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Emerging economic viability of grid defection in a northern climate using solar hybrid systems

Abhilash Kantamneni [a], Richelle Winkler [b], Lucia Gauchia [c,d], Joshua M. Pearce [c,e,*]

[a] Department of Computer Science, Michigan Technological University, Houghton, MI, USA
[b] Department of Social Sciences, Michigan Technological University, Houghton, MI, USA
[c] Department of Electrical and Computer Engineering, Michigan Technological University, Houghton, MI, USA
[d] Department of Mechanical Engineering-Engineering Mechanics, Michigan Technological University, Houghton, MI, USA
[e] Department of Materials Science and Engineering, Michigan Technological University, Houghton, MI, USA

HIGHLIGHTS

- Quantifies the economic viability of off-grid hybrid photovoltaic (PV) systems.
- PV is backed up with batteries and combined heat and power (CHP).
- Case study in Michigan by household size (energy demand) and income.
- By 2020, majority of single-family owner-occupied households can defect.
- To prevent mass-scale grid defection policies needed for grid-tied PV systems.

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ABSTRACT

High demand for photovoltaic (PV), battery, and small-scale combined heat and power (CHP) technologies are driving a virtuous cycle of technological improvements and cost reductions in off-grid electric systems that increasingly compete with the grid market. Using a case study in the Upper Peninsula of Michigan, this paper quantifies the economic viability of off-grid PV+battery+CHP adoption and evaluates potential implications for grid-based utility models. The analysis shows that already some households could save money by switching to a solar hybrid off-grid system in comparison to the effective electric rates they are currently paying. Across the region by 2020, 92% of seasonal households and ~75% of year-round households are projected to meet electricity demands with lower costs. Furthermore, ~65% of all Upper Peninsula single-family owner-occupied households will both meet grid parity and be able to afford the systems by 2020. The results imply that economic circumstances could spur a positive feedback loop whereby grid electricity prices continue to rise and increasing numbers of customers choose alternatives (sometimes referred to as a "utility death spiral"), particularly in areas with relatively high electric utility rates. Utility companies and policy makers must take the potential for grid defection seriously when evaluating energy supply strategies.

1. Introduction

Both the global and U.S. solar photovoltaic (PV) industries have been growing rapidly (SEIA, 2013) as technical improvements and scaling have significantly reduced PV module costs and public support of solar energy has led to favorable policies in many regions (Branker and Pearce, 2010; SEIA, 2011, 2014; BNEF, 2012; IREC, 2012; Feldman, 2014). PV technology converts sunlight to high-exergy electricity reliably, safely, sustainably (Pearce, 2002; Prindle et al., 2007; Timilsina et al., 2012; Pathak et al., 2014) and now economically (Branker et al., 2011; Bazilian et al., 2013). High demand for new PV projects is expected to continue, driving a virtuous cycle of PV-related cost reductions (McDonald and Schrattenholzer, 2001; van der Zwaan and Rabl, 2003; Watanabe et al., 2003; Nemet, 2006; Candelise et al., 2013; Barbose et al.,

* Corresponding author at: Department of Electrical and Computer Engineering, Michigan Technological University, 1400 Townsend Drive Houghton, MI 49931-1295, USA.
E-mail addresses: akantamn@mtu.edu (A. Kantamneni), rwinkler@mtu.edu (R. Winkler), gauchia@mtu.edu (L. Gauchia), pearce@mtu.edu (J.M. Pearce).

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2014). Already the solar levelized cost of electricity (LCOE), which the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime, from small-distributed on-grid PV systems is competitive with utility electrical rates throughout some regions in the U.S. (Branker et al., 2011; Breyer and Gerlach, 2013; Reichelstein and Yorston, 2013). On the other hand, utility electrical prices are expected to continue to climb from a combination of: i) aging infrastructure (Brown and Willis, 2006; Li and Guo, 2006; Willis and Schrieber, 2013); ii) increased regulation (Pudasainee et al., 2009; Celebi et al., 2012; Rallo et al., 2012; Gerrard and Welton , 2014); iii) resource scarcity [ability to extract fuels such as coal at a given investment] (De Cian et al., 2013; Kriegler et al., 2013; Murphy et al., 2014); and iv) potential liability from conventional pollution and now carbon-dioxide (CO_2) emissions being regulated as greenhouse gas pollution (Wilson, 2007; Burtraw, 2013; Burtraw, 2014; Pratson, 2013; Linn, 2014). For these reasons, solar PV represents a threat to the conventional electric utility model.

