Wind Load Calculations for Photovoltaic Arrays

Course No. R-2004

An Online Continuing Education Course for Engineers

Credit: 2 PDH
Wind Load Calculations for Photovoltaic Arrays

Executive Summary

Today’s photovoltaic (PV) industry must rely on licensed structural engineers’ various interpretations of building codes and standards to design PV mounting systems that will withstand wind-induced loads. This is a problem, because—although permitting agencies require assessments of the structural attachment of solar equipment to rooftops—the safety and sufficiency of these attachments are not adequately addressed in any codes or standards. The result is a multitude of code interpretations from a range of individuals and groups, often yielding different design loads for the same design specifications.

It is important to evaluate equipment and attachment methods to ensure that PV equipment will remain attached to structures during windstorm events, and that additional loads or load concentrations do not exceed the structural capacity of the building. ASCE Standard-7-05 (American Society of Civil Engineers Standard 7-05) is the standard for wind forces on structures, but it does not provide adequate guidance to the design professionals and code officials tasked with assessing PV installations.

This lack of guidance creates obstacles for the PV industry. The resulting problems include frustrated installers, unhappy customers, and wind-related structural failures. In addition, uncertainty about what constitutes a safe and secure installation for a given wind load can slow or even stop the approval process for PV installations and complicates the training of code officials.

In this course, sample calculations are provided for determining wind loads on PV arrays based on ASCE Standard 7-05. The focus is on applying the existing codes and standards to the typical residential application of PV arrays mounted parallel to the roof slope and relatively close (3 to 6 inches) to the roof surface. The course does not address other array configurations or building-integrated PV.

It will require much more work to gather information and develop standards specific to wind loading on rooftop PV installations. Although the information in this course does not completely solve the problem, it does provide initial guidance to designers and code officials.
This course recommends an approach for the structural design of roof-mounted PV systems based on ASCE Standard 7-05. Examples are provided that demonstrate a step-by-step procedure for calculating wind loads on PV arrays. The approach is applicable to PV modules mounted on rooftops that are no more than 60 feet high, when the PV array is oriented parallel to the roof surface, and when the mounting structure is sufficiently rigid. The PV array should be mounted a maximum of six inches above the roof surface. This distance is measured from the bottom of the PV frame to the roof surface, and is based on assumptions about typical mounting system configurations. The building should meet all requirements listed in Section 6.4.1.1 of ASCE Standard 7-05.

It is important that design professionals read and understand the appropriate codes and standards when designing rooftop PV systems. This course is not meant to be a substitute for existing codes and standards. It is also important for design professionals to stay current with existing codes and standards, because it is expected that the body of information about designing PV systems to withstand local wind loading to grow rapidly in the near future.

At the date of course publication, most 2010 State building codes require that wind loads shall be determined in accordance with ASCE 7-5, and have not yet adopted the newer ASCE 7-10 requirements. Therefore, ASCE 7-5 is the basis for this course. The course will revised in the future, as needed, when the state building codes adopt new wind load criteria.

Recommendations

1. It is recommended that you base the structural design of roof-mounted PV systems on the ASCE Standard 7-05 as follows:
   a. Section 6.5.12.2, main wind-force resisting system (MWFRS), is the recommended starting point for designing the PV mounting structure, with the PV module oriented above and parallel to the roof surface.
   b. Section 6.5.12.4.1 addresses wind loads on components and cladding. It is recommended to use Section 6.5.12.4.1 and supporting Figures only for the design of the PV module attachment clips and hardware to the structure, and for calculating loads on individual PV modules.
   c. It is not recommended to use Section 6.5.15, 6.5.15.1, and Figure 6-21 for the design of PV systems.
   d. This course provides basic guidance for applying ASCE Standard 7-05 to existing codes and standards for the typical residential application of PV arrays mounted parallel to the roof slope and relatively close (3 to 6 inches) to the roof surface.
2. It is recommended that wind tunnel testing be conducted for the most common rooftop PV installations to verify methods and calculations. The installation types include stand-off mounting parallel to the roof, stand-off mounting at an incline relative to the roof, and ballasted installations on flat roofs.

3. It is recommended that codes and standards be modified to specifically address the mounting of PV arrays to rooftops to eliminate potential barriers to market development in high wind regions.

Introduction

Today’s photovoltaic (PV) industry must rely on licensed structural engineers’ various interpretations of building codes and standards to design PV mounting systems that will withstand wind-induced loads. Ensuring that PV installations are safe and secure can involve custom testing methods such as wind tunnel testing or computer simulations, which are acceptable if approved by a structural engineer. The result is a multitude of code interpretations from a range of individuals and groups, often yielding different design loads for the same design specifications.

Please note that Chapter 6 of the ASCE Standard.7-05 describes the procedure for determining wind loads on buildings and structures. All figures, tables, and sections of Chapter 6 begin with the prefix “6.” For example, Figure 6-10, Table 6-3, and Section 6.3 are all parts of ASCE Standard.7-05, Chapter 6. These conventions have been adopted in this course, therefore any references to tables and figures beginning with a “6” refer to tables and figures in ASCE.Standard.7-05, while those that do not begin with a “6” are contained within the body of this course.

