DESIGNING THE POWERTRAIN OF UNMANNED AERIAL VEHICLE TO CARRY A 40KG PAYLOAD AT KABALE UNIVERSITY

BY

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DECLARATION

I, NALUMANSI MOUREEN declare that this report is the original copy of my written individual project report on the research work carried out during the project.

Sign………..

Date: 4th/01/2021

APPROVAL

This is to certify that NALUMANSI MOUREEN carried out the individual project about designing the powertrain of unmanned aerial vehicle to carry a 40kg payload at Kabale University. The report is ready for submission to the board of examiners of Kabale University
Faculty of Engineering with my full approval.

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ACKNOWLEDGEMENT

I am deeply grateful to the Almighty God who enabled me to complete my project well.

I acknowledge the department of electrical engineering, for their willingness to teach and guide me with patience.

Am thankful to the management of Kabale University for all the support rendered and sincerely thank Mr. Mugyema Morris, my project supervisor for the support and help he rendered during this period.

I owe sincere thanks to all my fellow students and classmates, for the encouragement and guidance in the different sections.

DEDICATION

I dedicate this report to my guardians Mr. and Mrs. Rogers and Diana Kitto, Mr. and Mrs. Buttnor, who have been supportive and encouraging, and for the love and respect they have for education.

I also dedicate this report to my siblings and all those who have been with me while in this due course.

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ABSTRACT

The project is about designing the powertrain of an unmanned aerial vehicle (UAV) to carry payload of 40kg payload. This UAV powertrain is a photovoltaic and battery powered system designed for agricultural application.

This is achieved by estimating the total weight and required power of the UAV, designing the motor and propeller unit parameters, and sizing the solar and battery system.

The powertrain is designed with four brushless DC motor and carbon fiber propellers because of their later on mentioned advantages and monocrystalline solar modules and lithium-ion batteries are considered.

Keywords; Powertrain, Unmanned Aerial Vehicle, Photovoltaic, Brushless DC motors, Payload and Lithium-ion batteries.

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ACRONYMS

UAV -Unmanned Aerial Vehic1e

DC -Direct Current

V -Voltage

A -Ampere

ICE -Internal combustion energy

PV -Photo- Voltaic

BLDC -Brushless Direct Current

UAS -Unmanned Aerial Systems

AUW -*All* Up Weight

MPPT -Maximum Power Point Tracker

SOC -State of Charge

STC -Standard Test Condition L VD

-Low Voltage Disconnect PWM

-Pulse Width Modulation NAS

-National Airspace System

CHAPTER ONE: INTRODUCTION

The unmanned aerial vehicle (UAV) is an aircraft without a human pilot aboard. UAVs are used for a variety of applications [1]. From military purposes such as surveillance, monitoring or mapping to recreation purposes like taking aerial video and photography and in the agricultural sector.

Figure I: Plant spraying and protection UAV

U AV s, have several drawbacks and one of the major one concerns the energy storage on board. This decreases their value and their usability. UAVs present are mainly powered by battery, internal combustion engines (ICE), and hybrid systems (both battery and ICE).

The general majority of UAVs use the battery as their power supply. The better-quality class of the UAVs with a battery source of energy can last in the air for half an hour, the best ones up to 60 minutes.

The hybrid systems would be better in terms of endurance [2] but the fuel engines decrease the pay-load of the UAV. Because of this problem, an alternative power source needs to be found.

Solar Energy is a renewable source of energy. It is the technology of target when it comes to renewable energy due to its accessibility and abundance. The incorporation of solar technology into the world of aerial robotics is not nascent; however, the exploration of a full and efficient system for such an integration is still an ongoing research as it is still at a 21 % efficiency i.e. only 21 % of the solar energy was converted into useful electrical energy (3].

Thus, the proposed project will be based on solar and battery system to increase the flight time at a payload of about 40kg.

1.1: PROBLEM STATEMENT

UAVs are now common all over the world, and they find application in various fields. There remains the underlying factor of maximum flight time and pay-load.

The energy for the available systems can only last for a short time in air. The recent improvements have only been able to lift up to 20kgs.

Thus, the aim is to propose a better energy utilization design for a UAV to lift up to 40kgs. ***l.1:***

OBJECTIVES

1.2.1: GENERAL OBJECTIVE

To design a power train for a UAV to lift up to 40kgs

1.2.2: SPECIFIC OBJECTIVES

1. To design the motor and propeller unit.
2. To size the energy storage unit of the UAV.
3. To size the solar system.

CHAPTER TWO: LITERATURE REVIEW

UAVs have been in production since before the Wright Brothers first took their historic flight. The earliest account can be traced back to the American Civil War, when an inventor patented an unmanned balloon [4] that carried explosives that could be dropped after a time-delay fuse mechanism triggered a basket to overturn its contents [5] and also the first military aerial reconnaissance photos were taken in 1898 during the Spanish-American War via a camera attached to a kite [6]. As the trend shows, many of the advancements in this technology arose during times of war [7] [8] .

In 1970s, Israel developed the Scout and the Pioneer [9], which started the development toward the more widely known glider-type UAVs. It was from this design that the most sophisticated UAV in existence to date were based on [5]. These drones have come a long way from the "balloons" of the past.

The structural design of UAVs has changed over their developmental history in order to serve a variety of purposes due to changes in technology and needs.

2.1: INTERNAL COMBUSTION ENGINES

These require relatively frequent refueling and in-flight refueling is a major obstacle for this type of propulsion system. One more type of fuel system is hydrogen, which is proposed for use with certain models of stratospheric persistent UAVs [10]. The AeroVironment's Global Observer is one such UAV. This aircraft runs on hydrogen and has a range of 7 days. The idea is for two of such UAVs to be used in tandem to provide continuous, uninterrupted operation 365 days a year [11].

The advantages include high energy density, which means greater endurance, Reliability: few moving parts and easy automation, Flexibility of operation: in that they are reversible, can work at high performance without interruption for a wide range of power demands, and can also rapidly change their power output; anyway, the latest point is not enough for demanding maneuvers like takeoff, thus the support, with batteries is often necessary, Modular and easy to implement, Direct energy conversion (no combustion), Negligible noise and vibration, Low or zero emissions, A variety of applications: in addition to propulsion systems in UAVs, they might be used in APUs, auxiliary power systems, ground control stations, and so forth [12].

Water, as well as heat and low oxygen-containing exhaust air, is side product of the fuel cell that could have other applications to compensate the weight disadvantages (particularly in large U AV s), such as water supply for other subsystems, deicing, or inerting of a fossil fuel tank [13].

2.2: THE BATTERY SYSTEMS

2.2.1: BATTERIES

These use the battery as their power supply. The better-quality class of the UAVs with a battery source of energy can last in the air for half an hour, the best ones up to 60 minutes. Majority of these existing UAVs carry a pay-load of less than 5kgs.

Batteries are electrochemical storage devices that serve as vessels for a reversible chemical reaction. Composed of cells, they do not require fuel or oxygen; they are self-contained units whose potential energy is only liberated when a load is applied across the terminals. In general, it consists of one or more voltaic cells, each of which is composed of an anode and cathode connected in series by the conductive electrolyte [14].

Rechargeable batteries are preferred. NiCad and metal-hydrides are typically used, but modern technology has introduced lithium-based battery technology [15]. Lithium is low on the periodic table, is the lightest elemental solid, is a powerful reducer, and has very low electronegativity.

