DRAFT

Proceedings of the ASME 2013 7th International Conference on Energy Sustainability &
11th Fuel Cell Science, Engineering and Technology Conference
ESFuelCell2013
July 14-19, 2013, Minneapolis, MN, USA

ES-FuelCell2013-18248

# ECONOMIC ANALYSIS OF SOLAR PV AND BATTERIES FOR COMMON RESIDENTIAL ELECTRICITY RATE STRUCTURES USING GREEN BUTTON DATA

**Mithun Mohan Nagabhairava**
Industrial Assessment Center
Department of Renewable and Clean Energy
University of Dayton
300 College Park, Dayton, OH 45469-0238
O: (937)-229-3343
F: (937)-229-4766
nagabhairavam1@udayton.edu

**Yin Ma**
Industrial Assessment Center
Department of Mechanical and Aerospace Engineering
University of Dayton
300 College Park, Dayton, OH 45469-0238
O: (937)-229-3343
F: (937)-229-4766
may001@udayton.edu

**Kelly Kissock, Ph.D, P.E.**
Chair / Director
Department of Mechanical and Aerospace Engineering
University of Dayton
300 College Park, Dayton, OH 45469-0238
kkissock@udayton.edu

## ABSTRACT

Put abstract text here.

## INTRODUCTION

### Overview

Utilities are increasingly offering a diverse choice of rate structures in an effort to capture the deregulated market. Simultaneously, residential consumers are embracing novel approaches to realize energy cost savings including renewable energy generation and energy storage devices. In this quest, consumers are aided by the increasing availability of high time-resolution energy use data of their residences such as Green Button data. This paper investigates how to use Green Button data in conjunction with a variety of residential electric rate structures to economically evaluate different sizes of solar photovoltaic (PV) and battery systems. This method could become a smartphone “app” or a web application that would make it easy for consumers to make informed choices regarding energy cost management.

### Background

***Trend of Electricity Cost***

In the United States, electricity prices stayed relatively stable from 1985 to 2000. Since 2000, prices have risen due to rising fuel costs, increased electricity demand, higher operating costs, investments in aging transmission and distribution infrastructure, and more stringent environmental standards. In addition, many long-term contracts, rate freezes and deferred cost recovery plans for consumers are at the end of their agreement periods. These factors suggest that the cost of electricity may continue to increase over the coming years (Basheda et al., 2006).

***Electricity Rate Structures***

Electric rate structures are a combination of service charges, generation charges, and transmission and distribution charges. Regulation and deregulation policies have increased the number and the complexity of rate structures available to electrical customers (Braithwait et. al., 2007). Determining which utility rate structure results in the lowest annual cost is not straightforward for most consumers. Especially since the cost is often dependent upon geographical location, the building energy profile, the customer's flexibility to shift loads to different times of the day, etc. Common rate structures available to residential customers include:

***Flat Rate Structure:***

In a flat rate structure, each unit of electricity consumed has a fixed unit price. The price doesn't vary with increase or decrease in energy consumption of the building. Customers with this rate structure can reduce energy costs by embracing energy efficiency measures and decreasing the energy consumption, but do not have any incentive to reduce the peak demand of the building.

***Block Rate Structure:***

In a block rate structure, the price of a unit of electricity varies with different levels of consumption of the building. The two different types of block rate structures are described below:

**Declining Block Structure:**

The price of a unit of electricity under this block structure decreases with increased levels of consumption. In other words, a declining block structure charges higher electricity prices for the initial quantity of electricity consumed and less for the subsequent consumption. This type of rate structure is preferable for large residential energy consumers.

**Inclining Block Structure:**

The price of a unit of electricity under this block structure increases with increased levels of consumption. In other words, an inclining block structure charges lower electricity prices for the initial quantity of electricity consumed and more for subsequent consumption. This block structure is also referred to as "Inverted Block Structure". This type of rate structure promotes energy conservation.

***Time-of-use Rate Structure:***

Time-of-use (TOU) rates are primarily based on the time of the day during when the electricity is consumed and the amount of electricity consumed over the entire billing period. Electricity prices in this rate structure are predefined in tiers for different time periods of the day such as on-peak, partial peak and off-peak. This rate structure emphasizes the importance of the timing of energy consumption along with the amount of energy consumed.

