Optimized Energy Management System

UNIVERSITY OF
SOUTH ALABAMA

Senior Design Project: EE 401-404, Fall 2020-Fall 2021

Students: Dustin Brothers, Rashard Andrews, and Jacob Lake

Advisors: Dr. Mohamed El-Sharkh and Dr. Daniela Touma

Sponsors: EPRI GridEd

Electrical Engineering Department
University of South Alabama, Mobile, AL

Acknowledgment

The students and the project advisors would like to thank the Grid Engineering Education of Electric Power Research Institute (EPRI-GridEd) and the Electrical Engineering department at the University of South Alabama for their support to complete this project.

Abstract

To increase the power available in the actual grid, different power companies offer the option for a residential consumer to have renewable power generation at home and sell the excess energy to the grid. The necessary investment for this application is not cheap since it requires special equipment, and thus its cost-benefit may be minor given that the power cost is low in some national regions. For this reason, residential users in areas like Alabama are not well motivated to install a microgrid with renewable energy in their residence. To address this issue, an economical optimized microgrid (MG) system including Photovoltaic Panels (PVP), Energy Storage Systems (ESS) and an optimized Energy Management System (EMS) may be considered. This project focuses on developing the MG system in residential areas while reducing unnecessary losses common in households. It studies different optimization algorithms for the EMS to use various sources such as PVP, ESS or the power grid to supply the load. The optimization considers aspects like the power price, the energy available from the sun and the energy stored in the ESS. The final product may work for future research as well as a mean of disseminating and motivating the usage of renewable energy in residences.

Introduction:

In a world that is ever moving towards an electrically powered society, it is important to have a constant source of electricity. It has been stated that a country's growth can be measured by its energy consumption. It can also be said that electrically powered devices have become a necessity to be successful in today's world. For those who are able to live in areas where the main power grid is easily accessible, it is a commodity that has been taken for granted. For those who do not have this access to the main grid, are being left behind and need other options. Although there are many feasible ideas, one option is installing a domestic microgrid powered by Solar Panels. This microgrid would provide people with a source of power that could either operate independently of the grid or be connected to the grid so that the excess power can be sold to the grid. This could be taken a step further where each microgrid is connected into a SMART-grid, which would optimize energy usage throughout the whole system. Of course, with innovation there always comes a new set of problems. Although users can save a large amount of money over time, this power system has a hefty installation price. There are various other factors to consider when building a microgrid, such as inclement weather conditions affecting the solar panels, as well as having the space to install these panels. For those who have easy access to the main power grid, this would still be an economically sound idea to save money over time. A microgrid would allow for the user to generate electricity for personal use and then sell the excess to the power company, therefore increasing the total power in the grid. In this project, we have taken on the task of creating an electrical energy generation system that also manages itself to work with the main electrical grid to power a load. When the system generates more electrical power than is needed, the system will then supply the main electrical grid the excess power. The scope of this project will not include how to build any of the actual components but rather what they are, how they are used and how to install and use them together. (i.e., a solar panel is used to convert sunlight into electricity, rather than the process of building a solar panel.)

Background

An energy system is a system which is designed to supply energy services to its end user. In 1881, two electricians built the world's first power system at Godalming in England. It was powered by two water wheels and produced an AC current that suppled seven Siemens arc lamps at 250 Volts and 34 incandescent lamps at 40 Volts. Today our electrical grid is more complicated, but it still has the same basic principle of delivering power.

There are different types of residential loads that consist of various smart home appliances that are considered. According to the inherent characteristics of home appliances, they are classified into three categories such as NSAs, TSAs, and PSAs. NSAs such as fans, TVs, lights, and refrigerators have fixed time and power consumption patterns according to the consumers' needs. So, the NSAs are not suitable for the load shifting process. TSAs, such as dishwashers, washing machines etc., which have continuous power consumption patterns can be shifted to preferable time slots. PSAs, such as water pumps, electric vehicles etc., have minimum and maximum powers limits for device operation. According to consumers' daily requirements, the power shiftable appliances' total energy consumption and their specific operating time periods can be fixed. Therefore, TSAs and PSAs are the most suitable loads for the load shifting process.

