Solar-Powered Charging Platform For Personal Devices: Design and Analysis

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Abstract— **This paper is the result of a semester-long senior year design project. The objective of this project is to propose a design for a renewable-source charging platform for personal devices, as well as to perform a qualitative analysis of its performance.**

***Keywords*— PV panel, renewable energy source, power consumption**

I. Introduction

One of the growing trends of power networks in the 21st century is the implementation of renewable energy sources. Despite their seemingly limitless reserves, RESs introduce an element of uncertainty into the generator input due to the inability to control their natural input, such as sunlight and wind force, which means introducing them into a grid adds a new level of complexity into power flow modelling.

But while the implementation of large-scale generators is a long and costly process, smaller-scale platforms can be designed such that they operate outside of the grid and reduce power consumption through direct input on the user-side.

One such example is the design of a charging platform for personal devices, such as smartphones. By switching the primary source of energy for personal devices from traditional DC power sources to a PV panel, a decrease in power demand for non-renewable sources is to be expected. This study will inform the design process, testing and analysis of such a platform.

II. Design

The design and assembly for the station can be broken down into the following few key components listed below:

A. PV Panel

A PV panel is utilized as the one and only energy source. The focus of this study will be to test and analyse the performance of this panel. The panel has a 22cm x 17cm surface area, 19% cell efficiency and a 6W, 6V peak output performance.

B. Charging Circuit

A Lithium Ion/Polymer charging circuit is utilized for voltage regulation and charging. While the standard output is 500mA, a 1ohm resistor was soldered in to increase that value to a 1A output. Fig. 1 displays the board in which the charging system:

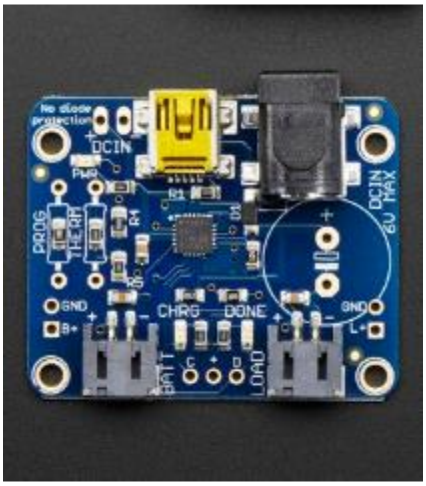

Fig. 1 Lithium Ion/Polymer charging circuit board.

C. Battery

A Lithium Ion, 6600mAh battery pack is implemented into the system. This allows for the platform to store up energy to be provided in low-irradiance situations, increasing its utility.

The relationship between components is depicted in the diagram in Fig. 2:

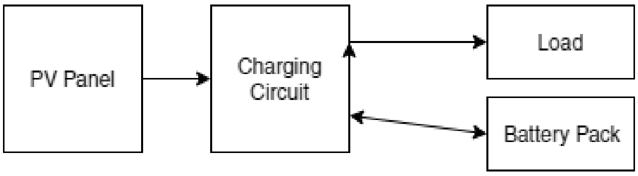

Fig. 2 Block Diagram depicting the relationships between the platform's components.

Fig. 3 below depicts the fully-assembled circuitry of the proposed platform, which matches the block diagram from Fig. 2:

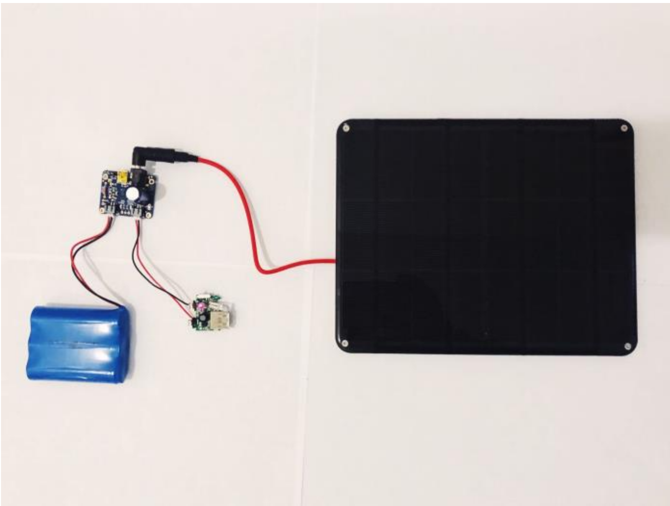

Fig. 3 Assembled circuitry of the proposed platform.

