ASHESI UNIVERSITY

Electric Vehicle Charging Infrastructure with Three-way Automatic Switch

CAPSTONE PROJECT

BSc. Electrical and Electronic Engineering

Justice Valentine Essuman

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Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical and Electronic Engineering

Justice Valentine Essuman

2019

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

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Candidate's Name:

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Date:

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I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University

Supervisor's Signature:

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Supervisor's Name:

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Abstract

Electric Vehicle (EV) technology is one of the steps in battling climate change through electrification of transport systems. Great advances in energy to size and energy to cost ratios have presented a great opportunity allowing all auto manufacturers to jumped for the idea of electrification as the future of transportation. The journey for better charging technologies is still a very important area of research. Among the main challenges in electrification of transport is inadequate charging stations on road networks to provide quick and reliable charging whenever EVs run out of power. This problem hinders people from adopting EVs especially in sub Saharan Africa where unreliable power supply and unstable grid energy infrastructure have become setbacks to deployment of current fast charging technologies. This capstone project showed that complimenting grid power with alternative decentralized energy sources will allow provision of reliable power to charging stations for charging of EVs. In this project eagle CAD is used in designing power switching and system controller to interface with pilot signaling, GFCI and relay circuits in controlling the charging of EV. Also, monitoring of the designed charging station as an IoT, a web application was built to monitor power sources and their frequency of switching on the main power circuit. While testing of most of the design modules on breadboard produced expected results, eagle designs of main power and system controller circuits generated 100% and 98% routed complete working circuits.

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Abbreviations

Abbreviation	Meaning
AC	Alternative Current (AC)
DC	Direct Current (DC)
PEV	Plug-in Electric Vehicles
BEV	Battery Electric Vehicle (BEV)
EVSE	Electric Vehicle Station Equipment
OBC	On Board Convertor
SAE	Society of Automotive Engineers
SoC	State of Charge
ADA	Americans with Disabilities Act
AHJ	Authorities having jurisdiction
DCFC	Direct Current Fast Charger
EPRI	Electric Power Research Institute
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
GFCI	Ground-Fault Circuit Interrupter
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
INL	Idaho National Laboratory
PHEV	Plug-in Hybrid Electric Vehicle
POS	Point of Sale
SAE	Society of Automotive Engineers

TOU	Time-of-Use

Chapter 1 : Introduction

1.1 Introduction

According to Zero to one, new technology has never been an automatic feature of history [1]. In recent decades the issue of climate change raises long-standing questions about the "better" world we claimed to be enjoying when we indirectly keep destroying the environment through our thirst for cheaper energy source to power our engineering developments and advanced technologies. As opined by World Bank, Ghana with about 14.5 kt CO_2 emission as of 2013, is among the countries with highest CO_2 in the sub-Saharan and this keeps increasing with additional CO_2 from transport every year [5]. Thus, it has become imperative for all futuristic and emerging economies keen on accelerating development through emerging technologies rely on clean energy as they allocate energy to meet demands of emerging technologies such as Battery Electric Vehicles (BEV) [3]. Ghana has a significant role to play in this futuristic endeavor.

There has been a considerable number of different forms of transportation introduced in Ghana: trains, trucks, caterpillars, buses, three-wheeled vehicles ("Abobo") including different models of saloon and four-wheeled drives from various manufacturers including Ghanaian Automaker, Kantanka. The high rate at which "second or third-hand" and high fuel consuming, and emission vehicles are used in Ghana and Africa adds to the continent's CO_2 foot prints. Recent automobile advances have led to introduction of Electric Vehicle (EV) which has dominated countries in Asia, America and Europe. However, Africa is yet to test the full potential of these technologies. These cars are great solutions to the continent's climate problems [4].

Even though most of the electric vehicles and other emerging technologies will eventually come into existence, they will be useful in their full capacities in Ghana when the country has the requisite energy infrastructure to power them [5]. Just like the high energy demand that came as a surprise to sub-Saharans due to the surge in the use of smart phones coupled with growing population, future technologies will present similar challenges. In view of this, countries like the United states, Japan and others in Europe have already started benefitting from the emergence of these new technologies through their great and relentless energy strives [6]. However, Africa having a 550 million megawatt solar and wind energy potential (3700 times current) has been slow to exploiting the full potential of these technologies due to setbacks with regards to energy and power [7]. With Africa urbanizing faster than any other continent, at a rate of 4% each year according to World Economic Forum, individual countries in Africa will have to prepare for the future while providing for the emerging trend that technology presents to smart cities, homes and automobiles [5]. With major auto-manufacturing companies moving to Electric Vehicles (EV), sub-Saharan Africa will need the powering infrastructure to embrace this technology in the next few years; from auto manufacturers or third parties [7]. Globally, the EV market is already accelerating at an exponential rate, with more than 3 million vehicles sold worldwide [7]. Ghana currently no electric car users, however, EVs are used in a few African countries like Uganda, Kenya, South Africa, Nigeria and Ethiopia. According to World Economic Forum, by 2040, 54% of new global car sales and 33% of the world's car fleet will be electric [5]. Figure 1.1 shows the annual EV sales by market.

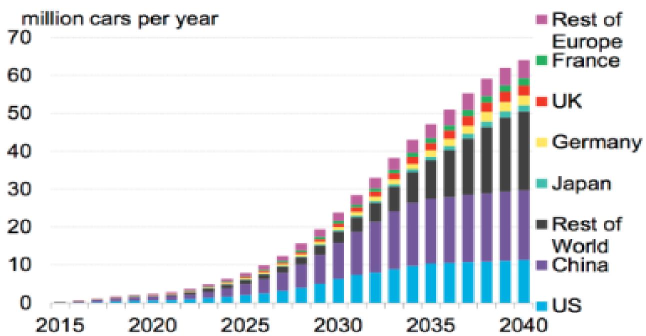


Figure 1.1: Three - way Power source switching Implementation Results

In order to welcome emerging technologies while accounting for the clean energy demand they come with, the United Nations Industrial Development Organization targeting the sustainable development Goal 9 through its Low Carbon Transport Pilot project, is working on deploying charging stations in Africa. Also, few countries have started taking small steps to the realization of the energy needs of its citizens, but the hope is that, these steps get accelerated to meet the impending future of transport electrification. The electrification of transports presents the need for distribution of charging infrastructures to meet energy needs for the use of EVs.

The current charging infrastructure are categorized into levels based on rated operation voltages and charging rate, C_{rate}. They include the Level 1 and Level 2 AC charging, 120V and 240V respectively and the upgrade DC charging energy supply equipment called fast chargers [8]. Some limitation of current fast charging systems is high charging currents warming up battery faster thus resulting in high temperatures in few minutes [8]. What is common among most of the existing charging systems is that they often depend on one power source. Notwithstanding, these regular and fast charging infrastructures are necessary because there is the need for energy supply equipment to be able to handle the recurrent power interruption Sub - Saharan Africa is known for. There is the need for them to provide reliable power from potential sources such as grid, solar and battery packs or battery generators.

This research investigates the possibilities of Ghana inspiring the adoption of EVs through availability of EV charging infrastructure powered by alternative energies like solar, grid and battery generators. The charging infrastructure is to be integrated with a smart three-way switch that enables reliable power supply from three power sources to the charging station. Various strategies will be investigated to choose an optimized charging technology that does not have negative influence on distribution grid in a Ghanaian context.

The second phase of this project involves the design and prototyping of this charging infrastructure and the possibility of optimizing and monitoring the usage of the infrastructure through a web application. The results will be compared and analyzed to show that reliable power through the mix of alternative power sources to compliment power from the grid will present foster the use of EVs in Ghana.

1.2 Problem Description

With the recent increase in automobile industries shifting to manufacturing of fully electric and hybrid vehicles and some African countries adopting this technology to counter air pollution, climate change and global warming, Africa lacks the power infrastructure required to adopt these new technologies [8].

The Tesla super charger is more than adequate for charging electric vehicles due to relatively stable supply of electricity in the U.S. However, due to the heavy financial burden it poses and the prevalence of power quality problems in Africa, especially in sub Saharan countries, adaptability seems almost implausible.

For home and building that rely on multiple power sources; grid, battery-generator and solar, there exist no electronic device that enable 3-way automatic transfer switch to enable provision of reliable power supply to a charging infrastructure.

1.3 Objectives of Project Work

The first objective of this project is to investigate and explore the composition of charging station and build the first pilot charging station for an Electric Vehicle in Ghana powered by a combination of grid power and renewable energy.

This part of the project will investigate the energy opportunity for meeting the energy requirements that comes with adoption of electric vehicles.

Present the economic, environmental and grid impact analysis on the proposed charging system.

The second objective of this project is to make the device an Internet of Thing (IoT), with switching analytics and enabling the provision of uninterrupted power supply and dynamic voltage restoring to overcome power quality problem for charging EVs.

The second phase will entail;

1. Model the structure of the charging station
2. Design a web application to enable monitoring and optimization of operation of the charging station
3. Make the charging station an IoT for switching frequency and usage monitoring

1.4 Motivation of the Project Topic

Firstly, Sub-Saharan Africa's transport systems is dominated by fuel-based vehicles which use poor engines with high fuel consumption. These contribute to a considerable amount of the carbon print in the atmosphere. Also, this places a high cost burden on citizens and a fiscal burden on countries like Ghana despite the fact that heavily subsidized fuels [7] affect economic development.

Bugatti - the fastest car in the world - uses just 5% of its fuel while EV allow 95% use of power from EV supply equipment. According to Elon Musk, EVs spend about one-third the annual amount of money for fueling on charging. Thus, a lot of money to be saved if EVs are adopted. The EV charging station presents the opportunity for powering smart homes as presented by some studies in Vehicle to Grid (V2G). Moreover, EVs present another opportunity for vehicle to grid system which allow them to support Grids during emergency needs.

The Future comes with adoption of EVs but how are individual nations preparing to embrace this technology with their history of unreliable power supply? In this project Ghana is used as the case.

1.5 Research Methodology Used

The research methods used in this project work include;

1. Computer modelling in Solidworks, Eagle CAD and programming in Arduino Idle and software implementation with python and Flask framework
2. Observational trials
3. Hardware prototyping, experimentations and testing
4. Review of research journal, articles, conferences, patents and open source projects, books and public papers
5. Review of circuits and safety standards

1.6 Facilities Used for the Research

The facilities used for the project work include;

1. Computer, internet and library facilities at Ashesi University

2. Ashesi's Electrical and Electronic (EE) lab and Mechanical Workshop
3. Electric vehicle online facilities

1.7 Scope of Work

This project is limited to the designing and building of a Charging Equipment for Electric Vehicles with three-way switch to cycle through alternative power sources.

1.8 Expected Outcomes of the Project Work

The expected outcomes at the end of this project include;

1. Modelled and built charging station with three-way automatic transfer switches for EVs
2. Improved charging station through IoT to enable future billing and monitoring of usage
3. A reduction of carbon monoxide emission by way of adoption of EVs

1.9 Chapter Organization

This project has been organized into series of Chapters, with main methods and results presented in final Chapters.

Chapter 1 explains the background and introduction of the project, highlighting the problems and objectives and research methodologies

Chapter 2 reviews existing literature on electric vehicles, charging methods and technologies, in addition to impact of charging infrastructure on electricity grid.

Chapter 3 discusses the design and implementation steps used to meet objectives and the method includes design decisions and specifications that advised the choice of the type of charging technologies and state machine for the smart automatic three-way switch.

Chapter 4 details out the testing process and explains the results that were obtained. It also presents changes and designs used and accuracies obtaining for software and hardware implementation

Chapter 5 finally summarizes the whole project, presenting the limitations and challenges faces during the design, implementation and testing stages of the project. This chapter also lists future works that can be done to improve the results from this project

References list all journal articles, conference papers and other online resources used in the project

Appendix holds sample figures and software and hardware codes using during project implementation and testing.

Chapter 2 : Literature Review

2.1 Introduction

According to United Nations Industrial Development Organization, "the transition to EV like any other technological transition has positive and negative sides, but the transition is unstoppable and positive at the long run". This transition presents the need to make EVs suitable for variety of use cases; for long distances [6] and usage in different parts of the world hence the need for charging infrastructures. Though there has been little work on charging infrastructure for sub-Saharan Africa, the adoption of EVs in Sub-Saharan Africa will place a huge energy demand proportional to the adoption rate. According to [9], the introduction of EVs presents a new challenge to the Ghana power industry. Ghana is faced with issues around unreliable power supply with generation deficit of 259MW as of 2016. Despite the stifling of energy by electric vehicles being a hinderance to the switch from internal combustion (IC) driven vehicles, the developments in decentralized energy through renewable energy (solar) curbs this problem. As this has been realized through the powering of infrastructures like the traffic lights in Ghana and other countries. Solar energy will also serve Charging stations, complimenting the grid and other energy sources; slowing the need for expansion of grid infrastructure to accommodate the penetration of EV.

However, the full complimenting power from solar is not achieved especially in the night and hence the need for another alternative power source. Other studies have assessed the contributions of PEV to grid and have presented the need for ancillary controls [9].

In the Africa Climate Week in Accra, carbon contributors, among which are owners of high- or low-grade engine vehicles, will soon be required to meet carbon pricing. A way to put burden of damage on CO_2 contributors and stimulate clean technologies. EV charging stations will enable citizens to have reliable and clean energy source for their vehicles a step towards reduction of carbon emission. The charging station is also a means to low cost of power for vehicles than gas.

Currently, there about 28 charging stations on the African continent as can be seen from Figure 2. The car manufacturing company, Jaguar, recently deployed 82 new charging stations in South Africa, adding to the already existing stations. These figures must increase in order for the continent to fully realize the benefits of electric vehicles technology. Figure 2.1 shows the current location of charging stations in Africa.

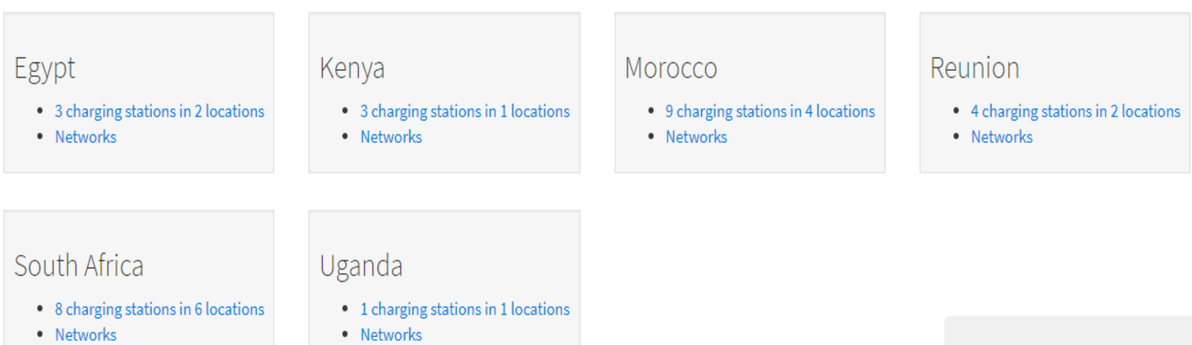


Figure 2.1 Charging Station Locations in Africa

Africa is new to adapting these technologies, therefore in this review chapter, we look at the composition of the charging systems and their influence on gird, charging technologies, standards, efficiency, and power ratings to serve as a foundation for designing a charging technology that will be feasible in a sub Saharan African country like Ghana.

