ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

Microgrids

Team #445

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Abstract

Our project focuses on building a microgrid system that combines power generation, energy storage, load management, and control subsystems. The power generation subsystem utilizes PV panels to convert solar energy into electrical power, while the chargeable batteries serve as the energy storage subsystem. The load subsystem comprises DC loads, AC loads, and a water pump, simulating real-world energy consumption scenarios. The DSP28377 control chip enables intelligent control and management, regulating power flow, energy storage, load balancing, and system performance. This integrated microgrid system offers efficient power generation, effective energy storage, realistic load emulation, and intelligent control, providing a reliable and sustainable energy solution for various applications.

Contents

1 Introduction

1.1 Problem

In recent years, the power system has faced challenges stemming from increasing load and transmission capacity, as well as high costs, operational difficulties, and weak regulation of large, interconnected power grids with centralized generation and long-distance transmission. However, advances in new power electronics technology have led to the proliferation of distributed generation based on renewable sources such as wind, solar, and storage. Distributed power generation offers various advantages, including high energy utilization, low environmental pollution, high power supply flexibility, and low input cost. Developing and utilizing efficient, economical, flexible, and reliable distributed power generation technology presents an effective approach to addressing the energy crisis and environmental issues.

The inherent characteristics of the grid itself, such as its security and isolation, make it impossible to perform certain system analyses based solely on the grid. Additionally, due to the complex nature of the grid, experimenting with the entire system can result in devastating consequences. Furthermore, the interconnected nature of the grid makes it challenging to move and partition specific parts of it independently. Moreover, the grid is not cost-effective, has a high environmental impact, and can lead to significant pollution.

Given these issues, it is imperative to explore alternative solutions that are mobile and independent of the grid while taking into account the unique characteristics of the grid. Such an approach would require a fundamental shift away from the grid-based model and towards more sustainable and eco-friendly alternatives. By doing so, we can reduce our dependence on traditional energy sources and move towards a more sustainable future.

Thus, the concept of microgrid, which aims to mitigate the impact of large-scale distributed power supply to the grid and leverage the benefits of distributed power generation technology[1], was introduced. The microgrid represents a promising solution to address the limited carrying capacity of the power system for the extensive penetration of distributed power supply

1.2 Solution

The feasibility of the microgrid design was assessed through the construction of a small-scale prototype on a PCB board. This prototype included all major components of the microgrid, such as the power generation subsystem, transmission subsystem, power consumption subsystem, energy storage device, and the parallel connection subsystem with the larger grid.

The prototype provided the opportunity to evaluate the microgrid's ability to perform critical power system functions, including load balancing and frequency regulation, and to test its ability to operate autonomously under varying conditions. We also validated the accuracy of the simulation models used to design the microgrid. An efficiency analysis of the microgrid model was conducted to ensure that it met the requirements of a green environment by reducing pollution to the surroundings.

The microgrid prototype provided a safe platform for conducting experiments and exploring the characteristics of the grid, enabling us to develop reliable and sustainable energy solutions for a wide range of applications. Furthermore, the flexibility provided by the microgrid has made it easy to relocate the grid as needed.

The results of the prototype testing will inform the design and implementation of larger scale microgrid systems. By developing reliable and sustainable energy solutions, we aim to reduce our dependence on fossil fuels and promote a cleaner and healthier environment.

1.3 Functionality

Our primary objective is to establish a comprehensive microgrid comprising power generation, storage, load, and bus bar modules. The microgrid will harness solar energy as its main power source, catering to the energy requirements of the entire grid. Furthermore, any surplus energy generated can be utilized in two ways: firstly, by directly charging the battery using solar energy, and secondly, by employing a specifically designed DC pump to store the excess energy. In instances of unfavorable lighting conditions, the battery will seamlessly provide energy to sustain the microgrid's operation. To ensure stability under various circumstances, such as solar input fluctuations or load switching, our DC bus is interlinked with the solar panel, battery, and load module, maintaining a consistent 24V±1V output through closed-loop control facilitated by dsp28377. In addition, our microgrid is capable of powering two small light bulbs, an electric fan, a DC water pump, and two AC motors. For the smooth functioning of the large motor, it provides a reliable 220V, 50Hz AC power supply, while the small motor operates efficiently with a steady 24V, 50Hz AC power supply.

1.4 Subsystem Overview

- Power Generation Module: The power generation module generates the power needed to operate the microgrid system and charge the load system. It meets the minimum power requirement of 80W - 100W, as specified in the high-level requirements.
- Energy Storage Module: The energy storage module utilizes a battery to store the energy generated by the power generation module. This module helps to ensure a reliable and stable power supply, especially during periods of low power generation or high demand.
- Control Module: The control system regulates and controls the microgrid system's operation. It utilizes a DSP board to monitor and manage the various subsystems, including the power generation and energy storage modules. The control sys-

tem ensures that the microgrid operates within the specified voltage and frequency range to maintain a stable power supply.

- Energy Consumption Module: The energy consumption module tests the microgrid system's ability to supply power to connected loads and secure the system. This module provides a load on the microgrid system to test its reliability and stability.
- Simulink Module: The Simulink module simulates the microgrid system and tests its stability, reliability, and performance. It allows for the evaluation of various scenarios and configurations to optimize the microgrid system's performance and ensure its feasibility.

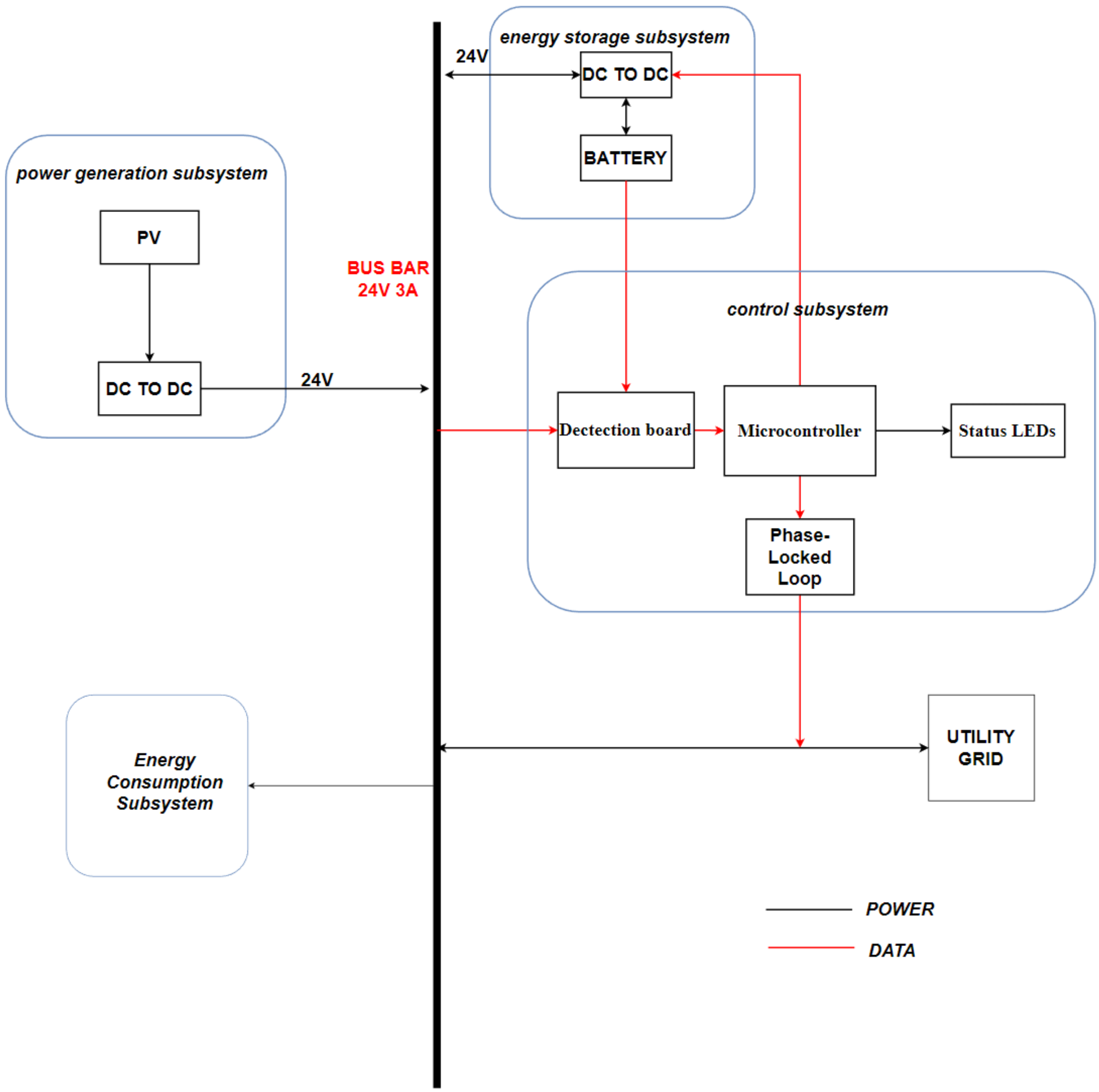


Figure 1: Block Diagram

These subsystems are essential for the successful development and implementation of a reliable and efficient microgrid system that meets the high-level requirements specified.