Background

The American Society of Civil Engineers (ASCE) Minimum Design Loads for Buildings and Other Structures (ASCE Standard 7-05) is the most comprehensive wind design standard in the United States. Other building codes such as the International Building Code (IBC) contain wind design requirements that are less comprehensive than ASCE Standard 7-05. This is especially true for design problems with atypical building geometry such as roof-mounted PV systems. Fortunately, the IBC and other building codes explicitly permit the use of the ASCE Standard 7-05 for the design of buildings and structures. However, it is difficult—and in some cases inappropriate—to derive the design loads on roof-mounted PV arrays from the existing standards, because there is no specific provision for these structures. The recommended design approach for roof-mounted PV systems presented in this course is based on ASCE standard, ASCE Standard 7-05 (ASCE 2006).

Existing Codes and Standards

This course recommends an approach for the structural design of roof-mounted PV systems that is based on the ASCE Standard 7-05. Examples are provided that demonstrate a step-by-step
procedure for calculating wind loads on PV arrays. The approach is applicable to PV modules mounted on rooftops that are no more than 60 feet high, when the modules are oriented parallel to the roof surface, the mounting structure is sufficiently rigid, and the PV array is mounted a maximum of six inches above the roof surface.

This distance is measured from the bottom of the PV frame to the roof surface and is based on assumptions about typical mounting system configurations. The building should meet all requirements listed in Section 6.4.1.1 of ASCE Standard 7-05.

Existing codes and standards do not cover PV modules oriented at an angle to the roof surface, and an analysis of this configuration is beyond the scope of this course. Designing for wind loading on this type of orientation and mounting structure is significantly more complex than designing for modules parallel and close to the roof, and will require further research and possible testing. This course also does not address building-integrated PV.

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1. Note: ASCE Standard 7-05, Section 6.2, defines rigid buildings and structures as having a fundamental frequency of at least 1 Hz. The 1 Hz limitation was developed as a worst-case value for high-rise buildings, and the application of this limitation has been the subject of some controversy in the ASCE community. PV mounting structures are typically less than 10 feet in height and often substantially shorter, and will likely have a fundamental frequency higher than 1 Hz. ASCE Standard 7-05 supports adopting the 1 Hz limitation for PV systems, but this should be verified as applicable by a licensed structural engineer on a case-by-case basis. Defining a maximum fundamental frequency for rigid PV structures will require further testing.

Experts in the areas of PV system design, aerodynamics, wind tunnel testing, and ASCE Standard 7-05 conducted a thorough review of the code. Based on this review, the team concluded that:

1. Unfortunately, there is no prescribed method in the standard that clearly addresses the specific geometry of roof-mounted PV systems.
2. Sections 6.5.15 and 6.5.15.1 and Figure 6-21 are not recommended for the design of PV systems.
3. Section 6.5.12.4.1 addresses wind loads on components and cladding, but the use of this section and the supporting figures are recommended only for the design of the PV module attachment clips and hardware to the structure, and for calculating loads on individual PV modules.
4. Section 6.5.12.2 (main wind-force resisting system [MWFRS]) is the recommended starting point for designing the PV mounting structure with the PV module oriented above and parallel to the roof surface.
Discussion

Section 6.5.15.1, “Rooftop Structures and Equipment for Buildings with h ≤=60 feet” is a new addition to ASCE 7-5 version of the standard. At first glance, the text would appear to be applicable to PV systems.

However, this may be due to a lack of clarity in the actual text. This section of the standard was intended to be applicable to roof-mounted structures with a prismatic shape, such as chimneys, air conditioners, etc. It was not intended for rooftop installations like PV systems that have gaps between the equipment and the roof. These gaps can allow pressurization below the surface of the PV modules independent of pressure in the building interior.

Put another way, ASCE Standard 7-05 was written for buildings, not the tops of buildings. Wind loading for installations like PV systems that leave gaps between the equipment and the roof surface is very different from wind loading for roof-mounted structures with a prismatic shape. For this reason, it is not recommended to use Section 6.5.15.1 or Figure 6-21 for the design of PV systems.

Section 6.5.12.4.1 addresses wind loads on components and cladding. “Components and cladding” is defined by ASCE as an “element of the building that does not qualify as the MWFRS.” Many structural engineers and PV designers have considered roof-mounted PV systems to qualify as components and cladding, and not the MWFRS, due to the fact that the PV support structure is not the wind resisting structure for the overall structure. The system generally receives wind loading from more than one surface.

Components receive wind forces directly or from the cladding system. Those loads are transferred to the MWFRS, which bears the structural loads. Based on the descriptions of the differences between components and cladding and the MWFRS, the PV modules themselves and the hardware that secures the modules to the structure could be considered components and cladding. However, the means of attachment to the roof is the MWFRS, because the PV mounting system provides support and stability for the overall structure. It is this means of attaching the modules to the structure (via the roof) that is of primary concern. Therefore, it is recommended to use Section 6.5.12.4.1 and the supporting figures for calculating loads on individual PV modules and attachment hardware, and Section 6.5.12.2 for the design of PV rooftop mounting structures.

ASCE Standard 7-05 differentiates between components and cladding, and the MWFRS because the small tributary area of components and cladding can result in higher instantaneous loads than...