2.2 Electric Vehicles (EVs)

An EV is an automobile that runs electric motors powered by battery technology often rechargeable lithium batteries [10]. Using the principle of an electric current, the power received from the battery in the power train is used to rotate the transmission to turn the wheels. Despite electric vehicle not being practical at early ages due to expensive and huge battery usage, concern about climate change, global warming and air pollution have revived the interest in these technologies once again. Moreover, great advances in battery technology have given electric cars ability to store more power and travel over 100 miles with speeds up to 65mph. Unlike combustion vehicles, EVs are quiet, easy to drive and have zero emissions and do not require high maintenance cost. Example of EVs includes the Tesla model S, 3 and the truck, Toyota RAV4 with rated battery size 41. 8kWh and driving range for about 113 miles and Nissan Leaf a plug-in hybrid [11]. Other kinds of EVs include PHEV and BEVs. Figure 2.2 shows the general composition of EVs indicating the power electronic converter sections.

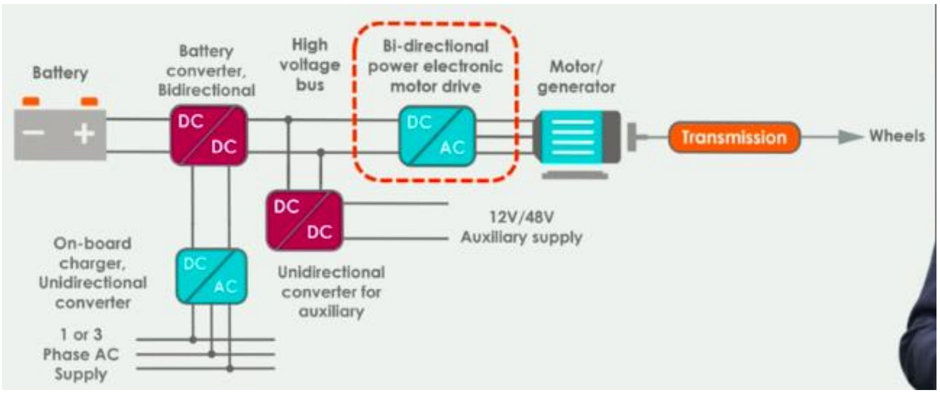


Figure 2.2 Composition of EVs showing power converters sections

2.3 Charging Infrastructure

An EV charging infrastructure, also called the charging point or station or EV Supply Equipment (EVSE) is an electrical system used for recharging various kinds of EVs [12].

2.3.1 Types of Charging Infrastructure

Generally, there are three broad techniques in charging EVs: the conductive, battery swapping and inductive charging i.e. wireless charging. The operation of the different charging techniques is explained below.

Conductive

The conductive charging system is more popular, and its current types are based on levels, modes and charging times. They include; Level 1 and Level 2 (AC charging) and Fast charging (DC charging). The AC charging system is supported by an on-board charger that converts AC from grid to DC to charge the traction battery at Level 1 or Level 2. Like charging a gadget, a charging cable connects the charging infrastructure to the car. With a charge controller the charging infrastructure communicates with the electric vehicle; providing information on current limit, fault condition and connectivity. Should there be any fault condition, charging is terminated, thus the charging lines is usually made up of the power line and communication line. The on-board converter (OBC) shown in Figure in the charger convert the power form AC to DC. Figure 2.3 shows the power flow of the AC charging system to the EV. The power control unit controls the current and voltage of the DC/DC charge convertor for controlling the charging process. The charging works-based on the battery voltage and current log provided by the Battery Management system (BMS) of the system. Also, a protection circuit is triggered in the system when there is a mismatch or fault. According to McKinsey, the AC Level 1 and Level 2 will overwhelmingly remain the dominant charging technology through 2030[13]. This presents a market opportunity for charging infrastructure for both public and private sectors [11].

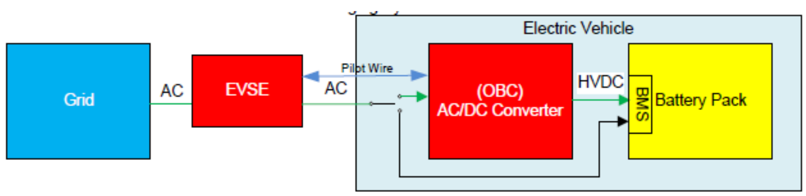


Figure 2.3 Showing AC charging Station; Level 1 and 2

Level 1

This is the slowest and lowest charging level available ranging from 110 V to 120 V AC with current peaks at 16 Amps. This typical level is similar to ones used in household outlet but this time with separate control circuit and breakers. It could have max power of 1.92 kW. It normally has low charging speed and provides between 2- 5 miles per hour of charging. They usually lack metering systems and user authentications; just plug and start charging.

Level 2

Under the SAEJ1772 standard, mid-range the level 2 is the highest level of AC charging. The earlier standard had 210- 240V and 32 amps allowing max power of 7.68 kW, but the 2009 update introduced a new peak current of 80 amps with corresponding peak power of 19.2kW. It provides 10 – 25 miles of range in an hour charging at home or at a public charging point. They are often sites in public areas like malls and parking stations. Early works have shown that Level 2 charger are more efficient than Level 1. An example as the research on the Chevrolet Volt which showed Level 2 is 2.7 % more efficient than the Level 1 [12] where it also presents that the Level 2 in addition to its short charging time, is hardly affected by ambient temperature. The charging rate of the different type of EV charging is shown in Table 2.1.

Table 2.1 Charging Rates for Premium Car with A power Consumption of 25kWh/ 100km and possibilities distance at typical charges

Charging Source	**Charging Power**	**Charging rate (range per hour)**	**Range after typical charge**
Home plug (AC, one phase)	3kW	12km/h	72 km(6h)
Home plug (AC, 3 phases)	9kW	36km/h	216 km(6h)
Fast charger (DC)	50kW	200km/h	350 km (3.5h)
Fast charger (DC)	125kW	500km/h	350 km(42min)
High Power Charger	350kW	1400km/h	350 km(15min)

Level 3 (DC fast charger)

The DC fast charging system is designed to charge EVs quickly in 30mins or less. With electric power ranging from 50 kW to 350 kW. The system is embedded with off board high power operating AC/DC and DC/DC converters as depicted by Figure 2.4. The electric components are lager and very expensive making the DC fast system off-board chargers taking no space in the vehicle. Just like the Level 1 and Level 2, the DC fast chargers have control circuit for energizing and de-energizing the EV connector. The battery management system of DC fast charging enables the communication of voltage and current charging rate of the vehicle. The connectors are combo 1 and 2 and unlike the Level 1 and 2 which use pulse width modulation (PWM) to control current or charging, DC fast chargers use power line communication (PLC). The combo chargers at 100 V to 200 V can deliver current of 350Amps, Max Power 350 kW. Other types of the DC like charger include the Chademo, Combo and Tesla Superchargers.

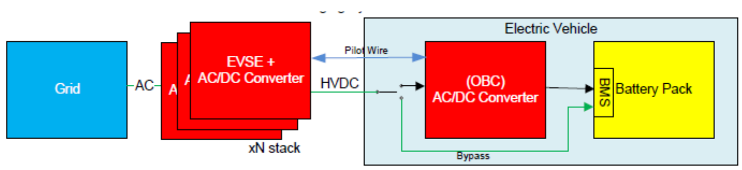


Figure 2.4 Power flow of a DC charging station for level 3

Despite fast chargers having about 200 km/h of charge they have a lot of disadvantages. There is so much negative influence of charging current on their efficiency [13]. It is also presented that the total charging time is not directly related to the value charging current [13] due to I^2R losses (quadratic dependency) in battery, buck converter, switching power loss and conducting power losses

Table 2.1 EVSE types with power supply, Charger power and charging rate

EVSE Type	**Power Supply**	**Charger Power**	**Charging time (Estimated) for 24kWH Battery**
AC Charging Station: L1 Residential	120/230 & 12A to 16A (Single Phase)	~1.44kW to ~1.92kW	~17Hours
AC Charging Station: L2 Commercial	208 ~240VAC & 15A ~ 80A (Single/ Split phase)	~3.1kW to ~19.2kW	~9Hours
DC Charging Station: L3	300 to 600V & (Max 400A) Polyphase	120kW up to 240 kW	~30Minutes

Fast Chargers`			

Inductive Charging

Inductive charging also called wireless charging involves the use of magnetic coupling as mode of energy transfer. This allows charging stations to transfer high voltage and current directly from grid into the battery of EV via an inductive paddle or pad built with an electromagnet that acts as half a transformer [15]. The other half of the inductive pad is often located outside of the EV and both pads must be in closed proximity before charging can begin. Though Inductive charging is safe under all conditions, they have long charging times and have poor efficiency. This technique of charging EV at still in early development stages and outside the scope of this project.

Battery Swapping Station

Battery swapping station is a facility where EV owners can exchange their low power battery for a fully-charged battery. an effective approach to recharging EVs while mitigating long waiting times in a Battery Charging Station (BCS) [15]. This technique of providing power to EVs is very fast compared to battery charging stations allowing drivers to recharge faster as refueling in gas station. According to [15], battery swapping will require consistent standardization of battery technologies for various EVs and leasing of company owned batteries to EV users. A great advantage with this technology is that it drastically reduces the cost of EVs since the battery is owned by the company. Though the concept of battery swapping has been exhibited by companies like Tesla the concept is still in study and trial stages.

Vehicle to Grid (V2G)

The vehicle to grid is a relatively new technology introduced into the power industry due to the advances in the Plug In Electric Vehicles allowing them to wirelessly or through a wired connection charge or discharge of electric vehicles batteries into the utility grid. This idea I sbeing extended through bidirectional system to allow vehicle to grid (V2G) and grid to vehicle (G2V). The system that enables this is the bi-directional charging infrastructure composed of generation source, battery switch station, control and communication and metering systems [9]. The main idea pushing the V2G concept is that electric vehicles are used for a meager 5% of the time and being parked for 95% of the time, thus an opportunity for the vehicles to be used as decentralized power sources. However, challenges of the bi-directional charging technique; increasing frequency of charging and discharging degrades batteries quickly and also the need for bi directional metering and protections introduces more cost. Study also present that future EV will focus on this technology and other integrations. Vehicle to grid is also out the scope of this project so we are not going delve deeper.

2.4 Charging Rate and Efficiency

The charging rate, (C_{rate}) is the measure of the rate at which a battery of EV is charged or discharged depends on the battery capacity. Charging rate depends on the acceptance rate of the EV as this different for various EV models. It is a ratio of battery discharging or charging current to nominal ampere hour of battery. Early studies showed charging time does not scale linearly with the vehicle supply equipment charge capacity. Equation (2.1) gives the equation for estimating the C_{rate}.

$$C_{rate} = \frac{P_{ev}}{E_{cap}} = \frac{I_{bat}}{Q_{nom}} \tag{2.1}$$

Where P_{ev} = power of the Ev and E_{cap} energy capaity

The charging of EV produces current profiles referred to as charging characteristic. The charging characteristic of electric vehicles according to [12] is similar that of mobile phones, or tablets. According to [12], fairly high constant current is required for batteries with zero state of charge, battery electric vehicles (BEV) limit the current for charging to certain value until the app 80% state of charge. On the other hand, higher current from fast chargers are noted for warming up batteries. Figure 2.5 is graph of high-power charging characteristic for electric vehicles showing the decrease in current over time during the charging process. The battery charging performance is communicated to the user and battery performance analyzed through state of charge (SOC) technology.

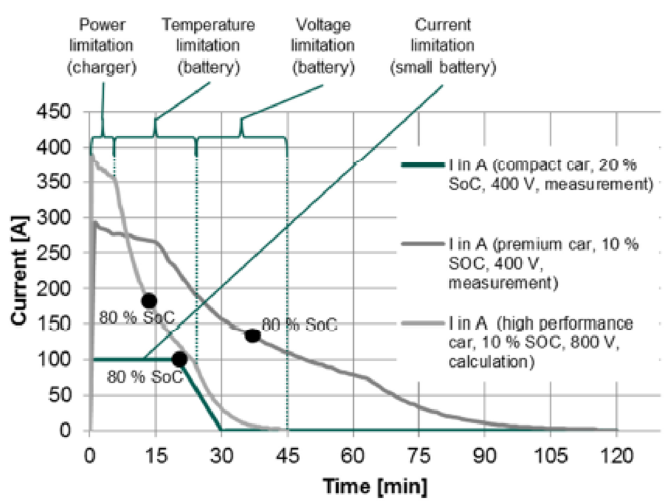


Figure 2.5 Current over time of Cars on high power charging

2.4.1 State of Charge

State of Charge is indication showing whether a battery is fully or partially charged [19]. SOC determines the available capacity of the battery; the maximum distance that battery travel and max speed the vehicle can be operated. SOC information allow users to plan their travel accordingly. The measure of SOC efficiently by the coulomb counting method; battery charge is measured before and after charging/discharging and integrated over time in Ampere hours (Ah). The SOC is determined from the current in and out of battery. Also, the great estimation of SOC is very important for the safe and healthy operation of batteries. Less than 20 % and more than 90 % State of Charge (SOC) are harmful to the battery [19]. Equation (2.2) represents the Coulomb Counting method;

$$SOC = \frac{Remaining\ Capacity}{Rated\ Capacity} \tag{2.2}$$

where SOC is the State of Charge

Using Ampere hour (Ah), the SOC and expressed as

$$SOC = SOC(t) - SOC(t_0) = \frac{1}{Ah\ Capcity}\int_{t_0}^{t} i(t)\ dt \tag{2.3}$$

Where Ah is the capacity of the battery in ampere

The concept of dynamic charging, where vehicle and the charging station communicate with each other for reservation of slot based on availability and cost function [17]. A scheduling management system is demonstrated; showing nearest charging station to the user based on SOC and cost function [17]. Although charging rate is going to increase based on changes in peak demand, demand will not be uniform at all charging station due to usage patterns and this unit cost per kWh variation will exist for charging stations. Equation (2.4) for kilowatt hour and charging cost.

$$Kilo\ Watt\ Hour = Battery\ Voltage\ \times Amp\ Hour \tag{2.4}$$

$$Charging\ Cost = kWh \times \frac{Cost}{kWh} \tag{2.5}$$

2.4.2 Charging Efficiency

This is the percentage of power drawn from the grid that is really taken by the electric vehicle. Charging efficiency is affected by a lot of factors. According to [13], the charging efficiency is affected by battery losses, switching losses, losses in buck convertor and losses in cables. Fast charging systems are explained as having high losses than standard making standard charging more efficient than fast charging methods.

