ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

High-renewable microgrid for Railway Power Conditioner(RPC)

Team #30

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March 24, 2023

Abstract

In real life, the external power supply system of electrified network is a three-phase power supply, while electrified railway traction network usually involves only two phases, Vdd and GND. Therefore, at the junction of lines with different two phases, the power line power consumption and phase will not match. In this regard, we designed a railway power conversion hub (RPC) to achieve power balance when the selected three-phase input on the break point of the traction network changes, and provide a method to improve energy efficiency by using regenerative braking energy. Finally, it can improve the power supply quality and the stability of traction network.

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1 Introduction

1.1 Problem and background

Electrified railways have the characteristics of high safety factors, high comfort, large transportation capacity, and low time consumption, which are effective means to solve traffic inconvenience. However, with the rapid development of electrified railways, power quality issues such as harmonics and negative sequence have also received widespread attention. At the same time, more and more issues in the traction power supply system where regenerative braking energy cannot be effectively utilized have also emerged. Currently, in traction substations, fees are charged based on the two-part electricity price, and the problem of ineffective utilization of regenerative braking energy can lead to higher fees charged by the two-part electricity price and significant economic impact. To be more specific, In real life, the external power supply system is in three-phase while the traction network of an electrified railway usually only involves two phases. If we randomly select two phases out of the three-phase power grid, there will be a mismatch in the power consumption for each power line. We need to come up with an idea to balance the power consumption on each power line. Besides, during the operation of electrified railways, the environment is not stable and small disturbances may exist on the system, which requires our system to have resilience in eliminating those disturbances. For example, the friction between the train and the ground varies in different areas and the train may climb up a ramp sometimes. In order to make the train operate at a uniform velocity, we cannot simply exert unified traction. It's also impossible for the power supply voltage to remain the same and there must be some small vibration. It's vital to make the train function properly unchanged when the outside environment changes.[1]

1.2 Solution

The investment in railway power conditioners has solved these problems very well. Our overall plan is to connect the three phases of the power grid circularly to the traction network at different sections of the railway. In other words, suppose the three phases are phase a, b, and c and we choose phase (a, b), phase (b, c), and phase (c, a) as input voltage periodically every few kilometers, the power supply grid will be close to balance in the large scale. To balance the power supply on the breakpoint of the traction network where the selected three phases input is changed, a Railway Power Conditioner (RPC, hub of power conversion) is designed to dynamically balance the interphase active power. A microgrid is also connected to the RPC and plays the role of a reservoir. It will absorb extra power or supply backup power during disruption, and it provides an approach to utilize regenerative braking energy to increase energy efficiency, which is the biggest innovation of our project. Control theorems are added to make the traction network stable and improve the quality of the power supply, which is also a big innovation.[2]