1.5 High-level requirements list

Our microgrid system was designed to meet the following high-level requirements:

1. Bus Voltage: The system must operate at a minimum bus voltage of 24V ($\pm 2V$) to support the use of larger circuit components. This requirement will allow us to design and implement the necessary functions of the microgrid, while also ensuring that the system can provide a reliable and efficient power source.

   Change: It is indeed necessary to set the tolerance. Here we set the tolerance to be $\pm 2V$, refer to the normal voltage tolerance of the utility power grid, which is +7% to -10%. However, the voltage of the bus is 24V but not $\pm 24V$, because our bus is a DC bus.

2. Power Requirement: The system must have a minimum power requirement of 80W - 100W to meet the energy needs of the microgrid. This requirement will enable us to ensure that the microgrid can provide power to its connected loads, while also allowing for scalability and expansion of the system as needed.

3. State Transition Time: The microgrid must have a carrier state transition time of less than 200ms to ensure that the system can seamlessly connect and disconnect from the larger power grid. This requirement will help to avoid any disruptions or instabilities in the power supply and maintain the reliability and stability of the system.

Meeting these high-level requirements was crucial for the successful development and implementation of our microgrid system. By meeting these requirements, we were able to ensure that our system was efficient, reliable, and scalable, providing a sustainable energy source for our needs.

2 Design

2.1 Review of Design

2.1.1 Design Procedure

Our project revolves around the development of a microgrid system that seamlessly integrates critical functions such as power generation, energy storage, DC load, and AC load. By adopting this comprehensive approach, our goal is to create a self-contained and highly efficient system that can effectively cater to a wide range of energy demands. Through the integration of these essential components, we aim to establish a robust microgrid solution that optimizes energy utilization and addresses diverse energy requirements.

Power Generation subsystem:After carefully evaluating various types of generators, our project has chosen photovoltaic (PV) panels as the primary power generation source for the microgrid system. This decision is based on three compelling reasons that align with your project's goals and available resources. Firstly, opting for PV panels as our power generation source aligns with your objective of utilizing green energy. PV panels harness sunlight and convert it into electricity through the photovoltaic effect, providing a renewable and environmentally friendly energy source. Secondly, considering the favorable light conditions during the summer, PV panels prove to be a suitable choice for power generation. The increased daylight hours and higher intensity of sunlight during summer months optimize the performance and output of solar panels.Lastly, the availability of PV panels from your sponsor's lab presents a practical advantage. Leveraging existing resources can significantly reduce project costs and accelerate the implementation process.

Energy Storage subsystem: The battery serves as the primary energy storage component in our microgrid system. We have chosen to utilize batteries as they are well-established commercial products that can be readily obtained. Moreover, batteries offer a high level of functional stability, allowing for reliable charging and discharging operations. By leveraging the advantages of batteries, we can ensure a robust and easily maintainable energy storage solution within our microgrid system.

Control subsystem: We have chosen to utilize the DSP 28377 microcontroller for our project due to its ability to generate a multitude of pulse-width modulation (PWM) waves with adjustable duty cycles. These PWM waves play a crucial role in controlling the switches of components such as MOSFETs and IGBTs. By programming the DSP, we can achieve precise control over these switches and tailor their behavior to meet our specific requirements. This capability empowers us to effectively regulate and manipulate the operation of various components within our system, enhancing its overall performance and functionality.

Energy Consumption subsystem: In constructing your energy consumption subsystems, we have chosen to incorporate both a DC load part and an AC load part. The DC load part consists of two bulbs and a fan, while the AC load part includes two AC motors.

This selection of components for our energy consumption subsystems is based on two primary considerations: accessibility and realistic simulation capabilities. The decision to use commercially available components, such as bulbs, a fan, and AC motors, stems from their wide availability in the market. These mature products are readily accessible and can be easily procured, reducing procurement challenges and simplifying the overall implementation process. these chosen load components offer the capability to simulate real-world working conditions. The two bulbs within the DC load part replicate lighting scenarios, allowing for the simulation of various levels of illumination. This enables the microgrid system to reflect real-world lighting conditions accurately.

2.1.2 Design Alternatives

Power Generation subsystem: While wind turbines and hand generators are alternative options that can be readily purchased and integrated into our system, we have chosen not to pursue these schemes due to concerns regarding the stability of generation. This decision reflects a thoughtful approach to prioritize reliability and consistent power generation within our microgrid system.

Energy Storage subsystem: In addition to batteries, energy can also be stored in a water tower within our microgrid system. Water towers have the ability to store a substantial amount of energy. This is achieved by converting electrical energy into the potential energy of water. When required, the stored potential energy can then be efficiently converted back into electrical energy.

Control subsystem: The Arduino may also be acceptable for our project. The Arduino platform offers several advantages that make it a compelling choice. Firstly, Arduino boards are widely available and easily accessible, making them convenient for procurement and experimentation. Secondly, Arduino provides a user-friendly development environment with a large community of developers and resources, facilitating rapid prototyping and efficient coding. Additionally, Arduino offers a range of compatible sensors, modules, and shields, simplifying the integration of various components into our microgrid system.

Energy Consumption subsystem: When considering the load part of your system, we initially contemplated incorporating additional components such as phone chargers. However, upon assessing the voltage limitations of our busbar, we have determined that our system may not meet the input voltage and current requirements of these more complex loads.

2.2 Design Details

2.2.1 Power Generation Subsystem

The power generation system is designed to harness solar energy and provide it to the Microgrid. It comprises a Photovoltaic (PV) board, a Maximum Power Point Tracking (MPPT) module and a DC-DC convertor. The PV board captures energy from the sun and supplies it to the Microgrid. The MPPT module detects the power generated by the PV board and adjusts the output power to achieve the highest possible output. This subsystem and the energy storage subsystem will form a hybrid power supply. This hybrid power supply arrangement will ensure a stable and reliable power supply for the microgrid, even under variable weather conditions that may affect the solar panel's output.[2].

Photovoltaic Panel: This part consists of PV panel and MPPT controller. It harnesses solar energy from the sun and supplies it to the Microgrid, allowing it to generate power and become self-sufficient. It will provide the power of approximately 100W. The MPPT module measures the current and voltage of the PV board to determine the output power. It then compares this value to the previous value and adjusts the reference voltage accordingly. If the current output power is greater than the previous value, the reference voltage is increased. If it is lower, the reference voltage is reduced. The output of MPPT module will change the duty cycle of the DC-DC convertor. Through this process, the MPPT module ensures that the system operates at maximum efficiency to produce the highest possible output..

