Feasibility for a Solar Powered Autonomous Drone Vertiport System

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In this paper, we aim to investigate the feasibility of a solar panel system. It has the capability to support contact-based charging systems for a number of autonomous drones that will be used for identifying and measuring emission sources of methane on sites. This charging system will be supporting the STEER system (*Sustainable verTiport framework for autonomous dronE swarm methane Emission measurement over oRphaned wells*) and it is mainly comprising of two major parts: 1) vertiport and 2) swarm of drones. The vertiport will be the main component that will house the charging system as well as the drones. The structure of the vertiport will be bioinspired by the resemblance of trees, that will allow the drones to be charged via a contact-based charging system powered by solar energy. Currently, the off the shelves system can support up to 8 drones throughout a day cycle. In this paper the data collected demonstrates the feasibility of an off-grid system supporting STEER.

I. Introduction

Methane (CH4) is recognized as a significant contributor to global warming, with orphaned wells standing out as prominent sources of methane emissions. According to a study conducted by the Environmental Protection Agency (EPA), approximately 7.11 million metric tons of Carbon-Di-Oxide (CO2) and Methane (CH4) are emitted annually from 2.15 million abandoned wells across the United States [1]. The escalating number of orphaned wells suggests a continual rise in these emissions, emphasizing the urgent need to control methane emissions by addressing unplugged abandoned wells, which also contributes to land restoration. However, tackling this issue is not only challenging but also entails substantial costs. Carbon Tracker, a climate-focused think tank, estimates that plugging all identified onshore active and inactive orphaned wells would require a staggering $280 Billion. To optimize costs, the identification and plugging of highly emitting orphaned wells would be more efficient.

Traditional methods of quantifying methane emissions, such as using Flux Chambers, prove to be expensive and inefficient due to the high capital and operational costs associated with deploying surface flux chambers. Additionally, the challenges include transporting these chambers and technicians to hard-to-reach locations, as well as the need for expert manpower to install and uninstall chambers on-site. Hence the development and use of the Sustainable verTiport framework for autonomous dronE swarm methane Emission measurement over oRphaned wells (STEER).

STEER presents an autonomous and efficient approach to quantify methane emissions from widely dispersed orphaned wells. The system operates independently and is powered by solar energy, yet the challenging part for the use of solar energy is meeting the quota for the energy use for the operation of the system, but also to charge the batteries of the drones. The charging of the drones will be through the use of contact-based charging. For the test of the feasibility of using solar energy, all of the experiments used off the shelf equipment for both the solar panels and battery.

In this paper we will present the data that was collected on the energy grid that will be used to operate the steer system. The bare grid consists of four 100W solar panels each being connected in parallel to a solar energy

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controller that will be used to charge the 12-volts 100-amp hour battery. The battery will then be parallel to an inverter that will be powering on the contact-based charger provided by SKYCHARGE.

II.Background and Setup

The final outcome of this project is to create a fully sustainable isolated system where drones will be able to head out of a vertiport system and complete a survey of methane emissions autonomously. Once the task is completed or the drone requires a recharge, it will return to the vertiport. The vertiport itself is a bio inspired structure resembling a tree like shape, having capsules as branches which will house and charge the drones. At the base of the vertiport is where the main battery and the central computing system will be housed. at the top of the vertiport is where the solar panels will be mounted, the angle of the solar panels will be moved by the linear actuator and controlled by the computing system. In between the solar panels will be the weather station for gathering data and sending it down to the computing system at the base. This data will be used to determine the safety of the drones at adverse weather conditions. Below is are two images of the current vertiport design:

a)

b)

