Maximum Power Point Tracking Problem Solution for Solar Airplane

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Abstract. Solar-rechargeable aircraft is very complex system, which should be designed in mind with many multidisciplinary approaches to gain ability of contrinous flight. This paper provides review for structure of solar-rechargeable aircraft and its main components such as its main solar power system, power system and communication subsystems. The main applicable to aircraft components of power subsystem were described and analysed, based on different factors that could be used during conceptual design: PV cells efficiency, MPPT characteristics, battery storage characteristics and ability of continuous flight. At this paper design of power system were proposed, with brief review of available MPPT algorithms, problem definition and their characteristics that could be suitable for aircraft. At the last section of paper, Simulink-based analysis tool developed for validation of continuous flight possibility and behaviour of energy subsystem with analysis of time diagram during the defined time-frame (48 hours) for solar-rechargeable aircraft which is under design.

1. Introduction

Solar-powered UAVs are a fairly promising type of aircraft, the high availability of solar radiation makes it quite in demand, as it is, in addition to being affordable, and one of the cleanest alternative energy sources. The use of this type of energy is that the presence of solar panels on board as an energy source can significantly increase the flight time. Solar-powered UAVs use solar panels to collect solar energy during daylight hours, once converted, can be used to maintain flight levels and aircraft systems [1].

Given an optimal aircraft design and suitable environmental conditions, it is possible that solar energy will be sufficient to charge the battery and then use the stored energy to stay at flight overnight. This is the so-called continuous flight capability, in which there is a cyclic use of the energy stored in the battery during the night period, and the battery recharging during the daytime.

As a result, these expectations from a solar-powered UAV open up many tasks that must be solved in a comprehensive manner, ranging from analysing and collecting requirements, calculating aircraft system components and ending with energy management, as well as introducing many different optimization algorithms and finding optimal operating modes for various subsystems [2].

Solar powered UAVs are excellent candidates for a number of potential applications: remote sensing, terrain surveillance, search and rescue, atmospheric platforms, remote weather surveys, continuous terrain patrols, telecommunications relaying, or large scale agricultural or industrial aerial inspection [3].

This work seeks to analyze the power plant of a solar UAV, taking into account the advantages of the technologies used, as well as the developments that have been over the past decade.

For the construction of this UAV the main technical subsystems are: solar panels, an energy storage subsystem, as well as an energy converter, in this case a DC-DC converter, in the form of an MPPT device. It is customary to place solar panels on most conventionally flat surfaces, such as wings and tail, the storage system is located in the fuselage, depending on the design, as well as control systems. The aircraft subsystems will be discussed in more detail below.

In the history of aviation [4, 5], many different solar-powered UAVs have already been developed and built.

2. Structure of Solar-Rechargeable Aircraft

Structurally, the solar rechargeable airplane has no difference from a conventional UAV it consists of: a fuselage, wings and tail, propulsion group and has a certain layout scheme. At figure 1 we could observe glider structure which is most common at solar-rechargeable aircraft designs [6].

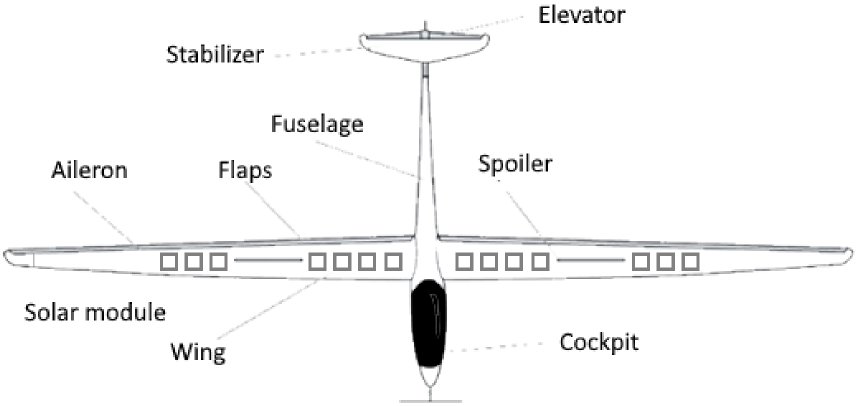

Figure 1. Glider aircraft layout.