Lithium batteries tend to be lighter and have higher-energy density per unit mass than other self-contained energy storage systems [16]. To date, the most economical battery is the basic cylindrical 18,650 (18 mm diameter with 650 mm length), with a capacity of 2,000mAh.

New variations in chemistries and crystalline structures (such as polymers, hydrides, gels, new crystalline structures, and exotic doping materials) are leading to ever-improving battery technology [15].

Battery packs are more than a simple configuration of cells. They are carefully engineered products with many safety features. The main components of a battery pack include the cells (the primary energy source) [17]; the battery management system (a printed circuit board assembly) that provides the intelligence of the system, with features such as the fuel gauging and protection circuitry; the enclosure (either a plastic enclosure, plastic exoskeleton frame, or shrink-wrap PVC wrapper); and external contacts or connectors.

Batteries chemically store direct current electrical energy for later use, during periods of cloudy weather and when a portable power source is desired [18]. Since a photovoltaic system's power output varies throughout any given day, the battery storage system can provide a relatively constant power source, even when the photovoltaic system is disconnected for repair and maintenance or producing minimal power in periods of reduced insolation [19].

2.2.2: BATTERY TYPES AND CLASSIFICATIONS

Many types and classifications of batteries are manufactured today, each with specific design and performance characteristics suited for particular applications. Each battery type or design has its individual strengths and weaknesses. In PV systems, *lead-acid* batteries are most common due to their wide availability in many sizes, low cost and well understood performance characteristics.

In a few critical, low temperature applications *nickel-cadmium* cells are used, but their high initial cost limits their use in most PV systems. There is no "perfect battery" and it is the task of the PV system designer to decide which battery type is most appropriate for each application.

In general, electrical storage batteries can be divided into two major categories, *primary* and *secondary* batteries. Primary batteries can store and deliver electrical energy, but *cannot be recharged.* Typical carbon-zinc and lithium batteries commonly used in consumer electronic devices are primary batteries. Primary batteries are not used in PV systems because they cannot he recharged. A secondary battery can store and deliver electrical energy, and *can also be recharged* by passing a current through it in an opposite direction to the discharge current. Common *lead-acid* batteries used in automobiles and PV systems are secondary batteries. A detailed discussion of each battery type follows.

LITHIUM-ION BATTERIES

Li-ion cells come in three basic form factors: cylindrical, prismatic (rectangular brick shape), and flat Lithium polymer cells. The most commonly used Li-ion cell is the cylindrical 18650 cells, which utilizes a steel or aluminum can. Prismatic or brick-shaped cells are available in a myriad ofrectangular sizes, and are packaged in a metal can. Lithium Polymer (Li-Po) cells, sometimes called laminate cells, can be encased in flexible aluminum foil laminate pouches that are just 0.1 mm thick, versus the 0.25 to 0.4 mm thick metal cans traditionally used with cylindrical or prismatic cells. Because of the lighter packaging of the Li-Po cell, it is the cell of choice for most UAV manufacturers.

Lithium Polymer (LiPo) Battery is the most commonly used Power Source because of its light weight and its high current rating. NiMH Battery is a cheaper alternative but is much heavier than LiPo Battery. A single LiPo cell can provide a voltage of up to 3.7 volt.

A LiPo battery has two characteristic parameters:

- Capacity

It is measure of how much energy is stored in battery. It is measured in mAh (Amp hour). A battery with capacity of 4000 mAh can power a 0.8 kg Quad rotor for 5 minutes of full throttle and 20 min of hovering.

- Discharge rate

This is the rare at which battery can discharge. It is also called C-rate and expressed in C units. The maximum current that can be drawn from a battery is simply product of Discharge rate and Capacity. A 4000mAh 30C 3S LiPo can give up to 120 Amps of maximum current

The biggest advantage of Li-Po cells is the variety of available sizes. Because Li-Po cells are often custom-sized and the manufacturing process is easily configurable, these cells are available in a myriad of sizes and a variety of shapes. They are assembled by stacking electrode and electrolyte materials in layers, rather than winding them around a mandrill and then inserting them into a hard metal can, as with other cylindrical or prismatic cells. Li-Po cell capacities range from 50 mAh or smaller for applications like smartwatches to 50 Ahr or more for a cell tailored to light electric vehicle use.

LEAD-ACID BATTERIES

There are several types of lead-acid batteries manufactured. The following sections describe the types of Lead-acid batteries commonly used in PV systems;

Lead-antimony batteries

Lead-antimony batteries are a type of lead-acid battery which use antimony (Sb) as the primary alloying element with lead in the plate grids. The use of lead-antimony alloys in the grids has both advantages and disadvantages. Advantages include providing greater *mechanical strength* than pure lead grids, and excellent *deep discharge* and *high discharge rate* performance.

Lead-antimony grids also limit the shedding of active material and have better lifetime than lead-calcium batteries when operated at higher temperatures.

Disadvantages of lead-antimony batteries are a *high self-discharge rate,* and as the result of necessary overcharge, require frequent water additions depending on the temperature and amount of overcharge. Most lead-antimony batteries are flooded, open vent types with removable caps to permit water additions. They are well suited to application in PV systems due to their deep cycle capability and ability to take abuse, however they do require periodic water additions. The frequency of water additions can be minimized by the use of *catalytic recombination caps* or battery designs with excess electrolyte reservoirs. The health of flooded, open vent leadantimony batteries can be easily checked by measuring the *specific gravity* of the electrolyte with a *hydrometer.*

Lead-antimony batteries with thick plates and robust design are generally classified as motive power or traction type batteries, are widely available and are typically used in electrically operated vehicles where deep cycle long-life performance is required.

Lead-Calcium Batteries

Lead-calcium batteries are a type of lead-acid battery which uses calcium (Ca) as the primary alloying element with lead in the plate grids. Like lead-antimony, the use of lead-calcium alloys in the grids has both advantages and disadvantages. Advantages include providing greater *mechanical strength* than pure lead grids, a *low self-discharge rate,* and *reduced gassing* resulting in lower water loss and lower maintenance requirements than for lead-antimony batteries. Disadvantages of lead-calcium batteries include *poor charge acceptance* after deep discharges and shortened battery life at higher operating temperatures and if discharged to greater than 25% *depth of discharge* repeatedly.

• Flooded Lead-Calcium, Open Vent- Often classified as stationary batteries, these batteries are typically supplied as individual 2-volt cells in capacity ranges up to and over 1000 ampere-hours. Flooded lead-calcium batteries have the advantages of low self-discharge and low water loss, and may last as long as 20 years in stand-by or float service. In PV applications, these batteries usually experience short lifetimes due to sulfation and stratification of the electrolyte unless they are charged properly.

• Flooded Lead-Calcium, Sealed Vent- Primarily developed as 'maintenance free' automotive starting batteries, the capacity for these batteries is typically in the range of 50 to 120 ampere-hours, in a nominal 12-volt unit. Like all lead-calcium designs, they are intolerant of overcharging, high operating temperatures and deep discharge cycles. They are "maintenance free" in the sense that you do not add water, but they are also limited by the fact that you cannot add water which generally limits their useful life. This battery design incorporates sufficient reserve electrolyte to operate over its typical service life without water additions. These batteries are often employed in small stand-alone PV systems such as in rural homes and lighting systems, au! must be carefully charged to achieve maximum performance and life. While they are low cost, they are really designed for shallow cycling, and will generally have a short life in most PV applications.

