Renewable Energy 60 (2013) 20–26

Contents lists available at SciVerse ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Optimum penetration of utility-scale grid-connected solar photovoltaic systems in Illinois

J.H. Jo [a,*], D.G. Loomis [b], M.R. Aldeman [c]

[a] Department of Technology, Illinois State University, Normal, IL 61790, USA
[b] Department of Economics, Illinois State University, USA
[c] Center for Renewable Energy, Illinois State University, USA

ARTICLE INFO

Article history:
Received 3 December 2012
Accepted 10 April 2013
Available online 10 May 2013

Keywords:
Utility scale solar PV
Renewable energy simulation
Peak electrical demand
Energy plan

ABSTRACT

Although solar photovoltaics (PV) are recognized as a promising source of clean energy production, researchers and policy makers need to know the optimum level of solar PV capacity penetration into the existing generation structure under the current fuel mix for the region. As the level of installed PV capacity increases, it is possible that the aggregated generation mix could produce electrical power exceeding electrical demand, thus requiring generator curtailment. Therefore, determining the optimum penetration of large-scale PV and aggregated technical and economic benefits is becoming an issue for both power utilities and policy makers. We report the development and validation of a new methodology for assessing the optimum capacity and benefits of state-wide grid-connected large scale solar PV systems in Illinois. The solar carve-out portion of the current renewable portfolio standard is also evaluated within the context of the state's sustainable energy plan for the near term future.

1. Introduction

1.1. Utility-scale solar photovoltaic systems in the US

Countries across the world are beginning to reduce their dependence on fossil fuels by integrating renewable energy electricity generation sources into their electric grids. The United States is not immune to this trend, and utility-scale solar installations in the U.S. have grown rapidly over the past few years. Including all types of photovoltaics, the U.S. installed approximately 1600 MW of grid-connected solar photovoltaic (PV) capacity in 2011, a 74% increase over the 918 MW installed in 2010 [1,3], and between 2000 and 2011 the cumulative installed capacity grew from 200 MW to 3.5 GW [2]. Although this growth rate is impressive, the United States has begun to lag behind a number of other developed countries in this area.

There are at least four reasons for this rapid growth of utility-scale solar PV systems. First, their cost has declined dramatically over the past decade. According to the Solar Energy Industries Association, utility system prices in the U.S. declined for the ninth consecutive quarter, dropping from \$3.20/W in the fourth quarter of 2011 to \$2.90/W in the first quarter of 2012 and \$2.60/W in the second quarter of 2012 [4], largely due to a decline in module prices. The second reason for the rapid growth in utility-scale solar PV systems is that technological advances have led to the development of new materials and better manufacturing processes, increasing efficiency and lowering the levelized cost of energy from utility-scale solar PV systems. Third, many states in the U.S. have introduced renewable portfolio standards (RPS) where an increasing percentage of the state's electricity must come from renewable energy. In some cases, the RPS includes a solar "carve-out" specifying that a portion of the renewable requirement must be provided by solar energy. This has created a demand for solar energy, especially utility-scale solar energy systems that are typically cheaper and easier to track in order to comply with these renewable portfolio standards. Finally, several states provide financial incentives to encourage the deployment of solar farms. Thus, the growth of solar energy generation across states is unequal even among states that have similar renewable portfolio standards.

New Jersey, Arizona and California are the top three U.S. states for utility-scale solar installations. Illinois ranks twenty-third in new installations of any type of solar PV system (not just utility-scale) [5]. As of January 2013, Illinois has three utility-scale solar farms in operation: Exelon City Solar is a 10 MW installation on the south side of Chicago, Grand Ridge Solar Farm is a 3 MW installation near Streator, IL, and the Rockford Solar Farm is a 20 MW installation near the Chicago Rockford International Airport. The question is, therefore, why is New Jersey one of the leading states

* Corresponding author.
E-mail addresses: jjo@ilstu.edu, urbankorea@gmail.com (J.H. Jo).

0960-1481/$ – see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.renene.2013.04.008

for solar farms while Illinois, which has nearly the same solar radiation, is so far behind?

The simplest answer to the question of why New Jersey is more advanced in solar installations than Illinois is policy. Beginning in 1999, New Jersey implemented a set of stable policies that incentivized the building of solar systems and this led to a rapid growth in solar PV systems in the state. Illinois is catching up, however: in August 2007 the state passed an RPS requiring 25% of Illinois' eligible electricity consumption to be sourced from renewable technologies by the year 2025. The RPS was created as part of the Illinois Power Agency Act (IPAA), which also designated the Illinois Power Agency (IPA) as the organization responsible for meeting these goals [6]. The RPS was later amended to include a 6% carve-out for solar energy, equivalent to 1.5% of the state's annual eligible retail electricity sales.