As a result, the structure can be described as a set of main blocks that must be taken into account and designed at the conceptual design stage, as well as during the aircraft equipment: body of UAV (layout and wing profile), solar energy power system, propulsion group, flight controller, sensors and navigation equipment, connection to a base station via radio channel, as well as telemetry equipment, payload which would be used by aircraft’s mission [7].

Regarding that part of the solar UAV, which is a kind of superstructure on top of the basic systems that convert solar energy to provide or support the aircraft onboard systems with energy, as well as to ensure the flight level. These systems are displayed in the energy structure of the UAV in figure 2, this structure includes 4 main groups of systems, including the solar energy subsystem, which we will discuss in more detail.

First of all, we should pay attention to solar panels, their typical placement on the wing of an airplane is covers the upper plane of the wing, since the wing profile is on a straight line, there are many different angles of incidence of solar lighting on solar modules. Note that there are many types of solar panels, they are classified according to the materials that were used in the production. Although there are many different types of solar panels on the market at the moment, not all of them are suitable for use on board solar UAVs, the reasons can be many: conversion efficiency, cost, environmental compliance, total weight, flexibility.

Regarding the main subsystems indicated in figure 2, we will consider each of them separately.

The solar subsystem converts solar energy into electrical energy in order to perform the function of powering on-board systems. Its consist of **solar panels** that give out "raw" energy, a **DC/DC converter** which is used to convert energy from solar panels in accordance with the norms of the on-board power network, the **MPPT module** is an auxiliary converter control module to find the maximum power point of solar panels (details in next section), as well as a **storage subsystem**, which consists of a charge controller and a battery, their main function is damping and buffering of the on-board network.
At this paper, we will not stop on propulsion group and communication subsystem, they are almost identical to any electrical UAV.