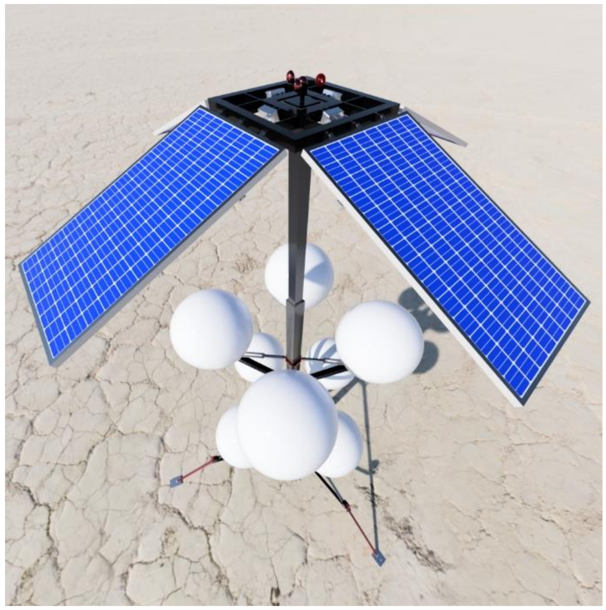

Fig 1-a. Entire Vertiport Structure

Fig. 1-b Top of the Vertiport Structure

Now that a clear image of the desired outcome, the first system that needs to be developed is the isolated grid that will give power to all of the electrical systems and be capable of recharging multiple drones during the day. If the electrical grid of the vertiport can't accomplish this, then there will be issues moving forward. Hence the primary focus on the paper will be on the solar powered charging system for vertiport system.

Solar panels consist of many different solar cells that are wired together in ether series or parallel depending on the needs of a system. The solar cells are just photoelectric diodes that have a voltage potential between the two electrodes junctions that are doped to create the p and n junction of a diode [2]. solar cells are dampened by two common conditions; angle of the sun and the temperature of the panels. When the sun is at the highest peak, the potential of the panel is at the maximum, but as the sun moves away from the normal of the surface of the panel the potential of the panel becomes a sinusoidal function dependent on the angle of the sun. When temperature increases, the efficiency of the solar panel decreases as the gap created by the P-N junction of the diode decreases, hence the open circuit voltage potential decreases having a negative relation with temperature. as for current is independent from temperature, meaning that there is little to no effect of current [3].

The four solar panels are connected to a voltage and current regulator known as a controller. This ensures that a constant voltage and current is fed into the battery without any issues. Now the controller can give some insight on the state of the battery and the solar panels, but is also used to protect the battery from overcharging or undercharging as well. A fuse is placed in between the solar panels and the controller, this is to protect the controller. The 12-volts 100-amp hour battery will be the powerhouse of the system when there is no sun, and should be able to support the system for at least the entire night cycle. This battery will be wired parallel to the inverter that will convert the DC voltage into AC 110V. Due to the inverter, a lot of the energy that was stored in the battery is lost in heat because of the inverter. The inverter is then connected to the contact-based charging source from the Skycharge. this is the bare grid for the final product of the STEER project, below is a schematic of the grid;

