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Influence of Wind Characteristics and Other Parameters on Module Mounting Structures

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Abstract: *As one of the most common and imperative contributing factors to clean energy aspect, solar energy takes a significant role around the whole world. Among neighbouring countries regarding the energy sources India has a relatively more potential for solar energy to decrease its energy dependence to the other countries and to increase awareness for sustainable, easily reachable, economical and continuous energy use. In the photovoltaic (PV) solar power plant projects, PV solar panel (SP) support structure is one of the main elements and limited numerical studies exist on PVSP ground mounting steel frames to be a research gap that has not be addressed adequately in the literature. In this paper, aiming to provide a contribution to this gap, a PVSP steel support structure and its key design parameters are described to obtain actual demand of environmental effect like loads wind, snow, and seismic loads.*

Keywords: Photovoltaic (PV), Solar Panel (SP), Steel, Support Structure, Ground-mounted Solar PV Plant, steel structure

I. INTRODUCTION

Solar energy is a hopeful, sustainable, new kind green energy which is never-ending, independent and plentiful. Solar panels (SPs) can be various cross-sections (e.g., square, rectangle) and sizes but their main purpose is to convert the sun light in order to make electricity. Normally, solar power systems can be separated into three used groups like

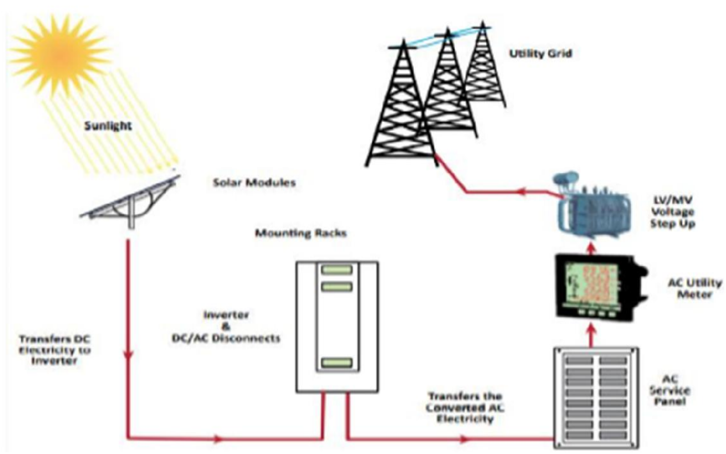
1. Concentrating solar power,
2. Solar-thermal absorbers and
3. Photovoltaic (PV) SPs.

PVSPs directly transform solar to electrical energy using semiconductor materials which can produce free electrons utilizing of sunlight energy (Parida et al., 2011). PVSPs have many usage fields, such as solar home systems, PV water pumping, remote building, solar cars and airplanes, satellites and space vehicles, etc (Kalogirou, 2004). Such a wide range of application fields increase demand for PVSPs due to the electrical power generation through PV transformation gives clean, safe and efficient way of supplying energy. The developments of current technology for PVSP field significantly vary, especially for installation methods and mounting locations (e.g., ground, roof, or integrated with the building envelope) affected by wind, snow and seismic loads differently. Experimental and numerical studies have been conducted by several researchers to show the effectiveness of different types SPs. Mihailidis et al. (2009) proposed a finite element analysis (FEA) of two different design approaches of SP support structures such as fixed support and adjustable support structure design. Cao et al. (2013) performed a wind tunnel experiment to evaluate wind loads on SPs mounted on the flat roofs. Lin et al. (2013) proposed a FEA approach to find the structural deformation and misalignment of solar radiation using the effects of self-weight and wind loads. The result shows that this technique was found to be sufficiently reliable to design PV systems. Aly and Bitsuamlak (2013) carried out experimental tests on large civil engineering structure models with geometric scale of 1:500 to 1:100 to produce an aerodynamic model of SP subjected to wind load and mounted on ground. Mathew et. al. (2013) studied on design and stability analysis of SP support structure made of mild steel. The result shows that the SP support structure can able to sustain a wind load with velocity $55ms{-}1$. Baetu et al. (2013) presented numerical simulations performed in ANSYS for analysis of wind action on SPs located on a flat roof with and without parapets to understand the location of mounting of SP support structure affects the SPs' performance. In recent years, the design of PVSP support system has become the focus of attention with the popularization and increasing application fields.

II. WORKING PRINCIPLE

Photovoltaics directly convert solar energy into electricity. They work on the principle of the photovoltaic effect. When certain materials are exposed to light, they absorb photons and release free electrons. This phenomenon is called as the photoelectric effect. Photovoltaic effect is a method of producing direct current electricity based on the principle of the photoelectric effect.