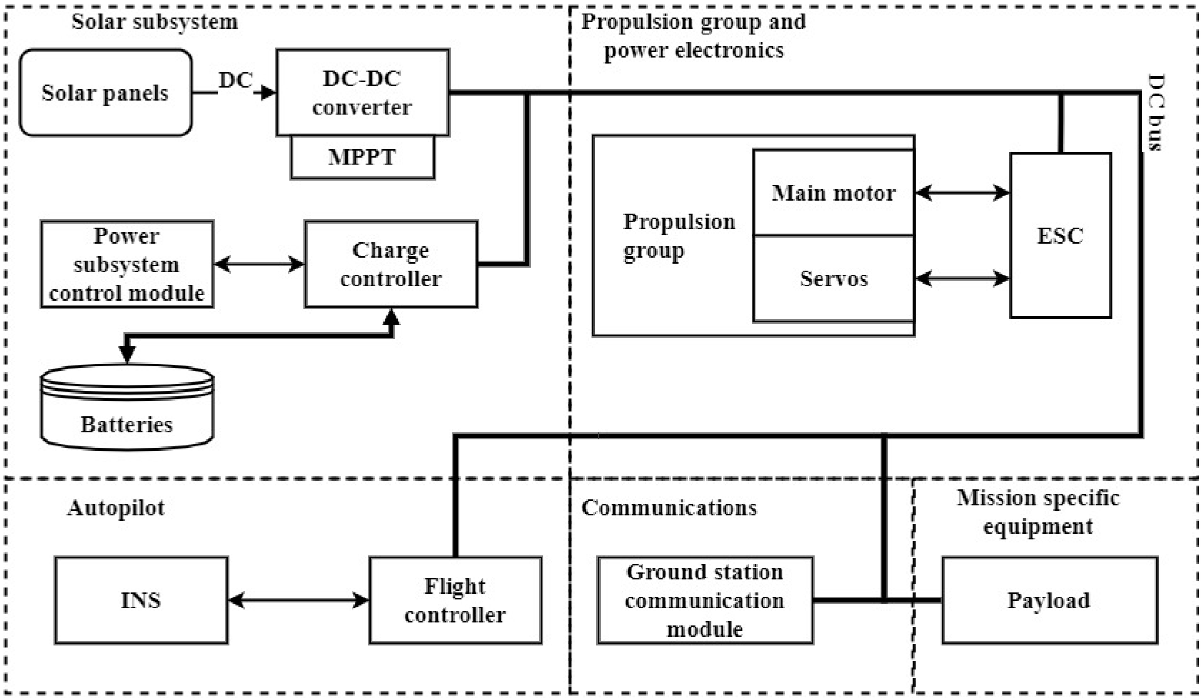

Figure 2. Structure of Solar UAV.

3. Maximum power point tracking

Maximum power point tracking is a principle that is used to find a point that is located on I-V curve of the solar cell (figure 3), importance of this is the solar cell operated in its optimum mode and generate maximum power. The nature of solar cells makes non-linear I-V characteristics and that is why the output power become very dependent on the operation conditions and the level solar irradiance, this conditions make the MPP fluctuates over I-V and P-V curves [8, 9]. To control power conversion efficiency DC/DC convertor is used, but as a algorithm how to find MPP and what duty cycle should be set various algorithms were proposed. Working near that point is very important, because of power lost.

Therefore, in order for the power plant of the aircraft to work in the most efficient mode, an algorithm with the maximum accuracy and tracking speed must be selected. This energy subsystem is shown on figure 2 at solar subsystem part [10].

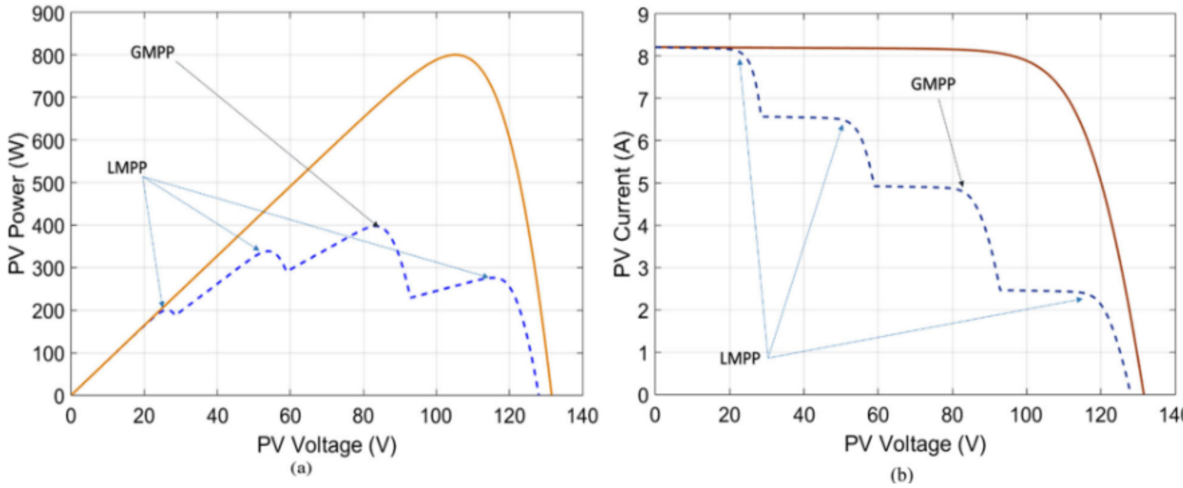

Figure 3. I-V and P-V curves of solar cells with effect of PSO.

