Development of an Electric Vehicle Charging Hub with Solar Energy System: An Alternative Energy Service Station for Rural Commuters

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Abstract- The world is transitioning to the adoption of electric vehicle (EV) over internal combustion engine (ICE) in the past decade, most EV chargng stations are powered from grid systems. The generation of power for the grid system relies mainly on coal and natural gas to produce electricity.Burning these fossil fuels release greenhouse gases which trap heat and warm the earth. The aforementioned Ev charge stations are predominant in urban centres(cities), which makes it a problem for commuters to recharge their vehicles while on transit via rural routes. This paper proposes the development of an electric vehicle charging hub for Electric Vehicles using renewable source(solar) for rural vehicles on transit. The system as designed provides storage for the continuous energization of EVs from the converted energy for rural dwellers and commuters utilization from the abundant sun. This reduces the emissions associated with traditional fossil fuel vehicles and promotes the use of clean and renewable energy sources for electric vehicle application. The system model was designed using proteus circuit design software and implemented using the Arduino Microcontroller, Dc-Dc buck converter, transformers, solar battery and solar panel. The result from the demonstrated prototype reveals that the PWM pulse has an AC voltage output of 228V with the charging variable voltage output within the 190-230V and a current output of less than an Amp. Further research effort would be geared towards upgrading the prototype to an industrial model.

Keywords: Charging Stations, Electric Vehicle, Solar Energy, Storage Device, Rural Commuters

1. Introduction

The mode and advancement in vehicle technology are evolving to sustaining human activities as well as the environment. One of such advancement is the introduction of electric vehicles (EV). The adoption of electric vehicles on a large scale is considered to be a crucial step in lowering greenhouse gas emissions and developing a sustainable energy system because transportation is a substantial source of emissions [1]. Electric vehicle (EV) use is increasing rapidly due to global warming and have proven it advantage over the combustion engine vehicles with high motor torque efficiency of 80%. In 2030, it is estimated that the production of combustion type of vehicles will be limited, if not banned and government in developed countries are pushing forward to implement transportation electrification laws. From research, EVs would secure 6-14% average share of road transport global fleet by 2040, this means that there would be larger EV manufacturing industries and more charging stations. The number of electric vehicles (EVs) on the road may increase swiftly, with plug-in electric vehicle (PEV) sales reaching 2.1 million globally in 2019 and by 2030, there would be 245 million automobiles growing by 36% yearly [2]. Due to their

lack of exhaust emissions and ability to run on renewable energy sources, electric vehicles (EVs) are viewed as a cleaner and more environmentally friendly alternative to gasoline powered vehicles. However, a number of issues, notably the scarcity of adequate and practical charging choices, prevent the mainstream adoption of EVs. The lack of charging stations can cause anxiety and uncertainty for EV owners, which may make it hesitant to purchase EVs or use it for long journies. To support this rise in EV use, robust and accessible charging infrastructure is needed. However, there is a need for the preparation of infrastructures to support the implementation of electric vehicles. The earth is made sustainable as electric vehicles plays a major role in achieving that by utilizing clean and natural friendly power source to harness easy charging station [3]. Solar energy are readily available since they are green and renewable, this power source requires little area to introduce, minimizes the use of fossil fuel which causes environmental pollution. Developing EV charging centres powered by renewable energy source is a significant step toward creating a more environmentally friendly transportation system. These charging hubs not only offer a useful method for charging EVs but also boost the use of clean and renewable energy sources, while also generating employment possibilities and assisting with the expansion of renewable energy. To build a complete and equitable pricing infrastructure, it's crucial to take everything into account. It is crucial to establish rules and regulations that encourage the development and implementation of this technology in order to achieve universal acceptance of renewable EV charging points. This may take the form of financial supports for the construction of charging hubs or rules requiring a certain proportion of new charging stations to be renewable source. Hence, the development of the proposed electric vehicle charging hub using a renewable energy source as it would help get closer to a sustainable and pollution-free transportation system by making better use of the solar energy now available to support charging hubs.

The problem associated with charging stations is the use of the grid system in that the grid system are usually overloaded. It is used to power homes, business centres, organizations etc. EV charging stations consist of grid conversion of power topology. [4]. Aggressive installation of these charging stations mounts a significant problem on the stability, function and control of grid system when hundreds of it are connected at a point continuously.This could lead to less power supply to the charging stations. Furthermore, the problems is that most of the electricity used by the grid system were mainly produced using coal and natural gas as such, burning these fuels releases greenhouse gases, which trap heat and warm the earth. This contributes to the depletion of the ozone layer and cause unhealthy climate changes. For this reason, the development of an electric vehicle charging hub using solar energy was proposed. This system makes use of a clean and renewable source of energy generated from the sun. Also it helps charging stations cut away from the grid system and mount the solar panels specifically for powering and charging electric vehicles. Furthermore, it is used by EV users at their homes to charge their vehicles at their own time, without having to join a queue at the public charging stations.

