Microgrid Energy Storage Branch

A Senior Project
Presented To
The Faculty of the Electrical Engineering Department
California Polytechnic State University - San Luis Obispo

In Partial Fulfillment
Of the Requirements for the Degree
Bachelor of Science

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Abstract

The microgrid is the future for the electrical utility system. Because of this, future power engineers need to be well-versed in this topic when they go into industry. Cal Poly has created a microgrid laboratory for this very purpose. However, it is missing its battery-based energy storage branch. Due to safety concerns, a traditional chemical battery is not suitable for student use. In order to maintain Cal Poly's learn-by-doing approach, an alternative solution must be implemented. A regenerative power supply meets the criteria for student use. It is capable of simulating the sinking and sourcing capabilities of a battery as well as having a smaller footprint for ease of storage and use in a laboratory environment. In this project we acquire the IT-M3633 power supply and write operation procedures for various use cases in Cal Poly's EE curriculum.

Battery energy storage systems are critical to the success of a microgrid infrastructure. Future power engineers need to be well-versed in this topic when they go into industry. The CalPoly Microgrid Lab requires an energy storage branch to complete the project. Due to safety reasons, a programmable power supply was chosen to simulate a battery instead. Its portability also allows for applications in other labs. The completion of the lab will allow students to learn about the microgrid in order to better prepare for the future.

Chapter 1: Introduction

Since the electrical grid has become a centralized utility, society has become much more advanced with its electricity usage. With advancing technologies in the areas of renewable generation and power electronics, there is a renewed interest in implementing a microgrid as a feasible alternative to the current electrical grid due to its advantages in reliability and power quality [1]-[3]. As defined by the U.S Department of Energy, a microgrid is "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid" [1]. These microgrids can connect and disconnect from the main power grid in order to operate in "grid-connected" or "island" mode [1]. Events such as February 2021's ERCOT blackout in Texas, could have been avoided if Texas' electrical grid had the ability to connect onto the national grid when its own generation couldn't supply enough power to keep up with demand [4].

In order for a microgrid to "island" itself from the main grid, its distributed generation resources must be able to handle peak local loads. These generation resources will most likely be from sustainable resources such as solar and wind due to the recent push towards sustainable energy generation [1][5]. The weather dependent nature of many renewable generation sources render them inadequate in meeting the necessary energy demand at all times of operation. In the case of photovoltaics, this results in what is known as the "duck curve", where solar generation is mismatched from energy demand. During noon time, when energy demand is lowest, solar generation is highest. However, when demand increases in the evening, solar generation is starting to taper off [5]. Because of the variable nature of renewables, and to help try and prevent overgeneration of energy, energy storage systems become critical in supporting these generation

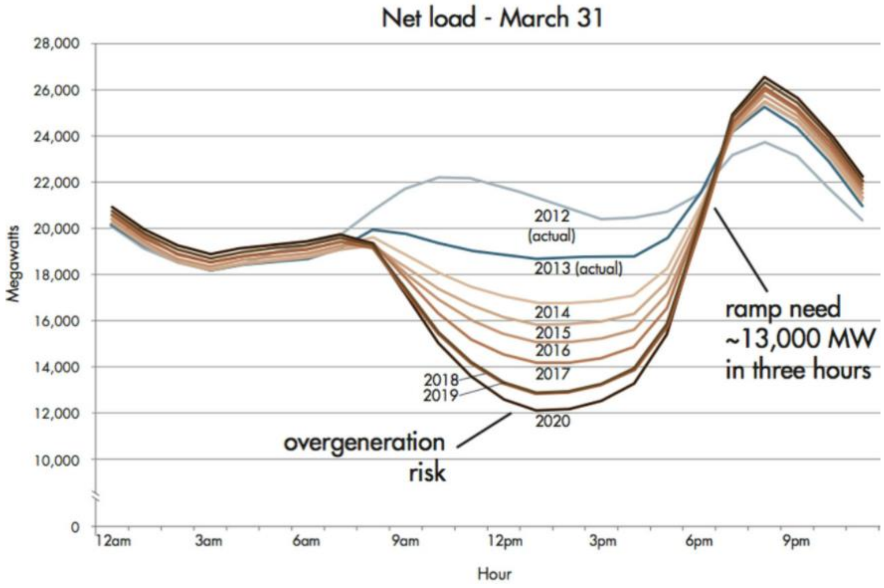


Figure 1-1. Duck Curve [5]

sources in providing a stable source of energy to store and distribute back onto the microgrid. For example, surplus photovoltaic based generation during the daytime can be stored for usage at night when solar generation capability drops. Compared to many other energy storage technologies such as hydro pumps and flywheels, battery-based energy storage systems offer good flexibility in capacity and response capabilities [6]. Sizing these battery based systems for a microgrid is a challenging problem due to the shifting generation capabilities of wind and solar power throughout the day as well as varying system load [7]. Utility providers must conduct cost-benefit analysis to balance hourly electrical rates with the costs associated with implementing larger batteries [7].

If a microgrid is to be connected to an existing electrical grid, there would be bidirectional energy transfer between the two grids. This specific type of energy transfer would be much more complex to protect, compared to the current radial configuration of the electrical grid [8]. Further complications arise when designing protection schemes for these generation resources. With new technologies, new protection schemes must be made in order to adequately prevent the damages that may occur when something happens with the equipment. In addition, due to the potential “islanded” mode of operation, there must also be a way for the devices both upstream and downstream of the microgrid and primary grid connection to detect the change in operation modes [8]. This requires increased consideration in how to detect faults and other issues when the microgrid is both connected to the main grid, and when it is in “islanded” mode. To do so, more research must be done to find out the best way to support the grid infrastructure while transitioning the current grid infrastructure.

Chapter 2: Background

In order to transition from the current electrical grid to a microgrid with distributed renewable generation, power engineers must be trained in microgrid technology. Currently, Cal Poly's Electrical Engineering curriculum does not offer any courses to teach students about the concepts and operations of a microgrid. To bridge this educational gap, the Electrical Engineering Department is developing a microgrid lab to prepare student engineers in their future careers [3]. However, before Cal Poly's microgrid lab can be offered as a course to students, it requires an energy storage system.

