IJERST

International Journal of Engineering Research and Science & Technology

ISSN : 2319-5991
Vol. 1, No. 2
April 2015

2nd National Conference on "Recent Advances in Science Engineering & Technologies" RASET 2015

Organized by

Department of EEE, Jay Shriram College of Technology, Tirupur, Tamil Nadu, India.

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International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
Special Issue, Vol. 1, No. 2, April 2015
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Research Paper

ENERGY HARVESTING IN SMART BUILDINGS

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Distributed generation (DG) uses many small onsite energy harvesting deployments at individual buildings to generate electricity. DG has the potential to make generation more efficient by reducing transmission and distribution losses, carbon emissions, and demand peaks. However, since renewables are intermittent and uncontrollable, buildings must still rely, in part, on the electric grid for power. While DG deployments today use net metering to offset costs and balance local supply and demand, scaling net metering for intermittent renewables to a large fraction of buildings is challenging. In this paper, we explore an alternative approach that combines market-based electricity pricing models with on-site renewables and modest energy storage (in the form of batteries) to incentivize DG. We propose a system architecture and optimization algorithm, called Green Charge, to efficiently manage the renewable energy and storage to reduce a building's electric bill. To determine when to charge and discharge the battery each day, the algorithm leverages prediction models for forecasting both future energy demand and future energy harvesting. We evaluate Green Charge in simulation using a collection of real-world data sets, and compare with an oracle that has perfect knowledge of future energy demand/harvesting and a system that only leverages a battery to lower costs (without any renewables). We show that Green Charge's savings for a typical home today are near 20%, which are greater than the savings from using only net metering

Keywords: Smart Grid, Energy storage, Peak Shaving, Renewable Energy

INTRODUCTION

In recent years, there has been an increase in the use of renewable energy due to the growing concern over the pollution caused by fossil fuel based energy. The increase in renewable energy systems with various sources becomes greater than before. There is an enormous need for integrated power converters that are capable of interfacing and controlling several power terminals with low cost and compact structure. Renewable energy sources such as wind, solar, fuel cells hold more potential to meet our energy demand. A large proportion of the world's population lives in remote rural areas that are geo graphically isolated and sparsely populated. Renewable energy sources such as photovoltaic (PV) can be used to enhance the safety, reliability, and sustainability and

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transmission efficiency of a power system. In this way renewable energy sources do not have the high external cost and social issues of the alternates. Renewable energy resources will be an increasingly important part of power generation in the new millennium.

Today Buildings consume more energy (41%) than either of society's other broad sectors of energy consumption— industry (30%) and transportation (29%) . As a result, even small improvements in building energy efficiency, if widely adopted, hold the potential for significant impact. The vast majority (70%) of building energy usage is in the form of electricity, which, due to environmental concerns, is generated at "dirty" power plants far from population centers. As a result, nearly half (47%) of energy use in residential buildings is lost in electricity transmission and distribution from far-away power plants to distant homes. An important way to decrease both T&D losses and carbon emissions is through distributed generation (DG) from many small on-site renewable energy sources deployed at individual buildings and homes.

DG primarily relies on solar panels and wind turbines that generate electricity intermittently based on uncontrollable and changing environmental conditions. Large base load power plants that produce the majority of grid energy are simply not agile enough to scale their own generation up and down to offset significant fractions of renewable generation. Thus far, current laws have not been an issue, since today's energy prices do not make DG financially attractive enough to reach even these low state caps. However, more widespread adoption of DG is critical to meeting existing goals for increasing the fraction of environmentally-friendly renewable energy sources. Given current laws, if and when DG becomes more widespread, buildings will have to look beyond net metering to balance on-site energy generation and consumption, while also reducing DG's costs. We envision consumers using a combination of on-site renewable, on-site battery-based energy storage, and the electric grid to satisfy their energy requirements, while also balancing local supply and demand.