1.3 Visual Aid

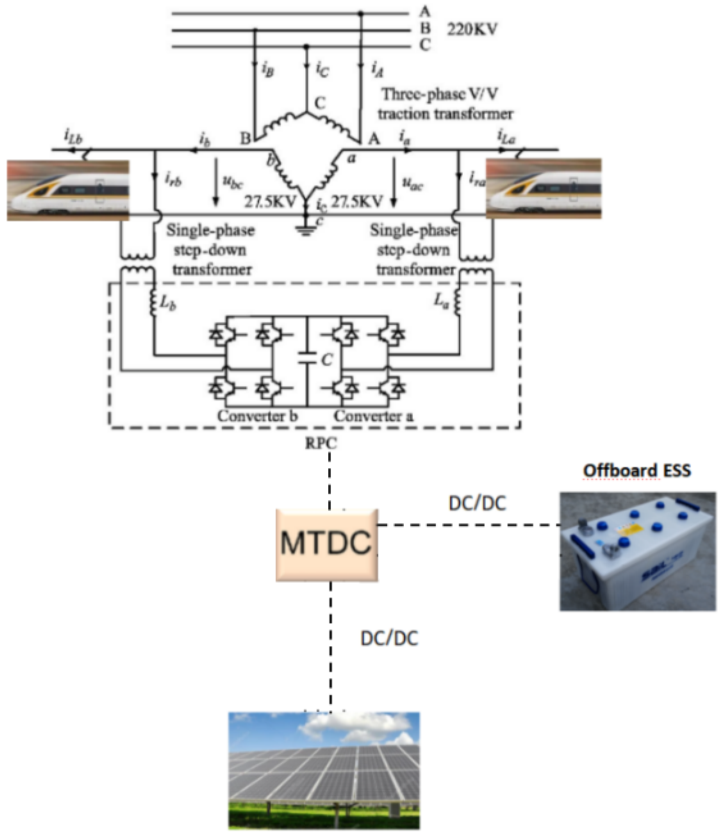

Figure 1: Visual Aid of RPC

1.4 High-Level Requirements List

We will have a list of three quantitative characteristics to solve the problem. These requirements are considerably important, which respectively prove that the whole system has great abilities for power-balance, anti-interference, and being stable.

1. The whole system has a great ability of anti-interference. We will exert some interference on the system to evaluate its stability. When we simulate that the train needs to increase traction during going uphill or upwind, we will connect potentiometers (0-10k) in series on the train load. The DC voltage at RPC will reach stability in 10 seconds to prove that the system has relatively good elasticity. At the same time, the voltage at both ends of the battery must not change.

2. RPC has perfect function to dynamically balance the interphase active power. Two AC voltage sources with different phases are converted into the same DC voltage through RPC, which means the two voltages on either side of the breakpoint are connected. At the same time, the power difference between the two phases cannot be too small. It must be

proved that RPC has the coordination ability to balance the power difference of at least 100W.

3. The voltage stability of each port of MTDC also needs to be guaranteed. In the final simulation, it can pass the test. RPC and battery ports should always be stable, even if there is disturbance (less than 1V), they must be very small. However, the port of the solar panel should change with time and load, in order to meet the maximum power extraction and make full use of renewable energy.

2 Design

2.1 Block Diagram

The high-level block diagram is shown in Figure 2. In order to prove our system can provide constant power between the breakpoints of traction network, we will build a model with four main systems together with some external power sources to simulate the real-life device. The four systems are traction system, RPC system, control system, and MTDC. Traction system filters out irrelevant sinusoids from external power grid and simulates the process of providing power to trains. RPC system connects two separate traction networks together by converting the ac voltages with phase difference on those networks into a unified dc voltage, which enables power transferring from one traction network to another. MTDC system provides interface for energy storage system and green energy source so that the system has resilience for interferences and is more environmentally friendly. And the control system monitor the voltage level on each part of the design and change the duty ratio on every converter so that each voltage level meets corresponding requirements.

