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Hybrid System on a Golf Cart

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Abstract

The urgent need to develop and implement renewable energy sources led to the design and construction of a solar golf cart in 2004 [Fig 1]. This first prototype proved to be very successful. The combination of unique features such as the tracking of the sun resulted in significant increase of output power with respect to other solar carts. However, in certain regions where the average irradiance level is low, an extra source of energy is needed if total independence from the utility grid is required. The incorporation of an extra source of energy which is a fuel cell requires a complex system. The system manages the energy delivered to the batteries from either the solar platform or the fuel cell system. If the cart undergoes severe hours of driving, both sources are on in order to supply the energy needed to keep the batteries charged. The cart with its different energy sources becomes a small power plant that can supply energy to an emergency load in case of a natural disaster. The cart can also be used as a maintenance cart. Utility tools such as hedge trimmers can be run off of the cart, or simply be charged from the cart.

Fig1. The solar golf cart collecting energy to charge the batteries

1. Introduction

The need for alternative energy sources has increased dramatically over the last few years. The demand for oil is higher than ever with emerging economies such as China and India which depleting the oil reserves faster than expected. In addition, there is a great concern about the emission of carbon dioxide. The high release of carbon dioxide is steadily creating a warming environment in the planet. It is of utmost importance to create and develop existing renewable energy sources. Solar energy has been in the forefront. The semiconductor material absorbs the photons to convert it into electrical energy. On the other hand, hydrogen has been suggested as the ultimate way to propel vehicles. Hydrogen is a good alternative as long as the hydrogen is produced without releasing greenhose gases. The following pages describe the existing solar golf cart, the incorporation of a fuel cell system, and the power management system which controls the two energy sources.

2. Solar Cells

Most of the solar cells in today's market are made out of silicon which is produced as single crystal or multi crystal. Single crystal silicon is the most efficient terrestrial technology but it is very expensive, and very energy intensive to produce since it requires the highest purity silicon [2]. Multi crystal silicon is not as efficient as the single crystal silicon, but the cost is considerably lower. It also requires less energy to be produced. The surface of the earth can receive up to 1 kW/m^2. The mono crystal technology has an average efficiency between 12-15%. That is to say, the cell can produce 120-150 W/m^2 if the irradiance level is 1 kW/m^2. As far as the multi crystal type of cells, the average efficiency is 11-14% [Table 1]. There are other materials that show great promise such as amorphous silicon and cadmium teluride. These materials have a much higher bandgap absorbtion, but they still need to be further developed to compete with the silicon type of cells.

Type	Typical module efficiency [%]	Maximum recorded module efficiency [%]	Maximum recorded laboratory efficiency [%]
Single crystalline silicon	12-15	22,7	24,7
Multicrystalline silicon	11-14	15,3	19,8
Amorphous silicon	5-7	-	12,7
Cadmium telluride	-	10.5	16.0
CIGS	-	12,1	18,2

Table 1. Solar cells materials and their efficiencies [1]

2.1 Solar Golf Cart

Photovoltaic has proved to be very reliable for remote applications where there are no transmission lines to deliver power. Photovoltaic has also been successfully implemented in residential applications all over the world. However, photovoltaic has not been implemented on electric vehicles. Why? The reason is because photovoltaic needs a rather large surface area in order to produce a significant amount of energy to drive an electric vehicle. This is not feasible for regular vehicles. However, for golf carts, it might work. The concept envisioned at FAU is to maximize all possible variables, so the most amount of energy can be produced in a surface area of 2.3 m^2. Some of the variables maximized are the tracking for the strongest rays, and the implementation of a high efficiency MPPT charge controller.

2.1.1 Solar Platform:

The solar platform consists of four 90W modules which produce a total output power of 360W, under ideal conditions. A safe number that takes all losses into account is 80% of the 360W. This means that a maximum of 288W can be achieved.

2.1.2 Tracking System

The tracking system consists of a lifting mechanism that raises the solar platform at an angle. By raising the platform, the output power can be increased to up to 25%. The mechanism is fully autonomous with a microcontroller that monitors all variables, so the best angle is achieved.

2.1.3 Maximum Power Point Tracking (MPPT) Charge Controller

The charge controller used on this prototype features a MPPT which matches the source and load I-V curves. By doing so, minimal waste of energy is accomplished.

2.2 Results

The solar cart was a proof of concept that proved to be very successful. During the months of highest irradiance level, the cart was able to give an extra 1.5 to 2 rounds of golf. This means that the cart did not have to be charged from the utility grid overnight. During the months of low irradiance level, the solar platform was still able to provide energy for a round of golf. In areas where the irradiance level is high throughout the year, this type of vehicle can make a significant difference.