Lead-Antimony/Lead-Calcium Hybrid

These are typically flooded batteries, with capacity ratings of over 200 ampere-hours. A common design for this battery type uses *lead-calcium* tubular *positive* electrodes and pasted *leadantimony negative* plates. This design combines the advantages of both lead-calcium and leadantimony design, including good deep cycle performance, low water loss and long life.

Stratification and *sulfation* can also be a problem with these batteries, and must be treated accordingly. These batteries are sometimes used in PV systems with larger capacity and deep cycle requirements.

NICKEL-CADMIUM BATTERIES

Nickel-cadmium (Ni Cd) batteries are *secondary* or *rechargeable* batteries, and have several advantages over lead-acid batteries that make them attractive for use in stand-alone PV systems.

These advantages include *long life, low maintenance,* survivability from excessive discharges, excellent low temperature *capacity retention,* and *non-critical voltage regulation* requirements.

The main disadvantages of nickel-cadmium batteries are their *high cost* and limited availability compared to lead-acid designs. A typical nickel-cadmium cell consists of positive electrodes made from *nickel-hydroxide* (NiO(OH)) and negative electrodes made from *cadmium* (Cd) and immersed in an alkaline *potassium hydroxide* (KOH) electrolyte solution. When a nickel-cadmium cell is discharged, the nickel hydroxide changes form (Ni(OH)2) and the cadmium becomes cadmium hydroxide (Cd(OH)2). The concentration of the electrolyte does not change during the reaction so the freezing point stays very low.

2.2.3: SPECIFYING BATTERIES

The following are considered when specifying a properly sized and installed battery storage system for a stand-alone photovoltaic system:

Depth of Discharge - This term is the percentage of the rated battery capacity that has been withdrawn from the battery. The capability of a battery to withstand discharge depends on its construction. The most common batteries have electrically active lead alloy plates immersed in a mild acid electrolyte. Plate types are Plante (pure lead), pasted, or tubular. The plates can be made with different thicknesses and different alloys, such as lead calcium, or lead antimony, for different applications.

Generally, the more massive the plates the better the battery will withstand discharge and recharge (cycling). Two terms, *shallow-cycle* and *deep-cycle*, are commonly used to describe batteries. Shallow Cycle batteries are lighter, Jess expensive, and will have a shorter lifetime particularly if recommended discharge levels are exceeded regularly. Many sealed (advertised as no maintenance) batteries are shallow-cycle types. Generally, the shallow-cycle batteries should not be discharged more than 25 percent.

Deep-cycle batteries are more often used for stand-alone PV systems. These units have thicker plates and most will withstand discharges up to 80 percent of their rated capacity. Most of these are flooded batteries which mean the plates are covered with the electrolyte. The electrolyte level must be monitored and distilled water added periodically to keep the plates fully covered.

Another type of battery using nickel cadmium (NiCd) plates can be used. Ni Cd batteries are more expensive but can withstand harsh weather conditions. NiCd batteries can be completely discharged without damage and the electrolyte will not freeze.

The maximum depth of discharge value used for sizing should be the worst-case discharge that the battery will experience. The battery charge controller should be set to prevent discharge below this level. Because nickel cadmium batteries can be discharged nearly 100 percent without damage, some designers do not use a controller ifNiCd batteries are used.

Temperature Correction - Batteries are sensitive to temperature extremes and a cold battery will not provide as much power as a warm one. Most manufacturers provide temperature correction curves. For instance, a battery at 25°C has 100 percent capacity if discharged at a current rate of C/20. (The discharge rate is given as a ratio of the rated capacity, C, of the battery.).

However, a battery operating at 0°C would have only 75 percent of the rated capacity if discharged at a C/20 rate. If the discharge rate is higher, say C/5, only 50 percent of the rated capacity will be available when the temperature is minus 20°C. Although more than the rated capacity can be obtained when the battery temperature is high, hot temperatures should be avoided because they will shorten battery life. Battery should be kept near room temperature.

Rated Battery Capacity This term indicates the maximum amount of energy that a battery can produce during a single discharge under specified conditions of temperature and discharge rate.

You will not be able to obtain rated capacity repeatedly when the batteries are used in PV systems. However, rated capacity sets a baseline on which to compare-battery performance. When comparing the rated capacity of different batteries, be sure the same discharge rate is being used.

State-of-Charge (SOC) -This is the amount of capacity remaining in a battery at any point in time. It is equal to 1 minus the depth of discharge given as a percentage.

Battery Life (cycles) - The lifetime of any battery is difficult to predict because it depends on a number of factors such as charge and discharge rates, depth of discharges, number of cycles, and operating temperatures. It would be unusual for a lead acid type battery to last longer than 15 years in a PV system but many last for 5-10 years. Nickel cadmium batteries will generally last _o:nger when operated under similar conditions and may operate satisfactorily for more than 15 years under optimum conditions.

Battery Safety - Batteries which are used in photovoltaic systems are potentially dangerous if improperly handled, installed, or maintained. Dangerous chemicals, heavy, weight and high voltages and currents are potential hazards and can result in electric shock, burns explosion or corrosive damage to your person or property.

Days of Autonomy - Autonomy refers to the number of days a battery system will provide a given load without being recharged by the photovoltaic array. Correctly selecting a number of days will depend on the system, its location, its total load and the nature of the system's load.

Weather conditions determine the number of no sun days which may be the most significant variable in determining autonomy.

2.2.4: FLIGHT TIME INCREMENT METHODS

Conventionally, the increase in flight time is achieved using any of the following methods. Addition of an extra battery to the power system of the quadcopter in order to increase redundancy and the effective capacity of the battery and Reduction of the weight of the quadcopter.

However, for the integration of solar technology for the increase of flight time, the following methods are considered; **Lone Solar Technology:** In this method, the solar power system is implemented to supply the on-board load from the quadcopter and simultaneously charge the mounted battery. **"N+1" Battery Combination:** This involves the recharge of an extra cell of the battery combination used for the load on the Quadcopter. If 'n' cells were available in the battery combination, then, 'n+ 1' cells would be used for the whole system where the extra cell would recharge the extra cell for the time when 'n' cells are supplying the load. Hence, when a cell is low or the extra cell has been recharged fully, then, an appropriate switching would be done. This would require fast charge.

Solar Power Supplement: Here, a combination of the solar power and the on-board battery is used to supply the load on the quadcopter. **Dual Battery Combination:** This implementation involves the use of two batteries where one battery would supply the entire system while the other is recharged by the solar technology.

Table I: EMT Aladin specifications [20]

SPECIFICATIONS	Values
Length	1.53m
Mass	3.2kg
Propulsion class	Battery (Li-po, 14V,9Ah)
Propulsion	BLDC Motor, 12V
Speed	45-90km/hr.

Range	More than 15km
Endurance	30-60min
Endurance	Approx.lhr

ADVANTAGES AND DISADVANTAGES OF BATTERY SYSTEMS

The advantages of battery-based systems are Silent, Lightweight, Efficient (reduced levels of waste heat), No waste products, Self-contained (No external reactants required, Reduced complexity), Rechargeable and Uses electric motor as the prime mover. Has advantages, including reliability, maintenance, control, and high-altitude operational benefits.

