Solar-hydrogen energy as an alternative energy source for mobile robots and the new-age car

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Abstract. The disastrous effects of climate change as witnessed in recent violent storms, and the stark reality that fossil fuels are not going to last forever, is certain to create renewed demands for alternative energy sources. One such alternative source, namely solar energy, although unreliable because of its dependence on available sunlight, can nevertheless be utilised to generate a secondary source of energy, namely hydrogen, which can be stored and thereby provide a constant and reliable source of energy. The only draw-back with hydrogen, though, is finding efficient means for its storage. This study demonstrates how this problem can be overcome by the use of metal hydrides which offers a very compact and safe way of storing hydrogen. It also provides a case study of how solar and hydrogen energy can be combined in an energy system to provide an efficient source of energy that can be applied for modern technologies such as a mobile robot. Hydrogen energy holds out the most promise amongst the various alternative energy sources, so much so that it is proving to be the energy source of choice for automobile manufacturers in their quest for alternative fuels to power their cars of the future.

1. Introduction

The most powerful storm ever recorded in world history has just struck our planet[4], prompting the leader of the world body[5] to issue a warning on climate change[6]. The utter devastation left in its wake is bound to give impetus to renewed public attention to climate change and mobilise world opinion against the continued reliance on fossil-based energy which is derived from the combustion of fossil fuels. Burning of fossil fuels to generate energy, causes carbon emissions which is considered to be the largest contributing factor to the release of green-house gases into the atmosphere, in turn leading to global warming and consequently climate change [1]. The result is catastrophic disasters such as the type we have witnessed with super typhoon Haiyan that struck the Phillipines.

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[4] Typhoon Haiyan, which struck the Phillipines on 7 November 2013.
[5] UN Secretary General, Ban Ki Moon.
[6] UN Framework Convention on Climate Change (UNFCC) in Warsaw, Poland, 19 November 2013.

To simply go on relying on fossil fuels for energy, although cheap, is just not sustainable. We are using up fossil fuels, such as coal, petroleum oil and natural gas many times faster than they are being formed in the earth's layers, with the result that these resources are expected to be depleted in a matter of a few decades, at the least [2]. The quest to develop alternative sources of energy has never been more pressing. This study, in some small measure, seeks to address just that. It takes a look at solar and hydrogen energy as an alternative energy source, and demonstrates in an actual case study how it can be applied in modern technologies such as a mobile robot.

Solar energy does not have any of the limitations or draw-backs of the type mentioned above for fossil-based fuels. There are no limitations as to the amount of sunlight that the sun can still continue to generate, and neither does the generation of solar power produce any harmful effects to the environment. It has all the advantages of being both a renewable source of energy, as well as being environmentally clean.

The problem though, is that solar energy is dependent on the availability of sunlight, and the reality is that sunlight is not always present, as for instance at night or even during daylight when cloudy conditions block out sunlight. This makes it necessary to seek an additional source of energy that would be available when no solar energy can be produced, so as to ensure that the supply of energy is constant.

For this, we can turn to Hydrogen, the simplest and most plentiful element in the universe. Although it is the lightest element, yet it has the highest energy content per unit weight of all fuels [1] Hydrogen's energy density is 52,000 Btu/lb, which is three times greater than that of gasoline. NASA has used liquid hydrogen since the 1970s to propel the space shuttle and other rockets into orbit. An atom of hydrogen consists of only one proton and one electron. Yet, despite its simplicity and abundance, it doesn't occur naturally on the earth like coal, oil or natural gas. It is always combined with other elements, as for example water (H_2O), which is a combination of hydrogen and oxygen [1,3,4].

To obtain hydrogen, one needs to separate it from the other element to which it is bound. Water is the most convenient source to obtain hydrogen, and this is achieved by separating it from the other element to which it is bound, namely oxygen, through the process of electrolysis [1-3]. This process requires electricity. However, it would be quite a waste to use up one form of energy, namely electricity, just to create another source of energy i.e. hydrogen, unless of course, the electricity that will be used for that process has been generated from a source that is free, renewable and does not result in any harmful waste products such as carbon emissions and toxic gases, which is the case when producing electricity generated from fossil fuels such as coal. This is where solar energy can provide the answer. Hence, a primary source of energy (i.e. solar energy derived directly from the sun), and a secondary source of energy (hydrogen obtained indirectly through the process of electrolysis) can be combined in an energy system which can serve as an efficient source of energy [5, 6].

2. The Solar-Hydrogen Energy System and its various Components

The process involved in the Solar-Hydrogen Energy System can best be illustrated by the Block Diagram in Figure 1. An explanation of each step in the Solar-Hydrogen system follows thereafter, with particular reference to the components that were used in this case study for the power generation of a mobile robot.

