ECE 445

SENIOR DESIGN LABORATORY

PROPOSAL

Microgrids

Team #445

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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.

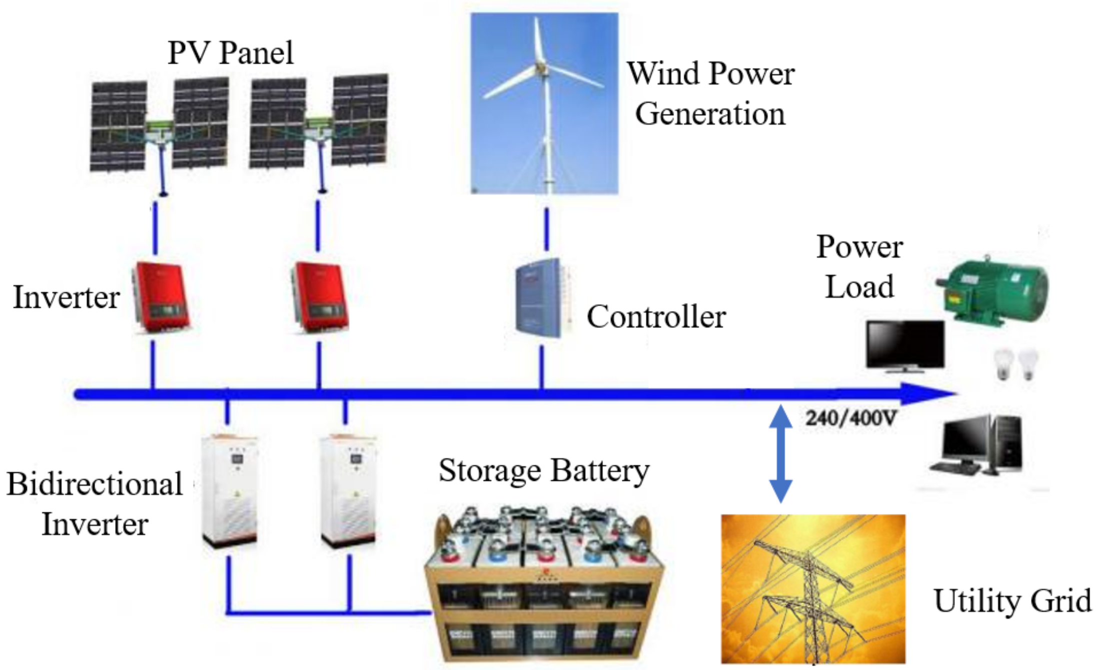
The concept of microgrid, which aims to mitigate the impact of large-scale distributed power supply to the grid and leverage the benefits of distributed power generation technology[1], was introduced. The microgrid represents a promising solution to address the limited carrying capacity of the power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

1.2 Solution

To assess the feasibility of the microgrid design, a small-scale prototype will be constructed on a PCB board. This prototype will incorporate all the major components of the microgrid, including the power generation subsystem (comprising of solar panels), the transmission subsystem (comprising of wires), the power consumption subsystem (including light bulbs and fans), the energy storage device (i.e., batteries), and the parallel connection subsystem with the larger grid.

The prototype will enable the testing of the microgrid's ability to operate autonomously and perform critical power system functions, such as load balancing and frequency regulation. Moreover, it will provide an opportunity to evaluate the system's performance under varying operating conditions and validate the accuracy of the simulation models used to design the microgrid. Ultimately, the results of the prototype testing will inform the design and implementation of larger-scale microgrid systems, enabling the deployment of reliable and sustainable energy solutions for a wide range of applications.

1.3 Visual Aid



(We redraw the Visual Aid.)

1.4 High-level requirements list

Our micro grid system must meet the following high-level requirements:

1. Bus Voltage: The system must operate at a minimum bus voltage of 50V 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.