Whereas the disadvantages of battery-based systems are Limited endurance, Battery recharge leading to Delays due to current limits and recharge rates, Heating associated with rapid recharge and also Battery discharge may be efficient, but recharge process is inefficient, Heating due to internal resistance, Performance sensitivity to environmental temperature conditions and Hazardous chemicals (corrosive internal chemistry)

Table 2: Technical issues experienced by Battery systems

Technical Issue	Applicability to UAV Context
Endurance	Endurance of batteries changes over the life of battery. So, the issue is where to set the margin of safety for duration of flight to avoid the risk of unexpected failure/loss of power.
Recharge/Discharge Rate	High current may dangerously overheat system, leading to burst or indeterminate internal states
Operating Temperature Sensitivity	Indeterministic behavior due to unexpected environmental Conditions
Hazardous Chemicals	Risk of leakage damaging local components, leading to critical Failure
Long-Term Reliability	Risk of unexpected failure due to shortened lifespan over time

2.3: HYBRID PROPULSION SYSTEMS

These combine both ICE and battery systems [21]. The need to install engines, in addition to other components, makes the system heavier, bulkier and more expensive than others.

However, it still has advantages especially from the standpoint of a definite adoption of alternative systems and the compensation for the low power density of fuel cells [22]. There are two possibilities: serial and parallel configurations of hybrid systems [23].

2.4: PHOTOVOLTAIC SYSTEMS

Solar power is the technology of obtaining usable electric power from sunlight. With sunlight as an effectively cost-free and inexhaustible resource, there is a growing demand to harness solar power for long-endurance systems to which it may be reasonably applied. Unfortunately, the intermittent availability of solar power (weather and/or daylight permitting) necessitates either short-term operation during peak sunlight hours, or some sort of auxiliary power storage.

Large surface areas are required to collect enough radiant solar energy to gain enough reserve power from available photovoltaic arrays at current efficiencies. Moreover, this need for enough sunlight intensity restricts flight of solar-based systems to operation in the mid-latitude regions.

2.4.1: PHOTOVOLTAIC MODULE

A photovoltaic module is a group of cells, wired in series. The electrical output from a single cell is small; so multiple cells are connected in series and encapsulated (usually behind glass) to form a module. PV modules are thus the principle building blocks of a PV system, and any number of modules can be connected to give the desired electrical output in a PV array or system. This modular structure is a considerable advantage of PV systems, because new panels can be added co an existing system as and when required.

The electric power generated from the solar cells depends on the temperature and the solar radiation conditions and the load electric characteristics. In order to efficiently use the solar cells, we attempt to force the solar cells to operate at the maximum power point through some mechanism called the MPPT. MPPT is often used in photovoltaic systems to maximize the solar panel output power, irrespective of the temperature and irradiation conditions and of the load electrical characteristics. The solar cell is a nonlinear device and can be represented as a current source model as shown below.

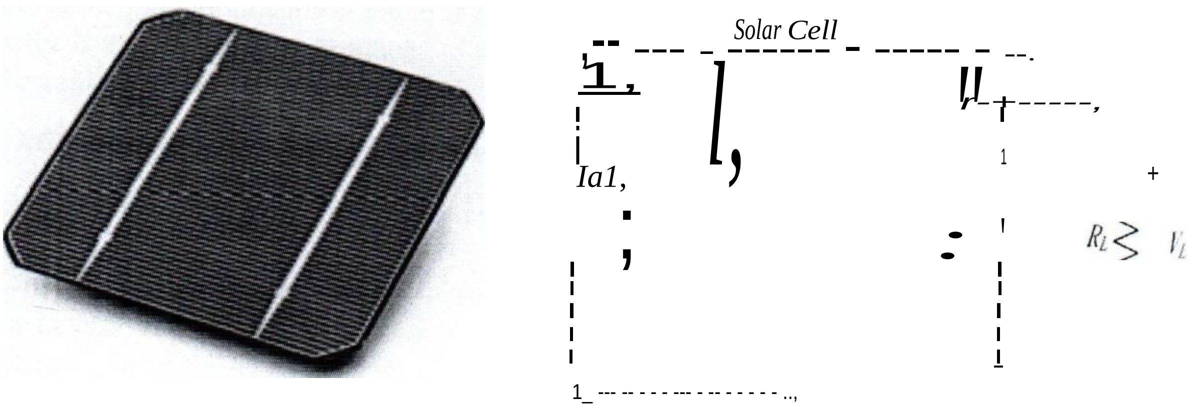

Figure 2: Solar cell model

There are four advanced thin film technologies for making PV modules. Their names are derived from the active cell materials. These include Cadmium telluride (CdTe), Copper indium selenide (CIS), Amorphous silicon (a-Si) and Thin film silicon (thin film-Si).

Amorphous silicon is in commercial production while the other three technologies are slowly reaching the market. Thin film modules are made directly on the substrate, without the need for the intermediate solar cell fabrication step.

PHOTOVOLTAIC MODULE PERFORMANCE

The total energy output wattage of a photovoltaic module equals its output voltage multiplied by its operating current. Unlike voltage sources such as batteries which produce current at relatively constant voltage, photovoltaic modules may produce current over a wide range of voltages. The output characteristics of a module are characterized by a performance curve called an I-V Curve which shows the relation between current and voltage output [24].

Typical I-V curves are given for the conditions of 1000 watts per square meter of sunlight and 25degrees C (77 degrees F) cell temperature. 1000 watts per square meter is often referred to as one 'Peak Sun.' There are three significant points of interest on the I-V curve;

Maximum Power Point (MPP) - is labelled Vmp, Imp on the I-V curve. This is the operating point at which the maximum output will be produced by the module at operating conditions indicated above.

The Open Circuit Voltage, (Voc) - is the maximum potential voltage achieved when no current is being drawn from the module. As shown by the figure the open circuit voltage (VOC) occurs when there is no current passing through the cell. V (at I=0) = VOC, VOC is also the maximum voltage difference across the cell for a forward-bias sweep in the power quadrant. VOC= VMAX for forward-bias power quadrant [24].

The Short Circuit Current, (Isc) - Is the maximum current output which could be reached by the module under the conditions of a circuit with no resistance. The short circuit current ISC corresponds to the short circuit condition when the impedance is low and is calculated when the voltage equals 0. I (at V=0) = ISC [25]. ISC occurs at the beginning of the forward-bias sweep and is the maximum current value in the power quadrant. For an ideal cell, this maximum current value is the total current produced in the solar cell by photon excitation. ISC = IMAX = It for forward-bias power quadrant [24].

FACTORS AFFECTING PHOTOVOLTAIC MODULE PERFORMANCE

Load Resistance- A load or battery will determine at what voltage the module will operate. For example, in a nominal 12volt battery system, the battery voltage is usually between 11.5 and 14 volts. In order for the battery to charge, the modules must operate at slightly higher voltage than the battery. If a load's resistance is well matched to a module's I- V curve, the module will operate at or near the maximum power point, resulting in the highest possible efficiency. As the load resistance increases, causing the photovoltaic module to operate at a voltage higher than the maximum power point, module efficiency decreases. Efficiency also decreases at voltages less than at the maximum power point.

Intensity of Sunlight- a photovoltaic module's output is proportionally affected by the intensity of solar radiation to which it is exposed. More intense sunlight will result in greater module output. Lower sunlight levels result in lower current output. Voltage is not changed appreciably by variations of sunlight intensity.

