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ORIGINAL RESEARCH ARTICLE

Development of Cost Efficient Solar Powered System for Rural Areas.

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ABSTRACT
We proposed a cost efficient, environmentally friendly commercial solar powered phone charging station for application in rural areas. Sun energy is tapped using photovoltaic solar panel (PV), the system converts the tapped energy into electricity, charge controller regulates the generated energy, part of the generated electricity is used during the day and part stored in a battery to be used at period where there is less shun shine or absent. Cost analysis of the developed system suggested its almost free and noiseless when compared with the conventional generator powered system.

INTRODUCTION

Mobile phones have become the most dominant portal of communication and information technology. As a results of its wide range of application mobile phones has become indispensable part of our life to the extent that people in both rural and urban area cannot do without it. Access to mobile connectivity has significantly increased over the years. In 2022, it was estimated that 92% and 88% of the Nigeria's adult male and female population have access to mobile phone respectively (Femitayo 2022). Despite the necessity of using phone and progress in mobile connectivity, a substantial number of individuals in Nigeria are facing difficulty in charging their phones especially village dwellers due to inadequate or complete absence of electricity.

Nigeria is counted within the countries with lowest access to electricity world over, with about 46% of her population lacking access to power (Tunde, 2022). This presents a distinctive challenge to charge mobile phones in both rural and urban areas which lead to frequent shutdown of the phones at every time and everywhere. To solve this problem, small scale investors have invested in small generators which they use to charge the phones in markets.

Generators uses conventional fossil fuel to generate electricity, as such, generator is never a fruitful option at all. Burning of fossils fuels has unpredictable but potentially catastrophic consequences. When such fuels are burnt, they normally emits toxic gases that are harmful to the environment and affect animal health (Omer, 2008). Incomplete combustion of fossil fuels produces carbon monoxide this has severe consequences on human and animal health. Complete burning of fossil fuels also releases carbon dioxide which is part of greenhouse gases (others are Nitrous oxide (N2O), Methane (CH4), Sulfur IV oxide) to atmosphere responsible for global warming. Further, it also causes the deflation of ozone, water pollution, greenhouse effect, radiation and possible radioactivity which cause skin cancer, hazardous air pollutants, acid rain e.t.c (Abam, *et al.,* 2014). Generators are also noisy which is injurious to hearing and also very expensive to operate due to the hike in price of petrol in the country. There is the need to find an efficient environmental friendly alternative way to generate electricity for charging phones other than the use of conventional electric generators which uses fossil fuel-based energy sources which are responsible for the above mentioned negative effect in our environment (Adewuyi, et al., 2020). Renewable energy may likely be the sole panacea to this up growing crisis.

Nigeria is blessed with a vast deposit of renewable energy potentials, including biomass, solar, wind, hydroelectricity (both small and large), etc. However, the most ubiquitous and available source of renewable energy are solar and wind. Nigeria has moderate wind regimes, with wind speeds in the south of the country ranging from 2.12 to 4.13 m/s, with the exception of coastal regions and offshore, and the north having rates ranging from 4.0 to 8.60 m/s. In the north and northeast of the country, the total actual exploitable wind energy reserves range from 8 to 97 Mwh/year (Lamin, et al., 2012, Adaramola 2012). This is practically nothing hen compared with the abundance of solar energy in the country.

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The use of solar energy has been prioritized as the most effective renewable energy source. It is described as nonpolluting primary source of energy, it needs low maintenance and very simple to operate. Thereby, it has no environmental impact which is almost zero (Ajayi, 2013). Due to its geographic location, Nigeria has an abundant source of solar energy as opposed to wind and other energy sources. It has an average irradiance of about 1,831.06 kWh with a total land area of 923,768 km^2 (Ilenikhena, 2010). It is estimated that an annual energy solar energy of $15x10^{10}$ kJ can be harnessed with 5% device efficiency. This amount to about 258.62 million barrels of oil or 4.2 x 10^5 GWh of electricity (Ilenikhena, 2010). The nation experiences 6.25 hours of sunlight on average per year, ranging from 3.5 hours in the coast to 9.0 hours in the north. Similar to this, the average daily solar radiation is 5.25kWh/m^2/day, with coastal zones receiving 3.5kWh/m^2/day and northern regions receiving 7.0kWh/m^2/day (Ohunakin, 2010). It is evident from this, that there is an enormous amount of energy that can be tapped from the sun that small sized solar panel with maximum power of 25w can charge 10 mobile phones simultaneously (Ajayi, 2020).