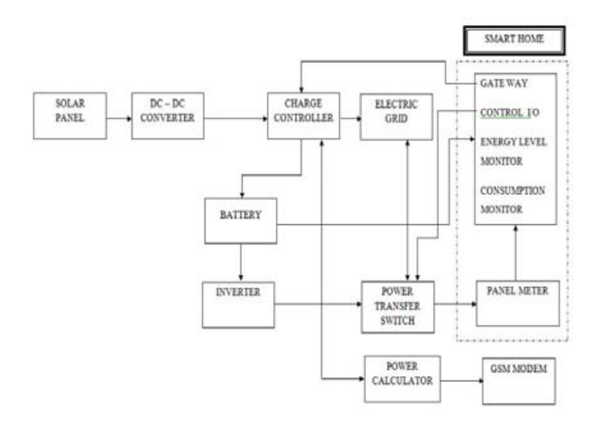
Many utilities are transitioning from conventional fixed-rate pricing models, which charge a flat fee per kilowatt-hour (kWh), to new market-based schemes, e.g., real-time or time of-use pricing, which more accurately reflect electricity's cost by raising and lowering prices during peak and off-peak periods, respectively. For instance, Illinois already requires utilities to provide residential customers the option of using hourly electricity prices based directly on wholesale prices, while Ontario charges residential customers based on a time-of-use scheme with three different price tiers (off-, mid-, and on-peak) each day.

PROPOSED SYSTEM GREEN CHARGE CONTROL

Greencharge Architecture

Green Charge's architecture, which utilizes a power transfer switch that is able to toggle the power source for the home's electrical panel between the grid and a DC! AC inverter connected to a battery array. On-site solar panels or wind turbines connect to, and charge, the battery array. A smart gateway server continuously monitors Electricity prices via the Internet, Household consumption via an in panel energy monitor, Renewable generation via current transducers, the battery's state of charge via voltage sensors.

Figure 1: Green Charge Architecture



Our Smart Charge system, which we compare against n this work, utilizes the same architecture, but does not use renewables. Before the start of each day, the server solves an optimization problem based on the next day's expected electricity prices, the home's expected consumption and generation pattern, and the battery array's capacity and current state of charge, to determine when to switch the home's power source between the grid and the battery array. The server also determines when to charge the battery array when the home uses grid power. In §VI, we provide a detailed estimate of Green Charge's installation and maintenance costs based on price quotes for widely-available commercial products.

The primary inputs The battery's current energy level ,A prediction of future solar/wind energy generation, A prediction of future energy consumption patterns, Market-based electricity prices. The output is the amount of power to consume from the grid, as well as the power to discharge or charge the battery from renewables or the grid, over each rate period.

CHARGE CONTROLLER

Charge controllers are sold to consumers as separate devices, often in conjunction with solar or wind power generators, for uses such as RV, boat, and off-the-grid home battery storage systems. In solar applications, charge controllers may also be called solar regulators. Some charge controllers / solar regulators have additional features, such as a low voltage disconnect (LDV), a separate circuit which powers down the load when the batteries become overly discharged. A series charge controller or series regulator disables further current flow into batteries when they are full. A shunt charge controller or shunt regulator diverts excess electricity to an auxiliary or "shunt" load, such as an electric water heater, when batteries are full.

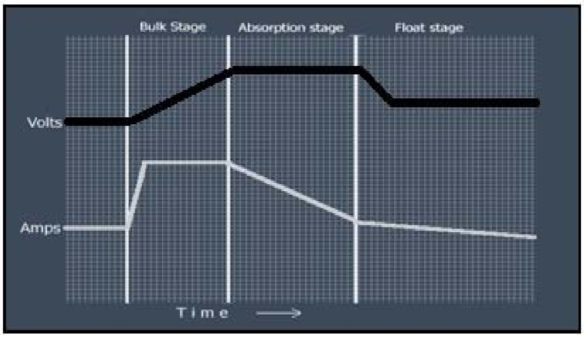
Simple charge controllers stop charging a battery when they exceed a set high voltage level, and re-enable charging when battery voltage drops back below that level. Pulse width modulation (PWM) and maximum power point tracker (MPPT) technologies are more electronically sophisticated, adjusting charging rates depending on the battery's level, to allow charging closer to its maximum capacity.