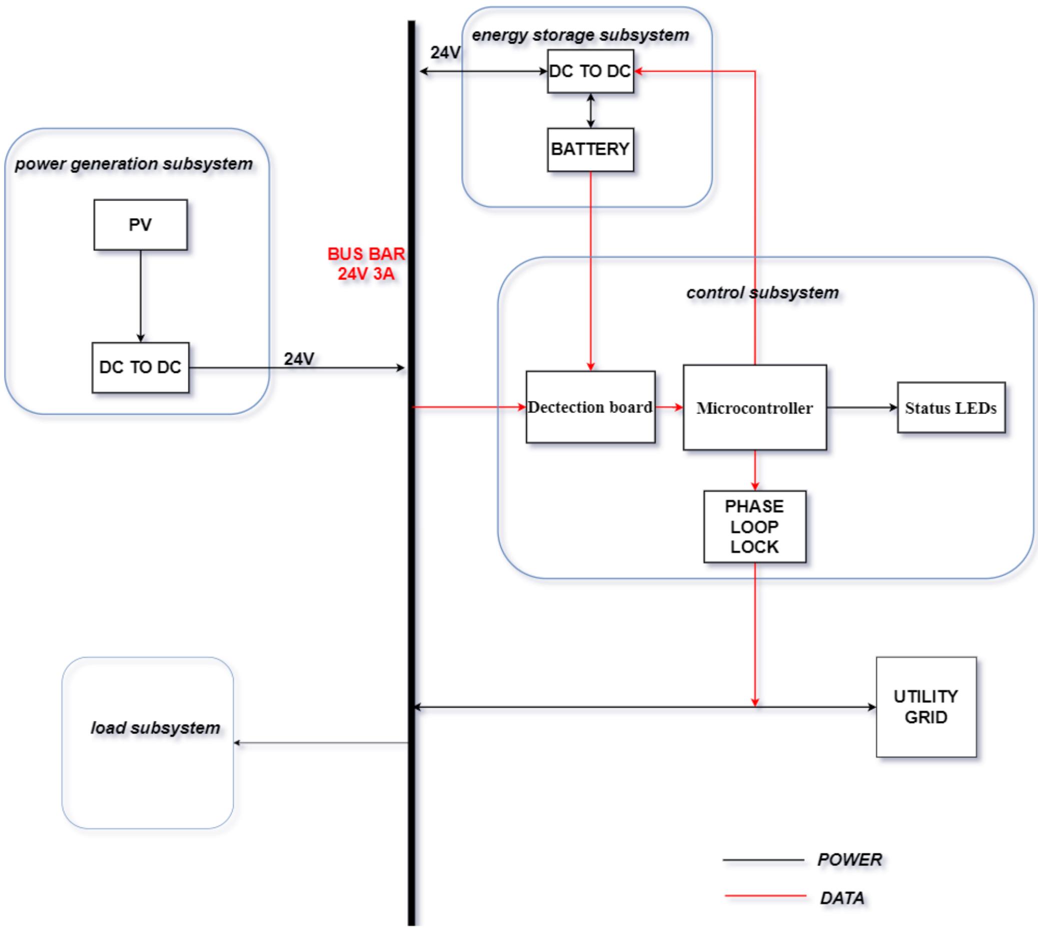
2. Power Requirement: The system must have a minimum power requirement of 100W to meet the energy needs of the microgrid. This requirement will enable us to ensure that the microgrid can provide power to its connected loads, while also allowing for scalability and expansion of the system as needed.

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.

These high-level requirements are crucial for the successful development and implementation of our micro grid system. By meeting these requirements, we can ensure that our system is efficient, reliable, and scalable, and can provide a sustainable energy source for our needs.

2 Design

2.1 Block Diagram



(We redraw the Block Diagram)

2.2 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 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 System: 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 system ensures that the microgrid operates within the specified voltage and frequency

range to maintain a stable power supply.

- Load Module: The load 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.

  (Refer to the new Block Diagram, We delete the connection subsystem and incorporate its functionality into the control subsystem.)

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

2.3 Subsystem Requirements

2.3.1 Power Generation

The proposed solution involves integrating a solar panel with a printed circuit board (PCB) to serve as a primary power source for the microgrid. The solar panel will primarily generate energy to power the microgrid. We plan to use a polar panel with an area of 10 m^2 to generate approximately 150 W of power for our microgrid. In the event that power generation is insufficient to meet the microgrid's energy demands, it will be possible to draw electricity from the larger grid by establishing a connection between the microgrid and the grid. 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].

The power generation module will provide a minimum of 50V, 2A electrical power to the Bus, which will be used by the load module and stored in the energy storage system.

2.3.2 Energy Storage

To enable energy storage for the microgrid, a battery will be integrated into the PCB board. The battery will function as an energy storage device that can capture, and store excess energy generated by the solar panel when the power generation exceeds the system load. Conversely, when the power generation is lower than the system load, the battery will discharge stored energy to supplement the power supply. This mechanism will contribute to a more stable and reliable power supply for the microgrid, reducing the potential for power outages or disruptions. Additionally, the battery's capacity and performance characteristics will be optimized to ensure efficient energy storage and discharge, and to prolong the battery's operational lifespan.

For the battery capacity requirement of the energy storage module, we need at least

40,000mAh capacity to store the excess energy of the whole microgrid, while guaranteeing the stability of the circuit when the power generation is insufficient

2.3.3 Load

The intended loads for the microgrid are primarily light bulbs and electric fans, with the possibility of integrating cell phone charging devices at a later stage if budget and technological feasibility permit. These loads have been selected based on their low power requirements and the ability to provide immediate benefits to end-users. Additionally, they are expected to be relatively easy to implement, and can serve as a starting point for the development of more complex microgrid applications in the future. Nonetheless, the potential inclusion of cell phone charging devices as part of the microgrid's load profile requires a careful assessment of the system's technical capabilities, as well as a thorough evaluation of the costs and benefits associated with such an expansion.

