Solar Vehicle for South Pole Exploration

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Abstract. This is a report on the feasibility study performed to find solar energy solution for Antarctic explorations. Antarctica is one of the world's last frontiers characterized by extreme environmental conditions. Travel is expensive and difficult due to the high cost of fuel and vehicle maintenance. Given the right conditions, a solar vehicle could be a viable form of transport during the summer months. Based on the study of previous investigations shown in the articles [2], [4], and [5], we have conducted comprehensive research on the feasibility of the solar car project. A working prototype of the solar car was used for testing. We have conducted various measurements before the car departure to the South Pole.

1 Introduction

Antarctica explorations have many challenges. Use of fossil fuels for transportation, comes at a great cost, both financially and environmentally. A considerable amount of planning and control must be used to ensure efficient usage in order to minimize pollution to the environment [1]. We are looking for alternative solutions. Development of photovoltaic cells (PV) will allow applications of this renewable energy source everywhere and also in Antarctica. Simultaneously, there is fast progression of electric vehicle's research. This project aims to present a solution which harbors both concepts in a vehicle which could be used in Antarctica.

2 Solar Power

An Antartic based solar vehicle operating in December, could receive approximately 800 - 1300 W/m^2 of solar irradiance, acting on the surface of the PV panels [6]. Experimental data has been collected for two 185W panels, vertically mounted to the Antartica horizon [9]. Graphical representation of the measurements is shown in Figure 1. We generated more power than expected.

The addition was contributed by Antarctica environmental characteristics as: high solar irradiance with clear air visability, low temperature, and high reflection off snow surface. Further additional power can be achieved by angling the PV panel perpendicular to the sun. More power can be gained due the reflectivity of Antarcticas suface. This allows cells that are not facing the sun to receive a portion of power. Results from the projects presented in [9] and [2] prove this.

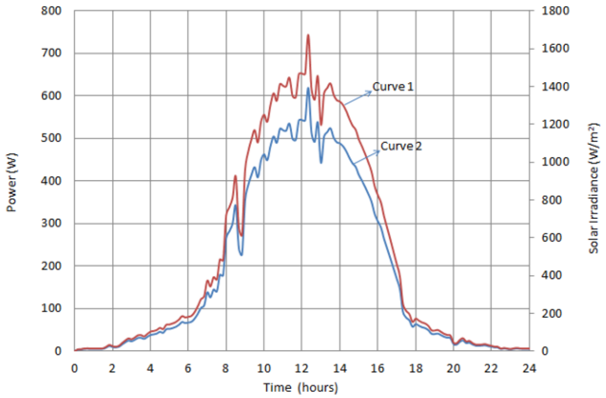

Fig. 1. Solar Power measure from 2 x 185 W PV within Antarctica, information is provided by team member Prof. John Storey [9]. (Curve 2: Power produced by 2 x 185 W vertical PV panels, Curve 1: Solar Irradiance)

3 Traction

The next step is to investigate energy requirements and losses. Resistance to the vehicle motion can be expressed by 3 components:

$$R = Ri + Rc + Ra \tag{1}$$

Where *Ri* represents total internal resistances, such as losses from the tires and road friction, and internal losses in the bearings and motors; *Ra* refers to the aerodynamic drag and *Rc* is a compaction resistance. Due to the low average speeds expected, power consumption will be mainly dominated by rolling resistance. Components *Ri*, and *Ra* can be defined from the results of the model vehicle physical testing. Because of the sinking, the vehicle needs to overcome the obstruction caused by the portion of snow in front of the leading wheels, as shown in Figure 2. Bekker [8], Wong [7], Richmond [5], and Lever *et al.* [2] formulated the following equations to calculate *Rc*:

Flexible tire:

$$Rc / W \approx 0.5\left(\frac{p_0^2 b}{Wk}\right) \tag{2}$$

Sinkage for flexible tire:

$$z_0 = \left(\frac{p_0}{k}\right)^{1/n} \tag{3}$$

where p_0 represents contact pressure, b is wheel width, W is the weight of the vehicle, D is the diameter of wheel, and finally as Lever *et al.* assume $n=1$, and $k \approx 1\ \mathrm{MPa.m^{-1}}$ [2].