Charge controllers may also monitor battery temperature to prevent overheating. Some charge controller systems also display data, transmit data to remote displays, and data logging to track electric flow over time. Charge Controller is necessary. Since the brighter the sunlight, the more voltage the solar cells produce, the excessive voltage could damage the batteries. A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array rises, the charge controller regulates the charge to the batteries preventing any overcharging.

The Charge Controller is installed between the Solar Panel array and the Batteries where it automatically maintains the charge on the batteries using the 3 stage charge cycle just described. The Power Inverter can also charge the batteries if it is connected to the AC utility grid or in the case of a standalone system, your own AC Generator. Charge regulators are the link between the PV modules, battery and load. They protect the battery from overcharge or excessive discharge. Charge and discharge voltage limits should be carefully selected to suit the battery type and the operating temperature. These settings can significantly affect maximum operational life of a battery.

The relationship between the current and the voltage during the 3 phases of the charge cycle can be shown visually by the graph below.

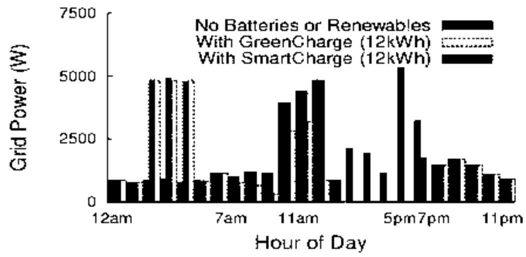
Figure 2: The Relationship Between The Current And The Voltage During The 3 Phases Of The Charge Cycle



GREENCHARGE ALGORITHM

Green Charge cuts electricity bills by combining on-site renewable generation with energy storage that stores energy during low-cost periods for use during high-cost periods. As discussed in §I, Green Charge extends our Smart Charge system that only uses energy storage to cut electricity bills without renewables. The total possible savings each day is a function of both the home's rate plan and its pattern of generation and consumption. Throughout the paper, we use power data from a real home we have monitored for the past two years as a case study to illustrate Green Charge's potential benefits.

Figure 3: Example from January 3rd with and without Green Charge using Illinois prices from Figure 7.2

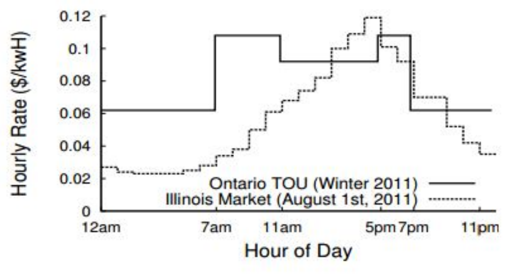


Market-based Electricity Pricing

Most utilities still use fixed-rate plans for residential customers that charge a flat fee per kilowatt-hour (kWh) at all times. In the past, market-based pricing plans were not possible, since the simple electromechanical meters installed at homes had to be read manually, e.g., once per month, and were unable to record when homes consumed power. However, utilities are in the process of replacing these old meters with smart meters that enable them to monitor electricity consumption in real time at fine granularities, e.g., every hour or less. As a result, utilities are increasingly experimenting

