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Modeling and Simulating the Photovoltaic System to Supply Electric Energy for a Two-Seater Plane with a 60 Kw Motor

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Abstract:- This study aims to investigate the emergence and achievements of solar aircraft in the aerospace industry and highlight the unexpected result of this trend. First, a brief history of solar aircraft is presented. Then, based on their characteristics, an aircraft suitable for the desired objectives is selected. Subsequently, photovoltaic cells, functions, types, and how to choose the type of cells are discussed. What's more, the design of the power supply system of an electric aircraft through photovoltaic cells is discussed based on parameters such as battery type, flight duration, and weight of the aircraft with regard to the power of 20 kW supplied by a 20 kW brushless motor. We select the desired battery by evaluating the types of batteries regarding weight, dimensions, and expected power, except for the power obtained from photovoltaic cells. Then, the types of inverters and how to choose the desired inverter are discussed based on the operation of the aircraft and voltage drop and rise. Finally, by simulating this plane in MATLAB and evaluating the expected results of the plane regarding the flight duration, maximum load bearing, and dimensions of the plane, we reach the desired design.

Keywords*: aircraft, photovoltaic, BLDC motor, torque, inverter*

1. Introduction

Over the past few years, the use of renewable energy has drawn human attention due to the foreseeable depletion of fossil energy sources. In this regard, due to its cheapness and ease of use, solar energy is extremely important. Due to many advantages such as continuous flight, high altitude, low speed, and very low cost of flight, solar aircraft has received much attention from aviation science researchers in recent years as an alternative to telecommunication satellites in exploratory, reconnaissance, telecommunication, agricultural management, and dealing with natural disasters. For example, NASA has invested $64 million and $33 million in solar aircraft projects between 1994-2000 and 2001-2003, respectively. These planes can complete the missions of ground and satellite systems more economically. The ability to return quickly in solar planes provides protection against unforeseen factors as well as good serviceability. The most important aspect of solar aircraft applications is the expansion of surveillance uses and services based on high-frequency communication and internet services. Using of solar planes in special missions such as missile defense and flying over other planets has also been proposed [1]. Fred Militky and Heino Brditschka (1973) converted a Brditschka HB-3 glider engine into the Militky MB-E1 electric aircraft, considered the first man carrier capable of flying under electric power. Heino flew this plane for 14 minutes in the same year. The non-profit CAFE Foundation (2007) held the first electric aircraft symposium in San Francisco. The first electric aircraft made its first flight in the same year.

2. SUNRISE II plane

The Militky MB-E1 (1973) in West Germany flew a full-size aircraft based solely on electric power. The aircraft used 10 kW (13 hp) NiCd batteries on a DC motor to provide power for 12 minutes.

The 27-pound (12 kg) AstroFlight Sunrise unmanned aircraft was built as a result of an ARPA contract and made the world's first purely solar-powered flight on November 4, 1974. An updated version, Sunrise II, flew at Nellis Air Force Base on September 27, 1975.

The first official solar-powered flight of a human-carrying aircraft was accomplished on April 29, 1979. The Mauro solar plane was built by Larry Mauro based on the UFM biplane. This aircraft uses photovoltaic cells providing 350 watts at 30 volts and is able to power the engine for 3 to 5 minutes after 1.5 hours of charging [2].

3. SOLAR I plane

The glider-based motor plane was built in the form of a pedal plane to cross the channel. The electric motor battery used is charged before flight by a solar cell array on the wing. The first flight of the Solar One was accomplished at Lasham Field Airport, New Hampshire on June 13, 1979. The Penguin is a smaller version of the Albatross that is entirely based on a solar battery system. The second prototype, the Solar Challenger, flew 262 kilometers (163 miles) from Paris to England. On July 7, 1981, this solar-powered aircraft flew 163 miles from Cormeilles-EN-Vexin near Paris across the English Channel to RAF Manston near London in 5 hours and 23 minutes. Solar Challenger, designed by Dr. Paul McCreity, set a record altitude of 14,300 feet.