Table 2.2 Comparison of Standard and Fast Charging

Method of Charging	E_{source}	E_{Cond}	E_{sw}	E_L	E_{Load}	E_{Total}
0.3 C	34.059	22.359	222.414	0.425	73.955	353.252
2 C	253.750	24.602	75.024	3.655	494.107	851.138

2.4.1 Effect of Charging Infrastructure on Distribution Networks

According to Hawkins [7], in addition to the advances to EV along with policy incentives, will allow further uptake of EV technologies in the near future [18]. This correlates with the number of different charging technologies i.e. Level 1, 2 and fast chargers to be used in the powering these vehicles. Envisioning the extra amount of energy demand due to BEV charging, grid operators will need to generate new concepts and update their models to meet the demand [12]. Optimized EV charging and discharging strategy have been identified by [17]. Existing distribution system need to be able to withstand this load demand penetration. Various charging systems obtain power from grid or complimented with high penetration renewable energies integrated with charging system to maintain flexibility [16]. There is the need for renewable energy integration especially in areas with weak grid infrastructure, due to the conservative and dear nature of designing whole new grid infrastructure [16]. This will support power systems with the enough reactive power to avoid power instabilities. According to [18], low distribution system should be able to hold the demand if EV charging rates are controlled (controlled EV charging) and restricted to off peak times. This is done by maximizing the power intake by EVs and ensuring that the network limits are not exceeded. This same idea is augment by [16] as it details out auxiliary services like frequency stability, voltage stability, operation management, black start procedures that will compliment charging infrastructure depending on renewable energy sources. Though suggested best charging times for EV are presented as around 10pm to 6am, [12] explains that charging infrastructure with voltage support are able to stabilize voltage profile of grid. Charging systems alone are just power consumer and do not stabilize voltage or frequency during events of stability or frequency problems [12]. Moreover, load forecasting can be used by energy venders to overcome energy shortages and avoid inconveniences to electric charging stations [16].

2.5 Electric Vehicle Charging System

With the growth in electrification in the transportation system, there has been an emergence of EV charging technologies to power these vehicles. However, the basic composition of AC charging technology is described below.

2.6 Charging Infrastructure Composition and Theory

The charging system of an EV consists of mainly power electronics like AD/DC or DC/ DC convertors, current sensors, relays, voltage regulators, current transformers, sensor wires and the plugs. The plug connects the Electric Vehicle Supply Equipment (EVSE) to the EV examples include SAE J1772 Coupler (AC lines 1 and 2, ground, control pilot and proximity detection) in

Figure 2.6 Picture of a SAEJ1772 plug

Table 2.3 EVSE plug types with their configuration and rated voltage and current

Plug	**Pin Configuration (Communication)**	**Voltage, Current, Power**
Type1 (SAE J1772)	3 power pins- L, N, E	1 phase 120V, ≤ 16A, 1.9kW 1 phase 240V, ≤ 80A, 19.2kW
Type 2	4 power pins – L1, L2, L3, N, E 2 control pins – CP, PP(PWM)	1 phase 230 V, ≤ 32A, 7.4kW 3 phase 400V, 63A, 43kW
Chademo	3 power pins- DC+, DC, -E 7 control pins (CAN communication)	200-500V, ≤ 400A, 200kW
CCS/ Combo	3 power pins- DC+, DC, -E 2 control pins – CP, PP (PLC over CP, PE)	200-1000V DC, ≤ 350A, 350kW
Tesla US	3 power pins- DC+, DC-, E (or) L1, N, E 2 control pins -CP, PP 2 control pins – CP, PP	Model S, 400V ≤ 300A, 120kW

The plug is the terminating part to a black box; a signaling circuitry Figure 8, which commences a "handshake" process between the charging equipment and the EV before charging begins. The theory of operation of the signaling circuit according to SAE 1772 standards requires EV negotiation through a State A-D transition. The state transitions involve the following process;

- Signal the presence of AC input with GFCI checks
- Detect the presence of a vehicle and prevent it from moving when connected or allow disconnection
- Indicate ready state to charge after vehicle is detected
- EV initiate energy flow after handshake and supply equipment monitor ground safety
- Supply current; determined by the battery capacity of EV
- Charging interrupted when plug is removed from the vehicle.

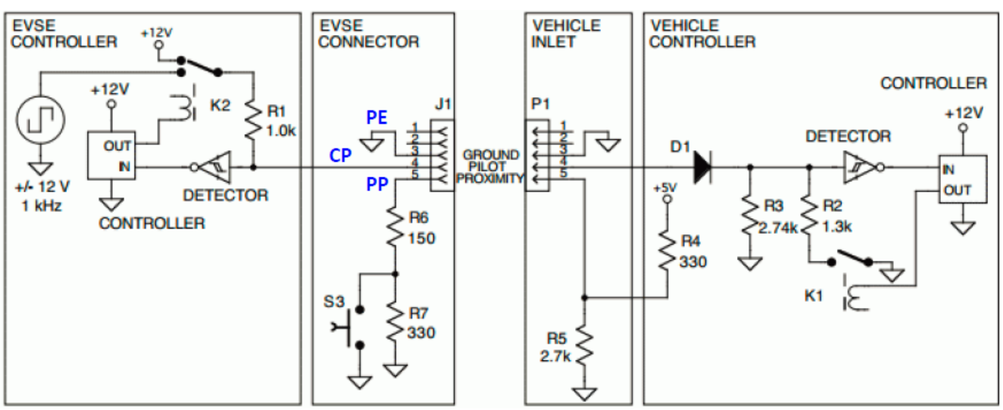


Figure 2.7 SAE J1772 basic signaling circuit diagram

Control Pilot (CP)

The CP produces the pilot signal i.e. a 1 khz square +-12-V PWM signal used that communicate with the vehicle to verify its presence. The vehicle can then respond by placing loads on the line that will lower the voltage at various voltage states [Texas]. The main AC line of the charging infrastructure is not live when CP and Proximity Pilot (PP) are not detected. The CP communicates with the car controlling the amount of current being supplied to the vehicle by varying duty cycle to meet corresponding charging states. Using duty cycle allowable charging current and to regulate charging.

The duty cycle tells the maximum current available for charging the EV; following the J1772 duty cycle. The current rating depends on the power electronics in the EVSE. Below is the relation between duty cycle and current for a 6A to 51A service [OpenEVSE].

$$Duty\ Cycle\ = \frac{Current/\ Ampere}{0.6} \tag{2.6}$$

Using the pilot signal, +12 V to -12 V across a variable resistance on the EV, the voltage read is determine as the state accordingly. And the PWM signal is going to be generated by the microcontroller timer module.

Proximity Detection Pilot

Allows for simple start up and shutdown of current flow and prevent movement of car while connected to charger. It is responsible for the detection of the presence of a vehicle to be charged by supplying voltage which the car passes through resistors to ground. Also prevents movement of car while in charging. It checks if the vehicle connector is connected properly. If the connection is not established the proximity pilot will detect it and the entire charging process will be disabled.

Pilot Signal Circuit

The pilot circuit is a bipolar +-12V signal circuit. The configuration is a simple rail to rail configuration of an opamp. The microcontroller drives the positive input of the opamp and the output through a potential divider to enable the microcontroller to read voltage during operation and detect the resistance of operation of the vehicle. Below is the pilot signal from Texas instrument.

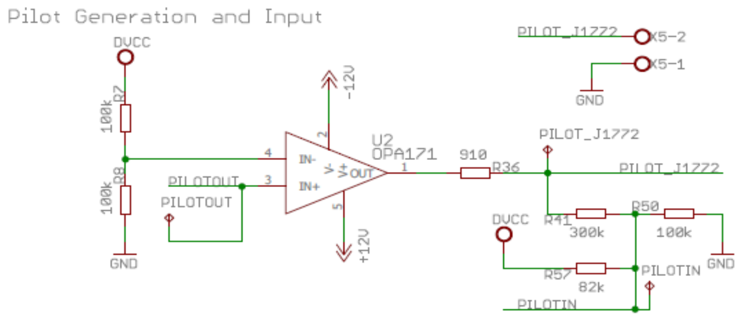


Figure 2.8 Pilot Signaling Circuit

Pilot Wire Handshake Process

Prior to detection the EVSE puts a 12V on the pilot State A. A compatible vehicle is detected when a 2.7 k-ohm is set by the car which drops the voltage to 9V, State B, the EV is ready to charge. At this stage the PWM is enabled to determine how much current the EV can draw. An additional car resistance of around 882 ohms, voltage drops to 6V, State C and the EVSE is signaled that charging has begun and normally finishes the handshake process. However, increasing resistance with an additional 246k ohms the care charges on ventilation. The EVSE will then turn on the AC power and commence charging. The charging process continues until the EV is done and stops drawing power; where an error signal is sent to cut power. Also charging ends when the cable is unplugged, returning the voltage to 12V. Below is the signal handshake circuit state transition for an EV and its charger.

Table 2.4 Shows the pilot signal state transitions with corresponding voltage

State	Pilot High Voltage	Pilot Low Voltage	Frequency	Resistance	Deescription
State A	12V	N/A	DC	N/A	Not connected
State B	9V	-12V	1 kHz	2.74	EV connected ready to charge
State C	6V	-12V	1 kHz	882	EV Charging
State D	3V	-12V	1 kHz	246	EV charging ventilation required
State E	0V	0	N/A	-	Error
State F	N/A	-12V	N/A	-	Unknown error

Ground Fault Circuit Interruption (GFCI)

According to NEC is intended for the protection of personnel that functions to deenergize a circuit or portion thereof within an established period of time when a current to ground exceeds some predetermined value that is less than that required to operate the overcurrent protective device of the supply circuit. It’s function is to calculate the difference in current out and current in. If there is a large difference the current trip. The output is sent to the microcontroller to trigger fault and open relay. Figure 2.9 gives the layout of GFCI.

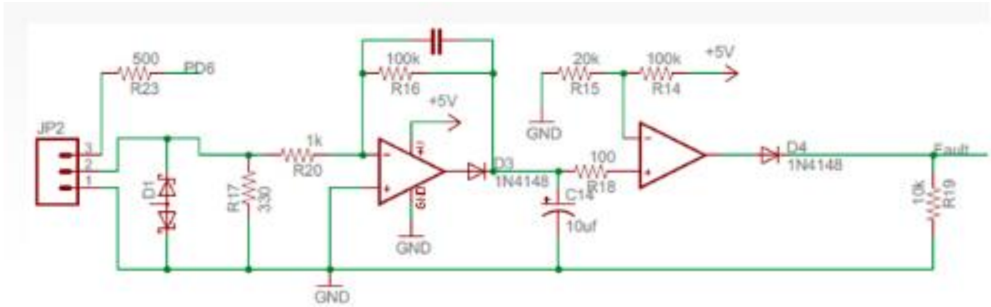


Figure 2.9 Ground Fault Circuit Interruption

Relay Control

The relay control allows the delivery of power from main to the plug. The relay is closed to after completion of GFCI checks and handshake between the EV and the charger start the charging process. The relay must have a power rating able to handle 230-240V and about 30A current. The power delivery is quite expandable when larger relays are used.

Microcontroller

The controller is mainly in charge of reading the state of the EV connected and also activating relays to open or close. It is in charge of making various checks; GCFI which send and interrupt when there a current difference due to fault. It checks on the AC test and also send pulse width signals to pilot circuit to control the handshake process. The ATMEL controller of the Arduino is often suitable of this as it is

2.7 Technologies and Standards

The development in conductive charging technology for EV as explained earlier are in different levels; Level 1, 2, and DC fast charging system based on the performance of the energy supply equipment and operating voltage.

But under the Society of Automotive Engineers (SAE) there are standards for Level 1 and 2 which most auto companies design their systems around. Figure 2.10 shows the SAE standard codes and norms for EV interfacing and batteries. Also, according to the International Electrotechnical Commission modes 62196, there are 4 modes of charging:

- Mode 1 - charging slow from a normal electrical socket (single phase or three phase)
- Mode 2 - also slow charging from a regular socket but equipped with some EV specific arrangement
- Mode 3 - fast or slow charging using a specific EV multi-pin socket with control and J1772 and IEC 62196)
- Mode 4 – fast charging using some special charger technology such as CHADEMO or Tesla Superchargers.

2.8 Related Works

[6] B. Zhu *et al*., "The Interoperability Test Study of Electric Vehicle A.C. Charging Spot," *2017 4th International Conference on Information Science and Control Engineering (ICISCE),* Changsha, 2017, pp. 1291-1294.doi: 10.1109/ICISCE.2017.268

This paper seeks to identify challenges with charging spot based on the new standard and new charging interoperability test specification by designing the interoperability testing device for AC charging spot for electric vehicles. By investigating the exceeding power supply ranges, standard charging control timing and the specific time for disconnection of AC power during unexpected power issues, the authors show the interaction and flow of power from power supply equipment to how power plug interfaces with vehicle socket before entering the charging equipment of the vehicle. By assuming an existing AC charging spot, their test device for the system was simplified through abstraction of power electronics involved to blocks. Though power cuts during unexpected power ranges, there was no mention of any automatic switching system to alternative power sources which I believe hits at the interoperability of a futuristic charging spot.

[23] D. Ransom, "Choosing the Correct Transfer Switch", *IEEE Transactions on Industry Applications*, vol. 49, no. 6, pp. 2820-2824, 2013.

This paper describes the impact of power interruptions hence the need to identify and choose the correct transfer switch depending on the application. By looking at the characteristics and operation of a transfer switch, such as the switching time and how is influence by power disturbance time, the author provides very key information for selecting a switch and how they are affected by different grounding methods. Moreover, he details out a guide for generator protection and analysis of troubleshooting transfer switches. However, he not investigates the bypass designed for transfer switches and how different they are from the normal transfer switches. He however does well to provide information on the mechanism and connection for transfer switch grounding.

[22] I. Khan, J. Zheng, D. Koval and V. Dinavahi, "Impact of Manual Versus Automatic Transfer Switching on the Reliability Levels of an Industrial Plant", *IEEE Transactions on Industry Applications*, vol. 41, no. 5, pp. 1329-1334, 2005.

This paper seeks to highlight the increasing importance of switching for reliability of power systems in industrial plant. It investigates the reliability of using manual transfer switch versus automatic ones, comparing their frequency and duration of load interruptions. Describing the operation and use of zone Branch methodology for reliability evaluation of restoration, switching and impact of protection failure on industrial power systems. However, he presents that load constraints and assumption of reliability models as difficulties to analyzing power systems.

