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Modeling distributed premises-based renewables integration using HOMER

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Abstract

This paper uses the Hybrid Optimization Model for Electric Renewables (HOMER) to model a domestic power system for a single family household in Boulder, Colorado. HOMER has been used to model systems as large as the aggregate electric grid in Boulder and as small as individual premises-based power systems at the point of energy use. Premises-based power systems suited for energy management are comprised of various combinations of distributed generators, storage devices, communication gateways, energy management devices, power conditioning equipment, smart inverter/chargers, power factor compensation devices, and advanced supply/demand response techniques. With the parameters used in this study to model a household power system, a PV/grid system is a lower cost alternative to a grid-only system for three of four Xcel Energy residential solar rebate options. The cost-effectiveness of PV can be improved with increasing capital rebates, increasing renewable energy credit (REC), increasing grid electricity prices, decreasing real interest rates, and decreasing converter costs. Although a battery bank is not cost-effective until a 90% price reduction, other functions provided by a battery bank, such as improved reliability, may justify the additional cost to some consumers.

1. INTRODUCTION

Increasing electric utility rates and decreasing solar photovoltaic (PV) costs are creating a fast-growing market for residential solar power systems. This paper examines the factors that affect the economics of these systems. The understanding from this analysis is valuable for informing the political, financial, and technical decisions that support society's transition to cleaner energy. The hybrid energy system modeling software, HOMER®, is used here to model domestic energy use for a single family household in Boulder, Colorado. One of the unique features of HOMER is the ability to interactively compare the effects of many variables through sensitivity analysis. This functionality makes the software ideal for studying the factors that define the transition in cost-effectiveness between grid-only and grid/PV household power systems. A discussion of grid/PV/battery load management is provided to examine the economic value and utility of advanced power system controls.

2. BACKGROUND

In its simplest definition, energy management is the continual process of adjusting power demand and supply using manual, semi-automated, or fully automated control strategies. Energy management can accomplish multiple objectives, including reduced cost, grid stability, and other interests. Load, storage, and generation devices can be managed by a control system at the premises of energy use or at a centralized facility operated by the utility. Distributed premises-based renewable energy systems, such as household solar PV, are well-suited for premises-based energy management. Energy management can be generally categorized by the time period of the managed action:

- Arbitrage (hours): Storage is discharged or loads are shutoff to avoid peak electricity rates or demand charges. Storage is charged or loads are scheduled during low-cost or low-load periods.
- Operating reserves (minutes): Loads are shed during system emergencies to give other power

sources the time to come online and stabilize the system.
- Frequency control (seconds): Load, generation, and storage devices are balanced to maintain a stable system frequency. Energy management over small time frames is also used for inrush current and power factor compensation.

2.1. HOMER®

The HOMER energy modeling software was originally developed by NREL beginning in 1992. In 2009 HOMER Energy, LLC was awarded the exclusive license to commercialize the software. The micropower optimization modeling software assists engineers and non-technical users to compare power system configurations across a wide range of applications. HOMER models the physical behavior of the power system and quantifies the total cost of installing and operating the system over its lifespan. Its graphical user interface allows users to interactively compare design options on their technical and economic merits. HOMER performs three principle tasks: simulation, optimization, and sensitivity analysis. HOMER performs chronological simulations over a one-year period for the range of micropower systems specified by the user. HOMER then identifies the system size and control strategy with the lowest net present cost. Sensitivity analysis is used to test the effect of assumptions and input parameters on system robustness.

Current energy management capabilities in HOMER include setting price set-points for buying and selling power to the grid, and charging or discharging batteries. HOMER can also defer loads to another time of day and use excess energy for thermal loads. Additional energy management options are available for islanded power systems that must maintain their own operating reserves. A more detailed discussion of HOMER algorithms and functionality is found in [Lambert et al. 2006].