AeroVironment bionic bat is an aircraft developed specifically for the Kramer Prize Speed Challenge organized by the Royal Aeronautical Society. This aircraft used an electric motor as a generator based on the pedal action of the pilot and charging Ni-CAD batteries. The stored energy was used to supplement pedal power by the pilot. In 1984, this aircraft won two parts of the Kramer Award Speed Challenge [3]. The SOLARI manned aircraft was developed by Günther Roecklet based on the design of Hans Farner. Wing-mounted solar cells provided between 1.8 kW (2.4 hp) and 2.2 kW (3 hp). This aircraft first flew in Untrossen, Germany on August 21, 1983, for duration of 5 hours and 41 minutes. Its fuel was mainly supplied with solar and thermal energy.

4. Selecting the type of aircraft

Considering the output power of 7500w and supplying 6kw through photovoltaic panels, we need a 1kw battery weighing 8kg and the total weight of the battery and photovoltaic cells reaches 48 kg. For this purpose, we use the SOLLAR II aircraft [4].

5. Solar panels

This section introduces a solar radiation energy converter to electrical energy without mechanical intervention. Photovoltaic panels consist of photovoltaic cells that are exposed to sunlight. It should be noted that the output current and voltage of these panels are of DC type. These panels are resistant to all environmental hardships such as polar extreme cold, desert heat, tropical humidity, and strong winds. However, there is a possibility of glass photovoltaic panels breaking due to heavy blows. The specifications and constituent elements change due to the need of the consumer's load and local weather conditions. Therefore, possible failures along with information about each part can be received from the control department. This system consists of several parts including battery, charging control, MPPT, inverter, and control system. Every consumer does not necessarily use all mentioned parts. According to the specifications and needs of each consumer, the power generation part includes some of the mentioned parts. The duties of the controller include homogenizing the performance of all system components (including MPPT, charge control, etc.), commanding different parts when necessary, collecting information from system performance, notifying system components, protecting the entire system, and grounding system protection [5].

6. Battery selection

Due to the need for a 1KW/h battery and for the desired battery weight (according to the selected SOLAR II aircraft), the lower price, and the higher energy density, we chose Li-ion batteries to supply the desired aircraft [6].

7. BLDC brushless motor control and drive

Brushless permanent magnet motors are used in computer equipment, robots, and electrical appliances. For low-speed applications, permanent magnet motors eliminate the need for a gearbox (similar to standard induction machines). An example of a BLDC motor is represented in Figure 1 [7].

Figure 1: BLDC motor

The commutation action in direct current motors with brushes is performed by the mechanical part of the brush. In such engines, every mechanical part needs maintenance. It reduces the friction between the components of the engine. The sparks from changing the poles increase the possibility of the engine firing. In order to solve these problems based on the properties of the magnetic field, DC motors are controlled electrically. The operation of this controller is done by detecting the position of the rotor. As a result, the motor's power can control the speed and torque and eliminate the need for an encoder [8].

8. Introduction of normal DC and BLDC motors

Due to the general use of AC generation, transmission, and distribution systems (instead of DCs), DC machines are now exclusively used as motors. In this regard, brushless motors (BLDC) are used in this study [9].

9. MPPT

9.1. P & O method (Perturbation & Observation)

The performance of the algorithm is as follows.

- Making changes in the working point (Figure 2)
- Measurement of P and V

- Comparing the new P with the old P regarding Vs

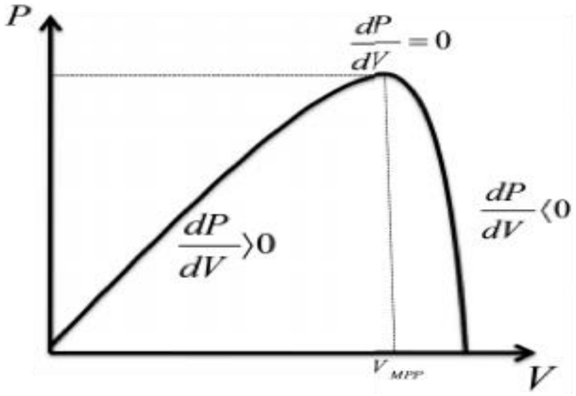

Figure 2: The effect of working point changes to achieve the optimal working point

In this simulation, the more common P&O model is used. The Simulink model of the P&O method is reflected in Figure 3.