Due to students being in the proximity of high-power devices, safety measures have to be taken. One solution would be creating a microgrid with low power devices and power electronics to remove the risk of injuries [9]. The experience Cal Poly students would have gained in their Energy Conversion Electromagnetics Lab should have taught them the risks associated with operating high voltage equipment. The microgrid lab's battery poses a new safety concern for students. To mitigate this risk, using a simulated battery eliminates the dangers posed with operating a chemical battery, while offering students the closest experience with working on a fully featured microgrid.

This project is a continuation of the Microgrid Protection Student Laboratory senior project by Ian Hellman-Wylie and Joey Navarro [10]. Figure 2-1 is an image of the one-line for the Microgrid Protection Student Laboratory. The boxed area is the Energy Storage Branch of the Lab. The entire branch consists of an SEL-700G relay, an inverter, and an energy storage device. The SEL-700G relay protects the branch should a fault occur on the microgrid itself, thus keeping the energy storage element intact. The inverter allows for the AC voltage from the grid to be converted to DC to be stored in the energy storage device. The energy storage device should be able to sink and source currents.

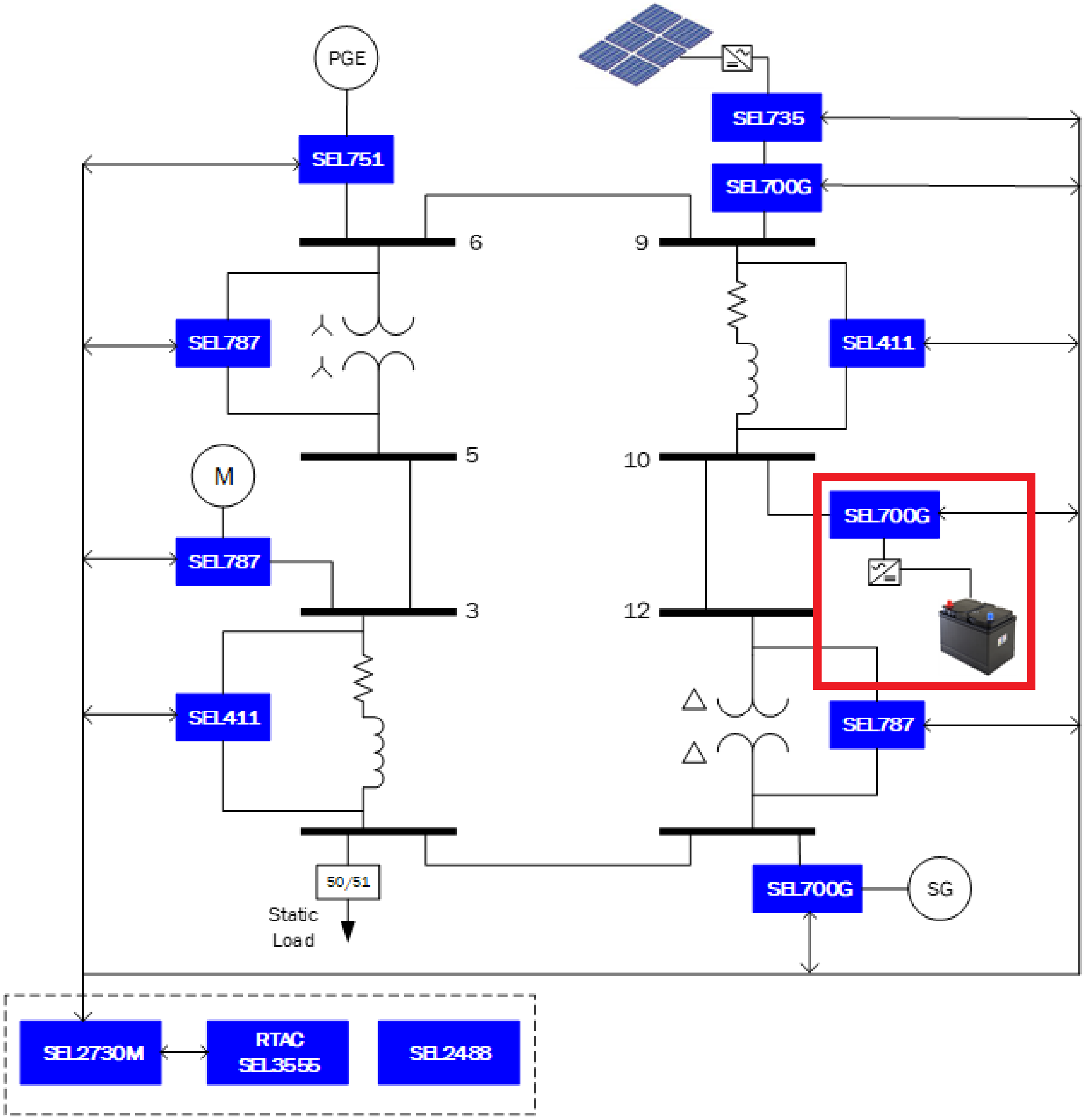


Figure 2-1: One-line of Microgrid Protection Student Laboratory

The Microgrid Energy Storage Branch aims to complete the remaining branch that is missing for the completion of the Microgrid Protection Student Laboratory. Therefore, this project aims to use a programmable power supply to simulate the charging and discharging of a battery. Because of the lab environment and student proximity, a traditional battery was avoided due to potential hazards that can arise due to the chemical nature of a traditional battery. The programmable power supply will be powered from a 240VAC input and be able to source and sink up to 1kW of power. In addition, the supply needs to be evaluated thoroughly to ensure that it can simulate the battery properly under all grid conditions. As microgrids are being explored more and personal generation is being implemented, a completed microgrid lab would give students a chance to learn about and interact with a microgrid before heading into industry.

Chapter 3: Design Requirements

Finishing the Microgrid Energy Storage Branch will allow for the creation of a lab to be taken by Cal Poly students. Note that although this senior project focuses only on acquiring the energy storage device, a holistic design requirement will be specified for the whole system due to the interconnected nature of the three components in the energy storage branch. The programmable power supply used to simulate the charging and discharging of a 500W-1kW battery is the primary component of this branch. The proposed portability of the device will allow for it to be moved around. The project will be implemented in building 20 room 102, the Energy Conversion Lab, Engineering West.