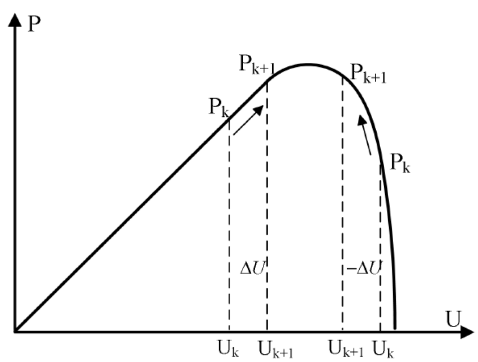


Figure 2: PU Curve

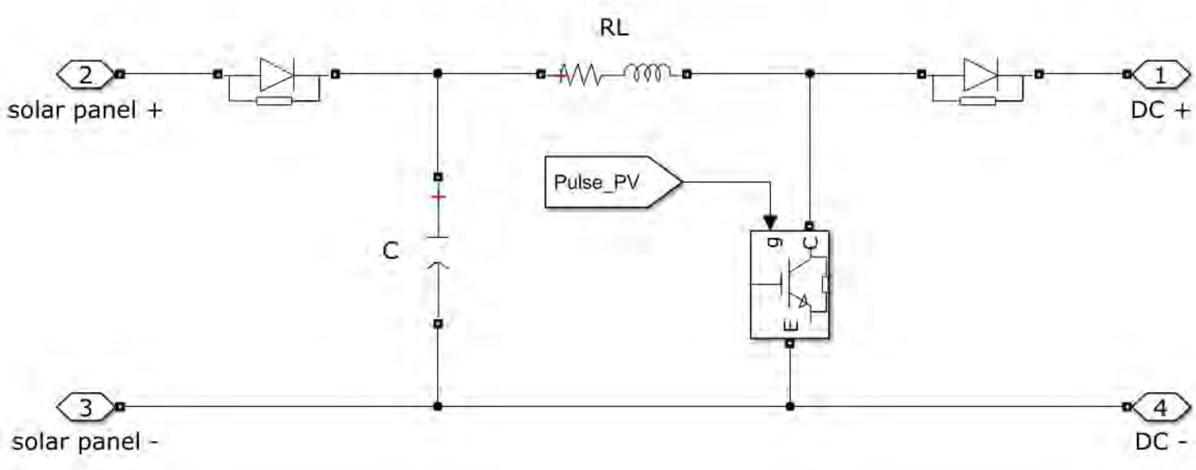


Figure 3: MPPT

Maximum Power Point Tracking (MPPT) module: The MPPT module measures the current and voltage of the PV Panel to determine the output power. It then compares this value to the previous value and adjusts the reference voltage accordingly. If the current output power is greater than the previous value, the reference voltage is increased. If it is lower, the reference voltage is reduced. The output of MPPT module will change the duty cycle of the DC-DC converter. Through this process, the MPPT module ensures that the system operates at maximum efficiency to produce the highest possible output.

DC-DC converter: In our microgrid system, the DC-DC converter plays a crucial role in regulating and converting the power generated by the photovoltaic (PV) panel to a suitable level for the microgrid bus-bar. The DC-DC converter acts as an interface between the PV panel and the microgrid, ensuring that the energy generated by the panel is efficiently transferred and utilized by the microgrid.

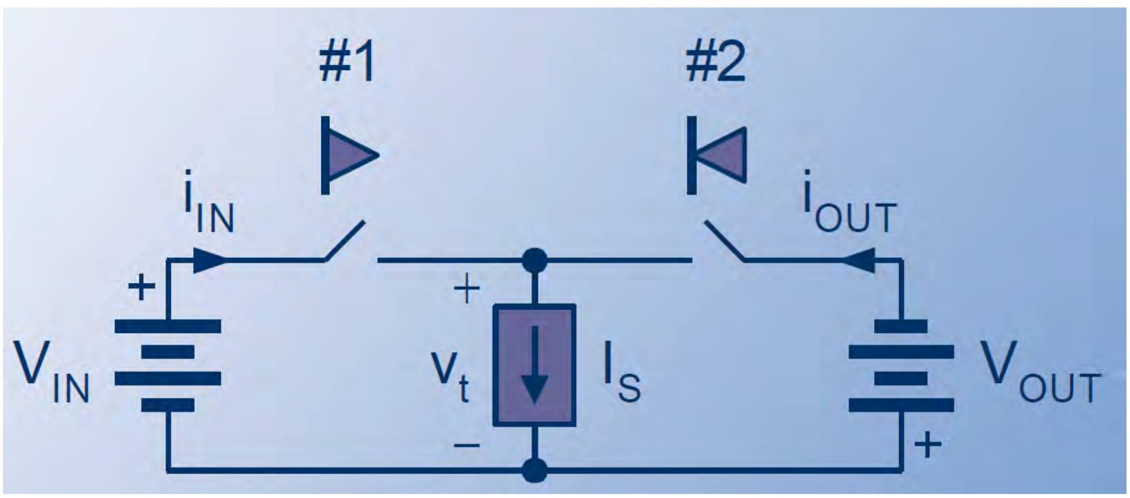


Figure 4: Buck-Boost Converter

The DC-DC converter here is a buck-boost converter that is designed to operate at a variable input voltage range, depending on the amount of solar radiation that the PV panel receives. It is implemented with a MOSFET switch that is controlled by a pulse-width modulation (PWM) signal generated by a microcontroller unit (MCU). The converter has a maximum efficiency of 95% and can regulate the output voltage to within 1% accuracy.

By KVL and KCL, it is easily to find the relationship:

$$
\begin{aligned}
& q_1+q_2=1 \\
& v_t=q_1 V_{\text{in}}-q_2 V_{\text{out}} \\
& v_t I_s=q_1 V_{\text{in}} I_s-q_2 V_{\text{oul}} I_s \\
& \langle v_t\rangle=D_1 V_{\text{in}}-D_2 V_{\text{out}} \\
& \langle v_t I_s\rangle=I_s\langle v_t\rangle=I_s\left(D_1 V_{\text{in}}-D_2 V_{\text{out}}\right)
\end{aligned}
$$

$\langle v_t \, I_s \rangle$ must be zero, not to have losses in the transfer source, which can be done if $D_1 V_{\text{in}} = D_2 V_{\text{out}}$ .Since $D_1 + D_2 = 1$, we have $D_1 V_{\text{in}} = (1 - D_1) V_{\text{out}}$. This finally becomes:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{D}{1 - D}$$

2.2.2 Energy Storage Subsystem

One of the key components of our microgrid system is the energy storage subsystem, which is composed of a rechargeable battery. The battery plays a critical role in ensuring the stability and reliability of the microgrid system by acting as an energy reservoir. During periods when the PV panel generates more energy than the microgrid requires, the excess energy is stored in the battery for later use. When the PV panel is unable to meet the microgrid's power demand due to low solar radiation, the battery is used to supplement the energy requirements, ensuring that the microgrid has a continuous and reliable power supply. This mechanism of energy storage helps to mitigate the effects of intermittency and variability of the PV panel, making the microgrid more stable and reliable.

In addition to its role in providing a continuous and reliable power supply, the battery also serves as a backup power source in the event of power outages. This ensures that critical loads in the microgrid, such as emergency lighting or medical equipment, can still receive power. The battery also allows for peak shaving, a strategy where energy stored in the battery is used to meet sudden spikes in energy demand. By doing so, the strain on the PV panel is reduced, and the overall efficiency of the system is increased. The battery's ability to act as a backup power source and its ability to store excess energy make it a crucial component of the microgrid system, enhancing the reliability and stability of the entire system.

Batteries: In our project, we have employed two batteries with a capacity of 6800-mAh and a voltage rating of 12.6V. The selection of these batteries is based on the power requirements of the microgrid and the need for a reliable and continuous power supply. Through the use of batteries as an energy storage subsystem, the microgrid can function efficiently and effectively, mitigating the effects of intermittency and variability of the PV panel.

Furthermore, the battery subsystem has been designed to meet the energy requirements of the microgrid for a considerable period of time, even under low solar radiation conditions. For instance, under no sunlight, the battery subsystem can support an 80W load for 2.142 hours. This highlights the capacity and capability of the battery subsystem to provide reliable and continuous power to the microgrid, enhancing its stability and efficiency.

