Cost and Performance Analysis of Home Level Microgrids

UNIVERSITY OF SOUTH ALABAMA

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Abstract

Managing the power during peak periods poses a challenge to power companies. During peak time, the drastic uptick in consumption causes exponential increases in the power losses which has a direct effect on the overall power cost. In addition, these drastic increases in demand can make the grid unstable. Recently, power companies such as Alabama Power have introduced a dynamic (or time of use) pricing scale to encourage consumers to shift their loads to the off-peak time. Instead of charging a flat rate, Alabama Power charges the consumers depending on when the power is consumed. Using power during peak time will result in a higher price compared to the off-peak time. During summer months, this price increase can be over three times that of off-peak times. If a consumer can find ways to exploit this dynamic pricing (I.E., don't use electricity during peak times), the consumer will have a significantly lower electric bill and the electric company will have less line losses and improved grid stability. The research in this paper focuses on developing and testing a microgrid system. The microgrid is expected to give the customer more freedom to use the power at low cost and to reduce the power losses for power companies. In addition, cost analysis based on the dynamic rate is performed to study the feasibility of the proposed system.

I. Introduction:

The current United States power grid relies on the centralized power model that is still largely unchanged since its creation over a century ago. In its current form, centralized power plants generate power using an "on-demand" model, with just approximately 2.6% of electricity being saved in Energy Storage Systems (ESS) [1]. The peaks of the load represent a challenge to electrical power, not only because the power companies must supply extra power during those peaks but also because of the excessive power losses in the transmission and the distribution systems. Due to the length of the lines and distance from the source, approximately 8% of power is lost through transmission. In addition, 20% of the country's generation is used for a short duration (5% of the time) during peak loads [2]. Extra power losses increase the total cost of the generation.

Improving reliability is also a primary focus among energy providers, especially given that most transmission lines and transformers are still in use since the initial installation of more than 25 years ago [3]. As it stands, almost 90% of all power outages occur along the distribution side of the system, where the majority are due to overhead lines and because of the adverse weather conditions [2].

Along with all these concerns, the United States has a constant growth rate of electricity consumption. It is expected to have an increase in power demand of 1% per year through the year 2030 [4]. Without substantial investments in improving the carrying capacity of the nation's transmission lines, power bottlenecks are predicted to arise, which could effectively prevent the system from delivering energy to certain portions of the United States [3]. Since residential loads consume 21% of the nation's energy [5], power companies have introduced a dynamic (or time of use) pricing scale to incentivize consumers to utilize grid storage and renewable energy generation. Price scale also benefits power companies in different ways such as reduction of losses on transmission lines in addition to the increase in grid stability and efficiency [6]. The pricing scale fluctuates the cost per kWh based on when the energy is consumed. The main objective of the pricing scale is to shift the customer's activity away from the peak periods. Therefore, it financially penalizes customers for using grid power during peak times and rewards customers for using grid power during the off-peak time.

To give the customer more freedom to use their loads at low cost even during the peak time, this research proposes the use of a microgrid system with different renewable energy sources. However, the implementation of renewable energy at the home level in a microgrid is not a viable option for the average consumer due to the complexity of the system and the initial capital investment [4]. Trying to reduce the consumption during peak hours, some authors suggested to control some of the appliance's operation by switching them off during peak times. This technique significantly diminishes the consumers' comfort and may lead the users to not utilize or to override the system. Other authors use advanced algorithms and models to maximize efficiency over a full day with renewables and storage [7].

This paper focuses on the use of alternative sources such as photovoltaic panels (PVP) and/or ESS during peak hours to allow the consumer to continue powering the load during peak hours with as little to no grid usage as possible. The systems main focus is to use renewables such as PVP and ESS only during Peak Time. The paper is organized as follows. Section II describes how the proposed system works. Section III presents how the system was tested whereas Section IV explains the cost analysis methodology to evaluate how the system performed. Measurement, results, and cost calculations are presented and analyzed in Section V. Finally, Section VI concludes the paper with remarks for consideration.