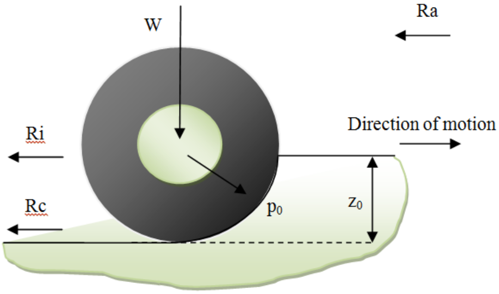

Fig. 2. Free body diagram of a wheel moving through a compressible medium.

4 Prototype Description and Physical Testing

A prototype vehicle has been built and used for testing. Main characteristics and subsystems are: Light weight with strong chassis; Large surface area of PV cells used to produce more energy; Battery subsystem for energy storage; Multiple wheels application, six in our case, in order to reduce sinkage; Large floatation tires to have low contact pressure to minimize sinkage.

The vehicle has a bespoke frame made from chromoly steel, covered in aluminum sheet and 6 wheels with the 4 rear wheels driven, each independently suspended with a single a-arm setup as shown in Figure 3. Permanent magnet (PM) electric motors with inbuilt 1:8 reduction gear boxes are used to propel the vehicle. The tires are low pressure ATV, used to help reduce sinkage. Overall vehicle weight is 270 kg, which includes battery pack and solar panel. With the floatation tires, a single a-arm suspension setup was used to ensure even tire contact independent of terrain.

Fig. 3. The Solar Dog, a prototype solar vehicle for an expedition in Antarctica

The prototype vehicle has an 8 m^2 PV panel made from 2 sets of 5 panels in series, coupled with a maximum power point tracker for each set. A 5 kWh lithium battery pack is used for energy storage and power buffering, and a dataTaker DT600 for data logging auxiliary sensors and driver controls. It is anticipated that the ‘Solar Dog’ will be installed with an additional 8 m^2 of PV cells before the expidition. These cells will be placed on the opposite side of the main panel. Additional cells will collect reflected sun power, during operation, but will be reoriented when the vehicle is not moving to collect direct sunlight. Figure 4 shows the expected solar power that could be generated by PV panel.

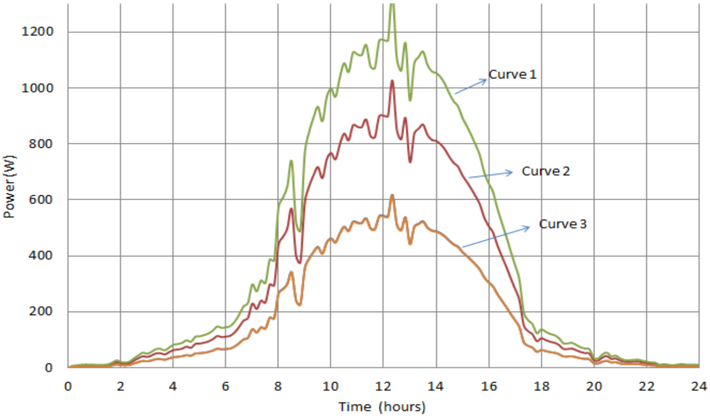

Fig. 4. Projected solar power over the course of a day for an 8m^2 panel. (Curve 1 refers to the Perpendicular panel to sun, Curve 2 refers to the Vertical panel, and Curve 3 refers to the Opposing to sun panel).

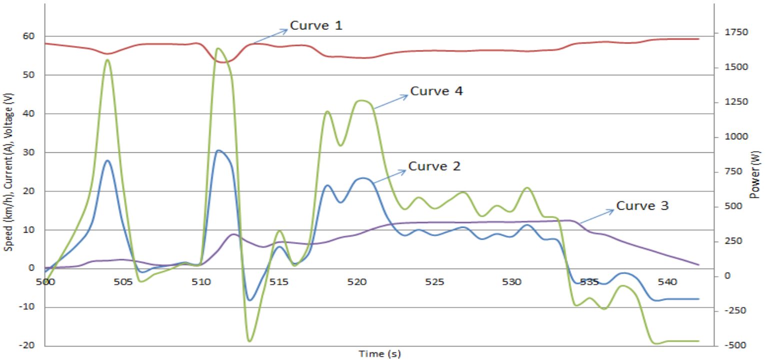

Fig. 5. Initial test data from datalogger for Solar Dog (Curve 1:Voltage, Curve 2: Current, Curve 3: Speed, Curve 4: Power)

Figure 5 shows the power as Solar Dog was in motion. The graph shows a simple run across asphalt and gravel. The maximum speed reached by the vehicle was 12 km/h. In that case the consumed power was only around 500 W while at constant speed. The negative power sections within figure 5 are due to input power ether from the PV panel or, power regeneration within the motors during braking.