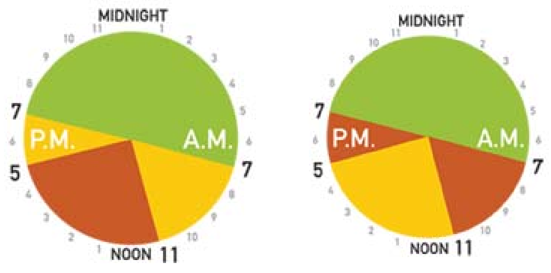
with market-based pricing plans for their residential customers. To cut electricity bills, Green Charge relies on residential market based pricing that varies the price of electricity within each day to more accurately reflect its cost. We expect many utilities to offer such plans in the future. There are multiple variants of market-based pricing. Figure 4 shows rates over a single day for both a time-of-use (TOU) pricing plan

Figure 4: Example TOU and Hourly Market-based Rate Plans in Ontario



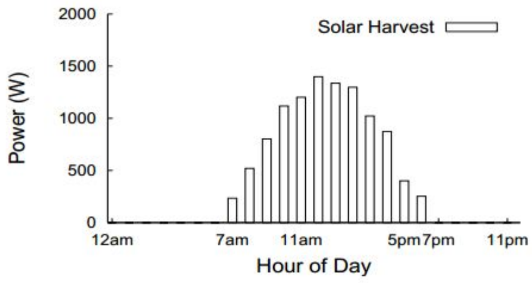
used in Ontario, and a real-time pricing plan used in Illinois. TOU plans divide the day into a small number of periods with different rates. The price within each period is known in advance and reset rarely, typically every month or season.

Figure 5: TOU On Summer and Winter



For example, the Ontario Electric Board divides the day into four periods (7pm-7am, 7am-11am, 11am-5pm, and 5pm-7pm) and charges either a off-peak-, mid-peak, or on-peak rate each period. However, while TOU pricing more accurately reflects costs than fixed-rate pricing, it is not truly market-based since actual prices vary continuously based on supply and demand.TOU pricing is a compromise between fixed-rate pricing and real-time pricing, where prices vary each hour (or less) and reflect the true market price of electricity. Unfortunately, real time pricing complicates planning. Since prices may change significantly each hour, consumers must continuously monitor prices and adjust their daily routines, which may now have different costs on different days. There are many possible ways for Green Charge's gateway server to monitor prices in real time.

Figure 5: Example solar harvest data from a day in August



In this case Green Charge's gateway server could interact with a building's local smart meter to discover prices. When using smart meters, utilities could disseminate prices using the smart meter's communication protocol, e.g., often cellular wireless or wired power line, rather than the public Internet. In transactive control, responsive demand assets are controlled by a single, shared, price-like value signal. It defines a hierarchical node structure and the signal path through these nodes, and includes the predicted day-ahead price values.

Potential Benefits

To better understand Green Charge's potential for savings, it is useful to consider a worst-case scenario where 100% of the home's consumption occurs during the day's highest rate period. Figure 7.5 then compares Green Charge using renewable production from Figure 3.3 with a home has only energy storage but not renewables (labeled Smart Charge), and home with no energy storage or renewables. To understand why energy consumption and generation patterns are important, consider the following scenario using the Ontario TOU pricing plan.

In Ontario, while Green Charge may fully charge its battery array during the lowest rate period (7pm-7am), it may also consume that stored energy during the day's first high 5 rate period (7am-11am). If the home expects to consume at least the battery array's entire usable capacity, even when accounting for renewable generation, during the day's second high rate period (5pm-9pm), it is cost-effective, assuming ideal batteries, to fully charge the batteries during the mid-rate period (11am-5pm) when electricity costs are 17% less than in the high rate period. In this case, charging the battery more than 20% wastes money. Introducing more price tiers, as in real-time markets, complicates the problem further. As a result, we frame the problem of minimizing the daily electricity bill as a linear optimization problem.

Problem Formulation

While batteries exhibit numerous limitations (e.g., charging rate, capacity), inefficiencies (e.g., energy conversion efficiency, self-discharge), and non-linear relationships (e.g., between capacity, lifetime, depth of discharge, discharge rate, ambient temperature, etc.), Green Charge's normal operation places it at the efficient end of these relationships. The system mostly charges the battery once a day during the night, which prevents stratification and extends battery lifetime by limiting the number of charge-discharge cycles.

