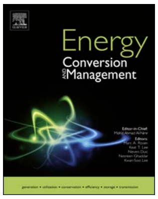
Energy Conversion and Management 154 (2017) 286–298

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman



# Power generation on a solar photovoltaic array integrated with lighter-than-air platform at low altitudes

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## ARTICLE INFO

*Keywords:*
Lighter-than-air platform
Aerostat
Solar photovoltaic array
Non-uniform illumination
Scanning window technique
Distributed maximum power point tracking

## ABSTRACT

Multiple challenges in solar photovoltaic (SPV) modules integrated with lighter-than-air platforms (LTAPs) such as choice of solar modules, determination of the optimal method of integration, and optimal design of the array layout to minimize the power loss due to non-uniform illumination (NUI), limit their applications. In this paper, we propose a method for designing such a system and overcoming the aforementioned challenges. We find that our methodology has implications in estimating the onboard power generation for contoured platforms. Also, the impact of the contour on illumination pattern has been determined. Interestingly, we find that the power generation can be enhanced by 8% using distributed maximum power point tracking (DMPPT) algorithm. Our proposed schemes have application in calculating the power generation for a given volume of LTAP. Further, this study also incorporates the sizing of the platform for developing various peak power systems using specific SPV technology.

## 1. Introduction

In recent years, lighter-than-air platforms (LTAPs) such as aerostats and airships have received renewed research interest because of their low deployment cost for extended periods in against fixed-wing aircraft and quadrotor drones. These platforms are being utilized in range of applications, from reconnaissance and surveillance at coastal and international border areas [1–3]; communication link setup in remote and disaster affected areas [4,5]; conducting geological surveys [6]; geographical mapping of forest, rural, urban, and semi-urban areas [6,7]. A steady and uninterrupted electrical power supply is required for these applications, this can be achieved through power generation in situ (i.e., onboard an airship or aerostat), either by harnessing solar energy, wind energy or by using hybrid power system (solar power –fuel cell). In this context, different concepts of power generation both at low and high altitudes have been studied. For example Yashwanth et al. has explored wind energy harvesting at high altitudes by using wind turbines [8] and its advantages and limitations were discussed elsewhere [8–10]. However, this system is not widely used because of the complexity of the energy conversion process; SPV modules are considered to be advantageous over such systems.

Alternatively hybrid power system (comprised of solar power – fuel cell) has also been investigated to provide operational energy for propulsion and control in the multibody advanced airship for transportation [11]. This concept was further elaborated by Chang [12] to study the power generation characteristics of SPV modules integrated on aircraft wings. Further, it leads to development of globally functional, solar powered, unmanned aerial vehicle by mounting SPV modules on the wings and scaling the dimension of the wings [13]. The other ways to harvest solar energy by using – (a) large satellites and transmitting it to the ground through microwave radiation [14–16] and (b) high-altitude aerostatic platform (HAAP) at an altitude of 6 km above sea level and transmits it to the ground through a cable [17,18] have been studied. Their drawbacks in terms of power transmission losses, control strategies for positioning the aerostat, and the economic viability of the concepts have also been discussed [19,20]. But, only spherical aerostats have been explored in all these cases despite the low aerodynamic stability of spherical shape. Although there are attempt to optimize solar PV array layout for the stratospheric airships using complex genetic algorithm based methodology which is only limited to the ellipsoidal airship with spherical cross section at stratospheric conditions [21]. The displacement of the aerostat from its desired position (termed as blow-by) [22,23] may cause disruption in incident solar irradiance pattern. Thus the stability of these platforms needs to be investigated for the purpose of maximum onboard power generation. Hence instead of spherical and ellipsoidal shaped aerostat, an

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http://dx.doi.org/10.1016/j.enconman.2017.10.039
Received 21 April 2017; Received in revised form 13 October 2017; Accepted 14 October 2017

aerodynamically efficient contoured aerostat with the G. N. V Rao shape (named after Prof. G. N. V. Rao, Indian Institute of Science, who proposed this shape) is found to be more suitable option for low-altitude operations [23]. But the understanding of power generation on such surfaces is lacking in the literature. Though Sharma et al. [24] conducted a feasibility study for generating power on an amorphous-Si solar PV module mounted on a curved surface, the effect of surface contour angle is yet to be explored in the context of the contour of a GNVR shaped LTAP to estimate its maximum power generation ability.

Given this scenario, here, we present a feasibility study for optimized electric power generation onboard an LTAP. Accordingly, we discuss the concept of envelope contour function (ECF) of a contoured structure like GNVR shape. We also demonstrate the corresponding NUI pattern as a function of ECF on a GNVR shaped platform. Based on NUI pattern, we develop a generic methodology to delimit the effective surface area for laying out solar PV array for harnessing optimized maximum power. We find that our methodology is helpful in – (a) determining the impact of contour on solar insolation pattern, (b) estimating the onboard power generation for a contoured platform for a particular SPV technology, (c) enhancing the power generation by ~8% using distributed maximum power point tracking (DMPPT) algorithm, and (d) calculating the power generation for a given volume of LTAP. Further, this study also incorporates the sizing of the platform for developing various peak power systems using specific SPV technology.