5 Power Budget

The following graph was created by applying equations (2) and (3) in order to determine the resistance to motion, for our prototype vehicle.

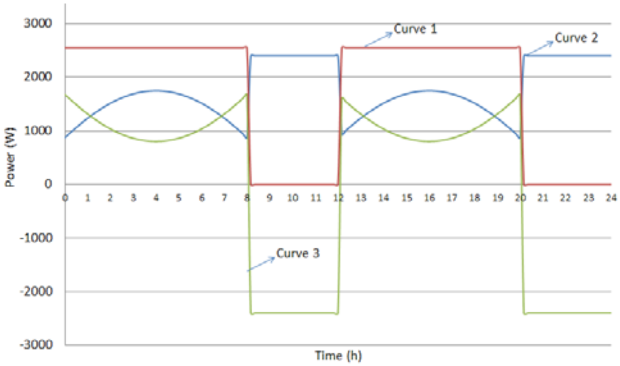

Fig. 6. Power requirements for "Solar Dog" over the course of 24 hours (Curve 1: Motor Power, Curve 2: Solar Power, Curve 3: Battery Power)

Figure 6 shows both the input and output power requirements for "Solar Dog" over the course of 24 hours within Antarctica. The assumptions made are: clear sky, smooth terrain with roughly about 2-3 cm of new snow, vehicle speed 15 km/h. A good strategy should be based on 8 hours of driving with 4 hours pause for battery system recharging. By defining speed and finding terrian characteristics, we can determine the required battery capacity and solar panel size which would enable solar vehicle to achieve desired performances.

6 Conclusion

After verification of the theoretical model with a purposely built prototype, we found that it is technically feasible for a solar power vehicle to be used for exploration within Antarctica. The next step is a trip to Antarctica.

Acknowledgments. Our working prototype is based on the "Solar Dog", a solar, electrical vehicle built by a well-known Australian entrepreneur Mr. Dick Smith. He has spent a number of years building the Solar Dog and dreaming about its' first trip to the South Pole. He has donated his vehicle to our research team to finalize design, perform testing and to realize his and our dreams. The team consists of Mr. Byron Kennedy from FASCO Asia Pacific, Dr. Milan Simic, Nicholas Lambert, Hugh Miles, Jonathan Perry from RMIT, Matthew Anson from La Trobe University and Mr. Robert Anson from Norden Body Works.

References

[1] Environmental Impact Assessment, ANNEX I to the Protocol on Environmental Protection to The Antarctic Treaty, The Madrid Protocol (viewed July 2011), `http://www.ats.aq/documents/recatt/Att008_e.pdf`

[2] Lever, J.H., Ray, L.R., Streeter, A., Price, A.: Solar power for an Antarctic rover. Hydrological Processes 20, 629–644 (2006)

[3] Grenfell, T.C., Warren, S.G., Mullen, P.C.: Reflection of solar radiation by the Antarctic snow surface at ultraviolet, visible, and near-infrared wavelengths. Journal of Geophysical Research 99(D9), 18668–18684 (1994)

[4] Luong-Van, D.M., Ashley, M.C.B., Cui, X., Everett, J.R., Feng, I., Gong, X., Hengst, S., Lawrence, J.S., Storey, J.W.V., Wang, L., Yang, H.J., Zhou, X., Zhu, Z.: Performance of the autonomous PLATO Antarctica Observatory, over two full years

[5] Richmond, P.W.: Motion Resistance of Wheeled Vehicle in Snow, CRREL Report 95-7 (1995)

[6] CMDL. Archive of the climate monitoring and diagnostics laboratory, meteorological data measured at Amundsen–Scott South Pole station (viewed April 2011), `http://www.cmdl.noaa.gov/obop/SPO/`

[7] Wong, J.Y.: Theory of Ground Vehicles, 3rd edn. Wiley-Interscience, New York (1993)

[8] Bekker, M.G.: Theory of Land Locomotion. University of Michigan Press, Ann Arbor (1956)

[9] PLATO dome A Robotic Observatory (viewed July 2011), `http://mcba11.phys.unsw.edu.au/~plato/plato.html`