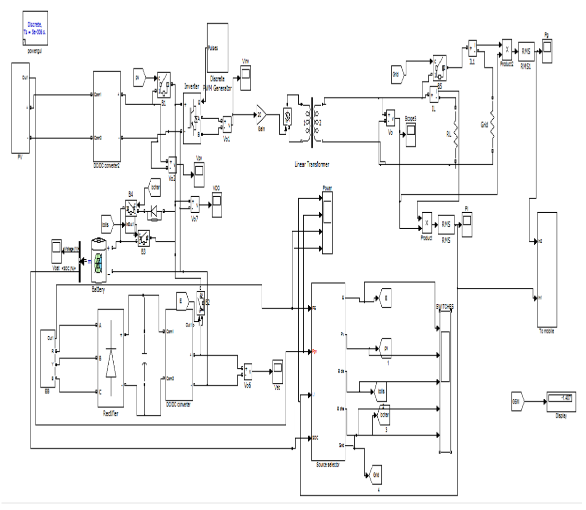
Additionally, depth of discharge (DOD) for sealed lead-acid batteries impacts their lifetime, i.e., the number of charge-discharge cycles, due to the crystallization of lead sulfate on the battery's metal plates. In our evaluation, we find that a DOD of 45% minimizes battery costs by balancing lifetime with usable storage capacity for a typical battery designed for home photovoltaic (PV) installations, e.g., the Sun Xtender PVX-2580L. The ambient temperature and rate of discharge also have an impact on usable capacity,

A discharge rate higher or lower than C/20 results in less or more usable capacity, respectively. Finally, sealed lead-acid batteries are capable of fast charging up to a C/3 rate, i.e., charges to full capacity in three hours. The objective is to minimize a home's electricity bill using a battery array with a usable capacity of C kWh.

EXPERIMENTAL RESULTS

The following model has been created using SIMULINK Fig.4 shows MATLAB model energy harvesting in smart buildings powered via a solar panel. This model contains renewable solar energy source, H- Bridge inverter, charge controller, Dc- Dc converter, Battery, Single phase inverter, zero comparator, GSM Modem

Figure 7: Simulink Model of Energy Harvesting In Smart Buildings



An experimental prototype can be developed to verify this theoretical value based on the design specified earlier.

The waveforms based on these calculations are shown as follows

Fig 8 shows the input voltage of 24V, which is obtained from solar mppt. As was previously explained, MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array.

Fig. 9 shows the output power is depend on the Input of Solar energy. The DC voltage is converting the AC voltage by the H-Bridge Inverter. Its generates the square Wave. The Square wave is convert sine wave by using the step up transformer. The output voltage is step up and the output power is used for Home appliances.

The switching ‘operation proposed model is the Availability of solar and Electricity, operation Battery charging and Discharging. Grid Supply as shown in this Fig 10

The proposed model of the power waveform as shown in Fig 11. In this waveform shows Amount of Solar power utilization, Output power