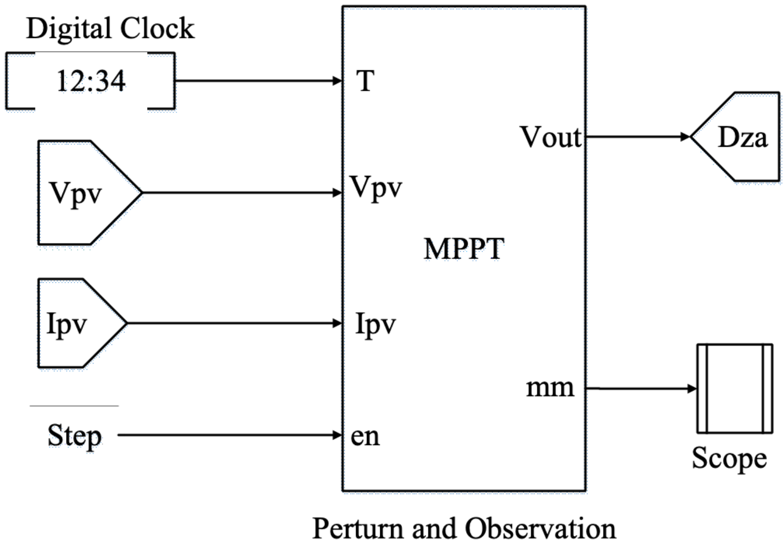

Figure 3: Simulink model of P&O method

10. Simulation of the power grid of the solar plane

In order to demonstrate the operation of a solar aircraft, a system including a photovoltaic (PV) array, a charge controller, a battery, and an electric motor has been built. The system diagram is represented in Figure 4. The system collects energy from the PV arrays. It then optimizes the collected energy to operate an electric motor or store it in a rechargeable battery for future use. This system has a control panel showing the output of the array, the battery, and the final current sent to the electric motor. The control panel is used to apply the output to the motor to control the speed. The entire system is configured for 12 VDC.

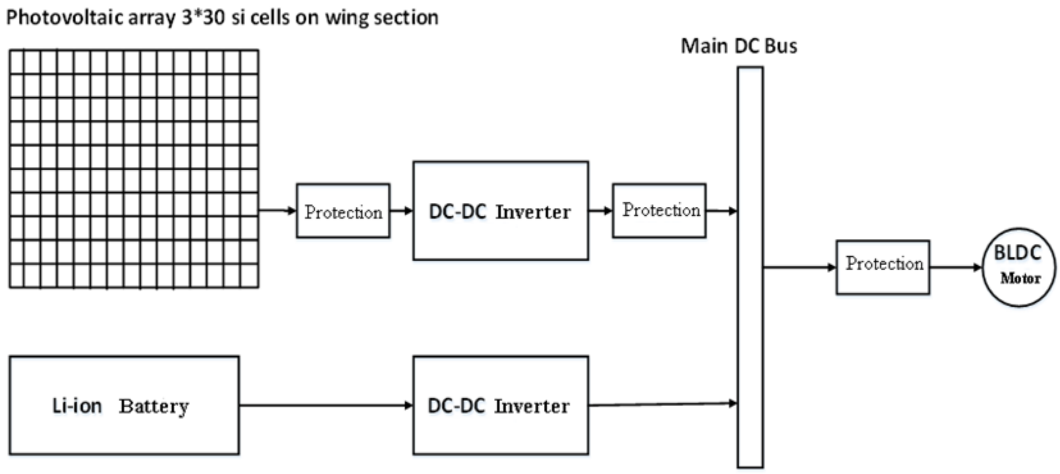

Figure 4: Aircraft electrical grid diagram

11. Simulation parameters

11.1 Speed (□)

The first simulation parameter is specific to the engine speed. The necessary power for the operation of the engine is provided according to the speed of the aircraft at the moment of take-off, deceleration during the flight, and the lowest speed at the moment of landing. The speed of Solar II aircraft reaches 36 km/h at the moment of take-off. According to the speed of the engine, power is produced at around 20 kW. Based on the protection set at the moment of 0.52 seconds, the power value reaches 160 kW. This power can provide maximum motor speed and panel voltage.

11.2 Torque (T)

Load torque is the second simulation parameter. The power value is obtained from the product of torque (Nm) and speed (rad/s) as follows:

By considering the parameters of speed and torque and their product, the required power (20 kW in this test) can be calculated. Figure 5 represents the BLDC motor output parameters.