***Real-time pricing Rate Structure:***

In real-time pricing (RTP), the unit cost electricity varies dynamically during each hour of the day in response to the utility's cost of generating or purchasing electricity. Unlike a TOU rate structure, the costs are not predefined. This rate structure is beneficial for customers who can shift their electrical loads according to the varying prices of electricity.

***Seasonal Flat Tariff Rate Structure:***

In a seasonal flat tariff rate structure, the year is divided into two or more seasons and the cost of electricity is set at different fixed unit prices for the different seasons. Customers with this rate structure can reduce energy costs by focusing on energy efficiency measures applicable to the season with the highest unit energy costs. For example, if costs are higher in the summer, measures such as investing in energy efficient air conditioners are especially cost effective.

***Tariffs with Demand Charges:***

In tariffs with demand charges, the total cost is the sum of the service charge, energy charge and demand charge. The energy charge is based on the total consumption over a billing period. The demand charge is based on the highest rate at which the electricity is consumed over a 15 or 30 minute interval. This rate structure favors consumers with more uniform electrical loads throughout the day.

As this summary of rate structures illustrates, the least-cost rate schedule depends on a customer's energy use patterns and ability to adapt those patterns. For customers who are considering adding a PV system, the choice becomes even more complicated due to the variance and time-dependent nature of solar electricity generation and how the utility treats solar electricity in their billing structure.

***Net Metering***

Traditional electricity meters are only capable of reading the electricity consumption of a building on a billing cycle basis, usually 27-33 days. With the advent of smart meters, utilities are now able to record the electricity consumption on an hourly or a 15-minute scale, thus providing customers with detailed information about their electricity bills. For buildings equipped with renewable energy sources, these meters are capable of accurately recording the electricity flow in both directions on the hourly or 15-minute time scale. Traditional meters turn forward when electricity is consumed from the grid and backwards when energy generated in excess of the building's demand is fed back into the grid; thus they can only measure the net energy use or generation over the billing cycle.

For buildings with onsite renewable energy sources, net electricity consumption is calculated by deducting the onsite renewable energy generation from a building's total energy consumption. Thus, both traditional and smart meters can calculate net electricity consumption or generation. This is often referred to as "net metering". Under the Energy Policy Act of 2005, all electricity utilities are now required to offer net metering service upon customer's request [1]. All though most states allow net metering, policies and requirements vary from state to state. These policies include Renewable Portfolio Standards (RPS), tax incentives, rebates or low-interest loans.

Net metering is playing a primary role in encouraging customers to embrace renewable energy sources since most utilities only reimburse the customer for the wholesale price of electricity generated and fed back into the grid rather than the retail price of electricity charged for electricity purchased from the grid. Without net metering all excess electricity generated by the renewable energy system and fed back into the grid is priced at wholesale rather than retail price of electricity. With net metering only the excess electricity generated by the renewable energy system and fed back into the grid at the end of a billing period is priced at the wholesale rather than retail price of electricity. Thus, net metering makes onsite generation of renewable energy much more cost attractive to a consumer, especially if the system is sized to minimize or eliminate electricity fed back into the grid at the end of the billing period.

According to the electricity monthly update released on January 23, 2013 by U.S Energy Information Administration (EIA), "Electricity consumers are participating in net-metering programs in growing numbers. Between 2003 and 2010, the average annual growth in customer participation was 56%. PV solar capacity in 2011 increased by 71% from 2010 as the number of customers rose by 45%. State policies and technological developments have been the main factors in the increased participation rates. While advances in the PV market are driving the pay-back period down for everyone, individual state policies and incentives also influence the number of customers with PV. As of 2011, every state plus the District of Columbia reported net-metered customers. Five states accounted for nearly three-quarters of the capacity and customers, with California being the clear leader in both categories." (U.S. EIA, 2013)

***Green Button Data***

Green Button data is a recent addition to the information available to electricity consumers, built upon policy objectives from the federal government and embraced by few in the energy industry, to help consumers navigate the increasingly complex energy management strategies. Green Button data is hourly or 15-minute interval electricity and cost data made available to residential and business customers in a computer friendly format. As of February 8th 2013, seven utilities have implemented the functionality to provide their customers with Green Button data information, while another 27 utilities have committed to the initiative. These efforts ensure that approximately 27 million households across the United States will soon be provided with detailed energy usage information [2].