DC-DC Bidirectional Converter: The bidirectional DC-DC converter is another key component in the energy storage subsystem, responsible for regulating voltage on both sides of the converter and enabling energy storage and charge functions. The converter plays an important role in ensuring seamless power transfer and efficient operation of the system, allowing for bidirectional power flow to charge the battery when excess power is available and discharge it when needed to supplement the PV panel's output.

Stability and reliability are critical factors in the performance of the microgrid system, and the DC-DC converter plays a crucial role in maintaining them. The converter uses pulse width modulation (PWM) to control the duty cycle of the switching device, regulating the output voltage and ensuring it stays within the acceptable range. Any voltage fluctuations or instability could cause damage to the components or result in system failure, underscoring the importance of the converter's function.

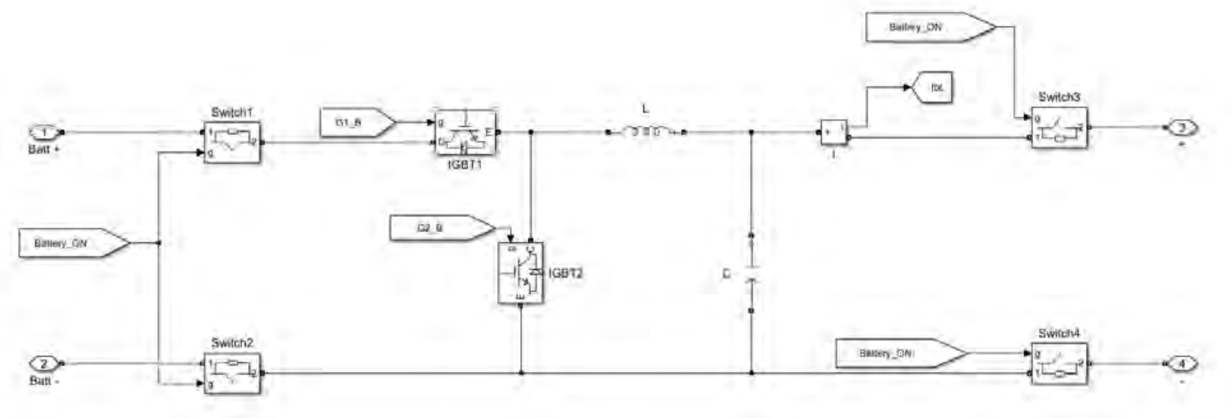


Figure 5: DC-DC Bidirectional Converter

2.2.3 Energy Transmission

The energy transmission subsystem plays a crucial role in the overall functionality and connectivity of the system. It comprises a robust busbar holder and house two busbars. These busbars, serving as vital conduits, are carefully inserted into the holder to ensure reliable and efficient electrical connections. The energy transmission subsystem serves as the pivotal link that interconnects various other subsystems within the larger framework. It serves as the central hub that facilitates the seamless integration of the power generation subsystem, energy consumption subsystem, and energy storage subsystem.

Busbar holder:The busbar holder securely holds the busbars in place to ensure reliable and efficient power distribution. In our project, we utilized 3D printing technology to create the busbar holder. The design includes two grooves on the boards to facilitate easy insertion of the busbars, which are then connected by an "I" shaped bayonet to increase the length of the busbar holder as needed.

By using 3D printing technology, we were able to create a customized and precise design for the busbar holder, tailored to the specific requirements of our microgrid system. The material used in the 3D printing process also ensures durability and long-term reliability of the holder. The grooves and "I" shaped bayonet design allow for easy assembly and disassembly of the busbars, making maintenance and repairs straightforward and efficient.

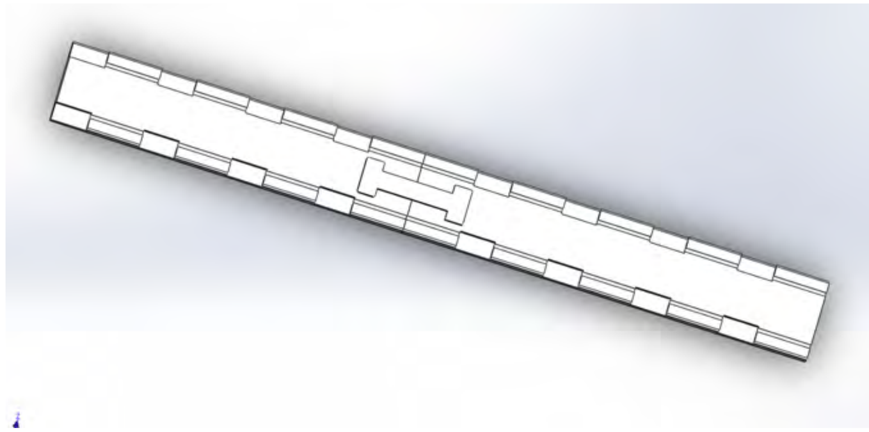


Figure 6: Busbar Assembly Drawing

Busbar:We use two copper conductors with diameter of 3mm to be our busbar. On each conductor, we strip off 7 segments to connect different load parts, generator and batteries.

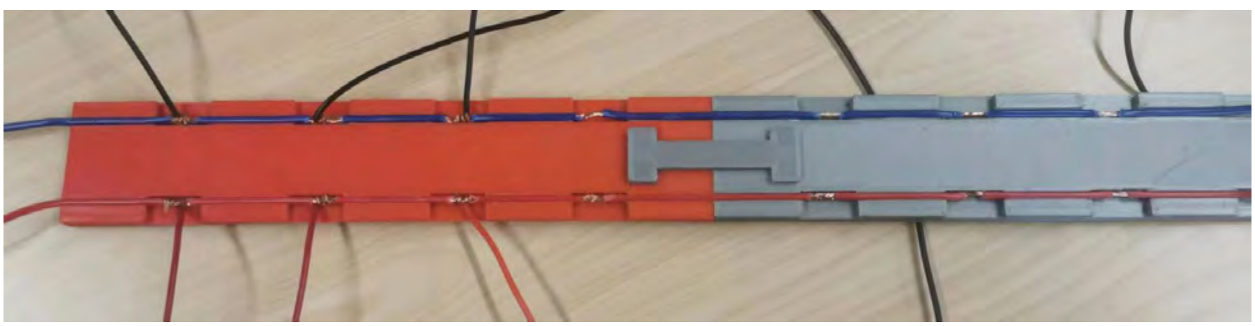
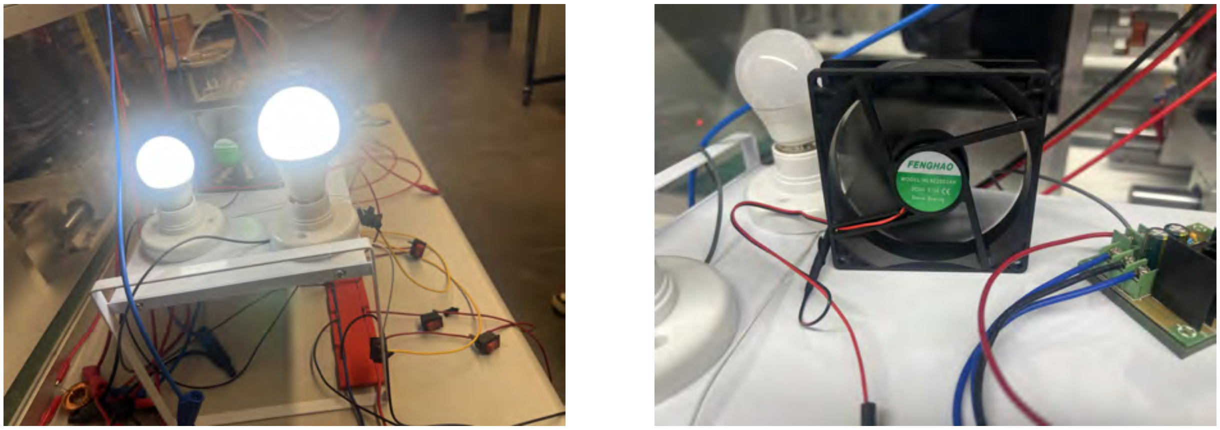


Figure 7: Busbar

2.2.4 Energy Consumption Subsystem

The energy consumption subsystem is a vital component within the overall system, comprising a diverse range of electrical devices. It incorporates two bulbs, a small fan, two AC motors, and a water pump, all of which contribute to simulating various conditions of electricity usage.

