CHAPTER ONE

1.1 BACKGROUND TO THE STUDY

Transportation is as old as human existence. As taught in elementary science that movement is one of the characteristics of a living thing; therefore, human beings being the most versatile of all creatures on earth are the most mobile. Non-living things are also moved from one place to another. Movement can be short or far, slow or fast, light or heavy; whichever the case may be, it can require some form of assistance. The assistance has developed over the years from primitive to highly sophisticated. It has also been a measure for civilization.

The stages of transportation have developed from use of animals (horses, donkeys, elephants etc), to two wheelers (carts, bicycles, etc), threewheelers (tricycles, drawn carts etc.) four wheelers (cars, lorries, etc.) to flying ones (airplanes: aero planes, helicopters etc.). Road transportation plays a defining role in a country's economic progress (Majumdar and Jash, 2015). In planning cities and settlements, provision is always made for easy movement; layout of communities is not only for esthetic purposes, but also for easy and free movement.

Development of types of automobiles for transportation depends on the use, regulations and standards and the technology available per time. Threewheeler is in the middle of two wheelers and four wheelers in commercial transportation. Its development date back to 1880s and it is more acceptable than the two wheelers for certain group of people who found themselves in the position of choosing between the two. The three wheels are designed such that the two rear wheels are the 'driver' while the one in the front is the 'steer'. One of the considerations for them is that it has a seat and a back rest depicting more comfortability similar to that of a car. It also has a body for safety in the event of an accident or crash. It can be used to carry loads and luggage from within a rather closed place like a market or a work yard.

The need for a transmission in an automobile is a consequence of the characteristics of the internal combustion engine. The threewheeler, considered in this research is the autorickshaw known as *keke napep* in Nigeria. However, autorickshaws make use of a set of gears for its transmission. Most research carried out on the autorickshaw has been on exhaust, pollution, fuel efficiency, economic values, prime mover (Pandey *et al*., 2015; Asghar, 2016; Reynolds *et al*., 2011 and Grieshop 2012). Little work has been done on the transmission, especially giving consideration to providing an alternative to the manual transmission common with the design, which is strenuous in gear change.

A Continuously Variable Transmission (CVT) (also known as a single-speed transmission, stepless transmission, variable pulley transmission, or, in case of motorcycles, a twist-and-go) is an automatic transmission that can change seamlessly through a continuous range of effective gear ratios. This contrasts with other mechanical transmissions that offer a finite number of gear ratios. The flexibility of a CVT allows the input shaft to maintain a constant angular velocity (Sanmugan, 2016). This mechanism is therefore considerd for use in the autorickshaw and performance characterisation carried out to observe the outcome in the output and performance of the selected autorickshaw.

1.2 PROBLEM STATEMENT

Autorickshaw is a major commercial means of transportation in surburbs in Nigeria. It plies interiors, streets, and areas where there is no much passenger that would warrant taxi cabs or when motorcycles are not allowed especially in wellstructured Estates. The design of the autorickshaw is an upgrade for the old vespa motorcycle, which is no longer in use in Nigeria except for some personal use in the Northern part of Nigeria.

Automobiles generally, are optimized for easy movement based on various driving conditions and topography and terrain where they are used. The transmission system is the major determinant of this effectiveness. Electronically actuated CVTs allow engine to operate at a wide range of speed which consequently results in optimal fuel consumption; therefore their use in hybrid vehicles.

A preliminary survey made to three clusters which serves as the park for *keke marwa* operators. Information about the autorickshaw were gathered from the drivers to determine the performance and operational ability coupled with the challenges faced in using the vehicle. It was revealed that the greatest challenge was in the gear change mechanism. It is located on the left arm lever which also supports the clutch. By this, both clutch and gear are engaged and disengaged using the left palm at the same time, by holding down the clutch lever and turning the arm to the desired gear number. The negative effect of this on the drivers is sprain on the left arm as it is stretched as many times the gear is changed. The gear is constantly changed due to the driving cycle of the vehicle and the location where they are used; where cruise condition is seldom attained.

1.3 AIM AND OBJECTIVES OF THE STUDY

The aim of this study is to verify the adaptability of a continuously variable transmission unit into an autorickshaw engine originally fitted with a manual gear transmission to eliminate the strenuous gear change associated with the autorickshaw.

The objectives of this study are;

- To design and fabricate a dynamometer for the test
- To construct a test rig that is adaptable for testing any kind of autorickshaw engine
- To retrofit the autorickshaw with a CVT
- To analyze and compare the result of the manual and the CVT retrofitted autorickshaw transmissions.

1.4 JUSTIFICATION

The increasing risks of accidents and the use for crimes associated with two wheelers especially motor bikes has already called for many states in Nigeria banning their use on major roads and high ways in the metropolis. This has given more acceptability and popularity to the autorickshaw which has a lower record of accidents. Developing and underdeveloped nations have the autorickshaw major transportation means in their major markets where both human beings and motor vehicles share the same road. The use of Autorickshaws otherwise known as Keke Marwa in Nigeria has come to stay (Radhakrishna, Srinivasa Rao and Sudhakara Rao, 2015).

A preliminary survey was carried out to get usage information on drivers using the autorickshaw for commercial purposes. The survey showed that the design of the autorickshaw has a flaw in the transmission. The flaw being that the handle otherwise serving as the steering has the left hand saddled with the responsibility of gear change combined with the engaging and disengaging the clutch. This is done by the driver opening wide his palm to release the clutch while turning the arm clockwise or counterclockwise for gear change. The rather negative short term effect of this exercise is that the driver soon experience strain in the palm which is more pronounced in the purlicue which is the flesh between the thumb and fore finger.