II. METHOD

The proposed microgrid prototype is composed of a roof-top solar panel (simulated using a DC power supply) together with batteries as ESS to power a small load, as shown in Fig. 1. It uses a maximum power point tracking controller (MPPT) to get the maximum power from the PVP, a battery charger controller to control the ESS charging and discharging, a rectifier to convert the AC power from the grid to 24 V in the DC bus, and inverters to power the AC load and/or sell power back to the grid.

The system is in island mode when it operates independently of the main power grid. When the load is partially/fully supplied from the grid or when the system supplies power to the grid, the system is in the grid-tie mode. An Arduino is used to control the switching of the relays to change the system between island mode or grid-tie mode according to the flowchart shown in Fig. 2.

LabVIEW software is used to facilitate the user interface for the system. The LabVIEW software is divided into two distinct programs. The first program serves as the main controlling program. The user can either enable the automatic function of the software that will automatically switch from Non-Peak Time to Peak Time operation depending on the time or can manually turn relays on and off at will. The second program serves as the data collection program. All the current and voltage sensors implemented within the circuit are displayed and archived using this program.

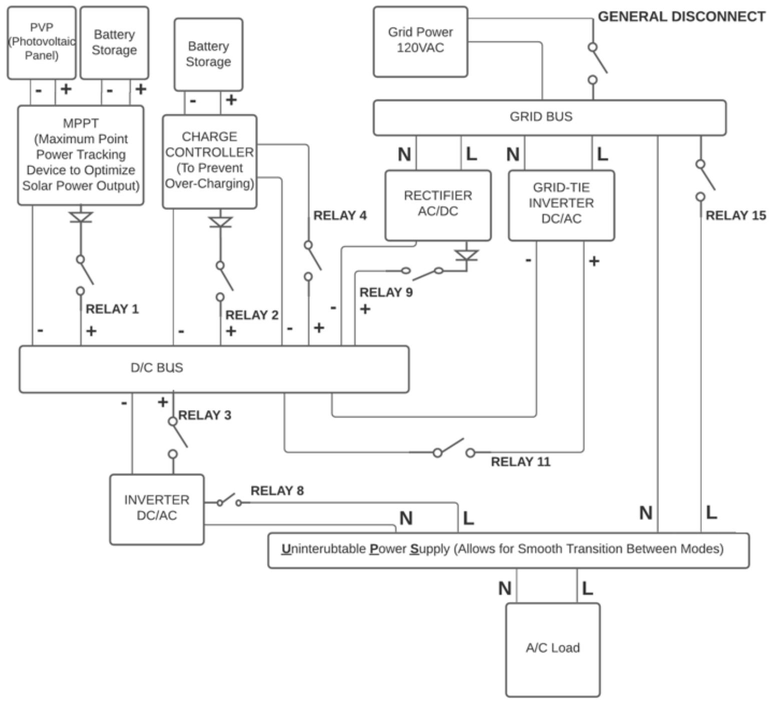

Fig. 1. Proposed Residential Microgrid Block Diagram.