Based on the principle of photovoltaic effect, solar cells or photovoltaic cells are made. They convert sunlight into direct current (DC) electricity. But, a single photovoltaic cell does not produce enough amount of electricity. Therefore, a number of photovoltaic cells are mounted on a supporting frame and are electrically connected to each other to form a photovoltaic module or solar panel. Commonly available solar panels range from several hundred watts (say 100 watts) up to few kilowatts (ever heard of a 5kW solar panel?). They are available in different sizes and different price ranges. Solar panels or modules are designed to supply electric power at a certain voltage (say 12v), but the current they produce is directly dependent on the incident light. As of now it is clear that photovoltaic modules produce DC electricity. But, for most of the times we require AC power and, hence, solar power system consists of an inverter too.



III. OBJECTIVE

These structures helps panels to rest com- portably, prevent from being damaged more importantly position them at precise tilt angle to harness maximum sun's energy. In order help that here the current objective focus is to study the Influencing Parameters for Module Mounting Strustures along with Wind Analysis..

IV. LITERATURE STUDY

Alex Mathew & B. Biju et al. studied design and stability analysis of solar panel supporting structure subjected to wind force. In this study the arrangement of solar panels in structure is similar to double sloped roof trusses. Due to this wind force, the structure experiences an overturning effect. This overturning couple imparts a reaction force at the base of the structure. The structure is symmetric along any vertical plane. They used CAD modelling software CREO 2.0, the test model of solar panel supporting structure was created steel. They concluded that the design of solar panel supporting structure is done and the effects of wind force on its structure stability are analyzed. Due to the wind force, a reaction force is experienced on the structure and the structure will retain its stable state, only if this reaction force is compensated by the force due the self-weight of the structure. This structure will be used as the fuel stations to meet the energy requirement of solar cars, as it can be used for domestic purpose, commercial purpose.

Mihailidis et al. represented the analysis of two different design approaches of solar panel support structures which are 1) Fixed support structure design, 2) Adjustable support structure design. They did analysis according to the following steps.

Load calculation, 2) Analysis of the structure, which includes the creation of a Finite element model using ANSA as pre processor. Loads calculated in the first step are applied to the model. As solver MSC Nastran is used. 3) Identification of the structure critical points. According to the results weak points are redesigned in order to increase the end.

Jinxin Cao et al. performed a wind tunnel experiment to evaluate wind loads on solar panels mounted on flat roofs. In order to find module force characteristics at different locations on the roof they use solar array which were fabricated with pressure taps. They consider two different cases 1) single array, 2) multi-array and find mean and peak module force co- efficient. They also find effect of mean module force co-efficient on design parameter of solar panel. They found effect of mean module force co-efficient on design parameters (tilt angle, height) of solar panel. The results show module force coefficient for single array cases is larger than multi array cases.

Chih-Kuang Lin et al. use FEA approach to find the effects of self weight and wind loads on structural deformation and misalignment of solar radiation. Sayana M. et al. studied Buckling analysis of solar panel supporting structures. In this study buckling analysis is done by 1) Eigen value buckling analysis, 2) Non Linear buckling analysis. In this project Finite element procedure is carrying out. In which the body is sub divided into small discrete regions known as finite elements. These elements are defined by nodes and interpolation functions. Governing equations are written for each element and these elements are assembled in to a global matrix. Loads and constraints are applied and the solution is then determined. ANSYS software which is finite element software has been used for this study. They concluded that the stability of a structure depends several factors such as sectional properties, sectional arrangements, modeling of the structure etc. From the results they concluded that the standard sections improve the stability of the structure, the arrangements of I, C, and L section affect the buckling behavior of the structure. Among these sections I section have more stability but it is not economical, and the C section is less stable during buckling. During loading such as due to the weight of the panel and the effect of wind, more stress occurring at the roof of the panel supporting structure, the L section is more suitable at the place of maximum stress.

V. METHODOLOGY

5.1 Design Methodology

- **a.** Adaptive Design of the Members.
- **b.** Theoretical Checking of individual members for structural safety.
- **c.** Modeling and Analysis of the panel structure for Strength.
- **d.** Optimization of Panel member strength.
    - **1)** ASSUMPTION The Modeling and analysis of supporting structure is based on various assumptions: a. The wind load is acting in horizontal direction. b. Wind load is acting with a constant velocity. c. Only wind force and weight of the panel are acting on the structure. Other forces are out of scope of this study.
    - **2)** MATERIAL a. Aluminum b. Galvanized Iron c. Steel d. posMAC
    - **3)** SOFTWARE a. For Modeling Staad-pro. b. For analysis ANSYS and CFD.