Solving this problem would make the autorickshaw friendlier for use in various areas and adapted for various types of vehicular need such as ambulances, taxis, shuttles cab, carriage and other relevant use. Its use is all over the country as an alternative to taxis and motor bikes popularly called *okada*. Some people prefer to make use of the autorickshaw rather than the motorbikes because it is safer. It is easier to manipulate the autorickshaw because of its narrow body (Radhakrishna, Srinivasa Rao and Sudhakara Rao, 2015), compared to taxis especially in areas where there is no much space for maneuvering.

It is also more fuel efficient compared to cabs and can take up to four passengers at a time thereby making the cost of transportation cheaper. The compactness of this means of transportation is another point of edge because it can be driven in busy areas especially in the clumsy markets which (Manchanda, 2016) are typical of most markets in Nigeria. This scenario is also common in certain parts of the Asia in countries like China, India, Banglasesh and others where they have adapted the autorickshaw to suit various needs.

Adapting the rubber belt CVTs for use in the autorickshaw is an option worth exploring as it has found acceptability in small motorized vehicles, where mechanical simplicity and ease of use outweigh comparative inefficiency. The majority of automotive vehicles manufactured today use fixed ratio transmissions, which results in the engine not operating at an optimum point at all times. This affects the fuel efficiency and increasing emissions. Meanwhile, vehicles equipped with CVT allows engine work at optimum rpm (Bell, 2011). Most snowmobiles, golf carts, scooters and utility vehicles, make use of CVTs. These automobiles have similar engine capacities as autorickshaw engines.

Dynamometers for automobile engine testing are very expensive, therefore there is the need to design and construct one that can be used in the laboratory, especially for this work. The dynamometer needed should also be able to subject the engine to varying load conditions which would mimic driving conditions; low load, medium load and overload.

1.5 SCOPE OF THE WORK

The scope of this work was limited to determination of the engine output parameters for defining the performance of an autorickshaw by testing it on a rig designed specifically for it. Also a dynamometer designed for this experiment produced various loading conditions to the engine while in operation. The output parameters were; Engine Speed, Engine Power and Energy output.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

2.1 Autorickshaw

India has the largest utilization and manufacture of the autorickshaw: it is a major means of transportation especially in the surburbs and urban areas. It is the most affordable means of transportation for local people in some underdeveloped countries like Kolkata metropolitan city in India, where over 57% of the autorickshaws in operation do not necessarily require license to operate (Asghar *et al*., 2016; Sen *et al*., 2011)

There is a great increase in the use of autorickshaw more rapidly than urbanization. India has more than 2.5 million autorickshaw with more than 250000 new ones sold yearly (Mulhall *et al*., 2010). Gore *et al*. (2015) was of the opinion that there would be a sharp rise in the use of threewheeler in the next two decades, because of its ease of adaptability for various transportation need. A Bajaj model of autorickshaw is presented in Fig 2.1. Mulhall and Emadi (2009) reported that the design of autorickshaw has remained crude and not updated since it was introduced.

It is the most affordable means of transportation in some countries (Asghar *et al*., 2016). Autorickshaw drivers face considerable criticism from public, media and policy makers with contentious public debates about faults in autorickshaw and their drivers and the policies to address them. Harding *et al*. (2016) worked on setting a balance for these group for a more effective consideration vis a vis autorickshaw users, traveling public in policy making. The major contentions discovered are congestion, safety and air pollution.
The autorickshaw has been adapted for use in various automobile applications and needs. An effort was made aimed at seeking a nationwide implementation of the autorickshaw for use as an out-of-hospital vehicle taking to consideration its abundance,

vehicle and driver limitations, limitation of ambulances, expenses for government and benefit to the community at large (Joshi *et al.*, 2008). There are also mechanized van rickshaws that are locally assembled and run mostly for load carrying (Majumdar and Jash, 2015).

2.2 History of Autorickshaw

According to Vera and Nantes (2015) rickshaw-like vehicles came from 17th century in France, under the reign of King Louis XIV, when mobile chairs appeared. Also, they were supposedly described as ‘mobile thrones’ which were usually pulled by two servants at a time. Jonathan Goble was credited as the inventor of the original design of the first pulled cycle rickshaw. The original rickshaw, was a human-drawn vehicle, much like the traditional ‘tuk-tuks’ found on the streets of Thailand (Dawn News, 2012). An offshoot of this was the bicycle driven rickshaw shown in Fig 2.2.

It was reported that Bajaj Auto Limited also known as ‘M/s Bachraj Trading Corporation Private Limited’ introduced these autorickshaws to India 1959 being inspired from Piaggio's Ape model design of the then popular ‘Vespa’. As it was the norm for Patency, Bajaj Auto Limited produced the earliest autorickshaws as seen in Fig. 2.3 having obtained license from Piaggio (Anand, 2013).

Fig 2.1: Taiwan autorickshaw

Fig 2.2: Bajaj RE autorickshaw

Autorickshaw became very popular in Japan by 1872, where 40 000 rickshaws were in operation in Tokyo. Within 10 years of the invention of autorickshaws, over 150,000 autorickshaws appeared in Japan. It was still massively used until World War II due to the increase in the cost of Petrol after which motorized vehicles were introduced. From here, it spread to other parts of Asia which includes; China, Singapore and Burma around the 20th Century. In 1914, the Chinese government gave permission for rickshaws to be used to transport people and soon which later spread to all the big cities of South Asia, and it was a source of livelihood for majority of immigrants resident in small villages. It was alive in South Africa for a while and it was then pulled by the Zulu tribe (Manchanda, 2016).

The Pakistani government outlawed the pulled rickshaw in the early 1960s. The government also resolved to turn shift to the use of Compressed Natural Gas (CNG) rickshaws by 2015, because they are environment-friendly, have reduce noise and air pollution and do not emit steady black smoke when started (Dawn News, 2012).

Recent changes to four-stroke engines as well as those powered by diesel, Compressed Natural Gas (CNG) or Liquefied Petroleum Gas (LPG) reduce the pollution and greenhouse gas emissions. To determine the possibility of using fuel cells for autorickshaw, two drive cycles of conventional autorickshaw and fuel cell hybrid autorickshaws were simulated (Abu *et al*., 2010). Some earlier autorickshaws made use of a mixture of diesel and kerosene for their fuel (Sen *et al*., 2011).