With Green Button data, customers can download hourly energy usage and cost data for a year or more from a utility website. The idea is to facilitate customers with the ability to use web and smartphone tools and make smart decisions to save energy and costs and reduce carbon footprint. Another goal of the Green Button initiative is to standardize the energy data information to customers in a common format, thus helping software developers focus more on creative analytic tools rather than adapting to different data formats. Green Button data is usually provided in Extensive Markup Language (XML) and in text document (txt) formats [2].

***Solar PV and Incentives***

Solar PV installed prices have been falling and continue to fall through 2011, due to decreases in both modular prices and non-modular costs. In 2011, the median installed price was $6.1/W for systems of 10kW or less and $5.6/W for larger systems (Barbose et. al., 2012). Among the growing number of consumers embracing net-metering, solar PV technology is the dominant choice, accounting for 93% of all net-metering capacity and 97% of all net-metering customers (U.S. EIA, 2013).

One of the key advantages of solar PV systems is their time-correlation with peak electrical demand (Denholm and Margolis, 2007). In many parts of the United States, peak electrical demand occurs during summer afternoons due to air-conditioning loads. For customers with a TOU rate structure, solar PV becomes even more attractive because the system can be sized to meet all or part of the on-peak loads, thereby offsetting the most expensive electricity purchased from the grid. The economic analysis of installing various capacities of solar PV systems for customers with TOU rate structure is discussed in detail in the later sections of this paper.

The success of the solar PV market in the United States crucially depends upon government incentives in the form of cash rebates, renewable energy credits (SRECS), renewables portfolio standards, and federal and state tax benefits. In addition, the SunShot Initiative by the U.S. Department of Energy (DOE) aims to reduce the cost of PV-generated electricity by 75% between 2010 and 2020. However, cash incentives and SRECS have been declining, and are currently about 20% of their historical peak (Barbose et. al., 2012).

***Solar PV and Rate Structures***

The number and the complexity of the residential rate structures is making it increasingly complex for consumers to determine the economics of onsite solar PV. A growing body of literature addresses the impact of rate structures on the economic performance of residential and commercial solar PV systems. For example, in an effort similar to this one, Borenstein (2007) studied the impacts of residential TOU and flat rate structures in California on the economics of solar PV. Ong et al. (2010) studied the impacts of commercial rate structures on the economics of solar PV. They concluded that for commercial buildings with solar PV, TOU tariffs and seasonal flat tariffs with higher prices in summer result in greater annual savings than flat rates.

This paper adds to the literature by proposing a methodology to analyze the economics of solar PV and battery systems using Green Button in conjunction with different residential electric rate structures. The methodology includes software to extract key data from Green Button data, synthesize hourly weather and solar data from measured average daily temperatures, simulate hourly solar and battery performance, and quantify energy costs using different rate structures.

The method is applied to Green Button data from a large residential building in Sacramento, CA. However, the average annual electricity consumption for a typical U.S. residential customer is considerably less [3]. Therefore, a scaled dataset for a typically sized building is also presented. The method is used with the time-of-use, inverted-block and flat rate structures from Pacific Gas and Electric Company (PG&E).

## METHODOLOGY

Figure 1 shows a block diagram representation of the proposed methodology. The function of each component is explained below.

1. The "GreenButtonDataReader" module obtains the hourly electricity consumption and costs, the electric rate structure and the location of the building from the Green Button data. The Green Button data is in XML file format. The Green Button data file used in this case study is for a large residential building in Sacramento, CA which is serviced by PG&E [4].
2. The ESim (Kissock, xxxx) module synthesizes hourly temperature and solar radiation data from average daily temperature and TMY3 data. The average daily temperature data is obtained from an archive maintained by the University of Dayton that posts average daily temperature for over 300 cities across the world from 1995 to present [5]. Typical Meteorological Year 3 (TMY3) data is obtained from the National Solar Radiation Database [X]. The method used to synthesize hourly solar and temperature data from average daily temperartures is described in (Kissock and Joseph, 1999).
3. The SolarSim (Kissock, xxxx) module simulates hourly solar PV production for various system capacities in a given location.
4. The "NetAnnualEnergyCalculator" module calculates net annual energy costs of buildings with different rate structures using output from the Green Button Data Reader, output from SolarSim and rate schedule information [X].
5. The "Economics Calculator" module determines return on investment and simple payback based on installation costs. Installation costs, incentives and rebates for solar PV systems are obtained from "Tracking the Sun V" report (Barbose et. al., 2012).Installation costs for battery systems are based on the battery purchase made by Sinclair Community College from a local battery supplier "Piqua Batteries" in Piqua, OH.