3. Fuel Cell and Hydrogen Storage Methods

In some regions where the amount of sunlight is low, the need to incorporate an additional energy source is inevitable if total independence from the utility grid is the goal. Fuel cells are thought by many as the ultimate alternative to propel vehicles. The technology is very simple, but it is still costly, and the issue regarding where the hydrogen comes from still creates controversy. There are many types of fuel cells, but the ones feasible for an electric vehicle are the proton exchange membrane fuel cell (PEMFC) and the direct methanol fuel cell (DMFC). In the case of the PEMFC that runs on gaseous hydrogen, special care has to be taken into account when it comes to storing the hydrogen. The following will cover the two types of fuel cells as well as the system of choice for the solar golf cart.

3.1 PEMFC

This type of fuel cell also called Solid Polymer Fuel Cell (SPFC) was first developed by General Electric for the Space Program during the 60's. It was further developed with the incorporation of the Nafion Membrane Electro Assembly (MEA) by Dupont. However, problems with the water management proved to be difficult to overcome. Therefore, NASA chose the Alkaline Fuel Cell (AFC) which is simpler (though, it requires pure oxygen at the cathode). Some of the characteristics of the PEMFC are as follows:

3.1.1 Low working temperature:

The PEMFC works at rather low temperatures (no higher than 90 celsius) due to thermal degradation. High temperature dehydrates the membrane electrode assembly which reduces the proton conductivity

3.1.2 Fast start up time:

Since the PEMFC works at low temperatures, it has a fast start up time

3.1.3 High efficiency:

Simple systems that are air cooled reach efficiencies close to 50%. This is the case of the NEXA fuel cell produced by Ballard [Fig 2]

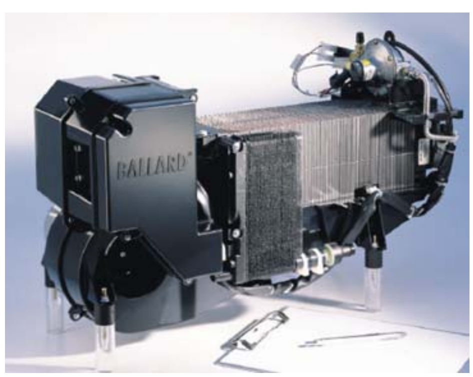

Fig 2 Nexa Fuel Cell System by Ballard

3.2 DMFC

This type of fuel cell also uses a proton exchange membrane (PEM), but there are many differences with respect to the PEMFC. First of all, it uses methanol (CH_3OH.) as fuel instead of pure gaseous hydrogen. This is a clear advantage because methanol is liquid which makes it much easier to handle. In addition, the methanol has a high energy density, and high hydrogen to carbon ratio. For some, this type of FC is very promising since it avoids the use of pure gaseous hydrogen. The usage of gaseous hydrogen has several disadvantages which are listed as follows [3]:

- Poor energy density per volume. Hydrogen has to be compressed at a very high level to reach a still poor energy density in terms of volume.
- Compression requires energy.
- High pressure vessels have to be of special composites.
- Metal hydride canisters can store a higher rate of H_2 per unit volume. However, they are rather heavy, and it requires to be cooled down as it recharges hydrogen. In addition, the rate of de-absorbtion depends on how warm the canister is kept

The major problem of this type of fuel cell is the fuel crossover. Methanol is easily mixed with water, so a significant amount of fuel passes through the MEA reaching the cathode. At the cathode, the methanol is oxidized, so the fuel can not be recovered. The fact that the fuel is easily mixed with water is a problem because the MEA becomes conductive when it is well hydrated. This means it needs to absorb water. In order to minimize the fuel crossover, the concentration of the catalysts is higher ($4mg/cm^2$), and the MEA is also thicker [4]. It cannot be very thick either because that increases the ohmic resistance. Therefore a balance has to be achieved. In addition, the concentration of methanol has to be very low (3%), so fuel crossover is further minimized. Some companies addressed the fuel crossover issue such as Polyfuel, which claims that they have minimized this problem by 25% [5].

3.3. Fuel System of Choice for the Solar Golf Cart

The scarce availability and high cost of the DMFC system led to the implementation of a PEMFC on the solar golf cart. The PEMFC to be used is a 300W water cooled system. At full load, it has an efficiency of 40%.

3.4 Hydrogen Storage Method of Choice for the Golf Cart

The storage of the hydrogen is an issue. The usage of carbon composite H_2 tanks was initially considered, but the issue of having a vessel at 6000 psi encountered resistance among the university authorities. Liquified hydrogen was not an option due to its complexity and evaporation rate. The remaining solution was to use metal hydride canisters which are further discussed below.

Metal Hydride canisters: The hydrogen is absorbed by a metal hydride powder. The hydrogen absorption rate depends on how cold the canister is kept. If the canister is recharged at room temperature, it takes about 24 hours to be recharged. If water is circulated around the canister, this rate is reduced to 1 hours. Finally, if ice is used, the absorption rate is only ½ hour. On the other hand, the release of hydrogen depends on how warm the canister can be kept. The heat released from the fuel cell can be used to keep the canister warm enough [6].