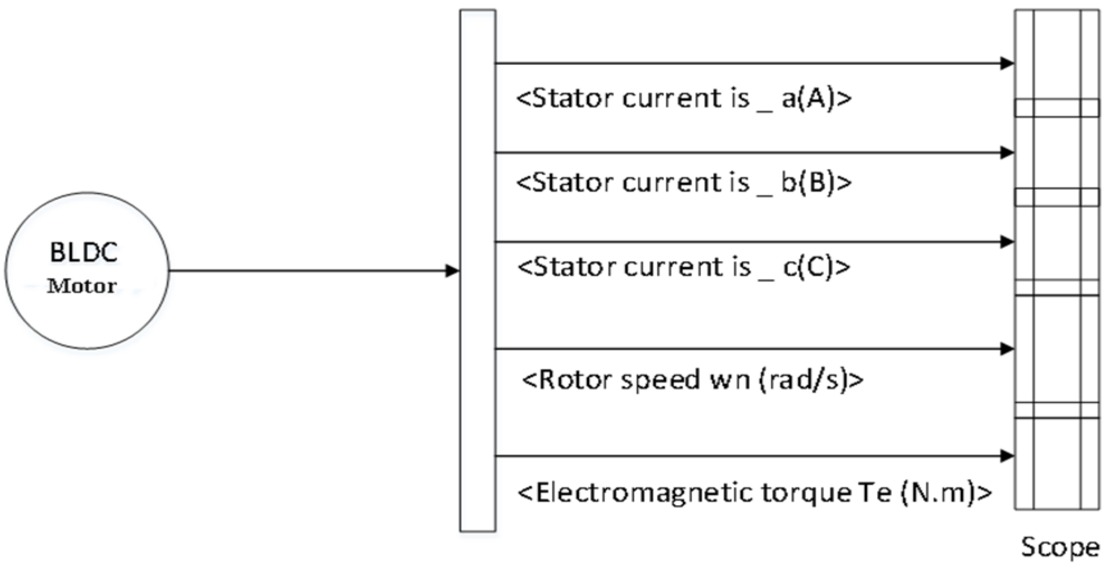

Figure 5: BLDC motor output parameters

Torque analysis

The average torque obtained in this simulation is 4.5 NM. The torque reaches 12NM at the moment the engine starts and fluctuates around point 11 and is responsible for providing the required power at the moment of take-off and reducing it along the way. This torque starts to fluctuate at the moment of 0.52 seconds and continues until the moments of 0.53, 0.55, and 0.6 seconds. The torque is fixed at 6.4 NM at the moment of 0.6 seconds. Subsequently at the moment of 0.12 seconds, it is fixed at 1500 rad/s and creates a power value of 18 kW.

5. Simulation results

In this section, the results obtained from the proposed model have been examined in different conditions of engine operation. The output current of the battery increases the attenuated voltage based on the boost converter. This current is represented in Figure 6. As shown in this figure, the current first starts at about 1900 amps and after 0.15 seconds it makes 3 oscillations. First, its direction changes up to 1200 amps and returns to the initial value of 1900 amps. Therefore, the DC power produced by the photovoltaic panels as well as the lithium-ion battery is converted to AC power by the selected inverter. According to the battery output voltage shown in Figure 7, one oscillation occurs every 0.005 seconds. Then the battery voltage increases to 530 volt and subsequently returns to the base value of 270 volt. This back-and-forth is caused by the accumulation of the charge of the photovoltaic panel in the battery and then discharging it to the required amount of 260 volt in aircraft's electric motor.