Cell Temperature- Photovoltaic modules operate less efficiently at higher cell temperatures. The operating voltage drops with increasing cell temperature. Heat, in this case may be thought of as an electrical resistance to flow of electrons. Effective current output may be significantly reduced decreased if the maximum power point of a module or array shifts to a much lower voltage than the operating voltage of the load. Generally, a module will lose approximately /% efficiency per degree centigrade of temperature rise between 80° and 90° C.

Shading- Even partial shading of photovoltaic modules will result in dramatic reduction of module's output. One completely shaded cell can reduce this module's output by as much as 80%. The effect of partial shading of three cells cuts the modules output in half when operating at 15 volts.

THE PHOTOVOLTAIC EFFECT

The basic unit of a photovoltaic system is the photovoltaic cell. It generates electricity because the cell's materials give it an electric potential and are sensitive to sunlight. The photovoltaic cell consists of thin layers of semi conducting material, prepared as wafers or films, most commonly made from silicon cells which are one of the earth's most abundant elements. Silicon's natural properties as a semiconductor of electricity make it an ideal material for photovoltaic cells. Its electric properties are modified by two other elements, boron and phosphorus, to create a permanent imbalance in the molecular charge of the material.

A solar cell is made up of two layers of semiconductor material. Two regions are created, a positively charged region and a negatively charged region. These layers create an electric potential within the cell. Light energy striking the cells free electrons from some of the atoms in the cell material. The cell's internal potential pushes these free electrons toward one of the layers. When one end of a wire is attached to this layer and the other end is attached to the second layer, the free electrons will flow through the wire, creating an electric current[2].

PHOTOVOLTAIC ARRAY

A photovoltaic array is a linked collection of photovoltaic modules, which are in tum made of multiple interconnected solar cells. The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array.

Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can plug into the existing infrastructure to power lights, motors, and other loads. The modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current. Solar arrays are typically measured by the electrical power they produce, in watts, kilowatts, or even megawatts.

2.4.2: ELECTRICAL CHARACTERISTICS OF PV MODULES

The industry standard against which all PV modules are rated and can be compared is called Standard Test Conditions (STC). STC is a defined set oflaboratory test conditions which approximate conditions under which PV modules might be used. The same standard is also used to evaluate potential installation locations, since it is the basis for Insolation values. STC includes three factors which are ***Irradiance*** (sunlight intensity or power), in Watts per square meter falling en a flat surface. The measurement standard is 1 kW per sq. m. (1,000 Watts/m2), ***Air Mass,*** refers to "thickness" and clarity of the air through which the sunlight passes to reach the modules (sun angle affects this value). The standard is 1.5 and ***Cell temperature,*** which will differ from ambient air temperature. STC defines cell testing temperature as 25 degrees C. [2]

EFFICIENCY *()*

Efficiency is the ratio of the electrical power output *Pout,* compared to the solar power input, *Pin,* into the PV cell. *Pout* can be taken to be *PMAX* since the solar cell can be operated up to its maximum power output to get the maximum efficiency. Pin is taken as the product of the irradiance of the incident light, measured in W/m2 or in suns (1000 W/m2), with the surface area of the solar cell [m2]. The maximum efficiency (nMAX) found from a light test is not only an indication of the performance of the device under test, but, like all of the I- V parameters, can also be affected by ambient conditions such as temperature and the intensity and spectrum of the incident light. For this reason, it is recommended to test and compare PV cells using similar lighting and temperature conditions.

An example of these type ofUAV in existence is the AC Propulsion Solong.

Table 3: AC Propulsion Solong specifications [26]

SPECIFICATIONS	
Vehicle Gross Weight	12.6 kg
Endurance Range/Time	48+ hrs.
Propulsion Subclass	Solar powered
Propulsion Unit Make	SunPower A300 solar cells
Power Output	Solar panel nominal power 225W

ADVANTAGES AND DISADVANTAGES OF PHOTOVOLTAIC SYSTEMS

The advantages of photovoltaic-based systems are reliability whereby even in harsh climates, photovoltaic systems have proven their reliability. Often, photovoltaic systems are chosen for systems that must remain operational at all times. Photovoltaic systems may prevent costly or dangerous power failures in situation where continuous operation is critical. In addition to this, these systems have a low Maintenance Cost. It is expensive to transport materials and personnel to remote areas for equipment maintenance. Since photovoltaic systems require only periodic inspection and occasional maintenance, these costs are usually less than with conventionally fueled equipment alternatives.

Also, being scale able and modular gives photovoltaic based systems an edge over the others. From providing milli-watts to power a calculator to acres of panels providing megawatts for grid connected supply on a commercial building roof or field, solar power products can be deployed in many sizes and configurations and can be installed quickly and almost anywhere in the world. As a distributed generation option, transmission and distribution costs are reduced.

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Universal Applications- Solar PV is the only renewable energy technology that can be installed on a truly global scale because of its versatility and because it generates power under virtually all conditions, i.e. even in overcast light conditions

Peak Shaving- The output of solar systems typically correlates with periods of high electricity demand where air conditioning systems create peak demands during hot sunny days. PV can shave peak-load demand, when energy is most constrained and expensive and therefore can move the load off the grid and alleviate the need to build new peak generating capacity. **Reliability-** With no fuel supply required and no moving parts, solar power systems are among the most reliable electric power generators, capable of powering the most sensitive applications, from space satellites to microwave stations in the mountains and other remote harsh environments. Solar panels typically carry warranties of 20 years or more.

Dual use- Solar panels are expected to increasingly serve as both a power generator and the skin of the building. Like architectural glass, solar panels can be installed on the roofs or facades of residential and commercial buildings.

Environmentally safe- Solar power systems produce no air or water emissions or greenhouse gases and produce no noise. Solar systems are generally far safer than other distributed energy systems, such as diesel generators and as such are the most suitable technology for urban on-site generation. PV is the only commercially available renewable technology generation option for urban areas.

The disadvantages of photovoltaic-based systems are cost as photovoltaic systems have a high initial cost. Each installation must be evaluated from an economic perspective and compared to existing alternatives. If the initial cost of the photovoltaic systems decreases and the cost of conventional fuel sources increases, photovoltaic systems will become more economically competitive. Variability of Available Solar Radiation can become a problem since the weather can adversely affect the power output of any PV system. If there is no sunshine there is no power.

Some photovoltaic systems use batteries for storing energy which will be used at a later time. The battery increases the system's size and cost can make the system more complex. Also, Photovoltaic systems use a new technology with which many people are unfamiliar. Few people understand its applicability. This lack of information slows market and technological growth.

Table 4: Technical issues of photovoltaic systems

Technical Issue	Applicability to UAS Context
Light Source Dependency	UAS may fly continuously without fatigue and therefore may allow intended operation above the restrictions of the NAS.
Array failure	Loss of primary energy source may not require an immediate forced landing (such as during night flight on battery backup), but detection mechanisms may be required even when the photovoltaic system is not in use
Energy-Buffering System Requirement	Requirements for a fail-operational backup may add an irreconcilable weight penalty.

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2.5: PHOTOVOLTAIC AND BATTERY SYSTEMS

These offer the potential for unlimited range and there is much research in this field. It is based on both photovoltaic and battery systems.

2.5.1: CHARGE CONTROLLERS

Charge controllers are included in most photovoltaic systems to protect the batteries from overcharge or excessive discharge. Overcharging can boil the electrolyte from the battery and cause failure. Allowing the battery to be discharged too much will cause premature battery failure and possible damage to the load. The controller is a critical component in the PV system. A controller's function is to control the system depending on the battery state-of-charge (SOC).