2.2. Energy management hardware

Although HOMER models energy management decisions in the computer simulation, hardware is needed in the home to realize the benefits of energy management. Figure 1 depicts a generalized home energy system architecture consisting of loads, generation sources, storage devices, a power conversion device, communication gateway, and energy management device [Schoechle 2010]. The Heart Transverter™ was selected as the power conversion device used in this study [Heart Transverter 2011] because its extensive data logging and control/monitoring capabilities, together with the gateway, make it ideal for future research in smart microgrid energy management.

A separate energy management device is needed to manage loads and plan dispatch strategies. It is included here only for discussion and not represented in the HOMER model. The household communication gateway communicates with both the utility and household devices. It makes energy management decisions between renewable energy sources, the grid, energy storage devices, and loads. Data can be stored by the gateway for later analysis in HOMER or analyzed in real-time to monitor the impact of energy management decisions.

2.3. Grid electricity and PV pricing

Grid electricity prices and solar PV rebate amounts were taken from Xcel Energy®. Of the five residential pricing plans available in Boulder, Xcel Energy specifies that the two-tiered rate structure be used for the solar rebate program [Xcel Energy 2011a]. However, this study models a more interesting energy management scenario of a PV/grid/battery system with time-of-use pricing. Time-of-use pricing specifies different electricity prices by the time of day, with higher rates during peak hours when electricity demand is high. This pricing structure is available in pilot programs and may soon be available for general use. Xcel Energy time-of-use rates are $0.09986 / kWh in off-peak hours, $0.24853 / kWh in peak hours between July and October, and $0.12053 / kWh in peak hours for other months of the year, including tariff adjustments and taxes [Public Service Company of Colorado 2011, Xcel Energy 2011b]. Peak hours occur during non-holiday weekdays from 2–8 p.m.

Xcel Energy provides rebates for solar power in two ways: (1) a one-time rebate based on the rated capacity of the PV array (watts), and (2) a monthly renewable energy credit (REC) based on the array throughput (watt-hours). Four rebate schemes are available based on the time of entry into the solar rebate program (Table 1). Net metering is used to credit the system with power generated by the array that is not used by the household at the time of production. Over the course of a year any net excess energy production beyond the total annual load can be sold back to Xcel Energy at the annual hourly incremental cost of electricity ($0.02857 / kWh in 2010) [Xcel Energy 2011a].