A study shows that over 72% of the pollution in New Delhi was caused by transportation, a large part of it by the autorickshaws and two wheelers, before the current anti-pollution regulations came into force. The world population will grow up to 11 billion people in 2050 and as this will happen mostly in non-OECD (OECD – Organisation for Economic Co-operation and Developement) countries, the rise in energy consumption will even be higher. It can thus be deduced that increase in population results in increase in automobiles and increase in pollution (Vezzini *et al*., 2005).
The small size and streamlined body of the autorickshaws make more navigation easy, so they are more appropriate for use especially in congested areas (Lukic *et al*., 2007). The Multi-Body Dynamic (MBD) of a three wheeler was developed using the commercial software ADAMS-CAR, where all components are initially assumed to be rigid. The essence was to model a vehicle that is close to reality to predict the frequency and damping of the wobble mode more accurately (Gore *et al*., 2015).

A solution that makes use of fewer mechanisms without the usual comfort and luxury as involved in vehicle to convey human beings which can fit perfectly well to the use desired and not expensive is what is usually sought for. Alternative energy sources have been introduced for use in the autorickshaw to help deal with noise and pollution. Some of these sources are; electric, solar, compressed natural gas (CNG) and liquefied petroleum gas (LPG) (Lukic *et al*., 2007) which are discussed in this chapter.

2.3 Energies and Fuels for Autorickshaw

Automobiles are mostly run by various forms of energy because it is a form of energy conversion: Chemical Energy from fuels (petrol, diesel, gas, LPG, CNG) and Battery; Water Energy; Electric Energy and Solar Energy.

A survey carried out by Lukic *et al* in India helped to derive a usage pattern for the autorickshaw by gathering information through the use of Global Positioning System (GPS) data and physical survey of autorickshaw drivers (Lukic *et al*., 2007). Autorickshaw have been suggested for use as dump collector in rural areas in India which have very narrow roads. It is more appropriate because of its narrow body, so it is a good replacement for the normal heavy trucks fitted with dump bodies. An autorickshaw dump body for 750 payloads was designed and stress analysis was carried out using finite element method to determine the best body shape design (Radhakrishna *et al*., 2015).

Data gathered from dynamometer test conducted for 40 Indian autorickshaws with three different fuel-engine combinations operating on the Indian Drive Cycle (IDC) were used to develop velocity-acceleration look up tables for fuel consumption,

CO_2 emission, CO, total hydrocarbons, nitrogen oxides and fine particulate matters for each fuel-engine combinations (Grieshop *et al.*, 2012). Also, emission characteristics of Indian Drive Cycle and a Modified Indian Drive Cycle were compared by Adak *et al*. (2016).

2.3.1 Electric Autorickshaw

They are usually referred to as E-Rickshaws. They have gained more popularity owing to the comfortable and economic mode of transportation. E-rickshaws are equipped with brushless DC motors for vehicle propulsion powered by lead-acid batteries

(Majumdar and Jash, 2015). In an electric vehicle, efficiency is more important than its direct effect on range coupled with the fact that the electric propulsion system is the only source of energy (Mulhall and Emadi, 2009).

A retrofitted emissions-free autorickshaw called ZERO, fuelled by a hybrid of solar, electric and human power was innovated. The factors considered in the final design were environmental impact, safety, ergonomics and cost. A decision matrix was used to choose the renewable energy among other alternatives that would best meet the design objectives of a solar/battery electric autorickshaw (Valerie and Swift, 2009).

In the design of an electric propulsion for an electric autorickshaw, Mulhall and Emadi (2009) varied size and speed capabilities of the motor in the ADVISOR to give the corresponding efficiency, vehicle gradeability and acceleration abilities of the vehicle for analysis.

In India, it was recorded that the average specific energy consumption of the electric autorickshaw given as 53.76 kJ/passenger-km is greater than that of others. This has helped to boost its chances of proper implementation in the public transport sector (Majumdar and Jash, 2015).

2.3.2 Solar powered Autorickshaw

The greatest problem facing the world today is Global Warming (Athavankar and Singh, 2016). The idea of automobile is need dependent, so also is the design, body building and the aesthetics. The conventional cars are elegantly built both within and without. But vehicles or automobiles built to address specific or peculiar needs may not be in the aesthetic order of the conventional automobiles.
Another factor is cost. These vehicles cannot be built to those standards because of cost. Part of the need being addressed is to present an effective, cheap and convenient means of transportation for whatever is needed to be transported (Prabhu and Manigandan, 2014).

In this design, energy is stored in batteries or otherwise cells. Four 12V, 20Ah rechargeable batteries were used in series to provide 48 Volts to the BLDC motor. These were lead-acid batteries each weighing 7.1 kg and 181 × 77 × 171 mm in dimension.

The batteries were accommodated inside the seats (Rahman *et al*., 2004). Energy storage capacities of batteries have been said to be averagely 25 times heavier than and 10 times the volume of fossil fuel which results in a heavier autorickshaw. It offers a cleaner and energy efficient vehicle, but reduced travel distance before recharging (Asghar *et al.*, 2016).

Athavankar and Singh (2016) presented various designs for a self-sufficient solar powered four (4) seater autorickshaw with speed range 25-40 km/hr, and has an average uphill inclination of 15^0 to 30^0. Conceptual infrastructure designs are modeled and optimized in the Hybrid Optimization Model for Electric Renewables software called HOMER. The Solar/Battery is meant to match the conventional vehicle's performance but with more intelligence and efficient design (Mulhall *et al.*, 2010).