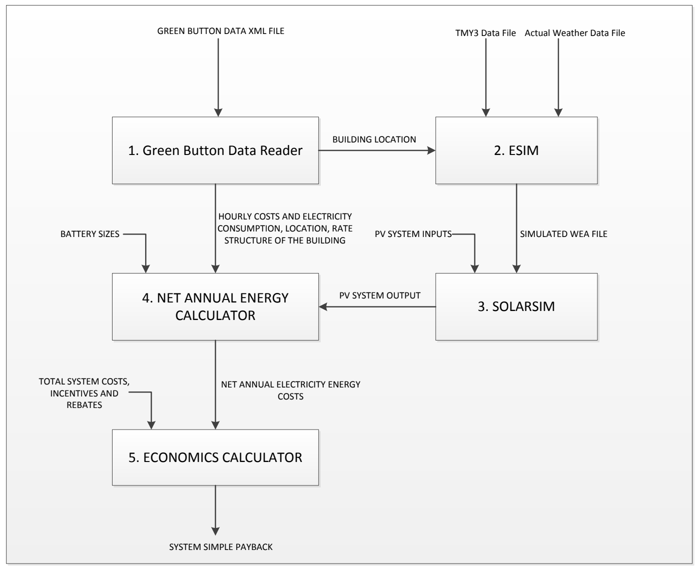

Figure 1: Overview of methodology

## RATE STRUCTURES, COSTS, INCENTIVES AND REBATES

This case study considers time-of-use and inverted-block rate structures from PG&E and a standard flat rate structure.

The TOU rate structure specifies a monthly baseline, dependent on customer location, upon which a successively more expensive block structure is applied. The block structure also includes a division of peak, partial-peak and off-peak rates based on the time of the day of electricity consumption. Further, this block structure is applied differently in the summer than in the winter. The details of this TOU rate structure are shown in Table 1.

Table 1: PG&E TOU (E6) rate breakdown for summer and winter months

| *PG&E Electric Schedule E6, Code B* | | | |
|---|---|---|---|
| **Summer**: May 1 through Oct 31 | | | |
| Baseline Usage (15.3 kWh/day) | Total Rates ($/kWh) | | |
| | **Peak** | **Partial-Peak** | **Off-Peak** |
| | 1pm -7pm Monday to Friday | 10am - 1pm & 7pm – 9pm - Monday to Friday 5pm – 8pm - Saturday & Sunday | All other times including holidays |
| Up to 100% | 0.27883 | 0.17017 | 0.09781 |
| 101% - 130% | 0.2964 | 0.18775 | 0.11538 |
| 131% - 200% | 0.44653 | 0.33788 | 0.26551 |
| Over 200% | 0.48653 | 0.33788 | 0.30551 |
| **Winter**: Nov 1 through Apr 30 | | | |
| Baseline Usage (15.3 kWh/day) | Total Rates ($/kWh) | | |
| | **Peak** | **Partial-Peak** | **Off-Peak** |
| | N.A | 5pm – 8pm Monday to Friday | All other times including holidays |
| Up to 100% | - | 0.11776 | 0.10189 |
| 101% - 130% | - | 0.13533 | 0.11947 |
| 131% - 200% | - | 0.28546 | 0.26959 |
| Over 200% | - | 0.32546 | 0.30959 |
| Total Meter Charge Rate : | $0.25298 per day | | |
| Total Minimum Charge Rate: | $0.14784 per day | | |

The Inverted Block rate structure specifies a monthly baseline, dependent on customer location, upon which a successively more expensive block structure is applied. The details of this Inverted Block rate structure are shown in Table 2.

Table 2: PG&E Inverted Block (E1) rate breakdown

| *PG&E Electric Schedule E1, Code B* | |
|---|---|
| Baseline Usage (15.3 kWh/day) | Total Rates ($/kWh) |
| Up to 100% | 0.1323 |
| 101% - 130% | 0.1504 |
| 131% - 200% | 0.30025 |
| Over 200% | 0.34025 |
| Total Minimum Charge Rate: $0.14784/day | |

The third rate structure included in this analysis is a Flat rate structure constructed to be comparable to the TOU rate structure in terms of annual electricity cost. This rate structure specifies a flat unit price of electricity independent of amount or time of usage. The flat rate in this analysis is taken to be the average billed unit price of electricity under the TOU rate structure, $0.2998 /kWh. Thus, the total annual electricity costs, by definition, are identical to the TOU rate structure.

the input parameters used in the economic analysis of solar PV systems are listed below.

