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Development of a solar-powered smart wheelchair

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Abstract

A self-propelled wheelchair that will aid the physically challenged with mobility and the aged who are challenged with mobility was developed. The smart wheelchair aims to help them by giving them the freedom to engage with their environment and improve their standard of living. A device that was able to measure the temperature of the atmosphere was incorporated as well as a universal serial bus and a means of illumination incorporated into the wheelchair. It has a solar power generation system that serves as the power source for the electric motor which propels the wheelchair, and a control system that controls the movement and the navigation of the wheelchair.

Keywords: Solar; Wheelchair; Mobility; Physically Challenged

1. Introduction

In recent years, science and technology have improved drastically, and several innovations have emerged in tackling challenges. This is obvious from the rapid development of engineering and technology, where the internet of things, machines, and robots have been designed towards the improvement of the living standard of human beings through overwhelming human challenges, either artificial or natural. Solar energy is fast becoming a very attractive renewable energy option, which is incredibly beneficial to the environment. The process of converting sunlight to electrical energy has improved dramatically over the last few decades. The use of solar energy has been around for years in small devices such as calculators, radios, lamps, etc. But in recent times its benefits have advanced towards powering of houses, devices, and businesses of these solar equipment.

A photovoltaic (PV) cell can function using energy derived from the sun. Every PV contains many different silicon cells or solar cells. These solar cells absorb sunlight, which is then converted into electricity with the help of PV. The PV cells installed on rooftops absorb sunlight (photons) from the sun. The Silicon and the conductors in the PV convert the sunlight into direct current (DC) electricity.

However, the living of the physically challenged people in the environment like the handicapped and the aged has been neglected, therefore, this development work concentrates on how a better living through free mobility is employed for the affected people through a solar-powered smart wheelchair. A smart wheelchair is a recent development that uses the frame and seating of a typical manual chair while replacing the standard rear wheels with wheels that have small battery-powered motors in the hubs. Smart wheelchairs are used by older adults and people with disabilities who do not have the physical ability to propel a manual wheelchair. There are different mobility solutions available in the market, examples are chairs that can climb stairs, obey voice commands (Scott et al, 2007), and respond to mobility for a person on indoor level surfaces, it is assumed that the user can see where he is going and can press a few switches for the forward motion, stop motion and backward motion. Most machines can go up a short ramp, but not steps.

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All conventional powered wheelchairs have two motors, one each, driving one of the main wheels on either side of the wheelchair, as in manual wheelchairs. All maneuvering is done by varying the relative speed of rotation of the wheels on either side. This is technically called “Differential steer”. In motorized wheelchairs, the differential steer is achieved by properly controlling the speed ratio of the two motors (Kazuhiko et al). Furthermore, apart from the main pair of driven wheels, there has to be a pair of castor wheels for support. These align automatically to roll in whichever direction they are pushed. As a result of the recent developments in science and technology, this development has drastically improved people’s lives in several ways. With the handicapped and the aged who are challenged with limited mobility, the smart wheelchair aims to provide aid to them by providing them with freedom to engage with their environment and improve their standard of living.

2. Methodology

2.1. Mechanism

The electrical method, which involves the use of an induction DC motor to give both forward and reverse direction by the reversal of its polarity, was utilized. This was because it has fewer moving parts, therefore it’s not subjected to as much fatigue as the mechanical method, tolerances are higher in electrical systems, and it increases the power efficiency of the solar panel when compared to the mechanical method. The smart wheelchair is powered by the battery, which receives power from the photovoltaic cells. Solar rays from the sun are trapped by the photovoltaic cells in the solar panel. The wheelchair is running in the forward direction. While in the reverse drive, an electrical switch is used to reverse the polarity of the battery terminals to give the reverse direction.

The solar-powered smart wheelchair design is shown in Figure 1:

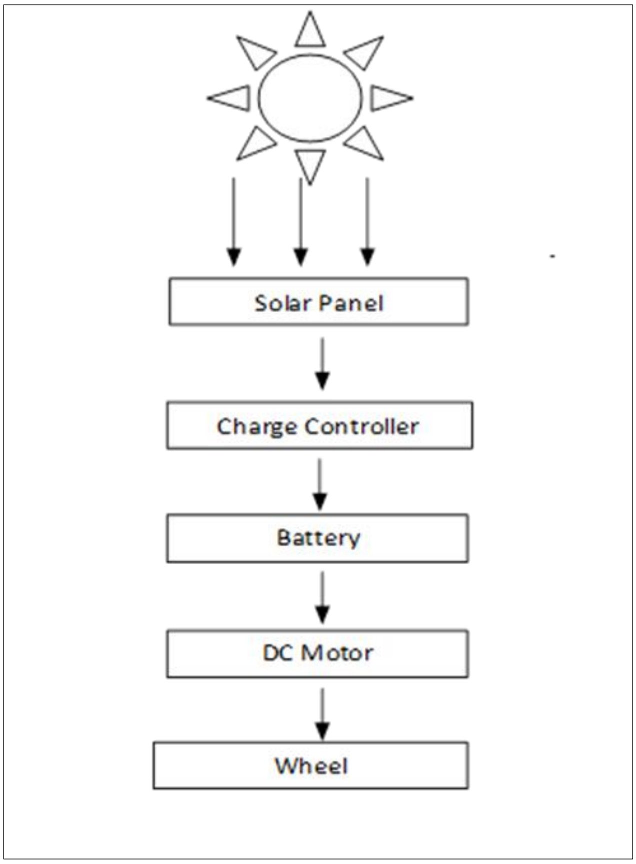

Figure 1 Design for a solar-powered smart wheelchair

Design steps and procedures are as follows: Configuration of the solar-powered wheelchair, the design load, selection of electric motor to power the design load, selection of the battery required to power the motor, determination of the size of the PV, selection of the material for the chassis or frame of the wheelchair, fabrication, weighing, comparison of load obtained after fabrication to the design load and testing.

2.2. Configuration

The tadpole configuration, which implies putting two wheels at the back and a caster at the front, was adopted for the project for easy transmission of power.

2.3. Design calculations

The component's weights are tabulated as shown in Table 1:

Table 1 Weight of the components

S/N	Components	Weight (Kg)
1	Battery	15
2	Electric Motor	10
3	Solar Panel	8
	Total Load	33

An average load of 20 Kg was assumed for the chassis and frames while 100 $Kg$was adopted for the driver's weight.

$$Design\ load\ =\ measured\ weight\ +\ assumed\ weight$$

$$Assumed\ weight\ =\ chassis\ and\ frame\ weight\ +\ users\ weight$$

$$Assumed\ weight\ =\ 20\ Kg\ +\ 100\ Kg\ =\ 120\ Kg$$

$$Design\ load\ =\ 33\ Kg\ +\ 120\ Kg = \ 153\ Kg$$

2.3.1. Electric motor specification

$$Input\ voltage\ =\ 100\ v$$

$$Power\ rating\ =\ 2625\ W\ (3.5\ hp)$$

$$Revolution\ =\ 4600\ rpm$$

$$Maximum\ load\ =\ 200\ Kg$$

$$Number\ of\ Battery\ to\ be\ used\ =\ 1$$

$$Battery\ amp - hour\ rating\ =\ 60\ Ah$$

$$Capacity\ of\ PV\ used;$$

$$Power\ =\ 100\ W$$

$$Panel\ current\ =\ 4.17\ A$$

2.3.2. Torque generated by the electric motor:

$From\ Power(P)\ =\ Torque\ (T)\ \times\ Angular\ Velocity\ (\omega)$

$T\ =\ P/\omega$

$$where\ \omega\ =\ 2\pi N/60\ in\ rad/s$$

$$N\ =\ number\ of\ revolutions\ (rpm)$$

$$T = \frac{2625}{(2 \times 3.142 \times 4600/60)}$$

$$T = 5.450\ Nm$$

2.3.3. Linear velocity of the electric motor

$$From\ V = \omega r$$

$$Where\ r = radius\ of\ the\ sprocket\ on\ the\ shaft\ of\ the\ electric\ motor$$