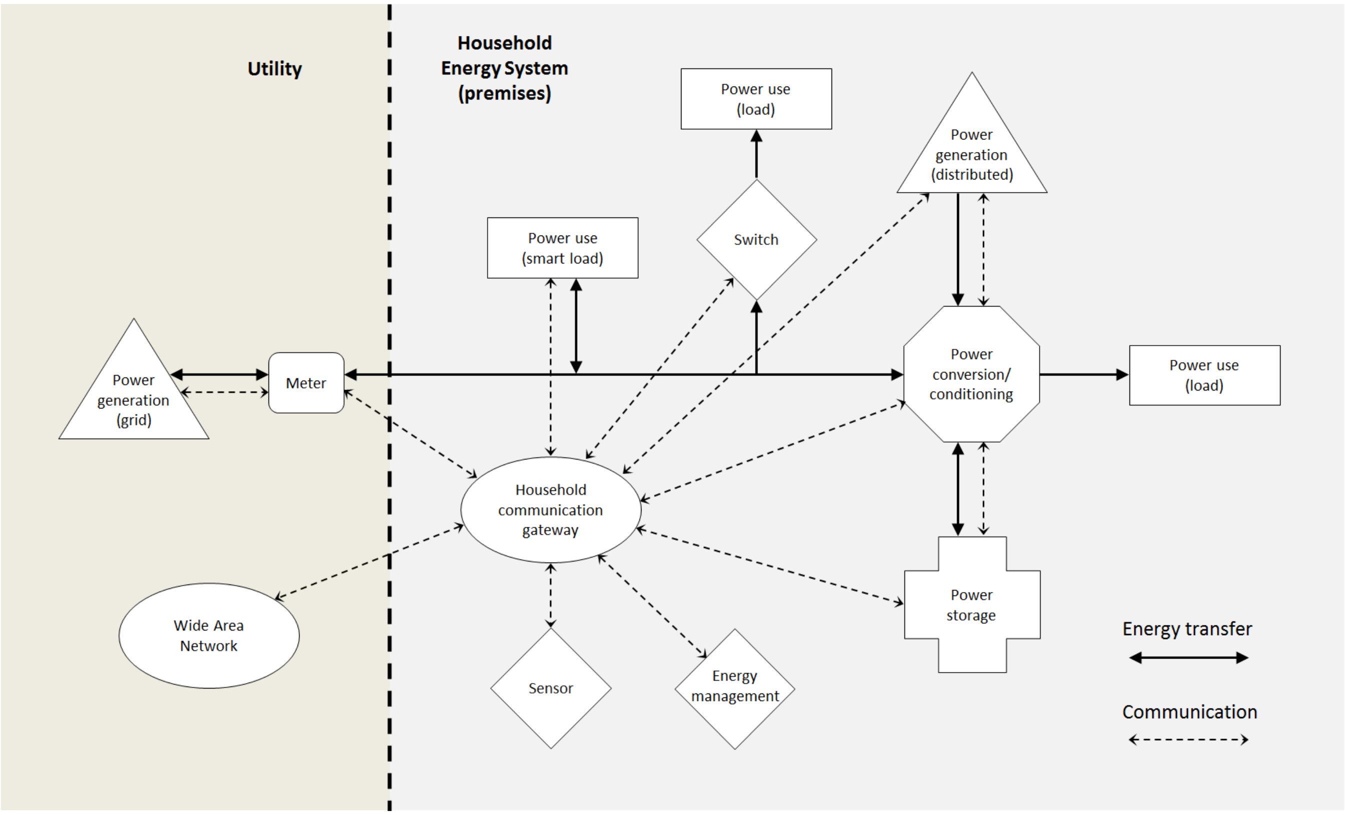

Figure 1. Generalized premises-based energy system architecture. Shapes represent technologies with different functions.

Table 1. Xcel Energy solar program rebates.

Step	Capacity rebate ($ / W)	REC ($ / kWh)
1	1.75	0.04
2	1.00	0.09
3	0.50	0.11
4	0.00	0.14

3. MODEL DEVELOPMENT

Power system components in the model are the load, grid, converter, solar PV, and battery. A HOMER schematic of these components and their connections with the AC bus and DC bus is shown in Fig. 2.

A load profile was created for a single family household—representative of residential consumption in Boulder, Colorado—with an average electricity consumption of 11 kWh / day and an annual 2.3 kW peak demand that occurs during the summer. The load profile was subjected to daily and hourly randomization in HOMER. This created realistic energy variability to test the power system configuration across a wide range of operating states.

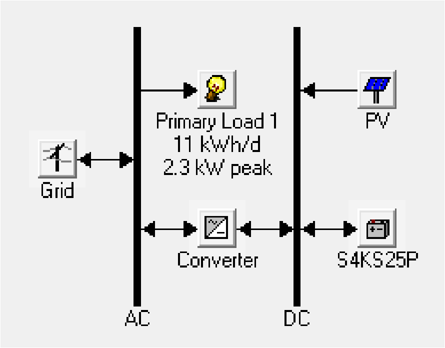

Figure 2. HOMER schematic of power system configuration options.

The incident solar radiative flux was calculated from data taken from NREL’s Climatological Solar Radiation Model.

Solar PV array size is limited by Xcel Energy’s rebate policy. The array should produce no more than 120% of power used in the last 12 months, or a rated capacity of 2.6 kW in this model. This is an upper constraint on PV capacity used in optimization. An average market value of $4,000 / kW is assumed for the initial and replacement costs, and a 25-year life.