The solar panel output power mostly relies on geographical locations and atmospheric conditions. The output power of a particular solar PV panel, (P_{pv}), at any time, t, is a function of atmospheric temperature and solar radiation, which can be expressed as:

$$P_{pv}(t) = P_{rat}\, f_{loss}[G_h/G_s][1 + \alpha_p(T_c - T_s)]$$

where P_{rat} is the power rated for the output capacity of the solar PV panel, f_{loss} is the loss factor of the solar panel due to shadow, dirt and temperature. G_h is the hourly solar radiation that interacts in between the sun and the solar PV panel (W/m^2), G_s is the standard optical phenomenon radiation (1000W/m^2), α_p is the coefficient of the temperature for the power based on the types of PV cell used, T_c is the solar PV panel cell temperature in the current time step and T_s is the solar PV panel cell temperature under standard test conditions which are 27°C and 25°C respectively.

The surplus energy in the micro-grid MG is absorbed in the ESS and the ESS will provide energy when the MG is in low power generation. The charging and discharging modes are being maintained and monitored within the specified limits. State of charge (SOC) of the battery storage can be calculated as:

$$SOC(t) = SOC(t\text{-}1) + \int I\ t/C_{bat}.dt$$

where the SOC(t-1) is the initial state of charge (%) for the battery, I is the charge or discharge current (A), and C_{bat} is the capacity for the battery (AH).

Due to non-linear characteristics of solar PV and atmospheric conditions, the efficiency of solar PV reduces drastically. Hence, the maximum power output from the solar PV system changes with respect to change in solar insolation and weather conditions. To maximize the transfer of power generated from solar PV to battery bank, a battery charger with a charge controller plays a vital role. The charge controller helps in tracking the maximum power by placing the solar panels at the maximum power points MPP irrespective of change in insolation, it also reduces the battery charging time to back-up the PV arrays. But most importantly, the charge controller limits the over-charging and discharging of the battery which enhances the lifetime of the ESS. The most common used type of solar PV charge controllers are the series, shunt, PWM and MPPT charge controllers. In this project we used both PWM and MPPT type charge controllers.

To control the flow of power in the system, relays are used. A relay is an electrical switch that uses a coil to operate contacts inside the casing. Reasons for using relays are the ability of using thinner cables which save weight, space and cost. Relays allow power to be routed to a device over the shortest distance, thereby reducing voltage loss. Additionally, heavy gauge cables only need to be used to connect a power source to the device.

The relays alone cannot control the route of the power; a microcontroller is also used to send commands to open or close the relays. In this research, an Arduino is programmed to switch the relays and control the power flow in the proposed system. A design with additional components could be used but with time constraints within the semester the project was simplified. By adding current sensors, different code could be written for the microcontroller that would optimize and make a more effective design.

Objective:

The main objective of this research is to increase the amount of power that is available in the grid by giving residents the option to install a solar-powered microgrid. This microgrid would generate electricity that would power the home, as well as give the user the option to sell the excess electricity generated back to the grid. This would cut down on the amount of power use as well as provide another source of power generation to the main grid. This concept is not necessarily a new one, in fact, there are many of these microgrid systems already in place across the world. The goal is to design the microgrid in such a way that it is cost efficient. This will be achieved by alternative ways of charging the batteries and distributing loads. The design will also be space efficient by using a compact design that would eliminate the need for large areas of the user's yard. These improvements are meant to entice residents in areas where power costs are low, to invest in this green power source.

Phase one of the project: Dustin Brothers and Rashard Andrews

Design

The task that is taken by the group is to build an affordable optimized energy management system for the average consumer. An Arduino is programed and used to control relay switches that direct the flow of power from each supply to the designated load. Items like charge controllers were used so that solar panels and batteries were used in the most optimal way possible. Inverters were implemented so that DC electricity could be changed to AC. Also, in future application a rectifier circuit could be used to change AC to DC.