2.3.3 Hybrid/Electric autorickshaws

Hybrid cars are cars with two sources of power, that is petrol and electricity. There are many sources of power for the electric autorickshaw (Fig 2.4) such as wind, thermal, chemical among others. Hybrids have been looked at as a possible solution to resolve consumption and pollution problems without having to reduce performance or range compared to a normal car. It has been discovered that the hybrid cars have more acceptable performance compared to either the electric vehicles or the ICE engines respectively. It can be classified under low emission vehicles (Vezzini *et al*., 2005). The basis of use of hybrid configuration is that when power supplied by the electric motor is not enough to drive the vehicle or the battery charge is very low, then the hybrid configuration is used otherwise, the electric system would continue to be in use (Ravitega *et al*., 2014). An array of electric autorickshaws are presented in Fig 2.5 below.
Problems caused by the gasoline engine on the environment and people, informed the idea of hybrid electric vehicles and electrical powered vehicles (Asghar *et al*., 2016). They also improve the social and economic status of the user (Hofman *et al*., 2009).

Abu *et al*. (2010) reported that in an experiment to compare the performance of the conventional rickshaw and a designed hybrid rickshaw, the Low Power Fuel Cell configuration was seen to be better than the conventional configuration when considering both the performance efficiency and the environment. Upon comparison and experimentation, it was also concluded that the Low Power Fuel Cell configuration is better than the High Power Fuel Cell model in both performance and cost.

A fully automated hybrid vehicle with 21% reduction in both fuel consumption and CO_2 emission was retrofitted into a two-stroke engine three-wheeler taxi according to Hofman *et al* (2009). Vezzini (2005) also presented charts illustrating the comparison between consumption in ICE engines (Fig 2.6), normal engine configuration (Fig 2.7) and series hybrid configuration (Fig 2.8) for autorickshaw.

There have traditionally been two main hybrid power train configurations; the series and parallel. The series configuration consists of an engine which drives a generator, producing electricity to drive the motor: This system operates a small engine at its most efficient condition, resulting in good fuel economy and low emissions while the parallel configuration permits both the engine and the motor to drive the vehicle through a torque coupler. The system is designed for the engine to work under high load conditions where the internal combustion engine offers its maximum efficiency (Vezzini, Sharan and Umanand, 2005).

Fig 2.3: A picture showing electric autorickshaws

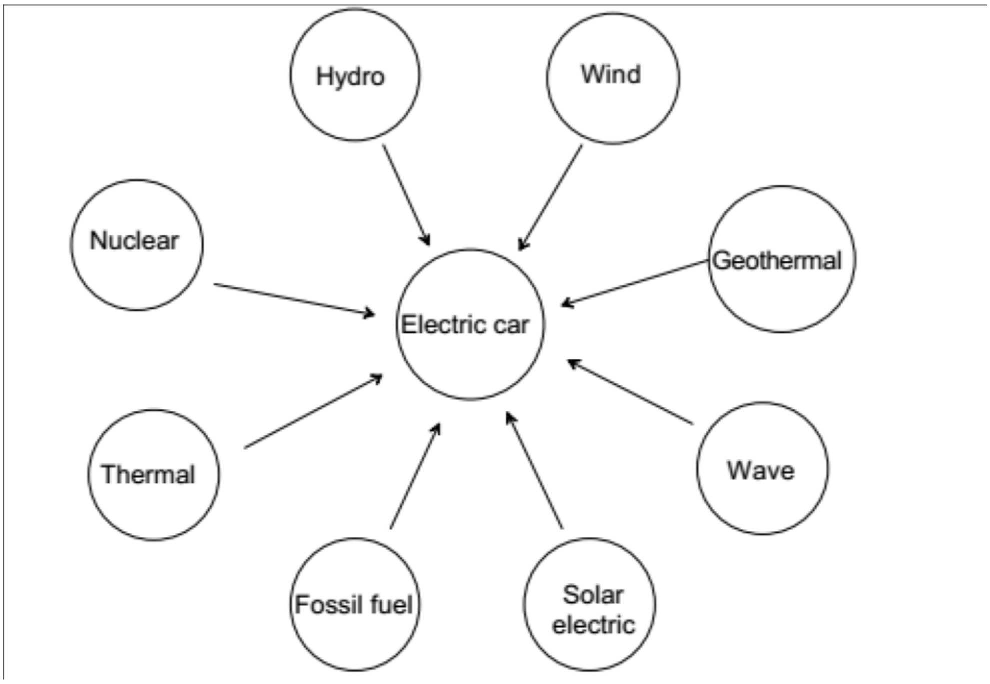


Fig 2.4: Energy Sources for an Electric Car (Vezzini *et al*., 2005)

Fig 2.5: Solar Vehicle Schematics (Rahman *et al.*, 2014)

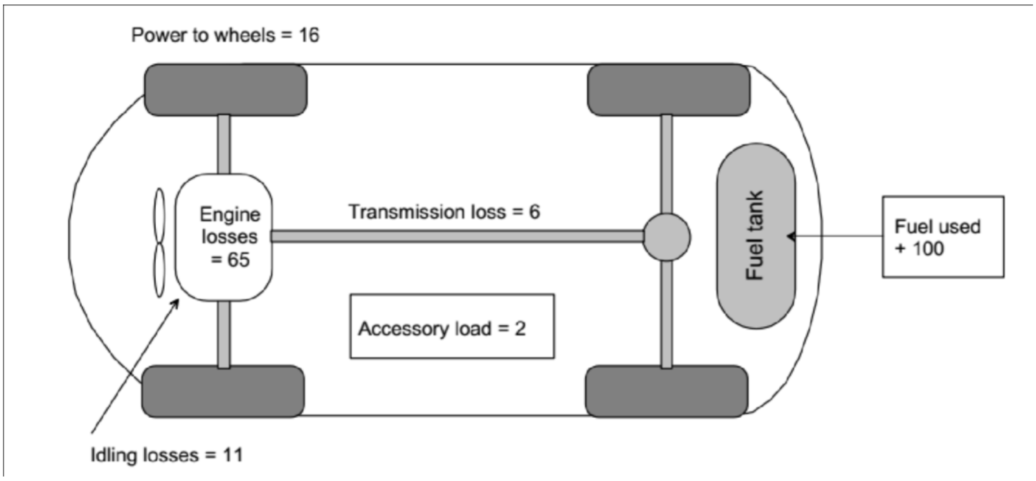


Fig 2.6: Normal internal combustion engine (ICE) vehicle configuration (Vezzini *et al*., 2005)