This paper explores the possibility of using solar as an alternative way of charging mobile phones in rural areas.

METHODOLOGY

Load Analysis

The load analysis of the system was done using the average power rating of cell phone. Mobile phones on average are rated 5W (5V/1A). Table 1 shows the average power rating of a cell phone, the number of phones we expect to charge per day, their power consumption and hours of operation of the system. The system is expected to be able to charge thirty (30) mobile phones for twelve hours for each day.

Table 1. The load assessment.

Loads	Rating (V/Amp)	Quantity	Watts	Hrs/day	Wh/ day
phones	5V/ 1A	30	150W	12	1800
lamp	5W	1	5W	12	60
total			155W		1860

The absolute power required to power one lamp and 30 mobile phones in a day is 1860Wh/day.

PV Panel Sizing

We used

$$Wpv = \frac{E}{PSH \times Tl \times Bl \times Wl}$$

to size the panel capacity required for the system

Where:
Wpv = Peak watt of array
PSH = Peak sunshine hours
E = Daily energy required (Wh)
Tl = Temperature looses (90%)
Bl = Battery Looses (85%)
Wl = Wiring looses (97%)

The lowest monthly average solar radiation was used in designing the system. In Katsina state, the average monthly sunlight hours vary from 7.09 hours in August (the height of the rainy season) to 8.75 hours in October (Kweku, 2018).

$$Wpv = \frac{1860}{7.09 \times 0.9 \times 0.85 \times 0.97} = 361W$$

≈ 400W

The size of the required solar panel is 400W.

The nominal voltage of the system proposed in this paper is 12v and the maximum current of the solar panel can be obtained by the relation.

$$Imax = \frac{power}{voltal} = \frac{400w}{12v} = 33.3A$$

The typical solar panel in this project is 200W. So that 2 solar panels are to be used in order to meet the requirement of the designed system.

Battery Sizing

$$Qn = In \times Tn$$

Was used in determining the capacity of the battery required. Where In and Tn are constants called discharge current (Amp) and discharge time (h) respectively. The battery needs to store energy enough to be used in the absence of sunshine without going over the DoDmax. The following equation can be used.

$$Q = \frac{E \times A}{V \times D \times \eta ca \times \eta inv}$$

Where:
Q = Minimum battery capacity required in Ampere-hour
E = Daily energy requirement in Watt-hour
A = Number of days of storage required
V = System DC voltage, V
D = Allowable depth of discharge
ηi=Inverter efficiency (if there is no inverter)
ηcab = Efficiency of the cable delivering the power from loads

$$Q = \frac{1860 \times 2}{12 \times 0.8 \times 0.85} = 227.94 \text{ Ah} \approx 250\text{Ah}$$

The capacity of the require battery is 250Ah/ 12V

Charge Controller Sizing

Charge controllers are used to overcome short-circuit current and regulate the maximum battery to the load current. We used:

$I = \frac{totalpower}{voltage} = \frac{400w}{12v} = 33.33A$
to calculate the circuit Load current .
However, for the purpose of short circuit current, we need additional 25% of the maximum current, that the charge controller must have 40A/ 12V

Cable Sizing

Selecting the right size of wire and type improves the efficiency of a PV system. As such, cable sizing is an important step in designing the system. In our system, copper wire was used whose cross sectional was determined using