A Surrette 4KS25P battery is used with a nominal 4V and 1,900 Ah capacity. Initial and replacement costs are assumed at $1,200 and operation and maintenance costs at $60 / battery / yr. Power is converted from DC to AC and AC to DC by the Transverter. Transverter operating parameters required by HOMER were taken from the manufacturer. Initial and replacement costs are assumed at $1,500.

Sensitivity analysis was completed on 7 parameters to understand their effect on the optimal power system configuration. These included:

- PV capital cost to examine the effect of Xcel's one-time rebate for array size
- PV operating cost to examine the effect of Xcel's monthly REC
- Energy management controls to explore the effect of price set-points on battery charging and discharging according to the time-of-use grid price of electricity
- Transverter costs
- Battery costs
- Grid electricity price
- Real interest rate

4. RESULTS

Graphical results from HOMER sensitivity analysis are shown in Fig. 3 that demonstrate the effect of PV capital cost and REC on the optimal power system. The PV capital cost is graphed instead of the Xcel Energy capacity rebate because the graph in Fig. 3 can be used to consider other forms of price reduction or even different capital costs based on decreasing market costs. The darker shaded region indicates when PV is cost-effective. Although the rebate plans reduce the net present cost of grid/PV systems by 23-32%, not all rebate plans provide a reduced cost compared to a grid-only system with the selected model parameters. Rebate Step 1 is on the cost-effective boundary between a grid-only and a PV/grid system. Steps 2–4 are cost-effective PV/grid options with Step 4 as the least expensive option at a 9% decrease in net present cost compared to a grid-only system. A linear regression of the points along the cost-effective boundary between grid and grid/PV provides the below equation. This indicates that each one-cent increase in REC offsets the capital cost of PV by $200 / kW.

$$\mathit{PV\ capital\ cost}\ (\$/\mathrm{kW}) = 1450 + 200 \times \mathit{REC}\ (¢/\mathrm{kWh})$$