DC Load:Our DC energy consuption subsystem features two bulbs, each designed to operate at an input voltage of 24 volts, with power ratings of 8 watts and 6 watts respectively. In conjunction with the bulbs, we have incorporated a fan into the DC load portion of the subsystem. Similar to the bulbs, the fan operates at an input voltage of 24 volts. While specific details regarding the fan's power consumption or wattage are not provided, it serves as an additional element in simulating the conditions and characteristics of a DC load.



(a) Light Bulbs (b) Electrical Fan

Figure 8: DC Load

AC Load:In addition to the DC load components previously mentioned, the energy consumption subsystem also incorporates two AC motors to simulate AC loads encountered in real-world scenarios.

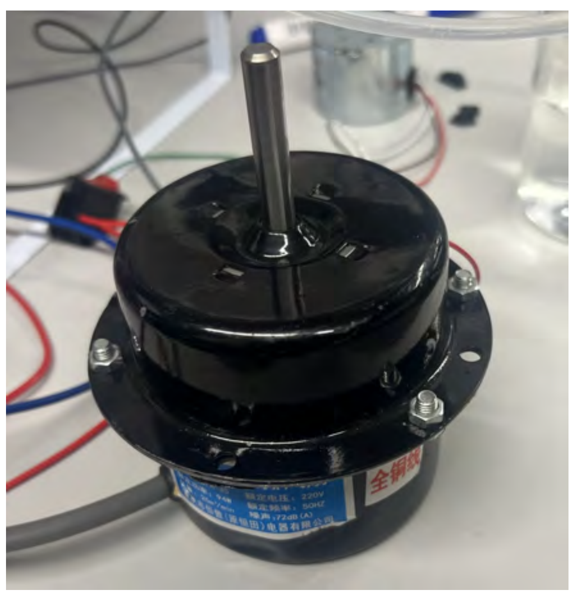


Figure 9: AC-220V Motor

One motor is designed to operate with a derived input voltage of 24V AC, while the other motor utilizes a derived input voltage of 220V AC. To facilitate the operation of these motors within the system, specific components, such as inverter modules and transformers, are integrated. By replicating the electrical characteristics and voltage requirements of both smaller and larger AC motors, the system can comprehensively test and evaluate the performance and behavior of AC loads within a controlled environment.

Water Pump:Within the energy consumption subsystem, an interesting component is the utilization of a water pump and two beakers to convert electrical energy into potential energy of water. This particular load configuration serves a dual purpose, functioning not only as a load but also as an energy storage mechanism. The water pump, in conjunction with the beakers, enables the transformation of electrical energy into potential energy stored within the water system. When excess electrical energy is generated by the system, surpassing the immediate demand, it can be channeled into powering the water pump. The pump utilizes this surplus energy to transfer water from one beaker to another, effectively raising the water level and accumulating potential energy within the system.

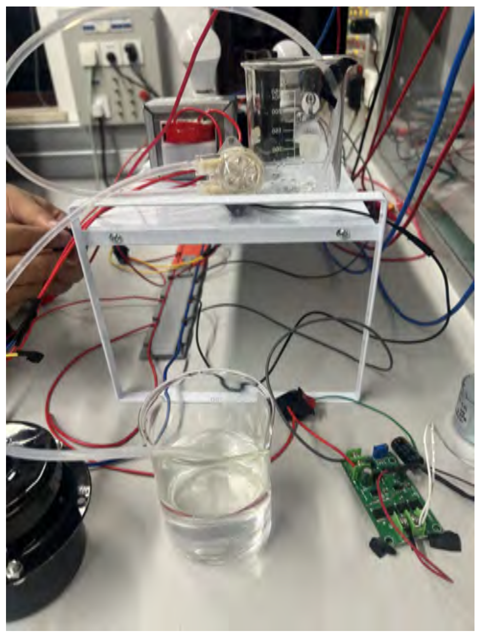


Figure 10: Water Pump

2.2.5 Control Subsystem

The control system employs a control method that relies on the DC bus voltage signal to regulate the performance of the grid. This method allows the control system to accurately detect the different operating states of the grid based on the network architecture, distributed power supply capacity, and load size. By analyzing this information, the control system can adjust the output of the distributed power supply to match the requirements of the grid, thus ensuring stable and reliable operation. Additionally, the control system can provide real-time feedback on the status of the grid, allowing operators to quickly identify and address any issues that may arise.

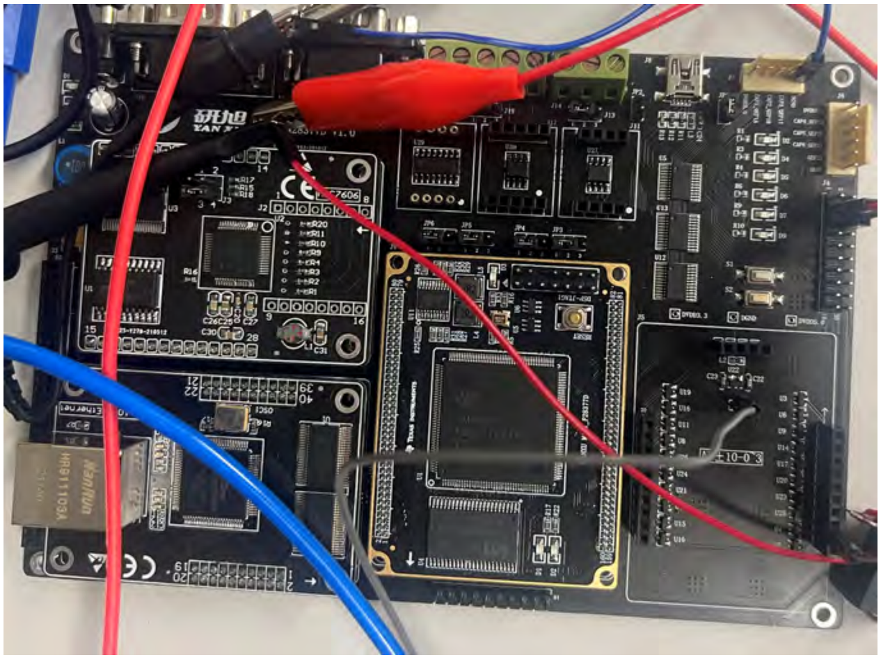


Figure 11: DSP Board

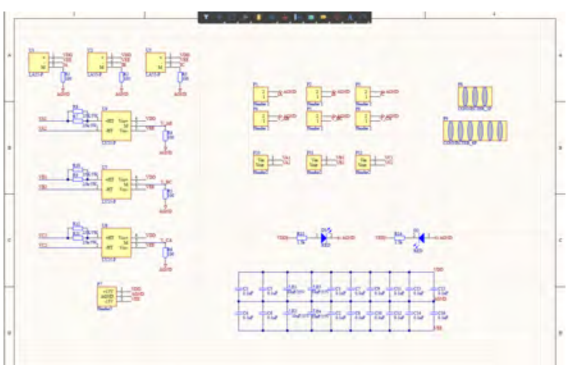
```c
interrupt void adca1_isr(void)
{
    AdcaResults[resultsIndex++] = AdcaResultRegs.ADCRESULT0;
    if(RESULTS_BUFFER_SIZE <= resultsIndex)
    {
        resultsIndex = 0;
        bufferFull = 1;
    }
////////////////////////////////////////
    V = (AdcaResultRegs.ADCRESULT0)*0.000732422; // /4096*3
//  V = (1326)*(7);
//  V = (AdcaResultRegs.ADCRESULT0);
    if( (V>Vwanted) && (D>=0.4) ) //da de
    {
        D = D-0.001; //0.5
    }
    if( (V<Vwanted) && (D<=0.6)) //xiao de
       {
           D = D+0.001; //0.5
       }
//  D = (V-1.0)/V;