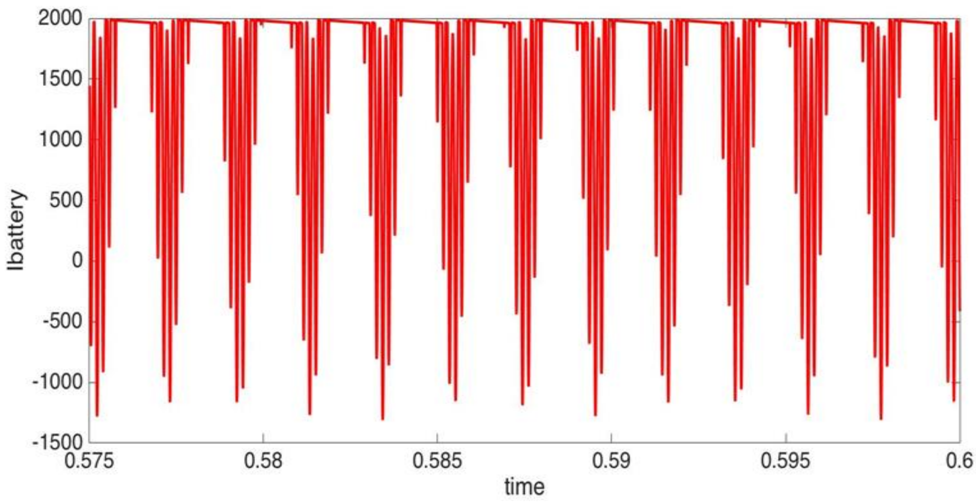

Figure 6: Output current from the battery

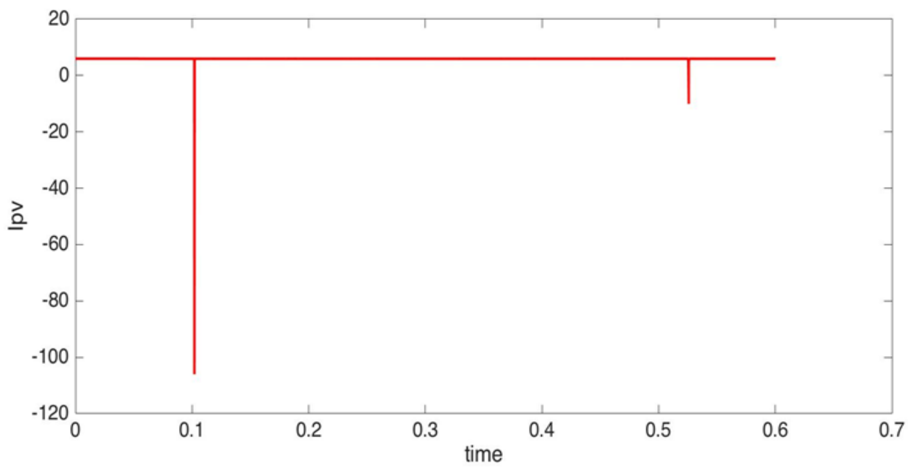

Figure 7: Battery output voltage

The current on both ends of the panel can be created during the voltage fluctuation in the opposite direction of the panel (Figure 8). From 0 to 0.1 seconds, the current value is 5 amps due to the absence of voltage fluctuation. At the moment of 0.1 seconds, the voltage reaches 1600 volt. The current increases up to 105 amps in the opposite direction of the panel and then returns to 5 amps. Then up to 0.52 seconds due to voltage fluctuations, it reaches 16 volt in the opposite direction of the panel and creates a power of 20 kilowatts.