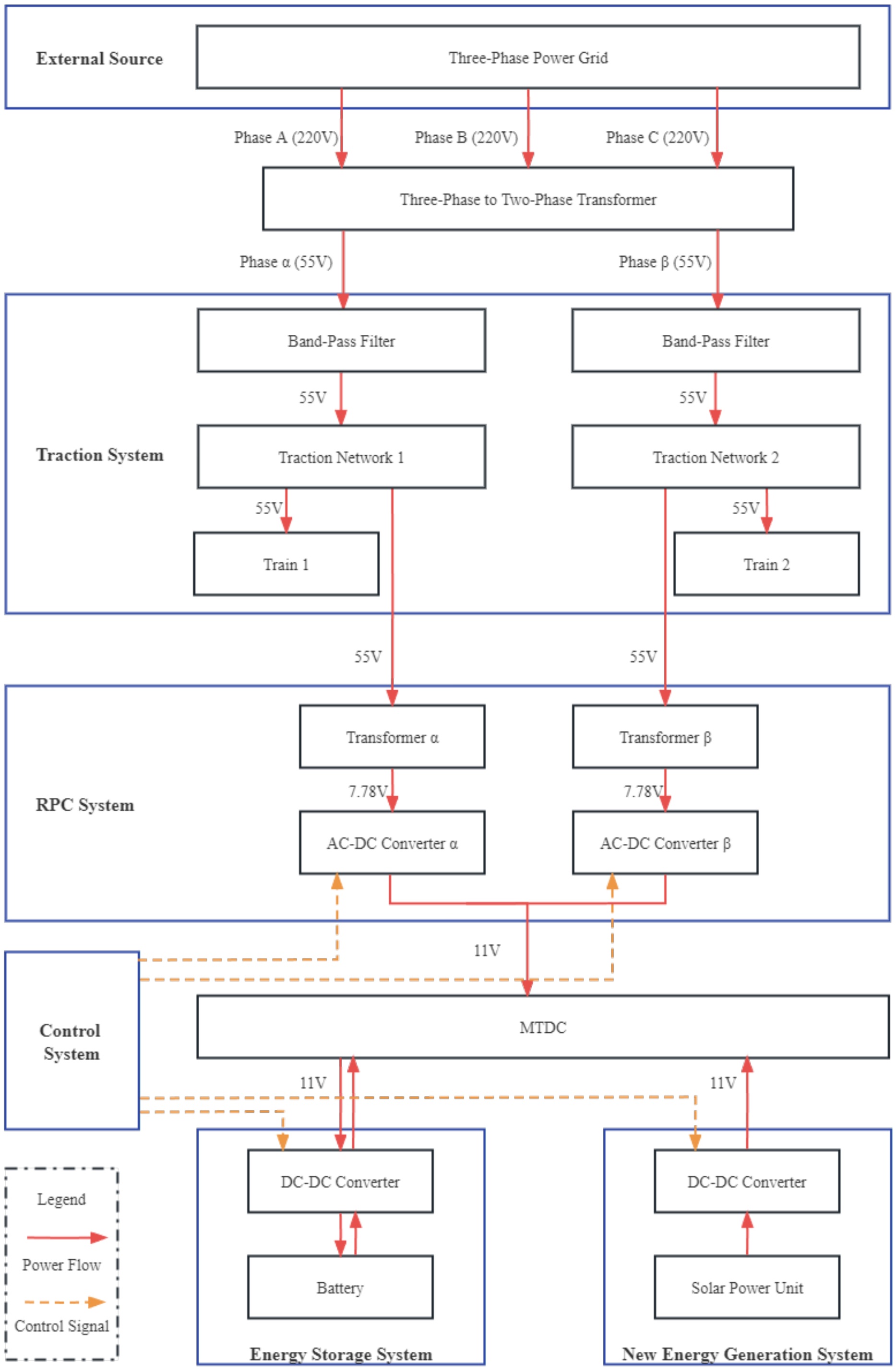

Figure 2: Block diagram for the RPC System.

2.2 Physical Design

Physical design is not applicable for our project. This is because the purpose of our project is to build a circuit that is independent of parameters such as the size and position of actual components.

2.3 Subsystem Overview

As shown in the figure, in principle, we first draw the external power grid, traction network, RPC system, MTDC, and Arduino. Then, we connect each subsystem based on the relationship between them.

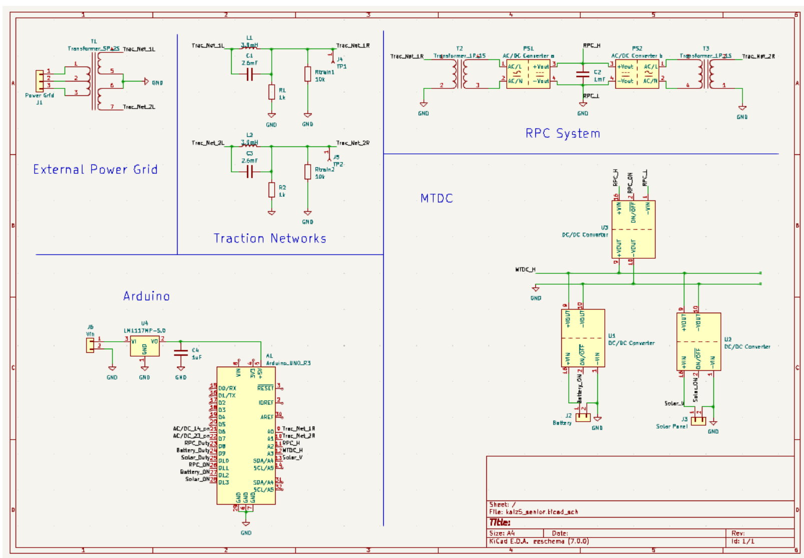

Figure 3: Overall schematic diagram of the subsystems.

2.3.1 Railway Power Conditioner (RPC)

RPC subsystem is the main subsystem of this project. The RPC system is connected to the traction system and MTDC. To be more specific, AC-DC converters are directly connected to transformers under two trains, and the whole system aims to dynamically balance the inter-phase active power, independently compensate the reactive power of each feeder and suppress its harmonics. We will use transformers and AC/DC converters in this subsystem. Transformers are used to step down the 55V high voltage at the traction network to a relatively safe low voltage (7.78V) to handle. AC/DC converters are used to eliminate the phase difference at the two sides of the breakpoint and make it possible to connect them.[3].

