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An optimization approach to parallel generation solar PV investments in the U.S.: Two applications illustrate the case for tariff reform

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HIGHLIGHTS

- Presents a novel approach to optimizing the size of behind-the-meter PV.
- Demonstrates interaction of tax and financial parameters with load and insolation data.
- Identifies how behind-the-meter operation raises risk to project economics.

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ABSTRACT

We construct a model to optimize the economics of distributed generation photovoltaics (DGPV) for a parallel generation (behind-the-meter) application. Applying the model to the short-interval load and insolation data for two similar dairy operations in the U.S. Upper Midwest region, we find that highly site-specific differences in parameters lead to strikingly divergent results. Operating behind-the-meter strongly rewards real-time concurrence between on-site generation and on-site load. Compared to operating under a value of solar tariff (VOST) or net energy metering (NEM), we argue that parallel generation tariffs amplify the existing, irreducible uncertainties of project economics, and discourage DGPV investment.

1. Introduction

The economic viability of distributed generation photovoltaics (DGPV) has improved dramatically in recent years (Barbose et al., 2014; Baker, et al., 2013), yet it remains essentially impossible to generalize about cost effectiveness in any particular application without some highly site- and enterprise-specific information. While some of this variation is irreducible, as we explain in detail below, another part of it is amplified by the tariff structure under which most installations take place in the U.S.

Where available, net energy metering (NEM) is attractive for its transparency and simplicity; however, such an approach is lately under considerable scrutiny for the way in which it redistributes fixed costs among customer classes (Kind, 2013; Borlick and Wood, 2014). The lack of access to NEM or to a similarly transparent tariff for valuing DGPV pushes developers and investors to explore and pursue *parallel generation* (a.k.a. *behind-the-meter*) applications under existing retail tariffs (Taylor, et al., 2015). To the extent there is concurrent on-site load, behind-the-meter generation offsets retail purchases, while to the extent that the real-time generation exceeds the real-time on-site load, the power is typically sold back to the grid at the inferior *avoided cost* rate. A parallel generation approach amounts to operating within the confines of an existing retail tariff that was never designed for distributed generation in the first place.

The cost of such an improvised approach is that it substantially complicates the economics of the investment, introducing a premium on the real-time concurrence of site-specific insolation and site-specific load. This, in turn, is mediated through a federal tax regime, one of 50 different state tax regimes, and a specific tariff from one of the approximately 3200 load serving entities in the U.S. The net effect is to magnify the existing site-to-site variations (in geographically-specific insolation, taxation, tariff structure, and load; see Wiser et al., 2007; Ong et al., 2010; Glassmire et al., 2012), making generalizations about economic viability virtually impossible – even where the solar resource and the project development costs are well understood.

To clarify DGPV project economics, we develop a math programming model that optimizes the economic viability of a

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parallel generation system. With a relatively small menu of site-specific inputs (including real-time historical data on insolation and load), the model can be applied to a wide variety of behind-the-meter applications in industry and agriculture. We demonstrate applicability by using data from two medium-sized dairies in West Central Minnesota and Eastern South Dakota, respectively. In each case, the objective is to identify the size of a PV array – possibly zero – that minimizes the net present cost of meeting the dairy's 25-year electricity demand.

Underscoring the point that project economics are highly sensitive to site-specific parameters, our results are strikingly different for the two cases examined – despite the fact that the cases were chosen for being similarly sized and situated. A slight difference in insolation resources is magnified through large differences in the alignment with load, tax treatment between neighboring states, and applicable tariffs at the two electrical co-operatives that serve the respective loads.

2. Methods

2.1. Related approaches

Other financial/engineering models are well developed for *pro forma* analyses of PV installations. Prominent among these is the U. S. National Renewable Energy Laboratory's (NREL's) System Advisory Model (SAM), along with several proprietary software packages including HOMER™, Energy Toolbase™, OnGrid™, Helioscope™, and others. Many solar developers have more simplified estimating tools of their own for calculating the back-of-the-envelope economics of particular installations.

Many of these platforms include a degree of engineering specificity that is well beyond what we attempt here. NREL's SAM, for example, allows the user to specify makes and models of inverters, panels, and other system elements. HOMER is particularly suited to integrated systems, which for example might include solar PV, battery storage, grid power, genset backup, etc. Many of the others are excellent for commercial PV applications, including fully articulated engineering and configuration options as well as simulation features that allow optimal choice from a utility's menu of commercial tariffs.