- Installed price of $6.1/W for PV systems of 10 kW or less and $5.6/W for larger systems. (Barbose et. al., 2012)
- The total system cost is reduced by federal tax credits of 30% of the total implementation cost [6].
- The total system cost is reduced by state and utility rebates equal to $0.90 /W. (Barbose et. al., 2012)
- Annual system savings are increased by SRECs sold at $30 per MWh of electricity generated (Bird et. al., 2011).

## RESULTS

Plots of the PV generation profile for a 15 kW system and electricity prices under the TOU rate structure in the highest block for an average summer day and an average winter day are presented in Figures 2 and 3. The plots show a mismatch between the peak solar PV generation and the peak price times defined under the TOU rate structure. Thus, this TOU rate structure does not result in maximum cost savings for PV systems.

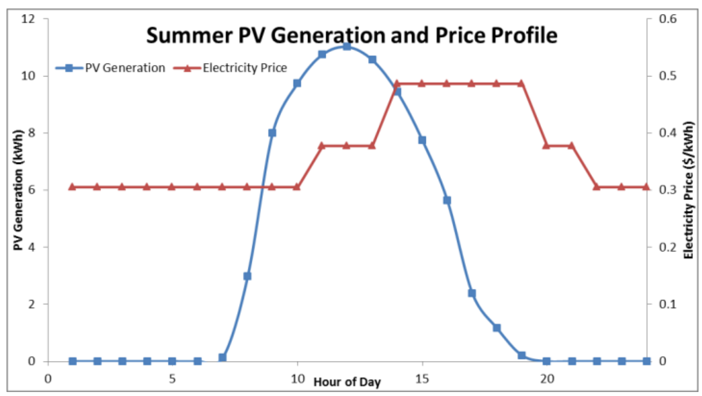


Figure 2: Correlation of TOU rate structure with solar PV production during summer months

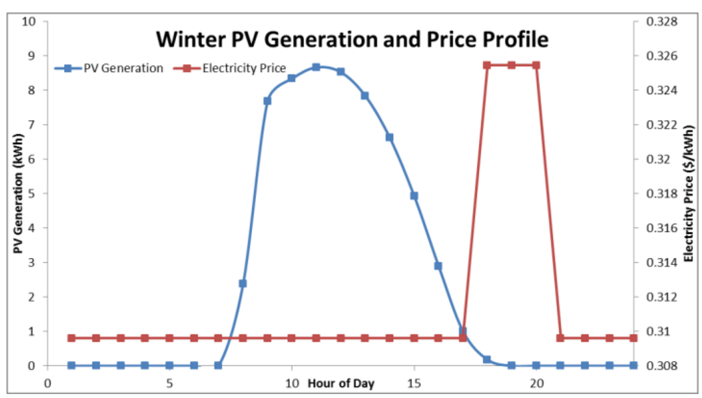


Figure 3: Correlation of TOU rate structure with solar PV production during winter months

Net electricity consumption and solar PV generation for PV systems ranging in size from 1 kW to 15 kW are shown in Figure 4. The results show that electrical generation from PV systems scales linearly with PV size. Similary, the net electricity consumption of the building decreases linearly with PV size.

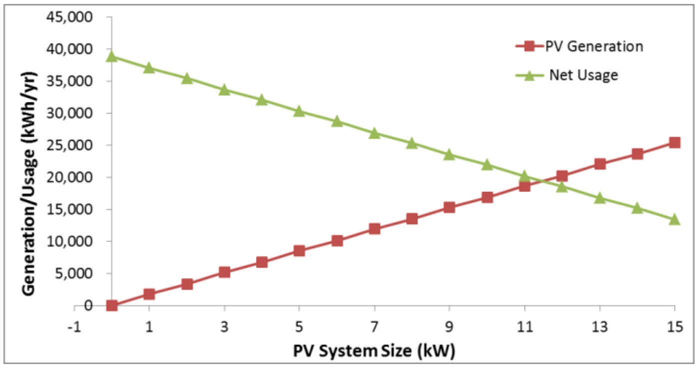


Figure 4: Solar PV Generation and Net Consumption (Base Case)

Figure 5 shows that cost savings for solar PV are virtually identical for TOU and Inverted block rate structures, and are slightly lower for the flat rate structure (Figure 5). This is because the PV system reduces consumption in the most expensive blocks under both the TOU and Inverted block rate structures.