2.1. Photo-voltaic Cells

As a first step, sunlight which is generated from the sun is converted to electricity by the use of Photo-voltaic (PV) cells. The term "photo-voltaic" gets its name from the process whereby light (photons) is converted to electricity (voltage). Hence the term "photo-voltaic". This process requires quite some detail to explain, but briefly put, what happens is that when sunlight strikes the PV cells, it knocks electrons loose from their atoms, allowing them to flow freely through the cell [7]. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw off that current for external use. The electricity that is produced by the PV panels is direct current

(DC). The PV system used in this study consists of 6 PV modules. The total installed power is 1.2kWp in standard conditions. The specifications of the solar modules are determined as follows: maximum power is 200 W; Open circuit voltage (V_{oc}) is 59.5V; Optimum operating voltage (V_{mp}) is 46.1V; Optimum operating current (I_{mp}) is 4.37A.

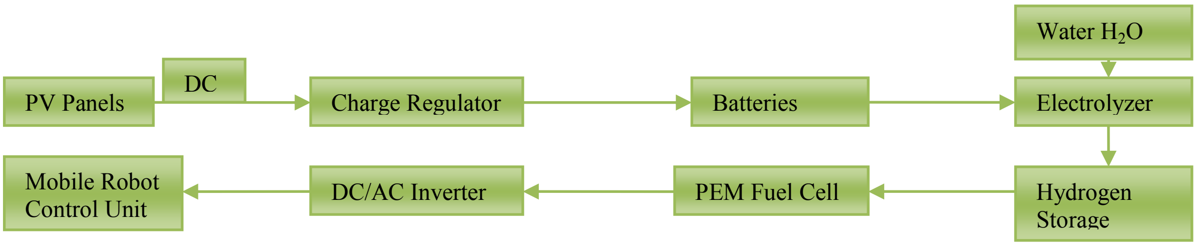

Fig. 1 Block diagram of the proposed power supply for the Mobile Robot

2.2. Charge Regulator and Solar Batteries
The current that is produced by the PV panels, which is in DC voltage, will pass through a Charge Regulator in order to maintain stable current flow, and regulated at 12V. From the Charge Regulator, the DC current will pass to the solar batteries where it will be stored so as to provide a constant supply of power even when the supply of current from the PV system is interrupted during periods when there is no sunlight. Each solar battery will have 12 V to 350 Ah, and there will be 4 solar batteries in total.

2.3. Electrolyzer
From the Solar Batteries, the DC current will pass to the Electrolyzer. Electrolyzers use electricity to split water into its constituent elements, namely hydrogen and oxygen, through the process of water electrolysis. A water molecule is formed by two elements: two positive Hydrogen ions and one negative Oxygen ion, and is held together by the electromagnetic attraction between these ions. When electricity is introduced to water through two electrodes, a cathode (negative) and an anode (positive), these ions are attracted to the oppositely charged electrode. Therefore the positively charged hydrogen ions will collect on the cathode, and the negatively charged oxygen will collect on the anode [1,4]. One now needs to find a suitable means of storing the hydrogen thus collected from the electrolysis process.

2.4. Hydrogen Storage Tank containing Metal Hydrides
The storage of hydrogen poses certain real challenges. That is because it is so light that it occupies so much of space. It is the lightest gas in the atmosphere, even lighter than air. It needs to be somehow squeezed to fit into a smaller space so that it is convenient to store and can be packaged in a form that is more compact and potable enough to be carried on-board a robot or motor vehicle that needs to utilise it as a power source. For this, it has to be pressurized in a container that can handle the extreme pressures of the hydrogen inside. One can achieve higher densities by storing the hydrogen in liquid form. The problem though, is that it will have to be kept at extremely low temperatures of -253°C (referred to as cryogenic temperatures) in order to maintain it in that liquid state. Whether as a compressed gas or cryogenic liquid, hydrogen is quite volatile and requires special handling [9]. It is this very aspect of storage that poses challenges in the use of hydrogen.

A promising alternative would be to store hydrogen in a solid state, using a metal alloy. A metal alloy is like a lattice structure of individual atoms with small spaces in between. When exposed to hydrogen at certain pressures and temperatures, the metal alloy is able to absorb large quantities of the hydrogen gas. The hydrogen gas splits to form two hydride ions. The hydride ion is very small, consisting of only a proton and an electron, and can fit into the small spaces in the metal lattice structure. In other words, the metal alloy acts like a porous sponge that can soak up large quantities of the hydrogen. When this happens, the hydrogen is distributed compactly throughout the metal lattice. When metal alloy combines with hydrogen in this way it forms simple chemical compounds called metal hydrides [10].

