Solar Powered Cushman Vehicles

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EECS 394

Introduction

CWRU plant services purchased four small Cushman vehicles. These vehicles are used by plant services to maintain CWRU campus. The Cushman vehicles are battery powered and are recharged every night by plugging them into a wall outlet. The purpose of this project is to research and make a recommendation on the feasibility on mounting a solar array on top of the vehicles to provide a trickle charge.

Vehicle Description

The electric vehicle is powered by a 6.5 hp (4.8 KW), 48-volt electric motor. Eight 6-volt batteries connected in series provide the power necessary to run the Cushman vehicles. The batteries provide a minimum of a 220 amp hour rating at SAE-20 hour rate. The batteries are charged by plugging an AC to DC converter into a wall outlet and plugging the charger into the system's charge receptacle which is connected across the batteries.

Plant services uses these vehicles to provide routine maintenance services to the CWRU community. They haul equipment ranging from ladders to small tools to electronic equipment and plants. Two of the four vehicles are also outfitted with a cargo box located on the rear of the vehicle.

For this project it was necessary to observe a few important points that the vehicle manual mentioned. The most important include:

- This equipment should not be modified or added to without the manufacturer's authorization
- Altering this equipment in any manner which adversely affects the equipment's operation, performance, durability or use, may cause hazardous condition
- Make sure the key switch is off when charging
- Hydrogen gas is produced during the charging process and is explosive

Solar Energy

The principle behind using solar cells is that electricity flows between two semiconductors when they are put into contact with each other and they are exposed to direct sun light. Normally solar power is collected by a photo-voltaic (PV) module which is a collection of cells constructed to generate the desired current flow. Most often these systems generate DC current which flows in a single direction.

There are two typical designs of a PV array. The first is a stand alone system. It consists of a battery storage unit and a charge controller. Some also include an inverter if AC power is desired. The second type of PV array is a grid connected system. This consists of a PV array whose current is directed into a DC to AC inverter. The inverter then feeds the power back to the power grid for storage. It is extremely important that the inverter produce a sin wave that is compatible with the power grid system.

The PV cells are made from silicon which must be at least 99.9999% pure. To be effective, the silicon must be doped N-type/P-type. The doping produces different semi-conductor layers that either lack or have an extra electron. When the N-type and P-type layers are put together, they create a junction that causes the material to generate electricity when it is exposed to a light source.

There are three basic types of PV cells: mono-crystalline, poly-crystalline, and amorphous. The mono-crystalline PV cells are made up of single crystals of silicon pulled from a bath of molten silicon. The crystals are sliced into the desired shapes normally a shape close to a square or pseudo-squares. Poly-crystalline cells are made by melting silicon into ceramic molds and cooling it slowly for many hours. This drives the impurities to the surface so that they can be cut away. The remaining silicon is then cut into the desired rectangular shapes. Poly-crystalline is usually cheaper but the price is based on the quantity of scrap silicon on the open market. Amorphous PV cells are made from silicon material that is vaporized and deposited on glass or stainless steel.

Mono-crystalline cells are slightly more efficient than poly-crystalline cells for the same area. The amorphous cells are less efficient, but they only require a thin film of silicon which makes their price cheaper. The chart below lists the efficiencies of the three different types of PV cells. These efficiencies were taken from BP cells.

	Typical Efficiency	Maximum Recorded Efficiency	Maximum Recorded Lab Efficiency
Mono-crystalline	12% - 15%	22.7%	24%
Poly-crystalline	11% - 14%	15.3%	18.6%
Amorphous	7% - 8%	10.2%	12.7%

To attain maximum output the PV array should be tilted to the global latitude of Cleveland. This angle will give the array optimal effect throughout the year and will allow the sun's rays to strike the panel at a 90° angle to its surface.. The angle of the panels can be tilted to +/- 15 degrees. If the panels are tilted +15 degrees, then the array will be more efficient during the winter months, and if the panels are tilted -15 degrees, then the panels will be more efficient during the summer months. The reason for this is that during the winter months, +15 degrees from the latitude gives a more perpendicular angle to the sun and during the summer months (the sun is lower in the sky), -15 degrees from the latitude gives a more perpendicular angle to the sun (the sun is higher in the sky). The best solution of course would be to have adjustable arrays, so that they can produce the most energy no matter what time of year it is. The adjustable voltaic arrays should be able to adjust from -15 degree from the latitude of Cleveland to +15 degrees.

There are some factors involved in estimating the output of a solar array. Some issues include amount of insolation (the amount and quality of the light that reaches the array), correct array orientation, tilt, and partial shading. The DC rated output of each solar module is provided by the PV manufacturer in the form of values taken under Standard Test Conditions (STC). These conditions create a specific solar environment by indicating:

- Solar Cell Temperature = 25 degrees Celsius (the temperature of each cell in module)
- Solar Irradiance = 1000 W/m^2 (the amount of light that shines on a module)
- ASTM Standard Spectrum (the type of light that shines on a module)

Since each module manufacturer rates the module output at STC, we can compare the ability of various manufacturer's modules and choose the best array. We have to remember that STC conditions are for measuring module output in a laboratory, but the actual cell temperature is much lower in the laboratory than is usually seen in the field. PV output decreases with increasing temperature and therefore, we might have to de-rate the array output stated by the manufacturers.

The cell temperatures of a solar array will vary drastically due to ambient conditions such as sun intensity, air temperature, wind speed, and other factors. How the array is mounted can also impact the module's cell temperature. Roof-mounted arrays typically yield peak cell temperatures in the range of 50 degrees Celsius to 75 degrees Celsius.

Arrays mounted outside in real world conditions eventually become covered with a fine layer of dirt and dust, decreasing the amount of light reaching each cell. The amount of power loss due to soiling depends on variables such as the location, the type of dust, and the length of time since the last rainfall.

There is also power loss due to resistance of the DC wiring in a system. With all the previous power losses taken into account, a module that was rated at 100 watts by the manufacturer can go down to 75 watts. There is also the loss of power due to the efficiency of the inverter in a system without batteries and an inverter going to the power grid. For a system with batteries, battery losses and conversion efficiency must be factored in.

For a typical 1000 watt system, it outputs an average of 670 watts for a system without batteries and an average of 580 watts for a system with batteries after losses are taken into account. These losses assume a perfectly sunny day and a properly designed and installed system.

Cleveland Weather and Information

One very important factor is Cleveland's weather. At this point we have not been able to find information relevant to this project. We have found information covering each day of every year from 1997 to the present that includes temperatures, rainfall, humidity etc… However, we have not found any data on the solar conditions that have existed in Cleveland's in the past. Nonetheless, we feel that this should not be an issue at this time. We will be doing further research on this subject as the project progresses.

Desired Measurements

One important measurement to take is the ~~voltage~~ current through the battery. This measurement will be extremely important when determining whether or not placing an array on top of the vehicles is feasible. It will allow us to determine the size of the solar array that we need to place on top of the vehicle to recharge/power the motor as it is running.

A Hall Effect Sensor will be used to measure the ~~voltage~~ current through the motor. Hall Effect Sensors are based on the principle that as current flows through a conductor (in this case a wire) that is in a magnetic field it produces a voltage that is perpendicular to the direction of the field and the flow of the current. In order to take this measurement we recommend the use of a HOBO Data logger with a Hall Effect sensor. The first necessary step is to disconnect the pertinent wires and fit them through a magnet. Next, the Hall Effect sensor is then placed in a little slot on the magnet. The sensor measures the current through the wire and outputs a voltage.

The second important piece of information is the amount of current that flows between the wall and the charger. This measurement is important for two reasons. The first reason is so that the efficiency of the charger can be calculated. If our calculations show that the charger is not very efficient, although we expect it is, we can look into designing or obtaining a new charger for the Cushman. The second piece of data this measurement will allow us to calculate is the actual amount of energy that must be put back into the car's batteries every day. This calculation can be used to determine the amount of energy that the other components of the car use. This measurement and calculation will allow for the creation of a solar panel that could supply energy to replenish the total amount of energy the car uses, not just the motor.

Photo Voltaic System Designs

We have come up with three possible designs for the PV system. The first is to mount the solar arrays on the Cushman vehicles. The panel would provide a continuous trickle charge into the vehicle's batteries. This setup has two benefits. The first is the constant recharge that the solar panel will provide. This charge should allow the cars to run at maximum capacity throughout the day. The second benefit is the exposure to the campus community. Renewable energy sources, like solar power, are something that would spark the interest of the campus. However, this setup has major drawbacks. The first is that the modification of the car would void the warranty that covers the vehicle. The manual states that, " This equipment should not be modified or added to without the manufacturer's authorization." Adding the solar array would void this warranty, unless we got permission from the Cushman Company. The second draw back is that the panels could be damaged very easily. The Plant Services Crew uses the Cushman vehicle's roof to carry ladders. A ladder, if removed carelessly could scratch and damage the entire array. The final drawback is the area limitations. If these arrays were to be mounted on top of the cars, there is a limited amount of space. There is not much room on the cab of the car and we already stated that it would be dangerous to put the array where the ladders are carried.

The second design consists of a fixed solar array with battery storage unit on campus. The array would be placed on top of one of the campus buildings and would feed the energy it produces into a battery storage unit for later use. This design would allow for a greater amount of solar energy collection because it would receive sunlight all day. Fixed arrays are also expandable. If the size of the array needed to be increased, solar cells could be ordered and attached to produce a greater output. A fixed array can also be adjusted to maintain maximal exposure to the sun all year long. As the months pass the position of the sun changes. The array may be tilted to maintain maximal exposure to the sun's rays. This design has two major drawbacks. The first is attaining site approval. Adding a solar array to the top of any building would require approval from CWRU. This could be a very bureaucratic process. The major drawback of this design is the inherent damager of charging batteries. When batteries are charged they produce hydrogen that is explosive. If proper precautions are not taken, an explosion that would endanger students and faculty could occur. How about staff?

The third design is very similar to the second. The main differences is that the energy produces by the solar panel will be fed back to the power grid for storage and a DC to AC inverter will be needed. This will require a meter that allows current to flow into and out of it. The current produced by the solar panel will be fed into an inverter. The inverter, which would be compatible with the power company's grid system, would feed the AC current through the meter and into the power grid. At the end of the day, the cars will be recharged at a "charging station" near the bi-directional meter. The meter will then monitor how much current is being pulled back out of the grid to recharge the Cushman vehicles. In addition to the benefits provided by the second design, this design has an important benefit that the second does not; it does not require that a battery storage unit be located on campus. This design lessens the responsibility that the University would have to undertake and eliminates the potential of an explosion due to hydrogen gas. Design three also has two drawbacks. Like the second design, it will require that an installation site be approved by CWRU administration. The other drawback is the incorporation of the utility company, Cleveland Public Power by way of the Medical Company. At this point we do not know if the utility company is capable or willing to meet the requirements of this design, i.e. installing a bi-directional meter and accepting power back into the grid. .

Final Recommendation

The final recommendation is to design the photovoltaic system that is described in scenario three using mono-crystalline cells. This design would require a few things. The first would be to install an array on the top of one of the campuses buildings. We think that the southern side of Veale Center would be appropriate. It is slightly angled and has a lot of potentially useful surface area. However, this will require approval from the campus administration. This design would also require the purchase of a DC to AC inverter that is compatible with Cleveland Public Power's grid system and a bi-direction meter. This will not be that expensive, but it will require that we work with the utility company. This could be a very long and drawn out process. As previously stated, we recommend the use of mono-crystalline cells. The reason is that they are the most efficient when it comes to producing energy. This is a very important factor in a region that has weather like Cleveland. Though they are the most expensive cells, the cost will be made up by the efficiency of the cells over time.

Future Steps

The next step of this project will be to begin gathering data. Early next semester, we want to use a data logger to measure the power requirements of the vehicle. The two principle pieces of equipment that will be needed are a Hall-Effect sensor, to measure the current, and a voltage diver to reduce the measured voltages to a level that the data logger can handle. Another important measurement will be the determination of the amount current that flows from the wall outlet and into the charger. This will tell us the total amount of energy used by the Cushman on a daily basis. This will allow for the design of a solar array that will have the capability to generate as much power as the vehicle uses. This measurement will also allow us to determine the efficiency of the battery charger. If we find that the battery is less than 95% efficient, we would like to design a new, more efficient charger.

By mid-semester, we hope to obtain, install, and test a solar panel. The size of the panel will be determined by measurements taken in the first few weeks of the semester. In addition, we will need to work with CWRU Plant Services to identify the most suitable location for the photovoltaic array. It will need to be placed on a building that faces South and has the capability to allow for overnight storage of the vehicles.

There are also two very difficult tasks to be accomplished. The first will be an attempt to establish a working partnership with BP that will lead to project support. The type of support has yet to be determined, however it could come in many forms, including: financial support, expertise in the development of PV arrays, and the donation of the solar cells to construct the solar panel. The second task will be to get Cleveland Public Power to install a bi-directional meter on campus. This meter will monitor the flow of power into and out of their grid from the location of the PV array. These two tasks will require the help of Plant Services and CWRU. They are more administrative and politically oriented than the design and installation, which the students will handle.

Syllabus

1. About Solar Power > How it Works: http://www.solarex.com/3rd-How.html

2. BP Solar, The Natural Source for Electricity: http://www.solarex.com/

3. Build Your Own Solar Car: http://www1.umn.edu/umnsvp/education/build_car/

4. How a Solar Car Works: http://www.engin.umich.edu/solarcar/HowItWorks/

5. MIT SEVT Building a Model Car:
   http://www.mit.edu/activities/solar-cars/generalinfo/modelcar.html

6. NWSFO Cleveland- Cleveland Climate:
   http://www.csuohio.edu/nws/climate/cle/climatecle.html

7. Photovoltaics: Basic Design Principles and Components:
   http://www.eren.doe.gov/erec/factsheets/pvbasics.html

8. Solar Assisted Golf Cart: http://www.solstice-ae.com/projects/golfcart/

9. Solar Cells for Racing Cars;
   http://members.aol.com/photontek/photon/photon3a.html

10. Solar Power Calculator: http://www.bigfrogmountain.com/calculators.cfm

11. Solarex Solar Panels: http://www.windsun.com/PV_Stuff/Solarex.htm