We plan to employ an electric fan as a test function to assess the performance of our load module. The fan is equipped with a DC motor and has a rated power of 60W, while operating at 220V and 50Hz. Its dimensions are 657*237*505mm. The use of the electric fan as a load test for our microgrid can help us obtain more transparent and comprehensible results. By analyzing the fan's rotation speed and the stability of its blade rotation, we can assess the microgrid's condition, such as its power output and the overall circuit stability.

2.3.4 Control system

The control module 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's power supply 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.

In our project, we are proposing to use the DSP28377 as the control module for our microgrid system. This is necessary because the microgrid system requires real-time control and monitoring of multiple parameters such as voltage, current, power, and frequency. The DSP28377 is capable of processing multiple tasks simultaneously, ensuring accurate and timely control of the microgrid system. It also has built-in analog-to-digital converters (ADCs) and pulse-width modulation (PWM) outputs, which allow us to interface with the power electronics and measure the system parameters with high accuracy.

The control system is also responsible for the connection of microgrid and utility grid, which means it will be able to control microgrid's operation mode transfer between islanding mode and parallel mode, with the objective of enhancing the system's flexibility and reliability[4]. To facilitate this transformation, a phase-locked loop (PLL) will be employed as the conversion device. The PLL will serve to match the frequency and phase of the larger grid within a relatively short timeframe, thereby enabling safe and reliable connection of the microgrid to the grid. This technology offers numerous benefits, including efficient frequency synchronization and robust performance characteristics. Additionally, it offers the flexibility to accommodate varying grid conditions, including changes in frequency and phase, ensuring that the microgrid remains operational and stable under different operating scenarios.

(We delete the connection subsystem and incorporate its functionality into the control subsystem refer to the new Block Diagram)

2.3.5 Simulink system

The simulation system includes a Matlab-based Simulink simulation of several other subsystems. Initially, we systematically built the Simulink simulation system and evaluated its feasibility by inputting the base input values that satisfy the minimum criteria. Subsequently, we gradually increased the input parameters to examine the maximum power and efficiency achievable by the system. The obtained results guided the modification and construction of the actual circuit. Therefore, the simulation system served as a valuable tool for optimizing the performance of the electrical circuit.

2.4 Tolerance Analysis

1. To mitigate the effects of damage to our circuit components during testing and operation, we have taken steps to prevent any resulting functional failures. Specifically, we have replaced the SMD capacitors and SMD transistors with plug-in components. Although this change has resulted in a slight reduction in the overall stability of the PCB board, we believe that the final result is still within acceptable tolerances.

2. The microgrid generates inherent delays between each component, while the voltage source and energy storage systems also produce potential delays. These factors together contribute to a significant overall delay. However, a certain level of delay is tolerable, as the entire system would be connected to the electrical grid. Therefore, as long as the delay does not affect the system's ability to perform its primary function, it is not of great importance.

3. In order to connect the microgrid in parallel with the unity grid, it is crucial to have proper control over the microgrid's voltage. While the Phase-locked loop and the accompanying variable voltage control cannot precisely regulate the bus voltage to 220V, they can maintain a voltage range of 219-223V, which does not impact the overall results. This fluctuation is tolerable within the larger voltage range and does not affect the microgrid's operation.

3 Ethics and Safety

3.1 Ethics

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[5]. 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[5]. 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[5]. 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.

(We re-write this subsection to better meet the requirement.)

3.2 Safety

Ensuring safety in the production process is of utmost importance to our team. As such, we have implemented several measures to maintain a safe environment in the laboratory. To begin with, we always ensure that there are at least two people present during production and processing. Moreover, we have made it mandatory for all students participating in experiments to complete the online safety training program of the laboratory and obtain certificates as proof of their competence in safety protocols.

The safety of production and use is paramount to our team when working with materials that have the potential to cause harm to the human body. As such, we have implemented strict safety protocols to mitigate any risks associated with the handling and processing of these materials. Our team ensures that all necessary safety equipment and protective gear are used during the production process, and we take every precaution to avoid any accidents or injuries. By prioritizing safety, we can ensure that our team members and those around us are protected from any potential harm.

When it comes to mechanical structure safety, our team takes every precaution to ensure the safety of our products. One of our primary measures is to carefully choose the safest shell shape and mechanical structure for each product. By doing so, we can reduce the risk of accidents or malfunctions. Our team adheres to industry best practices and standards when selecting the shell shape and mechanical structure to ensure that our products are not only effective but also safe to use.

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