$$Diameter\ of\ the\ sprocket = 14\ cm = 0.14\ m$$

$$R = 0.14/2 = 0.07\ m$$

$$V = 2\pi Nr/60$$

$$V = 2 \times 3.142 \times 4600 \times 0.07/60$$

$$V = 33.72 m/s$$

2.3.4. Number of revolutions of the wheel per minute

$$From\ N2/N1 = R1/R2$$

$$Where\ N2 = speed\ of\ the\ wheel\ in\ rpm$$

$$N1 = speed\ of\ the\ motor\ shaft\ in\ rpm$$

$$R2 = radius\ of\ sprocket\ on\ the\ wheel$$

$$R1 = radius\ of\ sprocket\ on\ the\ shaft\ of\ the\ motor$$

$$N2/4600 = 0.07/0.05$$

$$N2 = 6440\ rpm.$$

2.3.5. Torque transmitted to the wheel

$$T2 = P/\omega 2$$

$$\omega 2 = 2\pi N2/60$$

$$T2 = 2625/\ (2 \times 3.142 \times 6440/60)$$

$$T2 = 3.89\ N$$

2.3.6. Transverse force production on the wheel

$$Since\ Torque = FT \times r\ sin\theta$$

$$Therefore\ FT = T2/\ r\ sin\theta$$

$$At\ the\ maximum\ point;\ \theta = 900$$

$$FT = \frac{3.89}{0.1} = 38.9$$

2.3.7. Mechanical power delivered to the wheel

$$Pmech = FT \times V$$

$$Pmech = 38.9 \times 33.72$$

$$Pmech = 1311.70\,W$$

2.3.8. Efficiency of the Electric motor

$$\eta motor = \frac{Pmech}{Pin} \times 100\%$$

$$where\ Pin = 2625\,W$$

$$Therefore, \eta motor = \frac{1311.708}{2625} \times 100\%$$

$$\eta motor = 49.97\%$$

2.3.9. Number of batteries required

$$The\ capacity\ of\ the\ battery\ required\ in\ watts - hour\ (Wh) = Ah \times motor\ voltage$$

$$Where\ Efficiency = \frac{motor\ capacity}{Ah \times motor\ voltage}$$

$$\therefore Ah = \frac{motor\ capacity}{motor\ voltage \times efficiency}$$

$$= \frac{262512}{12 \times 0.4997} = 52.53\,Ah \approx 60\,Ah$$

$$\therefore The\ battery\ Amp - hour\ rating\ is\ 60\,Ah$$

2.4. Connection of the DC-DC converter

The purpose of a DC-DC converter is to help convert a higher or lower voltage DC output from a PV down to the required voltage needed to charge the battery. Also, the DC-DC converter serves as an interface between the photovoltaic and the load.

In addition, the DC-DC converter enables the optimum operation of the photovoltaic cells.

The photovoltaic system mainly consists of three parts, which are: solar panel or module, Interface part, or desired power section, to manage and induce electric energy obtained from the photovoltaic system and electrical load. The below diagram is the configuration of the photovoltaic power system.

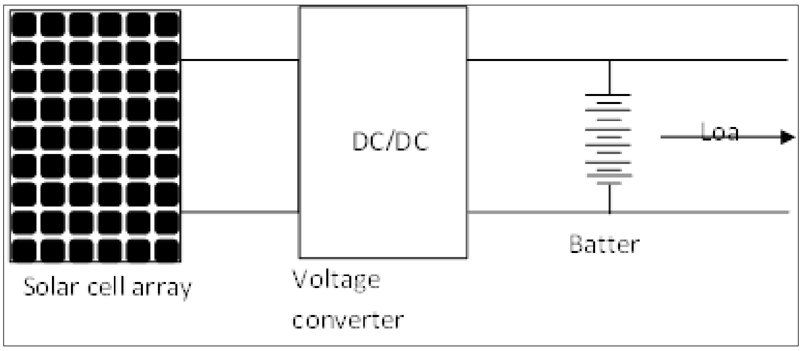

Figure 2 Photovoltaic power system

DC-DC converter has three different basic topologies of converters. These are the Buck converter, Boost converter, and Buck-Boost converter. However, for the benefit and purpose of this write-up, a buck-boost converter will be discussed.

Buck - Boost converter is a converter in which the output voltage from the PV is decreased and increased to a desired voltage.