Figure 8: Input Voltages

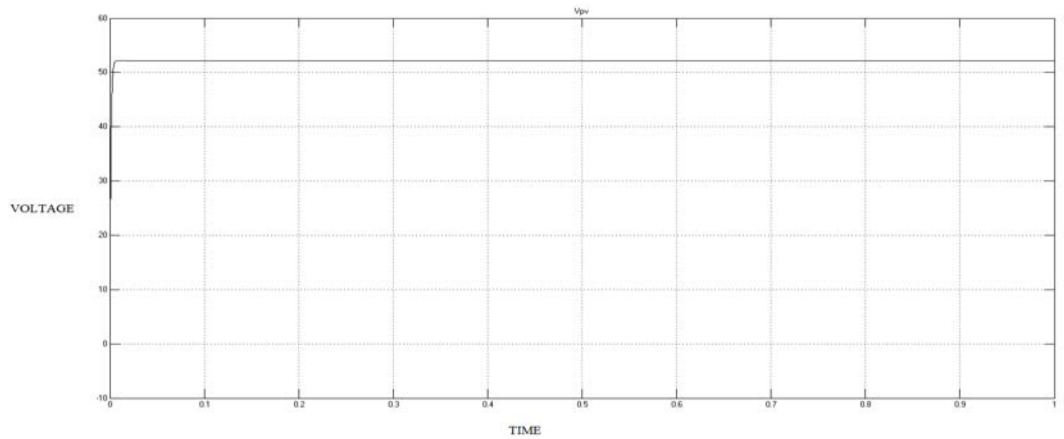


Figure 9: Output Power of the Proposed Model

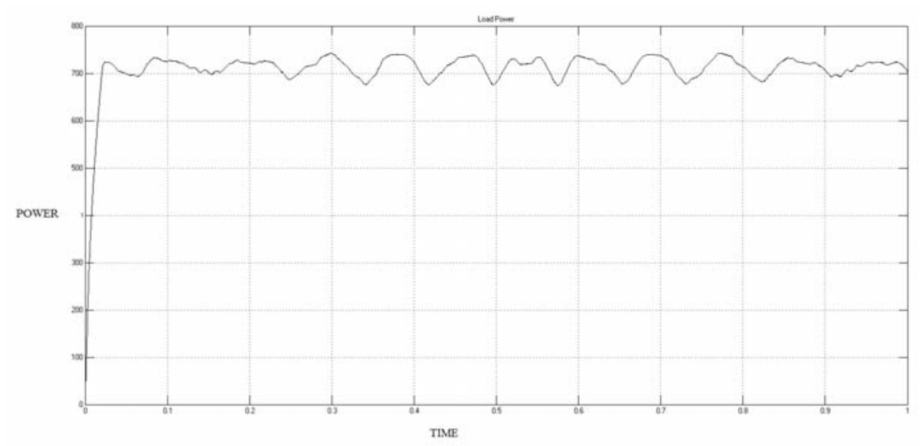


Figure 10: Operation of switches the Proposed Model

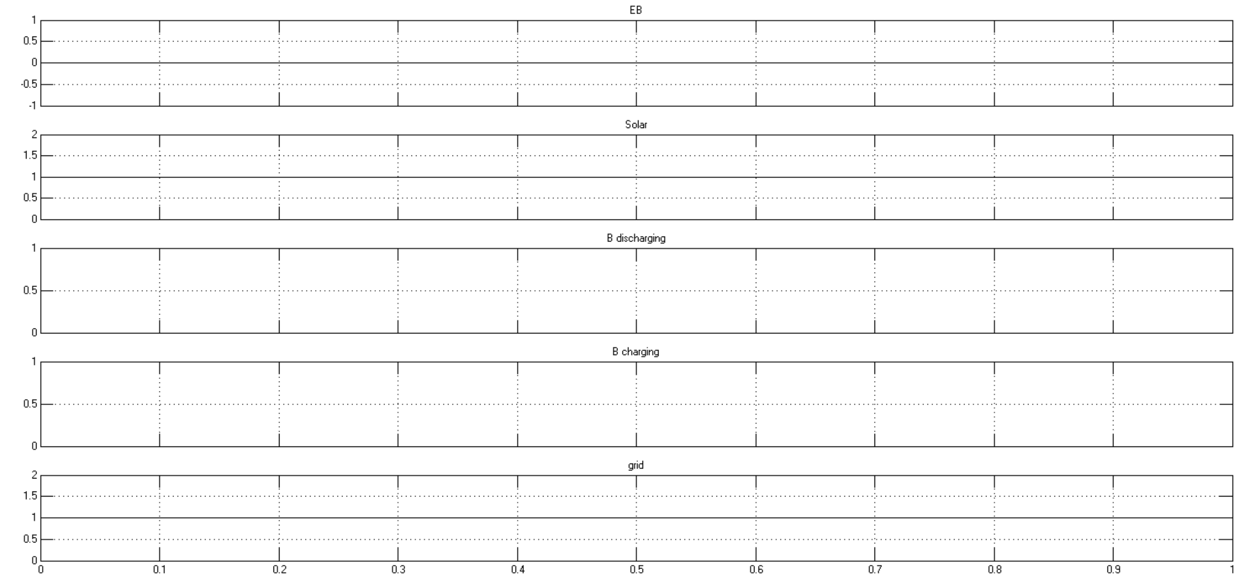
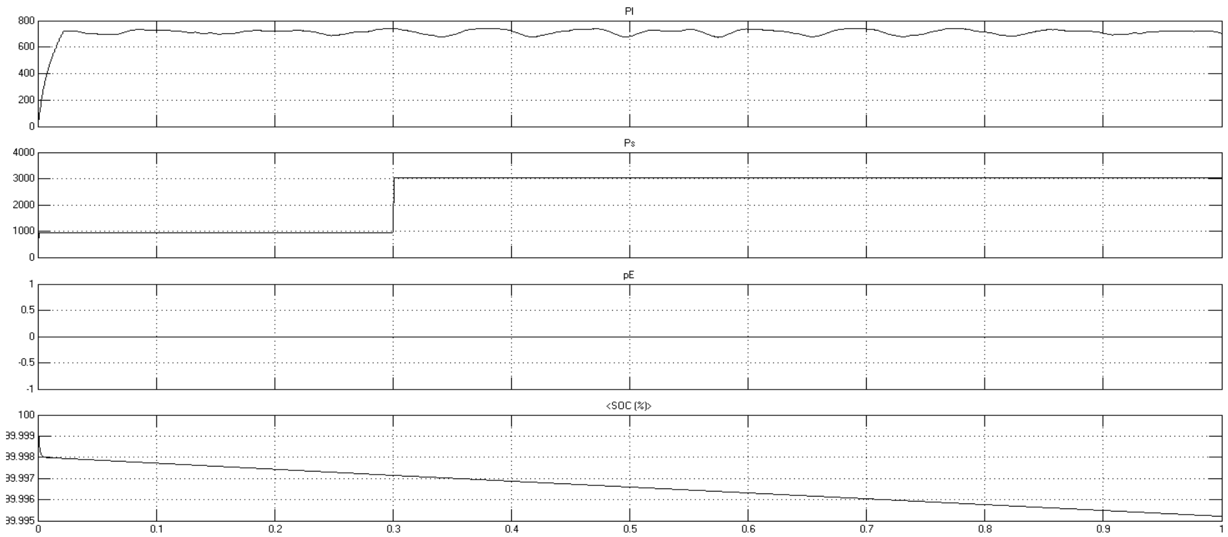


Figure 12: Usage of Power the Proposed Model



of the model, Amount of Utilization of Electricity, SOC Period of Battery

CONCLUSION

In this paper, we explore how to lower electric bills using Green Charge by storing low-cost energy for use during high cost periods. In addition, we also conduct experiments to analyze the peak reduction effects of energy storage in the grid using real data, as well as analyze the ROI for installing and maintaining the system. Finally, we include renewables into the system, as well as use a model for predicting renewable generation, which has not been considered in prior work to the best of our knowledge We show that typical savings today are near 20% per home with the potential for significant grid peak reduction (20% with our data). Finally,

Simulation shows that the proposed algorithm is very robust. In addition, its computational complexity is low and easy to implement. With the proposed algorithm, improve the Electricity and reduced the cost. Green Charge is proposed in this paper is accurate and effective and has a good theoretical and practical application potential. The result of this property would be the increase usage of renewables and reduced the Electricity bills . This system is suitable for Home and industrial applications.

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ISSN 2319-5991