## 2. Design methodology

The present study designed and developed a mobile airborne platform capable of power generation and transmission. This requires the design of an aerodynamically stable platform and its appropriate sizing to support the power system and its associated payloads at a certain altitude. Furthermore, additional safety factors should be considered in the design stage. The proposed system is demonstrated in Fig. 1a, whereas Fig. 1b depicts envelope contour function of a GNVR shaped LTAP.

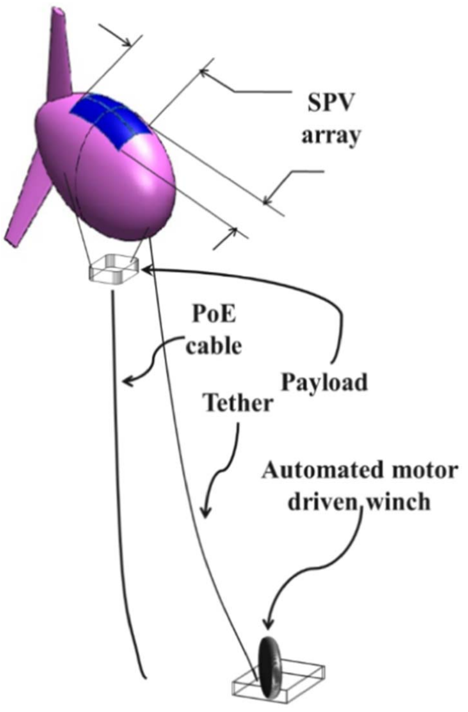

**Fig. 1a.** System diagram of SPV array integrated with LTAP. Onboard power is supplied to the ground through the Power over Ethernet (PoE) cable. Electronic payload is suspended from the system. Positioning of the entire system is controlled by motor driven winch.

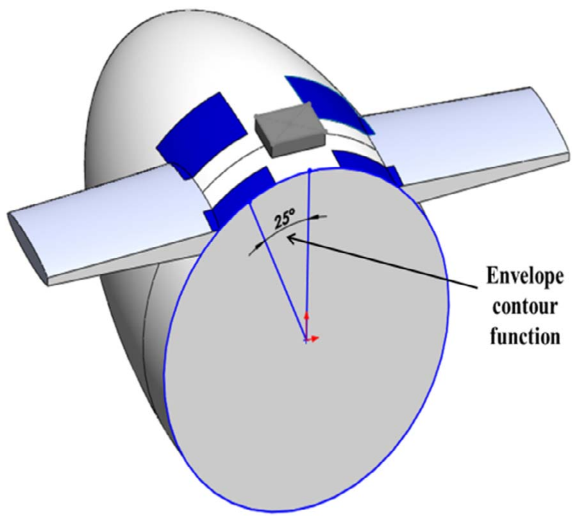

**Fig. 1b.** Envelope contour function of an LTAP. It conceptualizes the phenomenon of variable tilt experienced by the integrated SPV array on an LTAP.

This entire design process requires a series of procedures as follows:

### 2.1. Structural morphology of a GNVR shaped LTAP

A detailed analysis on the structure of the LTAP is required for mounting solar PV array. The structure should be aerodynamically stable and tethered to the ground. It is filled with lighter-than-air or buoyant gas (such as hydrogen or helium) to generate a buoyant lift and carry sophisticated instruments and sensor networks for monitoring atmospheric environment, surveillance, reconnaissance, and GIS. To supply power to these instruments, the SPV modules are placed on the top of the LTAP. These platforms are round and contoured, rather than flat, in shape, which results in stable aerodynamics. The effective surface area of the SPV array layout should be derived for lossless power generation on the contoured LTAP. The LTAP is constructed to have a GNVR shape, which consists of elliptical, circular, and parabolic shapes across the length of the platform. The entire geometry of the GNVR shape is parameterized in terms of maximum diameter, as shown in Fig. 2.

The governing equations for each section are as follows:

$$\frac{x^2}{(1.25D)^2}+\frac{y^2}{0.5D^2}=1 \tag{1}$$

$$x^2+(y{-}3.5D)^2=16D^2 \tag{2}$$

$$y^2=0.1373D(1.8D{-}x) \tag{3}$$

The GNVR shape is a body of revolution, which is a combination of elliptical, circular, and parabolic profiles. Because of its axisymmetric nature, the shape has an identical curved surface on both sides of the

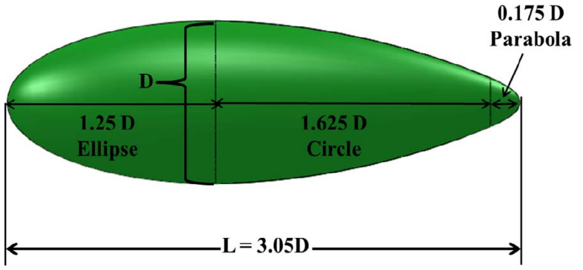

**Fig. 2.** Morphology of the GNVR structure. It is a combination of elliptical, circular and parabolic sections altogether. D is the maximum diameter of the structure. Different dimensions of the structure are represented in terms of D. This structure is aerodynamically stable due to low envelope drag coefficient $C_{DV} = 2.686E-02$ [22].