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Design of a Microgrid Laboratory with Distributed Energy Resource Visualization

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INTRODUCTION

Microgrids are a technological advancement with a potential for great change in the way that we know electric power. With ties to renewable energy especially, microgrids are a key topic of discussion in the world of energy. With funding from the EPRI GridEd program, we created our own small microgrid consisting of DER and a single load, otherwise known as a picogrid. This picogrid laboratory sits in the 8th floor Electric Power Systems Laboratory (EPSL) of the Swanson School of Engineering. This will be instrumental in allowing us to teach students about microgrids and DER through demonstration. Additionally, we can conduct research and run experiments involving microgrids and their applications.

The picogrid laboratory (schematic diagram shown in Figure 6 at the end of the document) in the EPSL consists of rooftop solar generation with Enphase M215 microinverters, Renogy lead-acid battery storage with a MagnaSine inverter-charger, and a load bench (see Figure 1) configured to mimic a residential load. These components of the picogrid operate on split-phase 240 V circuit, and the load bench is fed by a 208/240 V transformer. The picogrid is capable of islanding operation where it operates without a grid connection and the load is supplied using battery power.

PROJECT SUMMARY

Design Considerations

In our picogrid, most design decisions would revolve around the need to convert the bench and power sources from three phase to split phase. Because the MagnaSine inverter-charger operates only on 240 V split-phase, the bench would need to be modified. The incoming grid and solar feeds would need to be converted to 240 V split-phase as well.

The three-phase. 208 V grid power feed can be converted using a 208/240 V step-up transformer which was provided by Eaton. There are multiple options for how to deliver the solar feed to the load. The three-phase solar output could be fed through the step-up transformer, or the Enphase microinverters could be configured to produce a split-phase 240 V waveform. If the solar feed connects upstream of the transformer, then it should be connected downstream of the islanding contactor to allow for use of solar power during islanded operation.

Figure 1: Benedum Power Lab bench from Eaton.

Objective

The objective of this project is to create an freestanding picogrid system capable of supporting future laboratory experiments, specifically to demonstrate the function of machine learning algorithms controlling battery charging and dynamic load response.

Picogrid Implementation

We implemented the picogrid in the power lab through a few carefully planned steps. The lab benches in Pitt's Electric Power Systems Lab were provided to the University of Pittsburgh by Eaton. They have capacitive, inductive, and resistive loads, and they operate on 208 V, three-phase power. Our picogrid would consist of only one of these benches. However, our picogrid would operate on 240 V split-phase due to limitations from the battery-inverter. With some guidance from Eaton and the building electrician, we found the best way to implement all power sources and make our bench model a residential, 240 V split-phase picogrid.

During the planning period, we amassed information to ensure that we could make calculated decisions in the future. We gathered and combed through all data sheets and manuals associated with our equipment, especially the Enphase microinverters, the MagnaSine inverter-charger, and the Renogy 12 V 200Ah lead acid batteries. For ideas, we looked at example microgrids and schematics like the Tesla Powerwall system [1] and a MagnaSine example grid [2]. We also calculated total power needed to supply the bench to ensure that any changes we made to the load would still be covered by our batteries when islanded. We also used advice from Eaton to shape our design.

First, we ran the 208 V, three-phase utility power through a 208/240 V step-up transformer. This transformer converted our lab bench's voltage to split phase. The building electrician had to install the transformer because of safety concerns and building regulations. It's directly connected to the building's main power. The MagnaSine battery inverter already outputs split-phase, so all that remained was to convert the output of the Enphase microinverters from three-phase to split-phase output. To accomplish this, we switched out the old inverter connectors with Enphase Engage Cable ET10-240. The old cables had 5 conductors in them, 3 lines, a neutral, and a ground. The new cables had 4 conductors with the only difference being that it had only 2 lines. Since the microinverters are grid-tied, the inverters would sync to the two lines in the 240 V in our system. We did not need to change anything else with the inverter system.

Figure 2: 208/240 V split-phase transformer provided by Eaton.

With regards to safety and proper operation of the system, it was important where and how the solar power was tied into the system. If the system was islanded and solar panels were supplying more power than the loads could consume, this could lead to damage to the battery inverter or to the system. Following thorough research and consultations with Eaton, we determined that we would connect the solar feeds in parallel, upstream of the main power contactor and thus upstream of the battery power. There was also an added contactor between the solar microinverter and mainline power. This solar setup could allow us to help feed loads or even sell solar energy back to the utility.