An even greater threat is the coupling of PV to storage technologies, as batteries have also been advancing rapidly (Agnew and Dargusch, 2015). The dominant battery technology utilizes lithium-ion (Li-ion) due to its higher energy density (700 Wh/l). However, theoretical energy densities point to future improvements with nanostructures and new materials using abundant materials such as lithium-sulfur (LiS) (2600 Wh/kg) and lithium-air (Li-air) (11,000 Wh/kg) technologies (Amine et al., 2014). Along with these technological advancements, battery costs are dropping, with current costs being between $600–1000/kWh. The expectations are to reach $225/kWh in 2020 and to further drop below $150/kWh in the longer term (U.S. DOE, 2013). Economies of scale will also factor into future battery prices, especially with Tesla's increased battery manufacturing plans through its Giga-Factory, which plans to produce 500,000 batteries a year starting 2017 (Tesla, 2014). Battery packs (Power Wall) currently retail for $350/kWh for home use (Tesla, 2015). These developments have led to the potential for battery+PV levelized cost of electricity (LCOE) being less expensive than grid electricity, which could promote large-scale grid defection (Rocky Mountain Institute, 2014).

Recent analysis on grid defection (Rocky Mountain Institute, 2014) investigated state-level markets of special cases (New York, Kentucky, Texas, California and Hawaii) and found that grid parity of solar hybrid systems has already been achieved in some places (notably throughout most of Hawaii) and is imminent in several markets for tens of millions of customers in the United States by 2020. Grid parity occurs when an alternative energy source can generate power at a LCOE that is less than or equal to the price of purchasing power from the electricity grid. However, many regions in the U. S. (e.g. northern areas with limited solar potential and high heating demand during cold winter months) cannot have off-grid PV systems without prohibitively large battery systems. Small-scale combined heat and power (CHP) systems, which produce electricity as well as thermal energy that can be used for home heating, provide a potential solution for off-grid power backup of residential-scale PV+battery arrays CHP systems fueled by natural gas can be used to offset thermal loads from a conventional heating system while meeting household electric loads. CHP systems can be effective in recapturing waste heat that would normally be lost from the electricity generation process, while also minimizing emissions from conventional sources (Nosrat et al., 2014; Shah et al., 2015).

This paper investigates the potential for PV+battery+CHP systems to reach grid parity in the Upper Peninsula of Michigan (UP) – a mostly rural, remote region of the northern United States with a relatively low-income population. An analysis is performed from an economic standpoint using existing technologies, to determine if off-grid solar+battery+CHP systems can produce electricity at lower costs to consumers than that provided by conventional grid-tied electricity. The analysis integrates differential demand by household size and for seasonal and full-year residents in sizing systems and in estimating costs. The work extends prior research on grid parity by showing that even in unlikely places with low solar potential, such as the UP, design configurations are already becoming viable that make off-grid hybrid solar systems technologically and economically feasible.

Second, this study considers the economic viability of off-grid solar hybrid systems in a low income region. Even if grid parity is achieved, if households cannot afford the installment costs, then defecting from the grid is not economically feasible. The analysis considers households' financial ability to invest in solar hybrid systems based on income levels and access to funding. If economically viable systems are possible in this case region, with long cloudy winters and low solar penetration and a low income population, it would suggest that off-grid solar hybrid systems would be feasible alternatives for households across much of the United States.

2. Methods of analysis

This study models the point at which the financial costs of PV+battery+CHP systems reach grid parity for single-family homeowners, using the Upper Peninsula (UP) of Michigan as a case study. The goal is to estimate the number and proportion of homeowners in the UP for whom it is economically feasible to invest in off-grid solar hybrid systems. The analysis is restricted to single-family owner-occupied homes (including seasonal and year-round residents), because residents of these types of housing units have more control and personal incentive for investing in energy infrastructure for their home than do renters. There are four key steps to the analysis: (1) estimate electric consumption for UP households by size and type; (2) design generalized solar hybrid systems to meet those consumption needs; (3) model future solar-hybrid system prices and grid-based utility rates to determine the economic viability of grid defection for homeowners with various consumption levels; and finally (4) match demographic data to estimate the number and proportion of homeowners that are and will be in an economic position to defect given economic competitiveness of solar, based on their electric consumption and household income.

2.1. The upper Peninsula of Michigan case

The Upper Peninsula (UP) is situated between Lake Superior (along its northern border) and Wisconsin, Lake Michigan, and Lake Huron to the south. Altogether, it stretches about 320 miles from east to west and encompasses about 29% of Michigan's land area, but has only about 3% of its total population (US Census, 2010). At Census 2010, the UP was home to 311,361 residents and had a population density of just 19 people per square mile. There are no metropolitan counties within the UP, with the closest being Green Bay, Wisconsin, Duluth, MN, or Sault Saint Marie, Canada. Historically developed in association with mining and timber industries, today the land is heavily forested and the current economy is driven primarily by education, tourism, services, and government.

In many ways, the UP is fairly typical of a remote and rural location with scenic natural areas and abundant outdoor recreation. About 24% of all housing units are for seasonal, recreational or occasional use (US Census, 2010). This is similar to the proportion of seasonal homes in other rural natural amenity