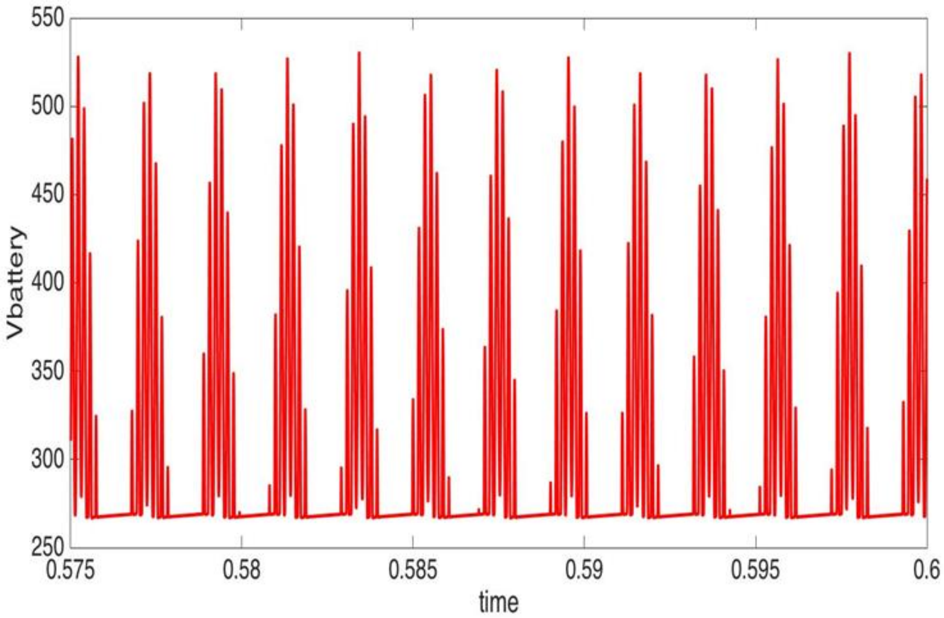

Figure 8: PV panel current

According to the intensity of light radiation as well as the maximum power, the voltage at both ends of the panel is pulsed at two different times. First, the voltage reaches 1600 volt in 0.1 seconds (Figure 9). Then it returns to its oscillating value of 300 volts and causes the power to fluctuate to about 160 kW. After increasing voltage to 350 volt, it reaches 1400 volt in 0.52 seconds and creates a pulse in the panel power. Finally, the power reaches 20 kW when protection is used (Figure 10).