The total cost of the components purchased to assemble this system is $130. The selling cost of a single platform, accounting for labour and some minor profit, could be set to approximately $200.

III. Simulations and Performance Testing

A. MATLAB Simulations

The performance of the PV Panel can be compared directly to data obtained from running its profile on Simulink, MATLAB's standard simulation package.

Fig. 4 below displays the IV and PV characteristics simulated for the panel utilized:

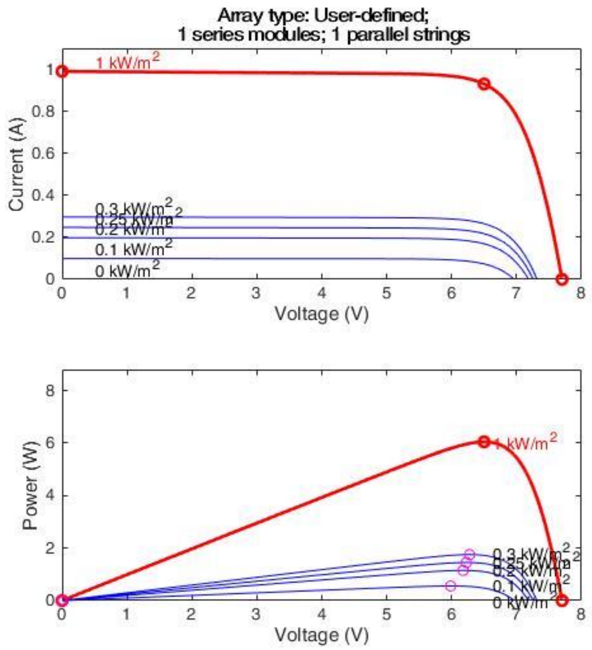

Fig. 4 IV (top) and PV (bottom) characteristics simulation for the PV panel.

The irradiances used for this simulation are calculations relating kW/m^2 values to common weather conditions. Table I depicts this relationship:

TABLE I
IRRADIANCES BY WEATHER CONDITION

Weather Condition	**Irradiance (kW/m^2)**
Full Daylight	1.0
Light Cloud Interference	0.7
Cloudy	0.5
Overcast Day	0.3
Very Dark Day	0.25
Twilight	0.2
Moonlight	0.1
Total Darkness	0.0

B. Test Data

The testing stage of this study consists of attempting to simulate the irradiance levels from Table I. With the desired approximations, the the output current of the platform can be measured. Due to inclement weather during most of the testing stage, materials with different light permeability were used instead, attempting to approximate the weather conditions discussed in Table I. Table II displays these approximations:

TABLE III
WEATHER CONDITION APPROXIMATIONS

Weather Condition	Approximation	Current (A)
Full Daylight	Direct contact	0.87
Light cloud interference	Soft plastic	0.73
Cloudy	Half of panel blocked out	0.58
Overcast	Sunglasses	0.42
Very Dark/Twilight	Three-quarters of panel blocked out	0.23
Moonlight	Soft cloth	0.01
Total Darkness	Paper	0

Fig. 5 depicts the direct relationship between the simulation results (coloured blue), and the test data (coloured red):

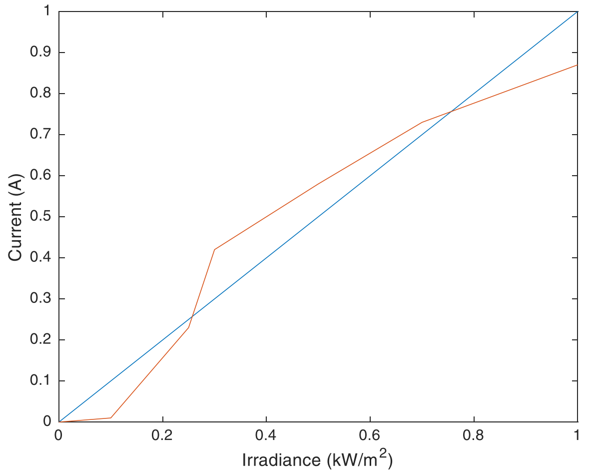

Fig. 5 Comparison between simulations and test data.