P-V curve represents power obtained from the solar cells, and equals zero when it in short circuited state or open circuit when there are no current from the panels, these points are I_{SC} and V_{SC} on the figure 3.
The maximum point is directly visible on P-V which is P_m and on I-V curve could be reached by:

$$P_m = I_m * V_m$$

where I_m and V_m is from P-V to I-V curve.
Analytically MPP could be found by looking up maximum on P-V curve:

$$\frac{dP}{dV} = 0$$

Next big issue that influence on maximum power extraction from solar cells is a usage of bypass diodes in solar arrays (strings configuration, figure 5). Partial shading condition – is effect name when working cells could have some hot points on its surface and can be irreversibly damage. These hot spots are forming after cell's power loss or degradations in string connected configuration. Because each cell at string should maintains constant current and part of lost power generated as heat. To remove those affect each cell (ideally) should be reverse biased with bypass diode, that will turn-off shaded or damaged cell [11, 12].

Table 1. MPPT Algorithms and characteristics.

Alg. name	***Tracking time***	***Response time***	***SSO***	***SC specific***	***GMPP***	***Compexity***
P&O	Var	Fast	No	No	No	Low
IncCnd	Fast	Fast	No	No	No	Low
RCC	Fast	Fast	No	No	No	Low
Fuzzy	Fast	Fast	No	Yes	No	High
PSO	Var	Var	No	Yes	Yes	Avg
Fuzzy Logic	Fast	Fast	No	Yes	Yes	High
Neural networks	Fast	Fast	No	Yes	Yes	High

This effect could dramatically degrade cell's characteristics and also introduces many local maximum power points (LMPP) and only one global maximum power point (GMPP) on P-V curve.

At result, there are three main groups of MPPT algorithms: traditional tracking methods – global maximum tracking is not guaranteed (could stuck on local maximum, example: perturb & observe, incremental conductance, ripple current correlation etc.), improved traditional tracking methods – modified traditional method to be ready for PSC and global maximum tracking methods – group of methods that was specially developed to find global maximum during shading conditions.

Comparision of the popular MPPT algorithms presented at table 2 [13, 14, 15] by the main characteristics: tracking time (time to find MPP), response time (detection of characteristics change due to environmental factors), steady-state oscillation time, and dependency to specific solar panels (if stated – requires calibration for specific solar cells), global maximum tracking ability, implementation complexity and cost.

4. Analysis of Solar Flight

To perform proper analysis during conceptual design of solar-rechargeable aircraft we should design a tool that will be use environmental, aircraft, power system design parameters specification with ability to implement modelling of all the subsystems of the aircraft [6].

Main models of this tool are (figure 4):

- irradiance model that represents the energy provided by the sun (requires environmental specification location, date and time)
- energy model that calculates power distribution (requires specification of solar cells parameters, battery bank parameters, MPPT algorithm)
- solar-rechargeable aircraft dynamic flight model (requires flight, mission parameters and power requirements).

Simulation models are implemented at Simulink software and shown at figure 5.

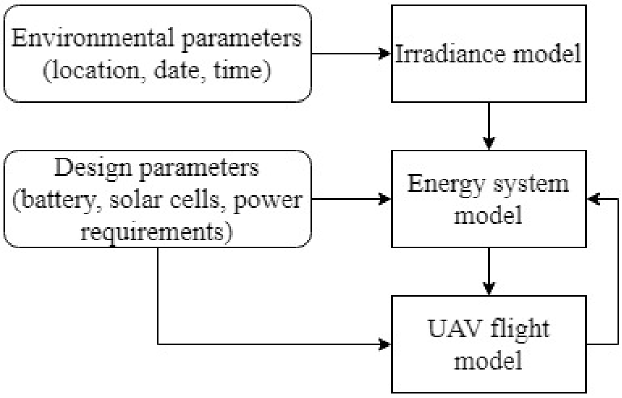

Figure 4. Analysis tool structure.

Functional blocks of simulation tool:

- Location Irradiance – irradiance model by Duffie and Beckman for calculation of irradiance by location and time;
- Irradiance to Power converter – solar cells model (single diode model) and power converter model with implemented MPPT algorithm;
- Battery Bank Power System - energy storage, simulates power management system (with charging, dumping and buffering ability) and declares power levels and state of charge for batteries;
- Flight Controller - flight strategy (holding altitude or gaining to store energy as potential energy) and power requirements.