2.3.2 Control system

Control system is the algorithm part of the project. We will use control theorems to make the train run in a safe and stable manner. It will connect and affect RPC and MTDC.

We will start with open-loop control, and we will design PID closed-loop control later. We will also try data-driven maximum power point tracking control to extract maximum power from the solar panel in ten seconds. Through designing control signals for switching functions from Arduino, some switches can be opened or closed to achieve the purpose of those converters.

2.3.3 MTDC (Multi-terminal dc transmission control system)

MTDC is the bus that connects RPC and other sources from the microgrid (like photovoltaic, battery, and even wind power). We need to design an MTDC that can satisfy our different expectations. For RPC and battery, we need a stable voltage reference, while for solar panels, we need to change the DC voltage value to extract maximum power. This can be realized by designing a proper DC/DC converter for each component.

2.3.4 Traction system

Traction system is a system that provides traction for trains, including trains, loads, power grids, and band-pass filters. The three-phase voltage source is the external voltage source that supplies power to the system. Band-pass (RC) filters are used to suppress harmonics from the output of the three-phase to two-phase transformer and provide a 50hz, 55VAC voltage to the traction network. We will use a safer 220V three-phase power socket instead of using a 110kV/220kV external power grid. We will build a microgrid to drive the train and use power detection to realize simulation.[4].

2.4 Subsystem Requirements

2.4.1 Traction system

First of all, there is a 220V three-phase power grid in this system. Secondly, we believe that the most important part of the system is the traction transformer, whose main function is to transform the three-phase high-voltage power provided by the power grid into single-phase power used by the traction network. In our project, we will convert 220V three-phase electricity into 55V single-phase electricity. For this transformer, we will connect two single-phase transformers in V-shape. The high-voltage side of the transformer is connected to the three-phase power grid, two section of the low-voltage side of the transformer is connected to the traction network, and the other end is connected to the return ground line in the form of a common endpoint. [5].

Rquirements	Verifications
The transformer successfully transforms the external three-phase power grid to two one-phase power supplies with 120° phase difference.	Connect the input end of the traction transformer to the wall socket in the laboratory, use oscilloscope to record one phase of input and the two outputs of the transformer. The output voltage waveform should meet the following requirements: 1. The RMS value of both waveforms should around 55V 2. Both outputs has the same sinusoid shape as the input 3. The phase difference between the two output phases is 120°.
The filter in the transformer filters out irrelevant harmonics and only keep sinusoidal waves around 50Hz	Connect the output voltage of the filter to an oscilloscope and perform a Fast Fourier Transfer on the voltage data. The highest peak should be around 50Hz, and its magnitude is much larger than other frequencies.
Bidirectional power flow is allowed between two traction networks	Use 1kΩ resistor to simulate one train and 10kΩ resistor for the other. Use two wattmeters to get the power on each traction networks. The reading on two wattmeters should be close all the time.

2.4.2 Railway Power Conditioner (RPC)

There are two transformers and, two AC-DC converters, and two high pass filters for each breakpoint in the traction network. These transformers are step-down transformers, which reduce the voltage in the power supply arms of traction network from 55V to 7.7V and connect it with the AC/DC converter. The outputs of these two AC/DC converters are connected as the output port to of RPC to MTDC. A capacitor is also connected to the output port and provides stable DC voltage to the two converters. The two converters of RPC can be controlled as a controlled current source, which can realize two-way flow of active power between two phases and carry out harmonic suppression and reactive compensation. In essence, the converter in RPC is a bidirectional PWM rectifier structure. The high pass filters are connected directly to the traction network to filter out high frequency irrelevant harmonics.

This is one of the AC/DC converters in RPC. It is the circuit represented by a block in the upper right of the schematic diagram in the Subsystem Overview. It consists of basic capacitors, resistors, inductors, and multiple SCR's. The data for each component is shown in the figure, and these are the results of our repeated simulations.