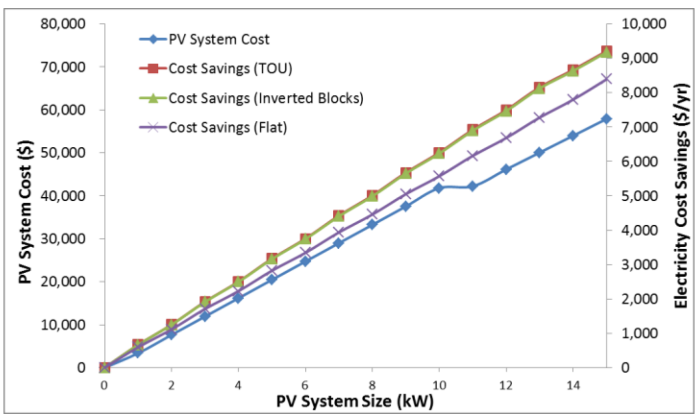


Figure 5: Annual Costs and Savings of Solar PV Installation for Common Rate Structures (Base Case)

The simple paybacks of PV installation under all three rate structures are presented in Figure 6. The simple paybacks for TOU and Inverted block rate structures are nearly identical, and consistently less than for the flat rate structure. The drop in simple payback as system sizes exceed 10 kW is because systems of 10 kW or more cost $5.6 /W compared to $6.1 /W for systems less than 10 kW.

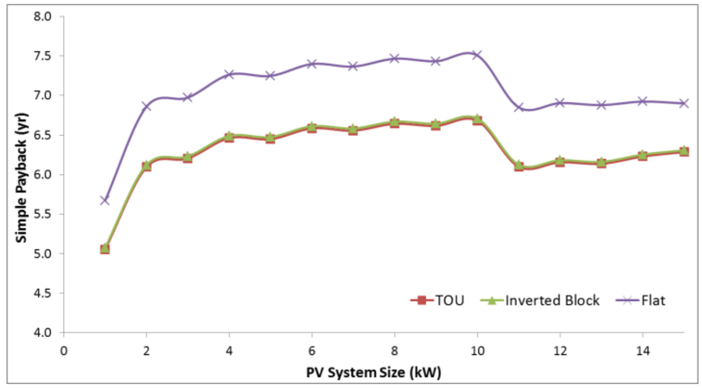


Figure 6: Simple Payback of PV systems for Common Rate Structures (Base Case)

**Typically-sized Case**

These results are somewhat dependent on the quantity of electricity consumed by the building. In this section, the same analysis is applied to a more typically sized residence that that uses 33% as much electricity as the residence with the Green Button data.

The cost and savings of PV installation for all three rate structures for a more typically sized residence are shown in Figure 7. Again, it can be observed that savings under both TOU and Inverted Block rates are similar, whereas the Flat rate results in lower savings at smaller system sizes. The slope of the savings curves for TOU and Inverted Block rates decreases continually under TOU and Inverted Blocks rate structure and remain constant under the Flat rate structure, due to the fact that additional PV capacity results in savings of electricity in increasingly less expensive blocks under the TOU and Inverted Blocks rate structures.

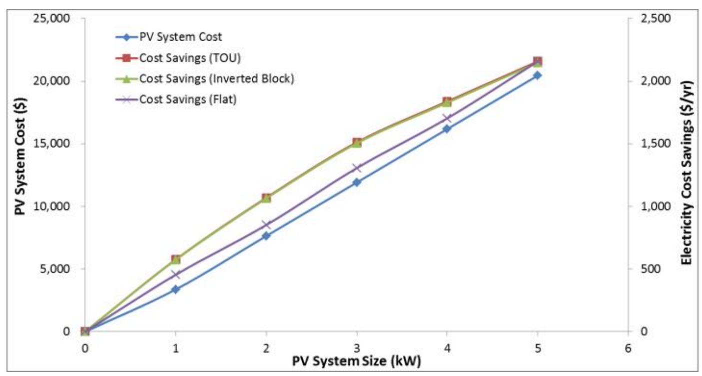


Figure 7: Annual Costs and Savings of Solar PV Installation for Common Rate Structures (Typically-sized Case)

In Figure 8, the simple payback under TOU and Inverted Block rate structures are more favorable than that under Flat rate structure, but the three quickly converge as the system size gets larger (Figure 8).