Given the state's new regulations requiring electricity production from solar sources and the increasing solar PV installation capacity, both researchers and local policy makers are now asking whether there is an optimum level of solar PV capacity penetration into the state's existing generation structure under the current fuel mix for the region. As the level of PV generation capacity increases, the electricity generated from solar PV systems may be wasted under certain conditions when the energy being generated by PV and other sources exceeds the electrical demand at the time, unless energy storage systems can support the solar PV system.

1.2. Research objective

Although a series of research studies and collaborative reports presented at industry solar conferences have attempted to address the limitation of large-scale PV deployment, few have assessed the optimum level of PV penetration into existing electrical power systems in the near and long terms. Denholm and Margolis [7] analyzed the potential for solar PV to be deployed on a very large scale to examine how the hourly availability of PV interacts with the limited flexibility of traditional electricity generation plants. They pointed out the problem discussed above, where under high penetration levels of PV deployment and existing grid-operation procedures and rules, the system is likely to suffer from excess PV generation at certain times of the year. Their results indicated that based on a minimum turndown (run) rate equal to 35% of the peak load, some PV generation becomes surplus once PV provides about 4% of the total annual electricity demand. However, this approach to assessing different PV capacity growth pathways to plan ideal PV penetration levels in accordance with clean energy regulation and policy was constrained by only addressing the theoretical limits on such systems. In addition, their proposed method failed to incorporate a realistic comparison between PV generation surplus and conventional electric power systems' electrical use for plant operation.

Shah et al. [8] examined the issue of why PV generators interact negatively on critical inter-area modes. Their analysis revealed that integrating PV into the system creates higher angular separation among synchronous generators, resulting in inter-area oscillations. They examined the impact of large-scale PV on low frequency oscillations in a large interconnected system for different penetrations and operating conditions, reporting that a dispersed penetration of PV is preferable to a concentrated penetration to promote inter-area mode damping. This study, however, did not address the issue of the optimum level of PV penetration to be integrated into existing generation systems.

Lund [9] analyzed the large-scale integration of wind, PV and wave power into a Danish reference energy system, focusing on the problems of integrating electricity production from fluctuating renewable energy sources into the electricity supply. The results indicated that combining different renewable energy sources (in this case, PV, wind, and wave power) can slow down the increase in excess (wasted) production and identified the optimal mix of these renewable energy sources that should be integrated into the Danish energy system. However, the issue of how this optimum mix could support Denmark's renewable energy policy and how best to gradually integrate this mix into the existing energy system was not addressed. Although this study did not specifically focus on PV system integration alone, it does provide valuable insights for studies seeking to find the optimum mix of solar PV and wind power in other regions.

Hudson and Heilscher [10] identified a number of challenges facing those managing the operation of a utility grid when incorporating high PV penetration levels. They described the technology involved in integrating large scale PV installations into existing power networks, including the codes and standards governing the utility interactivity requirements, and reported that short term variability of solar PV is significantly smoothed with larger PV implementation. They concluded that the maximum capacity of distributed generation needs to be evaluated and the need to balance the variable and increasing input of renewable energy sources is becoming a major issue.

Finally, Myers et al. [11] provided an assessment of the large-scale implementation of distributed solar photovoltaics in Wisconsin with regard to its integration with the utility grid, economics of varying levels of high penetration, and displaced emissions. They suggested that as the penetration rate of distributed PV systems increases, both economic and environmental benefits experience diminishing returns. We adopted their energy calculation methods to identify energy rejected and utilized from the solar PV electrical generation and further advanced their methods to develop our optimization matrix for large-scale PV system applications.

Although several prior works have tried to assess the large-scale solar PV integration into the utility grid, none of these studies has evaluated the large scale PV applications to provide a clear indication of the approach that should be used to determine the optimum level for seamlessly integrating grid-tied PV systems into the current generating structure without wasting electricity; neither has a suitable method for evaluating the effectiveness of state RPS plans been suggested.

The purpose of this paper is, therefore, (1) to evaluate the solar carve-out portion specified in the current Illinois RPS plan and (2) to determine the optimal amount of solar energy generation for the State of Illinois. Three research questions guided our evaluation of the solar carve-out: First, given the current solar carve-out of 6% specified in the state's RPS, how many Megawatts of capacity will be installed by 2025? Second, how much of the load will be met under this scenario? Third, can Illinois fully utilize all the solar energy that will be produced as a result of the 6% carve-out without wasting some of the generated electrical energy? In other words, is there sufficient demand during the hours of high solar production to use all of the electricity generated?

The 6% carve-out specified in Illinois' RPS represents a political compromise rather than a considered view based on the technical feasibility of solar PV penetration. Therefore, this investigation of the optimal solar penetration rate based on the state's solar radiation and hourly electrical demand is both timely and necessary. One criterion for determining the optimal carve-out would be to aim for a level of solar capacity such that no solar energy is generated that would be wasted at any time. In other words, what is the solar potential for the State of Illinois given the requirement that all of the solar energy available is fully utilized 100% of the time? Another option would be to allow some hours with excess solar power but to limit the percentage of time during which energy would be wasted to the same percentage of energy that is