Multifunctional Solar Charging Station for Electric Vehicles

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While electric vehicles are generally seen as clean vehicles, they are not completely clean because the production of electricity might generate emissions as well. This paper on a multifunctional solar charging station is a working solution to close the gap in achieving a truly renewable and clean vehicle. The proposed concept involves an elevated photovoltaic roof that is approximately the size of an average car park (4m by 2.65m). The photovoltaic roof produces 1.65kW electricity under standard sun conditions. Through multiple maximum power point tracers with integrated DC-DC converter, the solar produced DC electricity is directly used to charge multiple types/voltages of electric vehicles. The electric vehicles to be charged can be parked below the solar roof. Electric cars, electric motorbikes, electric bicycles, electric scooters, Segway’s, electric sweepers, electric lawn movers, electric boots, electric ultralight plains and other devices can be charged by this concept. By a DC-AC inverter with integrated charger, the system is able to provide 240V AC electricity to appliances such as mobile air conditionings enabling the conversion of the solar roof with additional side panels into an air-conditioned outdoor event space. Furthermore the DC-AC inverter can also put energy back in the grid when there are no electric vehicle to be charged. By doing this all the possible solar generated electricity can be used to reduce the time for a solar panel to produce back the energy needed for its own production. The DC-AC inverter with integrated charger also allows the usage of the electric vehicle battery as energy storage to provide energy back to the grid during peak demand. Moreover the integrated charger can draw additional charge from the grid to the vehicle battery if there is not enough solar electricity provided or in the event where the charge time needs to be shortened.

Keywords: Electric Vehicles, Photovoltaic, Charging, Renewable Energy

1 Introduction

In today’s world, fossil fuel is the main power source as it provides energy for automobiles, airplanes, and it is also used to produce electricity. However, fossil fuel cause environment problem by emitting CO\textsubscript{2} into atmosphere when producing energy, which eventually leads to global warming. For example in 2012, vehicles have contributed for 34.3\% of America’s energy-related CO\textsubscript{2} [1]. This shows that there is a need to change in vehicle system to reduce the pollution to the environment.
In order to solve this problem, there are two paths: first, through designs which consume less energy and improve fuel efficiency; second through usage of alternative energy with storage such as hydrogen or battery. Recently, in the field of automobiles, many companies have developed commercially available electric cars that consume alternative fuels. Nevertheless an electric car or electric vehicle is only as clean as the primary energy used to power it. That means we also have to look at clean electricity generation if we want to improve the traffic based air pollution with electric vehicles.

In National University of Singapore (NUS) in the Design Centric Program (DCP), Future Transportation Systems (FTS), we work on several electric vehicles; starting from small electric skate scooter, Segway’s, Pedelecs, electric motorcycle, electric car, electric assisted sail yard to electric flying multicopter. To provide clean energy to all this vehicles on land water or air we developed a multifunctional solar charging station.

The base design is a mobile solar car park roof. Today, there are few solar car park which are in the market which are mobile grid connected solar systems. The system discussed in this paper is a mobile multifunctional solar charge station which allows direct DC charging from the solar panel to different vehicle traction batteries. The Direct DC charging avoids the losses traditionally caused by the DC/AC inverters to the grid and AC/DC chargers from the grid to the battery. This means that there is a 10% to 15% efficiency gain compared to the standard AC Vehicle charger.

There is many benefits of solar car park, as it not only provides a shade for car during parking, it also generate electricity that can be used to charge the battery of the car.

2 Design and parts used

The design for solar car park is simple, a structure with rooftop made of solar panels and supports with rollers, attached with a storage box for charge electronic, DC/AC inverter, charger cable and an additional battery as in figure 1&2.

![Figure 1&2: Solar Car Park design and orientation of solar panel](image)

Currently, the choice of solar panel is YingLi Panda 60 cell monocrystalline solar solar panel of dimension 1.64m×0.99m with maximum power of 280W. As shown in the orientation, the total area of the solar car park roof is around2.63m×3.96m, which consists of 6 solar panels. This dimension is roughly same as a normal car park space. There is a roller in each support to make it easy to move. There is also a battery bank, which is a box for batteries storage. The batteries are used to collect the energy that is produced by the solar panel when the car is not parked so that energy harvest will not be wasted. When the car is parked under the solar car park, it can be charged by using the batteries instead of directly charge by solar panels. The maximum size of 4.00m times 2.65m allows to place the solar charging car park over an average car park in Singapore and park a medium sized electric car below for charging. The mobile design with lockable wheels allows mobile deployment in different locations. As a mobile structure it is not considered a permanent structure so it did not need a building permit. The mobile structure also allows a deployment as Electric Motorbike parking, electric bicycle parking and charging, charging of solar boots at the shore or electric ultralight fling vehicles at an air stripe.
Additional use is as portable deployed sales enclosure or advertising boots. For this use the sides can be partly or fully closed by fabric and the interior can be equipped with a portable air-conditioning system powered by the solar system.