```

Figure 12: Part of Program

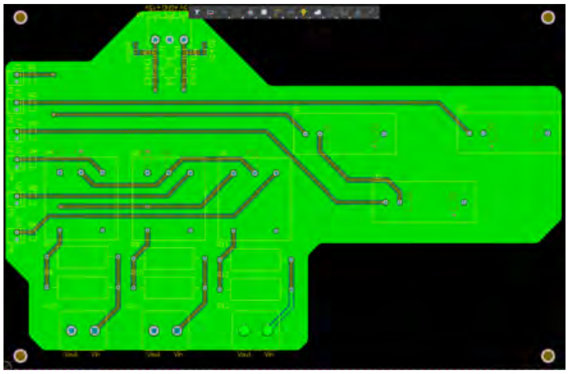
Microcontroller: The microcontroller employed for the microgrid is the DSP28377 chip, which receives analog control signals from other modules. To facilitate the desired control functionality, a C program will be implemented on the DSP28377 chip. This program will enable the control module to execute the necessary control algorithms to regulate the microgrid in accordance with the received signals. The use of the DSP28377 chip offers numerous advantages, including high performance, low power consumption, and flexible configurability[3]. The DSP28377 is a powerful digital signal processor (DSP) specifically designed for control applications. Its high computational power, real-time processing capability, and integrated control peripherals make it an ideal choice for implementing complex control algorithms with high precision and accuracy.

The DSP is capable of generating multiple pulse-width modulation (PWM) waves with adjustable duty cycles. These PWM waves are utilized to control the switching of components such as MOSFETs and IGBTs. In the DSP system, a voltage range of 0-3V corresponds to a digital signal ranging from 0 to 4096.Upon receiving the signal from the detection board, the program analyzes whether the voltage of the bus bar exceeds 24V. If the voltage is higher, the duty cycle of the PWM wave will be decreased. Conversely, if the voltage is lower, the duty cycle will be increased. This closed-loop control mechanism enables precise regulation and adjustment of the system based on the bus bar voltage.

Detection board: In order to achieve a stable bus voltage, we need to close the loop control of the power generator module and storage module connected to the bus via DSP28377. The prerequisite for closed-loop control is to know the voltage of these two modules, so we need the sampling board to sample the voltage of the battery as well as the solar panel.



(a) PCB Schematic



(b) PCB Layout

Figure 13: PCB board

The board comprises three LV25-P voltage sensors and three current LA55-P sensors, which work together to accurately measure voltage and current signals. The six outputs on the left side of the board represent the sampled signals obtained from the sensors. P1 to P3 would be used to detect current signal while P4 to P6 would be used to detect voltages.

Since the DSP28377 only receives analog control signals from 0-3v, we had to make sure the output of the sampling board was in the 0-3v range, otherwise it would burn out the DSP28377.

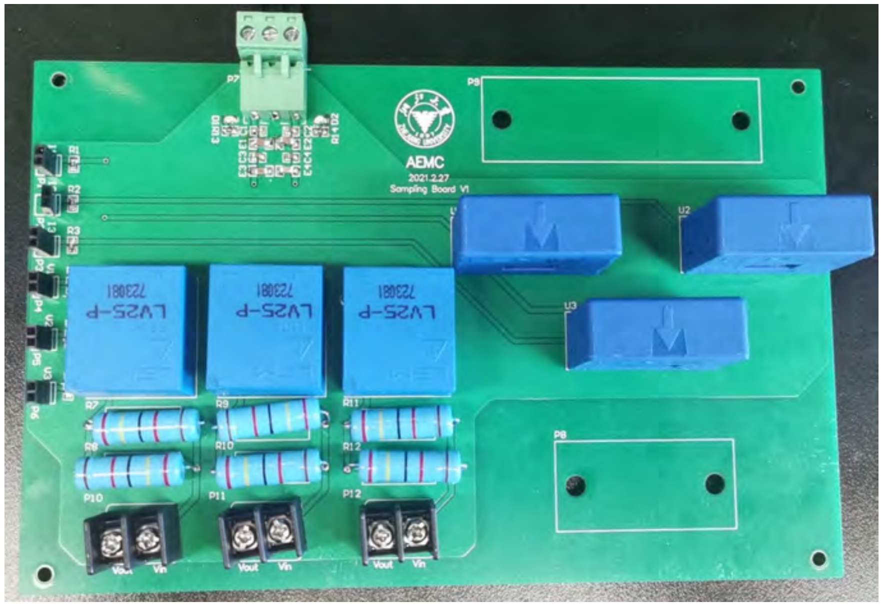


Figure 14: Detection Board

The original design of the sample board has a conversion ratio of 50:1, but we took into account that since our bus voltage is only 24v, the output after the sample board is only 0.48v, which can easily be taken as noise by the DSP28377. Therefore, we changed the pull-down resistor to 250 ohms and tested the corresponding sets of outputs.

Input voltage(V)	Maximum output(V)	Minimum output(V)	Mean output(V)
15	0.783	0.730	0.750
20	1.027	0.99	1.009
24	1.26	1.197	1.127
30	1.545	1.516	1.52
36	1.89	1.82	1.838

Table 1: Detection Output

We measured five different sets of inputs and found that although there is up to ±5% voltage fluctuation, it is acceptable for the chip. After completing this part, we connected the sample board directly with our control chip and found that we were able to read the corresponding analog signal, and the output analog signal could be controlled at around 1.2v, which protected our control chip, the DSP28377.

Status LEDs: The status LEDs play a crucial role in serving as indicators for both the detection board's status and the microcontroller's status. They provide visual feedback to the user, allowing them to quickly assess the current state and operation of the system.

For the detection board, the status LEDs can communicate various information such as power status and connectivity. For example, a lighted LED indicate that the detection board is powered on and functioning correctly, while a dark LED could signal an error or malfunction that requires attention. Similarly, the status LEDs also reflect the microcontroller's status. They can indicate whether the microcontroller is powered on, operational, or in a specific mode of operation.

By incorporating status LEDs for both the detection board and microcontroller, users can easily monitor the overall system's performance. The LEDs serve as a valuable visual aid, simplifying troubleshooting processes and enhancing the user experience with the microgrids project.

2.2.6 Simulink system

To validate our circuit design and ensure its practical implementation, it is imperative to undertake a comprehensive theoretical verification. This involves executing the complete functionality of our microgrid in Simulink.

Figure 15 is a big picture of Simulink. We have successfully constructed the solar power generation module, energy storage module, and load module. These components have been seamlessly interconnected with the grid via a transformer.

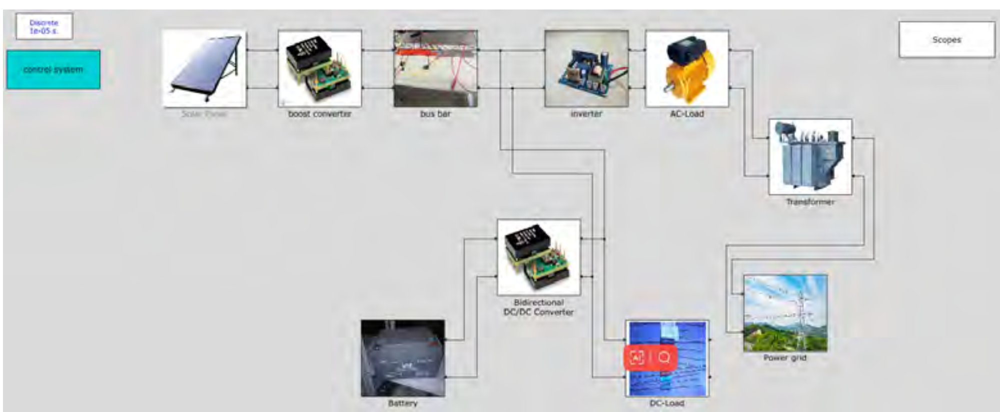


Figure 15: Simulink

Our control signal enables us to control the connection and disconnection of the load, battery, and grid. As shown in figure 16, when the signal is set to '1,' it indicates that the load or battery is connected to the circuit. Conversely, a value of '0' implies that this module has been removed from the circuit. By manipulating these signals, we can monitor the corresponding changes in power and ultimately conduct a comprehensive theoretical verification. Furthermore, we can discuss the obtained results and compare them with the performance of our actual circuit, thereby substantiating the feasibility of the experiment.