 

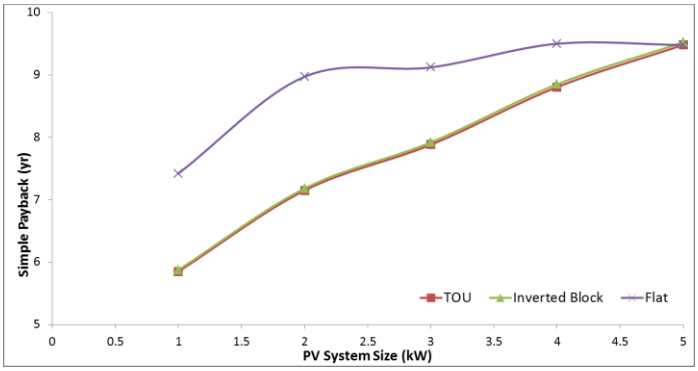

Figure 8: Simple Payback of PV systems for Common Rate Structures (Scaled Case)

**Batteries**

For customers with TOU rate structure, energy costs can be reduced by by storing energy during off-peak periods and offsetting the electricity consumption during peak periods using batteries. Assumptions used to model PV systems with batteries are:

- Inverter efficiency and state of discharge of the batteries are assumed to be 90% and 50% respectively.
- The installed price of a battery systems is $293/kWh. This price is calculated from a purchase of 8 185Ah batteries at 12 volts for $1,800 plus an additional 30% to account for non-modular costs.

The results of adding batteries to both the base case and the typically sized case are shown in Figures 10 and 11. Both Figures exhibit similar general trends; increasing the size of the PV system increases the simple payback time for any given battery size. In addition, increasing the size of the battery results in disproportionate increases in simple payback time for any PV system size. Moreover, larger energy users enjoy a lower simple payback time than smaller energy users.

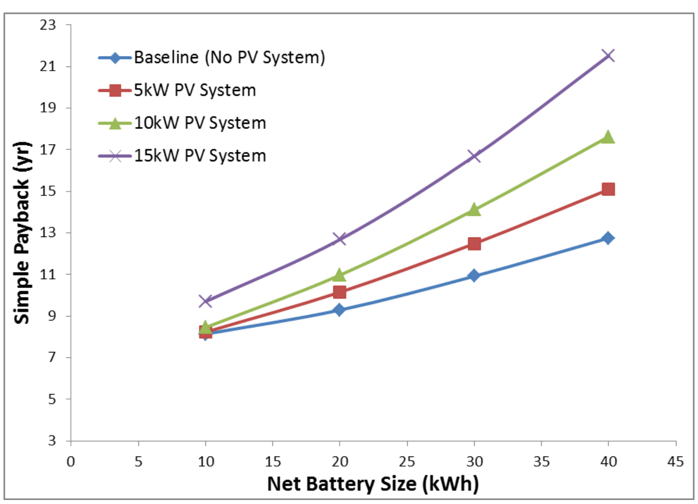

Figure 10: Simple Payback of Battery Sizing with PV system (Base Case)

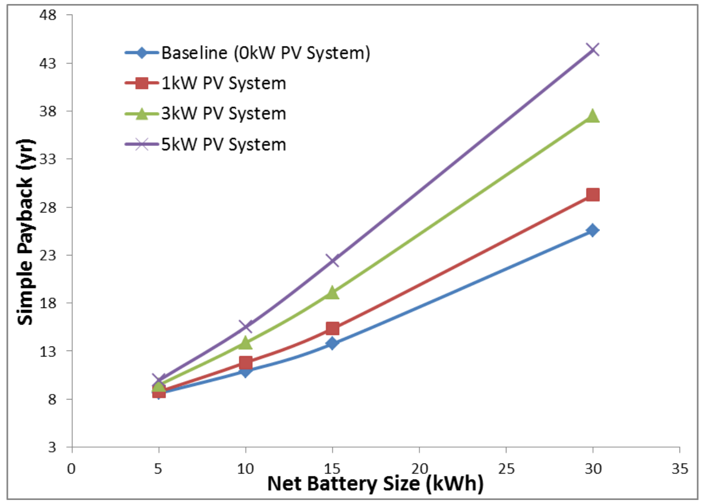

Figure 11: Simple Payback of Battery Sizing with PV system (Scaled Case)

## CONCLUSION

This paper demonstrates a methodology to help consumers integrate data shared by utilities with available software to make informed decisions about PV systems. If electricity prices continue to increase and the cost of solar PV systems continue to drop, a methodology such as this could be widely used as more customers investigate PV systems for their homes. PV system vendors could also benefit from this methodology in helping customers make informed decisions

The results of the case study indicate that the economics of PV systems are nearly identical under PG&E's TOU and Inverted Block rate structures, and are more favorable than under Flat rate structures with the same average cost per kWh. For both the large and typical size residences investigated here, simple paybacks remain well short of the typical life of PV systems. The simple payback for the addition of batteries is initially competitive with PV systems, but rises rapidly as battery size is increased.

This paper also lays the foundation for future work in related topics. The optimization of the division of financial capital among the various energy cost saving options (such as solar PV, wind turbine and batteries) for any given locations can be explored. Real-time pricing, a concept introduced in the background section of this paper, is likely to become more common in the future and would lend itself to analysis similar to that presented in this paper.

## ACKNOWLEDGMENTS

We gratefully acknowledge the support of the Department of Energy through the Industrial Assessment Program.

## REFERENCES

Ong, Sean; Denholm, P. and Doris, E., “The Impacts of Commercial Electric Utility Rate Structure Elements on the Economics of Photovoltaic Systems”, National Renewable Energy Laboratory, NREL/TP-6A2-46782, June, 2010.

Borenstein, Severin., “Electricity Rate Structures and the Economics of Solar PV: Could Mandatory Time-of-Use Rates Undermine California’s Solar Photovoltaic Subsidies?”, Center for the Study of Energy Markets, CSEM WP 172, September, 2007.

Basheda, Gregory; Chupka, W. Marc; Fox-Penner, P; Pfeifenberger, P.J and Schumacher, A., “Why are electricity prices increasing?”, The Edison Foundation, June, 2006.

Braithwait, Steven; Hansen, D. and O’Sheasy, M., “Retail Electricity Pricing and Rate Design In Evolving Markets”, Edison Electric Institute, July, 2007.

Kissock, Kelly and Joseph, H., “Synthesizing Hourly Meteorological Data To Improve The Accuracy Of Calibrated Simulation Models”, ASME International Solar Energy Conference, April, 1999.

Bird. Lori; Heeter J. and Kreycik. C., “Solar Renewable Energy Certificate (SREC) Markets: Status and Trends”, National Renewable Energy Laboratory, NREL/TP-6A20-52868, November, 2011

Barbose, Galen; Darghouth, N. and Wiser, R., “Tracking the Sun V”, Lawrence Berkeley National Laboratory, LBNL-5919E, November, 2012.

Denholm, P. and Margolis, R.., “Evaluating the Limits of Solar Photovoltaics (PV) in Traditional Electric Power Systems.”, Energy Policy (35:5); pp. 2853-2861.

U.S Energy Information Administration, Annual Electric Power Industry Report, Form EIA-861, January, 2013.

[1] Energy Policy Act of 2005:
http://en.wikipedia.org/wiki/Energy_Policy_Act_of_2005

[2] Green Button Data Initiative Adopters
http://www.greenbuttondata.org/greenadopt.html

[3] U.S Energy Information Administration, Electricity Information
http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3

[4] U.S Department of Energy Development Resources
http://energy.gov/developer-resources

[5] University of Dayton Average Daily Temperature Archive
http://academic.udayton.edu/kissock/http/Weather/default.htm

[6] DSIRE Residential Renewable Energy Tax Credit
http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US37F

Kissock, J.K., 1997. "ESim", Hourly transient building energy simulation software. Energy Information Systems, Dayton, OH.

Kissock, J.K., 1995. "SolarSim", Dynamic hourly thermal and photovoltaic system simulation software. University of Dayton, Dayton, OH.

## ANNEX A

## PUT ANNEX TITLE HERE

Put text of Annex here

Smart phone or web applications, which aim to analyze the economics of solar PV and batteries systems with different residential electric rate structures would include all the features described below.