[21] Ebenezer Nyarko Kumi. 2017. "The Electricity Situation in Ghana: Challenges and Opportunities." CGD Policy Paper. Washington, DC: Center for Global Development.
https://www.cgdev.org/publication/electricity-situation-ghana-challenges-and-opportunities
This report presents the power challenges and opportunities in Ghana considering the erractic power issues Ghana has experienced in the recent decade. By transition from the early power systems; generation, transmission and distribution, the reports investigates and presents distribution and transmission as the main area which power losses could be attributed to. In addition to the inadequate generation of power due to fuel supply setbacks, the reports also present the electrification vision 2020 how far Ghana is in achieve this vision. This report is vital for understand the energy generation status of Ghana and to know how the energy demand ofr electric vehicles will fit in the country.

[5] K. Hill, "Is sub-Saharan Africa ready for the electric vehicle revolution?", *World Economic Forum*, 2018. [Online]. Available: https://www.weforum.org/agenda/2018/07/sub-saharan-africa-electric-vehicle-revolution-evs/. [Accessed: 04- Oct- 2018].

This paper seeks to highlights the developments in electric vehicles serving as not only innovation but automobile industries but also technologies that the power sector can rely on to ensure reliable power supply. By investigating the power outages issues in Ghana, this paper explores how electric vehicles can serve in microgrids as power banks to ensure reliable power supply. The author explores and give an overview of the essential components of an electric vehicle their capacity and how they can contribute to the existing power loads; base, peak and intermediate.

2.9 Limitation of DC fast charging for Sub Saharan Setting

The limitations of the dc fast charging for sub Saharan setting include the following among others: harmonic contamination, high current demand on peak hours, restrictions to supply networks, higher, larger and more expensive power control circuits make them difficult to realize, higher losses in losses and charge and battery, thermal management due to high currents and cable max currents.

2.10 Research Gap and Contribution

Currently electric vehicle technologies, the biggest theme over the next 10 or 15 years [16] requires enough charging spots in locations; at homes and various destinations to enable recharging while on distant journey. However, one of the major issues in sub Saharan Africa is that electricity is not seen as a transport fuel and EVs penetration are hindered by heavy import duty. According to [10], most research focus on renewable energy power charging infrastructure as second option with primary focus on overnight using infrastructure in homes in developed areas with accessible electricity. There is less focus on decentralized energy systems powering charging stations in high to low setting areas not mention of how energy vendor will deal with peak hour loadings.

Although the recent charging station deployment in South Africa presents the urgency for the need of these infrastructure, there has been no study on the readiness of Africa's grid support to welcome electric vehicle. Existing charging infrastructures are very expensive due to additional cost from installations and tax. The prices of single port ranges form $300 - $1500 for Level 1, $400 - $6500 for Level 2 and $10,000 – $40,000 for DC fast charging. [10] excluding installation cost.

The recently added charging system in South Africa are 60KWh fast chargers, ‘100km of range will take around 20 mins’ each charging spot with 22kWh fast charger for plug in hybrids. Despite the advances in South Africa, charging infrastructure is one of the main things to look at to enable other countries with great grid infrastructure like Ghana welcome the technology. However, Ghana’s grid is not robust enough to welcome fast charging infrastructure because of the limitations of DC fast charging in the Sub Saharan Setting.

In view of this, fast charger is less feasible in sub Saharan grid systems since they introduce a lot of harmonics and power instability of local grids. However, If Ghana were adopting electric vehicles with average battery capacity of 32kWh. Ghana’s 3795MW installed generation as of 2016[3] will enable it to support about 4900 Electric vehicles with same capacity as indicated by calculations given in Equation (2.7) and Equation (2.8)

$$Generation\ in\ a\ day = \frac{3795MW}{24hours} = 158.125\ MWh$$

$$maximum\ nuber\ of\ EVs = \frac{158.125MWh}{32kWh} = 4941Evs$$

This implies, 4941 EVs will be able to provide power for Ghana in a day.

Chapter 3 : Design Methodology and Implementation

3.1 Introduction

This chapter delves into the technical specification required and methods used for the proposed design of prototype charging infrastructure in Ghana. It also presents the circuit design modules of the different sections of the project and choices of the hardware components using Puhg Matrix to decide on major components. The Hardware of the system is designed referencing from great EVSE from Texas instrument and EV opensource who have full ESE products. This ensures that the EVSE system is designed and built to follow the SAE standards for a Level 2 charging stations. The software design, state diagram and flowchart of the Internet of Things section of the project is implemented. The chapter also contains highly defined model of how the different circuit modules fits together.

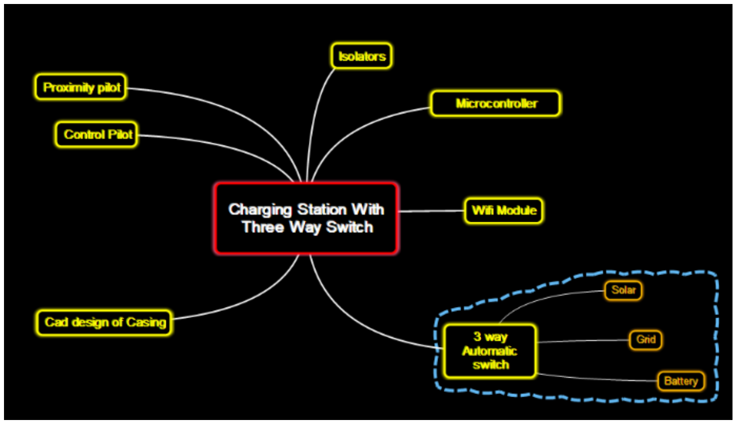


Figure 3.1 Modules of the Charging Infrastructure to be Implemented

Despite the growing number of charging stations worldwide to support the growing EVs, the existing charging infrastructure are very expensive $400 to $1140 and hardly have support for unreliable power sources thus the objective is to design and build a low-cost Level 2 240V 20A charging station fused with a three-way automatic transfer switch to enable monitored provision of reliable power for powering electric vehicle in Ghana. The introduction of this system is also aimed at providing environment for EV users in Ghana to get access to reliable public and home charging.

The Implementation of this project involves the software programming and hardware construction from electronics design and assembly to physical casing which required the acquisition of the following materials which are discussed late this chapter. The hardware or electronics part of the project is implemented in two section printed circuit boards (PCBs) the NodeMCU/Power section and the Atmega328p interfacing with pilot, GFCI and latch relay. We created header pin on the power section to allow interfacing between the two boards.

On the software side of the project which involve a web application using flask, the programming of an embedded system. The embedded system consists of two parts, the 3-way switch on the

NodeMCU and the programming of the Atmega328p microcontroller to control the charging process. We explain and illustrate the design and implementation process involved in project below.

3.2 Scope of the Design

Considering the systems-based approach, the system will be composed of hardware and software sections. The Hardware section consist of four sections; the power supply unit, Wifi – communication, the microcontroller circuit interfacing with relay circuit , the Pilot Circuit and the Ground Fault Circuit Interrupt (GFCI). The functions of most of these sections are explained in section [5]. On the other hand, the communication section uses a NodeMCU that prioritizes the available power sources to provide power for charging EV while publishing the states of the three power sources to a Web application using Message Queuing Telemetry Transport (MQTT)/HTTP Rest from clients. The main microcontroller, ATMEL mega 328p will control the charging of the EV by performing a handshake process through the Pilot Circuit followed by a fault checks using the GFCI. The charging begins when the microcontroller closes the Latch relay that open power for the EV. The system is also composed of a power supply section that provides a dual power +12V and -12V to power pilot circuit and also 5V to inverting inputs of GFCI and Pilot circuits.

The software is also consisting of two part; the IoT web application to serve the EVSE and the firmware that runs on the micro controllers to publish data to the website and also to control the handshake state transition between the EV and the charger.

3.3 Design Decisions

This section presents the design choices made concerning the system components for the hardware, software and mechanical design of the proposed charging infrastructure. Thus, the hardware: 3-

way switch for prioritization of power source, the choices of microcontroller, pilot, Ground Fault Circuit Interrupt (GFCI) and relay circuit designs. The software sections consist of the web application, user interface and data transfer ultimately with HTTP Rest api. The various high-level components of the design are given in Figure 3.2.

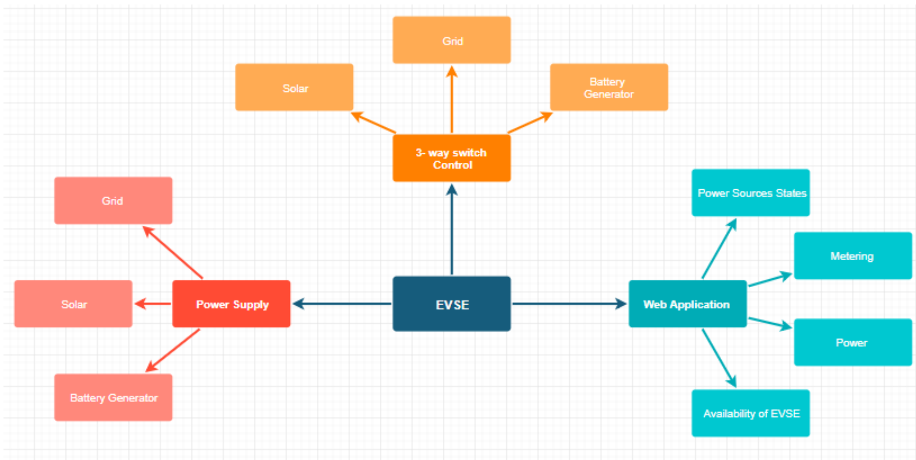


Figure 3.2 Design Mind Map

3.6 Pugh Matrix

The pugh matrix is used to facilitate design selection of major components used in the design by pointing to best or alternative components by scoring and comparing against base design or design component. The major parameters for choosing components in this design with focus on the electronics, the less power consumed the better. Considering the pugh matrix used in design selection of major parts i.e. best package for IOT application, the material choice for casing and best level of charging feasible in Africa.

Table 3.1 Pugh Matrix for Microcontroller Choice

System		**Baseline**	**weights**	**NodeMCU**	**Rasp. PI**	**Arduino**
Criteria		**IOT Core**				

1	Reliability	0	5	+6	+4	+5
2	Power Rating	0	5	+5	+5	+5
3	Compatibility	0	4	+4	0	0
4	Cost	0	3	+2	-5	+4
	Total			**+17**	**+6**	**+14**

Table 3.2 Show the Pugh Matrix for Material choice for design of Charging Station

Casing		**Baseline**	**Weight**	**Plastic**	**Wood**	**Comp.**	**Metal**
Criteria		**Super-charger**					
1	Accessibility	0	4	+8	+8	+4	0
2	Reliability	0	5	+5	-5	+5	0
3	Compatibility	0	4	+4	-4	0	- 4
4	Size	0	2	+2	-2	+2	- 2
	Total			**+19**	**-3**	**+11**	**-6**

Table 3.3 Pugh Chart of the Type of Charger Suitable for Ghana

System		**Baseline**	**weights**	**Level1**	**Level2**	**DC Fast**
Criteria		**Supercharger**				
1	Reliability	0	5	-5	+5	+5
2	Charge Rate	0	5	-5	-5	+5
3	Compatibility	0	4	+4	+4	-4
4	Cost	0	3	+3	+3	-3
	Total			-3	+7	3

Using the Pugh Matrixes above points Level 2 as the best alternative in relation to Level 1 and DC fast charging. In addition to section 2.8, the regular power outlet in Ghana is 230V making it easily support Level 2 when allowed to draw more 12A of current. In addition to the Level 2 supporting home and public usage, it less costly compared to DC fast chargers and reliable than level 1.

The Pugh Matrix also points to NodeMCU as the best IOT controller. Despite it having only on ADC pin it advantages include support for various hardware modules through serial and SPI interfaces. It costs less and consumes less power. The raspberry pi in not very portable compared to the ESP8266. Also, the Atmega328 is used because it great microcontroller for embedded system application. It can be easily programmed using the Arduino and transferred to a main embedded system. Additional advantage and specification of the Atmega328p can be found it documentation.

In selecting the material building the physical design. The Pugh matrix points to a good insulator since we are dealing with high voltage application. Though wood is readily available it can be destroyed by ants and socked with water during rainfall thus a nonconductive composite is pointed to by pugh matrix since it accessible in the lab and also can withstand rain. We these choices the system is easier to implementation

3.7 Design Methodology

The above EVSE is designed to be Level 2 charging station with 230V and 16-20A or more current. Its basic functional requirements are to deliver power using one standard SAE J1772 vehicle interface to an EV. The choice of J1772 enables the system to be compatible with most EVs through their onboard charger**.**

The system is designed to monitor that state all available power sources by reading their states through communication controller. Based on their status the controller chooses one of the power sources by prioritizing solar. The power line chosen is closed by a relay from which power some is tapped to power the system microcontroller and other circuit like the pilot circuit and the GFCI. Once handshake process is executed and completed when a car connects to the system, the AC power relay is closed to start the charging process. During the charging the power (voltage and current) in that line selected can be measured and supplied to the microcontroller. The system controller controls and monitors the charging status of EV. Once charging is completed the AC relay opens to stop the charging process.

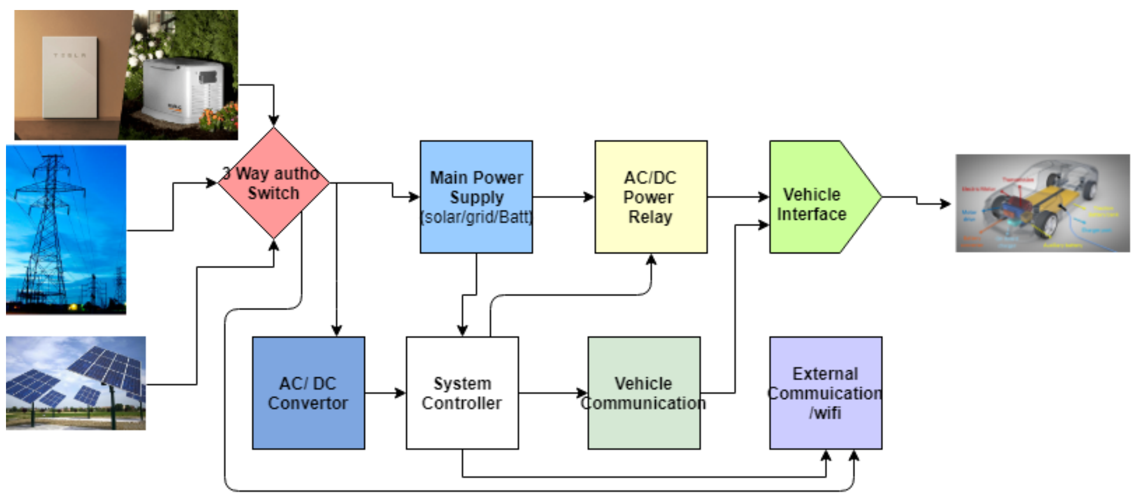


Figure 3.3 High Level Module of Level 2 Design

Considering the cheapest EV, a Ghanaian may afford, the Nissan leaf which has battery and charging system as follows; Lithium Ion, 350V, 40kWh battery capacity, battery charging time of 7.5 hrs. from 0 to 100 % and acceptance rate of 6.6. For the Level 2 proposed design we determine the charging times.