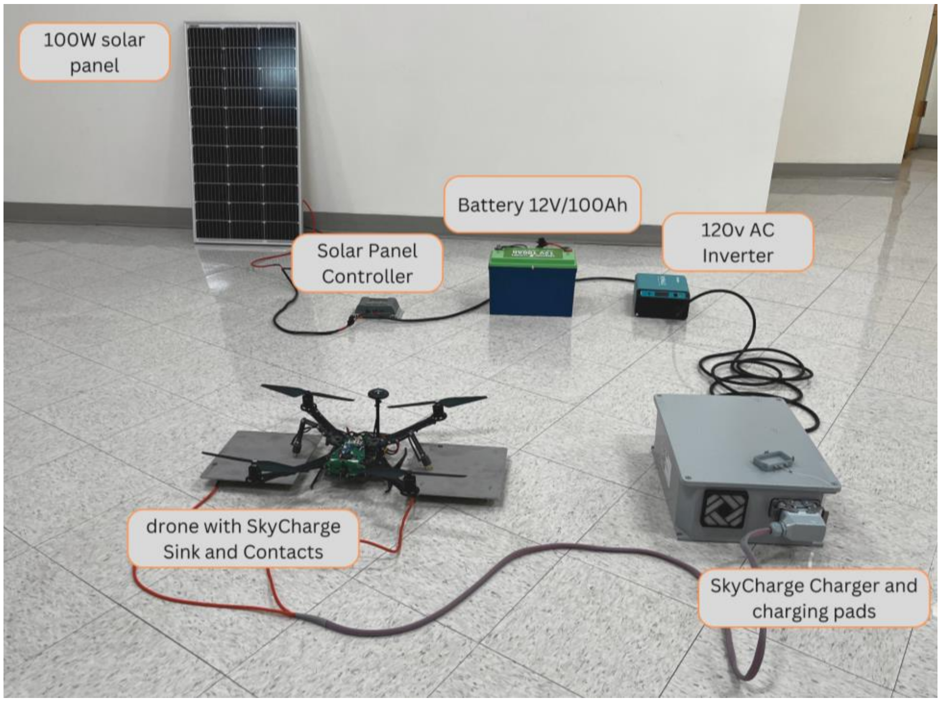

Fig 2. The System's Main Isolated Grid

The skycharge system has high functionality and degrees of freedom. First of which was important for collecting data. The skycharge system sends data of not just the drone battery, but can send the voltage supplied to battery, currents supplied to the battery, total amount of power used, current power forwarded to the drone battery, and the current time of the process of charging the battery. The degrees of freedom of the device are useful, in case that there is a need for a different type of battery, the system can be set up to charge the different battery.

The drone and the battery used for the testing is a VOXL m500 paired with the 4S Battery Pack - Gens Ace 3300mAh. The drone was tested to see how long it could last in the air before the battery needed to be charged. The battery was tested to measure the time needed to charge up the battery, but also to measure the amount of power it would take from the battery. There were in total two trials of experimentation, one for the day cycle (solar panels generating energy) and one for the night cycle (solar panels were inert). down the line a simulation was made to figure out an approximation of the number of drones the system can handle.

III.Result and Discussion

On a sunny day, we tested the whole system under the sun at 1:00 pm. and we collected data every 5 minutes for 1 hour. In the beginning the power-bank level was 97% and the drone battery charge was 0 Ah. It took 58 minutes to charge the drone battery fully, which is 3.3Ah. In the mean-time the power-bank level didn't decrease, rather it increased to 98%.

Fig 3. The orientation of the solar panels

The solar panels orientation is flat, this hinders the production of power due to the difference between the normal angle of the panels and the normal angle of the incoming flat wavefront of the sun. Even if the orientation of the panels is not ideal, the outcome of the experiment was a confirmation on the reliability of the solar panels. The energy produced during the time frame of 1 hour was able to support the drone battery charger, but also charge the battery at a slightly decreased rate. from the measurements between the inverter and the battery, both voltages remain the same, hence the currents are the main contributing factor. as the battery charges, the internal resistance increases, meaning that it takes a higher potential to charge the battery at the same rate therefore there is more current to power the inverter.

Table 1: collected data on the battery and solar panels.

Time	Solar Panel		Battery			
	Voltage	Current	Voltage from Controller	Voltage Actual	Current	Battery Level
12:50	14	15.1	13.8	13.5	15.1	97%
1:00	13.9	14.9	13.7	13.4	14.9	97%
1:05	13.9	14.9	13.7	13.4	14.9	97%
1:10	13.9	14.8	13.9	13.41	14.8	97%
1:15	13.9	14.7	13.7	13.42	14.7	97%
1:20	13.9	14.5	13.7	13.43	14.5	97%
1:25	13.9	14.4	13.7	13.43	14.4	97%
1:30	13.9	14.3	13.8	13.46	14.3	97%
1:35	14	14.1	13.8	13.51	14.1	97%
1:40	14	13.9	13.8	13.54	13.9	97%
1:45	14	13.8	13.9	13.56	13.8	97%
1:50	14	13.6	13.9	13.57	13.6	97%
1:55	14	13.4	13.9	13.58	13.4	98%
2:00	14	13.3	13.9	13.6	13.3	98%