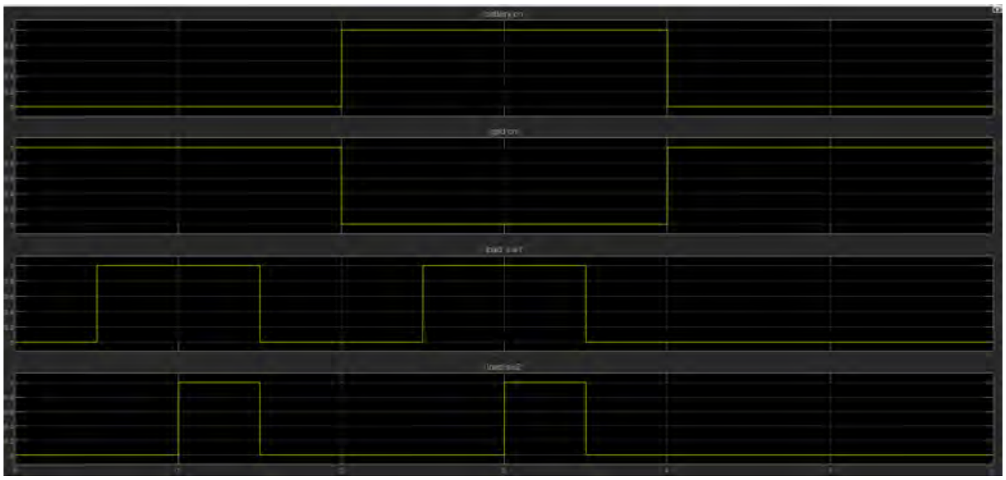


Figure 16: Event Signal

Figure 17 shows the output of simulation. Initially, within the first 0.5 seconds, the solar panel directly charges the grid as there is no load connected. However, after 1 second, both load1 and load2 are activated. Since the power generated by the solar panel is insufficient to support both loads simultaneously, the grid takes over and supplies power to the loads.

After 2 seconds, the battery is activated, and the grid is deactivated. Consequently, solar energy directly charges the battery. As load1 and load2 are subsequently switched on, it becomes apparent that the solar power alone cannot meet the demand, necessitating the discharge of the battery to provide energy to the loads.

At the 4-second mark, the battery is deactivated while the grid is reactivated. As there is no load connected during this period, the solar energy directly charges the grid. Consequently, the grid power becomes positive.

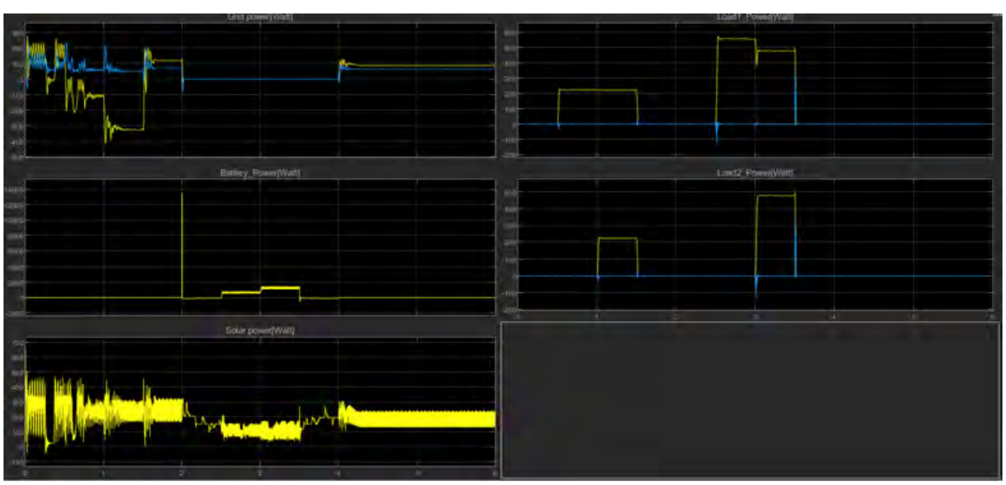


Figure 17: Simulation Output

3 Verification

3.1 power generation

Requirement	Verification
The PV panel should have output power of 8W - 10W under the MPPT controller in the condition of illumination intensity of about 700 lx.	Use Avometer to measure the output power of the PV when under the control of MPPT controller and illumination intensity of about 700 lx.

We conducted thorough testing under optimal lighting conditions which is at the noon and discovered that our solar panel boasts an impressive energy output of 8-10 watts. Remarkably, it is capable of flawlessly powering two small bulbs with a rating of 4 watts each, ensuring their simultaneous operation.

3.2 bus bar

Requirement	Verification
1.The bus bar must supply a stable voltage of 24V ± 1V and the output current of 3A ± 0.5A.	Use the oscilloscope and the current probe to measure the output voltage and the output current to ensure it fit the bus-bar voltage and current..
2.The transient time of the storage module connected to the bus must be less than 200ms. .	Capture the pulse time with the singular mode of the oscilloscope and measure it with cursor.

(a) Powermeter

(b) Oscilloscope

Figure 18: Output

For the first requirement, after activating the entire system, we proceeded to conduct various scenarios to assess the stability of the bus voltage. As part of this evaluation, we performed actions such as disconnecting and reconnecting the battery, as well as toggling the light bulb and fan in the load, all aimed at monitoring the voltage stability. As shown in Figure 21, we determined that our bus voltage consistently maintained stability at 24V±1V, irrespective of alterations in the load or the connection and disconnection of the storage module.

For the second requirement,using the oscilloscope's unique mode, we successfully captured the precise moment of voltage alteration and extracted the transient time associated with the voltage change. Output of the oscilloscope is shown in Figure 22. Analyzing the graph, it is evident that the transient time measures approximately 8.8ms, comfortably falling below the upper threshold of 200ms that we had established.

3.3 control

Requirement	Verification
1.The detection board must accurately measure the voltage at the point to be detected.	Apply a known voltage to the point to be detected and compare the voltage measured by the detection board to the actual voltage applied. The difference between the measured and actual voltage should be within a specified tolerance
2.Must be able to control multiple PWM channels simultaneously.	Generate PWM signals with different duty cycles and frequencies on multiple channels of the microcontroller. Confirm that the signals are accurate and synchronized, and that the microcontroller can adjust the PWM output on each channel in real-time.
3.Must be able to read analog inputs from multiple sensors.	Connect multiple sensors to analog inputs of the microcontroller and take readings from each sensor. Confirm that the readings are accurate and that the microcontroller can differentiate between the inputs from each sensor.

We have acquired a sample board featuring a turns ratio of 20:1. Considering our bus voltage is approximately 24V, this configuration yields a 1.2V analog voltage signal, which can be readily detected by the DSP28377.

The detection board demonstrates successful voltage measurement at the detection point. The design of the board ensures that the output voltage of the detection board is precisely 1/20th of the input voltage, as intended. This outcome aligns with the initial design specifications and confirms the accuracy of the detection board.

With the program written into the DSP, it is capable of generating controllable PWM waves. The DSP operates within a voltage range of 0-3V, which corresponds to a digital signal range of 0-4096. Additionally, the DSP can read the input signal from the output of the detection board.

3.4 storage module

Requirement	Verification
Has a capacity of 40000 MAh and can be charged when the PV board provides power larger than power we need for load; can charge the Microgrid system when the power provided by PV board is not enough.	Try to load power greater than the power of solar energy or less than the power of solar energy Measure the voltage of battery to make sure the station of battery (charged or supply).

In the scenario of a low power load, specifically when there is only one bulb in use, we can effectively charge the storage unit by harnessing solar energy through the solar panel. Additionally, by utilizing a DC-DC converter, we can guarantee the stability of the battery voltage at its rated level.

On the other hand, in situations where high power loads are present and the solar power source is disconnected, our batteries have the capability to autonomously provide energy to sustain the load.