When the battery nears full SOC the controller redirects or switches off all or part of the array current. When the battery is discharged below a preset level, some or the entire load is disconnected if the controller includes the low voltage disconnect (L VD) capability. Most controllers use a measurement of battery voltage to estimate the state-of-charge. Measuring battery temperature improves the SOC estimate and many controllers have a temperature probe for this purpose.

The controller voltage must be compatible with the nominal system voltage and it must be capable of handling the maximum current produced by the PV array.

TYPES OF CONTROLLERS

There are two basic types of controllers used for small PV systems, shunt and series controller. The Shunt controller redirects or shunts the charging current away from the battery. These controllers require a large heat sink to dissipate the excess current. Most shunt controllers are designed for smaller systems producing 30 amperes or less. While, the Series controller interrupts the charging current by open-circuiting the PV array. This switching controller is thus limited by the current handling capability of the components used to switch the de current.

Other classifications include the Single stage controllers which disconnect the array when the battery voltage reaches the high voltage level and the Multistage controllers which allow different charging currents as the battery nears full state-of charge. This technique also provides a more efficient method of charging the battery. As the battery nears full SOC, its internal resistance increases and using lower charging current wastes less energy.

BLOCKING REVERSE CURRENT

Photovoltaic panels work by pumping current through the battery in one direction. At night, the panels may pass a bit of current in the reverse direction, causing a slight discharge from the battery [27]. Battery here represents either a single battery or bank of batteries. The potential loss is minor, but it is easy to prevent. Some types of wind and hydro generators also draw reverse current when they stop (most do not except under fault conditions) [28].

In most controllers, charge current passes through a semiconductor (a transistor) which acts like a valve to control the current. It prevents reverse current without any extra effort or cost. In some

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controllers, an electromagnetic coil opens and closes a mechanical switch. This is called a relay. The relay switches off at night, to block reverse current [29].

If a PV array is being used only to trickle-charge a battery (a very small array relative to the size of the battery), then a charge controller may not be needed [30].

PREVENTING OVERCHARGE

When a battery reaches full charge, it can no longer store incoming energy. If energy continues to be applied at the full rate, the battery voltage gets too high. Water separates into hydrogen and oxygen and bubbles out rapidly. There is excessive loss of water, and a chance that the gasses can ignite and cause a small explosion. The battery will also degrade rapidly and may possibly overheat. Excessive voltage can also stress loads or cause the inverter to shut off [28].

Preventing overcharge is simply a matter of reducing the flow of energy to the battery when the battery reaches a specific voltage. When the voltage drops due to lower sun intensity or an increase in electrical usage, the controller again allows the maximum possible charge. This is called "voltage regulating." It is the most essential function of all charge controllers [27]. The controller "looks at" the voltage, and regulates the battery charging in response.

Some controllers regulate the flow of energy to the battery by switching the current fully on or fully off. This is called "on/off control." Others reduce the current gradually. This is called "pulse width modulation" (PWM). Both methods work well when set properly for your type of battery. A PWM controller holds the voltage more constant (30].

If it has two-stage regulation, it will first hold the voltage to a safe maximum for the battery to reach full charge. Then, it will drop the voltage lower, to sustain a "finish" or "trickle" charge. Two-stage regulating is important for a system that may experience many days or weeks of excess energy (or little use of energy) [30]. It maintains a full charge but minimizes water loss and stress.

The voltages at which the controller changes the charge rate are called set points. When determining the ideal set points, there is some compromise between charging quickly before the sun goes down, and mildly overcharging the battery. The determination of set points depends on the anticipated patterns of usage, the type of battery, and to some extent, the experience and philosophy of the system designer or operator. Some controllers have adjustable set points, while others do not.

CONTROL SET POINTS VS. TEMPERATURE

The ideal set points for charge control vary with a battery's temperature. Some controllers have a feature called "temperature compensation." When the controller senses a low battery temperature, it will raise the set points. Otherwise when the battery is cold, it will reduce the charge too soon. If the batteries are exposed to temperature swings greater than about 30° F (17° C), compensation is essential.

Some controllers have a temperature sensor built in. Such a controller must be mounted in a place where the temperature is close to that of the batteries. Better controllers have a remote

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temperature probe, on a small cable. The probe should be attached directly to a battery in order to report its temperature to the controller.

An alternative to automatic temperature compensation is to manually adjust the set points (if possible) according to the seasons.

CONTROL SET POINTS VS. BATTERY TYPE

The ideal set points for charge controlling depend on the design of the battery. The vast majority of RE systems use deep-cycle lead-acid batteries of either the flooded type or the sealed type.

Flooded batteries are filled with liquid. These are the standard, economical deep cycle batteries. Sealed batteries use saturated pads between the plates. They are also called "valve-regulated" or "absorbed glass mat," or simply "maintenance-free." They need to be regulated to a slightly lower voltage than flooded batteries or they will dry out and be ruined. Some controllers have a means to select the type of battery. Never use a controller that is not intended for your type of battery.

LOW VOLTAGE DISCONNECT (L VD)

The deep-cycle batteries used in renewable energy systems are designed to be discharged by about 80 percent. If they are discharged 100 percent, they are immediately damaged. Every time this happens, both the capacity and the life of the battery will be reduced by a small amount. If the battery sits in this over discharged state for days or weeks at a time, it can be ruined quickly.

The only way to prevent over discharge when all else fails, is to disconnect loads (appliances, lights, etc.), and then to reconnect them only when the voltage has recovered due to some substantial charging. When over discharge is approaching, a 12-volt battery drops below 11 volts (a 24 V battery drops below 22 V). A low voltage disconnect circuit will disconnect loads at that set point. It will reconnect the loads only when the battery voltage has substantially recovered due to the accumulation of some charge. A typical L VD reset point is 13 volts (26 V on a 24 V system).

OVERLOAD PROTECTION

A circuit is overloaded when the current flowing in it is higher than it can safely handle. This can cause overheating and can even be a fire hazard. Overload can be caused by a fault (short circuit) in the wiring, or by a faulty appliance (like a frozen water pump). Some charge controllers have overload protection built in, usually with a push-button reset.

Built-in overload protection can be useful, but most systems require additional protection in the form of fuses or circuit breakers. If you have a circuit with a wire size for which the safe carrying capacity (ampacity) is less than the overload limit of the controller, then you must protect that circuit with a fuse or breaker of a suitably lower amp rating.

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CHAPTERTHREE : METHODOLOGY

3.1: DESIGN OF MOTOR AND PROPELLOR UNIT

The brushless motor is the best suited for aircraft applications due to:

- ► Thrust-to-Weight Ratio
- ► High Efficiency

In order to choose a brushless motor for the application, it is required by de facto that a motor that can produce a thrust of about twice the weight of the frame and its components. This weight is usually called the AII-Up-Weight (AUW) i.e. Thrust Total > 2 * AUW.

From this, each motor is required to produce at least a thrust that is equivalent to the total thrust produced, i.e.,

$$Thrust_{motor} = \frac{Total\ thrust}{No\ of\ motors} = \frac{2 \times AUW}{No\ of\ motors}$$

$$I_m = \frac{U_m - \%/K}{R_m}$$

$$M_m = (I_m - I_o)\frac{30}{\pi K_v}$$

where *Im* and *Um* are the terminal voltage and current of the electric motor, respectively, *rm* is the terminal resistance, kv is the rotation speed constant, **n** is the rotation speed, *Mm* is the torque produced by the motor, and *I0* is the idle current without load.