Figure 3: MagnaSine inverter is run into the bench through a side vent where it is in line with the main power.

With the batteries, we wanted to prevent any potential overcurrent damaging our inverter or batteries, so we added a 100 A DC breaker in series. As another layer of protection for the batteries, the

MagnaSine inverter has a temperature sensor to measure the ambient temperature around the batteries. This temperature data is used by the inverter to adjust charging voltage to increase performance and prolong battery life [3].

Before we connected any of these sources, however, we needed to ensure that the bench was safe for split-phase operation. The benches include delta connected three-phase reactors and capacitors as well as other capacitive loads. These were taped off to ensure a safe and more realistic residential load.

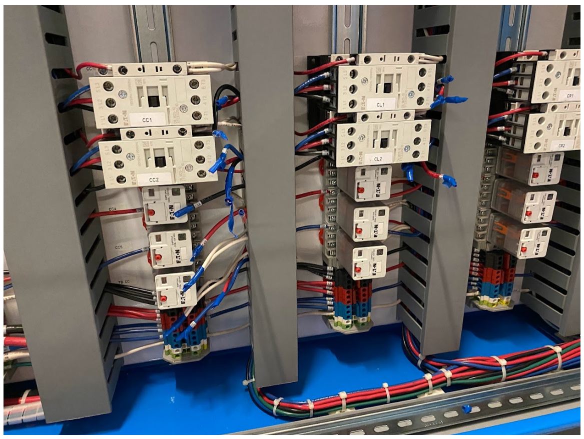
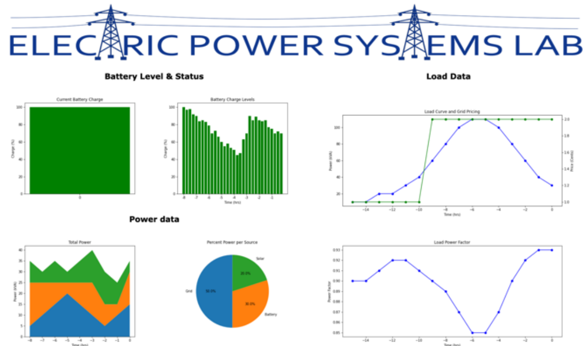


Figure 4: Loads taped off at the contactor level.

Once the plan was finalized and all the proper steps were taken, the picogrid was wired in the manner according to the attached schematic. The main power is fed through the transformer, paralleled with the rooftop solar, and fed through the bidirectional MagnaSine inverter. Now, we have a picogrid that can be used for various experiments, as discussed in the next section.

Visualization

A visualization GUI was developed using Python. This GUI accepts real-time data from the PV panels, the battery storage system, and the load bench. It is reconfigurable so that it can accept many different types of data as inputs. This visualization GUI is shown in Figure 5. This figure shows real time batt3ry charge, historical battery charge, power supplied to the picogrid by each individual source, historical load power factor, and historical load curve vs. real time energy pricing. With additional funding from Pitt's ECE department, we were able to acquire a Dell edge server which will store big data acquired by all the devices in the picogrid lab. This data will be able to be plotted in a historian fashion for several different time intervals.



CONCLUSION

Future improvements of the picogrid system will ideally increase the amount of time the system can operate in the islanded state. The inability of the current grid-tie solar microinverters to operate

Figure 5: Visualization GUI Screenshot

independent of grid power poses a limitation to the reliability of the picogrid. Switching to a grid-forming inverter will allow the solar to operate in the event the system is disconnected from grid power while the batteries are discharged or not supplying power. In the system's current state, the solar will be disconnected in an islanding event to prevent underloading of the solar inverters or a backwards power flow into the MagnaSine inverter. A future addition may be extra load capable of switching on during such an underloading scenario.

Other improvements include battery monitoring, greater load control - including possible expansion of loads to mimic residential HVAC systems, and a lithium-ion battery and charger to mimic an electric vehicle for V2G experiments.

A GUI has been developed for the monitoring of battery charge state and history. To put this software to use, and to properly collect data for machine learning battery control algorithms, a battery current shunt and a battery monitor are needed. The battery monitor must be able to export its data to the systems running the GUI and ML algorithms. The ML algorithms will operate through an external data center in the Power Lab. We have been granted access to the specification's communications protocol used by the Magnum inverter-charger and its accessories. With this information and the Magnum Energy Battery Monitoring Kit (ME-BMK), battery monitoring data can be exported to the relevant systems.