This research seeks to develop an electric vehicle charging hub for electric vehicles with a solar energy input for rural commuters as it designs a charging hub for electric vehicle and fabricate a low-cost system. It helps in solving the dependence of power grid in electric vehicles in a creative and eco-friendly way and gives room for intending users of EV to consider the installation of this system in their homes without the need to queue at a station to energize their vehicles. It contributes to encouraging the use of clean and renewable energy sources and reducing reliance on grid electricity and fossil fuels, which is consistent with the objective of developing a sustainable transportation system.

The proposed model seeks to address the issues of long distance travels through rural areas by reducing the road users fear on how to get their vehicle recharged on the account of shortage of charge in their vehicles. This addresses user anxiety and improve the confidence to travel through rural areas to other destinations. It encourage the purchase of more Electric vehicles as it could prove to be more reliable and reduce the use of grid systems and energy generated from hazardous sources.

2. Literature Review

Conventional working principle of charging hub is an alternating current (AC) provided from the electricity grid, but all EVs require direct current (DC). This is solved by introducing a bridge rectifier between the grid and battery as a converter.This conversion from AC to DC is done by the EV on-board rectifier for its usage.

Electric vehicle charging station have three levels of charging system, which are the level 1, level 2 and the level 3 charging.In level 1 charging, voltage of 120V is considered as the slowest level of charging. It is connected to an on-board charger with the help of a plug, and are commonly used at home. For the level 2 charging, it is an upgrade of level 1 having a Voltage between 208 - 240V AC and 30A current. These are mostly found in public places and have a mile range of 10 to 25 mile per hour. Whereas, level 3 charging, refers to as DC fast or rapid charging, it takes power from the grid and converts it to DC voltage within the charging station to charge the EV battery directly. They have a charging percentage of 80% and are effective [5].

There are typically three methods of charging: inductive charging, battery swapping and, conductive charging. In inductive charging wireless charging technique are deployed which makes use of different magnetic fields. For battery swapping, users can swap their empty battery for one that has been completely charged at a battery swapping station under the battery switching plan. Whereas conductive charging, involves making direct electrical contact between the power source and the vehicle through the charger.[6]

Figure 1. Typical EV Charging Station[7]

Several literature works have been put together regarding charging system for EVs. In [8] design was proposed and prototyping of low-cost charging station to make EV charge stations available using a keypad to input how much power would be purchased and LCD to monitor the charge status going into an EV with the help of a micro-controller. The prototype was built and tested to charge a Plug-in Hybrid Electric Vehicle (PHEV) car both in normal charging and fast charging with satisfactory results. [9] proposed a circuit design of single phase bi-directional on-board charger (OBC) using starter generator and its drive inverter in hybrid electric vehicles (HEVs), using MPCC method for an integrated charging system. The circuit was implemented not only for conventional starter-generator driving but also battery charging operation by controlling the power relay states. [10] designed and developed a light electric vehicle (EV) charger using alternating current (AC) to direct current (DC) converter power switch, which operates in quasi-resonant mode for high efficiency in wide input voltage range. The input voltage for this power converter was for universal input voltages (90VAC -265VAC/47Hz-63Hz).