The comparison between the two datasets indicates that, despite some discrepancies, which are expected due to losses not accounted for during simulation, as well as possible estimation errors, the panel's performance trendline matches that of the simulation quite well.

Among the losses expected are the natural losses caused by some minor resistances in the circuitry and wires, as well as the effect of temperature on the panel's performance. PV panels are at their peak efficiency on colder temperatures, becoming less and less efficient as their temperature rises. Due to the fact that a 1000W heating lamp was used to simulate direct sunlight contact with the panel surface, it can be assumed that prolonged exposure would result in the panel converting power in a non-optimal manner.

IV. Analysis

In order to conduct the analysis stage of the study, a few assumptions and simplifications were made:

a) The personal device utilized for testing is a common smartphone, equipped with a 5V, 1500mAh battery.

b) A study performed by [1] indicates that the average number of full cellphone charges in major US cities in 2015 was 2 times per day. With this in mind, the average capacity to be filled in a day is taken to be 3000mAh. Fig. 6, taken from [1], depicts the averages for the major US cities utilized.

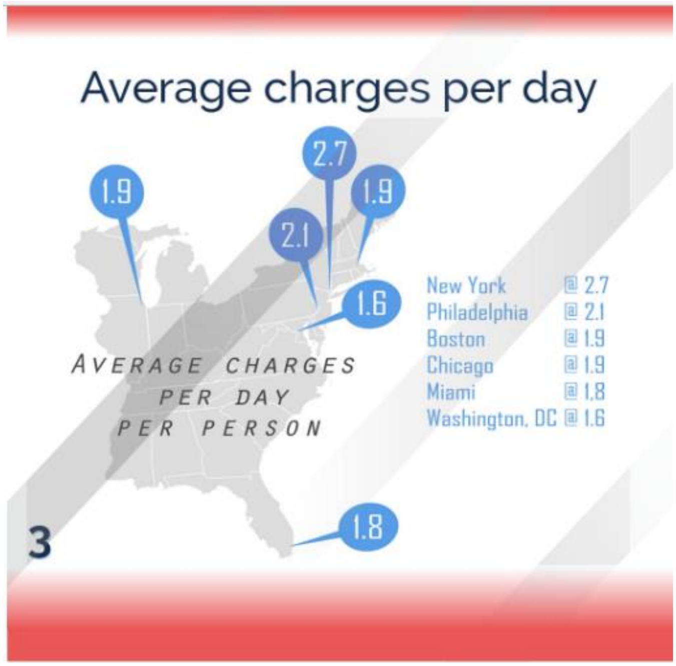

Fig. 6 Average charges per day, major US cities. [1]

c) The power consumption analysis will be constrained to the following four different weather conditions: Full sunlight, light cloud interference, cloudy, and overcast. The consumption savings will be averaged out in the end, under the assumption that the three conditions occur with the same per-day frequency throughout the year.

d) The bulk of the number of charges happen during daytime. The number of nighttime charges is offset by the presence of the battery pack, which would accumulate a moderate charge through the day.

e) According to [2], the average cost of energy in the US is approximately $0.10/kWh.

f) According to [3], the number of smartphone users in the US in 2015 was 190.64 million. Fig. 7 depicts the rising number of smartphone users in the US, from 2010 to 2022. Despite the wide range of years to choose from, 2015 was chosen to match the data from [1]:

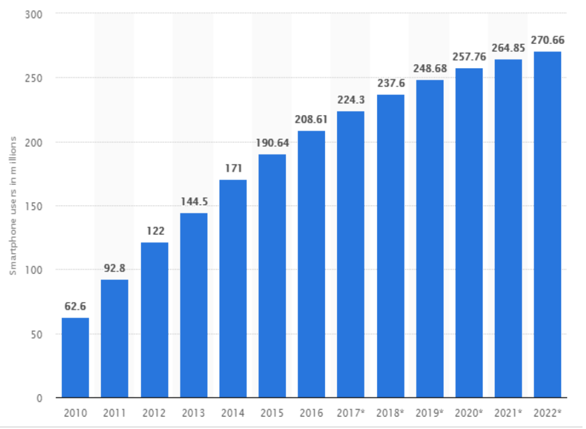

Fig. 7 Number of smartphone users . [3]

g) Lastly, the assumption is made that the platform requires no maintenance at all. Therefore, no costs besides the initial purchase cost are considered.