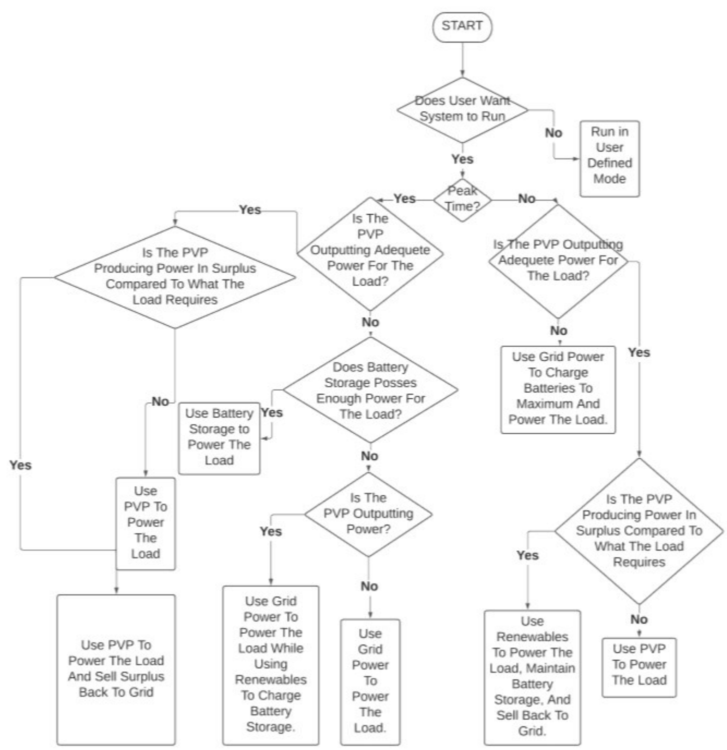

Fig. 2. Flowchart of how the Arduino and LabVIEW controls the switches.

III. SIMULATION STRUCTURE

In this section, the energy cost is calculated to show the advantage of using the proposed system. The consumer may choose between using dynamic price rate and flat rate [6]. Both rate options are analyzed in this paper.

A four-hour simulation was used as the basis of the cost analysis. The four-hour simulation was divided into Non-Peak and Peak Times based on summer peak time hours. Peak Time during Summer months is defined as between 1:00pm and 7:00pm on weekdays.

The first two hours of the simulation represented Non-Peak Time preceding Peak Time during a summer weekday. During Non-Peak Time, the system would support a 150-Watt load. During Non-Peak Time operation, the system is in grid-tie mode where it utilizes the grid to not only power the 150-Watt load, but also to charge the ESS for the use during peak time. The current sensors placed in the system collect the total grid input current, the charging current of the ESS, and the load current. These currents, as well as all subsequent currents mentioned later, are collected directly from the LabVIEW program that interfaces all the current sensors.

After two hours has elapsed, the simulation would begin its Peak Time interval. For the scaled four-hour simulation, Peak Time represented one hour of the simulation. During this interval, the load on the system would be increased to 200-Watts to show an increase in demand during Peak Time. In this interval, the relays connect the system in the island mode where it uses the ESS and MPPT to power the load. In addition, the grid-tie inverter is connected to sell back any excess energy back to the grid. To represent conservative solar panel performance, the DC power supply was energized for 15 minutes of the one-hour interval.

During the Peak Time interval, the discharging DC currents of the ESS and MPPT, the DC current of the grid-tie and pure sinewave inverter, and AC currents of the grid-tie inverter and load are collected.

After the one-hour interval representing Peak Time had concluded, the system switch back to Non-Peak Time operation and the load was decreased to 150-Watts. This second Non-Peak Time interval would last the remaining one-hour where the same current values of the first non-peak time interval were collected. Once the entire four-hour simulation was concluded, the stored current and voltage measurements were exported, plotted, and evaluated.

IV. COST ANALYSIS

The basis of the cost analysis is to compare the systems cost to run under Alabama Power's flat rate billing system and Alabama Power's Time-Advantage billing system. The following energy costs were used to execute cost analysis on the system.

A. Time Advantage:

Table I shows Alabama Power's Time Advantage billing system prices.

In this paper, Alabama Power's price is used. The Alabama Power dynamic price is defined at different times and seasons for peak time and off-peak time hours as shown in Table I [6]. In addition to the prices shown in Table I, a $25 base charge per month is added to each bill. It is noteworthy that Table I defines the peak time in Central Time and it is only for weekdays (Monday – Friday). Saturday and Sunday do not have peak time. Moreover, the months of April, May, and October have no peak time, and all hours are billed as off-peak time. Therefore, peak time hours per month is calculated as the number of weekdays multiplied by the number of peak time hours.

