Numerical investigation of impact of various wind loads on the structural stability and strength of solar panel supporting structure

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Abstract: Nowadays, the uses of renewable energy resources are growing rapidly. Several renewable resources such as hydro, wind, solar and tidal are commonly used all over the world. Following this trend, the implementation of large area solar arrays is considered to be necessary. Several design methodologies and approaches have been accessible in order to obtain maximum efficiency of solar panel supporting structure. In this study, Finite Element Method (FEM) was established to investigate the impact of various wind loads on the structural reliability and strength of solar panel supporting structures. The wind speeds of 20 m/s, 25 m/s, 30 m/s, 35 m/s and 40 m/s were used for the analysis of solar panel supporting structure. Wind loads were also calculated by mathematical approach. The results show that solar panel structure was significantly affected by wind loads applied on the surface of solar PV module. The results obtained from the FEM analysis that total deformation and maximum equivalent stresses were increased by increasing the wind loads. The maximum value of equivalent stress can be found at joint sections of solar panel supporting structure and total deformation is higher at centre of the structure as well as at base of the structure. The maximum and minimum value of equivalent stress 62.866 Mpa and 15.75 Mpa can be found at 40 m/s and 20 m/s respectively. Similarly, maximum and minimum value of total deformation 0.3631 mm and 0.0911 mm can be found at 40 m/s and 20 m/s respectively. The knowledge of stress distribution and deformation play a vital role for structure designs, stability and strength of hydro solar panel supporting structure.

Keywords: Numerical simulation, wind loads, structural stability, solar modules
1. Introduction

Nowadays, renewable energy resources have great potential for researchers and engineers to optimize their system as well as to enhance performance. The growing environmental pollution due to burning of fossil fuels all over the world, the researchers and engineers are tending to move alternate resources other than fossil fuels. There are several renewable energy resources like solar energy, hydro energy, wind energy and tidal energy which are used for energy production. Solar energy is also one of the most important renewable energy forms which are widely used all over the world [1]. In addition, there is various ways for the collection of solar radiation such as photovoltaic and thermal solar system. Solar energy obtained by collecting the sun lights as energy that the sun gives in the form of radiation. In thermal solar system the fluid was heated up by using the sun rays and obtained energy. There are several types of thermal systems which were used all over the world to produce energy. On the other hand, photovoltaic system uses solar panels or photovoltaic arrays for the production of electrical energy. There are also various types of photovoltaic systems exist for the production of electrical energy. Furthermore, there is another thermal power system called Concentrated Solar Power (CSP) system. In CSP system, various types of concentrating optical devices are used for focusing the solar radiations which are coming from the sun rays. The main purposes of optical devices are to focus the sun radiations at a small area of solar collector for obtaining electrical energy from sun [2]. Furthermore, in CSP system the fluids which are passing through the solar collectors convert into steam and this steam are used to drive a turbines leads to energy production.