2.1 Flexibility for direct solar charging of various different electric vehicle
Two Outback MPPT80 maximum power point tracer [2] get deployed for each array of 3 panels. The charge voltage can be adjusted to different battery Chemistries in a nominal Voltage range from 12-60V. Two MPPT chargers allow to charge vehicles simultaneously independently or with two connected parallel on vehicle in half the time or when connected in series vehicle traction batteries up to 120V nominal voltage.

2.2 DC-AC inverter with integrated Charge for island or smart grid operation.
The integration of an DC/AC inverter with 2.3kW 48V(DC) to 230V(AC) allows grid connected and grid independent operation.
In grid connected operation it allows to give electricity over supply from the solar system to the grid (for example at day time with no electric vehicle connected). In reverse it also to charge the connected battery in the vehicle from the grid (for example when no solar energy is available at night). It can also supply electricity to the grid from the vehicle battery (or stationary battery) when there is a peak demand of electricity in the grid and high prices can be achieved for the selling of electricity to the grid. Also emergency electric power supply for household use can be provided through the vehicle battery and DC/AC inverter.
In grid independent operation it allows to operate appliances like mobile air-conditioning systems, lighting, projectors and sound system grid independent either from solar, the vehicle battery or a stationary battery. This is very useful for events, advertising and sales boots, or constructions and on site repairs.

3 Efficiency and Possible Energy harvest
One of the most important factors of solar energy is the availability of solar radiation during daytime. Theoretically, solar radiation reaches the peak of 1000W/m2 at solar noon [3], which is around 12pm. Thanks to the location of Singapore, which is very close to the equator, the solar radiation at solar noon is very close to the theoretical value of 1000W/m2. However, due to several factors, it is nearly very hard to get the peak value of 1000w/m2.
First is the effect of cloud coverage, which causes rapid changes of solar radiation. According to SERIS report, in Singapore, the perfectly clear-sky days happen on less than 5 days per year [4]. This shows that the irradiance profiles of a typical day in Singapore fluctuates.
In addition, solar irradiation also depends on the direct and diffuse radiation ratio. Direct radiation is defined as the solar radiation traveling on a straight line from the sun down to the surface of the earth. On the other hand, diffuse radiation occur when the sunlight that has been scattered by molecules and particles in the atmosphere, such as dust, clouds and other, before reaching the surface of the earth [7]. Generally, diffuse radiation provides lower energy compare to direct radiation, thus the higher the percentage of diffuse radiation, the lesser the solar energy that can be harvested. According to SERIS report, Singapore has a high ratio of diffuse radiation, which is approximately 55% [4].

3.1 Solar radiation in Singapore
Figure 3 below shows the irradiance profile of a day in Singapore.

Figure 3: Irradiance profile of a single radiometer during a typical day with high variability in tropical Singapore (blue curve) and of a rare day with clear-sky conditions (red curve); Source: SERIS meteorological station, 1-min data.

Generally, the solar irradiance profile has a “bell curve” shape. Start from sun rise, which is around 7am, the solar radiation increase and reach it peak at solar noon. Then the solar radiation start to deceased and reach zero when sun set at around 7pm. The red curve on the graph shows the solar...
irradiance on a clear-sky day, while the blue curve shows a typical day in Singapore. The total solar irradiation per day can be calculated as the area under the graph. From the graph, we can notice that for a typical day, due to the fluctuation throughout the day, although at solar noon, the average solar irradiation is still much lower compare to a clear-sky day. From the data of Meteonorm version 7 [8], the annual irradiation at NUS Faculty of Engineering is 1638 kWh/m²•year. Therefore, on average, the solar radiation per day is as following (1):

\[ \text{Solar radiation per day} = \frac{1632 \text{kWh} \cdot \text{year}}{365 \text{days}} = 4.471 \text{kWh/m}^2\text{day} \]  

(1)

### 3.2 Calculation of harvested solar energy

For these six solar panels, they provide a total of 1680 Wh of power per hour under full sunshine (1000 Wh/m²). Theoretically 10 hours full sun shine would provide a 16.8 kWh electricity enough to drive 100km with a mid-size electric car. However, as discussed below in figure 1, it is very hard to achieve the maximum solar irradiation (1000 Wh/m²), even at solar noon of a clear sky day. As the result, the calculation for power harvest at solar noon is not meaningful as the values fluctuated. Therefore, rather than calculated the energy harvest at solar noon, we will calculate the average energy that can be harvest per day.