3.1 System Design Block Diagrams

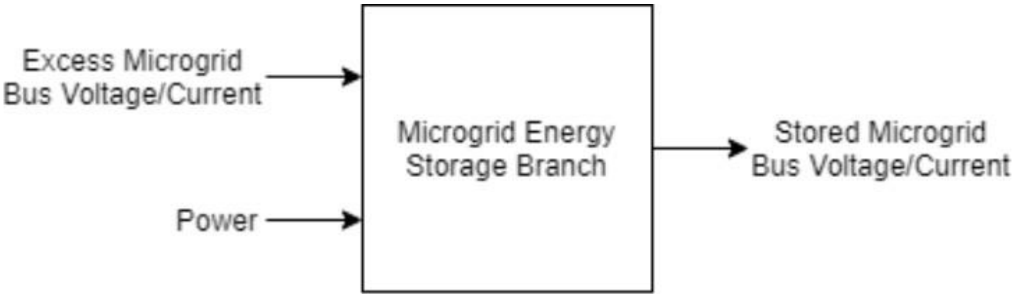


Figure 3-1: Level 0 Block Diagram

The high-level block diagram in Figure 3-1 includes the inputs and outputs of the energy storage branch for the microgrid. The inputs to the system are excess microgrid energy, 208V_{rms} AC at 60Hz, to be stored into the energy storage device as well as power for the components in the energy storage branch, 120V_{rms} AC at 60Hz. The system outputs the stored energy in the energy storage device back onto the microgrid at the same/similar voltage of 208V_{rms} AC at 60Hz.

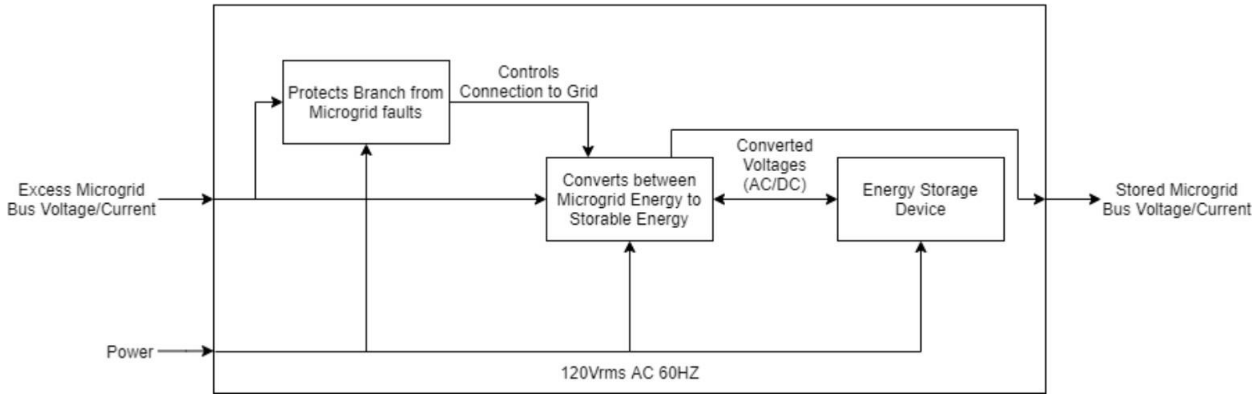


Figure 3-2: Level 1 Block Diagram

The level 1 block diagram in Figure 3-2 is a bit more complex, showing the main functional blocks in the energy storage branch. Some things to note are that the relay takes in the input voltages to monitor the status of the grid, but only outputs a control signal connecting or disconnecting the inverter’s connection to the grid. The inverter controls the bidirectional energy transfer between the grid and the energy storage device.

3.2 Energy Storage Device

Relative to a normal battery, a programmable power supply is safer to use in the lab environment. This programmable power supply simulates the charging and discharging of a 500-1kW battery. The device will also be placed on a cart and pushed around, allowing for portability. The output voltage from the supply is 12-24V_{DC}, and it will be connected to the AC grid through the inverter. It will be powered from a 208V_{rms} AC wall plug. The device will need to be easy to use for students to follow written lab manuals.

3.3 Inverter

The inverter will not be purchased for this senior project due to funding limits. However, its minimum functionality is specified for compatibility with the programmable power supply.

It should be bidirectional to allow for energy transfer from the AC microgrid to the DC power supply and vice versa. During the inversion mode of operation, the inverter must be able to sync the DC power from the energy storage device to the AC phases of the grid. There must also be a filtering stage between the inverter and the grid due to the current harmonics generated by this switching device. It must support the 208V_{rms} AC 60Hz from the grid as well as 12-24V_{DC} from the energy storage device.

3.4 SEL-700G Relay

For this project, the supplied SEL-700G relay will be used to protect the branch from surges or faults on the grid. It should also have a corresponding breaker to trip if such problems do occur.

Table 3-1 summarizes the engineering requirements for this project.

Table 3-1: Engineering Requirements

Engineering Specifications	Implementation	Notes
The device dimensions	The size was set by the device	The battery must be easily

occupy 1U (server rack unit).	specifications	transportable in a lab.
The device should not exceed 25 pounds.	The weight was set by the device specifications	The battery should be able to be carried if needed.
The device should not cost more than $3k	The cost was determined during the purchasing phase	Cal Poly funding would not easily support more than $3k.
The device is easily reconfigured to support various use cases.	We will program various use cases on a microgrid for the system to respond to	The power supply will be used in a lab environment, requiring it to be able to simulate various conditions.
The device should be easy to operate.	The learning curve shall be determined during testing	Students will be operating the device
The device should be easy to understand and write a one page summary for.	An operating sheet will be developed	Professors will need to write lab instructions for students.
The device is able to “store” 500VA-1kVA of power.	The capacity was set by the device specifications	The power supply will be used in a microgrid setting, so it must simulate a commercial scale device.

Chapter 4: Design and Simulation Results

The project aims to provide a simulated battery for the Microgrid Energy Storage Branch by integrating a programmable power supply into the Cal Poly microgrid laboratory. Upon scouting multiple programmable power supplies, and negotiating with companies, a power supply was chosen based on its price and features. The power supply extends the technological capabilities of the current microgrid setup. Adding the battery simulator will let students and faculty experiment with grid configurations where a DC based energy source can supply or store power from the grid.

