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# Development of a solar system for charging mobile phones with customized DC chargers for rural areas in Nigeria

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## Abstract

The introduction of mobile phones has redefined the world of communication in that it has turned the world into a global village as people can now make contact through phone calls within and across countries at affordable rates. Nowadays, almost every home has a functional mobile phone, be it a conventional, android, or iPhone, among others. These phones use non-self-charging rechargeable batteries that need to be recharged from time to time to meet the demands of the users. However, access to a reliable source of power to meet the energy demand, including mobile phone charging needs, of off-grid rural dwellers remains a global challenge. As a result, this study designed and implemented a solar-powered mobile phone charging system with customized DC chargers for use in remote off-grid areas. The test results showed that the system is very effective for charging mobile phones.

*Keywords: Customized DC chargers, mobile phones, Remote off-grid areas, solar system.*

## 1. Introduction

The introduction of mobile phones has redefined the world of communication in that it has turned the world into a global village(Abbas et al., 2019)as people can now make contact through phone calls within and across countries at affordable rates. Modern mobile phones are designed to deliver smart and seamless performance with a high level of affordability, flexibility, and reliability. They are built with several mobile applications such as Wi-Fi, GPRS, HSCSD, high-definition cameras, sound and video players, and USB support systems, among others. As a result, billions of mobile phone users (be they smart or non-smartphones) exist across the world(Chaudhary & Vrat, 2018), (Panigrahi et al., 2020), (Saxena & Saxena, 2020) including remote rural dwellers.

Mobile phones are powered by rechargeable lithium-ion (Li-ion) batteries (Cui et al., 2018), (Ghiji et al., 2020)whose strengths are specified in ampere-hours (Ah). The rates at which the batteries get drained (rundown) depend on the usage as well as the applications on the phone. These batteries need frequent recharging in other to meet the demands of the users. Consequently, mobile phones are provided with alternating current (ac) based battery chargers. However, it is not every user of mobile phones that has access to a sustainable alternating current source for charging the phone. Most rural dwellers fall into the category of mobile phone users that lack access to sustainable electricity for frequent charging of their devices. Some mobile phone users depend on fossil fuel-based power generators for phone charging purposes and can go the extra mile to put on their generators at any time of the day just to recharge their mobile phone batteries thereby contributing to environmental pollution and incurring a very high cost-benefit ratio.

Furthermore, some mobile phone users in rural areas that are not privileged owners of generators may have to defer the time to charge their devices to align with the time when the privileged owners of generators are most likely to put on their generators while others visit charging booths operating on fossil fuel-based generators to pay for charging services. The charges paid per phone in such charging booths are determined by the prevailing prices as well as the availability of fossil fuels which have recently become very scarce in most developing countries. As a result, there is a need to develop alternative means for charging mobile phones. One such means is the use of solar energy which is naturally available almost everywhere with a low environmental burden(Annuk et al., 2020), (Simeon et al., 2018),(Bataev et al., 2020), (Abass & Pavlyuchenko, 2019) for phone charging purposes. Thus, this study seeks to develop a solar-powered mobile phone charging booth with customized chargers for rural dwellers in Nigeria

Literature has shown that several authors have carried out various degrees of work on solar-powered mobile phone charging booths/kiosks. For example, Louie et al(Louie et al., 2015) designed and implemented a solar power kiosk for charging mobile phones and other electronic devices in rural Zambia. Similarly, Palmiro, Rayudu, and Ford (Palmiro et al., 2015)modeled and simulated a solar-powered kiosk for charging Lithium-ion batteries. Also, the authors (Dauenhauer et al., 2019) assessed the impact of solar-powered kiosks in Zambia. Other works on solar charging kiosks are presented in (Shoarinejad & Shokri, 2016), (Munro & Christiansen, 2016), (Frame et al., 2019), (Udayalakshmi & Sheik, 2018), and (Shoewu & Salau, 2018).

Despite that, a lot of work has been carried out on solar-powered charging booths/kiosks, but the design of a charging boot with customized chargers has not been presented. Thus, in this study, an ingredient of novelty involving the re-design or configuration of waste or thrown- out ac powered mobile phone chargers whose circuit elements might have been destroyed or burnt out as dc-dc converters for tapping the solar power for charging mobile phones is presented. By so doing waste mobile phone chargers are recycled for wealth creation toward achieving the 2030 sustainable development goals of the United Nations.