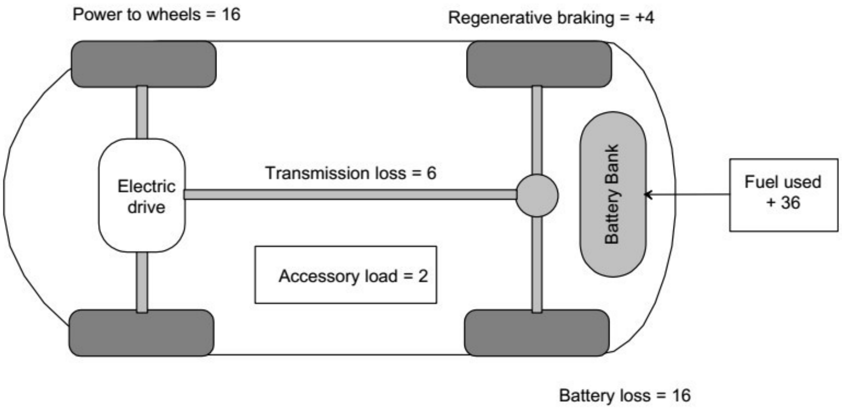


Fig 2.7: Normal electric vehicle configuration (Vezzini *et al*., 2005)

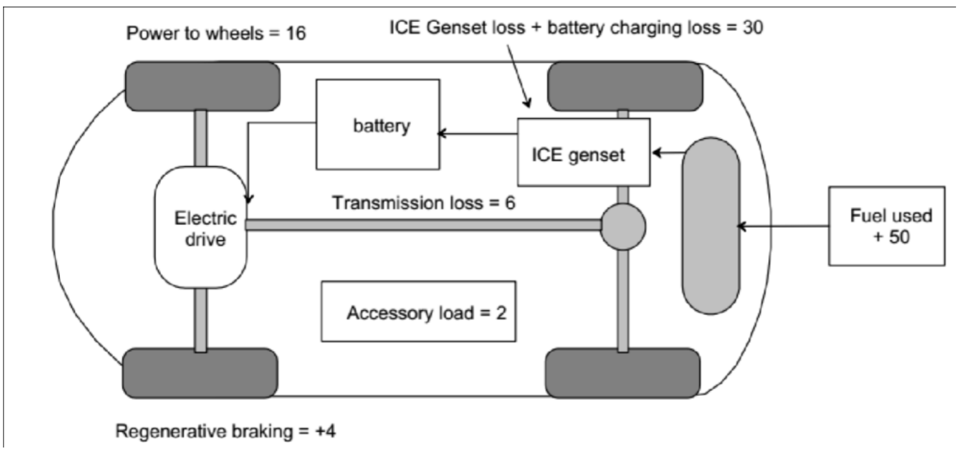


Fig 2.8: Series hybrid configuration (Vezzini *et al*., 2005)

2.3.4 Emission and other factors

Reynold *et al*. (2011) discovered that two stroke engines are categorized as high Particulate matter emitter (PM-emitter) compared to four stroke engines. They also have about 20% consumption rate and CO_2 emissions higher by conducting an observational inspection for oil-residing in exhaust pipe and visible smoke at engine start-up. Emission Factors (EF) for three vehicle categories; motor cycle, shared auto-rickshaw and passenger cars are presented in Fig 2.9 with passenger cars having the largest emission(Reynolds, Kandlikar and Badami, 2011)(Reynolds, Kandlikar and Badami, 2011)(Reynolds, Kandlikar and Badami, 2011). The emission of autorickshaw is very high at low speed and engine start up at stop-and-go where there is congestion or interrupted traffic flow. This happens mainly during peak and off-peak periods (Choudhary and Gokhale, 2016). Kim *et al*. (2017) worked on the various emission characteristics of an autorickshaw engine for a period of five years, comparing between gasoline powered engines, diesel powered engine and LPG powered engine: CO and NO_2 having the highest value as seen in Fig 2.10.

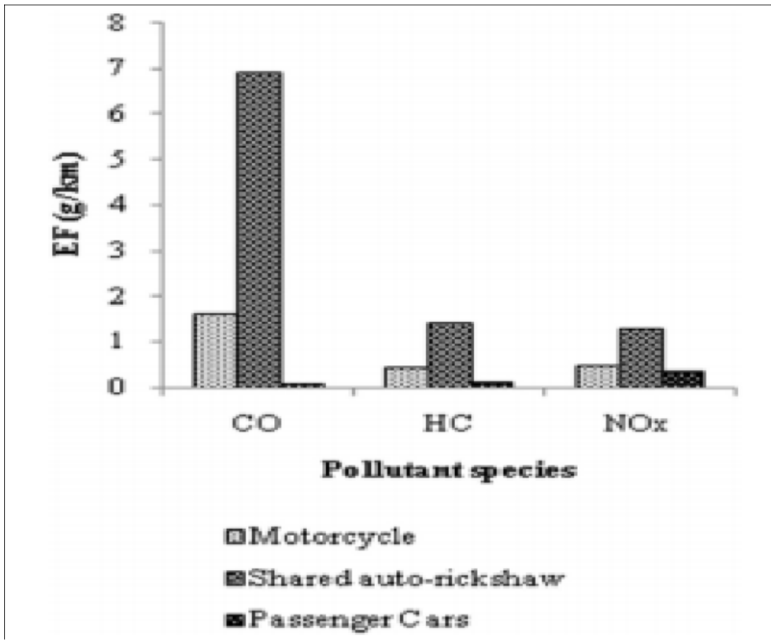


Fig 2.9: Emission factor of three vehicle categories (Adak *et al*., 2016)