$A = \frac{p \times l \times I \times 2}{vd}$

Where:

p = is resistivity of the wire, its constant for a particular materials, for copper p = 1.724 $\times 10^{-8}\Omega$m
L = length of the wire, measured in meter
A = is cross sectional area of the wire
I =current read by charge controller, Amps
Vd = voltage drop, volt

The voltage drop in any system, is not expected exceed 4%, we therefore design our system with such in mind.

i. Cable size between solar panel and charge controller

Voltage drop (4% minimum)

$Vd = \frac{4}{100} \times 12V = 0.96V$

$A = \frac{p \times l \times I \times 2}{Vd}$

p = 1.724 $\times 10^{-8}\Omega$m

let length of the cable be 2m

Imax = 40 amps

$A = \frac{1.724 \times 10^{-8}\Omega m \times 2 \times 33.3 \times 2}{0.96} = 2.9 \times 10^{-6} = 2.9mm^2$

For an efficient system, we need wire of cross sectional area 2.9 mm2, 33.33 amps and resistivity 1.724 $\times 10^{-8}\Omega$m between solar panel and charge controller.

ii. Cable size between charge controller and battery

$A = \frac{p \times l \times I \times 2}{vd}$

P = 1.724 $\times 10^{-8}\Omega$m
L = 3m
I = 33.3Amp
Vd = 0.96
$A = \frac{1.724 \times 10^{-8}\Omega m \times 3 \times 33.3 \times 2}{0.96} = 4.3mm^2$

We therefore need a wire of cross sectional are 4.3mm2, 33.33 amps and resistivity 1.724 $\times 10^{-8}\Omega$m for connecting charge controller and the battery.

MATERIALS AND METHODS

The heat and light from the sun are an energy source that may be used in many different ways.

Several different solar technologies, such as solar photovoltaic (PV) systems, solar heating, and solar cooling, have been created. The interest of this paper is to propose PV based technology commercial solar phone charging point. To design such a system, there is need for the assessment of solar radiation in the area of interest. The sun acts as emitter of solar radiation, with average of 1000W/m2 at standard test condition. It is believed that apart of this solar radiation is been removed by scattering and absorption by particles in the earth. Beam radiation is the radiation that hits the surface undiluted and directly. Diffuse radiation is the radiation that dispersed before it reached the earth (Tiwari,, 2015).

The average daily shortwave solar energy in Katsina ranges from 5.5 Kwh in January, which is maximum to 4.1 Kwh which is the minimum in September each year (Nimet, 2022).

Solar cells will be used to converts the solar energy into electricity. Solar cells are made from semiconductor materials. In order to turn solar energy into electricity, the solar cells utilized the photovoltaic effect. Whenever solar energy is incident on the solar cell, electrons are excited fro the valence band into the conduction band. This creates electron-hole pair (britannica). These charge carriers are responsible for generating electricity in the photovoltaic solar cell. Generally speaking, there are different type of solar cell, the solar cells can be categorize into polycrystalline, mono-crystalline or amorphous solar cells.

The flow of electric charges is regulated by the charge controller. This is done to prevent the battery from damage. Battery needs to be protected from overcharging and over-discharge. Overcharging causes corrosion of the battery plate, gassing and loosing of water. Overcharge causes the battery a permanent damage and reduce its life span. In selecting the charge controller , the power rating of the battery and the solar cells are to be considered. In this paper, MPPT charge controller is considered most suitable.

Energy storage is provided by the battery, this enable the use of the system even when there is no sunlight or during the nights. The two main readily available battery are Lead acid and Nickel-Cadmium (Ni-cad) cells. When choosing battery, Depth of the discharge (%) of the battery are considered, this is normally indicated on the battery. Cell life and whether battery cell are sealed or unsealed. In this work, Lead acid battery with 80% depth of discharge is chosen.