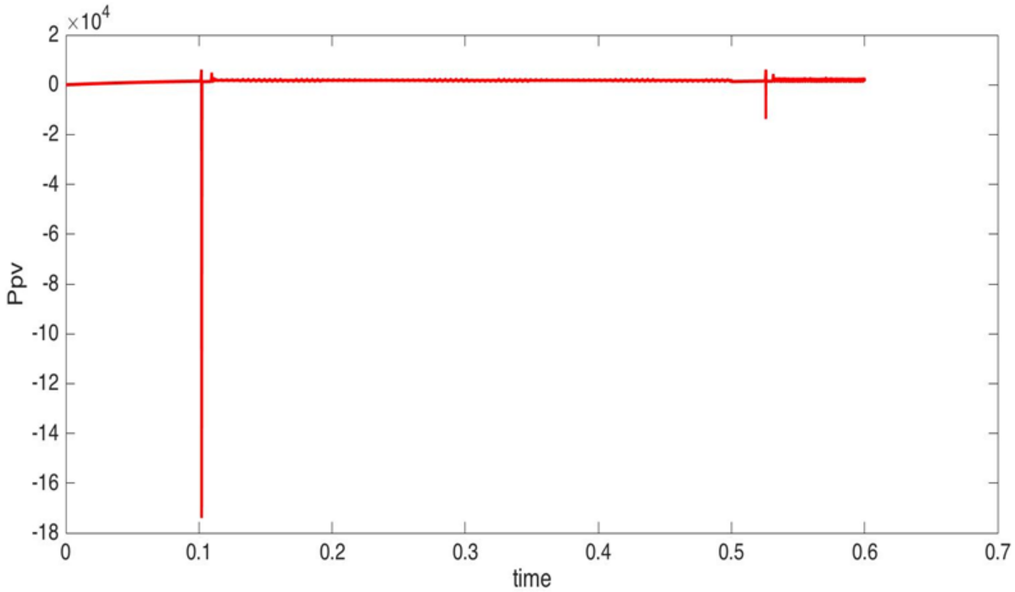

Figure 9: PV panel power

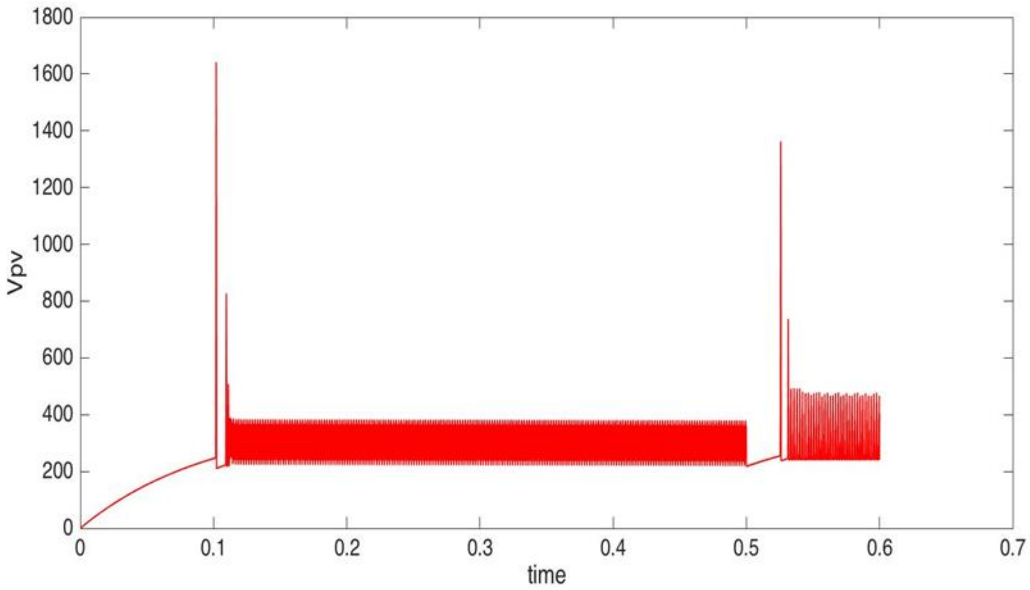

Figure 10: PV panel voltage

The voltage at both ends of the inverter is represented in Figure 11. Considering the maximum voltage of 2700 volt, first the dc to dc boost inverter is used to withstand the voltage of 3000 volt and protect the system from damage. As you can see, due to the battery and photovoltaic cells as well as the voltage control, the voltage first increased to about 2600 volt and then dropped to a constant value of 2400 volt and to 1800 volt. The voltage is constant at 2400 volt for 0.5 seconds. After overshooting in 0.5 seconds and being fixed at 2600 volt, it can provide the AC current required by the motor. In this study, we use a brushless motor (BLDC) due to its lower price than other motors and controllability feature in this problem.

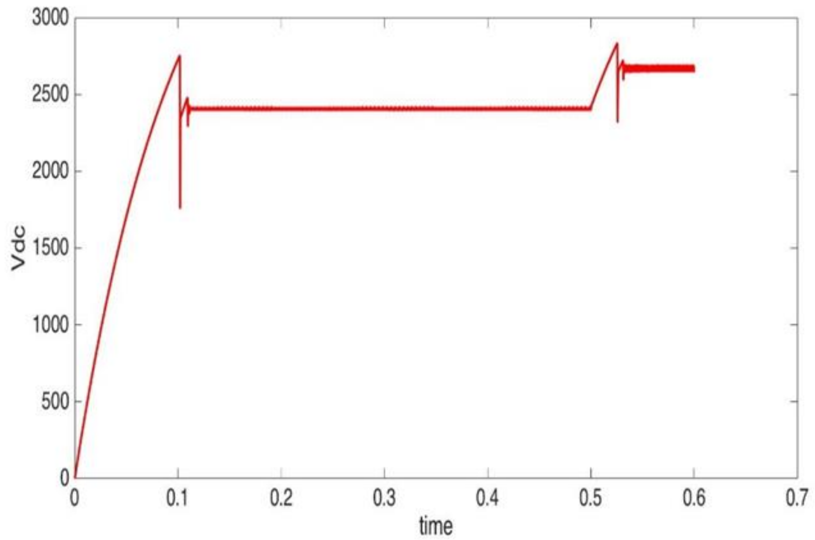

Figure 11: The voltage of both ends of the inverter

In order to investigate the effect of load torque changes on the output speed when the supply voltage and reference speed are constant, the parameters were set as follows: step time = 0.5 and Vt = 100. By applying a 20% increase in the amount of load and a 10% decrease in the load from the nominal value, the curve of speed changes and the speed error signal are represented in Figure 12. As shown in the figure, in 0.5 seconds, the speed has decreased by 0.7% due to the voltage drop of DC to DC converter. Then, in a period of less than 0.01 seconds, it is corrected again and returned to the reference speed. When reducing the load, the speed increased by 1% and returned to its initial value in 0.1 seconds, Due to the use of a lithium-ion battery (initial value 100 V and final value 900 V), we expect the speed to be somewhat higher than the final value and an increase to 0.015 radians/second.