4.1 Programmable Power Supply

Programmable power supplies from various retailers and manufacturers were looked at and contacted for a quote. Because the device needs to sink a large amount of energy, the bidirectional power supply either needs to be a regenerative device, which converts the energy sent to the device back onto the grid, or it must contain an additional power dissipation unit. Most of the regenerative power supplies were out of the budget (around $10,000) due to having much higher power capabilities than needed. The non-regenerative power supplies were within budget by themselves (around $3000), but when adding a power dissipation unit, the combined price would still be too expensive (around $6000).

The programmable supply chosen was the IT-M3633 Regenerative Power System. The device was chosen as it met the design requirements. Despite being slightly over the desired

Figure 4-1: Front Image of IT-M3633 Regenerative Power System

pricing at $3,880.60 including all additional fees, it is still much cheaper than the other options available. The size (450mm x 214mm x 43.5mm) is 1U half rack, which is half the target maximum size, meeting portability requirements. The device weighs approximately 5kg, or around 10lbs, allowing it to be easily moved by a single person when placed on a cart. The IT-M2633 can also be powered from 100VAC-240VAC allowing easy hookup to pre-established laboratory power outlets.

This model has a “Battery Emulation Function” that enables it to emulate a battery’s charge and discharge functions. It is able to do this because of the current bipolarity design and variable output impedance. Users will be able to set the initial charge state of the “battery” as desired (i.e. setting the battery to 50% charge to see how the microgrid responds). In addition, it allows for modification of various battery parameters, such as full and empty voltage values, internal resistance, capacity, and current limits.

In addition to the IT-M3633’s “Battery Emulation Function,” it can also act as a battery tester This means its usage is not strictly limited to the microgrid lab; it also has applications within the power electronics lab. A traditional setup for a battery tester includes a programmable power supply to charge the battery and an electronic load to act as a sink for the battery. This device combines the two into one package, which reduces the required space for the equipment, and also makes transferring the device between benches and lab rooms easier. The device will also be safer to operate, as students will not need to reconnect components when switching between charging and discharging the battery.

Table 4-1 lists the major equipment needed to setup the microgrid lab using the selected power supply, along with the cost.

Table 4-1. Bill of Materials

Count	**Value**	**Description**	**Size**	**Part Number**	**Manufacturer**	**Per Unit Cost $**
1	150V/12A/800W	Regenerative Power Supply	450mm x 214mm x 43.5mm	IT-M3633	ITECH	$3,306.00
1	N/A	USB & LAN Communication Card Accessory	N/A	IT-E1206	ITECH	$147.25
					Total	**$3,453.25**

Chapter 5: Proposed Hardware Setup and Operation

Introduction:

Due to multiple timeline issues involving ordering and shipping delays, we were not able to get the device to test in-person. Therefore, the following procedures detailing the setup and operation of the IT-M3633 are based on its user manual with no hands-on validation of the steps. We have listed the following procedures as shown in the outline below for quick reference. We have linked the IT-M3600 Series User Manual where further information can be found on each topic in the notes section.

A: First Time Setup

- Connecting the IT-M3633 to Power
- Connecting the IT-M36333 to a Communication Interface (USB+LAN)
- Connecting the IT-M3633 to a Device-Under-Test (DUT)
- How to use the USB Interface with the IT-3633
- How to use the LAN interface with the IT-3633

B: Setting the IT-M3633 to Battery Tester Mode (SOURCE MODE)

- Editing the Battery Test File
- Recalling and Viewing the Battery Test File
- Running the Battery Test File
- Stop Running and Re-running Battery Tester

C: Setting the IT-M3633 to Battery Emulation Mode (SOURCE MODE)

- Editing the Battery Emulation File

- Recalling and Viewing the Battery Emulation File
- Running the Battery Emulation File
- Stop Running and Re-running Battery Emulator
- Setting the Internal Resistance

D: Setting the IT-M3633 to Battery Simulation Mode (LOAD MODE)

E: Transporting the IT-M3633 Between Laboratory Rooms

F: General Notes for the IT-3633

Note: The specific device model is IT-3633 of the IT-3600 series. The user manual is written for devices in the IT-3600 series.

A: First Time Setup

Connecting the IT-M3633 to Power:

The IT-M3633 needs to be connected to a 120VAC 60Hz grounded AC outlet using the supplied line cord. This outlet can be easily found on most lab benches and will therefore not need any special accommodations. Before connecting the device to the outlet, ensure the device's power switch is in the off position.

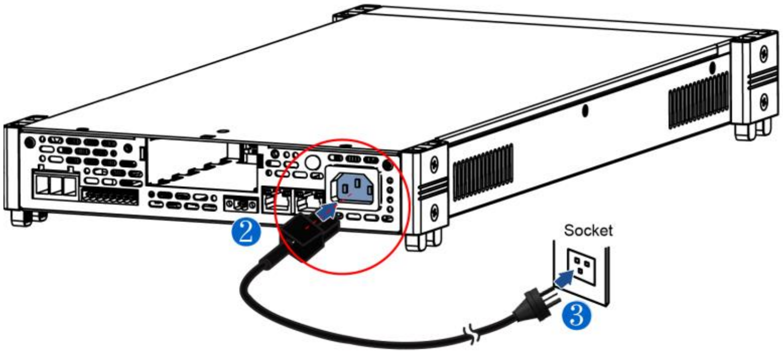


Figure 5-1: How to connect the IT-M3633 to AC Power

Connecting the IT-M3633 to a Communication Interface (USB+LAN):

Ensure the AC power plug is removed from the rear panel interface. Press a flathead screwdriver (a), into the clip-on top of the upper panel opening, while using another flathead screwdriver (b), to stir the slot behind it until the plastic plug is forced out. Push the USB+LAN interface into the slot and secure it with the included screws.