The project was broken into two different design aspects, the first being hardware and the second being software. Hardware products were researched and decided upon so that a scaled model could be built. A 100 Watt solar panel, 12 Volt battery, and the grid were used as power sources. A DC bus was used to connect all sources except for when the grid would power the load by itself. A MPPT controller was used to connect the solar panels and EMS. This is to maximize the power of the solar panel and to control the charging and discharging of the battery. By controlling the charging and discharging of the battery to the correct standards, the maximum lifetime of the battery is achieved reducing the cost of the system. There were two inverters in the design so that DC to AC conversion can be performed. A pure sine-wave inverter was implemented before the load, since this is what is needed for most house-hold appliances. A grid-tied inverter that has synchronization capabilities was implemented to allow selling back any additional power that the renewable energy sources might produce.

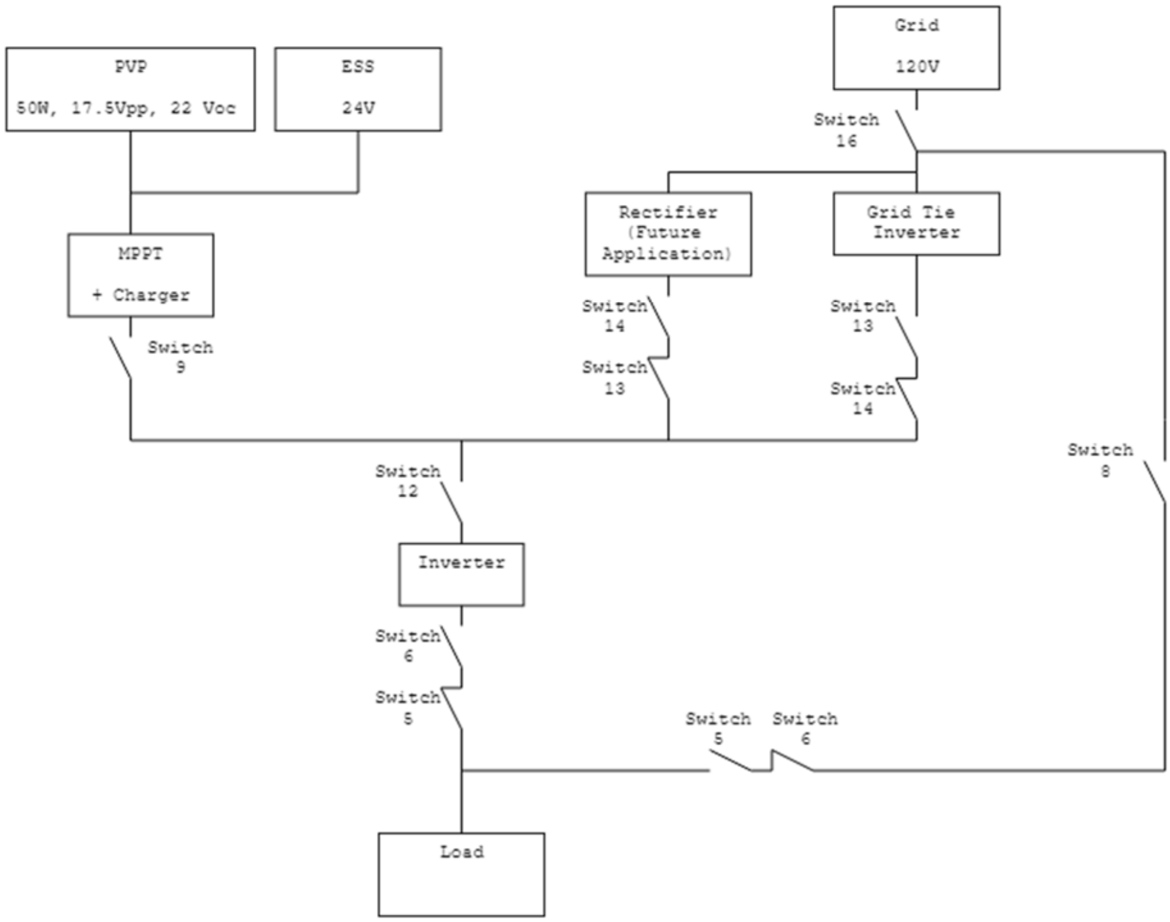

Figure 1 – Block Diagram of Project

The proposed system allows for different modes of operation to account for certain situations. The switching method worked in a few different modes. Island mode is where the renewable energy sources and ESS would be the only sources of power. Island mode would be in the case of a power outage of the grid. This can be achieved by switching the relay disconnect of the grid to an off state and switching all the relays that connect the renewable energies to the load to an on state. Another mode of operation that would be possible would be a grid only mode, which would be the opposite of the previous except for allowing the current to run though the rectifier circuit and being able to charge the ESS if needed. The last mode of operation is grid-tied in which the grid is disconnected from the load directly but instead flows through the rectifier unit, also all renewable energy sources switches are on so that all sources can be used. This is then fed into the DC bus which runs to the load inverter and switched to usable power for the load.