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In order to more accurately model a residential load, the power draw of the lab bench should be adjustable on a granular level. The current setup allows this to some degree, as each of the 300W equivalent CFL bulbs in the bench is controlled individually. To simulate residential HVAC load, a blower fan may be connected to the load bench. It may be, however, that the inductive banks present in the load bench already provide an acceptable model of the motor load of HVAC systems and other appliances.

Our team would also like to adapt and apply the developed battery charging control algorithms to electric vehicle batteries. Vehicle to grid (V2G) connection has complicating factors when compared to dedicated energy storage. In V2G, the vehicle battery cannot be drained to its full usable depth of discharge, as that would render the vehicle unusable. The vehicle is not always present in the system, and while some trips, such as commutes, are predictable, others are random. These trips also drain the battery a variable amount, depending on trip distance, road conditions, mid-trip charging, and other factors. The planned equipment to model an electric vehicle is a lithium-ion battery with an inverter-charger and a discharge resistor to simulate battery drain due to driving.

SOURCES

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ADDITIONAL SOURCES

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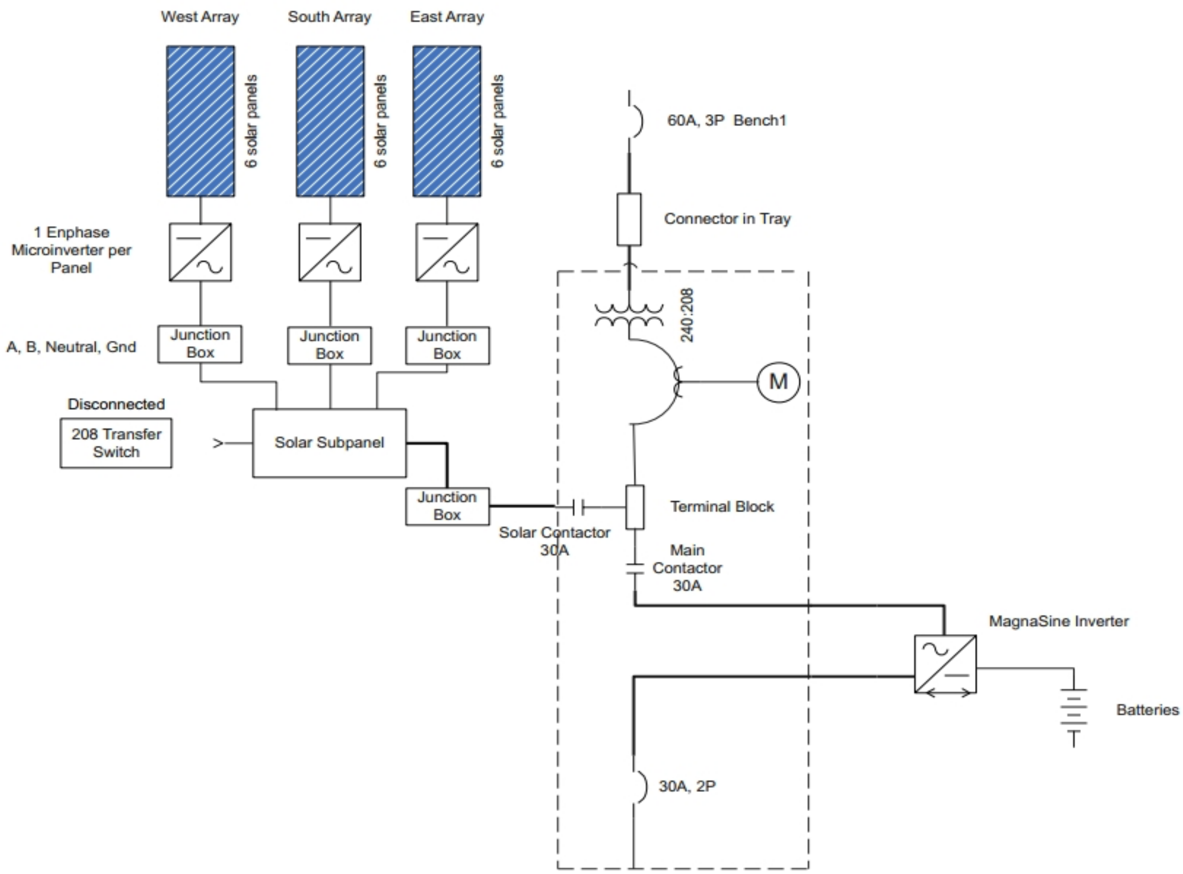

Figure 4: Schematic of Pitt Picogrid Laboratory