Solar panel structure for photovoltaic system also has a great potential to design and optimize their design for researchers and engineers. Solar panel structure carries a load of solar PV plates as well as bears a wind pressure which was acting on the surface area of structure. Failure occurs in the solar panel supporting structure due to exerted pressure by wind flow and itself load acting on the structure. Typically in design, wind loads are exerted in the form of equivalent static loads which is recommended by Structural Association of California (SEAOC) [3]. Finite element analysis FEA tool play a vital role to determine stresses, strain and deformation in the solar panel supporting structure. According to FEM method Von Mises criterion is generally used to estimate the strength and failure of the solar panel supporting structure. If the value of maximum equivalent stress is greater than the yield strength, the criterion predicts that the design will fail. Several steps include geometry modeling, meshing, and physical setup or constrained, solution.
and then results are used in FEM method. One of the main steps is meshing which impact significantly on the outcomes of the solution but all other steps have equal importance which impact on the results. A detailed literature about solar panel structure was carried out by various researchers. Ana Camelia SAuCA et al. [4] performed a numerical analysis at different turbulence flow over a solar panel to investigate the flow behavior over the solar panel structure. They calculated the drag and lift force and compare the numerical results with the guidelines of national standard. Sayana M et al. [5] conducted a buckling analysis of solar panel structure to enhance their design performance and stability. They also investigated the effect of those factors which affected the stability and strength of solar panel structure. K. Srinivasa Rao et al. [6] performed a numerical simulations of solar panel supporting structure under various angle of rotation to enhance their design performance and withstanding capability. Numerical analysis was performed using ANSYS commercial software. Numerical analysis was also performed to examine the aerodynamics behavior of solar panel supporting structure. Gadhavi Akash G. et al. [7] conducted a review study about solar panel supporting structure. They conducted a review study about design, structure strength under various climate conditions such as under wind effect, under structure load and also under height of the structure. Gasser Farouk Abdelale et al. [8] performed a fatigue thermal analysis which is based on 2D Finite Difference Method (FDM) and 3D Finite Element Method (FEM) to investigate the solar panel structure performance during micro-satellite life time. First of all 2D FDM method was applied to observe the temperature profile during one orbit. Aly Mousaad Aly et al. [9] performed a numerical analysis of the evaluation of wind on the solar panel by using CFD. They performed numerical analysis at various wind loads and examine the behavior of air flow pressure and velocity on the solar panel. The results obtained by numerical simulations are then compared to wind tunnel data to investigate the results validity. Ping-Han Chung et al. [10] experimentally investigated the wind loads on the solar PV arrays. The free stream velocity was 14.5 m/s and the turbulence intensity was 0.3%. Lift coefficient was measured by using the mean surface pressure measurements. Samir Benammar et al. [11] presented the numerically and analytically study to enhance and improve the understanding of the response to wind load on the reliability of heliostat structure. They have been modeled heliostat components such as torque tube, frame and pedestal at various azimuth and elevation angles. Chih-Kuang Lin et al. [12] developed a Computer Aided Engineering (CAE) technique to investigate the structural integrity and deformation induced
misalignment of solar radiation in a 2 kW tracking PV system. Finite Element Analysis (FEA) approach was used to investigate the structural behavior of solar panel structure. FEA analysis was performed to investigate the effect of self-weight and different wind loads on the structure of solar PV panels. Andreas Schellenberg et al. [13] evaluated the aerodynamics behavior of solar array as well as structural response under various wind loading and locations. Pressure distribution along the solar panel arrays was also measure experimentally in the wind tunnel. In previous literature review, it is investigated that Finite Element Analysis (FEA) technique can be utilized to investigate the structure reliability of solar panel structure. According to previous literature review many authors published their work by using CFD tool and very less work is done by using FEA technique.

In this study Finite Element Method (FEM) was established to investigate the impact of various wind loads on the structure reliability and strength of solar panel supporting structure. ANSYS Workbench Static Structural module was used to simulate the numerical analysis of solar panel supporting structure. It was observed from the results that the impact of various wind loads have a significant importance for the structural behavior and design optimization of solar panel supporting structure.

2. Methodology

2.1. Wind load calculations

The arrangement of the solar panel structure is more similar to double sloped roof trusses. The expression for the measurements of wind pressure is given by the following equation which is very important equations in this study to solve the simulation problems throughout this work for the structural loads [14];

\[ P_{\text{wind}} = 0.6 \times U^2 \] (1)

Where \( U \) is the wind speed

Wind force = Effective area of pane x wind pressure

\[ F_{\text{wind}} = A_e \times P_{\text{wind}} \] (2)

Where \( A_e \) is the effective area of solar panel modules. Arrangement of slopped roof is shown in Figure 1.
Projected area line = Total area line x Sin α

\[ A_e = A \times \sin \alpha \]  

(3)

\[ F_{\text{wind}} = P_{\text{wind}} \times A \times \sin \alpha \]  

(4)

Design velocity can be calculated by another way which is given below [15];

\[ U = k_1 k_2 k_3 V_b \]  

(5)

Where \( K_1 \) is the risk coefficient, \( K_2 \) is the terrain, height and structure size factor, \( K_3 \) is topography factor and \( V_b \) basic wind speed.