Metal hydrides represent an exciting method for storing hydrogen. They have a higher volumetric hydrogen storage capacity. Some hydrides can actually store twice the amount of hydrogen than can be stored in the same volume of liquid hydrogen. When compared with the volume of space that hydrogen occupies in its original form as gas, as a metal hydride the hydrogen is compacted into a solid form which is one thousand times smaller than the original hydrogen gas.

Thus, the component to be used in this experiment for the storage of hydrogen, will be a Hydrogen Tank containing a metal alloy in granular form. Metal alloys have the advantage of not only being able to absorb the hydrogen for the purposes of storage, but they are also able to release (de-sorb) the hydrogen so that it can be used when needed to produce energy, as will be demonstrated in the next step [9,10].

2.5. Fuel Cell and DC/AC Inverter

Just as how electricity is applied to water (H_2O) to produce Hydrogen (H_2) and Oxygen (O) in electrolysis, this whole process can be reversed. By combining Hydrogen with Oxygen one can produce electricity [11]. It is like "reverse electrolysis". This process is achieved by means of a Fuel Cell. The fuel cell is connected to the Hydrogen Storage Tank from which it gets a constant supply of hydrogen. For as long as there is a flow of hydrogen to the Fuel Cell, it never goes dead. Electricity will just simply continue to flow out of the Fuel Cell [12, 13]. The electricity produced by the Fuel Cell is in DC voltage and will be converted to AC current by means of DC/AC inverter so that the current is in the required form to power the mobile robot.

3. The Experiment Set-up

For practical considerations, it may not be possible to incorporate all the components of the Solar-Hydrogen Energy system on-board the mobile robot, particularly with regard to the solar panels which would make a robot unwieldy. In this model it is envisaged that the solar-energy generation process, as well as the electrolysis and production of the hydrogen will be done at a station. Those components that would be incorporated on-board the mobile robot for the power supply, is illustrated in Figure 2.

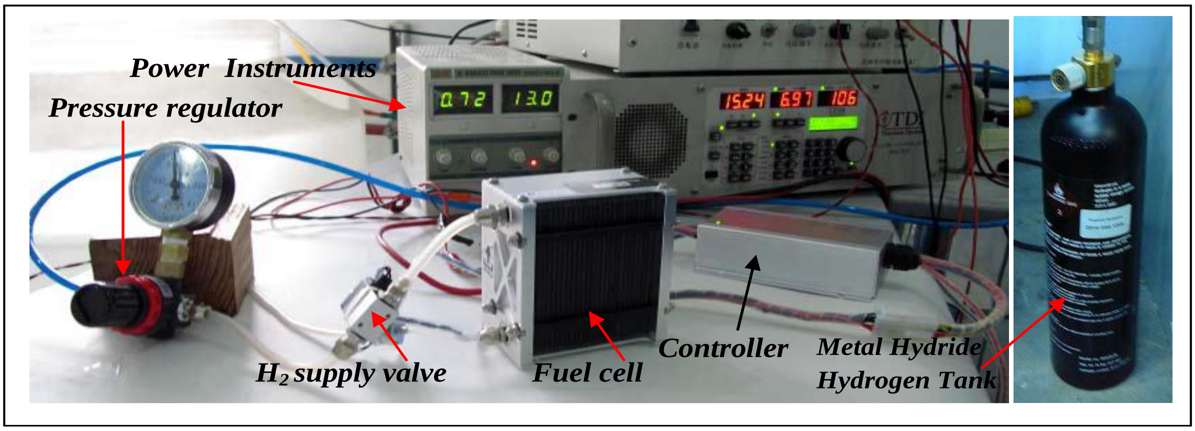

Fig. 2 Experiment set-up showing the Hydrogen Storage System and Power Supply.

4. Mechanical Design and Hardware Architecture

The robot used for this experiment is designed for an industrial and manufacturing setting. It is an Industrial Mobile Robot Platform (IMRP) in the form of a unit load carrier that is capable of carrying a pay-load of up to 40 kg on its deck. The deck is a moving platform, which is powered by a 12V DC Motor. The frame-work for the IMRP has been made from square tubing (38mm x 38mm) (see Figure 3). The overall gross weight of the IMRP will be 120kg.

For improved manoeuvrability, the IMRP has been given omni-directional capabilities by means of mecanum wheels, as illustrated in Figure 3. A mecanum wheel consists of a hub with a number of individual rollers arranged around its circumference. Each roller is mounted on the contact surface of the wheel at a 45° angle to the wheel axis, and is able to rotate about its own axis. Using this type of wheel, a vehicle can be propelled directly in a sideway motion without having to make the vehicle move forward at the same time, as is the case for a conventional vehicle. A vehicle with mecanum wheels can be made to move in various directions by choosing different combinations of wheel rotation direction for the four wheels [14]. This requires that each wheel be driven independently with a separate motor. For the IMRP, four 12V DC motors are used.