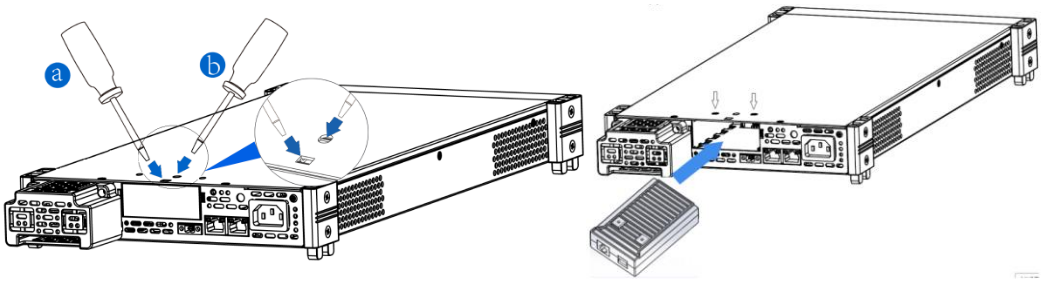
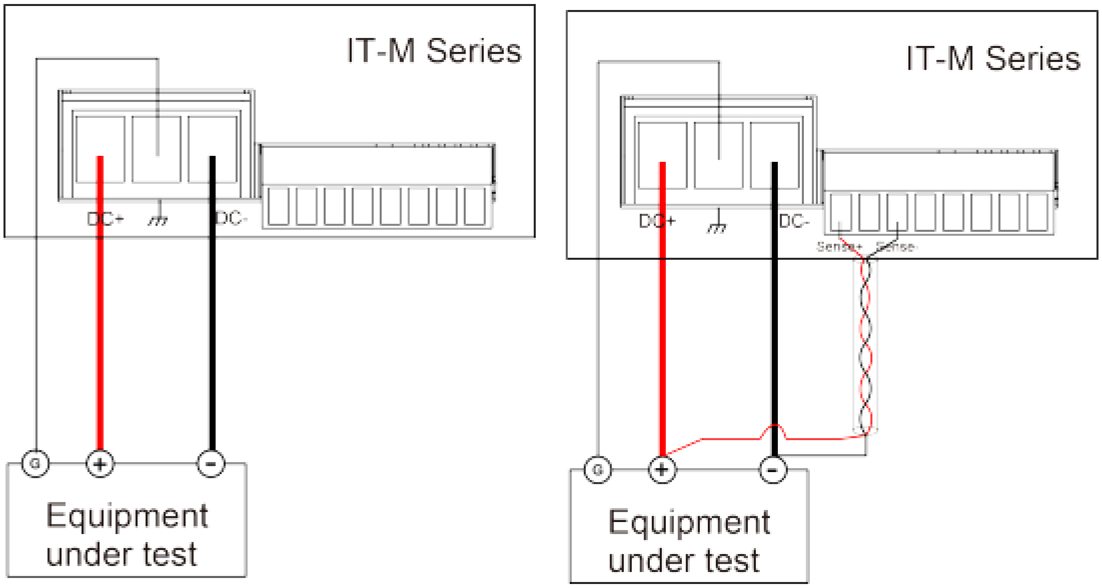


Figure 5-2: How to connect the communication interface card to the IT-M3633

Connecting the IT-M3633 to a Device-Under-Test (DUT):

The following procedure details how to connect a DUT to the IT-M3633.



Figures 5-3 and 5-4: Diagrams to connect a DUT to the IT-M3633 rear panel. Local Measurement (Left) & Remote Sensing (Right)

The IT-M3633 can be connected to a DUT in two different ways as shown in Figures 5.3 and 5.4. The Remote Sensing method is used in applications with large current draw, where there is a non-negligible voltage drop across the DC+/- cables, such as battery testing. The manufacturer recommends using shielded twisted-pair cables to ensure stability of the system.

How to use the USB Interface with the IT-3633

After the USB+LAN interface is installed, follow this procedure to connect the IT-3633 to a computer through USB.

1. Connect the USB port on the back of the IT-3633 to a USB port on a computer
2. Press **[Shift]+[P-Set]**(System) for system menu interface
3. Use arrow keys or knob to select **I/O Config** and press **[Enter]**
4. Use arrow keys or knob to select **USB** and press **[Enter]**
    a. Use arrow keys or knob to select **TMC** or **VCP** and press **[Enter]**
        i. TMC: USB_TMC interface
        ii. VCP (Virtual Serial Port): Need driver from ITECH website or agent, computer device manager will show “Prolific USB-to-Serial-COM-Port” after installed
5. Press **[Esc]** to exit

How to use the LAN Interface with the IT-3633

After the USB+LAN interface is installed, follow this procedure to connect the IT-3633 to a computer through LAN.

IT-3633 supports two types of LAN connections. Private LAN is a direct connection from the IT-M3633 to a computer, while site LAN connects to a computer through a router or network. Because we expect this device to be frequently moved across different lab rooms, we will only detail the procedure for a private LAN connection.

1. Use a LAN cable to connect the IT-M3633 to a computer
    a. Ensure the gateway address of the instrument is consistent with the computer and the IP address is on the same network segment with the PC's IP address
    b. If neither of the LEDs are lit on the LAN port, the network is not connected. The green LED will light up if the LAN port is connected. When the orange LED blinks, the LAN port is receiving or sending a message.
2. Press **[Shift]+[P-set]**(System) for system menu interface
3. Use arrow keys or knob to select **I/O Config** and press **[Enter]**
4. Use arrow keys or knob to select **LAN** and press **[Enter]**
5. Use arrow keys or knob to select **Lan Config** and press **[Enter]**
6. The menu item **IP-Mode** configures the instrument address
    a. **Auto**: automatically configure the addressing of the instrument
    b. **Manual**: manually configure the addressing of the instrument
        i. Set **IP Addr** and **Sub Net** if Manual is selected *(See user manual for full details)*
6. Press **[Esc]** to exit

Note: The IT-M3633 has a built-in web interface to monitor and control the instrument. To use the IT-M3633's web interface, connect the instrument to a computer with LAN and enter the instrument's IP address into the computer's web browser.

B: Setting the IT-M3633 to Battery Tester Mode (SOURCE MODE):

When the IT-M3633 is set in the **SOURCE** mode, the device can be used as a charging and discharging test function for a battery. The device would be used in this mode in order to test the usability of batteries that are either bought or created. The following procedures detail how to configure the IT-M3633 for its battery tester mode.

1. Make sure the IT-3633 is plugged in as detailed in the First Time Setup section.
2. Make sure that the device is in source mode. If it is not, press **[Source]** on the front panel to put the device into source mode.
3. Rotate the knob to select **Run**, **Recall**, or **Edit**, depending on whether the user wants to run, recall, or edit a battery test file. For help with any option, please refer to the following sections.

Editing the Battery Test File

If the battery test file needs to be changed, please refer below for instructions.

1. In the battery test function setting interface, select **Edit** to enter the file menu.
2. Select the desired file number to be edited. The maximum number of files that can be saved is 10.

