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Return on investment analysis and simulation of a 9.12 kW (kW) solar photovoltaic system

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ABSTRACT

Residential solar photovoltaic (PV) systems have been emerging as an economically feasible energy source. In the United States, an extension of the federal solar investment tax credit was granted in December 2015 to encourage solar investments by giving residential users a 30% discount on start-up costs (equipment and installation costs) with the 30% discount decreasing slightly each year until it expires in 2023. This article presents a simulation of the return on investment of a residential solar PV system in College Park, Maryland, using weather conditions and tax credits specific to the Maryland area. A bundle package was selected with components that are cost-effective in residential applications, and the total amount of expected energy production was calculated by inputting information regarding the location, components, and design into the "PV Watts Calculator" tool available from the National Renewable Energy Laboratory (NREL) along with eligible tax credits. An analysis of the conditions that affect the long-term return on investment including reliability and changing tax credit structures is then presented.

1. Introduction

Solar photovoltaic (PV) systems are used in residential and large-scale settings to convert sunlight to electricity. These systems consist of modules that contain semiconductor material capable of absorbing photons from the sun to produce an electric current (Knier, 2002). The solar PV modules are electrically connected to an inverter, which converts the direct current (DC) generated from the panels to alternating current (AC). In residential applications, these inverters are then connected to either a storage battery or the utility grid. Fig. 1 shows a solar PV system on the University of Maryland campus. The PV panel array absorbs electricity in the form of direct current, the micro-inverters (small inverters placed on each individual panel, unlike a central inverter which handles energy conversion for several panels) convert DC to AC, and then the AC is sent to the electric grid. Mounting equipment holds the components of the PV system in place.

Solar PV systems are becoming more prevalent worldwide as a source of renewable energy. In the third quarter of 2015, the United States installed 1361 megawatts (MW) of solar PV capacity (Solar Energy Industries Association, 2016). Large-scale installation contributed to 42% of this total, and residential installation made up 41% (Munsell, 2015). From the third quarter of 2014 to the third quarter of 2015, residential installation grew by about 69%. In the first half of 2016, over four gigawatts (GW) were installed in the United States (Solar Energy Industries Association, 2017). This represented a 45% growth compared to the first half of 2015. Decreasing solar PV life cycle costs are expected to help increase the global capacity of solar PV and compete with the global capacity of major nonrenewable fossil fuel energy sources including coal, natural gas, and petroleum. In 2014, fossil fuels accounted for 78.3% of global energy capacity, whereas renewable energy only contributed 19.2% (Sawin et al., 2016).

Solar PV systems have high start-up costs due to the price of the components (inverters, panels) and installation. Residential solar PV systems in the U.S. are usually tied to utility grids so users can receive tax credits on the start-up costs and supply energy to the grid to receive additional production-based tax credits. Grid-tied systems do not require a costly storage battery because the grid supplies electricity when the PV system is not producing energy due to a lack of sunlight. While off-grid battery storage systems are often considered the most effective for the customer, they are more costly and used in less than 10% of solar PV power installations in the U.S.; thus this study focuses on grid-tied systems (Masson et al., 2014).

Before installing a solar PV system, owners should have an accurate estimate of the return of investment (ROI) to determine

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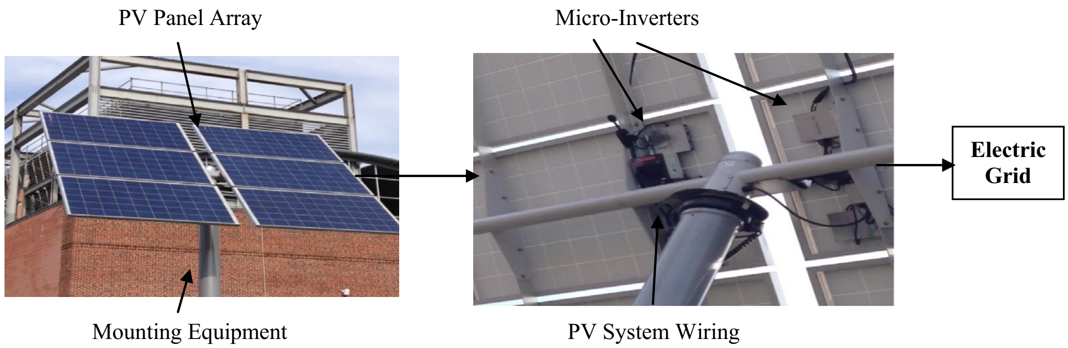

Fig. 1. Configuration of a grid-tied solar PV system.

if it is indeed a promising investment compared to using standard electricity. The ROI is the gain made from an investment, in this case, the amount saved by using a solar PV system compared to standard electricity divided by the initial start-up costs. Before discussing a detailed ROI simulation of a PV system, the factors that affect the ROI of a solar PV system and a literature review will be presented.