Calculating Charging Time

How long it takes to charge the battery of an EV depends charging infrastructure, the battery capacity and acceptance rate of your electric vehicle. For our case of charging the Nissan Battery

We calculate the load power supplied by the charging infrastructure as given in Equation (3.1)

$$Power_{Level\ 2} = V \times I = 230V \times 20A = 4.6kW \qquad (3.1)$$

The average battery capacity, 40kW is divided by the load power

$$Time\ to\ charge = \frac{40kW}{4.6kW} = 8.6956\ hrs \qquad (3.2)$$

3.7.1 Main power supply

A major requirement of the system is its robustness in providing unreliable power supply for user of this the system which raise the need for alternative power supply to compliment the unreliable grid power supply. The power section the system is thus designed to have three terminal blocks to allow input of power from Grid power, Solar power and Battery Generator. The power sources are assumed to be lumped and have same rating of one phase 220V to 230V AC. However, 3 powers sources are stepped down using three DIY voltage regulator modules from 230 AC to 5V DC which are sent to the NodeMCU for prioritization of power sources. The three DIY power modules where used because they are lumped and cheap very accessible. One of these power sources is chosen to supply both the system and the car once the final Latch relay closed after completion of handshake process to charge the EV. The main power section provides the interfaces; terminal ports and power transistors for controlling latch relays to allow controlling of three power sources Grid, Solar and Gen-battery. Also, a battery to provide 12V for powering the system when all power sources are not available. More importantly the charging station must have less losses, it must charge car with same power from chosen power source. This is achieved by using low powered components

The choice of power source is based on a priority checks logic and 3-way switching code running on the NodeMCU. Figure 3.4 shows numbering of power sources based on priority of power source, with Solar as number 1. Electronic Switches, Latched Relays rated 20-40A Relay – these are electromechanical switches that close the line of any of the 3 power sources chosen by activation of their coil. The NodeMCU also cut off all relays to cut off power source from entire system when fault is detected. With the system being designed to be connected as an Internet of thing, it presents the need for data transmission which is discussed in section 3.8.7

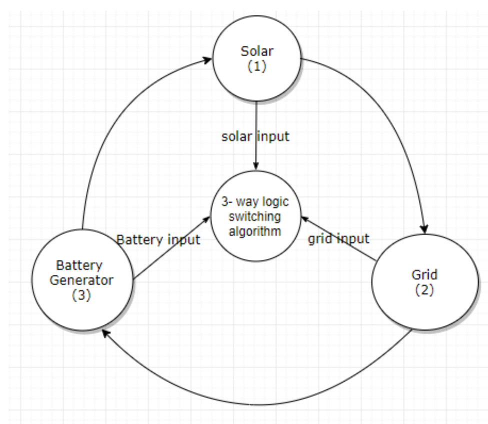
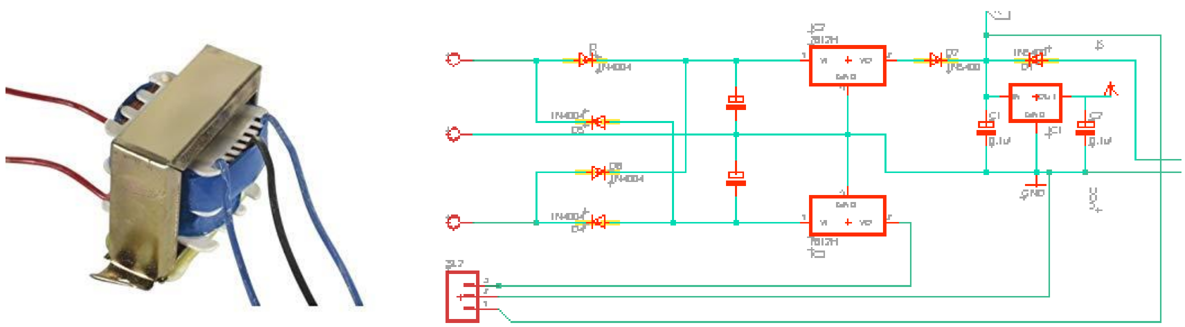


Figure 3.4 Power Sources Prioritizing Solar, Gird and Battery-Gen

3.7.1 Sub Power Supply Unit (AC- DC)

The power supply is another major requirement of the system that powers the major sub sections of the circuits. It is one of the major components that increases the price of EVSE thus building one from low cost materials reduced the general price of the EVSE. To realize this design, we choose to step down voltage from active power source using a center tap 230/15 V transformer, with $+-15V$ output which is then rectified with diodes bridge and regulated with LM7812 and LM7912 and smoothened down to a dual supply $+12\,/-12\,V$ using appropriate $2200uf$ capacitors. The output voltage is supplied to power the operational amplifiers of the pilot signaling circuit. A 5V power is generated to by voltage regulation with LM7805 to power the microcontrollers (Atmega and NodeMCU) and also to supply voltage to the operational amplifiers in Figure 3.6.



a) b)

Figure 3.5 (a) Center Tap Transformer to (b)Create Sub Power Supply

Implementation of Main Power Supply and NodeMCU

The first part that is implemented is eagle ciruit design and generation of the schematic diagram containing the main power interfaces, AC step down modules, sub power unit and NodeMCU that control the latching relays. The .brd file is genereated in Eagle by setting the routing wire and pad value to 25mil and manually routing the components together. The components are the arranged and solded on the printed PCB. In the Eagle schematic implementation below figure 3.6, the headers are included to enable interfacing.

To avoid the stalling of the project while waiting for the PCB to finished, the pilot circuit and GFCI circuit are built on a bread board and powered with a sub power supply created from the center tap transformer.

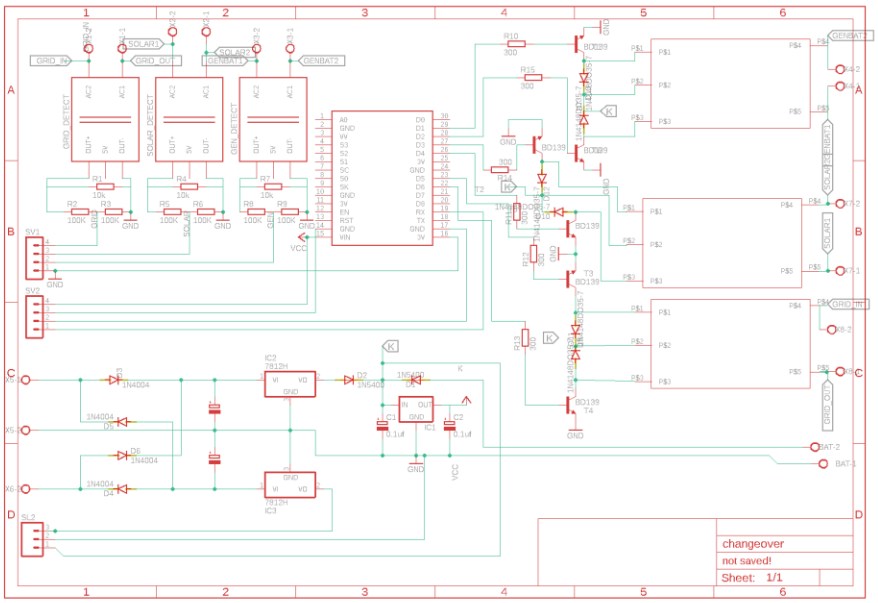


Figure 3.6 Power Change-over Design with NodeMCU Eagle Schematic Implementation

3.7.2 System Microcontroller

The main system controller is an Atmega 328p. Its specifications include 32 kB internal memory, 1KB EEPROM, with 6 PWM pins, 8 pins for ADC, and programmable serial pins. It operates on $3.3V - 5V$ and $6V - 20V$ powering outlet. This is the central control of the system for controlling the charging of the EV by regulating the state transitioning during the handshake process by reading the pilot signal through an analogue pin. Also, by sending PWM signal to the positive pin of an operational amplifier of the pilot circuit the system to controls maximum current supplied to the car. The Atmega328p It also controls the final electronic switch; Latch relay to plug or SAE1772 connector via two relay pins for set and reset. The status of the station is shown through RED, GREEN and BLUE LEDs which denote Error, Ready and Charge respectively. It checks for ground faults through interrupts from GFCI pin.

What's more, it receives data from pzem-004, an energy module about to be added to allow metering via serial communication. This will also require a current transformer and voltage transducer will be connected to the A/D pins on the microcontroller.

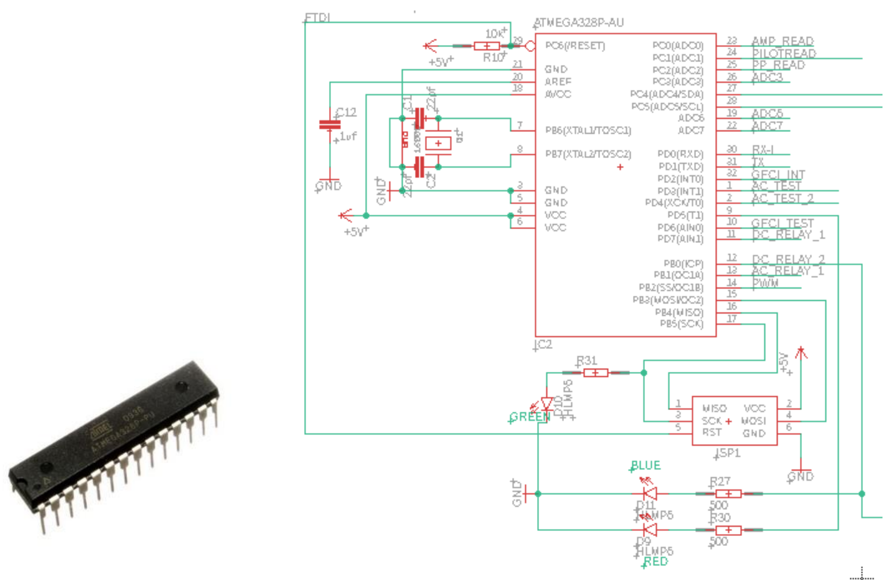


Figure 3.7 Atmega328 System Microcontroller with Interfacing Pins

The Atmega328p chip with its interfacing pins is also prototyped on a bread board to while running design and interfacing iteration on Eagle CAD software. This section is built by arranging the resistor, capacitor and oscillator components and connecting them to their appropriate pins flowing the schematic in the design section. With the same circuitry existing in Arduino we implement this section using the Arduino microcontroller. The Arduino is therefore used in controlling the Latch relay using a set and reset control pins to activate and deactivate the coils. The Arduino is also used in reading all values labelled in the schematic design.

3.7.3 Vehicle Communication - Pilot Circuit Design

Communication between an EV and Charging station is achieved using the Pilot Circuit. The function of the pilot signaling circuit as explained in the review controls the handshake process between the EVSE and the EV. Just like reference designs from Texas and Open EVSE the pilot signal output from the noninverting comparator circuit is sent to the microcontroller through ADC to read voltage using voltage divider to scale down the voltage for the microcontroller. However, to prevent the vehicle from straining the output of the Opamp, a resistor is placed at it output. A variable PWM (0-1023) signal is used an non inverting input to able the duty cycle of the signal allowing for control of maximum current being delivered.

$$V_{in} = \frac{R9}{R9 + R8} \times 5V = \frac{100k}{100k + 100k} \times 5 = 2.5V \qquad (3.3)$$

where Vin is inverting input of the pilot opamp

Also, from the pilot circuit we implement the proximity pilot (PP) from the 5V using a potential divide just the pilot signal input to the Atmega328p. This PP line is also added to the Pilot, AC line and Ground that connects to the J1772 plug. To enable the controller to make decision thus connection or disconnection of the car the Proximity pilot signal is also sent an input to the Atmega328p.

$$PP = \frac{10k}{1k + 10k} \times 5 = 4.545V \qquad (3.4)$$

where PP is the value of the proximity pin

The Pilot circuit is built and powered by power +12 and -12V to feed non-inverting comparator circuit of dual supply configuration Opamp (LM358V). This is to prevent the output from being grounded and produces a steady output. The comparator circuit is given a non-inverting input of Vin and PWM from the Atmega. Comparing the voltages, it generates a gain leads to +12V output.

We implement the same design in eagle built them on breadboard. By varying the PWM signal using Arduino, the duty cycle of the wave form generated to vary current.

The proximity signal is sent as a pilot output is then scoped and visualized using the analogues discovery.

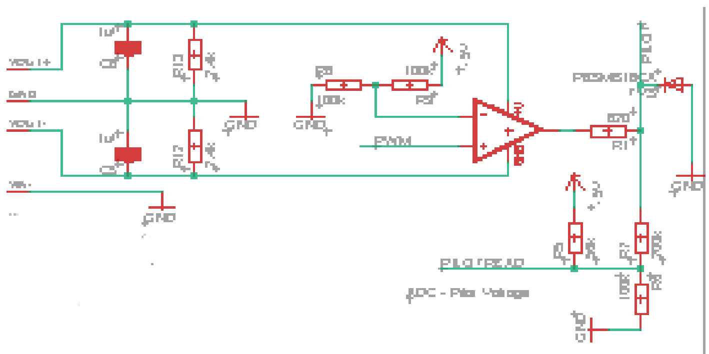


Figure 3.8 Pilot Circuit Eagle Implementation with non pin hole components

3.7.4 GFCI Circuit Design

The system is designed with a protection mechanism for ground fault checks called the GFCI. It is designed to take input from a current transform which generates a minimal voltage difference when difference in current is sensed. The circuit is designed to first amplify the measured the voltage form the current transformer with an integrator AC integrator circuit and passed through non inverting input of a comparator. Both integrator and comparator circuits are designed using LM358V operational amplifiers.

