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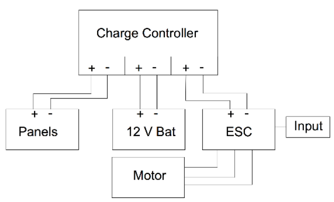
Investigating the Conceptual Design of a Solar Powered Four Wheel Moving Device

Conventional vehicles fueled by gas or diesel pollute the air by the emissions of carbon dioxide, nitrogen oxide, and unburned hydrocarbons. As emission concerns grow, electric vehicles are becoming a greener alternative that emit no gases from consuming the internal power source's energy. However, the electricity required to charge the internal power sources may be generated from a power plantation that uses natural gas or coal. Therefore, the pollution emissions of the whole power plant and electric vehicle system is now dependent on the power plants environmental friendliness. Implying to eliminate the entire system's gas emission, the vehicle is constrained to only charging at regions where the power plant that generated the electricity comes from a clean source such as solar or wind. To overcome this regional dependence, an alternative vehicle that generates its own power from a clean source such as solar can be utilized.

To prototype such a vehicle, this project investigates the conceptual design of a small scale four wheel movable device with handlebars that is very much like a Segway without the self-balancing component and two extra wheels. The goal is for it to generate all its energy using solar panels, have a variable speed controller, and to be stable enough not to constantly break down, however; the focus on this paper is on the major system and its properties.

Connectivity and Schematic

There are three main electrical systems which consist of solar panels, a battery, and an electronic speed controller. The three systems are connected by a solar charge controller as seen in Fig A1. The battery and charge controller are mounted on top of a base that is balanced by four wheels attached near the corners as seen on Fig A2. At this stage neither the solar panels nor the handlebar is attached, but future developments will have them implemented. The prototype in Fig A3 incorporates a 12 Volt Battery, a PWM charge controller, and a programmable ESC. The motors are regulated by the ESC, which gets its energy from the battery via the charge controller. The battery on this prototype was manually charged by the wall outlet, but in the next revision will only be charged by photovoltaic cells.



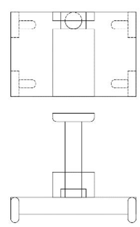



Fig A1, A2, and A3: Schematic of Electric Systems (left), Front and Top View(Center), Prototype without Solar Panels attached (Right)

The motors and ESC in the prototype are underneath the board. The motors are mounted to the back wheels and are connected to the wheel with a timing belt pulley system as seen in Fig A4. The 3D printed gear inside the belt resembles the upper sliced of Fig A5. Due to motor heating issues, in the future metal gears from SDP-SI will be used to act as heat sink Figure A6

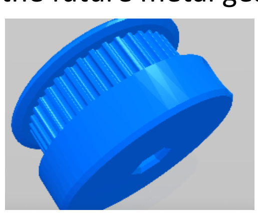
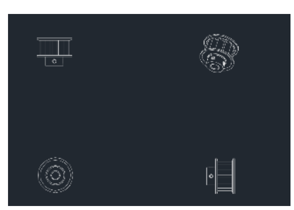
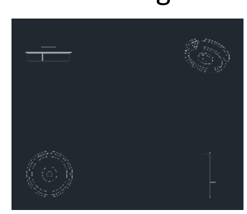





Fig A4, A5, A6, and A7: Timing belt connects motor and wheel (Left Most), STL file of 3D Part Design Used (Inner Left - Thingiverse), Small Gear for Future (Inner Right - SDP-SI), Big Gear for Future (Right Most- SDP-SI)

Charge Controller

The main purpose of the charge controller is to regulate the voltage and current coming from the solar panels. It is the bridge between the solar panels, battery, and ESC. The PWM charge controller utilized was designed to prevent discharge of the battery when the voltage of the battery is greater than the photovoltaic cells, protect against over-charging/over-discharging of the battery, and drops excess voltage. In ideal conditions (solar panel produces 100W with 18V, zero energy lost due to heat, efficiency is 100%) switching from a PWM to an MMPT charge controller would increase the power input to the battery by 21.4 W as shown in the calculations bellow. Since the MMPT controller will convert the excess voltage into current, rather than create a voltage drop like a PWM.

$100\ W\ 18\ V_{Std}$ $I = \frac{P}{V} = \frac{100\ W}{18\ V} = 5.56\ A$ $\frac{18\ V}{14\ V} = 1.28{:}\ 1$ $1.28 * 5.56\ A = 7.1\ A$	**MMPT converting excess voltage to current** 1) Assumption of 100 W and 18 V generated from Solar Panel Spec Sheet. 2) Find Current (Ohm's Law on 1) 3) Find Ratio that will be converted to current 4) Multiply current by ratio 5) Find power for charging battery.
$100\ W\ 18\ V_{Std}$ $I = \frac{P}{V} = \frac{100\ W}{18\ V} = 5.56\ A$ $14V * 5.56\ A = 78\ W$	**PWM dropping excess voltage** 1) Assumption of 100 W and 18 V generated from Solar Panel Spec Sheet. 2) Find Current (Ohm's Law on 1) 3) Find power for charging battery.
$\Delta\mathrm{P} = 99.4W - 78W = 21.4W$	

The charge controller is rated for only 30 Amps, so in the prototype the motors used had a max current of 24 amps to prevent damage toward the charge controller. The motor that will be used in the next revision has a max rating of 60 Amps, which implies the charge controller has to be able to provide more than 60 Amps out of its load terminal. With a motor that has a potential for a higher current drawing from the battery, a charge controller that is PWM is no longer acceptable unless its efficiency rating is considerably higher than an MMPT, which is unlikely.

ESC + Motor

The motor is one of the most important parts of the device and there are many to choose from. This project exclusively uses brushless DC motor because we wanted to go fast (10 mph), don't want the brushes to wear out, don't care about precision controls at low speeds (less than 1mph), and want to easily regulate the speed. The motors used in the prototype are DLFPV 2300 KV Brushless Motors (Fig B2) and the motor that will be used in the next revision is the Turnigy Aerodrive SK3 5055 280 KV Brushless Outrunner (Fig B1). The DLFPV motor was used mainly because the current charge controller limited the max amps to 30 A. It has just enough torque to move a lightweight battery and charge controller system. The Turnigy Aerodrive SK3 is a more powerful motor that will be able to move a person (178 lb). The key factors to look for in these motors is the KV rating, size, and max input current. KV is a measure of revolutions per minute per volt. For this project the ideal range was between 160 to 300 KV. Lower KV ratings imply less RPM and higher torque, while higher KV ratings imply more RPM and less torque. Based on the spec sheet and project design, the theoretical speed for the next revision is 13.23 MPH.

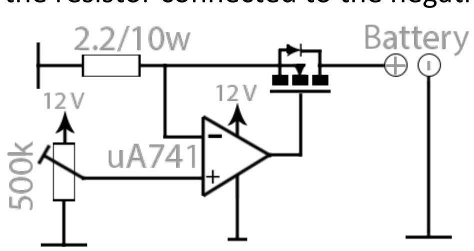
$D_{size} = .09\ m, G_m = 14\ teeth, G_t = 40\ teeth$ $cl = 4, V_{cl} = 3.2\ V, \eta = .9$ $V = 3.2V * 4 = 12.8\ V$ $RPM = 12.8\ V * 280KV = 3584\ RPM$ $Gear\ Ratio = \frac{40}{14} = 2.857{:}\,1$ $s = 3584\ RPM * 60\frac{min}{mile} * .09m * \pi * \frac{14}{40} * \frac{1\ mi}{1609\ m}$ $s = 13.23\ MPH$	1) Assumptions: 90 mm wheels, 14 teeth motor gear, 40 teeth wheel gear, 4 cell LiFePo4 Battery, 90 % efficiency 2) Nominal Voltage of four cell LiFePo4 3) RPM=Volt*RPM/Volt 4) Find gear ratio 5) S_MPH=RPM*Min/Mile*D_size*pi*(Gear Ratio)^(-1)*(mi/m)