[11] proposed a design and power management of electric vehicle charging station integrating a renewable energy source and a large Storage tank system for maximum current. With MPPT, PID and current control for optimal power management between solar, BESS, grid with the EVs in the charging station. The result for the charging station was formulated and validated using MATLAB/Simulink.[3] proposed a solar fast tag charger for electrical vehicle, utilizing clean and natural friendly power sources to harness easy DC charging station with RFID reader and micro-controller for display output. [12] proposed a topology with managing system using photovoltaic cells to reduce continuous conversions of DC - DC converters. The proposed design focus on energy flow managing system unit between PV, storage tank and inverter for standalone charging station, accommodating 2-5 EVs at the same time with adequate efficiency, reducing cost and less system complication. Although [4] gave analysis on the impact and continuous use of electric vehicles on power grid system. Expectation of 11 to 28% global share of road transport fleet by 2040 is possible. The increase peak loads are a serious challenge for the stability on grid system. [13] proposed a concept of DC level 1 high current charging power for electric vehicle, using unidirectional dual bridge (IUDB) DC/DC converter to supply power absorbed from solar PV, the storage battery and AC grid to the EV.[14] discussed the different methods and types of EV charging. He stated that the conductive charging is best used because it easier and of less cost. Also, there is a possibility of greater use of inductive method of EV charging in the future. This paper has a value academically because it presents different point of view comparison to help manufacturers in interpreting the modes, types, and levels of charging EV.Using a mathematical model that replicates the charging process of EVs, [15] suggests a charging strategy for electric vehicles (EVs) using solar energy. The study's strength is that it offers a workable and efficient method for charging EVs with renewable energy sources like solar power. The study's shortcomings were based on a particular location and set of weather circumstances, and that it does not take into account other aspects like the overall energy consumption of EVs or the effect of charging on the power system.An electric vehicle (EV) charging station combines solar photovoltaic (PV), battery storage, and diesel generator power sources was designed and put into operation. In order to provide a dependable supply of power for EV charging,[16] suggest a system that uses solar PV and battery storage as the main power sources and a diesel engine as a backup. The performance was put to the test, and evaluated in terms of power management and charging efficiency. To maximize fuel economy, power from DG was programmed to constantly run at optimum operation of 80–85%.In the research [17], a model of a quick electric vehicle charging station was connected to the grid and provides quality power transmission with low harmonic currents was presented. The charging station was made out of a converter that connects the grid to a DC bus where electric vehicles are connected using battery chargers. The procedure for managing individual car charging was decentralized. A separate control offers to handle the transfer of power from the AC grid to the DC bus. Solar PV generation system integrated with a charging station was also added as part of an energy management approach based on optimal power flow to lessen the effect of fast charging on the grid.The integrated technology lowers the net energy supplied by the grid, hence reducing the load on the grid and minimizing conversion losses. It also increases the power output of the EV fleet batteries available at the charging station. A design of DC/DC bi-directional converter was carried out by [18] integrated level 2 electric vehicle charging, also known as vehicle to grid (V2G) applications, which transmit electricity from batteries to the grid. The DC-DC converter was constructed by combining buck and boost converters, and as a result, it works in both buck and boost modes (charging and discharging). The proposed circuit offers incredibly high-power density and quick control. The use of energy storage system in EV charging stations was examined by [19] in this literature review, along with the possibilities for load balancing, lowering peak demand on the electric grid, and incorporating renewable energy sources into EV charging stations. Further analysis reveals that the costs, difficulties, and technical requirements of incorporating battery storage tanks into EV charging stations were issues that requires urgent research attention. Focusing on the advantages and cost-benefit analysis of battery storage tanks for EV charging stations were strengths of some of the assessed literature.

The paper reviewed encampsulates previous works done by researchers on charging stations for electric vehicles using solar panels on general terms without looking into how the use of solar energy could be essential in rural areas to enable long distance journies for EV users. This paper proposes the development of an electric vehicle charging hub using solar energy system for rural commuters. The system mounted at strategic rural areas where charging stations aren’t found so that an EV user on transit can take a stop and refill their vehicle.

3. Methodology

a. *System Design*

The design of the electric vehicle charging hub using photovoltaic cells consist of some parts- hardware and software which includes: sensor, microcontroller Arduino Uno, solar panel, Charge tank, Transformer, SG3524, LEDs, Capacitors, Resistors, Drivers, current sensor, fuse, Adapter, Alphanumerical keypad, Arduino IDE and Proteus design suite etc.

Figure 2. shows block diagram of the Electric Vehicle charging hub using solar panel. Considerations made during this design include:

i. Solar power as the source of energy generation for the charging stations. (18V 0.7A)
ii. The Electric vehicle battery having ratings of 6V 4.5Ah
iii. Charging station hub designed to charge one EV battery at time as a demo.
iv. The solar converter with efficiency greater than 92% was deployed.