The energy that able to harvest for the solar car park can be calculate theoretically. For one solar panel, it has a dimension of \(1.64 \times 0.99 m\) and it provide 280 W peak power. Thus, the power per m² of the solar panel is:

\[ \text{Power per m}^2 = \frac{280}{1.64 \times 0.99} = 172.456 \text{W/m}^2 \]

Thus, the efficiency of the solar panel is:

\[ \eta = \frac{172.456}{1000} \times 100\% = 17.2456\% \]

By taking the average solar irradiation per day in Singapore (Figure 3) as 4.47 kWh/m²-day, we can get the total power that we can harvest per day with a single solar panel (2, 3), when the car park under the Sun for whole daytime from 7am to 7pm, (Sunrise and sunset is at the Equatorial country of Singapore is year round nearly the same)

\[ \text{Energy per m}^2\text{per day} = 4471 \cdot 17.25\% \]

(2)

\[ = 771.05 \text{Wh per m}^2\text{per day} \]

Total Energy per panel = 771.05 \cdot (1.64 \cdot 0.99) \]

(3)

\[ = 1251.88 \text{Wh per day} \]

For the six solar panels on the solar car park, the total energy that can be harvest is:

\[ \text{Total Energy} = 1251.88 \cdot 6 = 7511.26 \text{Wh/day} \]

(4)

If we consider a commuter which has a solar charging roof a his workplace we consider working hour from 9am to 6pm, the total energy will be 8.95% less for the non-used morning and evening hours.:  

\[ \text{Total Energy (9am to 6pm)} = \]

\[ 7511.26 \cdot (100 - 8.95)\% = 6839 \text{Wh/day} \]

(5)

But still 6.8 kWh.

### 3.3 Traveling distance with one day sun charging for different vehicles.

What traveling distance will be achieved by one average day sun charging in Singapore with the proposed multifunctional solar charging station? The results for different vehicles are given in Figure 4 to 8. The first figure is the distance cover in kilometre by 1 kWh of electricity. The second figure is the distance possible to cover on one average day of sunshine in Singapore harvested by the multifunctional solar charging station (7.511 kWh per day).

Figure 4 shows the NUS, electric ARC which is a conversion of a combustion engine car to electric car, the Electric Caterham 7 project. The original Caterham 7 is a lightweight two-seater sports car, which based on the Lotus Seven. The car is now mounted with two permanent magnet brushless motors, which connected individually to each rear wheel. The Electric Caterham 7 batteries capacity is 9.6 kWh this allows a range of 57 km.

Figure 5 shows the NUS Frog Works Electric Motorcycle on the WAVE electric Vehicle Rally 2014. The Electric Motorcycle and the Electric Caterham are the main user of the solar charging station.
Figure 4. Electric ARC, classic British sports car conversion. 5.83 km per kWh, 43.8 km with one day solar charging.

Figure 5. Electric Motorcycle converted by NUS team FrogWorks. 12.0 km per kWh, 90.1 km for one day solar charging.

Figure 6. Sailboat from NUS team FrogWorks with additional electric propulsion. Distance covered by Electric Propulsion only (without sailing) 4 km per kWh, 30 km with one day solar charging.

Figure 7. Volocopter pure electric helicopter for two pax. 1 minute flight time per kWh, 7 minutes 30 seconds with one day solar charging.

Figure 8. Gocycle electric bicycle (Pedelec) and Zoom electric skate scooter. 100 km per kWh, 751 km for one day solar charging, or charge 15 15 Pedelecs or E-scooter in one day with 50 km range each.

4 Conclusion

The multifunctional solar charging station is a functional design of a universal charging system. The mobility makes a deployment on different locations easy and literally enable the charging of electric land, water, and air vehicle. The mobile design did not require building permit and makes also the usage as grid independent event booth possible. With integrated power supply for appliances, the modular approach makes it easily scalable with multiple units deployed.

The advantage of DC direct charging from solar to vehicle traction battery has an advantage of less energy losses through conversion. (ca10% improvement). A wide range of vehicle batteries can be charged with nominal Voltage between 12 V to 120 V. Nevertheless, higher voltage vehicle batteries cannot be charged directly with the current configuration. Standardised DC connection and communication of vehicle to set the right charging parameter automatically is the next implementation step. The Energy Bus standard is a promising solution to be implemented for this [9].
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References

Authors
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Low Wen Bin is a four year National University of Singapore Mechanical Engineering student with specialization in automotive engineering. He is currently investigates with his final year project the effect of on-board and stationary solar charging for an electric Caterham car project.

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Luo Yi is pursuing a Bachelor degree in Mechanical Engineering with a minor in Information Systems at the National University of Singapore. As a part of the Design Centric Program, she has been involved in successful conversion of a petrol motorcycle into an electric bike. Yi has keen interest in the battery mounting and energy balance analysis. She did a statistical report on the energy consumption and regeneration of the converted electric bike.