To come up with these concepts, research on different websites were done, such as IEEE and science direct. Also, academic advising from Dr. El-Sharkh and Dr. Touma played critical roles in the conceptualization and development of the project. Parts were ordered from Amazon and Digi-Key.

The project delivered a model that shows a basic design that could be used to optimize energy management by using the provided method above.

Test and Evaluation:

The design was first tested by checking each source and finding out the open circuit voltage and the short circuit current V_{OC} and I_{SC} of each renewable resource to know if they are working and are close to its rating. Next testing of each source was performed with a resistive load to check if the source is viable as an energy source. These tests were done with an oscilloscope and multimeters. Components were bought according to the design of the project. These components were connected to each source individually to check if the output is what is expected. Code was written and checked in small increments so that trouble shooting could be done quickly. For the design to work properly it must produce 12VDC that leads into an inverter that switches it to 120VAC to power the load.

Status/Results:

Although many obstacles occurred during the development of the project. A working model was produced that simulated a scaled down project due to resources. Code was written, by Dustin for the Arduino, and the relays, which were wired by Rashard, would switch relays to optimize energy usage according to time of day, as shown in figure 2.

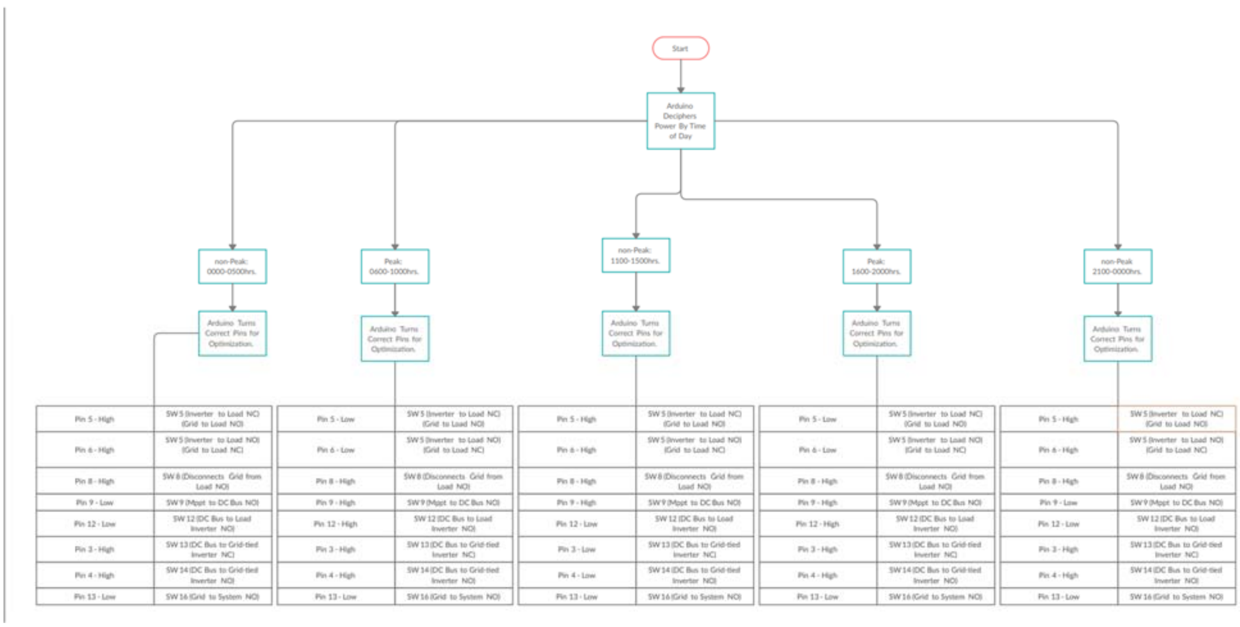

Figure 2 – flow chart of relay switching

The project also simulated selling power back to the grid without connecting to the grid but rather using a lamp and a wired outlet to show a proof of concept.