   `Edit File = 1/10`

3. Press **[Enter]** to confirm. Below is an example test file.

   `1 : Batt Mode= Charge`

   `2 : Charge V = 1.00V`

```
3 : Charge I = 1.00A

4 : Charge Time = 60S

5 : Cut Off V = 8.00V

6 : Cut Off I = 5.00A

7 : Cut Off Q = 10AH
```

When the battery mode is set to discharging, the device will perform a discharging test instead.

4. Set the attributes as desired. After setting, press **[Esc]** to exit.

Recalling and Viewing the Battery Test File

To recall and/or view a previously used/edited test file, please refer below for instructions.

1. In the battery test function setting interface, select **Recall** then **[Enter]** to enter the file menu.
2. Rotate the knob to select the file to be recalled. If the selected number is empty, then the file selected is also empty. The user must then select the file again or return and enter the Edit menu to edit the file.

   ```
   Recall Batt = 1/10
   ```

3. After successfully recalling a file, the user can view the setting information of the existing file. The test parameter can only be viewed and not edited. If the user wants to edit the file, return to the battery test function setting interface, and follow the instructions in the **Editing the Battery Test File** section.
4. Press the **[Esc]** key to exit to the previous page.

Running the Battery Test File

To run a previously used/edited test file, please refer below for instructions.

1. After the battery test files are edited, the user needs to select **Run** to enable the battery test function and return to the main interface to trigger the running.

```
12.000V   10.000A
00.00:01  0.00Ah
```

The first line shows the voltage and current value while the second line shows the testing time and battery capacity.

During testing, if there is no SDS module, the alert box will appear with “No SDS Module Detected, Continue? No/Yes.” After “Yes” is selected, the testing will be continued. As long as any one of the cut-off conditions are met, the test stops.

Stop Running and Re-running Battery Tester

During the running of the battery test file, the user can press **[Shift]+[I-set]**(Function) to display the running state control interface of the existing file. The user can press **Stop** to stop the existing test and turn off the List function or press **Restart** to restart a new test.

C: Setting the IT-M3633 to Battery Emulation Mode (SOURCE MODE):

When the IT-M3633 is set in the **SOURCE** mode, the device can emulate the charge and discharge properties of a battery. The device would be used in this mode in order to test the function of devices under various battery conditions. The following procedures detail how to configure the IT-M3633 for its battery emulator mode.

1. In SOURCE mode, press **[Shift]+[I-Set]**(Function) to access the Function menu
2. Rotate knob to select **Batt Emulator** and press **[Enter]**.
3. Rotate the knob to select **Run**, **Recall**, or **Edit**, depending on whether the user wants to run, recall, or edit a battery emulation file. For help with any option, please refer to the following sections.

Editing the Battery Emulation File

If the battery emulation file needs to be changed, please refer below for instructions.

1. In the battery test function setting interface, select **Edit** to enter the editing menu
2. Select the desired file number to be edited. The maximum number of files that can be saved is 10.

   ```
   Edit Emul = 1/10
   ```

3. Set the following parameters in succession.
   a. Cell Properties: Set battery properties: full/empty-state voltage value, internal resistance, and capacity.
   b. Parallel: Set number of emulated batteries in parallel.
   c. Series: Set number of emulated batteries in series.
   d. I_Limit+/I_Limit-: Maximum current limits for charge/discharge.
4. Press **[Enter]** to confirm each parameter. Below is an example emulation file.

   ```
   1: Cell Properties
   2: Parallel =1
   3: Series =1
   ```

```
4: I_Limit + = 2.00A

5: I_Limit - = -2.00A

6. - -EXIT- -
```

5. After setting, press **[Esc]** to exit.

Recalling and Viewing the Battery Emulation File

To recall and/or view a previously used/edited emulation file, please refer below for instructions.

1. In the battery test function setting interface, select **Recall** to enter the file menu.
2. Rotate the knob to select the file to be recalled. If the selected number is empty, then the file selected is also empty. The user must then select the file again or return and enter the Edit menu to edit the file.

   ```
   Recall Emul = 1/10
   ```

3. After successfully recalling a file, the user can view the setting information of the existing file. The emulation parameter can only be viewed and not edited. If the user wants to edit the file, return to the battery test function setting interface, and follow the instructions in the **Editing the Battery Emulation File** section.
4. Press the **[Esc]** key to exit to the previous page.

Running the Battery Emulation File

To run a previously used/edited emulation file, please refer below for instructions.

1. After the battery emulation files are edited, the user needs to select **Run** to start running the battery emulation function.
2. Set initial State-of-Charge (SOC) of the existing battery and press **[Enter]**

   ```
   Initial SOC = 0.00%
   ```

3. Below is an example of the main interface while running the battery emulator.

```
12.000V   10.000A
 0.00AH   0.00%SOC
```

The first line shows the voltage and current value while the second line shows the state of charge and battery capacity.

During emulation, battery over-charge and over-discharge protection is supported. When charging capacity is higher than 110% or discharging capacity is lower than -10%, the test stops automatically.

Stop Running and Re-running Battery Emulator

During the running of the battery emulation file, the user can press **[Shift]+[I-set]**(Function) to display the running state control interface of the existing file. The user can press **Stop** to stop the existing test and turn off the emulation function, or press **Reset** to restart a new test.

Setting the Internal Resistance

The following procedure details another way to set the internal resistance of the power supply in SOURCE mode.

1. Press **[Shift]+[V-set]**(Config) for Config menu
2. Rotate knob to select **Output R** and press **[Enter]**
    a. Use arrow keys to select the desired internal resistance and press **[Enter]**
3. Press **[Esc]** to exit

D: Setting the IT-M3633 to Battery Simulation Mode (LOAD MODE):

When the IT-M3633 is set in the **LOAD** mode, the device can be used as a discharge function test for a charger. A simulated battery voltage can be set, which allows the charge to detect a reliable and correct voltage before it enters the charging state. The following procedures detail how to configure the IT-M3600 for its battery simulator mode.

1. Press **[Shift]+[V-set]**(Config) for Config menu
2. Rotate knob to select **Battery Sim** as **Mode** and press **[Enter]**
    a. **V-set** should light up and allow to user to set the voltage value of the battery
3. Press **[Esc]** to exit

E: Transporting the IT-M3633 Between Laboratory Rooms:

The intended operation of the IT-M3633 is to have it movable between the Power Electronics Laboratory and the Microgrid Laboratory. We plan to situate the IT-M3633 on a cart which can be easily moved by students and faculty. The following procedure details the safe transport of the device.

