WIND FORCES ON INCLINED SOLAR PANELS ON FLAT ROOFS

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ABSTRACT

The current impetus for alternative energy sources is increasing the demand for rooftop solar energy technologies in urban areas. The vulnerability of these solar arrays to damage due to wind forces escalates with the increase in building height. Thus, it’s imperative that solar arrays are designed for appropriate wind loading. Although wind tunnel studies have been conducted worldwide on Rooftop Solar Arrays (RSA), no guidance is provided either in Indian codes IS 875 Pt-3 1987 and IS 875 Pt-3 Draft or in American codes ASCE-7 2002 and 2005. In this paper an attempt has been made to estimate wind loads on a RSA using both the aforesaid codes. In this study RSA has been approximated as a mono-slope free standing roof. The pressure coefficients obtained from published wind tunnel studies on solar arrays are also compared to those obtained using above standards. The uplift forces experienced by the considered RSA is found maximum with ASCE-7 2005 and minimum with ASCE-7 2002 for different panel inclinations and building heights. It is also seen that loads load estimate with American codes are significantly conservative as compared to Indian wind Codes.

Keywords: Rooftop Solar Arrays, mono-slope free standing roof, pressure coefficients

Introduction

Now-a-day’s inclined solar arrays are being extensively used in urban areas on building roofs as a source of alternative energy (Fig. 1). The wind flow around buildings is still a complex phenomenon which becomes far more complicated in the presence of obstructions placed on its top. This makes the RSA really very sensitive to wind loading. Design standards and codes of practice offer little assistance to the designers regarding provisions for wind-induced loading on RSA. Various wind tunnel studies have been conducted worldwide for ground and roof mounted solar arrays considering parameters viz. wind direction (θ), building height(H), tilt(ϕ), roof slope, roof location etc. as highlighted by: Chevalien et al.1979, Radu et al. 1986, Radu and Axinte 1989, Wood et al. 2001, Kopp et al. 2002, Chung et al.2008, Shademan et al.2009, Ruscheweyh and Windhovel 2011, Stathopoulos et al. 2012, 2013 etc. Banks et al. (2008) published some guidelines to calculate wind loads on roof-mounted solar panels utilizing ASCE 7-05. Uematsu et al. (2008), made several wind tunnel testing on free standing canopy roofs in order to determine the characteristics of wind loads on these types of structures. Barkaszi et al. (2010) summarized wind load calculations for solar panel arrays using the ASCE-7 2005 for estimation of wind loads on solar panel arrays installed on pitched roofs. Researchers often recommend wind tunnel tests for rooftop panel installation for verification of installation and calculations.

Fig. 1 Rooftop Solar Arrays (RSA) in urban areas
Methodology for wind load estimation

In this study, a particular solar array consisting of five panels (Panel size: 1.96 x 0.98 m) is considered for estimation of wind loads when located centrally on flat roof tops (Fig.2). The wind load on the solar array is estimated for five building heights (H) where H = 10m, 20m, 50m, 100m and 200m situated in urban areas and for four tilts (\(\phi\)) where \(\phi = 15^\circ, 20^\circ, 25^\circ\) and \(30^\circ\). The standards followed for this purpose are IS 875 Pt-3 (1987), IS 875 Pt-3 Draft (2011), ASCE-7 (2002) and ASCE-7 (2005). Since pressure coefficients (\(C_p\)) for different H and \(\phi\) are not presently available in aforesaid codes, \(C_p\) values for mono-slope free standing canopies (open building) are used to estimate wind loads on RSA. Similar approach has been suggested by researchers such as Banks (2008) and Barkaszi et al. (2010) with an exception to the roof corner and edge regions. Although the approach used in this paper can give wind loads on RSA for all wind speed zones and terrains the results are shown for dense urban areas (emphasis to metropolitan cities) over flat terrain coming under high wind speed zones (55 m/s) as per IS 875 Pt-3 1987.