According to the most recent data from the U.S. Energy Information Administration, in August 2016 retail electricity was estimated to cost an average $0.13 per kilowatt hour (kW h) U.S. Energy Information Administration, 2016. Solar PV electricity is currently about $3.00 per watt in residential applications (Munsell, 2020), and GTM Research estimates that by 2020 the U.S. Department of Energy will reach their goal of decreasing the price of solar PV electricity to below $1.00 per watt for large utility-scale solar plants. As of August 2016, the price for panels was at an all-time low of $0.45 per watt (Ryan, 2016). Furthermore, the average cost of solar PV electricity is projected to decrease by 59% from 2016 to 2025 (Habboush and Carpenter, 2016). In addition to hardware costs, residential solar PV users in the U.S. qualify for the Solar Investment Tax Credit, which offers residential users a 30% tax credit from 2016 until the end of 2019, a 26% credit from the end of 2019 until the end of 2020, and then a 22% credit from the end of 2020 until the expiration of the tax credit at the end of 2023 (Solar Energy Industries Association, 2015). There are also state and local tax credits to encourage residential users to invest in solar PV systems.

Huld et al. (2014) calculated the levelized cost energy for a solar PV system to measure the competitiveness of solar PV prices compared to other forms of electricity in Europe. The levelized cost of electricity is a measurement of an energy system investment that takes into account costs over the lifetime of an energy system, including the initial investment, operation and maintenance, capital costs, and fuel costs. It measures the net present value of the electricity cost per unit over the lifetime of the energy system. Their analysis took into account start-up costs (e.g., panel, inverter, and installation costs), sales tax, capital for the ROI, and operation and maintenance. They compared the levelized cost of electricity from solar PV to standard residential rates from utility companies and concluded that solar PV electricity is less than or equal to residential utility prices for 79.5% of the European population.

Yang et al. (2015) simulated the payback period and ROI for a 6.7-kW residential solar PV system in Gainesville, Florida. The payback period is the time it takes to fully recoup the costs of the initial investment. Their study used Suntech 280-W solar panels with 14.4% efficiency and assumed that the inverter would be 95.5% efficient. Calculations of the total start-up cost of the PV system included 24 Suntech 280-W panels, 2 solar panel cables, 2 fuse holders, 1 inverter, 2 lightning arrestors, 1 combiner box, 1 direct current disconnect, and the mounting system. They noted that when using federal credits and the solar electric rebates offered by Florida, which provide credits for users based on the amount of power produced from their system, the payback period would be 2.77 years for a self-installed system and 12 years for a contractor-installed system. Users who apply for the Solar Electric System Rebate Program in Florida are not permitted to also apply for the feed-in tariff (FIT) program, which offers credits based on utility companies buying electricity from solar PV customers at a rate of $0.21 per kW h for systems equal to or less than 10 kW. When using the FIT program, the payback period was projected to be 5.26 years for self-installed systems and 10.2 years for contractor-installed systems. Their calculations assumed the annual ROI would be the same every year and did not account for degradation of PV cells and the reliability of components.

Matthews and Matthews (2016) simulated the ROI of a stand-alone residential PV system in South Africa. They used the market price for the panels, the inverter, and a Tesla Powerwall lithium-ion battery; a constant rate of inflation of about 6% per year; and lifetimes for the components of the solar PV system until the end of the warranty period. They then calculated the initial start-up costs and assumed a constant energy production based on data local to South Africa and efficiency rates of standard panels and inverters. For a medium income household with a PV system producing 855.45 kW h of power, they calculated the payback period to be about 7.52 years. They concluded that even though solar PV systems can achieve a payback period of less than 10 years the high start-up costs can deter people from investing.

Ahsan et al. (2016) simulated the energy production and initial investment of a 1-kW residential solar PV system in India using "PVsyst" software. Their start-up costs were about $1200, and they concluded their 1-kW system could generate 8109 watts of energy per day using conditions in India and efficiency data from manufacturers. Their simulation did not specify a payback period or provide life-cycle cost analysis.

Shouman et al. (2016) conducted a life-cycle cost analysis case study of a grid-tied 10-MW large-scale PV system and an off-grid PV system to supply 5.075 kW h of electricity to a residential home in Egypt. The estimated payback period for an on-grid PV system was 6.08 years. With the off-grid system, the total life-cycle costs over 25 years and cost of electricity per kW h were calculated using local weather data and the assumption that the battery would need replacement every 7–8 years. Their calculations took into account the costs of the initial purchase and installation as well as maintenance and replacement. The reduction in electricity production due to degradation of the system was also part of the calculations. They concluded that the life-cycle cost of the PV system will be about $3600 over a 25-year span and the cost of energy will be about $0.17 per kW h, which is competitive with utility rates in Egypt.

Muhammad-Sukki et al. (2011) analyzed the payback period under various feed-in tariff (FIT) schemes for solar PV systems in