1. Power off the device and disconnect from AC mains power
2. Ensure device and power cord is securely on the cart before moving
3. Transport the device on the cart to the desired destination
4. Connect the device to AC mains power. See section **Connecting the IT-M3633 to Power** for more information on the hook up procedure.

F: General Notes for the IT-M3633

This section includes various helpful notes for operating the device.

Note: In order to ensure the accuracy of measurement, it is recommended to operate the instrument half an hour after start-up.

Note: Pressing the knob is equivalent to pressing **[Enter]** when changing settings.

Note: For any other details, please refer to the user manual located below.

https://www.altoo.dk/files/itech/manuals/IT-M3600-User-Manual.pdf [11]

Chapter 6: Conclusion

With the addition of this programmable power supply, Cal Poly's Microgrid Protection Student Laboratory is one step closer to completion. The power supply allows students to learn about microgrid concepts in a hands-on fashion without the traditional safety hazards involved with a chemical battery. The completion of this lab will give student power engineers an excellent opportunity to learn about the microgrid, which will give them knowledge in preparation for their future careers in the utility industry. Furthermore, the IT-M3633's portable size allows it to be transported between the microgrid laboratory and the power electronics laboratory where it can be used as a battery tester and simulator. This senior project also contains a step-by-step procedure for using the power supply in the applications mentioned above.

Future work needs to be done in verifying the procedures written in this report. Because of unforeseen ordering and shipping delays, we were not able to test the power supply for its safe operation and functionality. The scope of the original project was also narrowed due to funding limits. Mainly a bidirectional inverter still needs to be purchased for the microgrid to interface the programmable power supply with the microgrid. The SEL-700G relay also needs to be configured to protect the power supply. A cart still needs to be allocated to carry the power supply across the EE laboratories. Compared to the current curriculum, where microgrids are only covered in one lab during EE 444 Power Systems Laboratory, a new course can be dedicated around microgrid protection and operation concepts.

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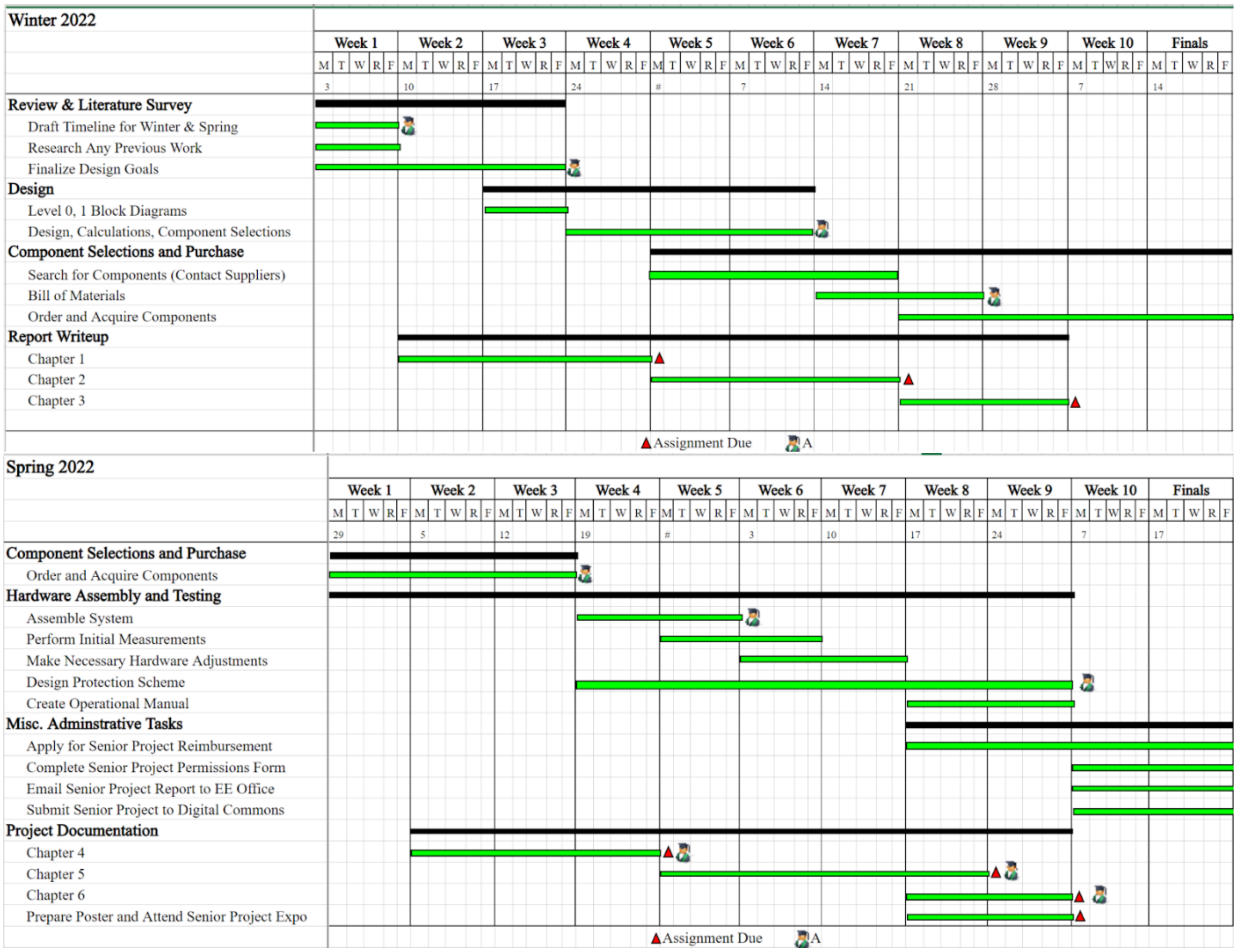
Appendix A: Bill of Materials

Count	**Value**	**Description**	**Size**	**Part Number**	**Manufacturer**	**Per Unit Cost $**
1	150V/12A/800W	Regenerative Power Supply	450mm x 214mm x 43.5mm	IT-M3633	ITECH	$3,306.00
1	N/A	USB & LAN Communication Card Accessory	N/A	IT-E1206	ITECH	$147.25
					Total	**$3,453.25**

Appendix B: Gantt Chart



Appendix C: Analysis of Senior Project Design

Project Title: Microgrid Energy Storage Branch

Students' Names : Evan Luu, Jeffrey Shieh

Advisor's Name: Taufik

Date: 2022

Summary of Functional Requirements

The programmable power supply simulates a battery storage system which can sink or source 800W to and from the microgrid lab. It gives students the opportunity to learn about the effects of high-capacity batteries on a microgrid without the traditional hazards of a chemical battery. In addition to its usage in the microgrid lab, its portable size allows it to be used in other laboratories such as the power electronics lab as a battery tester.

