While Use cases can be used to cover a large overall business plan, it is also common to break this down into smaller tasks.
3. Normal tasks
    - 3.1. The description of the major steps that are performed to execute the response to the event, the inputs used for the steps, and the outputs produced by the steps. This lists the steps that will be performed when the system works effectively.
4. Summary inputs and outputs
    - 4.1. The description of the major steps that are performed to execute the response to the event, the inputs used for the steps, and the outputs produced by the steps. This is also the description of the major steps that are performed to execute the response to the event, the inputs used for the steps, and the outputs produced by the steps.

Creating Use Cases

When designing use cases the trigger event is the first thing to be identified, whether external internal or temporary. Next the steps to approach to using the input trigger to produce needed outputs and responses to the event. Then take a look back and deeply evaluate the steps and identify more specifically the inputs and outputs for each response. Finally test the system with a multitude of different inputs to see if the outputs happen correctly.

Conclusion

After some deliberation, it was decided that the optimal circuit to use for the project is an LCL type resonant DC-to-DC converter. Its advantages include having a wide range of input and output voltages, versatility in step up and step down configurations, minimal output current ripples, and reduced EMI. The desired operating range is CCM because of the more effective charging current for our high power requirements. Safety precautions will be taken in the design by implementing a magnetic coupling circuit to ensure that improperly disconnecting the charger doesn’t result in exposed conductors and damage to the charging structure or EV. The final component of the charger design is the Arduino microcontroller used in the control unit. Arduino was chosen because of its open-source electronics prototyping platform, it’s versatile I/O capabilities, and its programming language’s similarity to C++.

The remaining tasks to be completed before the final report is tabled are the calculation of component values in the LCL converter circuit, control unit design, and investigation into magnetic coupling charging interfaces and potential patent issues that may arise from such a design. Following the resolution of these items, the final report and presentation will be assembled by the team by the posted deadlines.

References

[1] Arduino, "Arduino," 11 June 2012. [Online]. Available: http://arduino.cc. [Accessed 1 July 2012].

[2] S. Ben-Yaakov, S. Bronstein and G. Ivensky, "Approximate Analysis of the Resonant LCL DC-DC Converter," in *Power Electronics Laboratory Department of Electrical and Computer Engineering*, Tel-Aviv, 23rd IEEE Israel Convention, 2004, pp. 44-48.

[3] M. Annamalai and D. M. Vijaya Kumar, "Design Simulation of Cll Resonant Dc-To-Dc Converter for Stand Alone Wind Energy System," *International Journal of Computer and Electrical Engineering,* vol. 2, no. 5, pp. 1793-8163, 2010.

[4] e. a. Rohrbach, "USPTO Patent Full-Text and Image Database: Magnetic connector for electronic device," 26 September 2005. [Online]. Available: http://patft.uspto.gov/netacgi/nph-Parser?Sect2=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/search-bool.html&r=1&f=G&l=50&d=PALL&RefSrch=yes&Query=PN/7311526. [Accessed 29 June 2012].

ELEC/CENG 399 Design Project I Progress Report II Evaluation Form

<u>To be filled by students:</u>

Project Title:	**Design and Build a DC-DC Convertor for Charging Electric Vehicle Batteries**
Group #:	**14**
Group members:	**Allen Houle, Brayden Macdonald, Jason Small, Nathan Bellmore, Neil Hindle**
Supervisor(s):	**Ashoka Bhat**

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<tr><td colspan="3">Progress report distributed to the supervisors for grading: <u>Friday, July 6, 2012.</u></td></tr>
<tr><td colspan="3">Please complete the progress report grading by: <u>Monday, July 23, 2012.</u></td></tr>
<tr><td colspan="3">Please refer to the rubric for grading.</td></tr>
<tr><th>Topics</th><th>Subtopics</th><th>Grade [%]</th></tr>
<tr><td rowspan="4">[10%]Overall presentation</td><td>[3%]Table of contents is presented according to the sample report attached;</td><td></td></tr>
<tr><td>[3%]Citations are properly used;</td><td></td></tr>
<tr><td>[4%]Conclusion is written in a clear professional technical language;</td><td></td></tr>
<tr><td>subtotal [10%]:</td><td>0.0</td></tr>
<tr><td rowspan="2">[10%]Chapter 1, Project Proposal</td><td>[10%] Proposal revised according to the feedback from the supervisor(s);</td><td></td></tr>
<tr><td>subtotal [10%]:</td><td>0.0</td></tr>
<tr><td rowspan="4">[60%]Chapter 2, Progress Review</td><td>[20%] This chapter is written in a clear professional technical language;</td><td></td></tr>
<tr><td>[20%] Milestones/Deadlines described in Chapter 1 are met in timely fashion;</td><td></td></tr>
<tr><td>[20%] Overall progress is satisfactory;</td><td></td></tr>
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<tr><td rowspan="3">[20%]Chapter 3 Textbook Review</td><td>[10%]Write the textbook review in a clear professional technical language;</td><td></td></tr>
<tr><td>[10%]Meet minimum page requirement (2 pages).</td><td></td></tr>
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Comments by the supervisor: