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Solar Energy Integration In Uav

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Abstract: This paper explores the integration of solar energy in Unmanned Aerial Vehicles (UAVs) to extend flight endurance and reduce reliance on conventional power sources. It examines the use of solar panels, lightweight batteries, and energy management systems for optimal performance. Challenges such as weight, energy efficiency, and environmental factors are discussed. The integration of solar power is used which offers a sustainable solution for long-duration UAV operations. Due to solar and battery hybrid system, it enhance its efficiency and flight time.

Index Terms – Introduction of UAV, Drone Circuit and Components, Introduction of solar cell, MATLAB simulation, Battery and solar characteristics, Formulas and Equations of solar and UAV, Calculations, Challenges, Conclusion, References.

1. INTRODUCTION OF UAV:

Currently, unmanned aerial vehicles (UAVs) have become the focus of attention of several institutions and companies, this market segment is fast-growing with a potentially bright future. The increasing demand for Unmanned Aerial Vehicles (UAVs) across various industries, including surveillance, environmental monitoring, agriculture, and logistics, has led to the exploration of new ways to enhance their performance and operational efficiency. A promising solution is the integration of solar energy systems, which can significantly extend flight times, reduce reliance on traditional energy sources, and improve the sustainability of UAV operations. Solar energy, as a renewable power source, offers the potential to provide continuous energy for UAVs, enabling long-duration flights without the need for frequent recharging or fuel consumption.

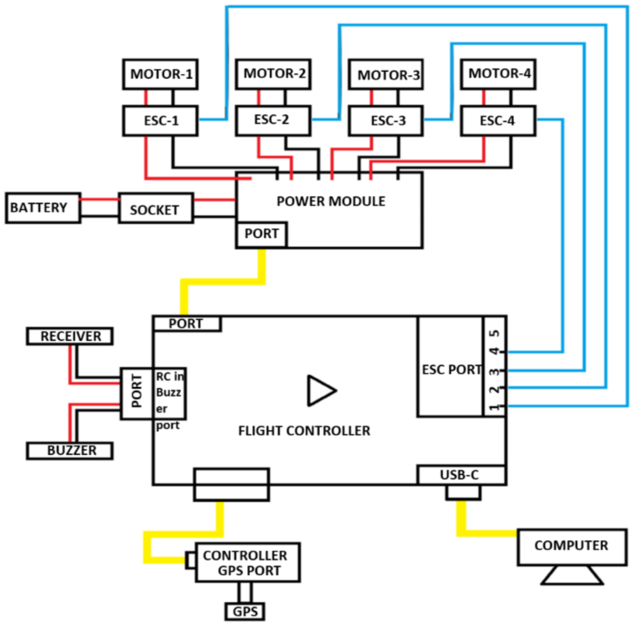
Solar mini drones typically feature a built-in rechargeable battery that stores the solar energy for use during flight. The solar panels on the drone's body or wings continually charge the battery while the drone is exposed to sunlight. This allows the drone to fly for extended periods without the need for frequent recharging or battery replacements.

The integration of solar energy with drones is an innovative approach that aims to enhance the endurance, sustainability, and autonomy of unmanned aerial vehicles (UAVs). This integration is particularly beneficial for long-endurance missions such as surveillance, environmental monitoring, and search-and-rescue operations, where continuous flight time is crucial. Solar-powered drones can significantly reduce the reliance on traditional battery or fuel-powered systems, decreasing operational costs and environmental impact. As solar technology advances, its application in UAVs promises to transform the capabilities of autonomous flight, offering a greener and more efficient alternative to conventional power systems. solar energy integration with drones represents a significant step toward the future of greener, more efficient, and autonomous UAV systems, with potential applications in a variety of industries and services.

This paper explores the potential of solar energy integration in UAVs, examining both the benefits and the technological challenges that must be overcome to realize its full potential.

2. DRONE CIRCUIT AND COMPONENTS:

Apart from solar system in drone, there is another circuitry used which is known as Drone's components circuitry. It refers to the electrical components and connections that enable a drone to function. It involves various systems and components working together to ensure the drone can fly, communicate, and respond to inputs. The basic concept is to use solar panels to recharge the drone's battery during flight or when it's stationary (on the ground). The power from solar goes to the battery and recharge it. After this, the recharge battery transferred the power to the drone's circuit.



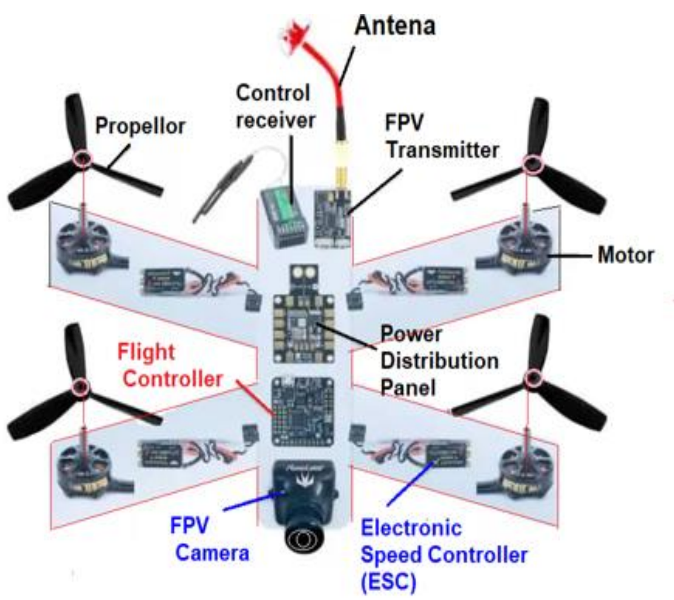


Fig. a) Basic diagram of Drone's components circuitry Fig. b) Diagram of Drone's components

3. INTRODUCTION OF SOLAR CELL:

Solar cells are used to convert electricity from sunlight, Solar cells are the electronic components that produce electricity when exposed to sunlight using the photovoltaic effect. The phenomenon of the generation of electric current or voltage in a circuit when it is exposed to light is known as the photovoltaic effect.

3.1 Working of solar cell:

When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction. Similarly, the holes in the depletion can quickly come to the p-type side of the junction. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction. Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of the junction. As the concentration of electrons becomes higher in one side, i.e. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.

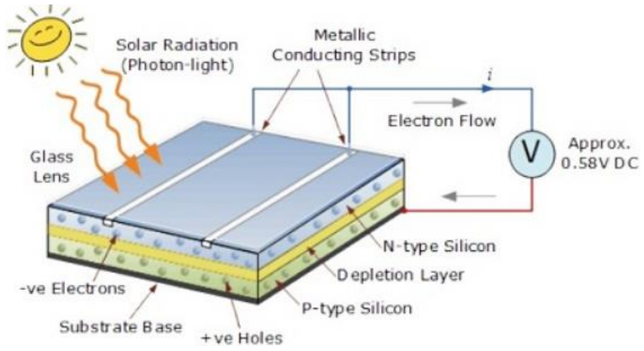


Fig. c) Working diagram of solar cell

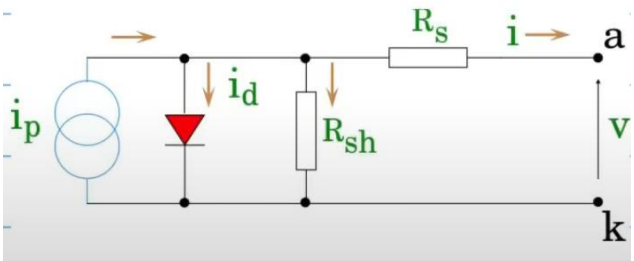


Fig. d) Model diagram of solar cell

3.2 The relation between Voc and Isc (V-I Characteristics):

Isc is the short circuit current and it is measured by short circuiting the terminals. Voc is the open circuit voltage and it is measured when no load is connected. Pm is maximum power, Imp is maximum current, Vmp is maximum voltage and it occurs at the bend of the characteristic curve. The power delivered by a single solar cell or panel is the product of its output current and voltage (I x V). With the solar cell open-circuited, that is not connected to any load, the current will be at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cells open circuit voltage, or Voc. At the other extreme, when the solar cell is short circuited, that is the positive and negative leads connected together, the voltage across the cell is at its minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells short circuit current, or Isc.

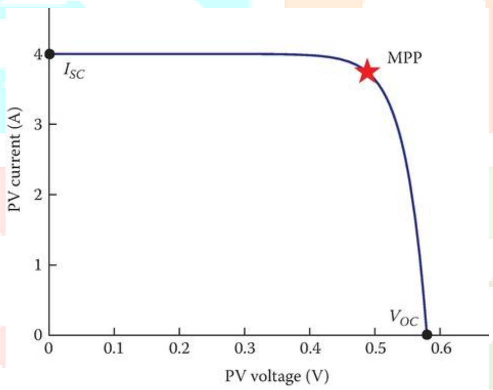


Fig. e) V-I characteristics of solar cell

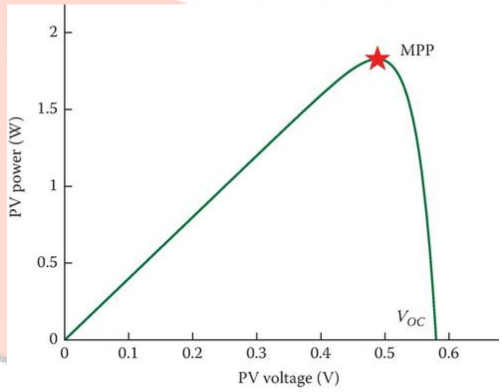
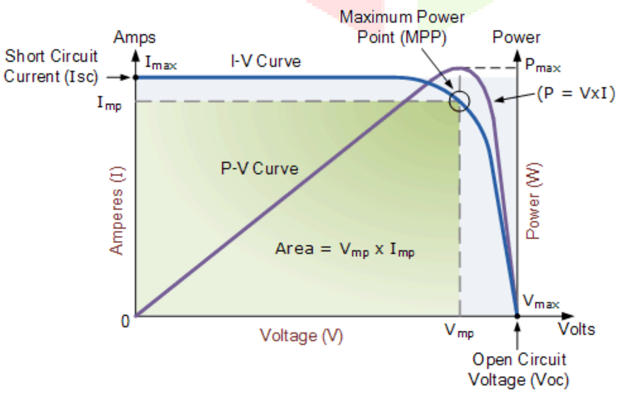


Fig. f) PV curve of solar cell



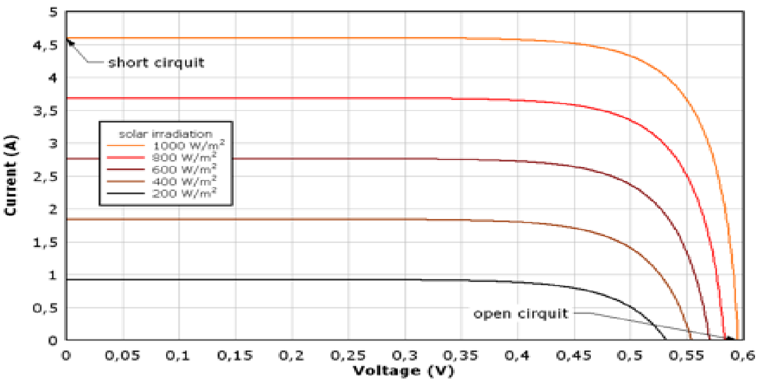


Fig. g) Overall performance of solar cell

Fig. h) V-I Characteristics according to variation of Voc and Isc in solar cell

As solar irradiance change, the I–V curve will also change. The irradiance is directly proportional to the current characteristics. As the irradiance increases, the short-circuit current and MPP current will also increase. If the incident solar power changes the variation of Voc (logarithmically manner). So Ip increases (due to increase of solar radiation). The Voc will increase (logarithmically) and Isc will also increases (linearly) due to increase in incident solar power.

3.3 Integration of Solar and Battery (Hybrid System):

The combination of the battery and solar drone is known as Hybrid system of the drone. The power consumed by the drone must be delivered by both battery and solar system. In this system, we integrate the both parts. Integrating solar power with a drone's battery system can be a great way to extend flight time and helping the drone to reduce the reliance on battery power alone.

3.4 Basic concept:

The basic concept is to use solar panels to recharge the drone's battery during flight or when it's stationary (on the ground). The power from solar goes to the battery and recharge it. After this, the recharge battery send the power to the drone's circuit. But for this, we have to maintain the battery and solar voltage by using the maximum power point tracker and voltage regulation.

MPPT: It is known as Maximum Power Point Tracking. It is used to give Maximum power (Pmax) most of the time to the drone so that drone can take flight at its high efficiency and it make sure that maximum power is delivered to drone.

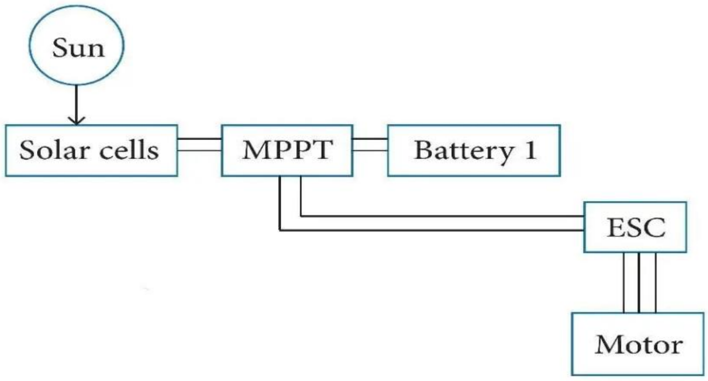


Fig. i) Integrating circuit of solar and battery

3.5 Working:

The solar power supplied from solar cell to MPPT, where the voltage level maintained. After this, it goes into the battery. Then from battery, it goes to ESC, power module, flight controller and other part of the drone.

3.6 Battery Management System (BMS):

Battery is the main unit in drone's circuit. It is essential for storing excess solar energy to power the drone during periods of low or no sunlight. Lithium polymer (LiPo) batteries are commonly used due to their high energy density and lightweight nature. Supercapacitors can be employed for quick energy storage. They also have the high charge rate so quick charging is also possible. We must know, while choosing a battery that how much current drone can draw, Like the current drawn from the motor also from other components.

3.7 Power flow in UAV (solar to battery to drone's circuit):

At first, due to the sunlight, the solar cell convert the sunlight into dc power. After this, the power went to MPPT kit where, due to the specific value of Isc and Voc, we get the maximum power (Pm) of the solar cell. After this, if the UAV is not flying or at the stand still position, the power is transferred to battery to charge it after passing voltage regulator. This process is used to reducing its charging time and reduce the dependencies of power supply by battery alone.

If the UAV is flying, the solar power transferred to the battery to charge it and reduce its charging time.

Then, the power transferred to the different components like power module which transferred the power to ESC and then four stepper motor used in drone. It also transferred the power to flight controller which control all the basic information like flight time, direction, forward and backward controllability etc. After then, Flight controller transferred the power to all the components like receiver, buzzer, sensors etc.

4. MATLAB SIMULATION:

4.1 Solar and Battery Integration:

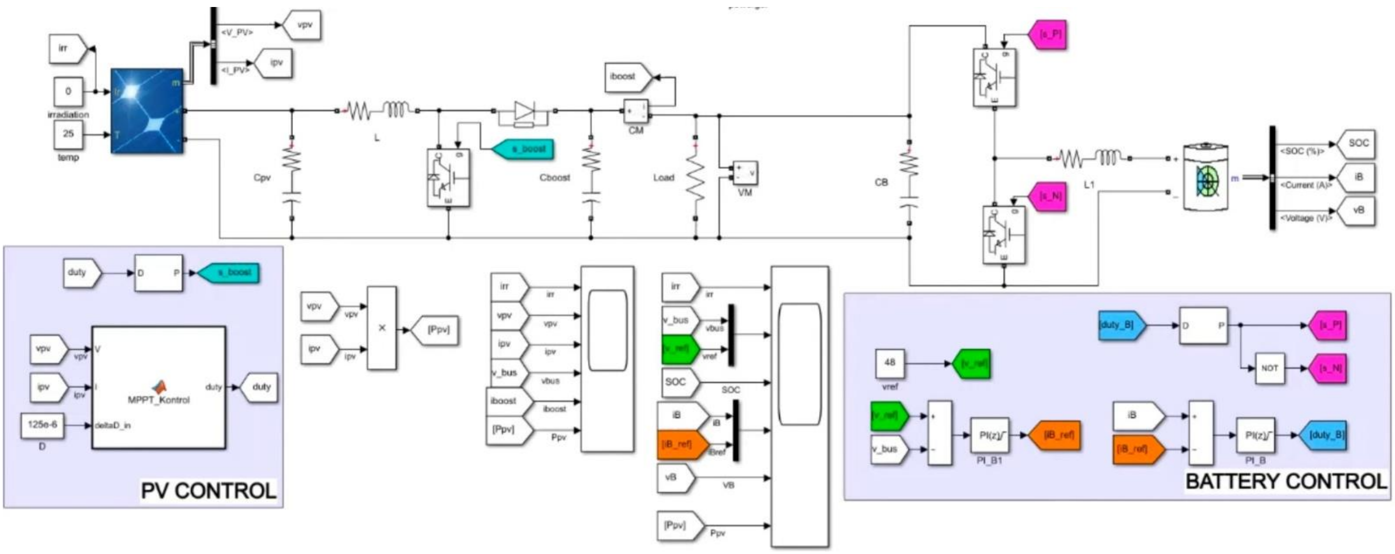


Fig. j) PV cell and Battery Integration

4.2 Circuit analysis of solar and battery integration in UAV:

The above figure has the circuit diagram of PV cell and battery integration which is done in the MATLAB, In this circuit diagram, we have two components.
They are solar cell, battery, their coupling and their control circuit.