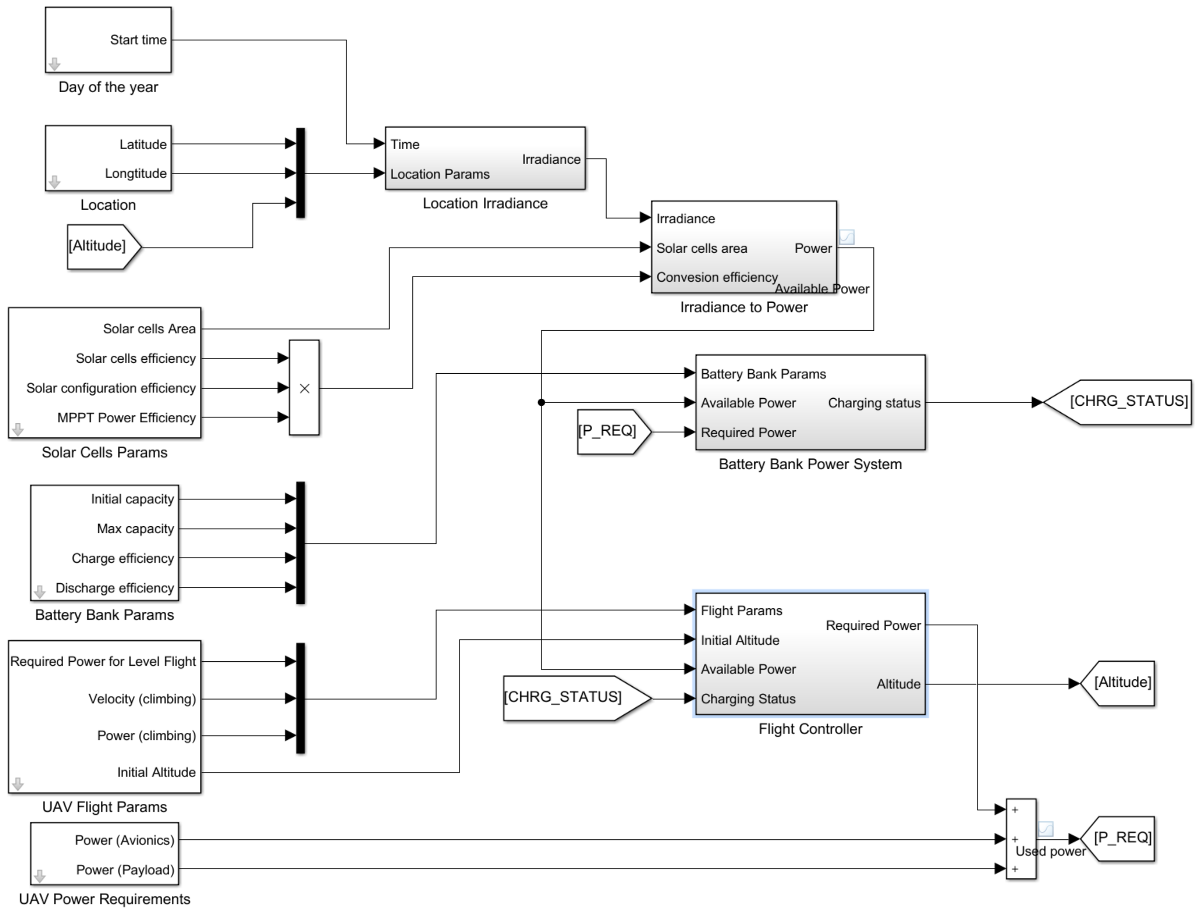

Figure 5. Analysis tool of Solar UAV.

Simulation Results are done by using parameters stated at table 2 for validation of possible continuous flight ability. All internal states of subsystems extracted by using probes.