Primary Constraints

The project had faced significant challenges and issues with finding and ordering components. With safety of students being a primary concern, chemical batteries were not looked at for energy storage. Instead, a programmable power supply was the device pursued for simulating energy storage. It was difficult to find a suitable device with high power capability while still falling under the $3,600 funding limit. For example, power supplies from manufacturers such as Keysight cost about $5,000 and needed an additional $3,000 for a heatsink to enable the power sinking capability. Other manufacturers gave us quotes of up to $20,000 which was far above our budget. In order to meet our budget requirements, the capabilities of the power supply was changed from the original target of 1kW-2kW to 800W. We also faced major delays in our timeline due to the slow nature of communications with the power supply manufacturers. After choosing the power supply, purchasing delays with Cal Poly prevented us from receiving the device on time for us to test in person. Due to these factors, we were limited to writing an operating procedure for the device without hands-on testing.

Economic

The project directly impacts electrical engineers going into the power utility industry as the power supply brings Cal Poly's microgrid lab one step closer to completion. After the completion of the lab, faculty can teach students microgrid concepts in a new course. Getting more students in this field grows the microgrid technology industry leading to the creation of products such as microgrid protection relays and microgrid battery energy systems. Research on battery-based microgrid technology can lead to increased demand in utility scale batteries. These batteries allow renewable energy generators such as solar, to continue selling energy even as demand falls below supply to charging battery energy storage systems.

The costs of the project are accrued during the creation of the microgrid lab where components must be purchased to implement each part of the microgrid. Further costs are accrued during the development of new courses and lab experiments using the power supply. Benefits for this project are obtained once a new course is developed for students to learn about microgrids. The creation of new courses will also attract potential students to Cal Poly's EE department, bringing benefits in the form of tuition. Operating the power supply requires electricity from the local utility PG&E which is paid for by Cal Poly. The original estimated cost of components was less than $2,500. However, after speaking with various power supply vendors, we realized this budget was too small to purchase the device we needed. The final cost of the project ended up being $3,453.25 as seen in the bill of materials in Appendix A. The project was completely funded by Professor Taufik with his research grant. As mentioned above, the project can help develop the microgrid lab and other various battery related research at the Cal Poly EE department. Cal Poly University will profit in the long run as students can be attracted to the power EE program. Compared to our original Gantt chart, the time it took to search for components extended into the Spring Quarter. This further delayed the ordering of components, as that had to be done after a component was found. The project will be developed further in a future senior project or master's thesis where the various functionalities of the power supply and procedures in this report can be verified in person. In addition, proper implementation of the device, with the inverter and relay, onto the grid can be done.

If manufactured on a commercial basis:

The microgrid lab is intended to provide significant educational value to students interested in the evolving power landscape. In order for the microgrid lab to function, the energy storage is critical to lab experiments being created. Because the lab cannot be sold as a commercial product, there is not a monetary value that can be placed on it. Instead, the value comes from the experiments themselves and from the experience of the students.

Environmental

While we did not manufacture the power supply, the device is created from raw mined materials used to create the circuitry. Usage of this device also requires electrical power from the grid. When used in the microgrid lab, the device can sink renewable energy generated from the solar panels and wind turbines back onto the electrical grid. During its sourcing state in the microgrid lab, the device uses electrical power from PG&E which is mainly produced from clean energy as seen from their 2021 generation profile.

Manufacturability

ITECH Electronic manufactured the power supply used in this project. Because the supply was not manufactured by us, the expectation is that the device works according to the specifications provided by ITECH's datasheets and user manuals. These references should provide helpful background information for usage of the product.

Sustainability

The biggest challenge in maintaining the power comes from keeping the device in good condition. It must be stored in a temperate climate to maintain proper operation of electronic components to ensure maximum lifespan. As mentioned previously, the product itself gives renewable energy produced by the microrid's wind and solar generation the ability to send energy back onto the grid. Excess energy could also be stored during low load hours for later use. The biggest upgrade that could be made to the project is the purchase of a power supply with a higher rating. This upgrade would allow for more capacity, but would cost significantly more. A possible upgrade to the power supply would be buying identical units and operating them in parallel as described in the manual.

Ethical

The ethical concerns from this project arise from the safety of the power supply. Similar to the other power supplies in electrical engineering laboratories, this device can injure students or faculty if used improperly. The Cal Poly Microgrid Lab's completion may also impact course scheduling since the lab also hosts other required labs in the EE curriculum such as EE 295. By taking away lab times for required courses, students may find it harder to finish their degree due to less lab time offerings.

Health and Safety

In addition to usual safety concerns with operating a power supply in the laboratory environment, the high sinking and sourcing capabilities of the power supply can put students at additional risk when connecting high power sources to the device. However, detailed safety procedures included in the report will help mitigate user error during operation.

Social and Political

This project directly impacts Cal Poly EE students and faculty. For students interested in power, this can be a good lab for them to learn more about power systems. This lab has the potential to be a graduate level course as well, providing some needed hands-on experience at the graduate level. However, the creation of a new lab gives faculty more work to create new content for students, regardless of whether or not the lab is decided to be a graduate level or undergraduate level course.

Development

Operation of the power supply is the primary obstacle for this project. In addition, because of its usage in multiple labs, knowledge of the respective course work is required. In the case of microgrid usage, proper knowledge of relays, inverters, and batteries are needed in order to properly use the device. In the case of battery testing, proper knowledge of batteries and their limits are needed in order to use the device safely. The literature search for this device primarily included datasheets and the user manual. Because ITECH is a Taiwanese company, support for the device may be more limited.