At the solar side, we have solar cell which have initial temperature of 25°C and maximum temperature of 45°C.
It also have the solar irradiance of
1kw/m square = 1000 watt/10000 cm square
1000/10000 = 0.1 watt/cm square
It means, 1 cm square is generating 0.1 watt.

Due to this, we get Ipv and Vpv and a specific amount of power is generated. Then the specific value of power transferred to the PV control and Boost converter.
In the **PV control circuit**, there is MPPT kit which gives the maximum power value and the duty cycle.
Then the output signal is given to PWM to give the pure switching signal. After this, the switching signal given to the gate of IGBT to obtain the boost current.

Also, the output power of the solar cell is transferred to the boost converter. (It is the combination of components like RC circuit, RL circuit, diode and IGBT.) which basically step up the input voltage and frequency of dc supply (output power of solar cell) and we get the step up voltage.

There is a coupling, which connects the battery and solar side of the drone circuit.

At the battery side, we obtained battery current, battery voltage, state of charge.

At first, By the use of boost converter from the solar side, the dc voltage is step up and then dc power transferred to battery side. When boost voltage and current enter into the battery side, then there are RC and RL circuit and two IGBT are connected in opposite way. They are connected in such a way, because some time the recharging of the battery occurs and sometimes the discharging of the battery occurs.

In the **battery control circuit**, two IGBT, have positive switching signal and negative switching signal at the gate side. These switching signals are obtained by following process.
Due to the Vbus and Vref, we get Ib ref.
Due to ib and ib ref. multiplication, the obtained value transferred to the PID CONTROLLER.

After this, we obtain Ib duty cycle, then ib duty cycle went to PWM and we get two signals.
we get one signal at a time by connecting NOT signal. If positive switching signal occurs, then negative does not. If negative signal occurs, then positive does not.

Due to this, we get the state of charge, battery current (Ib) and battery voltage (Vb). So from here, we obtained solar and battery integration, used for power supply in drone circuit

4.3 PV Side and Battery Side Circuit Characteristic:

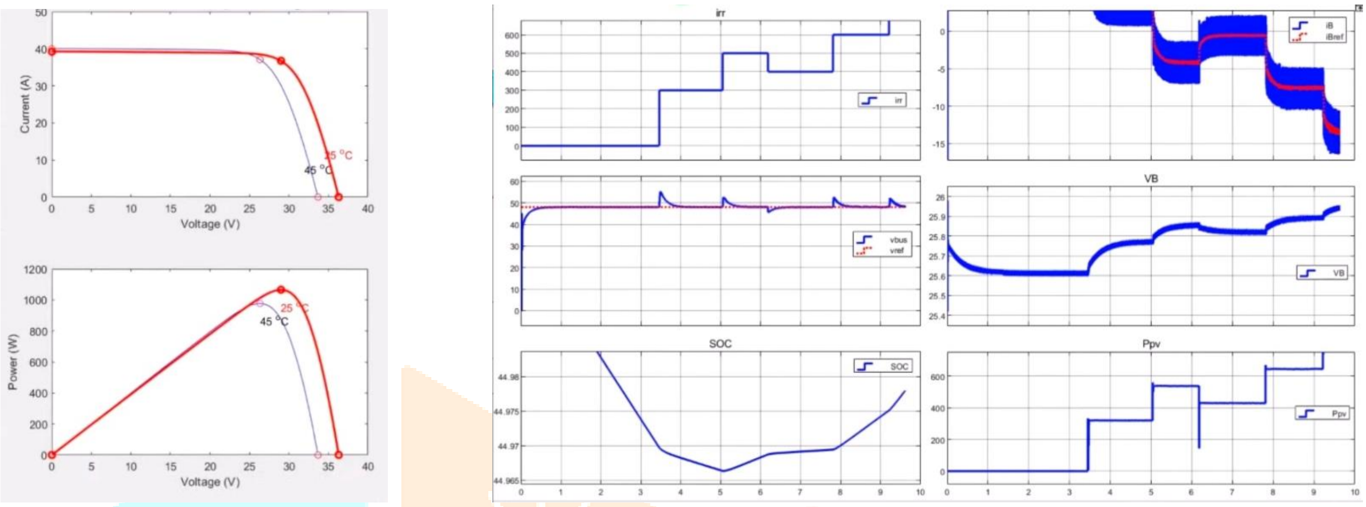


Fig. k) Battery side circuit characteristic

Left side shows the I-V characteristics of solar cell and PV curve which shows the MPP point curve due to the temperature and
Irradiance variation.