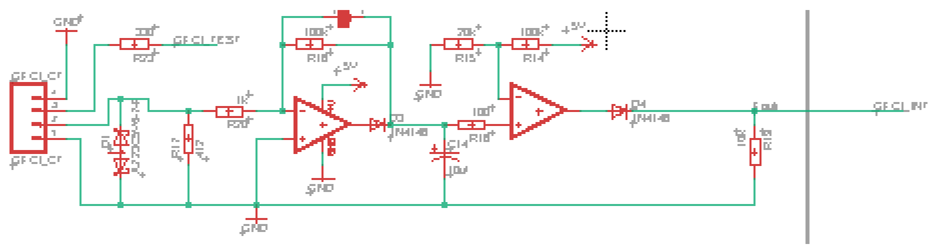


Figure 3.9 GFCI Circuit

Just like Pilot circuit, the GFCI circuit is first built on a bread board as of design while implementing the main circuit on Eagle together with the main microcontroller and other section of the project. The circuit is built by first generating voltage from a current transformer using full watt incandescent build that can be powered by a 230V. This is to mimic current running through a line to charge an EV providing a voltage we can supply to the GFCI circuit. The measure voltage is connected across an integrator and output supplied to the comparator circuit. The ultimate output is sent an input to the Atmega328p as interrupt. During the building process the output at each section of the circuit is scoped with an Analogue Discovery and visualized in Waveforms software on the laptop as show in Figure 3.10.

3.7.5 Wifi Communication and Data Transmission

The NodeMCU is the major controller that allows the system to communicate over the internet to a web application. NodeMCU is chosen over GSM because NodeMCU is more suited for IoT application. Moreover, it is a low powered microcontroller rated gigahertz transmission 3V. Its function is to read the states of available power sources via digital pins and sends (publishes) the states of the Web application.

3.8 Software Design

This section discusses the high-level architectural design and implementation of the IoT Web application for the EVSE and the programming of Atmega328p to control the charging of EV. The implementation of the 3-way switching of power sources based on availability is also discussed in this section.

3.8.1 Charging Station Web Application Design

The charging station application will enable EVs users to know the status and availability of the charging station through the station dashboard. Using MQTT protocol the web application as client subscribe to a MQTT broker that allows it access the station data being sent or published to the broker. Using MQTT allows minimal and efficient data transmission from charging station to web application on digital oceans. It also allows web application to be lightweight permitting quick updating of displayed information. Alternatively, second design option is using NodeMCU to transfer data using HTTP Rest API protocol format. The web application will show the states of power sources and the status of the EVSE on its dashboard. The dataflow of the system is shown in figure 3.10.

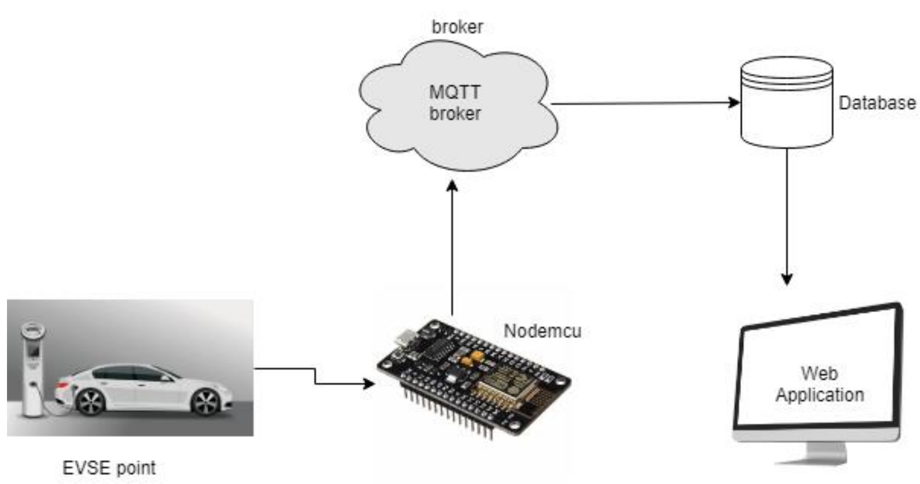


Figure 3.10 Data Transfer Flow through MQTT broker to Web Application

Data from the NodeMCU as of designed will be stored in a SQL alchemy database where it will be queried and displayed on user dashboard that will be displaying all power sources and energy information. The dashboard will also display a real time graph of frequency and time of switching of the three power sources with trends of undecided length of time in line graphs in range of one week or month. Figure 3.11 shows the flow of data from NodeMCU to web application.

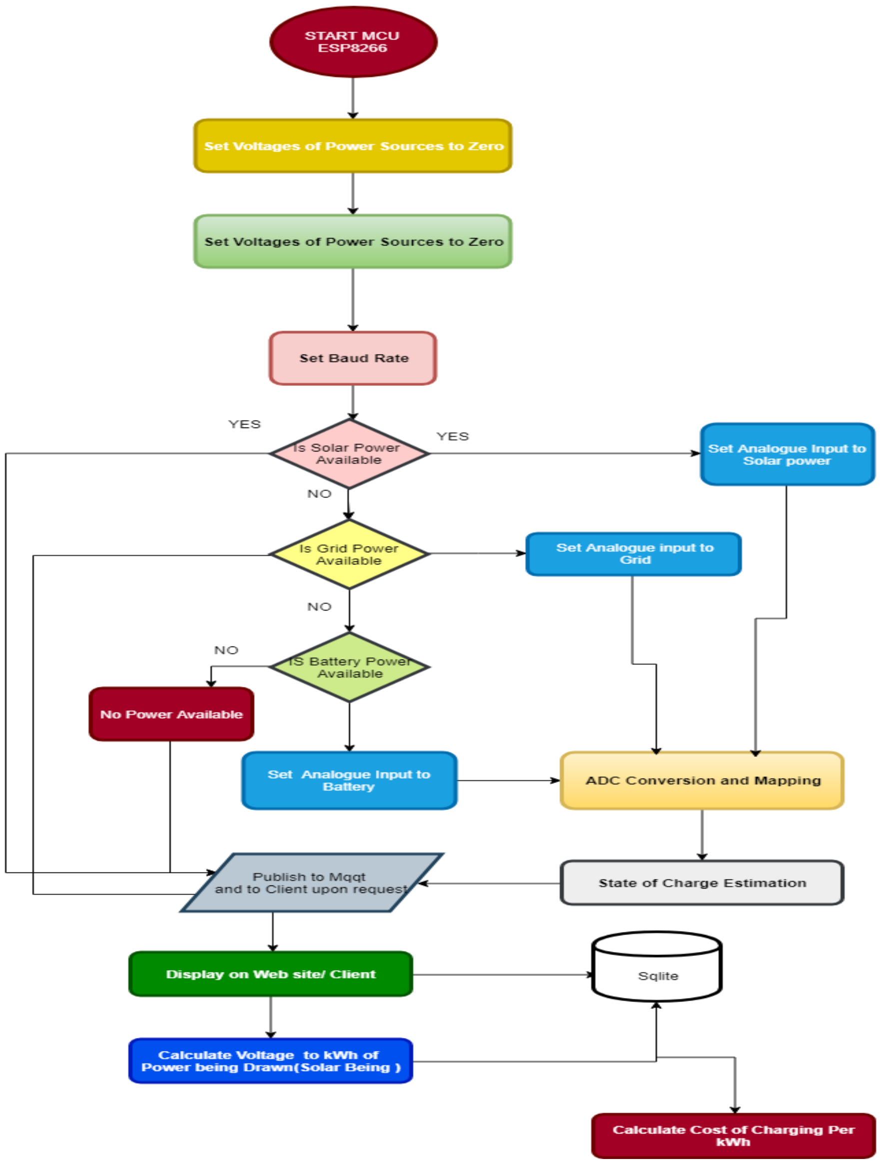


Figure 3.11 Data Flowchart of Operation of Charging Station

3.8.2 Web application Implementation

The concept of the IoT implemented in Thingspeak, an IoT platform by Mathworks to allow visualization and monitoring of the three power sources interfacing with the NodeMCU. From the Api-key section, a write key and GET url are provided after channels are created on Thingspeak.

```
GET https://api.thingspeak.com/update?api_key=6P22Y3OLK1AWLN7O&field1=0
```

Application Requirements

The application involves building an IoT server using digital oceans to host the web application. The implementation of the web application, frontend and backend using Flask framework using the following libraries, dependencies and software listed below.

- Python3-venv: Python3-venv is used in creating a virtual environment in which a project folder can be created to hold project dependencies
- Flask: this framework allows creating of web application using python
- Sql-achemy: this is the SQL-lite database used in to store web application data
- Bootstrap: this is front end framework containing the html and CSS files used in developing the dashboard and home page.
- Render template**:** this a library used in place of request to lunch page or html files
- Pytz: this library used together with the datetime library allows getting of different format of time and at a particular- time zone
- NodeMCU: this IoT microcontroller that interfaces with web application

Sql alchemy (SQL lite) Database

Focusing on the dashboard, the database implementation is discussed as it holds the application's data. The data queried from the database are parsed to the html files and using "Jinga" templating are displayed on the web application. The database holds a single table that has the following fields in addition to the id;

- Mac Address: Every charging station has a MAC address for identification. This allows view of data from a specific charging station. Also charging station cannot send data to EVSE IoT Server if its MAC address is not known
- Datetime: To generate time stamps of all power source data points that are received by the application
- Field: Three fields; 1,2 and 3 correspond to the 3 power sources solar, grid and battery-Gen respectively.
- Data: This field hold the value or state of the power sources 1 and 0 for On and OFF.
- Status: This field determines where the station is use or not based on the state of the final or 4th relay.

```
db = SQLAlchemy(app)

class Power(db.Model):
        id = db.Column(db.Integer, primary_key=True)
        api_key = db.Column(db.Text, nullable=False)
        datetime = db.Column(db.DateTime(),nullable=False,default=datetime.utcnow)
        mac = db.Column(db.Text,  nullable=False)
        field = db.Column(db.Integer, nullable=False)
        data = db.Column(db.Float, nullable=False)
        status = db.Column(db.Integer, nullable=False)
```

Figure 3.12 SQL Database fields

3.8.3 Charging Control Program of the ATmega328p

It is worth pointing out that prior to charging the pilot signal is +12V but starts PWM only after the vehicle is connected and sense by the proximity pin. Also, the SAEJ1772 is state changing voltages are in range also using +-50hz around its 1kz pilot PWM. Programming of the Atmega328p involves the following processes;

- Checking the presence of connected vehicle using the proximity pilot
- Generating PWM signal and reading the pilot signal pulses from the pilot pin
- Detection of charging request and controlling the red, blue and green LEDs to indicate the charging state.
- Turning on final relay to closed to commence charging.

PWM configuration

In performing the PWM with Arduino to generate 1Khz signal, the timer register is used for more control over duty cycle and frequency

The default PWM of the

- the comparator by reconfiguring the timer module of Atmega328p
- In choosing the duty cycle for the analogue signal 255 represents full DC thus 50% duty cycle correspond to 128

```
pinMode(3, OUTPUT);
  pinMode(11, OUTPUT);
  TCCR2A = _BV(COM2A1) | _BV(COM2B1) | _BV(WGM21) | _BV(WGM20);
  TCCR2B = _BV(CS22);
  OCR2A = 180;
  OCR2B = 50;
```

Figure 3.13 PWM signal timer configuration from Arduino

3.8.4 Programming the Node-MCU

Using the Node-MCU a state transition code is implemented to choose a power source the three-power source supplied to the board that hold the main power supply and Node-MCU show in figure 3.6. The pseudo code for the implementation in shown below. Once a power source is chosen a Latch relay is opened to send power to the control circuit in figure 3.6. The

```
//if solar is on
if(solar_State == 0 and grid_State == 0 and batt_State == 0){
    Serial.print("No available power");
  }
if(solar_State == 0 and grid_State == 0 and batt_State == 1 ){
    Serial.print("Switch is on battery power ");
  }
if(solar_State == 0 and grid_State == 1 and batt_State == 0){
    Serial.print("Switch is on Grid power");
  }
 if(solar_State == 0 and grid_State == 1 and batt_State == 1){
    Serial.print("Switch is on Grid power");
  }
 if(solar_State == 1 and  grid_State == 0 and batt_State == 0){
    Serial.print("Switch is on Solar power");
  }
  if(solar_State == 1 and  grid_State == 0 and batt_State == 1){
    Serial.print("Switch is on Solar power");
  }
  if(solar_State == 1 and  grid_State == 1 and batt_State == 0 ){
    Serial.print("Switch is on Solar power");
  }
  if(solar_State == 1 and  grid_State == 1 and batt_State == 1 ){
    Serial.print("Switch is on Solar power");
  }
```

Figure 3.14 Three Power Sources Switching

3.9 Physical Casing and Iteration

Considering the high voltages involved, a charging point with protection is designed to able to ground any voltage spark. The design is able to stand heavy forces from winds and push. The designed to be used outside with $240\ V$ AC inlets and outlet to the car. Like the filing station, the design must have slot to hold the charging plug when not in use. The station must have slots to hold lighting indicators (RED, YELLOW and GREEN) to display charging status of the infrastructure. To allow easy identification of the charging station it has to be tagged with the EV charging symbol.

Chapter 4 : Experimentation, Results and Discussions

4.1 Introduction

This Chapter discusses the experiments which were conducted, and changes that were made to enhance the performance of the various hardware and software parts. This was all aimed at to improving the results of the experiments. It is worth highlighting that the Chapter covers observed results from main sub groups of the project namely, the software and hardware implementations.

4.2 Hardware Testing

Testing was performed on all the circuit modules implemented in the Chapter 3 to verify the correct circuit connection of all electronics components. As stated earlier the hardware comprises of the main power source interfacing with the NodeMCU, +- 12 Sub power source, Pilot signaling circuit, the GFCI all interfacing with the microcontroller which ultimately energizes the last relay. The testing was also performed to identify damaged components especially the DIY ones so they can be replaced.