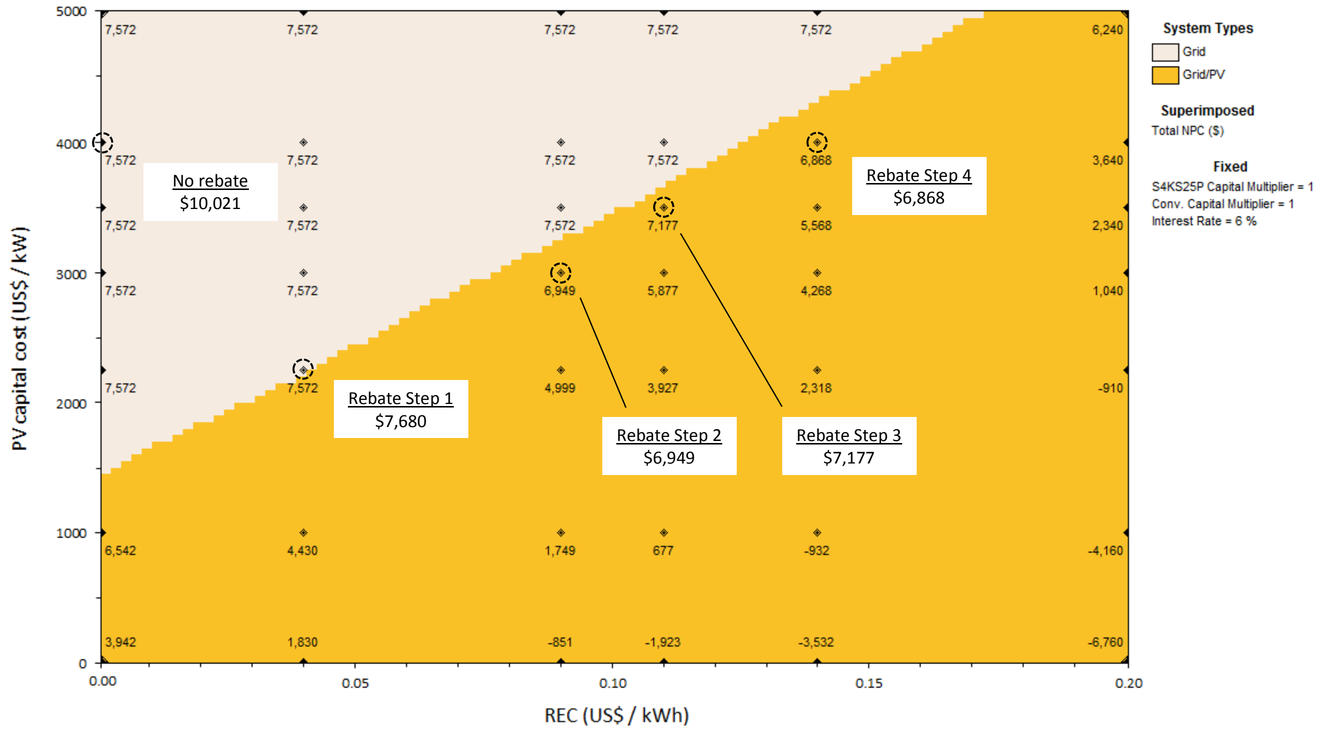

Figure 3. Optimal system type graph with net present cost overlay of rebate plans.

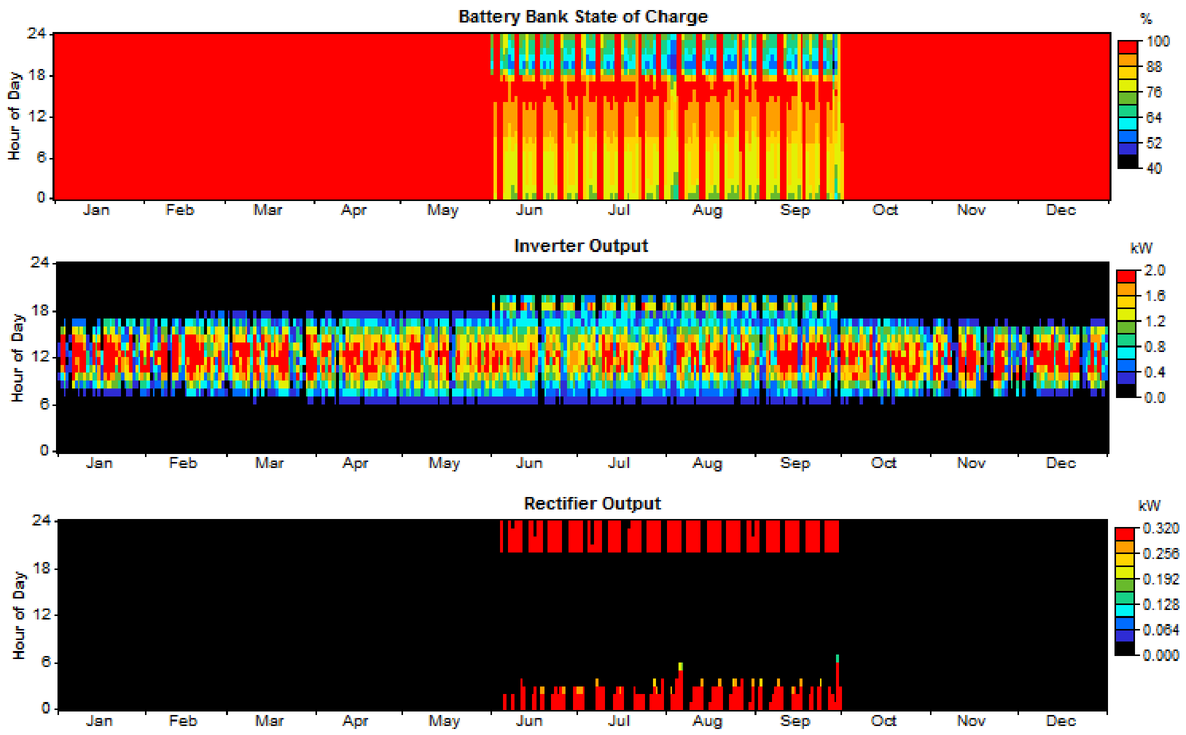

Figure 4. Battery state of charge and Transverter power conversion for 8,760 hourly simulations in one year.