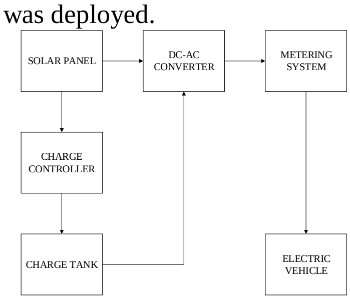

Figure. 2. Block Diagram of electric charging hub

b. *Solar panel selection*

$$Maximum\ power\ required\ for\ the\ EV = 6 \times 4.5 = 27Wh$$

$$Total\ input\ power\ required = \frac{27Wh}{0.92} = 29.35Wh$$

$$\text{Average global horizontal irradiance} = 5.86\text{kWh/m}^2\text{/day}$$

[20]

$$Power\ requirement\ of\ the\ system = \frac{0.02935kWh}{5.86} = 5W$$

c. *Charge Controller*

The charge controller keeps the tank from being overcharged, which could harm it or reduce its lifespan. The charge controller with voltage regulator built-in to make sure the voltage provided to the storage tank doesn't go above the maximum safe level, preventing overcharging which restricts the current which could enter the battery storage tank. The control unit was designed to provide a constant charging voltage of 13.5V to the charge tank.

d. *DC-AC Converter*

The inverter device was responisible for conversion from direct current to alternating current and the power generated from the sun was used to charge the charge tank which was a dc supply, so an inverter is required to convert it to Ac supply and stepped up using a transformer to 220V for level 2 charging.

e. *Metering System*

Figure 8 shows the metering system measures the amount of charge flowing to the Electric Vehicle and calculates the bill accrued for payment by the EV user after the vehicle was fully charged.

Implementing the electric vehicle charge metering system to successfully compute the bill to be paid once the EV were fully charged involves some mathematical computations.

To calculate the bill payment, first you consider the energy drawn from the charging station to the Electric Vehicle in kilo-watt hour (kwh) which is given by

$$E = V \times I \times t \qquad (1)$$

Where E = charge, V= charging voltage, I = charging current, t= charging time.

How long the Vehicle takes to fully charge can be calculated mathematically. This is given by

$$Charging\ time = \frac{EV\ Battery\ Capacity}{Charging\ Current} \qquad (2)$$

Lastly, the Energy consumed by the EV is multiplied by the amount charged by the station per Kwh of charge

$$Bill = Energy\ consumed \times Amount\ per\ Kwh \qquad (3)$$

Figure 3. shows block diagram of the Electric Vehicle Metering System. Power was converted from Ac to Dc and was fed to the DC-DC buck converter where the voltage and current were adjusted to required charging voltage and current. From there, the relay was responsible for allowing or disallowing flow of current and was controlled by the microcontroller (Arduino Uno) based on the state of charge of the EV. The current sensor communicates the current status as it passes to the EV from the microcontroller.

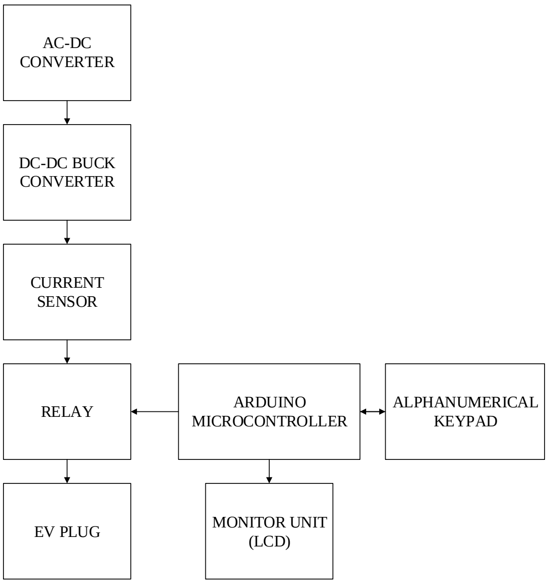

Figure. 3. The Block Architecture of the Electric Vehicle Charge Metering System

Pseudo code

Initialize the charging hub,
If Start button is pressed
then input battery capacity
If battery capacity not 4.5ah
then display not compatible
If battery capacity is 4.5ah
then initialize charging and stopwatch
If battery is fully charged
then display bill for the charge
else if restart button is pressed
then restart the whole system

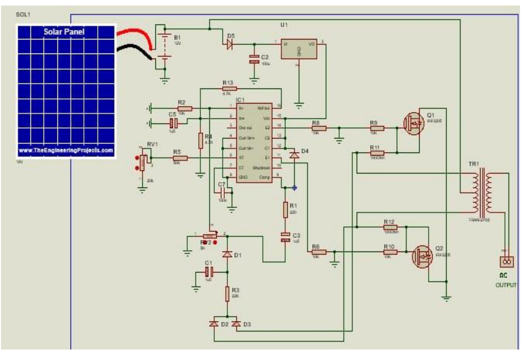

Figure. 5. Circuit Diagram of Electric Vehicle Charging Hub

The approach used in this research utilizes a number of components such as the solar panel, dc-dc buck converter and transformers. These components were put together to implement the Electric Vehicle charging hub using solar panels and were tested to ascertain their workability as in Figure 5.