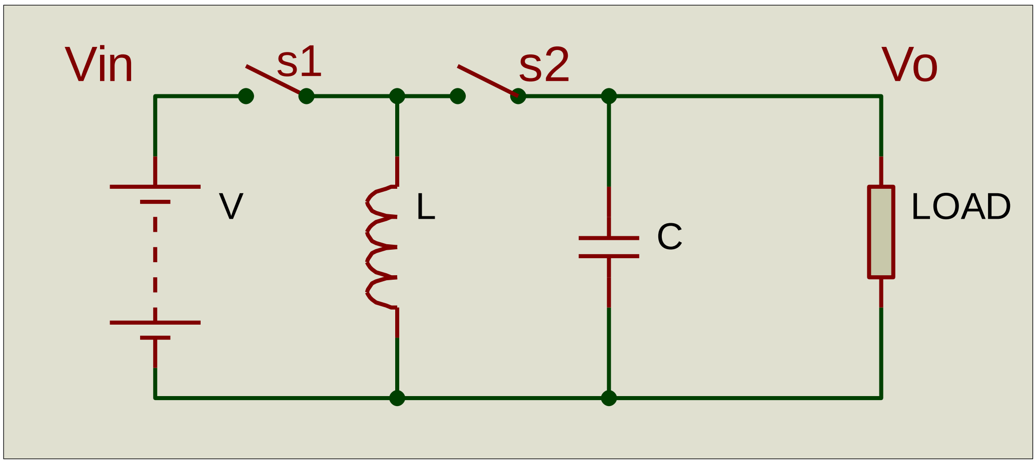

Figure 3 Buck-Boost DC-DC Converter Circuit

According to the above circuit diagram, there are two modes of operation: buck and boost.

During the buck mode V_{in} is greater than V_{out}, switch 1operate as a buck regulator, and switch 2 is closed. While at boost mode, V_{in} is less than V_{out}, switch 1 is closed, and switch 2 operates as a boost regulator. Furthermore, the inductor tends to resist changes in current which enables the boost function. When charging, the inductor acts as a load and stores energy, when discharging, it acts as an energy source. In addition, the capacitor connected to the converter's output reduces output voltage ripple.

2.5. Material selection for the frame

Mild steel was used in the construction of the frame

The average mechanical property of mild steel has the following parameters

$$Sut \ = ultimate\ stress \ = 527 \ \times 106\ N/mm2$$

$$Sy \ = yield\ stress(design\ stress) \ = 296 \ \times 106\ N/mm2$$

$$Factor\ of\ Safety \ = ultimate\ stress/design\ stress$$

$$Fs \ = Sut/Sy \ = 527/296 \ = 1.78$$

2.6. Mechanical construction section

This is the section where the irons, wheels, bolts, and nuts were joined together and welded.

Figure 4 Smart wheelchair frame construction

2.7. Electrical construction section

This is the section where other materials like electrical equipment's materials and other materials were installed. Therefore, after the installation of these materials. This design finally attained the title solar-powered smart wheelchair.

Figure 5 Smart wheelchair electrical construction

2.8. Artwork

The artwork involved the painting of the wheelchair frame, which enhanced it appearance and protected it from rusting. Also, in this section, the upholstery work of the wheelchair was accomplished.

Figure 6 Smart wheelchair art and upholstery work

3. Testing and Discussion

The following results were obtained after the completion of the testing.

Table 2 Electrical ratings of components

Components	Output Voltage (volt)	Current (Ampere)	Power (wattage)	Frequency (hz)
Photovoltaic cells	17.9	5.59	100	50
Battery	12	1.3	15.6	50
Electric Dc motor	12	33	396	50
Charge controller	12	20	240	50
Universal serial bus (USB PORTS)	5	1.5	7.5	50

However, the total speed of the wheelchair without a user:

$$Speed = \frac{distance}{time}$$

$$= 2.9m/14s$$

$$= 0.21m/s$$

Speed of the wheelchair with user:

$$= \frac{2.9m}{30s} = 0.1m/s$$

After the completion of the construction work, the solar-powered smart wheelchair was tested, which works perfectly well and as expected. The operation of the smart wheelchair was carried out by being powered by PV, which absorbs sunlight from the sun in the form of sunlight energy and converts it to electrical energy and produces direct current.

Therefore, the direct current was used to charge the battery and the charging of the battery was controlled by the solar charge controller. However, the battery serves as the main supply to the electric motors, the bulb, and the joystick. In addition, the smart wheelchair can be propelled while charging and off charging, which therefore constitutes the two major modes of operation of the self-propelled wheelchair

4. Conclusion

A self-propelled wheelchair which will aid the physically challenged with mobility and the aged who are challenged with limited mobility was developed. The smart wheelchair aims to aid them by giving them the freedom to engage with their environment and improve their standard of living. A device that was able to measure the temperature of the environment was incorporated as well as a universal serial bus and a means of illumination incorporated into the wheelchair. The following are recommendations for further improvement on the developed machine: incorporation of a microcontroller for the movement of the wheelchair, a solar battery should be employed, to increase the efficiency of the electric motors instead of the vehicle battery that was used, the single electric motor should be employed for all the wheels, screws, bolts and nuts should be used in joining all the materials together and making a temporary joint instead of the permanent joint employed through welding.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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