## 5. Materials and methods

The materials used to implement the solar system for charging mobile phones with customized dc chargers include waste ac based mobile phone chargers, a solar panel, a solar battery, a Charge controller, charging outlets (13 A double sockets), connecting cables, and a wooden cabinet.

The method used in this work can be broken down into two parts. The first part deals with the design of solar-powered mobile phone charging systems while the second part deals with the sourcing and configuration of waste ac based mobile phone chargers to suit the need at hand.

### 2.1 The solar powered mobile phone charging system design

The block diagram of the proposed solar system for charging mobile phones is shown in Fig. 1.

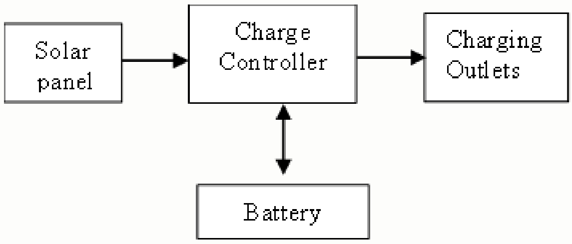


**Fig. 1.** Block diagram of the solar system for charging mobile phones.

Thorough and accurate sizing of the solar panel, the charge controller, and the battery is required for optimal performance and cost minimization while the choice of the charging outlets is influenced by the ease with which the customized charger can fit in. As a result, the detailed sizing of the solar panel, the charge controller, and the battery is carried out in this study

#### 2.1.1 Load specification

The first point of reference in any solar system design is the load the system is expected to power which in this study are mobile phones whose battery specifications are used to determine the load size.

Several varieties (or makes) of mobile phones with different battery specifications exist as reported in (Liang et al., 2019) and (Diouf et al., 2015). The authors (Liang et al., 2019) reported the highest existing mobile phone battery capacity to be 3.82V, 4200 mAH (for Huawei mate 20p). To ensure that the proposed system can charge any type of mobile phone, the battery specifications for the Huawei mate 20p were used to size the components of the solar system used in the design of the mobile phone charging system. The load data determined from the battery specification is shown in Table 1.

**Table 1.** Load data for the solar mobile phone charging system

| Type of Load | Voltage (V) | Ampere-hour (Ah) | Watt-hour (W-h) | Quantity, Q (units) | Total W-h |
|---|---|---|---|---|---|
| Mobile Phone | 3.82 | 4.2 | 16.044 | 48 | 770.0112 |

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### 2.1.2 Sizing of the solar battery storage

The solar battery storage for the system was sized using equation (1) (Orovwode et al., 2022).

$$B_S = \frac{T_{Wh} \times N}{B_V \times DoD \times \epsilon_{cable}} \quad (1)$$

Where;
$B_S$ =Minimum battery capacity (Ah)
$T_{Wh}$ =Maximumwatt-hour required/day
N = Number of days of autonomy
$B_V$ = DC voltage of the battery (V)
DoD = Depth of discharge allowed for the battery

Using a 12 $V_{DC}$ battery storage system used with the other parameters in equation (1) defined as follows:
$T_{Wh} = 770.0112$ Wh (from table 1)
N = 1 day, the choice of which is influenced by 0% diversity
$\epsilon_{cable}$= Efficiency of the connecting cables linking the battery and the loads = 98%

$$B_S = \frac{770.0112 \times 1}{12 \times 0.7 \times 0.98} = 93.54 \text{ Ah}$$

Therefore 100 Ah which is the nearest available size of battery was used in this design.

### 2.1.3 Sizing of the solar PV panel

The solar mobile phone charging system designed in this study is intended for use at Abule-Ticha which is a remote rural area in Ado Ota Local Government Area of Ogun State. Since the Local Government shares a boundary with Lagos State, the NASA data on the solar insolation for Lagos, Nigeria was used to determine the size of the required PV panel.