4.1.1 Main Power Supply and NodeMCU Testing and Results

After the power and NodeMCU schematic design Figure, printed circuit board (PCB) is generated after multiple routing of the components to one another using right thickness of wires on the board. The three power sources terminal can be traced through the 230V – 5V DIY modules to the NodeMCU and also from the NodeMCU to the control for choosing the power source that gets to be used in controlling the EV charging. It is worth also pointing out that the sub power supply +-

12 V which is also regulated to 5V is also hosted on this board. Most of the various circuits were implemented and tested on the breadboard. The result of the PCB generated is shown in figure 4.1

The following results were expected;

- Three LEDs used were expected to turn on once all 3 powers grid, solar and battery-generator are connected to the board
- The NodeMCU must be able to read the states of the three power sources from 4 pin hears
- The NodeMCU must be able to set and reset the latch relays to open or close power to choose power for EV
- +-12 V sub power supply must generate voltage outputs to supply

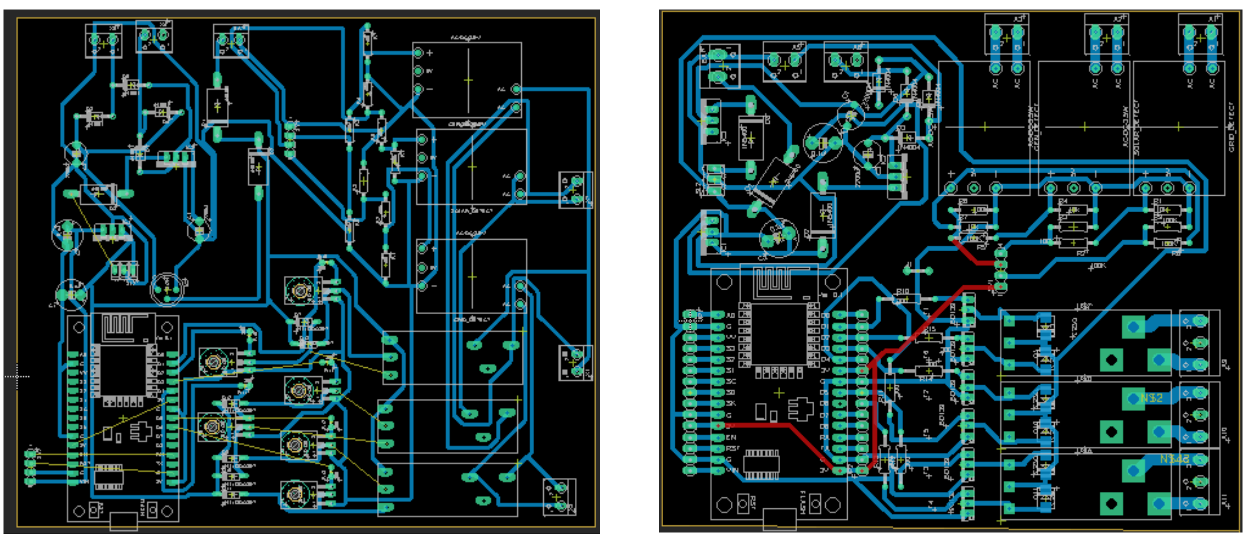


Figure 4.1 Rendered Printed Circuit Board

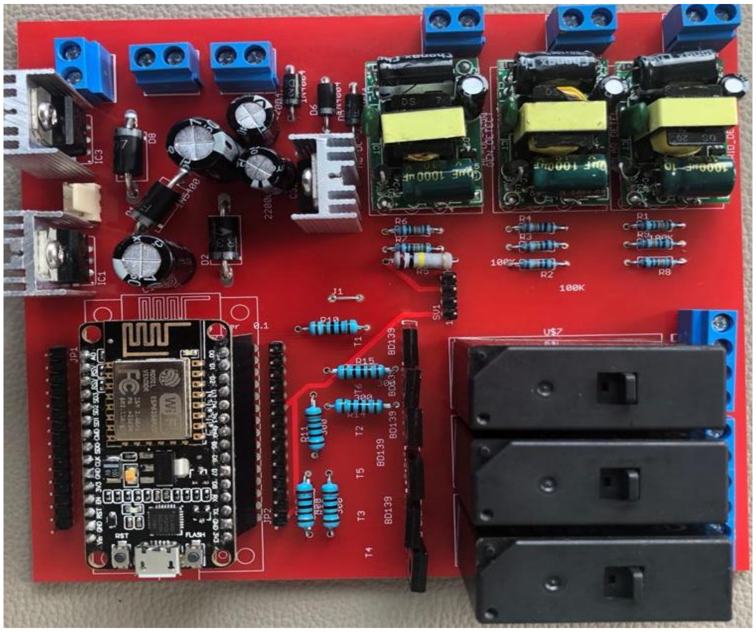
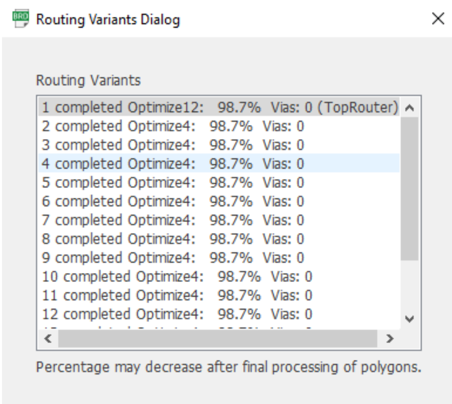


Figure 4.2 Show the main power supply PCB with components assembled

4.1.2 System Microcontroller, Pilot and GFCI Testing and Results

This section makes up the second circuit board that connects with the Main power / NodeMCU board in figure 4.1 above. The interfacing of the Atmega328p with the Pilot Signaling circuit, the GFCI and DC relay circuit which were implemented in the Eagle schematics diagram in Figure 3.2 were routed bottom routing to generate PCB. Testing of the various components of this board was performed on the bread board and later on the printed circuit board. It is worth pointing out that because the PCB was designed to be locally printed on single side achieving 100% routing is difficult due the many components on the board. Using manual routing and jumpers connected in red enable complete 98.7 routed pins. The rest of the pins indicated with yellow lines are to be connected externally using jumper wires. Also, the SPI header had to be changed to 8pin header and rearranged to prevent crossing of wires and using multiple jumpers. The result of the PCB generated can be see below in figure 4.2



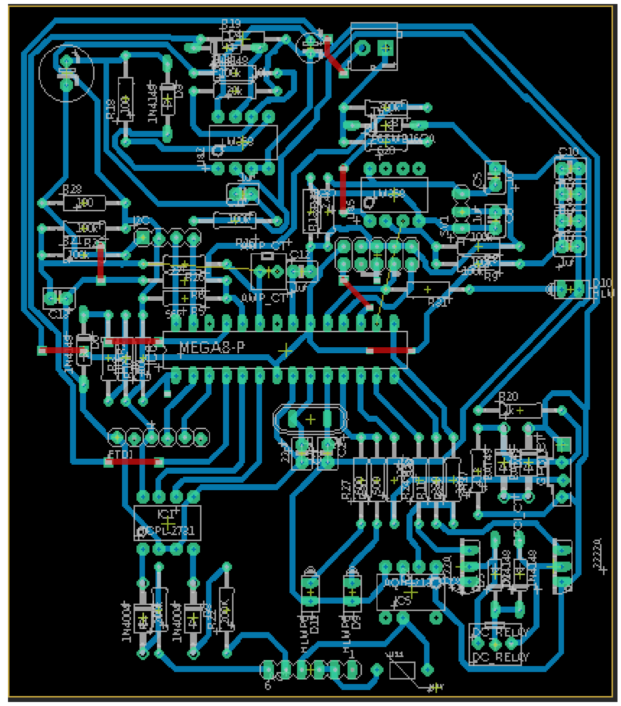


Figure 4.3 PCB result of Atmega328p interfacing with Pilot, GFCI and Relay circuits

In testing this circuit on a bread board, the results obtained are discussed in relation to our expected results mention in section for sub power supply, the output of the pilot signaling circuit, the GFCI circuit and the relay control. In determining most of these result, analogue discovery, multimeter, Arduino instead of Atmega328p and 230V incandescent lamp which comes on when charging begins.

Sub power supply

- Sub power dual supply generated an output of +-12.03 V

Pilot Signaling Circuit

- This dual supply power the pilot signaling circuit, an output of 11.3V

- For the handshake state transitions, -V, V and were obtained when resistors 2.74ohms, 884 and 274 ohms were placed across the pilot signal to represent an EV connection change in state

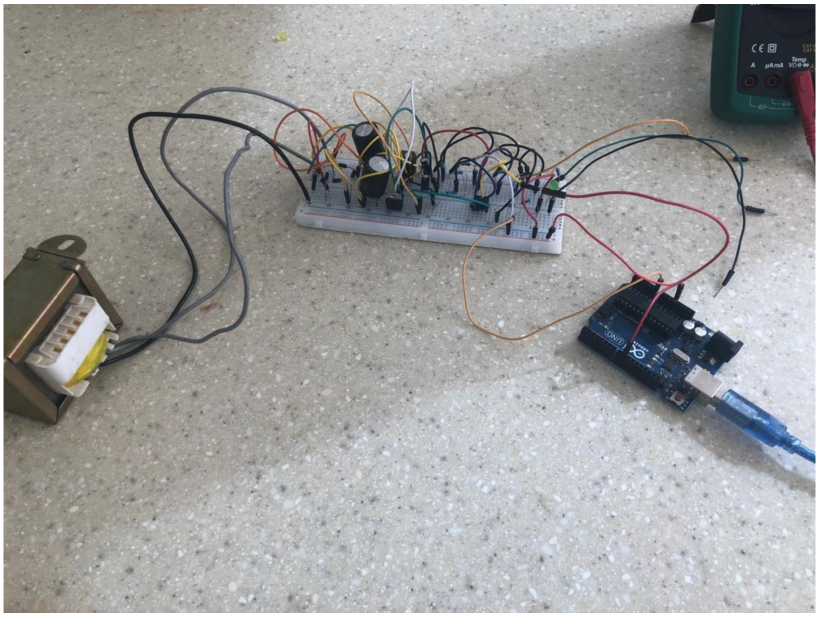


Figure 4.4 Picture of Dual +/-12V Supply to Pilot from Transformer

Microcontroller and Relay

- The Arduino outputs PWM signal to the pilot comparator as expected
- The LEDs turn on at various stages of handshake process
- The final relay is set to close the line to start charging once the LED turns green

GFCI

- For the GFCI, using an incandescent lamp rate 230V the CT outputs 0.33V which get amplified to about 3.3V shown in figure. However, the comparator was not operating as expected as at writing of his paper, so fault detection in full operation

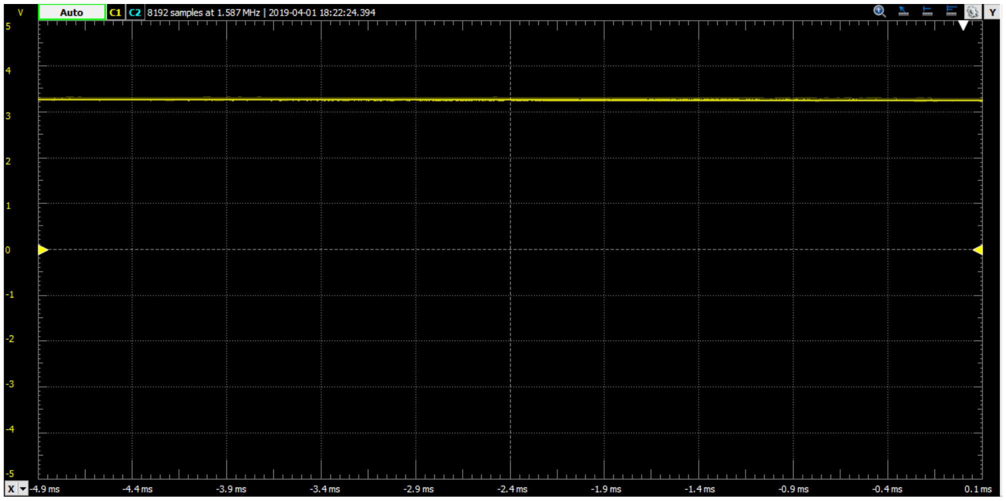


Figure 4.5 The amplified signal from GFCI circuit to Comparator

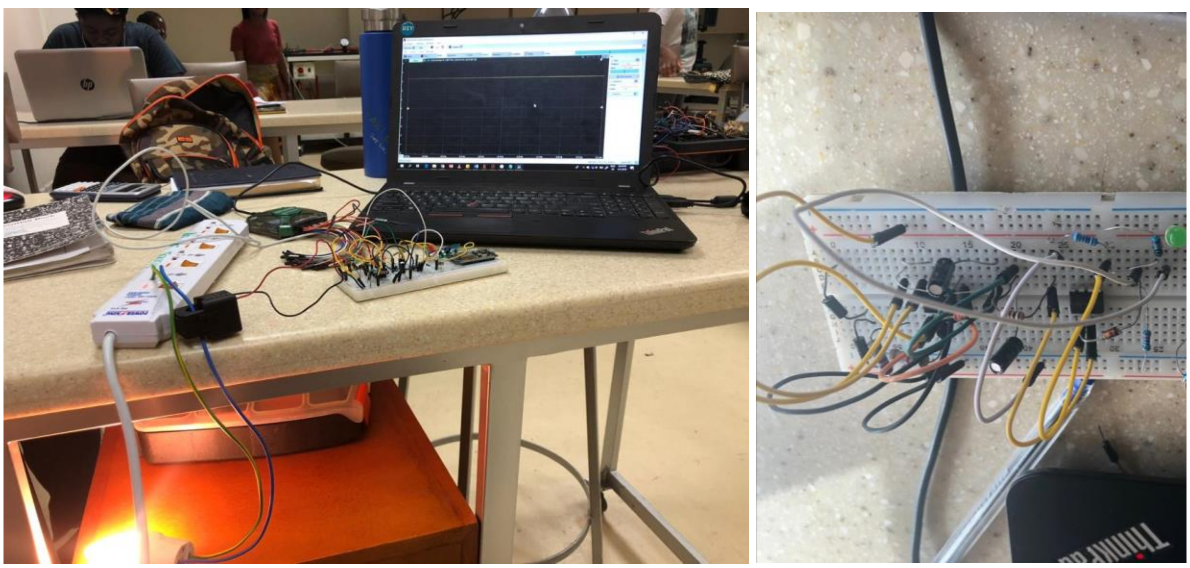


Figure 4.6 Picture of GFCI testing

4.3 Results of Software Development

Testing of selection of power source by the NodeMCU and the transfer of data from it to the web application was done following the implementation in Chapter 3. It was also performed to identify possible loops in the data transfer and visualization.

4.3.1 Programming NodeMCU Power Switching

Testing of the power switching was performed by print the selected power source available on the Arduino serial monitor after the chosen relay is activated. A delay is added to ensure that old active power source opened before the new selected relay is closed.