VI. MATERIALS

When we decide to install solar plant, the most important thing of the solar plant is to choose the solar mounting structure material, and the material used for the structure affect the solar plant property, safety and solar plant life directly. A good mounting structure can not only wear the weight of solar modules, but can also withstand extreme weather conditions like storms and floods. A variety of materials ranging from wood to polymers have been used to create strong and durable mounting structure for solar panels. Stainless steel has been the popular choice in most cases. Give in the plant location and life cycle, stainless steel has traditionally been the most cost-effective option. However, recent trends show an increased utilization of aluminium hot dip galvanized state along with steel for better protection against rust formation.

Aluminum ideal for strength to weight ratio limitations Existing system typically were not designed to support the weight of a solar installation. But the low density of aluminum helps to make a solar installation feasible, especially on those field that simply cannot handle the high weight of a steel frame structure. Aluminum extrusions deliver superior design flexibility, high strength-to-weight ratio, excellent corrosion resistance and ease of handling and assembly – all of which are essential for a successful commercial rooftop installation. These characteristics make aluminum the metal choice for solar frame structures installed in agricultural applications like solar water pump. Aluminum is "the green metal" and offers a number of advantages over steel for solar structures. An aluminum frame will outlast the life of the solar panel modules yet is cost competitive with steel structures that will rust out before the solar panels wear out. This frees you to design your solar installation for the life of the panels rather than the frame structure, giving you a significant competitive advantage. When its time to replace your solar structure, aluminum is 100 percent recyclable. But, environmental considerations start at the beginning of the process with the raw material used to extrude your components. Using recycled aluminum billet from Hydro reduces the environmental impact of your project by reducing the impact of sourcing and processing raw metal out of the ground.

Aluminum has a unique and unbeatable combination of properties that make it versatile, effective, and attractive for a vast array of applications:

- **Weight** - Aluminum is light with a density one third that of steel (0.097 lbs/in3).
- **Strength** - Aluminum is strong with a tensile strength of 10 to 100 KSI, depending on the alloy and manufacturing process. Extrusions of the right alloy and design are as strong as structural steel.
- **Elasticity** -The Young's modulus for aluminum is a third that of steel (10,008 KSI). This means that the moment of inertia has to be three times as great for an aluminum extrusion to achieve the same deflection as a steel profile.
- **Formability** - Aluminum has good formability, a characteristic that is used to the fullest extent in extruding, facilitating shaping and bending of extruded parts. Aluminum can also be cast, drawn, and milled.
- **Machining** - Aluminum is very easy to machine. Ordinary machining equipment such as saws and drills can be used along with more sophisticated CNC equipment.
- **Joining** - Aluminum can be joined using normal methods such as welding, soldering, adhesive bonding, and riveting. Additionally, Friction Stir Welding (FSW) is an alternative in certain applications.
- **Corrosion resistance** - A thin layer of oxide is formed in contact with air, which provides very good protection against corrosion even in extremely corrosive environments. This layer can be further strengthened by surface treatments such as anodizing or powder coating. And corrosion resistance can be enhanced through alloy selection. Reflectivity - Aluminum is a good reflector of light and heat.
- **Thermal conductivity** -Thermal conductivity is very good even when compared with copper. Furthermore, an aluminum conductor has only half the weight of an equivalent copper conductor. Electrical conductivity -When compared to copper, aluminum has good electrical conductivity. Linear expansion - Aluminum has a relatively high coefficient of linear expansion compared to other metals. Differences in expansion can be accommodated at the design stage, or in manufacturing. Pure aluminum is only used in a limited way commercially. The majority of extrusions are made from aluminum alloyed with other elements. The most common elements used are magnesium (Mg), silicon (Si), manganese (Mn), zinc (Zn) and copper (Cu). Most aluminum extrusions are made from the alloy series listed below:
    - 1000 series Al
    - 3000 series Al + Mn
    - 5000 series Al + Mg
    - 6000 series Al + Mg + Si
    - 7000 series Al + Zn + Mg

VII. DESIGN CONSIDERATION AND LOAD CALCULATION

The dead load includes loads that are relatively constant over time, including the weight of the structure itself, and immovable fixtures such as walls, plasterboard or carpet. The roof is also a dead load. Dead loads are also known as permanent or static loads. The weight of solar panel is dominant dead load in design of solar mounting structure. This calculation of load is invariant hence can be calculated accurately. Clamps, bolts, weight is in negligible amount hence the clamping equipment's weight is neglected.