The size of the required PV panel was determined using equation (2) (Orovwode et al., 2018):

$$S_{PV} = \frac{T_{Wh}}{N_{ph} * \epsilon_{sys}} \quad (2)$$

Where;
$S_{PV}$ = Total wattage of the required panels (Watts)
$T_{Wh}$ = MaximumWatt-hour required per day
$N_{ph}$ = peak hours per day = $5.43 kW/m^2/day$ (NASA Data for Lagos)
$\epsilon_{sys}$ = Total system efficiency

But, $T_{Wh} = 770.0112 Wh$ with zero tolerance due to the adoption of 0% diversity

$$\epsilon_{sys} = \epsilon_{PV} \times \epsilon_{cable1} \times \epsilon_{cc} \times \epsilon_{Batt} \times \epsilon_{c2} \quad (3)$$

Where;

$\epsilon_{PV} = PV\ modules Efficiency = 80\%$
$\epsilon_{cable1} = Efficiency\ of\ the\ connecting\ cables\ linking\ the\ solar\ panel\ array\ and\ the\ battery = 95\%$
$\epsilon_{cc}$ = efficiency of charge controller = 90%
$\epsilon_{Batt} = Battery\ efficiency = 90\%$
$\epsilon_{cable}$= Efficiency of the connecting cables linking the battery and the loads = 0.95

$$\therefore \epsilon_{sys} = 0.8 \times 0.95 \times 0.9 \times 0.90 \times 0.95 = 0.58$$

$$\therefore S_{PV} = \frac{770.0112}{5.43 \times 0.58} = 244.49 \text{ W}$$

To make the system more efficient, a 280 W mono-crystalline panel was used.

### 2.1.4 Sizing of charge controller

The charge controller employed in the design is the Pulse Width Modulated (PWM) type whose size is given by equation (4) (Benjamin & Dickson, 2017)

$$CCS = I_{sp} \times S_f \quad (4)$$

Where;
CCS = size of the charge controller,
$I_{sp}$ =specified short circuit current of the panel,
$S_f$ = safety factor = 1.25

Now, from the nameplate of the 280 W panel (shown in Fig. 2) used, $I_{sp}$ = 10.38 A

Putting the values of $I_{sp}$ into equation (4) will give;

$$CCS = 10.38 \times 1.25 = 13.03 \text{ A}$$

The nearest available charge controller size (20 A) was used in this design.

| SUNPOWER SOLAR MODULE<br>280 mono solar panel | |
|---|---|
| Maximum Power/Pmax(W) | 250 |
| Maximum Power tolerance (%) | X3% |
| Open Circuit Voltage/ Voc(V) | 36.85 |
| Short-Circuit Current / StC(A) | 10.38 |
| Max Power Voltage/ Vmp(V) | 31.5 |
| Max Power Current/Imp(A) | 8.88 |
| Power Spectiations at STC: 1000W/m², AM1.5, Cell 25 C | |
| Weight (kg) | 19.3 |
| Dimensions(mm) | 1640*952*35 |
| Max System Voltage (V) | 1000 |
| Max Over current Protecting rating(A) | 1.5 |
| efficiency | 16.65 |
| Module Application Circuit | A |

**Fig. 2.** Name plate of the 280 W panel used

### 2.2 Sourcing and reconfiguration of AC-based waste chargers

The solar charging system designed in this study is purely a direct current (DC) system requiring no inverter for energy conversion. By so doing, the system cost is minimized. However, the fact that mobile phones are provided with AC-based battery chargers

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becomes a serious bottleneck to overcome. To overcome the bottleneck, this study sourced and reconfigured waste/burnt-out AC-based chargers to form the desired DC chargers which are code-named 'customized DC chargers'.

The waste/burnt-out AC-based mobile phone chargers were sourced from several households at the Indomie Estate, Atan, a community in the Ado-Odo Local Government Area of Ogun State, Nigeria. From the waste chargers gathered, only the three-pin plugs were configured for use to avoid polarity interchange. The internal circuitries of the three-pin plugs waste chargers were reconfigured using the circuit diagram of Fig. 3. The choice of the LM7805 voltage regulator was motivated by the fact that a regulated voltage of 5 V is required to charge a mobile phone (Ramli et al., 2019), (Hanif et al., 2020), (Maulidyna et al., 2021).