Right side shows the battery side control circuit characteristics which tell about irradiance, state of charge, Photovoltaic power, battery voltage, battery current as irradiance increases or decreases.

When the temperature increases, the Irr is also increases and vice versa. The SOC (state of charge) is inversely proportional to the battery drawn but it is proportional to the temperature and the solar irradiance. The Vb is also proportional to the temperature. Ppv is also proportional to the temperature and the solar irradiance. Ib is also proportional to the temperature and the solar irradiance , it increases or decreases as the temperature increases and decreases.

5. Battery And Solar Characteristics:

5.1 Solar characteristics:

Polycrystalline Solar Panel: It is most common type of solar panel. The efficiency rate of poly crystalline solar panel is around 16%-17%. These panels are best to work under extreme weather conditions. To manufacture polycrystalline solar panels, low purity silicon is used. polycrystalline solar panels are much more budget-friendly than monocrystalline solar panels.

No of cells used: 3 solar cells are used

Dimension of each cell
Solar cell 1&2 - 8cm x 4 cm
Solar cell 3- 5.7cm x 2.5cm
Specifications: 3-6 volts, 60 mah of 1st & 2nd solar cells
3-6 volts, 30 mah of 3rd cell

Material: Polycrystalline Silicon

5.2 Battery characteristics:
Battery capacity -1800 mah
Power - It give us 6.66 watt
Voltage Per Cell – 3.7v
C-rating – 50-100 cycles
Battery type - Lithium-polymer battery (li-po battery)
C-Rating: It tells us how quickly the battery can safely discharge.

6. FORMULAS AND EQUATIONS OF SOLAR AND UAV:

There are many technical UAV and solar related equations used in the solar integrated UAV.

6.1 UAV related equations:

Lift (Generated by Propellers): $T = C_t \cdot \rho \cdot A \cdot v^2$
T: Thrust
C_t: Thrust coefficient
P: Air density
A: Area swept by propeller
v: Velocity of air moved by propeller

Power Required: $P = T \cdot v$
P: Power
T: Thrust
v: Induced velocity of air through the propeller

Drag Force: $D = (1/2) \cdot \rho \cdot v^2 \cdot C_D \cdot A_{frontal}$
D: Drag force
C_d: Drag coefficient
$A_{frontal}$: Frontal area of the drone
v: Velocity of the drone relative to the air

Angular Velocity: $\tau = C_Q \cdot \rho \cdot n^2 \cdot D^5$
τ : Torque
C_Q: Torque Coefficient
n: Rotational Speed
D: Propeller Diameter

Flight Dynamics: $F_{net} = m \cdot a$
F_{net}: Net Force
m: Mass of Drone
a: Acceleration
For vertical motion $F_{net} = T - (m \cdot g)$
For horizontal motion $F_{net} = T_{horizontal} - D$

Battery Life Estimation: $t = E/P$
t: Flight time
E: Battery energy
P: Total power consumption

6.2 Solar related equations:

Photocurrent (I_p): $I_p = q \cdot G \cdot A \cdot \eta$
The photocurrent is the current generated by the solar cell when light is absorbed.
I_p: photocurrent

Q: charge of an electron (1.602×10−19 C)
G: incident light intensity (W/m²)
A: area of the solar cell (m²)
η: quantum efficiency (the fraction of photons absorbed by the cell that generate electron-hole pairs)

Open-Circuit Voltage (Voc): Voc=(Kt/q)ln[(Iph/Io)+1]
This is the voltage when the solar cell is not connected to an external load (no current is flowing).
V*oc*: open-circuit voltage
K: Boltzmann constant (1.38×10−23 J/K)
T: temperature in Kelvin
Q: electron charge (1.602×10−19 C)
I*ph*: photocurrent
I*o*: saturation current of the solar cell