Also;

$$n_{m\,max} = \frac{(U_{m\,max} - R_m I_{m\,max})K_v U_{m_0}}{U_{m_0} - R_m I_{m_o}}$$

$$M_{m\,max} = \frac{30\left(I_{m\,max} - I_{m_o}\right)\cdot\left(U_{m_o} - R_m I_{m_o}\right)}{\pi K_v U_{m_o}}$$

$$I_m = \frac{\pi M_m K_v U_{m_0}}{30(U_{m_o} - R_m I_{m_o})} + I_{m_o}$$

$$U_m = R_m \cdot I_{m\,max} + \frac{U_{m_o} - R_m I_{m_o}}{K_v U_{m_o}} + n_p$$

$$\eta_m = \left(1 - \frac{I_m R_m}{U_m}\right)\cdot\left(1 - \frac{I_{m_0}}{I_m}\right)$$

$$M = \frac{\eta_m \cdot I_m \cdot U_m}{2\pi n / 60}$$

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$$E, = n \cdot ha \cdot U$$

Where UMo and IMo are motor no-load voltage and current, nm-max and Mm-max are maximum value of rev/min and torque, n, and Mp are speed and torque of propulsion unit connected to motor, IM and UM are current and voltage of motor, MM and PM are delivered torque and mechanical power and n is motor efficiency.

PROPELLERS

Propeller is a type of fan that converts rotational motion into thrust. Generally, propellers are classified on the basis of their diameter and pitch and are represented in terms of product of diameter and pitch. The mostly used types of propeller are nylon, carbon and plastic propellers.

$$n_P = 60\sqrt{\frac{T_p}{C_T \rho D_p{}^4}}$$

$$M, = CuP\, a, \left(\frac{Np}{\,}\right)^2 D»^5$$

$$C_T = K_{t_0} N_P Q_P$$

$$C_M = K_{m_0} N_P{}^2 \left(K_{m_1} + K_{m_2} \cdot Q_P{}^2\right)$$

$$1J = \frac{F \cdot V}{2rT,n,}$$

$$F = \frac{on,^\circ crD,' \; T,}{crD»}$$

$$r, = \frac{Cr \cdot V}{2rCmn4D»}$$

Where CT and CM are propeller thrust and torque coefficient, T p and D are propeller thrust and diameter, Q is propeller blade angle, Fis thrust force and n is torque efficiency. Kto, Kmo, Km1 and Km2 are parameters depending on the shape and aerodynamics of propeller blades.

ELECTRONIC SPEED CONTROL

The brushless motors are normally 3 phased, so direct supply of DC power will not tum the motors on. Electronic Speed Controllers generate three high frequency signals, with different but controllable phases, continuously to keep the motor turning.

ESC has a battery input and three phase output for the motor. Each ESC is controlled independently by a PPM signal (similar to PWM). The frequency of the signals varies a lot, but for a Quadcopter it is recommended that the controller should support high frequency signal, so the motor speeds can be adjusted quick enough for optimal stability (i.e. at least 200 Hz or even better 300 Hz PPM signal).

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The speed controller is dependent on the type of brushless motor chosen. It is safe to choose an ESC that has a current rating that is 1.5times greater than the current draw of the brushless motor it controls.

Hence, *ESCcurrent ~ BLDCcurrent* * 1.5

UEsc ma = *Um max*

VEsc ma = *hmax*

Uinput = *Saat* * *Nominal voltage of a single battery cell I U*

PWF *m m*

UEesc max · I ESC max

(Una- Ra., - PTFd - PWE)) 77Esc

Unput

$$P_{ESC} = I_m U_m$$

I _ *(PEsclYJEsc)*

ESC

Unut

Where UEesc and IEsc are ESC nominal voltage and current, Rbat is battery resistance, nsc is ESC efficiency, PTF is part throttle factor, PWF is the power factor and Uinput is nominal value of the battery voltage that the ESC receives in input.

3.2: PHOTOVOLTAIC SYSTEM SIZING

Sizing a photovoltaic system for a stand-alone photovoltaic power system involves a four-step process which will allow the photovoltaic system designer or user to accurately size a system based on users projected needs, goals and budget. These steps include estimating the Electric Load, sizing and Specifying Batteries, sizing and Specifying an Array and finally specifying A Controller

3.2.1: ESTIMATING THE ELECTRIC LOAD

The first task for any photovoltaic system design is to determine the system load.

The following steps are followed for Electric Load Estimation; firstly, identify each load and the number of hours of use per day. Enter the load current in amperes and the operating voltage for each load and calculate the power demand. The power demand is the product of the current and the voltage. Secondly group the loads by type and operating voltage and sum the Power demand for each group. And lastly, after selecting the system voltage, calculate the total daily ampere hours required at this voltage.

The load determination is straightforward the power requirements of any electrical device that will be included in the system are calculated and multiplied by the amount of time that specific

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appliances will operate each day. The power required by an appliance can be measured or obtained from manufacturer's data sheets. However, the amount of time the appliance will be used per day, week, or month must be estimated.

Average daily load = Total connected watts x *Hours of use per day* **3.2.2: SIZING AND**

SPECIFYING A BATTERY

The best battery for the quadcopter or general flight applications is the Lithium Polymer batteries. This is because of their High Discharge rate, High capacity and Light weight

In order to choose the right battery, the BLDC has to be considered, some require 3-cell LiPo batteries while some others require 4-cell LiPo.

Battery capacity=Total current draw x Flight time *Total power consumed*

Total current draw= $\frac{B\qquad l}{attery\ voltage}$

With higher specific power, lithium-ion batteries remedy the limitation of fuel cells. The rechargeable characteristic enhances the utilization efficiency of the PV panel by storing the surplus solar energy when the power demand is low. The battery also provides a relatively stable operation voltage on DC bus for the BLDC motor.

Before making these choices, the concept of system availability and battery parameters should be taken into consideration. Some of the considerations made when sizing the battery are;

First, the amount of back-up energy to be stored is calculated for the given application. This is usually expressed as a number of no sun days, in other words, for how many cloudy days must the system operate using energy stored in batteries. This depends on the application, the type of battery, and the system availability desired.

When specifying, the difference between rated battery capacity and usable capacity should be enumerated. Many Battery manufacturers publish a rated battery capacity (the amount of energy that their battery will provide if discharged once under favorable conditions of temperature and discharge rate). This is usually much higher than the amount of energy that can be taken out of the battery repeatedly in application.

The best recommendation for the number of days of storage is to put in as much battery capacity as can be afforded. Obviously, for areas with extended periods of cloudiness need more storage capacity to keep the load going during these periods of inclement weather. Also, if it is critical that loads have power at all times, it is advisable to have a large battery capacity. A smaller battery size can be specified if one can live with some power outage.

The system design takes into consideration all these aspects plus more when choosing the battery type and size.

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Some factors can outweigh the technical sizing decision. For instance, if batteries can be obtained locally thus making savings in shipping costs. This savings can be used to buy more batteries.

Finally, it is important to understand the close interrelation between the battery and the charge controller. When a battery is bought, a compatible charge controller should also be purchased. A charge controller is an electronic device that attempts to maintain the battery state-of-charge (SOC) between preset limits. The battery voltage is measured and used as the primary estimator of SOC. (Some charge controllers measure battery temperature in addition to voltage to improve the estimate of SOC.) If the charge controller does not operate properly the battery may be over charged or allowed to discharge too much. Either way the lifetime of the battery will be shortened and more money will be spent to replace the batteries.