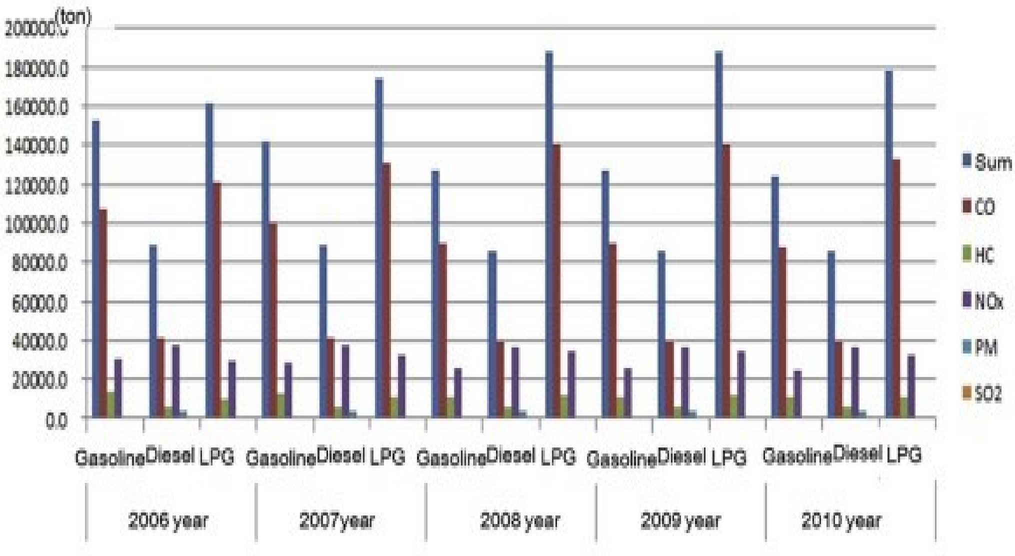


Fig 2.10: Annual air pollution by fuel (Kim, Lee and Kim, 2017)

A good noise characteristic of autorickshaws running on CNG (Compressed Natural Gas) is that its noise is moderate with increased speed compared to buses and taxis/cars (Anyogita *et al*., 2004). Reynolds *et al*. (2009) did a project aimed at measuring pollution emission factor in autorickshaw. The PM concentration was estimated in real-time using optical scattering and the particles were collected using transmission-electron microscope.

2.3.5 Others researches on autorickshaw

In order to reasonably compare the performance of hybrid autorickshaw with the conventional ICE engine models, it is better to compare the power-train performance (Abu *et al.,* 2010). The hybrid autorickshaw was seen to be the most accessible vehicle during a medical emergency (Joshi *et al*., 2008).

A study on the attitude of autorickshaw drivers carrying school children while driving on the highway and while overtaking, coupled with the attitude of other drivers overtaking autorickshaw carrying school children. The survey proved right the hypothesis that each group allows sufficient space between them while carrying school children which are not the case when other passenger/commuters are in the autorickshaw. The result revealed; 40% rear end collision, 10% head on, 25% unknown and others (side swipe, right angle etc) sharing the remaining 25% (Pandey *et al*., 2015).

2.4 Need for transmission system

When a vehicle runs, it encounters opposition to its motion. It is therefore necessary to build a system that will help overcome the resistance, so that the vehicle continues to move. This is called a tractive force/ driving force according to Prabhu and Manigandan (2014). If the tractive force is less than the resistance to the acceleration of the car, the car speed will be reduced and can eventually stop.

Vehicle acceleration = Tractive effort – total resistance affecting the movement of the vehicle ……………………………………………….. (2.1) (Prabhu and

Manigandan 2014)

2.5 Dynamometer

The main purpose of a dynamometer is to mimic driving condition in an indoor controlled condition. Dynamometer is used to measure such parameters as torque, speed, power and fuel consumption. Every invention and design has to be tested by creating all operating conditions of operation of the invention in a laboratory condition. Engine effective power evaluation can either be direct or indirect method. Direct methods usually make use of brakes or measuring speed and torque simultaneously while the indirect method uses approximate means (Chibowski, 2008).

A hydrostatic dynamometer was built to test various components of a four-wheel drive military vehicle by Rolewicz which makes use of pumps. The dynamometer uses pre-set data along with other vehicle parameter to calculate the proper torque needed to be applied at the vehicle's wheels at each instant throughout the drive cycle based on measured speed and acceleration. The measured parameters include fuel consumption, temperature and emissions (Rolewicz, 1987; Kohring, 2012).

A PC-based data acquisition micrometer was used for a dynamometer. The micrometer provided it with the ability to collect, analyze, display and store the data generated by the help of routines which subsequently simplifies the calibration of the sensors and provides verification of input signals read by the data acquisition system (Wagner *et al.*, 1990).

The entire energy and power produced by the engine in the absorption type of dynamometer is absorbed by the friction resistances of the brake which is wasted as heat energy. But in the transmission dynamometer, the energy is used in doing work by transmitting to other parts of the machine which measures the power developed (Gopinath, 2014).

2.6 Applications of dynamometer

Dynamometers are used for the following:

a) automobile engine performance testing
b) ascertain conformity of new engines to standard plots of power, torque and speed

c) to compare performance of different engines

A fractional horsepower dynamometer is used in Mechatronics, non-linear and adaptive control laboratory experiments because of its ability for generating arbitrary external torque load disturbances (Tarte and Chen, 2006).