Table 2. Parameters of analyzed UAV.

Parameter	***Value***	**Parameter**	***Value***
Start time	1/Aug/2018 10:00	Battery Capacity	168Wh
Location	Kyiv, Ukraine	Charge/Discharge efficiency	0.98
Simulated Altitude	100m	Level flight power	12W
Solar cells area	0.6m^2	Velocity (climbing)	0.1m/s
Solar cells efficiency	0.18	Power (climbing)	14W
Solar configuration eff	0.95	Power Avionics	2.5W
MPPT efficiency	0.98	Power Payload	0.5W
Battery initial SoC	168Wh		

After finishing the simulation, its results show that continuous flight is possible for defined conceptual design of the solar-rechargeable aircraft. At fig. 6a there are comparison of available power, required power by all of the systems and charging power. At fig. 6b represents state of charge of the battery.

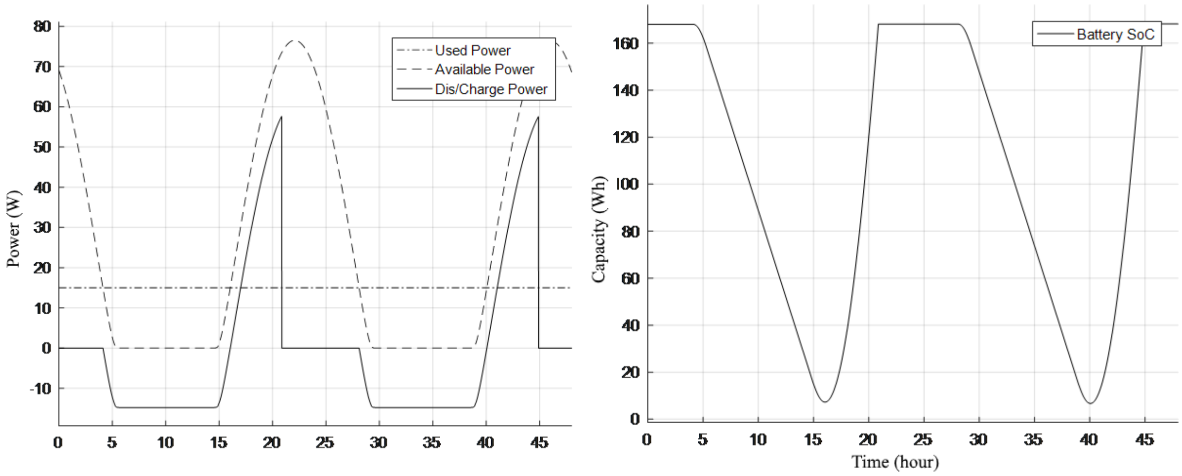

Figure 6. (a) Comparison of available/used/charge power; (b) battery state of charge. This simulation is split to main 3 phases: initial start and flying at daylight (phase 1), followed by flying at night time (phase 2) and phase 3 is a proof that continuous flight is possible by reaching all required energy levels to repeat phase 1 and 2. At this simulation, it is shown as straight horizontal line in time interval (21-28h) where battery is already charged before starting phase 1 and 2.

Conclusions

Solar-rechargeable aircraft is very complex system, which should be designed in mind with many multidisciplinary ideas; at this paper we made a stop on power system oriented approach to solve the problems of this design, such as an MPPT problem which is very important during power system implantation and conceptual design validation by designing the simulation tool. For the part of MPPT it is feasible to implement any tracking algorithm that supports tracking of global maximum power point, but algorithms characteristics should be in mind and very suit to the mission of that aircraft. For the part of simulation tool, it could be used on the last step of conceptual design for the result validation or be a part of multidisciplinary optimization tool for result validation step. There are future steps to improve it, such as adding dynamic payload functional block, feedback line between flight dynamics and angle of incidence of solar beams to surface of solar cells and improving accuracy of the all used models to be more precise during simulation.

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