Advantage: The Hydrogen is kept at a very low pressure (300 psi). The canisters are almost unbreakable. If there is a sudden leak of hydrogen, the rate of release will be slowed down since the canister cools down preventing a large amount of hydrogen release at once. Metal hydride can also hold a higher density of hydrogen than high pressure vessels in terms of volume [table 2]

Technology	Volume [liters]	Weight [kg]	Density [Wt. % H_2]
35 MPa (350 bar) compressed H_2	145	45	6.7
70 MPa (700 bar) compressed H_2	100	50	6.0
Cryogenic liquid H_2	90	40	7.5
Low-temperature metal hydride	55	215	1.4

Table 2. Different hydrogen storage methods with respect to the weight and volume. The table is based on a 3 kg of hydrogen storage [7]

3.5 Systems Installation:

The cart will undergo minor modifications. The components used that take up the most amount of space are the metal hydride canisters and the fuel cell system. The two hydride canisters will be installed right behind the seat. This way, there is easy access when it comes to replace the canisters. On the other hand, the fuel cell system is placed where the rear basket is. The area is of easy access as well as it is close to the metal hydride canisters. This helps in case some of the heat dissipated from the fuel cell is needed for the canisters to release the hydrogen at a faster rate. A model has been drawn using SolidWorks. The blue tanks are the hydrogen tanks, and the gray box placed in the rear basket is the size of the fuel cell system [Fig 3]

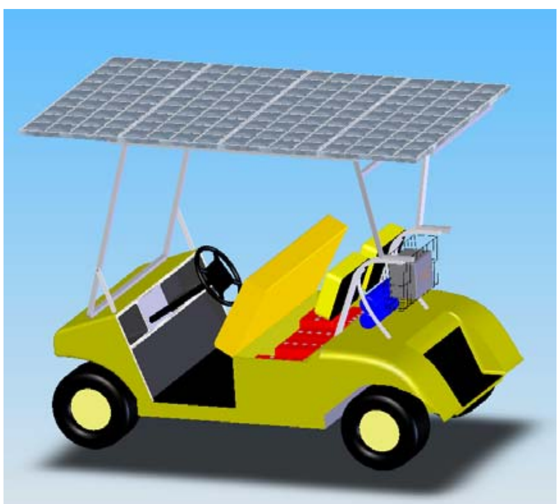


Figure 3. Solar-powered golf cart with a PEMFC and two metal hydride canisters

6 Design and Implementation of Embedded Electronics

The electronics will differ from the solar cart. The microcontroller unit (MCU) used is an HC12 family manufactured by Motorola. The MCU has a large number of 10 bit A/D channels, which will improve the accuracy of the reading. In addition, the MCU has a real time clock which will be used to accurately measure the state of charge of the batteries. The New LCD incorporated will have a large number of menus. The user will be able to adjust some of parameters such as the depth of discharge of the batteries in case the batteries are supplying energy to an emergency load [fig 4].

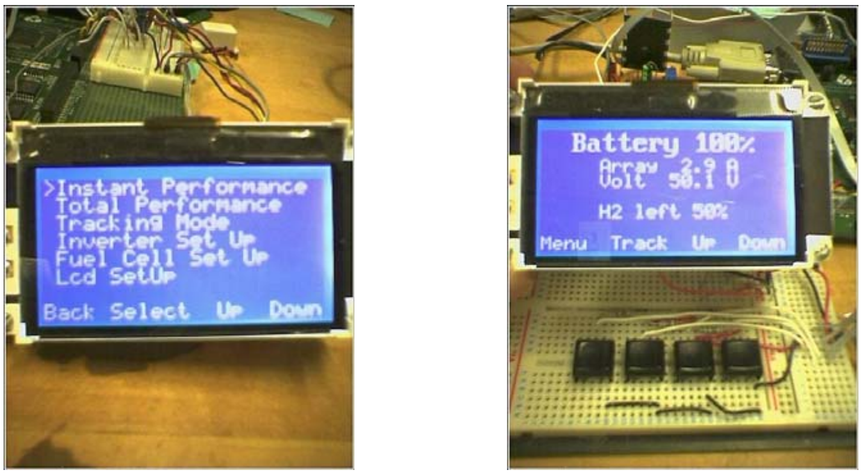

Figure 4. LCD and push buttons

6.1 Power Management

The usage of three energy sources requires a complex system that maximizes the range of the cart, and the least amount of hydrogen used. Lead acid batteries decrease their output voltage as the battery is discharged. However, the state of the charge of the batteries cannot be measured strictly from the battery voltage unless the batteries have not been used for 6 hours. This is the time the batteries required for the voltage to be stable. The measure of the state of the batteries will be determined by the current in and out of the battery. This procedure is not 100% reliable since at higher discharge rates, the batteries waste energy as heat due to its internal resistance. In order to overcome this problem, the state of charge of the batteries will be updated once the batteries haven't been used for a certain period of time. In addition, as the discharge rate increases, there will be a coefficient in which takes into account the higher discharge rate. This way, the state of charge of the batteries can be accurately measured.

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