The commercial metrics under the four proposed weather conditions are as follows:

1. *Full sunlight*
Under full sunlight, the total average charge time is *3000/870 = 3.44* hours/day, and the power consumption is *5x0.87 = 4.35W*/h, or 0.00435kW/h. Thus, the daily cost of consumption is $0.001496/day or $0.546/year for a single device, and $104.09 million/year for the US.

2. *Light Cloud Interference*
Under light cloud interference, the total average charge time is *3000/730 = 4.10* hours/day, and the power consumption is *5x0.87 = 3.65W*/h, or 0.00435kW/h. Thus, the daily cost of consumption is $0.001496/day or $0.546/year for a single device, and $104.09 million/year for the US.

3. *Cloudy*
Under cloudy weather, the average charge time is 5.17 h/day, and the power consumed 2.9W/h. The daily cost of a single device is $0.547/year and $104.28 million/year for every device in the US.

4. *Overcast*
Under overcast weather, the average charge time is 7.14 h/day, and the power consumed 2.1W/h. The daily cost of a single device is once again $0.547/year and $104.28 million/year for every device in the US.

Table 3 indicates the relationship between the analysis data for the three conditions considered:

TABLE IIIII
SAVINGS FOR DIFFERENT WEATHER CONDITIONS

Weather Condition	**Single device savings/year**	**Collective device savings/year (million)**
Full Daylight	$0.546	$104.09
Light Cloud Interference	$0.546	$104.09
Cloudy	$0.547	$104.28
Overcast	$0.547	$104.28

On average, if every smartphone user in the US owned one of the proposed charging platforms proposed, and relied solely on it to charge their personal device, a collective total of over $104.21 million would be saved per year. The collective purchase cost required to supply every single user with a platform would amount to approximately $38 billion.

If a full return in investment were to be desired from this platform, every single smartphone user in the US would need to charge their device twice a day, everyday, for approximately 365 years.

Therefore, under current energy market standards and the parameters established, this solution is not currently viable.

However, a few factors could change its viability, be they different parameters or changes in power economics in the future. Some factors to consider include:

a) As the dependency on personal devices increases, users might turn to charging more times per day.

b) The cost estimate for the purchase of platforms assumes that every single user would own their own. However, should it be the case that a single platform satisfies multiple users (e.g. members of a household), the cost could be cut down considerably.

c) Moreover, the estimate assumes every user owns only one personal device. Users who own more than one personal device, such as a second smartphone (such as a company phone), tablets and other smaller-scale electronics would logically utilize the platform more times than initially estimated. This would, therefore, increase the amount of savings in power consumption. Under the bold assumption that every user owns an average of two devices and charges both twice a day, the amount saved would double.

d) In the event of an energy crisis, during which the consumption price for the conventional grid spikes, the amount saved by switching to the platform could drastically increase, further mitigating the purchase cost of the platform.

e) While the proposed platform may not be viable for the current power market in the US, it could find some niche usage in other territories. The investment in the distribution of platforms as a charitable action could provide developing nations with more alternatives to small-scale power generation solutions. In regions of the world where traditional power generation is scarce or expensive, an investment in RES powered platforms could result in a decrease in costs incurred by power consumption. This is argument is given further credibility due to the growing number of cellphone users in developing nations, in which landlines are often eschewed in favor of mobile devices.

V. Future Improvements

There are a few possible improvements to be made to the design and testing procedures. The pursuit of a more cost-effective design would be pivotal in reducing the market cost of the platform. The components utilized were the most efficient found on common electronics retailers. However, cheaper components could be designed specifically to meet the performance needs of the platform.

VI. Conclusions

This study grants a few key insights into replacing conventional power generation for RES, even in small-scale applications.

Despite the possibility for efficient, relatively costless (once active) power generation, the barriers of entry which must be overcome in order to activate an RES-powered platform (namely, the initial financial investment) make the design commercially inviable for present-day implementation.

However, the implementation of RES platforms must not be ruled out in the future, considering the finite nature of non-renewable power generation resources. Although not viable at present-time, it could be considered as an emergency alternative in the event of a crisis in power economics systems as they are known today.

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