Results and Discussion

- The \(C_p\) values obtained from earlier as well as recently published wind tunnel studies for RSA are coincident at certain points with \(C_p\) values from IS 875 Pt-3 1987 for a free standing mono-slope roof. This is clear from Fig.3 which shows comparison of \(C_p\) versus \(\theta\) at \(\phi = 30^\circ\) and Fig.4 which shows comparison of \(C_p\) versus \(\phi\) at \(\theta = 135^\circ\).

![Fig.2 Schematic of considered RSA on flat roof with a magnified view on the right](image)

![Fig.3 Comparison of \(C_p\) values at \(\phi = 30^\circ\) and \(\theta = 0^\circ\) to \(180^\circ\)](image)

![Fig.4 Comparison of \(C_p\) values at \(\phi = 20^\circ, 25^\circ\) & \(30^\circ\) and \(\theta = 135^\circ\)](image)
Fig. 5 shows the variation of uplift force (F) with H for each of the codes at $\phi = 15^\circ$, $20^\circ$, $25^\circ$ and $30^\circ$ respectively. The important observations are as follows:

- A sharp transition in ‘F’ for all ‘$\phi$’ from H = 20m to 50m with both the IS codes in comparison to the smooth transition with ASCE codes. This difference is possibly because of the drastic increase in the terrain, height factor, $k_2$ between these heights in the IS codes.
- At ‘$\phi$’ = 30°, the values of ‘F’ as per IS 875 Pt-3 Draft approaches closer to that of ASCE-7 2005 at H = 50 m and 100m after which it diverges.
- The uplift forces (F) as per ASCE-7 2002 are significantly less in comparison to all other codes. This notable difference is basically due to low force coefficient values available as compared to the high $C_p$ values present in other codes for mono-slope free roofs.

Fig 5 Curves representing uplift forces (F) versus H for different codes (a) $\phi$=15° (b) $\phi$=20° (c) $\phi$ = 25° (d) $\phi$ = 30°

The observed percentage change in values of ‘F’ for respective codes with transition in $\phi$ for all considered ‘H’ values is shown in Fig. 6. It is evident that the percentage change in uplift forces with transition in ‘$\phi$’ remains same for both the Indian codes although magnitude wise Draft code is greater (Fig.5). In case of ASCE-7 2002 there is a significant difference for $\phi$ from 15° to 20° which further reduces and remains equal. On the other hand, in ASCE-7 2005 the difference is initially small and further diminishes with transition in ‘$\phi$’.
The bar chart representation in Fig. 7 gives a clear idea on the magnitude of uplift on RSA for each of the considered codes for varying building heights at separate ‘θ’ value. The following important observations are as follows:

- The uplift forces according to IS 875 Pt-3 Draft code are conservative by 15% over IS 875 Pt-3 1987 at all ‘θ’ values on an average for the considered H values.
- The uplift forces according to ASCE-7 2005 code are significantly conservative over ASCE-7 2002. i.e almost two times at θ = 30° and up to three times at θ = 15°, 20° & 25° on an average for the considered H values.
- The uplift forces according to ASCE-7 2005 code are conservative by 24% over IS 875 Pt-3 Draft code at ‘θ’ = 30°, around 35% at ‘θ’ = 15° & 25° and almost by 53% at ‘θ’ = 20° on an average for the considered H values.

Fig. 6 Percentage difference in uplift forces (F) for each code with transition in ‘φ’ at all H

Fig 7 Bar Charts representing uplift forces for different building heights at each ‘φ’

The bar chart representation in Fig. 7 gives a clear idea on the magnitude of uplift on RSA for each of the considered codes for varying building heights at separate ‘θ’ value.
Conclusion

1. The estimated wind loads as per ASCE-7 2005 are found to be significantly conservative over Indian Draft code, varying from a minimum of 24% to a maximum of 53% at various ‘ϕ’ on an average for the considered H values.
2. The good agreement of Cp values for mono-slope free standing roofs (in IS code) with those of the established wind tunnel results (for inclined solar panels) gives confidence of using them in wind load calculations.
3. Although wind tunnel studies are more accurate; but until and unless these things appear in the standards such approximate estimation may be employed for the present situation.
4. Besides, CFD technique can be used as an effective tool for determination of wind loads on inclined roof top solar panels until some design guidelines get’s incorporated in these codes

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