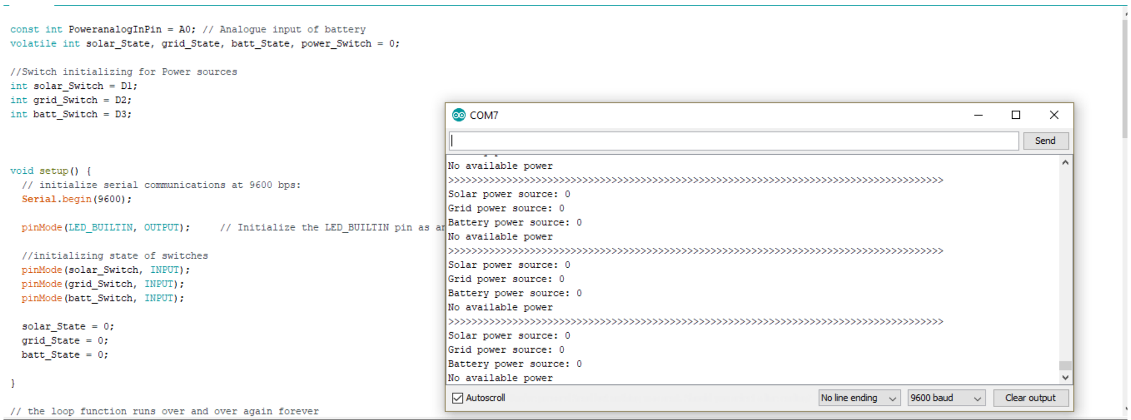


Figure 4.7 Three - way Power source switching Implementation Results

4.3.2 System Microcontroller Charging Control Results

It is worth pointing out that during the testing with Arduino pins like AC test1 and test 2 were not used. However, they were routed in the PCB of the system controller board shown in figure 4.8 Also, during the component arrangement on the PCB, a yellow LED was used in place of a blue LED. Since testing on Arduino worked as expected, the PCB is expected to produce great result after arrangement of components. During the charging control testing on a breadboard, the following results were obtained;

- PWM on the pilot pin generated the PWM and varying the duty cycle altered the current as expected
- The pilot read values ranged from 882 to 52 and
- The detection of a ready to charge state closes the final relay that turns on the lamp used

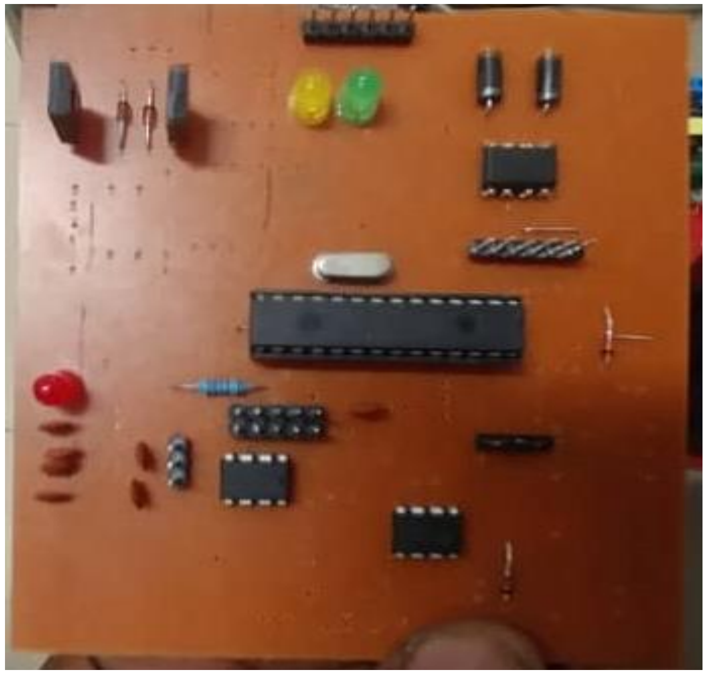


Figure 4.8 Shows a picture of system controller PCB during component arrangement

4.3.3 Web Application Testing and Result

Using Thingspeak, the results obtained for states of the three power sources are plotted in their corresponding graphs below. Result from Thingspeak proved a web application can be created for the web application.

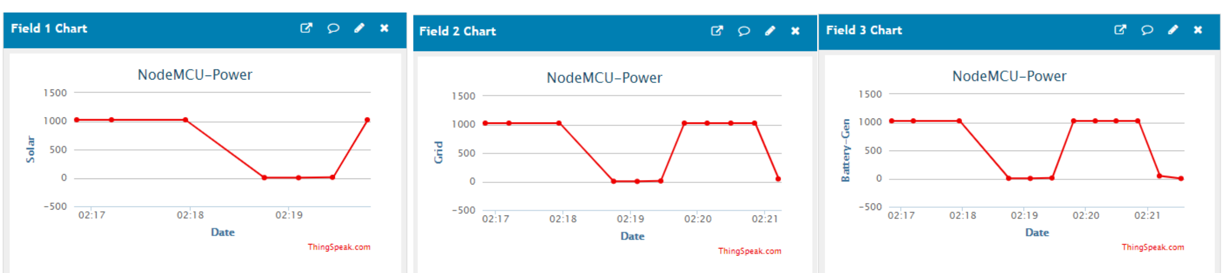


Figure 4.9 Solar, Grid and Battery-Gen State data on Thingspeak

Homepage

The result of the Flask web application shows a home web page form which user of EV will navigate to the dashboard of charging station to view it status. The home page is to help education Africans on evolution and trends on EVs and EV Charging through blogs.

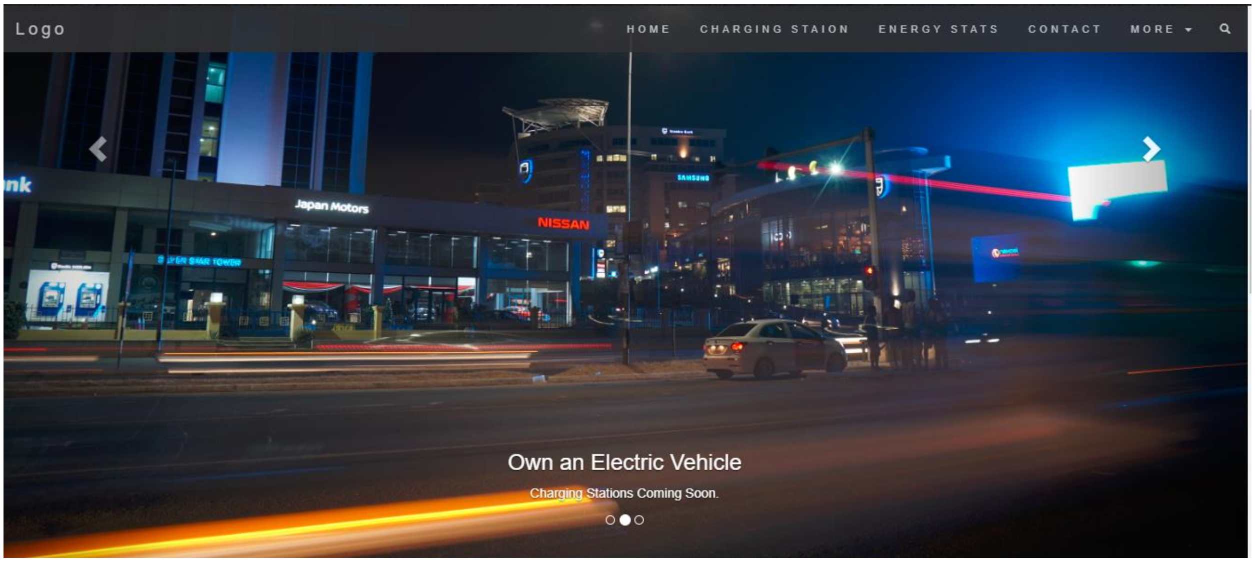


Figure 4.10 EVSE Web application homepage

Dashboard

The data, states of the available power sources and status of the charging station are shown in figure below of the dashboard as power table, state buttons and graphs respectively. The time stamps provide the registered time of every power source received by the application from the NodeMCU. The figure below

………………

Chapter 5 : Conclusion, Limitation and Future work

5.1 Conclusion

Although the take-over of Electric Vehicles by Ford model T combustion cars in 1912, research development in recent years have presented steady progress in energy to size ratio of battery technology that has amounted to great advances in electric vehicles. The zero-emission technology of EV has the potential in saving the planet from climate change and millions of lives that are lost through air pollution especially in Africa. Despite the global shift to electrification of transport systems, high carbon contribution form Ghana's transports according to DVLA has presented the need for adoption of EV. However, unreliable power supply and lack of charging stations deter the adoption of EV. The aim of this project was to bridge this space by building an affordable Level 2 charging station to welcome EVs in Ghana.

This project explored the design and implementation of Level 2 charging infrastructure as an IoT system in the visualization, monitoring of status and selection of available power sources for reliable charging of EV. Using techniques like automatic power switching, pilot signaling and GFCI to control charging of the EV and a web application to interface with the charging station.

The results of the from testing and implementation shows the charging station serving as an IoT interfacing with charging station in near real time. The result of the charging handshake and control results from testing are consistent with literature result of pilot signaling wave forms during handshake the SAEJ1771 level 2 charging standards. In attempt to welcome the adoption of EV in sub Saharan Africa, this is the first pilot project of its kind (to the best of my knowledge) to provide uninterrupted power supply for charging EV from alternative power sources.

5.2 Limitation and Challenges

This section is dedicated to discussing the several challenges faced which affected results of obtained for the performance of the charging station and its power switching circuit during testing.

1. The SAEJ1772 cable plug was too expensive and was not acquired. Also, because there is no EV in Ghana, testing of the charging station with an actual EV cannot be done even if the SAEJ1772 was acquire

2. The charging station not been testing with an actual However an incandescent lamp was used in most of the testing.
3. Despite voltage from the CT being amplified by the integrator circuit the GFCI output was not working as expected because of issue with the comparator circuit
4. The two circuit boards, main power supplies and the atmega328p were not make us one because of high voltage running through the main power supply section. Apart from the sub power section, the main power supplies connection to the NodeMCU could not be implemented and on a bread board because it was going to damage the breadboard.
5. On the software side, MQTT protocol could not be used for data transfer. Though publishing of data to remote and local broker via MQTT using the NodeMCU as a client was successful, subscribing to the broker using flask was unsuccessful
6. Due the use of single layer PCB to allow printing of the board locally, 98% routing was not achieved for the system controller board. Therefore, jumper wires were used to connecting the remaining unrouted pins externally.

5.3 Future Works

- Importing of EVs and EV charging trends on home page of web application to educate Africans especially new EV users on the evolution of EV and their charging technologies
- The current EVSE system is designed to be used for free but in the near future the estimation of tie of charging and calculation of corresponding cost must be implemented allowing charging of EV users.

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Appendix A

SAE J-1766	Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing
SAE J-1797	Recommended Practice for Packaging of Electric Vehicle Battery Modules
SAE J-1798	Recommended Practice for Performance Rating of Electric Vehicle Battery Modules
SAE J-2288	Life Cycle Testing of Electric Vehicle Battery Modules
SAE J-2289	Electric Vehicle Battery Pack System: Functional Guidelines
SAE J-2380	Vibration Testing of Electric Vehicle Batteries
ISO/CD 12405-1	Electrically propelled road vehicles—Test specification for lithium-ion traction battery packs and systems—Part1 High power applications
SAE J-1772	SAE Electric Vehicle Conductive Charge Coupler
SAE J-1773	SAE Electric Vehicle Inductive Coupled Charging
SAE J-1850	Class B Data Communications Network Interface
SAE J-2293 Part 2	Energy Transfer System for EV Part2: Communication Requirements and Network Architecture
SAE J-2836 Part 1	Use Cases for Communications between Plug-In Vehicles and Utility Grid
SAE J-2836 Part 2	Use Cases for Communications between Plug-In Vehicles and the Supply Equipment (EVSE)
SAE J-2836 Part 3	Use Cases for Communications between Plug-In Vehicles and the Utility Grid for Reverse Flow
SAE J-2847 Part 1	Communications between Plug-In Vehicles and Utility Grid
SAE J-2847 Part 2	Communications between Plug-In Vehicles and the Supply Equipment (EVSE)
SAE J-2847 Part 3	Communications between Plug-In Vehicles and the Utility Grid for Reverse Flow

Appendix A 1 Shows the SAEJ1772 standards

Appendix B

```
const int pilotRead = A0;

const int pilotPinPWM = 3;

const int setRelay = 12;

const int resetRelay = 11;

const int ChargeRequestPin = 2;

const int VehiDetectionPin = 5; // vehcile detection pin


// at the prior to charging

bool vehiclePrescence = false;

bool ChargeRequested = false;


// state of charging

const int led_red = 9;

const int led_blue = 12;// indicat car is plugges in

const int led_green = 17;


void setup() {

// put your setup code here, to run once:

pinMode(pilotPin, OUTPUT);

TCCR2A = _BV(COM2A1) | _BV(COM2B1) | _BV(WGM21) | _BV(WGM20);

TCCR2B = _BV(CS22);

OCR2A = 180;

OCR2B = 50;


pinMode(ChargeRequestPin, INPUT_PULLUP);

pinMode(vehiclePrescence, INPUT_PULLUP);

pinMode(setRelay, OUTPUT);

pinMode(resetRelay, OUTPUT);

}
```

Appendix B 1 Shows the void setup code of the system controller Atmega328p

```
void loop() {
 // put your main code here, to run repeatedly:
  if(vehiclePrescence == true){
   digitalWrite(led_blue, HIGH);
   analogWrite(pilotPin, 64); //pwm signal now has pwm on it. 001% duty cycle
   }
  else{
   digitalWrite(led_blue, LOW);
   analogWrite(pilotPin,255); //back to full dc signal
   }


  if(vehicleDetected==true && ChargeRequested==true){
   delay(1000);
   checkStatus();
  //GFCI checking
  if(vehicleDetected==true && ChargeRequested==true){
   digitalWrite(led_blue, HIGH);
   digitalWrite(setRelay, HIGH);
     digitalWrite(led_green, HIGH);
   }
   else{
     digitalWrite(led_blue, LOW);
     digitalWrite(resetRelay, LOW);
     digitalWrite(led_green, LOW);
     }
   }
```

Appendix B 2 Shows the loop code of the Atmega328p

```
void checkStatus(){
 //check if vehicle is connected
 //check if vehcile is requesting a charge
 vehiclePresence = !(digitalRead(proximityDetctionPin));
 //if receiving pulses, then no car is requesting a a charge
 //else if charge is request puls eis zero
 if(pulseIn(ChargRequestPin, HIGH, 5000)> 0 ){
  ChargeRequested = false;
  }else{
   ChargeRequested = true ;
   }
 }
```

Appendix B 3 Shows the “checkstatus” function that checks the state of a Vehicle

Appendix C

```
@app.route("/update/API_key=<api_key>/mac=<mac>/field=<int:field>/data=<data>", methods=['GET'])
def update(api_key, mac, field, data):
    print(data)
    if(api_key == API_key and mac == MAC):
        print('Confiuration checks')
        print("data:", data)
        print("Connecting to database")
        time = datetime.datetime.now(tz=pytz.timezone('Africa/Accra'))
        date_time_str = time.isoformat()
        charge = Power(api_key = api_key ,mac = mac, field = field, data = data )
        db.session.add(charge)
        db.session.commit()

        print('database updated')
        print('Successful update')
        return render_template("recent.html", data= data, time_stamp = date_time_str)
    else:
        return render_template("error.html")
```

Appendix C 1 Shows how HTTP API for data transfer

```
@app.route("/charging")
def dashboard():
    data = Power.query.all()
    solar_data = Power.query.filter_by(field='1').all()
    for sdata in solar_data:
        print(sdata)
    print("?????????????????????????????????????????????????????????????")

    grid_data = Power.query.filter_by(field='2').all()
    for gdata in grid_data:
        print(grid_data)

    print("?????????????????????????????????????????????????????????????")
    batt_data = Power.query.filter_by(field='3').all()
    for bdata in batt_data:
        print(bdata)
```

Appendix C 2 Show how power sources are queried