Table 2: collected data on the SkyCharge device

Time	SkyCharge System			
	Energy (Wh)	Voltage	Current	Battery Charge (Ah)
12:50	0	0	0	0
1:00	0.39	14.25	3.6	0.034
1:05	5.8	15.933	5.009	0.376
1:10	14.7	16.27	5.009	0.918
1:15	18.542	16.322	5.009	1.154
1:20	25.996	16.45	5.009	1.62
1:25	31.609	16.634	5.009	1.971
1:30	40.056	16.79	4.374	2.501
1:35	45.899	16.79	2.864	2.835
1:40	48.86	16.764	1.997	2.999
1:45	50.776	16.764	1.466	3.122
1:50	52.286	16.764	0.952	3.206
1:55	53.537	16.764	0.582	3.285
2:00	53.985	0	0	3.312

Both of the tables above show the voltages and currents that are provided to the main battery and the drone battery. The data that was collected was in a span of one hour because that is how long it takes the battery of the drone to charge. The way that the contact-based charging device communicates with the computer to pull the data is through the terminal of the computer. One of the major problems is that without a DHCP server, the charging device will not be discoverable within the local network. The best work around to the problem is via the use of a router, this will provide an IP address to the device making it possible to SSH into the command window within the device. This means that the inverter is not only drawing current to power the charger meaning that there is more of an active load that is drawing from the inverter. What is meant as active is that the router is drawing more power than the charger in search mode. From the data that we collected we can see that as time passed by the power generation of the solar panel decreased. From the following plot we can observe that the power generation decrement rate was almost steady.

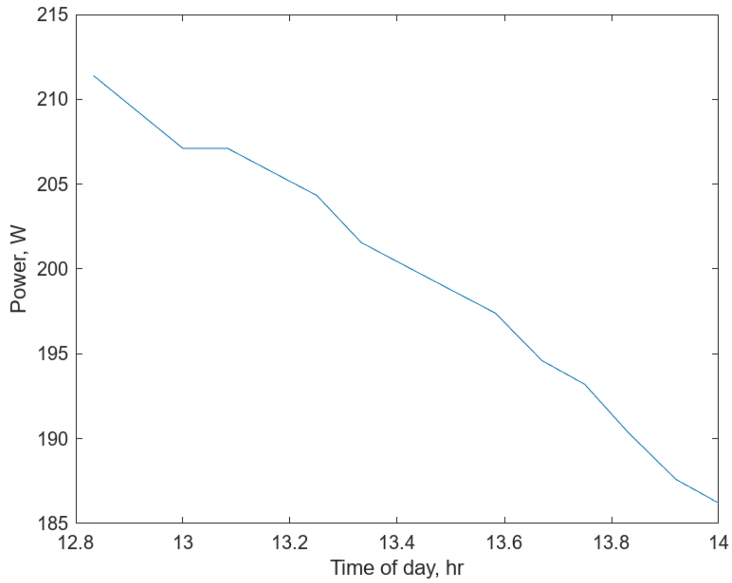

Fig 4. Power from solar panels with active charging system

The following plot gives us an idea about the voltage and current of the battery. We took the data of the battery voltage and current from the controller display. We also measured the voltage of the battery with a multimeter directly from the positive and negative poles of the battery. We can observe that the actual voltage of the battery that we measured directly from the poles of the battery is little less than the voltage displayed on the controller. And as time passed by, the flow of current decreased. Here the battery current and the solar panel current was the same for every measurement.

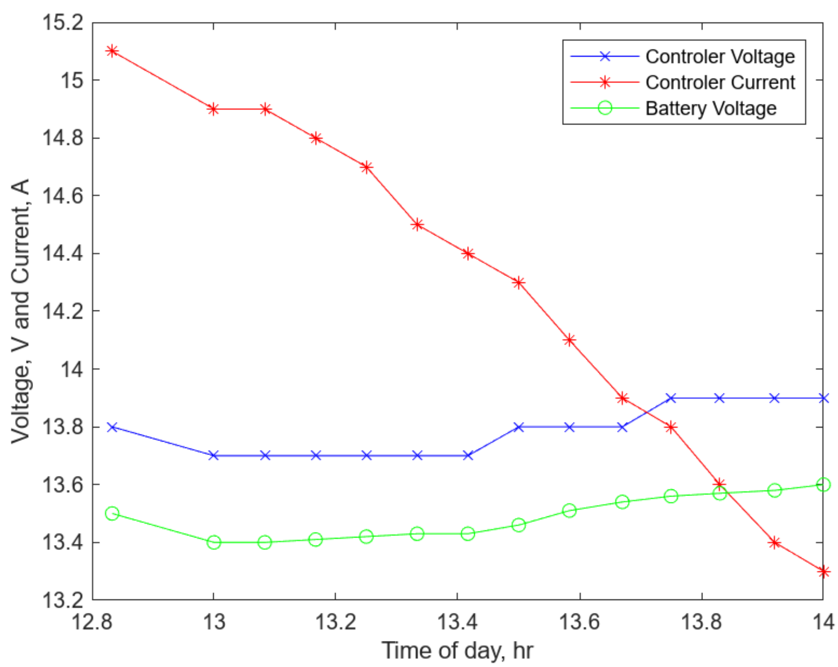

Fig 5. Voltage and current from solar panels with active charging system

The more important detail that can be pulled from the figure above is the fact that there is a slight decrease in the voltage when the contact-based charging system initializes. Yet as the power is used by the charger, the solar panels are still capable of providing the power necessary to continue the charging of the main battery. We gathered battery voltage and current data from the controller display, along with directly measuring the battery voltage using a multimeter connected to its positive and negative terminals. It became evident that the voltage measured directly from the battery terminals was slightly lower than the voltage indicated on the controller. Additionally, over time, the current flow decreased. Notably, the currents from both the battery and the solar panel remained consistent across all measurements.

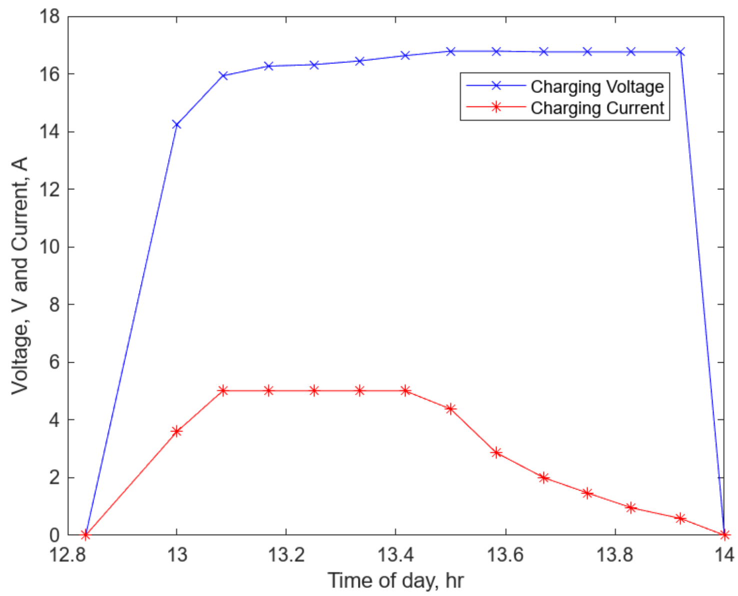

Fig 6. charging system data for drone battery

The plot above represents the voltage and current provided to the charging tiles for charging the drone battery by the Source of the charging system. The Source was drawing power from the inverter, and the inverter was connected parallelly with the battery and the solar panel. We observed that the voltage and current increased gradually up to a certain point, and after that, it was almost constant for a limited time period to charge the drone battery. As the drone battery charge was increasing, the voltage was the same but the current decreased gradually. When the battery charge is full, both the voltage and the current become zero. The current started to decrease when the charging system detected that the battery is 90% charged, meaning that once the decreasing current appears the drone will be ready for flight again. After the full day of processing the data, the next step is to approximate how many drones this system will be able to support throughout the day. These calculations were done by hand. The data that was used for these calculations were collected on a different day where the conditions were similar. This time the setup of the experiment was just the solar panels, controller, and the main battery. taking measurements in the span of 30 minutes for 5 hours. Below is a graph of the recorded power throughout the day:

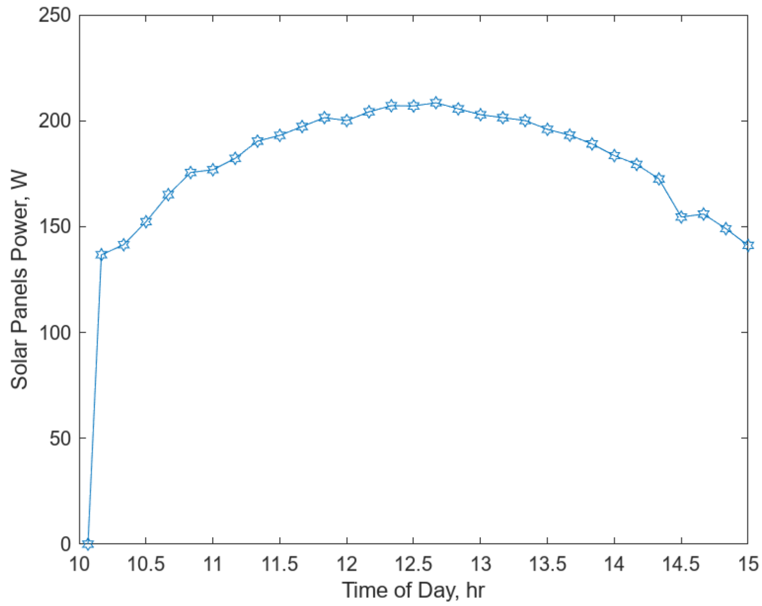

Fig 7. Power from solar panels throughout the day

From the graph above, the function of power can be related to a sinusoidal pattern. and as stated before that the highest peak is at noon. Therefore, the best time is noon to test the entire system with the drone charging system with the solar panels to experiment with the charge rate of the main battery at the peak of the sun's output. This led to the meticulous calculations using figure 5 and figure 6 plus a handy calculator with a plus and minus function, seeing how the charge rate would change as the number of drones would increase. The maximum drones that can be supported is around ideally 7 drones with a maximum of 8 drones. the figure is down below:

Fig 8. Estimated charging pattern for 8 drones

the estimation of drones gives reassurance for supporting multiple drones and having energy left over to power other components of the vertiport. This quality will give a degree of freedom when it comes to deciding the number of drones and the duty cycle of each drone. while keeping in mind the extra consumption of energy from the vertiport components.

IV.Future Research

With the grid of the **STEER** system being able to support the charging system, our next step is to look into the automation of our drone which includes Trajectory planning with collision avoidance and precision landing. What this means is that our drone must be able to fly autonomously from point A to Point B, then Back to Point A. While it is back at point A, the drone must be able to land on the charging pad. the area of the charging contact tiles will be only 2In by 8In. The drone will have to land with a low error percentile for contacts to charge the drone effectively. The method for performing this is through the use of Apriltags and deep learning models capable of detecting, referencing, and distancing the tags. The drones will have to have the capability of differentiating different landing pads in case the vertiport will be supporting multiple drones to avoid collisions. the main plan is to test the limitations of the sensor attached to the drones to decide on the best size of the Apriltags, but also the best operating distance for the drone.

Another side objective that is being worked on is decreasing the waste of energy through the dissipation of heat in the inverter. Again, the inverter is used to convert the DC voltage from the main battery into an AC signal that the drone charger can use. The plan method of reducing the use of energy is via the removal of the AC component of the contact-based charging system. While the AC component is being removed, we are also planning to shrink down and integrate the charging system with the vertiport. The main components will be housed inside of the trunk of the main pillar of the vertiport.

V.Conclusion

Demonstrated by the results, the grid of the system should be able to support multiple drones and the subsystems of the vertiport. The mythology of the experiment was to test the solar panels and see the power output throughout the day and finally test the grid with the entirety of the system with charging 1 drone to see the change of the charge rate of the main battery. The main major concerns were that the solar panels would not be able to generate an ideal amount of power to both support and charge the main battery. The data collected showed that even in a non-ideal position and orientation of the panels, they were still able to support the charger and charge the battery at a decent rate. The main point of these experiments was to test off the shelf products and see if it's feasible to create a grid capable of charging a swarm of drones when the vertiport is off the electrical grid. now that it became apparent for the possibility for a full grid to support the STEER system. The next step is to now work on the automation of the drone and decrease unnecessary loss of energy.

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