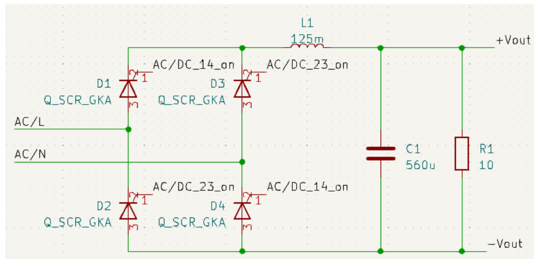

Figure 4: AC/DC converter.

Rquirements	Verifications
The RPC system enables the bidirectional power flow and give be a stable DC output voltage regardless of the traction force of the trains, (the resistances that simulate the trains).	Use 1kΩ resistor to simulate one train and 10kΩ resistor for the other. Connect the currents of both input and the output voltage of the RPC system to an oscillator. One input current is positive and the other is negative. The output voltage is 11V.
The RPC system outputs a stable DC voltage and has high resilience of the vibration of external power grid or the traction force of the trains, (the resistances that simulate the trains).	Use potentiometer to step down the external power grid by 10V. Use oscillator to check the output voltage is still 11V. Add a 1kΩ resistor in parallel with one train resistor and suddenly remove it. The output voltage returns to 11V within 10s.

2.4.3 MTDC

As a bus connecting RPC and coordinating the energy system, MTDC is an indispensable connection hub. It can meet our different expectations, for example, to make the most efficient use of sustainable energy such as solar energy.

The energy system acts as a large reservoir. During the period, it will absorb additional power or provide backup power, and use renewable energy. As shown in the figure, the energy system is divided into energy storage system and new energy generation system. The energy storage system is also irreplaceable. Once it is lost, the system will not be able to compensate the power to the traction system, and the unused additional power of the grid will also be lost, which is not in line with the principle of sustainable development.

The energy storage system is mainly composed of DC/DC converter and battery. The battery can provide additional energy for the traction system at necessary time or store excess energy. The bidirectional DC/DC converter connected to it is designed to maintain a stable voltage of 11V (adjustable) at both ends of the battery and compensate at least 100W of power. We can charge or discharge the energy storage medium by controlling the bidirectional DC/DC converter. When the bidirectional DC/DC converter is in the buck mode, the storage device is charged. When the bidirectional DC/DC converter is in boost mode, the storage device is discharged.

The new energy generation system is the environmentally friendly goal of our project. It will maximize the use of solar energy and even wind energy to compensate the power of the entire railway system. The DC/DC converter of the solar panel should not ensure that the voltage at both ends of the solar panel is always 11V (adjustable), but should ensure that the current (power) is changeable to extract maximum power instead. If we use additional wind energy to generate electricity, we must use AC/DC converter to ensure that the constant DC voltage output to the bus is 11V (adjustable). Since the capacity of new energy varies with the environment, we do not request it to provide a constant amount of power.

DC/DC converters that connect various other components are the core part of MTDC. The following is a schematic diagram of DC/DC converters, which is an invisible part of the Subsystem Overview. Obviously, when a DC/DC converter is connected to a battery, it can change to a buck mode or boost mode depending on the situation.

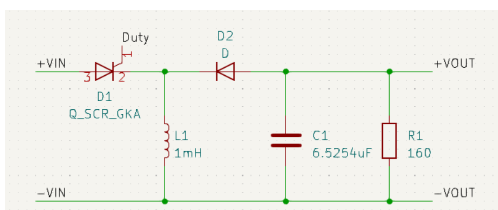

Figure 5: DC/DC converter.

Rquirements	Verifications
The DC/DC converter that is in the energy storage system could stabilize the voltage at both ends.	Connect the MTDC end of the DC/DC converter to a voltage generator, and then connect the battery end of the DC/DC converter to the oscilloscope. Change the voltage level of voltage generator between 5V and 20V, the battery end should be 12V all the time.
The DC/DC converter that is in the new energy generation system is operating normally.	Use Arduino to scan different output voltage and get an I-V characteristic and thus P-V plot of the solar panel. Use oscillator to check the solar panel end of the DC/DC converter. The voltage at the end should be the voltage that maximize power in the P-V plot.

2.4.4 Control System

The control system is the pivot of the entire circuit.

Rquirements	Verifications
Use Arduino to scan different output voltage and get an I-V characteristic and thus P-V plot of the solar panel. Use oscillator to check the solar panel end of the DC/DC converter. The voltage at the end should be the voltage that maximize power in the P-V plot.	Compare the voltage obtained from oscillator and from Arduino interface. The error should be within ±5% Connect the MTDC end of the DC/DC converter to a voltage generator and change the magnitude of voltage generator between 5V and 20V. The output duty ratio should be smaller when the voltage level is larger.