2.7 Specific applications of the dynamometer

A dynamometer was developed to directly measure power output for a piezoelectric actuator energy output (Gyllendahl and Tran, 2012; Steltz and Fearing, 2009). In 2014, a rope brake dynamometer coupled with brake and motor was designed which measures the minimum torque and various factors involved while the design is done. The theory of this dynamometer is such that for every revolution of the shaft, rotor covers distance 2πRF against the coupling force which equals to the work done (Gopinath, 2014)

A comparison between Kin-Con dynamometer and an external recording system for force, angle and velocity from the Kin-Con dynamometer against known weights, angles and user velocities was analyzed using R^2 and its reliability determined using Intra correlation coefficient (ICC/2,1). The result was over 0.99 for the two consecutive days considered (Mayhew *et al.*, 1994)

Wagner *et al*. (1990), designed and built a dynamometer with PC-based data acquisition program for use in an electric motor dynamometer for research and educational use. The program was written in C-Language and a commercial library package was used to construct the menu system. The data acquisition system records motor torque and speed data, ambient air and motor winding temperatures and also motor power, current, voltage and power factor.

2.8 Handheld dynamometer

Souza *et al*. (2014) reported a study to determine hand grip strength in healthy children to synthesize with their weight, height, body composition and handedness by using a bulb dynamometer. The outcome proved the dynamometer's capability to effectively measure grip strength.

A three-point hitch dynamometer consisting of three telescoping beams was designed and used to measure forces between a tractor and implements. The measurement was made possible by adopting the use of strain gauges attached to a cantilever beam connected to a Wheatstone bridge (Al-Jalil *et al*., 2001). In another application, a chassis dynamometer was used to describe and refine the European Driving Cycle (EDC) (Casadei and Maggioni, 2016).

2.9 Tachometer

2.9.1 Description

This is the equipment used to measure speed of rotation of a shaft otherwise known as rotation per minute (rpm). Most mechanical dynamic systems are non-linear and so are described using non-linear equations of motion. It measures the number of rotation made within a second. Analytical and Computational results obtained were used to describe the characteristics of a rotational tachometer with vibrating support (Ge and Shiue, 2003) They can either be Non-contact or Contact sensing tachometers.

2.9.2 Contact Tachometer

A tachometer for oceanographic measurements was developed. It can be used for measuring the rate of descent of the cables and it consists of a DC generator and two meters. It is attached to the meter wheel for adequate measurement. The output was read at various locations on the ship (Cook, 1972).

2.9.3 Non-Contact Tachometer

The Non-contact tachometers make use of infra-red rays pointed at a reflective tape. It measures the speed of rotation by counting the light pulses reflected from a marker on a rotor. A tachometric marker with right angles V groove surfaces by silicon micromachining technique was presented by Weng and Shie (1990).

Graham and White Instruments Limited presented a portable, battery operated photo tachometer which required no mechanical or electrical connections to the rotating part whose speed is being measured. It has a sensing distance up to 20 inches and can read up to 20000 rpm with 1.5% accuracy range (Norgren, 1969).

High resolution telemetry, laser tachometer was used during the characterization of flow-induced rotation in a wind tunnel experiment. It was observed that there was a linear relationship between the pitching frequency and the wind speed (Jin *et al*., 2016). Digital tachometers are particularly suitable for the precision measurement and monitoring of all time related quantities, which are able to be converted into a proportional frequency using appropriate sensors. Time-related quantities include rotational and linear velocity, flow rate and related quantities. The instrument can be programmed to measure absolute values ratio, or proportional difference (Elektronik, 2017).

Maas and Beach in 2009 replaced a mechanical tachometer with an electronic tachometer for an Austin-Healey car and the operation of the tachometer was examined. Electronic tachometers count pulses generated by ignition system of the car or magnetic pickup sender. Anisotropic chemical etching was adopted to obtain the retro-reflective marker for an optical tachometer by Weng and Shie (2008).

2.10 Continuously Variable Transmission

Continuously Variable Transmission is usually abbreviated as CVT. It is the term used for a transmission with a range of speed ratio which changes seamlessly. It is an ideal power transmission device which allows power from the engine to be transmitted continuously to the ground. It is preferred to the conventional gear box transmission which takes time to shift gears, for engine and wheel disengagement which results in a loss of momentum.

CVT is a progressive gearbox able to develop a continuous range and infinite gear ratio between established minimum and maximum (Alessandro, 2013). The CVT also allows the engine operate at a constant speed, that is the speed which produces maximum power. This is very important and the best for automobiles with small range of power delivery. It also allows the angular velocity of the driving shaft to be maintained throughout the various driving conditions (Aher and Shelke, 2014)

2.10.1 Components of a VDCVT

The Variable Diameter Continuously Variable Diameter operates on three main mechanical components which are flyweights (cams), springs and ramps which are described as follows;

2.10.1.1 Flyweights: These are housed in the primary clutch and swivel on a pin. There can be more than one cam in the primary clutch depending on the application and are equally spaced around the housing. As the primary clutch rotates directly with the engine, the cams swing outward with a force governed by their mass and a direction based on their geometry. Therefore, in tuning the clutch, only the mass is variable (has to be changed to suit the output required) since other parts are predetermined.

2.10.1.2 Springs: They are located in both the primary and secondary clutch. The primary spring is a pressure spring and is located with the housing and works axially to hold the sheaves closed. The secondary spring is a torque spring which works to hold the sheaves open. These two springs work in alternative directions to each other. When the primary spring causes the primary sheave to open, the secondary spring closes the secondary spring.

2.10.1.3 Ramps: This is also known as torque sensitive cam and is located in the secondary clutch. There are three of them, evenly spaced around a cylindrical surface and the rollers act against them or roll over them. They work based on the angle and radius they are set to. A change in the angle is inversely proportional to the force exerted on the secondary sheave. It is illustrated mathematically thus;

[redacted] ………………………………………………………......(2.2)

Where T is the Torque

$M_{shift}$is the CVT shift ratio

$r_{ramp}$is the ramp radius

α is the angle of the ramp measured from the horizontal (angle the ramp makes with the horizontal). For CVT efficiency to be maximized, the engine has to be operated at its peak power or close to it (Ravitega *et al.,* 2014).