Problems arose during the design from things such as obtaining the correct voltage for the original components that were bought. Due to time constraints, other components were bought and the project was scaled down to fit the specifications of those components. One of these problems would be that a 24 Volt 16 module relay board could not be found.

This project allowed for the participants to get hands on experience with power components and also coding, while also learning how to work with other team members to accomplish a goal that takes different skills and knowledge.

Although the project did have many complications and had a rocky start, the team created a working project that simulates how the objective could be implemented. If allowed more time, more could be added to the project to further optimize the EMS. Components such as current sensors, different relay mechanism, a rectifier circuit, and new code could all be implemented to update the project.

Safety:

While constructing the design of the project, lab procedures were taken in account. Since a relatively low DC power was being used, the primary concern was more focused on not destroying any of the equipment and making sure that all equipment was rated for the voltage and current that would be used. When the AC part of the project was applied, more attention was focused on the hazard of being shocked. All lab and electrical precautions were taken. In case of an accident, team members were informed of the proper actions and safety procedures to perform. Such as, if a fire were to happen, team members before-hand located fire extinguishers and designated tasks in case of an emergency. If the proposed design is released to the public, we recommend that a professional should installs it. If not the individual should do research in electrical safety and check with their utility company.

Ethics:

Disasters affect populations in many ways that require external intervention in the form of aid. The nature of disasters commonly places considerable constraints on the capacity of infrastructure to transport and deliver aid to affected populations. Such constraints force aid providers to make decisions about aid rationing. In other words, the way that the grid is built now if a disaster happens and the grid goes down, there are only so many workers to fix the problem. Many times businesses get deemed more important and individuals that live in more rural areas are addressed last. With these microgrids put in place, it will alleviate the problems faced when the grid is down.

Public Health/Welfare:

As stated in the section above it would allow people to have more freedom from the grid in the case of disasters which severely damage quality of life and health during major disasters.

Environment:

These microgrids are expected to lower environmental and sound pollution while also lowering carbon emissions. One factor that wasn't researched that can be further point of research is the impact of making the renewable energy sources and how they can be disposed at the end of its life cycle.

Global Factors/Political and cultural:

Since many countries are pushing towards a net-zero carbon emission stance. If individuals decided to add the proposed system to their homes, it would coincide with the goal that many countries are trying to achieve. This may also help with the climate change, which is believed to be happening partially due to carbon emissions. In addition, governments may also give incentives for their citizens to establish these types of microgrids.

Sustainability:

Analysis reveals that under reasonable assumptions reflecting the current state of microgrid technologies, microgrids may constitute a viable, cost-effective alternative to additional central power plants requiring new investments in transmission and distribution infrastructure.

Phase two of the project: Jacob lake

In the second phase of the project the proposed system is updated and a new Arduino program is written as shown in Figure 3 and 4. The proposed system has the capability to supply the power from a solar panel which has it is own energy storage system. In addition, the overall system has it is own ESS that can be used during peak times. Also the system can use the grid supply to power the load if the solar panel and the ESS do not produce enough power to supply the load. Also, the grid can be used to charge the main energy storage system during the off-peak time of the grid and can use the ESS to supply the load during the peak time or to sell the system's excess energy back to the grid.

One of the problems that arose during the second phase of the project is the solar panel is not able to produce enough energy in the lab environment. This problem will be addressed in the third phase of the project by using a hardware simulator for the solar panels. The hardware simulator will enable us to simulate different scenarios of the solar panel operation in a lab environment. The system was tested thoroughly and showed a variability to supply different loads with a grid connection or in island mode.

The system is then used to test how much potential savings the system can offer to residential customers. For that purpose, the dynamic pricing of Alabama power company is used. Then the system is tested under different loading conditions (off-peak and peak time). Results shows that using the proposed system could save the power user a considerable amount of money. The collected data and analysis of the result are sent for possible publication in the IEEE SoutheastCon 2022.

