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Review

# A review of technical requirements for plug-and-play solar photovoltaic microinverter systems in the United States

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ABSTRACT

The average American is highly supportive of solar photovoltaic (PV) technology and has the opportunity to earn a high return of investment from a PV investment for their own home. Unfortunately, the average American does not have easy access to capital/financing to install a PV system able to meet their aggregate annual electric needs. One method to overcome this challenge is to allow 'plug-and-play solar', which is defined as a fully inclusive, commercial, off-the-shelf PV system (normally consisting of a PV module and microinverter), which a prosumer can install by plugging it into an electric outlet and avoiding the need for significant permitting, inspection and interconnection processes. Many advanced countries already allow plug-and-play solar, yet U.S. regulations have lagged behind. In order to assist the U.S. overcome regulatory obstructions to greater PV penetration, this article first reviews the relevant codes and standards from the National Electric Code, local jurisdictions and utilities for PV with a specific focus on plug-and-play solar. Next, commercially available microinverters and alternating current (AC) modules are reviewed for their technical and safety compliance to these standards and all were found to be compliant. The technical requirements are then compared to regulatory and utility requirements using case studies in Michigan, which were found to create arbitrary non-technically-valid barriers to grid entry. The analysis also exposed the redundancy of the utility accessed AC disconnect switch for residential and small commercial grid connected solar PV. It is clear that the AC disconnect switch is not necessary technically and thus imposing it is an economic barrier to grid entry for solar PV systems with UL (Underwriters Laboratories) certified microinverters. To reduce consumer and utility workload and the concomitant soft costs, this article provides a streamlined application with only technical requirements and free and open source software to ease utility implementation. Finally, the advantages of supporting plug-and-play solar PV with UL certified microinverters include greater PV system performance, faster uptake and higher PV penetration levels, improved prosumer economics, and more environmentally responsible electric generation.



**Contents**



*Abbreviations:* AC, alternating current; AHJ, authorities having jurisdiction; BOS, balance of system; $C_S$, average solar PV system cost ($); DC, direct current; $D_f$, derate factor rate; DR, distributed resources; $E_l$, average electricity load demand (kW h); EPS, electric power system; FIT, feed-in-tariff; GFDI, Ground-Fault Detection and Interruption IBC, International Building Code; IEEE, Institute of Electrical and Electronics Engineers; $I_{cont}$, continuous current; $I_{max}$, maximum current; LCOE, levelized cost of electricity; $M_S$, average solar PV installation cost per Watt ($/W); NEC, National Electric Code; OCPD, over current protective devices; $P_{ave}$, average installed PV power (kW); PD, Project Developer; POA, Parallel Operating Agreement; $P_S$, solar PV power (kW); PV, photovoltaic; RET, renewable energy technology; ROI, return on investment; RPS, renewable portfolio standards; $S_H$, solar irradiance; UEDS, utility external disconnect switch; UL, Underwriters Laboratories.

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## 1. Introduction

Technical improvements (Harmon, 2000; Palm, 2015; Pillai, 2015; Surek, 2005) and scaling (Harmon, 2000, REN21, 2010) have resulted in a significant reduction in solar photovoltaic (PV) module costs, which catalyzed PV industry growth both globally as well as in the United States (Honeyman and Kimbis, 2014). As the demand for PV installations continues to increase, the costs continue to decline; feeding a virtuous cycle (McDonald and Schrattenholzer, 2001; Van der Zwaan and Rabl, 2003; Watanabe et al., 2003; Nemet, 2006; Candelise et al., 2013; Barbose et al., 2015; Rubin et al., 2015). This has enabled the solar levelized cost of electricity (LCOE) (Branker et al., 2011) to sometimes surpass grid parity (Christian and Gerlach, 2013) and now small-distributed on-grid PV systems are competitive with conventional utility electrical rates in many instances (Stefan and Yorston, 2013). This has led to a surge of distributed generation, with PV installations up by 30% in 2014 over 2013 reaching 6.2 GW of cumulative solar photovoltaic electric capacity (Solar Energy Industries Association, 2014). According to SEIA, by the second quarter of 2015, 22.7 GW of total installed solar electric capacity was operating in U.S., which is enough to power 4.6 million American homes (Kann et al., 2014). There is a large popular support for solar energy in the U.S. (Riffkin, 2015; Solar Energy Industries Association, 2015; Shahan, 2012). Globally such popular support often leads to political support (Worldwatch Institute, 2013) and a mix of pro-solar policies (Dutzik and Sargent, 2013; Solar Energy Industries Association, 2012; Yang, 2010; Sahu, 2015) such as net metering (Price and Margoli, 2010; Dufo-Lopez and Bernal-Agustín, 2015; Poullikkas, 2013), renewable portfolio standards (RPS) (Price and Margoli, 2010; Wiser et al., 2011; Novacheck and Johnson, 2015), strong statewide interconnection policies (Price and Margoli, 2010; Shrimali and Jenner, 2013), and financing policies (Price and Margoli, 2010; Amelia and Kammena, 2014; Branker and Pearce, 2010). This has made solar energy generation the fastest growing energy source over the past decade, having more than tripled globally in the past 5 years (Resch, 2015; Solar Energy Industries Association, 2015; Linder and Di Capua, 2012). In addition, many of the world's governments are carrying out steps to provide policy-supported financial incentive programs such as feed-in-tariffs (FITs) (Martinot and Sawin, 2009). A FIT is set to be a financially rewarding rate the utility pays for electricity being generated by the local renewable energy generators. Many countries who have adopted this mechanism have experienced the largest renewable energy technology (RET) deployments (Price and Margoli, 2010; Martinot and Sawin, 2009; Pietruszko, 2006; Solar Generation, 2008; Lin et al., 2014; Ahmad et al., 2015; White et al., 2013; Sovacool, 2010). However, even with the popularity and steps taken by various state and federal governments to support solar PV, it is contributing only 0.54% of the electricity generation in the U.S. by April of 2015 (U.S. Energy Information Administration, 2005, 2015).

PV can earn individuals a significant return on investment (ROI) throughout the U.S. even in sub-optimal locations such as the relatively snowy (Heidari et al., 2015) Houghton, MI (Kantamneni, 2014; Kantamneni et al., 2016), which is served by two of the most expensive Michigan electric utilities OCREA and UPPCO. Yet, why has the growth in solar failed to reach saturation on the market with most southern facing rooftops generating solar energy? This puzzle can in part be explained by simple lack of capital and the requisite financing available to the general population (Pietruszko, 2006; Wilkins, 2002; Alafita and Pearce, 2014; Beck and Martinot, 2004; Branker et al., 2011; IFC, 2007). Installing a solar PV system is expensive for an average homeowner (Esource, 2008) and many simply lack access to credit (Pietruszko, 2006; Wilkins, 2002). Although the median net worth of U.S. households was $81,400 (Business Insider, 2013), the majority of the wealth (89%) has been aggregated in the top 20% (of which the top 1% holds 35% of the wealth (Wolff, 2012), indicating that the majority of Americans may not have the capital to invest in full PV power for their households. This can be quantified with the following assumptions. If the average family needs approximately 10,000 kW h per year (U.S. Energy Information Administration, 2015), and the average solar hours per day in U.