TABLE I. ALABAMA POWER DYNAMIC (TIME-ADVANTAGE) PRICING [6]

Month	**Peak Time period (CST)**	**Price (cents/kWh)** [a]	
		Peak Time Cost ($\$_{Peak}$)	***Off-Peak Time Cost ($\$_{NonPeak}$)***
January to March	5:00 am to 9:00 am	9.5359	7.5359
April / May	N/A	N/A	7.5359
June to September	1:00 pm to 7:00 pm	27.5359	7.5359
October	N/A	N/A	7.5359
November / December	5:00 am to 9:00 am	9.5359	7.5359

[a] In addition to the prices shown in the table, a $25 Base Charge Per Month is added to each bill

B. Flat Rate

Table II shows Alabama Power's Flat Rate billing system.

The system's performance during the simulation was extrapolated to run for an entire year. Then, the loads utilized during the simulation, 150-Watts and 200-Watts, were used to develop monthly kWh demand. The Peak Time and Non-Peak Time kWh's were then subjected to cost analysis to see if the system would result in cost savings under Time-Advantage.

TABLE II. ALABAMA POWER FLAT PRICING

Month	**Price (cents/kWh)** [b]			
	First 1000 kWh ($\$_{1000}$)	***Over 1000 kWh ($\$_{>1000}$)***	***First 750 kWh ($\$_{750}$)***	***Over 750 kWh ($\$_{>750}$)***
January to May	N/A	N/A	10.6618	9.4618
June to September	10.6618	10.9147	N/A	N/A
October to December	N/A	N/A	10.6618	9.4618

[b] In addition to the prices shown in the table, a $14.50 Base Charge Per Month is added to each bill

V. RESULTS

Observing the results shown in Fig. 5, the system provided energy cost savings under Alabama Power's Time-Advantage billing system. Whether the system relies only on the ESS being charged during Non-Peak Time to be used during Peak-Time, or if the system utilizes an auxiliary source for charging (PVP), the energy costs are reduced.

Energy Savings

• Grid Storage: $42.46

• Grid Storage + Renewables (25% Peak Load): $46.08

• Grid Storage + Renewables (50% Peak Load): $49.70

• Grid Storage + Renewables (100% Peak Load): $56.93

It is important to note that the monthly administrative fee does affect the systems overall cost savings. Comparing the Flat Rate and Time-Advantage monthly administrative fee, the Time-Advantage rate results in an additional $127 in monthly fees compared to the Flat Rate. In this paper, only energy costs were analyzed.

Due to the limited output of the grid-tie inverter coupled with the price structure of the prosumer rate outlined by Alabama Power, grid-tie performance was not accounted for in cost analysis.