### 2.2. Finite element analysis modeling

Finite Element Analysis (FEA) analysis is very important tool used for structural analysis. Structural analysis is performed on solar panel supporting structure at different wind loading condition by using FEA tool. Brief description of FEA modeling is described in the subsequent subsections [16].

### 2.4. Geometry Modeling

First of all in FEA, modeling of solar panel supporting structure was done to create 3D-geometry according to given geometric parameters. 3D-geometry is created in SOLIDWORKS. The schematic diagram of ground based solar panel supporting structure is shown in Figure 2. The appropriate material is selected for FEM modeling is structural steel which have following mechanical and thermal properties: young`s modulus elasticity 210 GPa, density 7850 kg/m3, reference temperature 22 °C, poissions ratio 0.3, coefficient of thermal expansion 1.21×10^{-5} per °C, bulk modules 165.6 GPa, tensile yield strength 251 Mpa, tensile ultimate strength 460 Mpa, compressive yield strength 250 Mpa [17].
2.5. Grid Generation

Grid or Mesh can be defined as small shapes formed after discretization of computational domain. Mesh strongly affected on the numerical simulation results, hence mesh quality play a vital role to obtain suitable results. Meshing plays a vital role in numerical simulations. It is concluded from previous literature that mesh generation dictated the simulation time or computational time and also impact on the simulations results. Coarse or rough class mesh generation cause an inaccurate simulation results. So mesh quality cannot be compromise. Generation of mesh needs high capable and skillful person during numerical simulations. Hence the meshing skills, competence and its acquaintance are of same worth as much as that of the solver processes. Meshing is a thought-provoking operation in which the expert has to keep precise mesh density as well as ensure that the mesh count is not unfeasibly higher. After making of 3D-geometry model it is important to generate mesh of solid model. 3D solid model is imported into ANSYS static structural mesh tool to generate mesh shown in Figure 3. Tetrahedral unstructured mesh has been generated in ANSYS static structural mesh tool consisted of 723460 nodes and 194429 elements.
2.6. **Loading Condition**

The solar panel supporting structure is exposed into two different loads under normal operating conditions. Solar panel supporting structure was exerted by self-weight of solar supporting structure and environmental loads such as wind load. Both loads are important for FEM analysis consideration to examine the structure behavior of solar panel supporting structure [18].

2.7. **Boundary Condition**

Boundary conditions or constrained of solid model of solar panel supporting structure are shown in Figure 4. Bottom End of the supporting legs are fixed, the applied wind pressure are acting on the surfaces of solar panels and self-weight acting on the supporting edges of the structure. Wind pressure which is acting on the surfaces of solar panel supporting structure applied horizontally. A load combination results when more than one load type acts on the structure. Building codes usually specify a variety of load combinations together with load factors (weightings) for each load type in order to ensure the safety of the structure under different maximum expected loading scenarios. For example, in designing a staircase, a dead load factor may be 1.2 times the weight of the structure, and a live load factor may be 1.6 times the maximum expected live load. These two "factored loads" are combined (added) to determine the "required strength" of the staircase. The reason for the disparity between factors for dead load and live load, and thus the reason the loads are initially categorized as dead or live is because while it is not unreasonable to expect a large number of people ascending the staircase at once, it is less likely that the structure will experience much change in its permanent load.

![Figure 3 Meshing of solar panel structure](image-url)
3. Results and Discussion

Structural analysis of solar panel supporting structure was conducted by using ANSYS STATIC STRUCTURAL 19.0 module. Structural analyses of solar panel supporting structure were performed at various wind loads which were applied on the surface of the solar PV panel. Solar panel supporting structure were analyzed at various wind speed of 20 m/s, 25 m/s, 30 m/s, 35 m/s and 40 m/s. Figures 5 & 6 show the responses of deformation and maximum equivalent stress. It is evident form Figure 5 & 6 that deformation and maximum equivalent stresses are increasing with the increasing wind loads on the surfaces of solar PV module. When wind load increase on the solar PV module, the supporting structure also deforms and tends to failure. It was also observed from the obtained results that the maximum value of deformation was 0.3631 mm at wind speed of 40 m/s. Similarly, the minimum value of deformation was 0.0911 mm was observed at wind speed of 20 m/s.