2.5 PCB board

After the simulation, we have tried PCB Board:

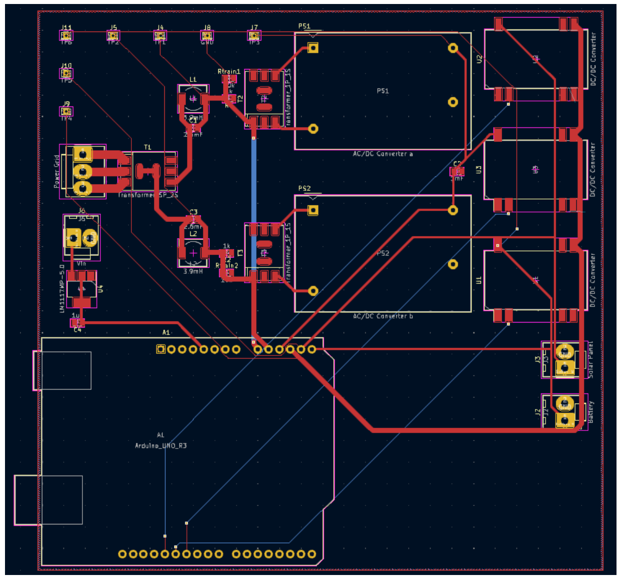

Figure 6: Overall schematic diagram of PCB.

2.6 Tolerance Analysis

1. The voltage of our whole system is reduced from 220V domestic electricity, so there is a huge gap between it and the actual 220kV railway power grid. This may mean that when the voltage level of the three-phase power grid changes, some of the electric component will fail (require greater compensation and anti-interference functions), and the whole system will not meet the requirements of power balance. Although this is a huge challenge of the project, we can still adjust it by replacing those capacitors, inductors, resistors or transistors with power electronics devices that can tolerant large voltage or current. These devices may have new electronic characteristics, but we can redesign the voltage level of each wire to meet these requirements.

2. Since it takes time for the semiconductors to act in response to the changing input, the whole system has inevitable delay between each part. For example, there are AC/DC converters in the RPC (Railway Power Conditioner), and there also are converters between RPC port and recyclable energy connected by MTDC. The accumulation of these delays will inevitably increase the delay time and create greater uncertainty. However, we have an extra control system that is in charge of the behavior of those converter. We can record the delay in the past and use proper control method to eliminate the effects of delay in advance.

3. The connection mode of our project is based on the traditional v-v transformer. Although it has simple wiring and high-capacity utilization, it is also easy to form single-phase power supply and negative sequence serious power supply environment. To ensure the stability of RPC intermediate DC voltage, we can optimize the control strategy. For example, we can use double closed-loop control strategy and different transformer structures (Scott traction transformer). In addition, it has unique advantages in power quality control of traction power supply system.

4. The 220V domestic electricity is not stable and there may be some small variation signals, and the train may not move smoothly and need larger or smaller traction from time to time. As a result, the voltage of traction network may not be stable and thus the voltage of the RPC port on MTDC may vary. We can solve this problem by connecting a high pass filter to each traction network and filter out variations at higher frequencies. Mainly the original 50Hz AC signal is left on the traction network and the whole system will be more stable.

Through our simulation on MATLAB, we design a filter that obtains 50HZ and filters out other frequencies. We use RCL loops for analysis. We select the appropriate specifications for resistors, capacitors, and inductors. The values of each component and the principle formula of the filter are shown below. At the same time, we simulate the filtration curve of the filter for different frequencies.

$$R = 1000\Omega$$

$$C = 3.9 \times 10^{-3} F$$

$$L = 2.6 \times 10^{-3} H$$

$$\left.\frac{V_{\text{out}}}{V_{\text{in}}}\right|_{pLC} = \frac{j\omega L}{R_S\left(1-\omega^2 LC\right)+j\omega L}$$

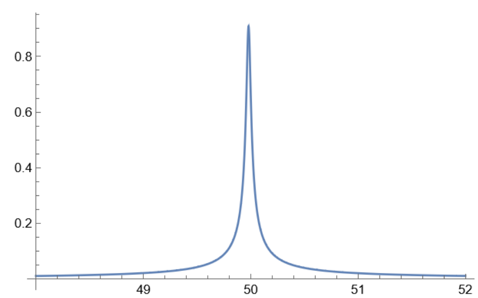

Figure 7: The filtration curve.