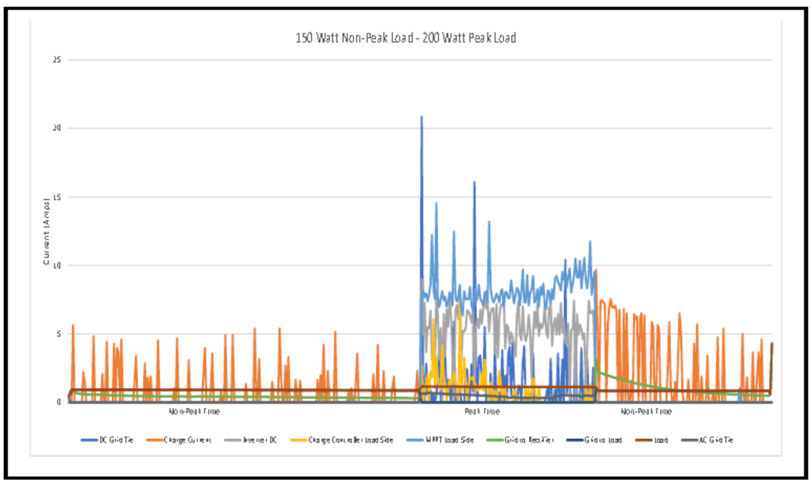

Fig. 3. Current Plots of Four-Hour Simulation

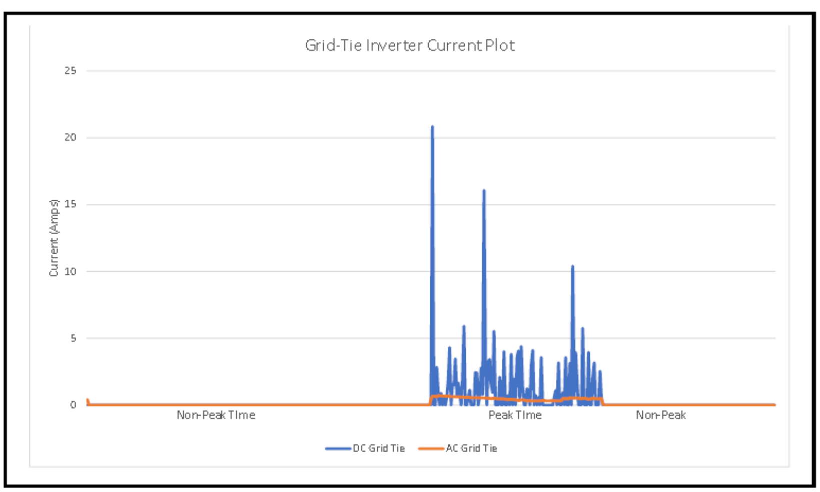

Fig. 4. AC and DC Current Plots of Grid-Tie Inverter Operating Behavior

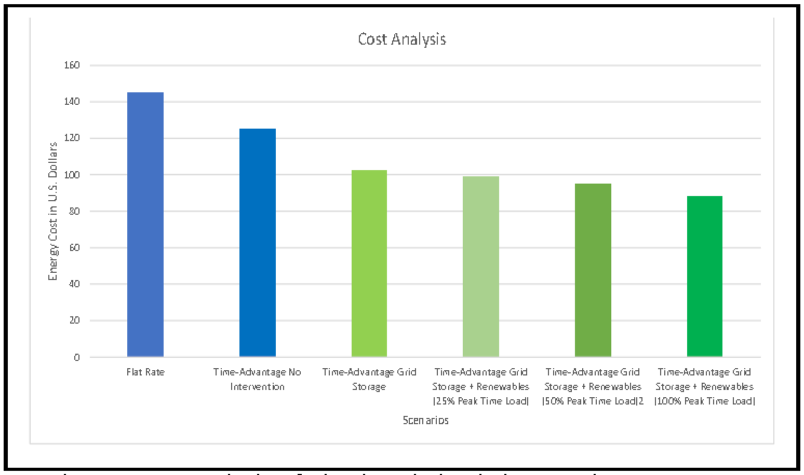

Fig. 5. Cost Analysis of Circuit and Simulation Results

VI. FINAL REMARKS

The system constructed and tested in this paper proved to provide energy cost savings under Alabama Power's Time-Advantage billing system. This system differs from other microgrids and systems as it is only concerned with a predetermined span of time throughout the day. The system has only one function; maintain load continuity during peak time without using grid energy. With this simplification of scope for the system, this allows for the systems 'work to be cut out' and condense and simplify much of the controlling software. Widespread implementation of a system such as the one developed in this paper could fundamentally reshape and redefine the demand characteristics of the current United States electric grid. It is suggested that power companies be the ones who develop and offer systems such as these for two main reasons. First, power companies can have more control on how the system operates to better fit their network's needs. Whether it be scheduling and coordinating ESS charging times to being able to ensure the system itself does not harm their networks in anyway. If a system such as this is developed by the power companies directly, the power companies can build a system they want on their networks. Second, if this system is offered by power companies, it will allow for easier financing for the customer of the initial capital investment. Easier financial accessibility will lead to more systems being added to the network.

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