Fill Factor (FF): F=(V*mp*·I*mp*)/(V*oc*·I*sc*)
The fill factor is a measure of how efficiently the solar cell converts the energy from sunlight into electricity. It is the ratio of the maximum power point (Pmax) to the product of V*oc* and I*sc* (the short-circuit current).
FF: fill factor
V*mp*: voltage at maximum power point
I*mp*: current at maximum power point
V*oc*: open-circuit voltage
I*sc*: short-circuit current

Maximum Power (Pmax): P*max*=V*mp*·I*mp*
The maximum power output of a solar cell is the product of the voltage and current at the maximum power point.
P*max:* maximum power
V*mp*: voltage at maximum power point
I*mp*: current at maximum power point

Solar Cell Efficiency (η): η=P*max*/P*in*
The efficiency of the solar cell is the ratio of the electrical power output to the incident solar power.
η: efficiency
P*max*: maximum power output
P*in*: incident solar power

7. CALCULATIONS:

7.1 Solar Panel Dimension and its Output:
(8cm *4cm) x2 solar cell = 64 cm square.
5.7cm x 2.5cm = 14.25cm square
Total area =78.25 cm square
Approx area = 78 cm square.

Standard Solar Isolation
1kw/m square = 1000 watt/10000 cm square
1000/10000 = 0.1 watt/cm square
It means, 1 cm square is generating 0.1 watt.

So total energy = 0.1 watt * 78cm square
= 7.8watt
Now, the efficiency of the cell = 16.5%
Solar output = 7.8 * 16.5/100
= 1.287 watt

7.2 Battery Output:

Battery Capacity = 1800 mah
1 Ampere = 1000 Milli ampere
So, 1800/1000 = 1.8 Ampere

The battery giving total voltage - 3.7volt

Power Contain in battery= 3.7 * 1.8 = 6.66 watt

Due to energy transfer from battery to circuit in drone. So, loss occurs about 10 – 30 %
Now, energy transfer = 6.66 * 7/10 = 4.66 watt

Time to charge
1 hour = 1.28 watt generated.
Power in 1 min = 1.28 watt/60 min = 0.02 watt
Charging Time = 4.66 watt/0.02 watt = approx.210 min

7.3 Practical on Hardware:

For a 600 g quadcopter hovering with four 0.05 m radius propellers:
Weight = 0.6·9.81 = 5.88 N
Thrust per propeller = 5.88/4 = 1.47 N
Disk area per propeller = π·(0.05)^2 = 0.00785 m^2
Using the thrust equation and solving for v with an assumed Ct = 0.5:
1.47 = 0.5 · 1.225 · 0.0314 · v^2 ,
v^2 = 24m/s = 4.89
Power per motor ≈ 1.47 · 4.89 = 7.18 w.

8. CHALLENGES:

There are many challenges related to UAV. They are:

8.1 Weight and Structural Constraints:

Solar PV panels, even thin-film or lightweight versions, add extra weight to drones, which are typically designed to be as light as possible for efficient flight. Balancing the energy generation capacity of the panels with the drone's payload limits is tricky. Larger panels might produce more power but can compromise aerodynamics and battery life.

8.2 Limited Sunlight Availability:

Solar drones rely heavily on sunlight to generate power, making them less effective in cloudy weather, at night, or in regions with shorter daylight hours. Even with energy storage systems like batteries, their operational time can be significantly reduced during unfavorable conditions, limiting continuous flight capabilities.

8.3 Energy Efficiency and Conversion:

The efficiency of solar panels, though improving, is still limited. Converting sunlight into usable electrical energy doesn't always provide enough power for sustained flight, especially for drones carrying heavier payloads or operating at high altitudes. Balancing energy generation with consumption remains a technical challenge.

8.4 Cost and Scalability:

The advanced technology required—such as efficient solar cells, lightweight materials, and energy management systems—drives up the initial cost of solar drones. This can be a barrier for smaller organizations or industries looking to adopt the technology on a budget.

8.5 Regulatory and Safety Issues:

Solar panels are susceptible to damage from environmental factors like dust, debris, or impacts, requiring regular maintenance to ensure peak performance. This adds to operational costs and complexity, particularly in remote or harsh environments.

9. Conclusion:

Solar Energy Integrated Drone allow to recharge their batteries or energy storage components while in operation. By integrating the power of the sun, these drones can fly higher, fly longer. A lightweight solar-powered flying drone is being developed for environmental monitoring purposes with low consumption of renewable energy and can reduce the usage of batteries.