4.0. RESULTS AND DISCUSSION

The components and designed units were tested individually to ensure they are in good working condition and thereafter connected to make the charging hub system. The proposed system development was tested using two digital multi-meters.

a. Implementation

i. Output Voltage of the designed Charging Hub

In Figure 6 , the Pulse Width Modulation AC voltage output was measured and the displayed voltage was 228V. The charging system was designed for variable output voltage ranges from 190 to 230V.

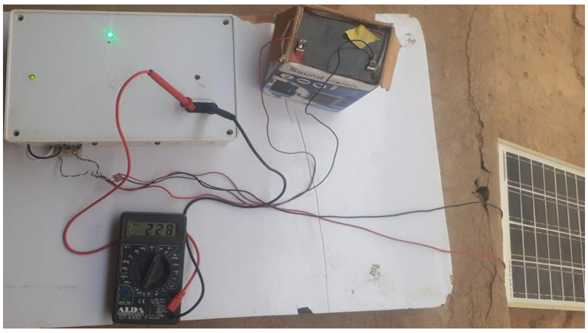

Figure. 6. The design charging hub with solar cells

ii. Off-load Current of the Charge Tank

From Figure 7, the current drawn by the hub system from charge tank gives 0.17A.

iii. Output Voltage and Current on Load Connection

Figure 7 shows two multi-meters connected to both the hub system and the charge tank simultaneously as the metering system was connected to the outlet of the hub system and connected to the EV battery (6V 4.5A). The current drawn from the charge tank by the hub system was 0.39A while the output voltage was 192V.

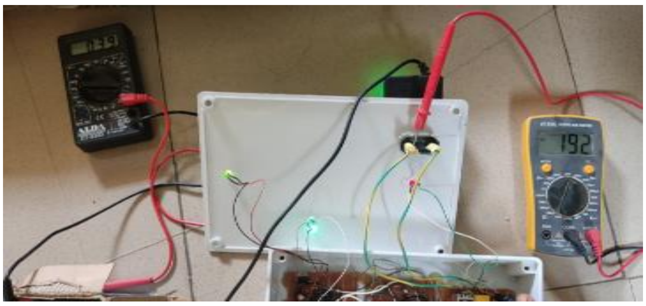

Figure. 7. The Current and Voltage Output Measurement

Figure. 8. The Metering System with the Electric Vehicle Charging Hub

To determine the daily sun hours, sunny and rainy days were put into consideration to randomly get the average sun hours for the month of December to April as shown in table 1. This helps to know the hours needed to fully charge the charge tank (12V 5A battery).

Table 1. Average Peak Sun Hours

Month	Average Sun Hours
December	8
January	7.5
February	9
March	10
April	8.5

Figure.9. represents the average peak sun hours from the experimented location. It was revealed that the sun shines brightest during the months of February and March.

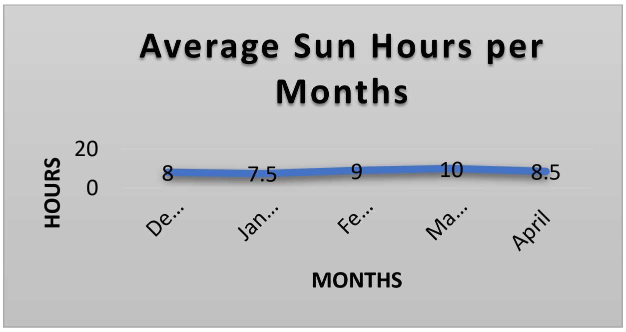

Figure.9. The Average Sun Hours per month

From the result covered in this section, it was clearly shown that there was an increase in voltage and decrease in current when the system was not connected to a load (EV battery).
However, when load was connected to the system, there was reduction in voltage from the output of the system and an increase in current drawn by the system from the charge tank.

5.0.Conclusion

The Electric vehicle charging hub using solar energy developed for rural commuters was spectacular approach to electric vehicle charging as its enables EV users travel long distances without the fear of running out of vehicle charge. The charging stations are found at rural settlements by making use of the solar energy charging concept. Its also helps in improving the climate conditions as no fuel are burned to produce electricity rather natural source of energy (solar energy) were used to generate power for the charging stations. Improvements could be made on this prototype system by upgrading it to engendered energize real life electric vehicles with more faster charging methods introduced so that vehicles on transit won't take long number of hours in charging their vehicles.

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