Step 1: *Average Amp hour per day load* = $\frac{\text{Average daily load}}{\text{DC system vo tage}}$

T l b . *Average Amp hour* x *Days of autonomy*

[ep ; *Old)Q[Der]es c*
Discharge limit xbattery amp hour capacity

3.2.3: SIZING AND SPECIFYING AN ARRAY

The design method for the array uses current (amperes) instead of power (watts) to describe the load requirement because it is easier to make a meaningful comparison of PV module performance, i.e., specifying PV modules that will produce 30 amperes at 12 volts and a specified operating temperature rather than try to compare 50watt modules that may have different operating points. The module specifications are obtained for available modules so that a comparison of performance, physical size, and cost can be made. Generally, there are several modules that will meet a given set of requirements.

The worksheet requests the entry of rated module current. This is the current produced at standard test conditions (STC) of l ,000w/m^2 irradiance and 25°C temperature. The value used in the worksheet for rated module current should be Isc.

However, the operating voltage of a PV array is determined by the battery voltage. This varies over a narrow range depending on the battery state of charge and ambient temperature but is usually 1 to 4 volts lower than the voltage at which peak power figures are quoted by module manufacturers.

Also, if a blocking diode is used between the module and the battery, this will cause a voltage drop of about 0. 7 volts. The module must be able to sustain this drop plus any voltage drops caused by the wires and still supply enough voltage to fully charge the battery.

The number of parallel-connected modules required to produce the design current is rarely a whole number, the design must make a decision whether to round up or round down. The system availability requirements should be considered when making this decision.

Step 1: To begin this section the battery inefficiency is calculated. This value can be taken from manufacturer's data sheets. The Average Amp Hour per Day Load is then divided by an estimated "Battery Energy Efficiency" which is usually about 0.8. This figure includes the balance of system inefficiencies and is the amp-hour production required of the array. The result is divided by the number of "Peak Sun Hours per Day" available and this will give the "Array Peak Amps".

$$\text{Array peak amps} = \frac{\text{Average Amp hour per day load}}{\text{Battery energy efficiency} \times \text{Peak sun hours per day}}$$

Step 2: Peak sun hours may be adjusted to account for other variables such as added reflectance or shading. The Array Peak Amps is then divided by "Peak Amps per Module". The Peak amps per Module is a tested value at one peak sun and should be found in a module manufacturer's module specifications. This calculation will result in the number of modules in parallel which the system will require.

Total solar modules = *2P&GK d"PY*

Peak amps per module

3.2.4: SPECIFYING A CONTROLLER

The controller must not only be able to handle typical or rated voltages and currents, but must also be sized to handle expected peak or surge conditions from the PV array or required by the electrical loads that may be connected to the controller. It is extremely important that the controller be adequately sized for the intended application. If an undersized controller is used and fails during operation, the costs of service and replacement will be higher than what would have been spent on a controller that was initially oversized for the application.

Typically, it is expected that a PV module or array produces no more than its rated maximum power current at 1000 W /rn2 irradiance and 25°C module temperature.

The size of a controller is determined by multiplying the peak rated current from the module by the modules or strings in parallel. To be conservative, the short-circuit current (Isc) is generally used. Charge controllers should be sized according to the voltages and currents expected during operation of the PV system.

Maximum array amps = Module short circuit current x *total modules* **BLOCK DIAGRAM OF THE UAV POWERTRAIN**

SOLAR MODULES

BLOC MOTOR1 1

BATTERIES

ESCs

BLOC MOTOR2

RI DC MTR

SYSTEMS CONTROL UNIT

BLOC MOTOR4

►

CHAPTERFOUR : RESULTS

4.1: SIZED ENERGY UNIT

DESIGN ASSUMPTIONS

Choosing a T-Motor of 50V at 75% throttle, If

flight time = 1 hr

System voltage = 48V

4.1.1: ESTIMATED ELECTRIC LOADS

Table 5: UJ 5llKV80 T-motor specifications [31}

voltage	50V
Current	56.2A
Thrust	18900g ,,
Weight	1740g
Dimensions	147.5*64 mm
Maximum continuous current	143A

Total connected watts= Total Motor wattage + *Onboard comonents wattage*

(50 x **56.2** x **4)** + **(5** x **2)** = 11,250W

Average daily load = *Total connected watts* x *Hours of use per day* = **11,250 x 1**

= 11,250Wh

4.1.2: SIZED BATTERY

Table 6: Battery specifications from manufacturer's datasheet [32}

Battery capacity	lOOAh
Approx. Weight	3.17
Dimension LWH)	16957220 mm

$$\text{Average Amp hour per day load} = \frac{\text{Average daily load}}{\text{DC system voltage}}$$

$$= \frac{11{,}250}{48} = 234.38\text{Ah}$$

Step 2: $$\text{Total batteries} \quad \frac{\text{Average Amp hour} \times \text{Days of autonomy}}{\text{Discharge limit x battery amp hour capacity}}$$

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$$\frac{\mathbf{234.38}\ x\ \mathbf{1}}{0.6\ x\ 10} > 3.9 = 4\,batteries$$

4.1.3: SIZED ARRAY

Table 7: The Go Power! Flexible solar specifications [33]

Module type	Monocrystalline
Maximum current	11.36A
Short circuit current	12.56A
Weight	17002
Dimensions	(11345443) mm

$$Aray\ pea\ amps = \frac{Average\ Amp\ hour\ per\ day\ load}{Battery\ energy\ ef\ f\ iciency\ xPeak\ sun\ hours\ per\ day}$$

$$\frac{234.38}{0.85XSg} 50.134$$

$$Total\ solar\ modules = \frac{Array\ peak\ amps}{Peak\ amps\ per\ module}$$

$$= \frac{50.13}{ll._{36}} = 4.41 = 5\ Solar\ modules$$

4.1.4: SIZED MPPT CHARGE CONTROLLER

$$Maximum\ array\ amps = Module\ short\ circuit\ current\ x\ total\ modules$$

$$= 12.56x5 = 62.84 = 704$$

ESTIMATED WEIGHT OF THE UA V

COMPONENT	QUANTITY	UNIT WEIGHT(kg)	TOTAL WEIGHT(kg)
motors	4	1.74	6.96
Batteries	4	3.17	12.68
Solar modules	5	1.7	8.5
Frame			2
Propeller (carbon-fiber)	4	0.2	0.8
Pay load			40
TOTAL			70.94

►

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS 5.1: CONCLUSION

With an estimated load of 10.45kW-Hr, approximately 4 batteries of lOOAh capacity, five 11.36A per solar modules with a charge controller of 70A maximum de load amperes can be used to construct the powertrain of a four rotor UAV, to carry a pay load of 40kg.

5.2: RECOMMENDATIONS

Prototype implementation of the designed powertrain of the Unmanned Aerial Vehicle.

There should be a protective covering for the solar panel as they are very fragile. This can be glass covering or any material that does not affect the power output of the solar panel. Also, the weight of this covering should be considered.

Any redundant weight in the UAV system should be removed in order to reduce the weight that is to be overcome by the thrust of the motors. This can be done by making spaces in the frame to allow airflow, while not comprising the strength of the frame.

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