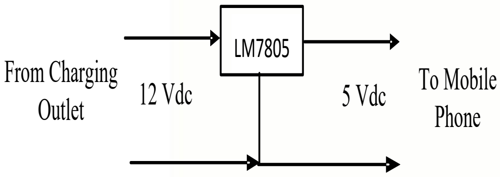


**Fig. 3.** The circuit diagram of the customized DC mobile phone charger

# 3 Implementation and testing

## 3.1 Implementation of the solar mobile phone charging system

The implementation of the solar charging system involved two stages including the implementation of the kiosk and that of the customized chargers

### 3.1.1 Implementation of the solar charging kiosk

The solar charging kiosk was implemented in a wooden enclosure shown in Fig. 4. The upper compartments (one on each side) of the enclosure were used for mounting the charging outlets (13 A double sockets) as shown in Fig. 5 while the lower compartment housed the battery and the charge controller as shown in Fig. 6. The solar panel was mounted on top of the enclosure with tilt-adjustable hangers for maximum solar energy harvesting. Provisions were also made for two wheels at the base of the kiosk for ease of mobility.

**Fig. 4.** The solar charging kiosk with all the doors closed

**Fig. 5.** The kiosk showing the arrangement of the charging Outlets

**Fig. 6.** The base compartment of the kiosk showing the battery and charge controller arrangement

### 3.1.2 Implementation of the customized DC chargers

The Customized DC chargers were implemented by opening the links between the charging ports of the waste charges and the input terminals (the plugs) and replacing them with the configuration shown in Fig. 3. The front and the back view of the internal circuitries of a sample of the implemented charger are shown in Fig. 7 and Fig. 8 respectively while the finished charger is shown in Fig. 9.

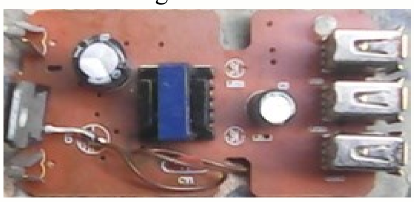

**Fig. 7.** The Front view of the internal circuitry of the customized DC charger

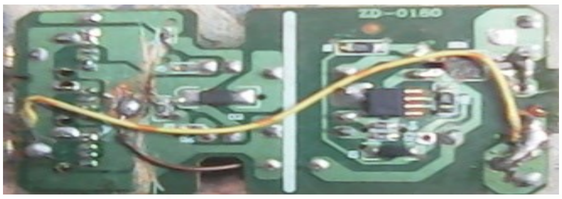


**Fig. 8.** The back view of the internal circuitry of the customized DC charger

**Fig. 9.** The customized DC charger

## 3.2 Testing

The Kiosk was tested to verify its usability for charging mobile phones. A sample of the photograph taken during the testing is shown in Fig. 10.

**Fig. 10.** Sample system testing photograph

The system was tested on six different types of Android mobile phones. The mobile phones with the batteries drained to various degrees were plugged into the system for charging and monitored for three hours. The result of the test is tabulated as shown in Table 2.

**Table 2.** Mobile phone charging test results

| Battery Type | Initial Charge (%) | Time Used (hr) | Final Charge (%) |
|---|---|---|---|
| Umidigi A3S | 10% | 3 | 100 |
| Itel A33 | 0% | 3 | 100 |
| Samsung Galaxy A03 | 20% | 3 | 100 |
| Infinix Hot 5 | 13% | 3 | 100 |
| Tecno Spark 8P | 10% | 3 | 100 |
| Tecno POP 5 Pro | 30% | 3 | 100 |

## 4. Conclusion

In this study, the availability of electrical power for charging mobile phones was identified as one of the challenges faced by most rural dwellers. The increasing cost of fossil fuel and the associated dangers of carbon emission as well as the quest for conversion of waste to wealth for poverty alleviation motivated the authors to design and implement a mobile solar-powered mobile phone charging system with customized chargers. The system was designed with the capacity to charge up to 48 mobile phones at a time. The charging test conducted on the system validated the effectiveness of the system for charging mobile phones. Further works shall consider the techno-economic analysis of the system

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