Solar-integrated drones present a promising future for multiple industries, offering benefits in sustainability, operational efficiency, and extended flight times. To fully realize their potential, continued development in solar technology, battery management, and hybrid systems is essential. Additionally, fostering a regulatory framework and practical applications will help drive the broader adoption of these innovative drones across sectors such as agriculture, infrastructure inspection, disaster response, and environmental monitoring. By addressing technological challenges and capitalizing on their unique advantages, solar-powered drones can become a cornerstone of future drone technology.

9.1 Future Scope Enhancements:

There are many ways for enhancing the solar drones such as by adding sensors and cameras and GPS. It is a prototype so it can be
enhanced with more powerful stepper motor, high-capacity battery and solar panel with high power. Because of this , the size of the
drone can be huge & big which increase its power and performance and stability. We can also add alarm signal, in case of drone lost or to inform its location / presence. In future, there will be more enhanced drones with high efficiency in doing many task and operations.

10. References:

[1] David W. Hall et al. A Preliminary Study of Solar Powered Aircraft. Tech. rep. 3699. Dec. 1983. url: http://ntrs.nasa.gov/archive/nasa/casi. ntrs.nasa.gov/19840005126_1984005126

[2] Wang, Li, and Xiong. Li-polymer Battery Packs Specification. 585460. Version 2.0. Mar. 16, 2006. url: http://www.cs.wmich.edu/~sunseeker/files/A-300%20data%20sheet.pdf

[3] How to Design a Solar-Powered Computing Device. Tech. rep. 320586. Version 001US. 2008. url: ftp://download.intel.com/design/intarch/PAPERS/32058f

[4] Oettershagen, P.; Melzer, A.; Mantel, T.; Rudin, K.; Stastny, T.; Wawrzacz, B.; Hinzmann, T.; Leutenegger, S.; Alexis, K.; Siegwart, R. Design of small hand-launched solar-powered UAVs: From concept study to a multi-day world endurance record flight. J. Field Robot. 2017, 34, 1352–1377

[5] Morton, S.; D'Sa, R.; Papanikolopoulos, N. Solar Powered UAV: Design and Experiments. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Hamburg, Germany, 28 September–3 October 2015.

[6] Green, M.A.; Dunlop, E.D.; Levi, D.H.; Hohl-Ebinger, J.; Yoshita, M.; Ho-Baillie, A.W.Y. Solar cell efficiency tables (version 54). Prog. Photovolt. Res. Appl. 2019, 27, 565–575. [CrossRef]

[7] Tyagi, T.; Rahim, N.A.A.; Rahim, N.A.; Selvaraj, J. Progress in solar PV technology: Research and achievement. Renew. Sustain. Energy Rev. 2013, 20, 443–461.

[8] Bhatnagar, P.; Nema, R.K. Maximum power point tracking control techniques: State-of-the-art in photovoltaic applications. Renew. Sustain. Energy Rev. 2013, 23, 224–241

[9] Ghosh, K.; Guha, A.; Duttagupta, S.P. Power generation on a solar photovoltaic array integrated with lighter-than-air platform at low altitudes. Energy Convers. Manag. 2017, 154, 286–298.

[10] Liang, H.; Lee, S.-C.; Bae, W.; Kim, J.; Seo, S. Towards UAVs in Construction: Advancements, Challenges, and Future Directions for Monitoring and Inspection. Drones 2023, 7, 202

[11] Wang, G.; Xie, J.; Wang, S. Application of Artificial Intelligence in Power System Monitoring and Fault Diagnosis. Energies 2023, 16, 5477.

[12] Morando, L.; Recchiuto, C.T.; Calla, J.; Scuteri, P.; Sgorbissa, A. Thermal and Visual Tracking of Photovoltaic Plants for Autonomous UAVInspection. Drones 2022, 6, 347

[13] Romero, H.F.M.; Rebollo, M.G.; Cardeñoso-Payo, V.; Gómez, V.A.; Plaza, A.R.; Moyo, R.T.; Hernández-Callejo, L. Applications of Artificial Intelligence to Photovoltaic Systems: A Review. Appl. Sci. 2022, 12, 10056.

[14] Naija, M.; Khemiri, R.; Exposito, E. Failsafe Mechanism to Hazard Analysis and Risk Mitigation in Unmanned Aerial Vehicle based on NCES. In Proceedings of the 15th International Conference on Software Technologies, Online, 7–9 July 2020; pp. 220–227.

[15] Kakaes, K.; Greenwood, F. Chp1-Drones and Aerial Observation: New Technologies for Property Rights, Human Rights, and Global Development: A Primer Observation; New America: Washington, DC, USA, 2015.