The above-mentioned programs are particularly suited to address the question: “What are the economics of a PV system of configuration *x*?” Our approach, by contrast, is to characterize the engineering parameters in a simple capital cost function, which enables us to optimize economically over the size of the installation. Combining the cost function with site-specific historical load data, a generation simulator that uses site-specific insolation data, and the utility's tariff structure (along with a variety of other financial parameters), we address the question: “What size PV array for this user, in this location, yields the maximum net present value as an investment?”[1] Or, equivalently: “What size array minimizes the net present cost of meeting the firm's electric demand, over the 25-year expected life of the investment?”

2.2. Model specification

Specifically, the model's objective function seeks the optimal array size (s) so as to minimize the net present cost of meeting the firm's 25-year (index t) energy load, subject to various technical, financial, tax, and material balance constraints. The time horizon corresponds to the solar array's expected useful life. The present value of costs comprises retail power purchases from the utility ($PVP(s)$) and costs associated with on-site power generation from the solar array ($PVC(s)$):

$$\mathrm{MIN}_s[PVP(s) + PVC(s)] \tag{1}$$

s.t.

$$PVP(s) = \sum_{t=1}^{25} [NetD_t(s)*P_t^E + DemC_t(s)]*(1 + r)^{(1-t)} \tag{2}$$

$$PVC(s) = NetCapC(s) + \sum_{t=1}^{25} [OperC_t(s) - DepB_t(s) - NetS_t^E(s) *P_t^{AC}]*(1 + r)^{(1-t)} \tag{3}$$

The present value of purchases ($PVP(s)$) is the discounted value of net purchases of energy ($NetD_t(s)$: the residual demand after on-site production and consumption), valued at the retail rate P^E, plus the present value of demand charges applied to the residual demand vector ($DemC_t(s)$). [2] The present value of solar array costs comprises the net up-front capital cost ($NetCapC(s)$, already in current dollar terms) and the discounted sum of operating costs ($OperC_t(s)$), depreciation benefits ($DepB_t(s)$) and net energy sales back to the grid ($NetS_t^E(s)$ only present when residual demand is negative, valued at the avoided cost rate P^{AC}).

The net demand vector merits special discussion. We use short-interval (15 min) demand data from the client's utility, reflecting actual historical load for the facility and meter in question. We generate a matching supply vector (at hourly intervals) by using the location-specific 10 km resolution gridded insolation estimates a.k.a. the SolarAnywhere™ dataset, and the generation simulator *PV Watts*™.[3] We create a supply vector for a 1 kw installation, which scales linearly with the array itself. A net demand vector is created by subtracting the historical load (compiled from quarter-hourly into hourly, to match the periodicity of the weather file data) from the putative supply. When elements of this vector are negative, power will be sold back to the grid at the prevailing avoided cost rate; when elements are positive, they are credited with saving the client the retail cost of the associated power. The variable $NetD_t(s)$ sums all instances across the year's 8760 hours when demand exceeds supply; the variable $NetS_t(s)$ sums all instances when supply exceeds demand.

Demand charges vary among utilities not only in size but in manner of calculation. Generally, the demand charge applies to commercial and/or industrial rates, and is calculated on the basis of the largest short-interval (often 15 min) power usage, over some range of dates (often one month). In many cases the applicable charge varies by season. For commercial and industrial users, it is not uncommon for the demand charge to amount to a third or more of the overall utility bill.

Depreciation is based on the Modified Accelerated Cost Recovery System (MACRS) for eligible renewable energy projects, according to which costs may be deducted from income over a six-year horizon. Depreciation benefits are calculated for each year by figuring the allowable depreciation number, multiplying by the marginal tax rate, and discounting the benefit back into present value terms. The allowable depreciation benefit in a given year

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[1] A more recent and very interesting development in the field is the application of real options analysis to the optimal timing of PV investments (Bauner and Crago, 2013; Ansar and Sparks, 2009). This approach has not yet incorporated the complexities of tariff schedules, taxes, time-of-use, etc.

[2] Future values are discounted by an imputed real, pre-tax hurdle rate of 3%. (Sensitivity tests are performed in Section 3.1). While we are unaware of any attempts to estimate the hurdle rate for behind-the-meter PV in the U.S., a number of studies, summarized in NERA (2014), p.107, estimate the hurdle rate for solar PV in Germany. Real pre-tax estimates range from 2.7–5.3%.

[3] *PV Watts* ™ is “a web application developed by the National Renewable Energy Laboratory (NREL) to estimate the electricity production of a grid-connected roof- or ground-mounted photovoltaic (PV) system.” http://www.nrel.gov/rredc/pvwatts/ (last accessed 2/12/15).