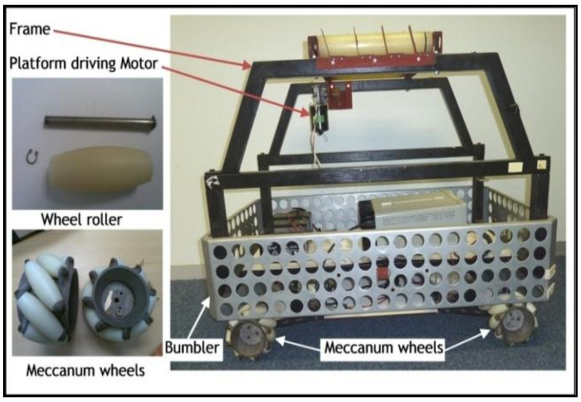

Fig. 3 Mobile robot system showing the mecanum wheels

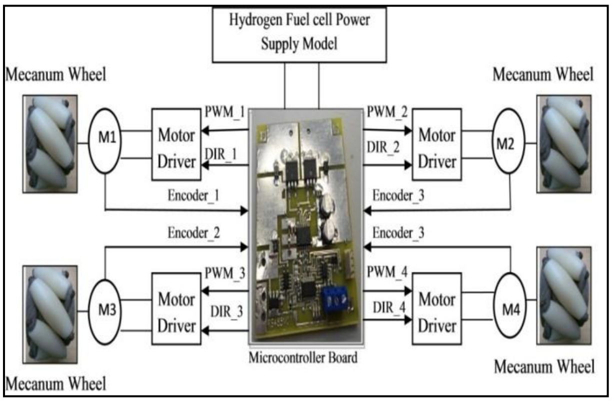

Fig. 4 Hardware architecture of the Mobile Robot system

The control of these motors would require a Motor Driver Circuit Board, which in turn will interface with an on-board processor with intelligent functionality, namely a Micro-controller Board that will have the ability to generate four independent PWM signals for each of the four wheels [15].

The control of movement of each wheel will have to be calculated independently of the other wheels, and the various permutations involved will require higher level computation and this will be carried out by a Main Computer, supported by software specifically written for this purpose [16]. The computer will be controlled by an operator from a remote location, which will transmit digital signals by means of Radio Frequency to the Micro-controller Board, using a Telemetry System.

Figure 4 illustrates that part of the Hardware Architecture that is to be installed on-board the IMRP.

5. The Simulation Model

To analyse the efficiency of the energy system in this study, a software simulation tool is used. The system chosen for this study is TRNSYS (Transient Energy System Simulation) which has a wide range of use in renewable energy and emerging technologies. The TRNSYS model simulates the performance of the entire energy-system.

6. Vibrant interest in Hydrogen for other Technologies : The Automobile Industry

The biggest challenge in the automobile industry in producing a commercially available hydrogen car, has been the high cost associated with the fuel cell technology. For motor cars, one needs a catalyst in the fuel cell that can speed up the chemical reaction so as to yield energy fast enough. Only platinum can achieve the desired effect. But the trouble is that platinum is rarer than gold and more costly. And it is this factor that has stood in the way of making hydrogen powered cars a reality. But new research by Associate Professor Matthias Arenz, of the Department of Chemistry, Copenhagen University, Denmark, has now brought this technology a step closer. "By placing the platinum differently inside the catalyst, we can drastically reduce the platinum requirement. This means that fuel cells will be much cheaper to produce in the future," according to a new study co-authored by him[7]. Already, the

[7] "Hydrogen cars now one step closer" ScienceNordic,, Aug 11,2013 sciencenordic.com

world's biggest car producer (Toyota) is combining forces with the world's biggest luxury car-producer (BMW) on hydrogen fuel cell research, as also Ford, Daimler and Nissan in a separate deal[8].

7. Conclusion

Studies such as this on alternative energy sources, are not merely of academic importance only. The perceived difficulties in alternative energy sources such as solar and hydrogen can be overcome to make these technologies a reality. As this study demonstrates, the seeming unreliability of solar energy because of its intermittent supply, which is due the nature of sunlight which is not always available, can be overcome by combining it in a system with another alternative energy source such as hydrogen. Likewise the challenges posed by hydrogen energy relating to its storage and safe handling can also be overcome by the use of metal hydrides. And finally, the prohibitive costs associated with fuel cell technology which made the concept of hydrogen cars a distant dream, is now one step closer to reality with new emerging research.

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