3 Cost and Schedule

3.1 Cost Analysis

Our fixed development costs are estimated to be 45¥/hour, 10 hours/week, in total 8 weeks for four people.

$$4 \times \frac{45}{hr} \times \frac{10hr}{\mathrm{k}} \times 8\mathrm{wk} = 14400$$

Our parts and manufacturing prototype costs are estimated as flows.

Description	Quantity	Manufacturer	Part number	Vendor	Total cost
Traction transformer: (three-phase to two-phase transformer) transfer 220V to 55V	1	Undefined	Undefined	Taobao	900¥
Step-down transformer: (transformer α and transformer β)	2	Pulse Electronics	PA0510NL	Taobao	300¥
train (0-10kΩ potentiometers))	10	ALPS ELECTRIC CO	RK097111080J	Taobao	47¥
6V-100 Ah storage battery	1	Panasonic	Undefined	Taobao	180¥
Solar power unit: 6V-10W solar panel	1	Kaiwen	Undefined	Taobao	195¥
Resister, capacitor, diode and inductor	Several	Digikey	Undefined	Taobao	30¥
SCR	10	Cornell Dubilier Electronics	SCRN216R-F	Taobao	80¥
Total					16132¥

Three-phase power grid is the common power supply for our household, and other parts not involved (like MTDC and traction network) are actually wires, which can be obtained in the laboratory.

We did not include converters (AC-DC and DC-DC converters) in the above devices because we built the converter ourselves. An AC-DC converter consists of four SCRs, one capacitor, one inductor, and one resistor. A DC-DC converter consists of an SCR, a diode, a capacitor, an inductor, and a resistor. We will buy a little more than we actually use for replacement after damage.

We also did not include band-pass filter in the above devices because we will built it ourselves. A band-pass filter consists of a resistor, a capacitor and an inductor.

For the above devices, in addition to those provided by the laboratory, our team will determine the specifications of other devices, and then report them to Sponsor, who will contact the merchant for procurement. Therefore, the final component information like manufacturer and part number may differ from here. We will appreciate it a lot if the instructor could understand it and forgive us.

Due to the need for customization of many components, the prices given above are the common prices for components of this specification, and the specific prices will be determined after consultation with the supplier.

3.2 Schedule

Week	Jiebang Xia	Yongcan Wang	Kai Zhang	Jiakai Lin
3/13	Decide my part of the project. Learn the structure and principle of AC/DC converter and all DC/DC converters.	Learn the structure and principle of traction transformer	Learn and understand the overall working principle of the High-renewable microgrid for Railway Power Conditioner.	Write the proposal in Latex and search for the opponents on Taobao.
3/20	Understand how converters accomplish the mission in our project and emphasize their role. Finish the draft of the proposal.	Learn the principle of step-down transformer and learn in detail the role of transformers in specific circuits	Understand how converters accomplish the mission in our project and emphasize their role. Finish the draft of the proposal.	Learning P-I-D control theorem, understanding maximum power point tracking algorithm.
3/27	Report the simulation results. Design appropriate type of converters. Finish the draft of the design.	Do simulation together and find appropriate type of traction and step-down transformer	Complete the whole simulation of converters, transformers, filters and power grid. Check that the design is acceptable	Start writing code on ArduinoIDE to demonstrate the algorithms. Implement basic control function.

4/3	Discuss the results of our simulation with the instructor, and focus on my part of the converter (including reporting the types and specifications).	Discuss the results of our simulation with the instructor, and focus on my part of the transformer (including reporting the types and specifications).	Design the optimization and implementation of microgrid on PCB. Discuss the results of our simulation with our sponsor.	Achieve and check the functionality of control code.
4/10	Build RPC and integrate the back to back converter structure in RPC. Debug them and optimize them.	The instructor will help us purchase devices, and I will install transformers into the circuit and debug and optimize them.	Help build circuits and assemble the base module components. Finish debug procedure and optimize every module.	Try to implement the control system on the circuit using Arduino.
4/17	Establish two band-pass filters to increase the anti-interference ability of the micro grid. Also, connect and combine the other parts of the circuit.	Complete the remaining circuit parts to assist other team members in circuit optimization	Complete the remaining circuit parts to assist other team members in circuit optimization	Try and compare different MTTP algorithms and choose the most suitable one.
4/24	Debug the overall circuit effect and optimize the whole circuit with other members.	Test the overall circuit effect and optimize the whole circuit.	Debug the overall circuit effect and optimize the whole circuit with other members.	Complete and make sure the code runs properly on the hardware
5/1	Prepare the hardware section for presentation.	Start to Write final report.	Prepare the hardware section for presentation.	Prepare the software section for presentation.