We intend to use DC chargers to charge the phones directly in order to minimize cost. The DC voltage can be stepped down using an integrated Circuit like IC 7805 if there is the need. The other component for the system are transistors that amplify the current, LED for visual indication of the activity of the charger, input and output capacitors for filtering the ripples and reducing the AC noise.

RESULT AND DISCUSSION

Based on the analysis carried out in this paper, the public phone charging center in which 30 mobile phones are charged simultaneously can be powered by the following materials which were obtained based on the result of their evaluation.

Table 2 Required devices

S/N	ITEMS	Rating (V)	Quantity
1	Solar Panel	12V 400W	2 of 200W
2	Charge Controller	12V, 40A	1
3	Battery	12V, 200Ah	2 of 200Ah battery
4	Copper wire	$3mm^2$	2m
5	Copper wire	$4mm^2$	3m

We used commercial phone charging centers in Dandume Local Government to evaluate the efficacy of our proposed system. Table 2 presents required devices for our proposed system, table 3, the cost of establishing and maintaining a conventional phone charging center, table 4 , the cost of our proposed solar charging system. On average, commercial charging centers use small sized 1.5KvA generator for charging the average of 30 phones simultaneously in which 4 set of 30 phones can be fully charged in a day with ₦100/phone generating over ₦12,000/day and ₦360,000 per month.

Table 3 conventional system and cost.

S/N	Items	Duration	Cost	Annual cost
1	1.5kvA generator	6 months	₦52,000	₦104,000
2	Petrol and Diesel	Daily	₦6,960	₦2,539,950
3	Lubrication	Weekly	₦1,700	₦81,600
4	Service	Monthly	₦2,500	₦30,000
5	Transport	Weekly	₦4,000	₦192,000
6	Chargers			₦45,000
7		Total=2,992,550		

The average daily expenditure without considering cost of chargers since they dont require frequent replacement is ₦8,075 which accounts 67% of the daily income.

Table 4 cost of our proposed system

S/N	Items	Rating	Type	Price
1	Solar panel	400W 12V	Monocrystalline	₦120,000
2	Battery	200Ah 12V	Lead-acid Battery	₦500,000
3	Charge controller	12V 40A	MPPT	₦20,000
5	Wiring cables	$3mm^2$ & $4mm^2$	Copper wire	₦12,000
6	DC charger	12Vin -5Vout		₦20,000
7			Total = ₦672,000	

The economic viability as well as technical analysis of a stand-alone solar PV system in comparison with petrol generator has been analyzed for the energy demand in public charging center. With the analysis, it is now clear that using solar panel is much more economical than using generator as four month expenditure on fossil fuels is enough to pay the initial cost of the PV system installation with no further operational cost. Solar panel, when compared to 1.5KvA petrol generator, is costly but for the initial expenses. However, it will later be seen to be cheap or free after few months since the system needs no petrol for its operation, it uses sunlight which is free. However, on average, 4 sets of 30 phones can be charged which can generate about the sum of ₦180,000 per month. This monthly income is enough to pay the cost of the entire solar system components in less than three months and saves a huge amount of money. After these three months, the system will be free because when the complete payment is done, it is done once and for all. And everything you get after payment is profit. The use of generators to power the charging centares, a part from been noisy, has severe consequences on the environment, one of such is global warming. In recent years, the increased in greenhouse gases has been linked to a number of unfortunate weather events, like flooding, storms, cyclones, severe heat and drought (britannica).

CONCLUSION

In this paper, the load assessment is carried out and the daily power consumption of public phone charging center is determined. A solar photovoltaic system for powering a public phone charging center capable of accommodating thirty phones simultaneously was . The system includes 12V, 400W monocrystalline solar panels, two 12V 200Ah lead-acid battery, 12V/40A MPPT charge controller, USB voltage regulator (DC Charger). The size of each component of the PV system is obtained using accurate mathematical calculation to meet up the power requirement. The DC charger accept 12V coming from the source to 5V as output voltage which is the required cell phone battery voltage.

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