Figure 4 Solar Panel Supporting Structure Constraints
On the other hand, maximum equivalent stresses were also increase with the increasing of wind loads on the surface of solar PV module [19], [20]. The maximum and minimum values of equivalent stress were observed 62.866 Mpa and 15.75 Mpa respectively. Figure 7 & 8 are also show the distribution of total deformation and maximum equivalent stresses on the supporting structure of solar panel.

**Figure 5** Variation of Deformation with different wind load

**Figure 6** Variation of Maximum Equivalent stress with different wind load
It is evident from Figure 7 that maximum deformation was observed at upper surface of the structure due applied wind loads on the upper surface solar panel. Self-weight solar PV module was also considered during FEA structure analysis. Self-weight of solar panel was applied downward due to gravity force of earth. So the combination of wind loads on the upper surface of solar panel and downward self-weight of solar panel combine leads tend to failure of solar panel structure. Wind loads were calculated and investigated by wind speed. Wind loads applied on the upper surface of solar panel horizontally which deform the structure. Figure 8 shows the distribution of maximum equivalent stresses on the solar panel structure. It is evident from the Figure 8 that maximum equivalent stresses occur at the joint section of solar panel structure. In most of the cases, stress concentration is higher at the joint section of the structure.

For example, the aircraft, loading is divided into two major categories: limit loads and ultimate loads. Limit loads are the maximum loads a component or structure may carry safely. Ultimate loads are the limit loads times a factor of 1.5 or the point beyond which the component or structure will fail. Structural loads are an important consideration in the design of buildings. Building codes require that structures be designed and built to safely resist all actions that they are likely to face during their service life, while remaining fit for use. Minimum loads or actions are specified in these building codes for types of structures, geographic locations, usage and materials of construction. Structural loads are split into categories by their originating cause. In terms of the actual load on a structure, there is no difference between dead or live loading, but the split occurs for use in safety calculations or ease of analysis on complex models. To meet the requirement that design strength be higher than maximum loads, building codes prescribe that, for structural design, loads are increased by load factors. These load factors are, roughly, a ratio of the theoretical design strength to the maximum load expected in service. They are developed to help achieve the desired level of reliability of a structure based on probabilistic studies that take into account the load's originating cause, recurrence, distribution, and static or dynamic nature.
Figure 7 Distribution of total deformation at various wind loads
Figure 8 Distribution of maximum equivalent Stress at various wind loads
4. Conclusion

Structural analysis of solar panel supporting structure has been conducted to investigate the structural properties and structural stability at various wind loads. The conclusions drawn by this study is given below;

- The maximum equivalent stress distribution and total deformation in the turbine runner has been greatly affected by various wind loads.
- Total deformation and maximum equivalent stress increase with the increasing of wind load on the surface of solar PV module. The maximum value of equivalent stress can be found at joint sections of solar panel supporting structure and total deformation is higher at centre of the structure as well as at base of the structure.
- The maximum and minimum value of equivalent stress 62.866 Mpa and 15.75 Mpa can be found at 40 m/s and 20 m/s respectively. Similarly, maximum and minimum value of total deformation 0.3631 mm and 0.0911 mm can be found at 40 m/s and 20 m/s respectively.
- According to current research, it is also concluded that further work is needed for the solar panel structure under other various parameters such as different solar panel structure materials. It is also considered from the current research, vibrational analysis, fatigue analysis can be analyzed for solar panel structure. The knowledge of stress distribution and deformation play a vital role for structure designs, stability and strength of hydro solar panel supporting structure.

References


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**Dedication**

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**Conflicts of Interest**

There are no conflicts to declare.

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