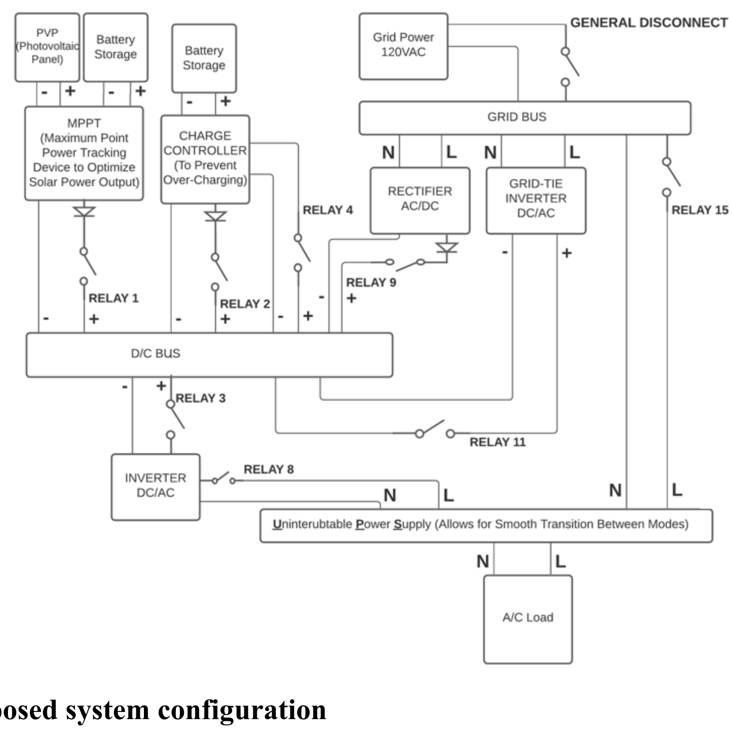

Figure 3, New proposed system configuration

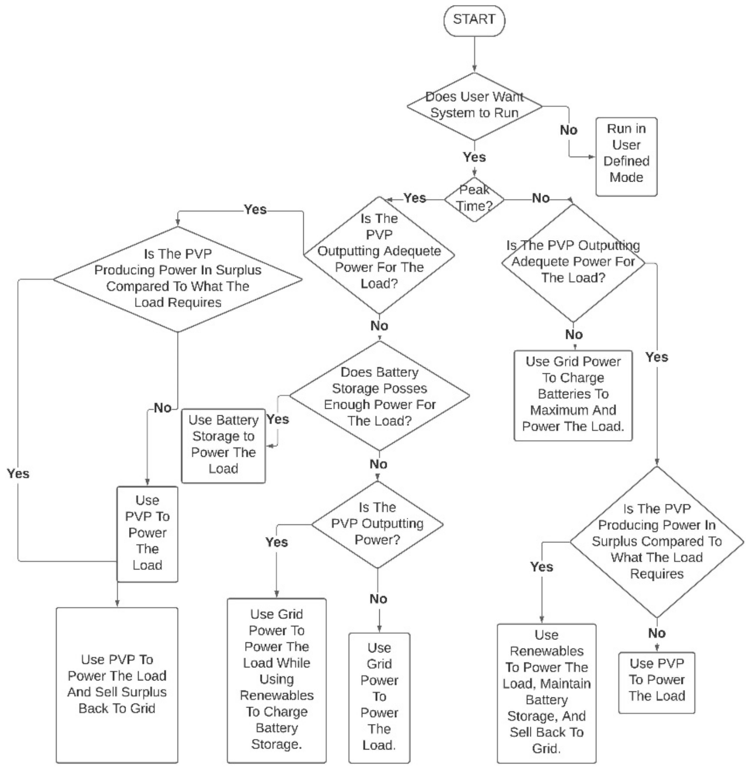

Figure 4, New flow chart

Phase three of the project: (Future work)

A hardware simulator will be used to simulate different operational scenarios of the solar panels. The cost analysis will include the solar panel and the ESS in conjunction with the grid to supply the power to different loads. In addition, a user friendly interface will be created to display the microgrid's status and to allow the customers to include their preference in the system's operation.