The electronic speed controller is responsible for directly controlling the speeds of a brushless DC motor. The max current rating on an ESC should be slightly above the motors max current, so that the ESC doesn’t get overworked. The ESC in the prototype was rated for 30 Amps and the next ESC will be rated over 60 Amps to account for the Turnigy Aerodrive SK3. An ideal speed controller for the next revision will have variable breaking with no regenerative breaking. A VESC is a special type of ESC that is more controllable (allows custom cutoff voltage and draw current). Although it less plug and play, it offers more flexibility than a regular ESC. The compromise of getting a VESC is that the max will more than likely be rated for only 50 Amps. An ESC with regenerative breaking will require a two battery setup because most charge controllers have a diode to ensure current going to the load won't switch directions or simply fry if a reverse current is provided.

Fig B1, B2: The Turnigy Aerodrive SK3 280 KV Motor (Left) and the DLFPV 2300 KV Brushless Motors (Right)

Battery and Battery Capacitance Measurements

The battery used was a LiFePo4 Battery because of its light weight and its very minimal decline in voltage as it discharges. An important property of a battery is its capacitance. Battery capacitance is defined as the coulometric charge expended from a fully charge state to the cut off voltage where the cut off voltage is the minimum voltage a battery is rated for. Although our battery was rated for 5Ah, the experimental capacitance was calculated to be 4.52Ah with a 9.6% error using a constant current load. It took the battery 50.2 minutes to go from a fully charged state defined as when the voltage is 13.8 Volts to a dead state defined as when the voltage is 12 volts. The schematic to construct a constant current load is shown below. If a constant current load were not used than the current would decrease as the battery depletes requiring that a Riemann sum approximation to be used to measure the current. This would involve constantly measuring the current values at different time intervals and would overall decrease the accuracy of the calculation. The parts used were: 500k POT, u741 Op Amp, 813600 MOS FET, and a Heat Sink. To prevent overheating there were five cool off times where the battery was temporary disconnected. The MOS FET in the schematic allows current flow between the drain and source when voltage is applied to the gate and source. The operational amplifier acts as a voltage comparator in the circuit. The operational amplifier acts as a voltage comparator in the circuit. The constant current is equal to the V_in of the Op Amp divided by the resistor connected to the negative terminal of the operational amplifier.



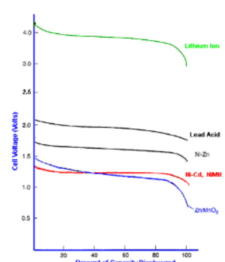
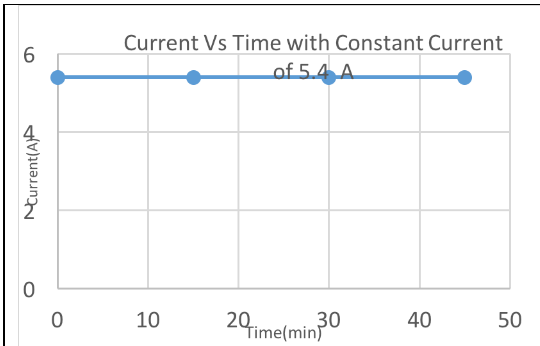


Fig C1, C2: Schematic of constant current circuit (Left) and Voltage Measurement Vs % Discharge Graph of other batteries (Right).



$$V_{max} = 13.8\ V$$
$$V_{min} = 12\ V$$
$$Q = \int_{t_v\,max}^{t_v\,min} Idt = I\Delta t = 5.4A\ (50.2\ Min) = 4.52\ Ah$$
$$Q_{specSheet} = 5Ah$$
$$Q\_specSheet = 9.6\ \%\ Error$$

Cool off times: 5, 10, 15, 20, 30, 40 min