3.5 load

Requirement	Verification
1.The electric motor will have a rated power of 25W when supplied by voltage of 220V 50HZ.	Use Avometer to measure the power of the motor when being supplied by voltage of 220V 50Hz
2.The LEDs must be visible from a distance of at least 3 meters in daylight conditions.	Conduct visual testing under daylight conditions from a distance of 3 meters to ensure that the LEDs are clearly visible. The testing can involve a group of people, where each individual will confirm if the LEDs are visible or not.

Our AC motors are capable of stable operation with 220v as well as 50hz AC power provided by the microgrid. Our small bulbs can also emit enough light to make it possible from 3 meters away.

4 Cost and Schedule

Our fixed development costs are estimated to be 40¥/hour, 10 hours/week, in total 8 weeks for four people.

Member	CHY/Hrs	Hrs/Week	Weeks	Multiplier	Total(CNY)
Ao Dong	40	18	8	2.5	14400
Kaijie Xu	40	18	8	2.5	14400
Bohao Zhang	40	18	8	2.5	14400
Yuqiu Zhang	40	18	8	2.5	14400

Table 2: Labor Cost

Below is an estimate of our purchasing cost:

Description	Quantity	Manufacturer	Vendor	Cost/unit(CNY)	Total cost (CNY)
Storage battery	1	Chenke	Taobao	69.8	69.8
Fan	3	Qinyang	Taobao	6	18
LED bulb	4	Bull	Taobao	8.415	33.66
XDS200 emulator	1	Yanxu	Taobao	580	580
DSP28377	2	Yanxu	Taobao	800	1600
Switch	12	Risym	Taobao	1.035	12.42
Elecrromotor	1	Haorui	Taobao	31	31
Water suction pump	1	Lifu	Taobao	67.9	67.9

Table 3: Purchasing Cost

For the quoted machine shop labor hours, the cost will be:

$$100/\text{hour} \cdot 10\text{hours/week} \cdot 5\text{weeks} = 5,000(CNY) \quad (1)$$

Above all, the total cost of our project is:

$$14400 \cdot 4 + 69.8 + 18 + 33.66 + 580 + 1600 + 12.42 + 31 + 67.9 + 5000 = 65012.78(CNY) \quad (2)$$

4.1 Schedule

Week	Ao Dong	Kaijie Xu	Bohao Zhang	Yuqiu Zhang
3/13/23 - 3/19/23	Research and select appropriate energy storage components	Research and select appropriate microgrid control algorithms	Research and select appropriate power generation components	Research and select appropriate voltage regulation components
3/20/23 - 3/26/23	Design and model energy storage components in Simulink	Design and model microgrid control algorithms in Simulink	Design and model power generation components in Simulink	Design and model voltage regulation components in Simulink
3/27/23 - 4/2/23	Implement energy storage components in the hardware	Implement microgrid control algorithms in the hardware	Implement power generation components in the hardware	Implement voltage regulation components in the hardware
4/3/23 - 4/9/23	Test and debug energy storage components	Test and debug microgrid control algorithms	Test and debug power generation components	Test and debug voltage regulation components
4/10/23 - 4/16/23	Integrate energy storage components with microgrid control system	Integrate microgrid control system with power generation components	Integrate power generation components with voltage regulation system	Design and model connection subsystem in Simulink
4/17/23 - 4/23/23	Conduct system-level testing and optimization	Conduct system-level testing and optimization	Conduct system-level testing and optimization	Implement connection subsystem in the hardware
4/24/23 - 4/30/23	Finalize documentation and prepare for the Demo	Finalize documentation and prepare for the Demo	Finalize documentation and prepare for the Demo	Finalize documentation and prepare for the Demo
5/1/23 - 5/7/23	Practice Demo	Practice Demo	Practice Demo	Practice Demo

Table 4: Schedule

5 Conclusion

5.1 Accomplishments

Our project successfully implements the fundamental functionalities of microgrids, fulfilling three key high-level requirements outlined in the Design Document. In addition to generating, storing, and supplying power to the load system, our microgrid system incorporates closed-loop control to maintain the busbar voltage within a narrow range of 24V ±1V, ensuring stable and reliable operation. Furthermore, our system achieves a power output of 90 Watts, exceeding the minimum requirement of 80 Watts. Additionally, it can synchronize the frequency and phase of the utility grid within a rapid response time of 50 milliseconds, enabling a safe and dependable connection between the microgrid and the main grid. These achievements demonstrate the effectiveness and capability of our microgrid system in meeting crucial performance and reliability standards.

5.2 Uncertainties

Due to our reliance on PV panels for power generation, the performance of our power generation subsystem is heavily dependent on the availability of sufficient sunlight. In cases where the light conditions are inadequate, our battery becomes the sole power supply module, and simultaneous operation of the loads may not be possible. It is important to note that during periods of limited sunlight, the power output from the PV panels may be insufficient to meet the demands of the loads.

Regarding the water pump part, we have not incorporated a generator to convert the potential energy stored in the water back into electrical energy. As a result, the energy stored in the water system through the pump primarily remains in the form of potential energy and cannot be readily converted back to electrical energy for use by other components of the microgrid system.

5.3 Future Work

In future developments of our microgrid system, we are actively considering the addition of supplementary generators to serve as backup power sources when the PV panels are not functioning optimally. By incorporating these backup generators, we aim to enhance the reliability and stability of our system, ensuring a continuous power supply even during periods of insufficient sunlight.

Furthermore, we recognize the potential for utilizing the stored energy in the water system by introducing a generator connected to the beakers. This addition would enable the conversion of the potential energy stored in the water back into electrical energy, providing an additional source of power for the microgrid system. By leveraging this stored energy, we can further optimize the utilization of resources and enhance the overall efficiency of the system.

5.4 Ethical Consideration

As a team, we are dedicated to following the IEEE Code of Ethics 1, which emphasizes the paramount importance of ensuring the safety, health, and welfare of the public[4]. In accordance with this, our approach to designing microgrids involves a comprehensive consideration of the potential impacts on public safety and health, as well as a commitment to maximizing the contribution of microgrids to public welfare. We believe that ethical design and sustainable development practices are crucial to the long-term success and viability of microgrid technology, and we strive to embody these principles in all aspects of our work. With a focus on safety, health, and sustainability, we are confident that our microgrid solutions will benefit communities and society as a whole.

Our project aligns with the IEEE Code of Ethics 5, which calls for the honest evaluation and constructive criticism of technical work and the acknowledgement and correction of errors[4]. We recognize that in conducting a microgrid project, mistakes are bound to happen. However, we believe that true progress can only be achieved through the willingness to address and rectify these mistakes. As such, we are committed to being transparent and accountable in our work, and we value constructive feedback that can help us improve our project at every step. By prioritizing the pursuit of knowledge and continuous improvement, we are confident in our ability to create effective and sustainable microgrid solutions that meet the needs of communities and contribute to the greater good.

At the core of our values is the IEEE Code of Ethics 7, which emphasizes the importance of treating all individuals with fairness and respect[4]. In a world where discrimination is a growing concern, we believe that it is essential for each of us to examine our own biases and stereotypes, and to prioritize treating others with dignity and respect. We strive to create an inclusive and welcoming environment where all team members and stakeholders feel valued and heard, regardless of their race, ethnicity, gender identity, sexual orientation, or any other characteristic.

References

[1] B. A. K. M. H. Saeed W. Fangzong and S. Iqbal. ""A Review on Microgrids' Challenges and Perspectives"." (2021), [Online]. Available: https://ieeexplore.ieee.org/document/9648165 (visited on 03/08/2023).

[2] Y. Luo, D. Yang, Z. Yin, B. Zhou, and Q. Sun, "Optimal configuration of hybrid-energy microgrid considering the correlation and randomness of the wind power and photovoltaic power," *IET Renewable Power Generation*, vol. 14, no. 4, 2019.

[3] R. F. Bastos, G. H. Fuzato, C. R. Aguiar, R. Neves, and R. Q. Machado, "Model, design and implementation of a low-cost hil for power converter and microgrid emulation using dsp," *IET Power Electronics*, no. 14, p. 12, 2019.

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