4 Ethics

4.1 Safety

In the project of High-renewable microgrid for Railway Power Conditioner (RPC), we must first ensure the personal safety and property integrity of citizens. The RPC circuit must be reasonable and safe. We will strictly test and check the circuit to prevent accidents. We must follow the ACM Code of Ethics and Professional Conduct 1.2 Avoid harm[6].

4.2 Environmental protection

High-renewable is our second purpose. We must ensure that all parts of the project must not cause unreasonable damage to the environment, especially the battery and three-phase voltage source. In order to ensure the public welfare of the world, we adhere to ethical design and sustainable development practices, which follow the IEEE Ethics guidelines 1.1[7].

4.3 Privacy

Our control subsystem must ensure that the train operates in a safe and stable manner, which inevitably contains train data (public privacy). The data of the train must be properly and safely stored. Without explicit consent, others are not allowed to access and share personally. We must follow the ACM Code of Ethics and Professional Conduct 1.6 Respect privacy[6].

5 Safety

Safety is the most important for us. We must complete the project on the premise of ensuring safety.

First of all, we will strictly abide by the basic safety principles. For example, at least two people are present when we do experiments in the laboratory. Each of our team members will complete the safety training in the laboratory and get high marks in the test.

Secondly, we have different safety requirements for each component, and we will study the safety of components. For example, the transformer will produce a large voltage, so we will focus on checking its safety. Before use, we will check its fuse, check its insulating sleeve, and detect its load during use. If during the experiment, a transformer experiences some faults that generate a large current, the fuse can be immediately disconnected to ensure the safety of the experimenter's life. When using the converters, we will check whether the incoming line voltage of the power supply is normal before starting the machine, and we will check that all indicators and marker lights are in good condition. According to our design, the input and output voltage of the converters are far less than the safe voltage (36V) that the human body can withstand, so even if all safety measures fail, the experimenter will not be in danger. Besides, when we select components, we will select the components that are most suitable for our operation and have the highest safety factor.

In addition, because many circuit components are used, we will check the short circuit problem of the circuit, and wear insulating gloves and other insulating equipment to avoid direct contact with electricity. We also cut off the power supply when detecting or replacing components to avoid live operation.

References

[1] F. Ma, Q. Xu, Z. He, *et al.*, "A railway traction power conditioner using modular multilevel converter and its control strategy for high-speed railway system," *IEEE Transactions on Transportation Electrification*, vol. 2, no. 1, pp. 96–109, 2016.

[2] Z. Shu, S. Xie, K. Lu, *et al.*, "Digital detection, control, and distribution system for co-phase traction power supply application," *Industrial Electronics, IEEE Transactions on*, vol. 60, no. 5, p.1831–1839, 2013.

[3] W. Wei, L. Wu, J. Wang, and S. Mei, "Expansion planning of urban electrified transportation networks: A mixed-integer convex programming approach," *IEEE Transactions on Transportation Electrification*, vol. PP, no. 1, pp. 1–1, 2017.

[4] M. E. Choi, S. W. Kim, and S. W. Seo, "Energy management optimization in a battery/supercapacitor hybrid energy storage system," *IEEE Transactions on Smart Grid*, vol. 3, no. 1, pp. 463–472, 2012.

[5] S. F. Tie and C. W. Tan, "A review of energy sources and energy management system in electric vehicles," *Renewable sustainable energy reviews*, no. Apr. P. 20, 2013.

[6] ACM. ""ACM Code of Ethics and Professional Conduct"." (2018), [Online]. Available: https://www.acm.org/code-of-ethics (visited on 03/08/2023).

[7] IEEE. ""IEEE Code of Ethics"." (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 03/08/2023).