Weight of individual solar panel = 22kg

Dimension of solar panel = 2m * 1m* 0.04m

Number of solar panels used = 8

Area of solar panel = 2 m2

Total area of solar panel = 16m2

Dead load on the perlin and rafter is = weight one 1 solar panel * no. of solar panel = 8 * 22 = 176 kg

Taking 1kg = 9.81 N

The total dead load of solar panels is = 176 * 9.81 =1726.56 N

Considering factor of safety = 1.5

Load considering factor of safety =2589.84

Live load is a civil engineering term that refers to a load that can change over time. The weight of the load is variable or shifts locations, such as when people are walking around in a building. Anything in a building that is not fixed to the structure can result in a live load, since it can be moved around. So the live load on solar panel is also needed to be considered for design calculations. Though it is not similar to that of other civil structure in which large loads of vehicle, man, machineries are considered but chances of putting object and hanging bags on solar panel structure for temporary purpose or chances of climbing of animals like monkeys, dogs, hens, etc. can't be neglected. In some critical situation like putting heavy object by taking support of solar structure can induce excess force on the solar structure. Live load is considered as 20 N / m2

7.1 Wind Load Calculations

Area of solar panel = 2 m2

Dimension of solar panel = 2m * 1m* 0.04m

Total area of solar panel array = 16m2

Wind press on the structure is calculated by using following formula P wind = 0.6 x V 2 To select basic velocity of air India wind zone map is studied. It shows maximum speed in the different region of the India. From map it shows maximum velocity of air in India can reach up to 33 m/sec to 50 m/s according to region. Considering the Maharashtra state the speed is varying less than 33 to 44 m/sec. the high velocity region is Kokan of Maharashtra and eastern part where velocity is in between 39-44 m/sec. Southern part of Maharashtra having max velocity less than 33 m/sec and remaining middle and northern part has 33-39m/sec. By analysing data, for satisfactory performance of structure in such critical condition of maximum air velocity mostly in storm, it is needed to design to withstand this air force. Hence we need to consider basic velocity of air for design of this critical situation. The basic velocity of air V,V = 45 m/sec

Design velocity, V can be calculate by using the equation

V= k1.k2.k3.

Vb k1 =Risk coefficient or probability factor.

For all general building and structures with a wind velocity of 55m/s, it is 1.

Various values are given in table. k2 = Terrain, height and structure size factor. For terrain category 2 and class A structures, it is 1. A value of this coefficient is given in table.3 Category 2 terrain contains is contained with scattered obstructions having heights usually between 1.5m to 10m above ground surface. Class A are the structures and/or their components such as cladding, roofing etc. having maximum dimensions is less than 20m above ground surface. k3 = Topography factor.

Its value is taken as unity, if the slope of ground is < 30.

While calculating design velocity the k2, k3are taken as unity Design velocity Vd = K1 * k2 * k3 * V 0.91* 1 *1 * 44 = 40.04approx 40

Wind pressure Pwind = 0.6* vd2 960 N/ m2

Calculating projected area of solar panel and F wind acting on the solar panel

From above chart we are selecting 13 degree 18 degree and 0 degree angles for annual functioning of solar panel. The selection of tilt is considered according to the geological location of Maharashtra (considering pune data as representing Maharashtra due to central location) From above the maximum force that will be induced on solar panel structure due to wind load is 4746.24 N. this is a critical wind load condition for storm like situation.

Partial factor of safety for loads, for limit states,

Limit state is a condition just before collapse. A structure designed by limit state should give proper strength and serviceability throughout its life. In limit state method, the limit state of collapse deals with the safety of structure and limit state of serviceability deals with the durability of structure. Serviceability refers to the conditions under which a building is still considered useful. Should these limit states be exceeded, a structure that may still be structurally sound would nevertheless be considered unfit.

VIII. CONCLUSION

One of the largest areas of innovation within solar involves mounting system. Probably the most competitive solar product market (still it's just a drop in the bucket), mounting system are an important element of solar array, they secure solar panels to roof or ground. As per industry estimates, module mounting structures accounts for 9-15 percent of n total cost of solar power plant, depending on the size of the plant. In smaller plants, mounting structure make up about 9 percent of total project costs, while their share increase on large plants. The modified solar mounting structure is based on the analysis of wind velocity considering constants regions velocity and different boundary conditions. The material used for the modified design is appropriate for all the surrounding conditions and cost friendly.

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