Default HOMER energy management logic makes decisions to use the battery based on the battery's marginal cost of energy. Other logic that can be programmed into the Transverter is left for future study. In this model, the battery is discharged when its marginal cost of energy is less than the electricity grid price. Figure 4 shows the battery state of charge using this logic, and the related AC-to-DC and DC-to-AC conversion, for all 8,760 hours simulated during the year.

At its current cost, the battery sits idle for non-summer months because the differential between the peak and off-peak electric rate is not sufficient to compensate for the wear on the battery. Only after a 90% decrease in battery cost will it become an optimal solution in economic terms with the specified model parameters. However, the utility of a battery may include more than the cost of energy. Ancillary services, such as backup power, frequency regulation, reactive power support, and operating reserves are other valuable functions provided by a battery bank. HOMER users can interactively compare power system configurations to consider these and other criteria not easily expressed in economic terms. The user's interest in these functions may outweigh the increase in net present cost of $2,300 for each battery. Additionally, this expense could be subsidized by power utilities seeking alternative means for load shedding and increased grid reliability.

Reduced interest rates improve the cost-effectiveness of PV/grid systems compared to grid-only systems. Table 2 provides the effective capital cost, after inclusion of rebates, at which PV/grid becomes cost-effective over a range of interest rates.

Table 2. Cost-effective price point for PV/grid systems based on PV capital cost, assuming no REC.

Interest rate (%)	PV capital cost ($ / kW)
6	1,450
4	1,850
2	2,450
0	3,350

Additionally, the following findings can be drawn from the study:

- The maximum PV array size allowed by Xcel Energy's rebate structure can create enough electricity during the daylight hours to meet

household power requirements for the entire day, on average. Although this power cannot be stored cost-effectively, net metering allows the excess to be credited to the consumer to improve the cost-effectiveness of the PV array.
- A $1,000 decrease in Transverter cost is equivalent to a reduction in PV capital cost of $500 to $800 / kW. This increases the cost-effectiveness price points listed in Table 2.
- Increases in grid electricity prices have an eight-fold greater effect on the cost of grid-only systems compared to PV/grid systems.

5. DISCUSSION AND FUTURE WORK

This paper examined the cost-effectiveness of PV systems for a single family residential household in Boulder, Colorado. The hybrid power system modeling software HOMER was used to optimize systems on lowest net present cost and provide an interactive platform to compare systems against economic, technical, and additional user-defined merits. Using energy devices and HOMER model parameters from this study, a PV/grid system is a lower cost alternative to a grid-only system for Steps 2–4 of the Xcel Energy residential solar rebate program. The cost-effectiveness of PV was improved with increasing capital rebates, increasing REC, increasing grid electricity prices, decreasing real interest rates, and decreasing Transverter costs. Considering only the arbitrage value created by the differential between summer peak and off-peak electric prices, the battery bank selected in this study would be economical after a 90% decrease in cost. This is partly because the battery would only be used for approximately 90 cycles per year (non-holiday, summer weekdays) at its present cost. However, the other functions of a battery bank are useful and may justify the additional cost to some consumers, particularly if the value to the utility could be monetized for the consumer.

Analysis of other household and commercial load profiles and of various premises-based and grid control strategies is needed to gain a more complete understanding of financial policies and incentives for PV and battery systems. This may become more important with future transactive control strategies for energy management using grid price adjustments over minutes instead of hours. Additional energy management functionality is planned for a later release of HOMER. Such functionality will include:

- Individual load modeling
- Prioritization of loads
- Controls for individual household loads
- Programmable dispatch decisions
- Intermittent grid failures
- Load shedding

6. ACKNOWLEDGEMENTS

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