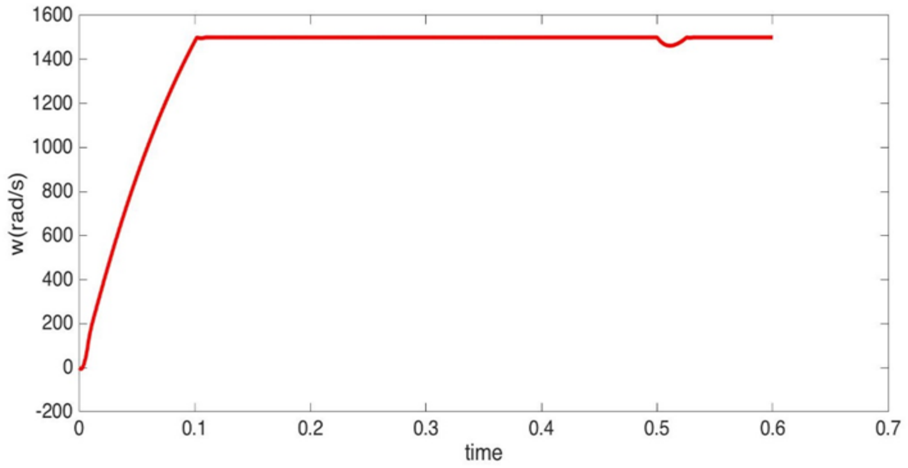

Figure 12: Speed regarding radians per second

As shown in the figure, after increasing the reference speed, the output speed without overshoot reaches the desired speed in less than 0.01 seconds. When reducing the reference speed, the output speed reaches the desired speed without undershoot and within 0.02 seconds. We can get the power value of 20 kW by the product of speed and torque (Figure 13).

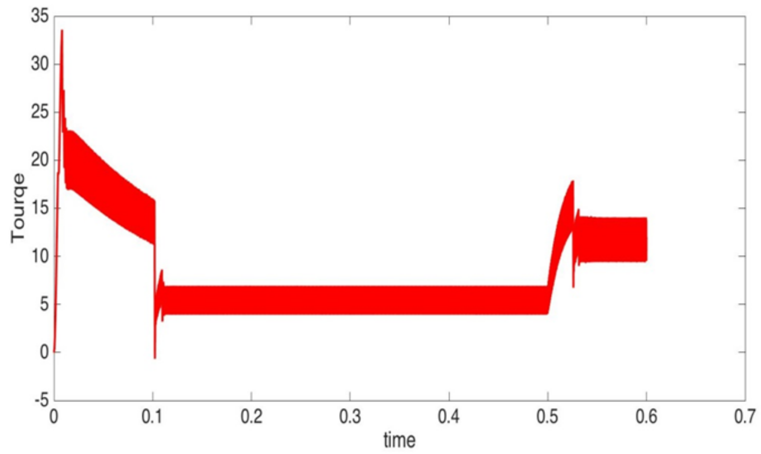

Figure 13: Output torque plot

As shown in the figure, due to the switching voltage, the initial torque increased to about 18 Nm and reached the desired value in less than 0.05 seconds. The realization of this overshoot is caused by the initial increase in load and switching accumulation. The product of the outputs of this simulation, i.e. speed w and torque T can provide the required power (20 kW). This value is the power used in most monoplanes, water jets, drones, and military aircraft. It is possible to adjust the speed and obtain the torque value by changing the input and the possibility of reaching higher powers for more powerful engines.

10. Conclusion

In this study, a solar system is designed and simulated in MATLAB. The design of solar aircraft depends not only on the mission but on the type of aircraft. Based on the characteristics of each mission, the design of the aircraft is variable. According to the characteristics of the mission and the aircraft, it is possible to calculate the energy of the aircraft through design and simulation. The science of solar flight often deals with the design, construction, and testing of aircraft, with special attention to advanced materials, lightweight structures, and the integration of solar energy systems into aircraft. Many projects related to solar flights remain classified or confidential. In many parts of the world, there is a need for airline operations from major airports and big fuel stations. The ideal solution would be a solar-powered transport capable of flying in and out of the small terrains. After years of research on electric vehicles, solar flight has become one of the applications of next-generation aircrafts. To achieve the best aerodynamic performance, the wing structure is optimized based on a large adjustable curved flap, for short take-offs and landings. The main power source is a lithium battery pack. Some equipments can be installed in part of the cargo compartment, including a generator operating on unleaded fuel. In the future, most of the aircrafts will be equipped with electric power supply equipment. Safety and reliability will be improved in aviation and flight's impact on the environment will be greatly reduced. One of the biggest challenges facing aviation industry is environmental protection. Aircraft must become more efficient, cleaner, and quieter. In the field of solar flights and with further development of electric aircrafts, commitments to environmental issues are strengthened. With 28 years of experience in designing, building, and flying solar aircrafts, this new configuration has more potential to permeate other projects in future.

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