The study of a parallel hybrid configuration for speed and torque addition comparison was made involving an ICE engine and a DC motor. The model configuration designed adds speed by connecting the engine output through a CVT to the stator of an electric hub motor. Meanwhile the torque addition arrangement in use, couples engine output through CVT to a DC motor with the use of a gear transmission. The output power of the design was much higher for a low power requirement (Ravitega *et al*., 2014).

The behaviour of transmission can be changed by varying both the rollers acting on the plate of the drive pulley, and the stiffness of the spring that presses the plates of the driven pulley (Alessandro, 2013).

2.10.2 History of CVT

Clutch tuning has its effect on acceleration and fuel economy. It is also known as Single-speed transmission, stepless transmission, variable pulley transmission or twist and go. Its flexibility allows the input shaft maintain a constant angular speed.

CVTs have been used in aircraft electrical power generating system since the 1950s and in Formula 500 race cars in the early 1970s. The main advantages of

CVT are;

a) Increased driving comfort due to smooth transmission ration changes
b) Low fuel consumption due to large spread of gear ratio
c) Excellent dynamic of movement

At a period before 1994, the highest torque capacity of CVTs was between 150 Nm and 200 Nm, where the latter was produced in Japan. Presently, wider range of torque capacity CVTs are available in the market and in use. For example, CVTs of more than 300 Nm torque capacity were produced and in circulation at the Technical University of Karlsruhe (Faust and Linnenbrugger, 1995).

The followings are the factors that influences clamping force

a) Engine torque which is dependent on the driver and the electronic engine controls
b) Converter torque multiplication and clutch or lock-up clutch controls
c) The gear ratio
d) Lowest occurring friction coefficient
e) Nature and amount of torque required to drive wheels (Faust and Linnenbrugger, 1995)

2.10.3 Actuation methods of CVT

2.10.3.1 Hydraulically actuated CVT

Pesgen *et al.* (2003) designed a hydraulically actuated CVT. The controller was such that one makes clamping pressure act point to be minimal while the other was raised above this level for ratio shifting purpose. This approach enhanced the tracking of the CVT, increased efficiency and subsequently wear reduction. Each of the pulley which consist of moveable sheaves, are operated by an attached hydraulic cylinder each. The cylinders are pressurized at a range of pressures to give compressive and detractive forces on the moveable sheaves as illustrated in Fig 2.11 (Pesgens *et al*., 2006), while an exploded view of a CVT is presented in Fig 2.12.

Hydraulic actuation method for CVT has the greatest energy loss among other forms of Variable Diameter sheave (VDS) CVTs. A solution to this loss is to reduce the clamping force on the pulleys bearing in mind not to exceed the point where there would be much slip between the belt and the pulley. A nonlinear approach proposed by Bonsen *et al.* (2005) showed how slip can be effectively controlled to peak torque.

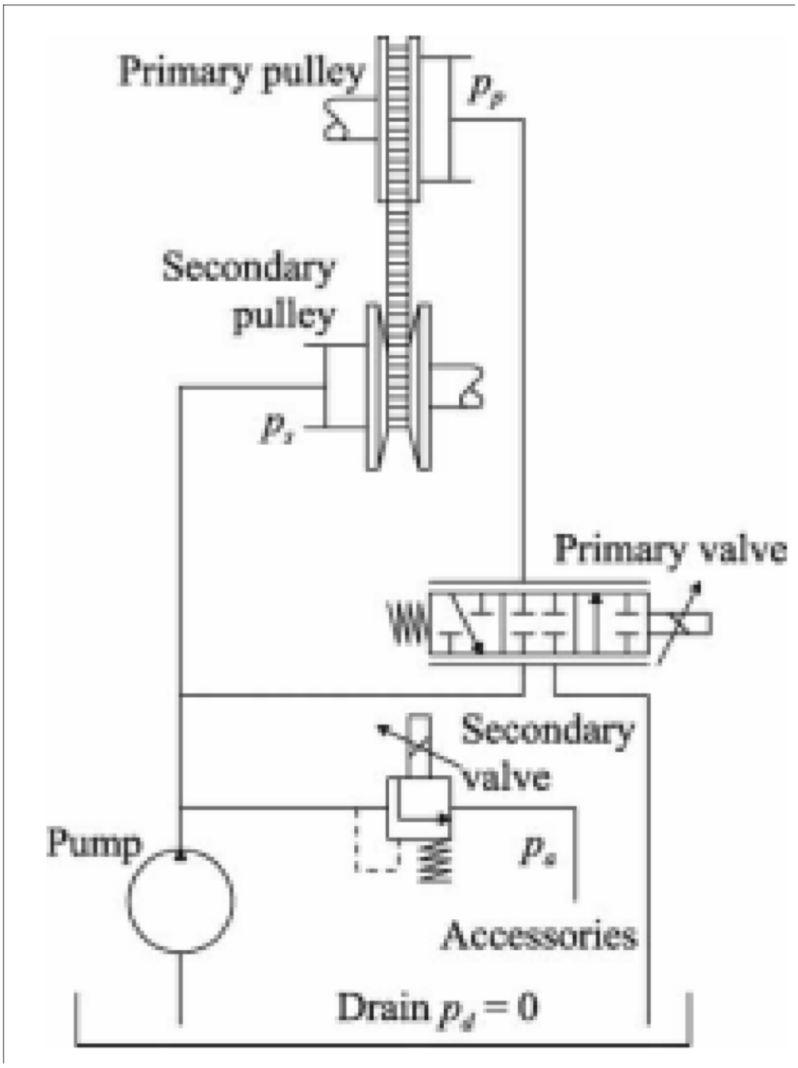


Fig 2.11 :Hydraulically Actuated CVT (Pesgens *et al*., 2006)

2.10.3.2 Electromechanically actuated CVT

Most CVTs have constraints in their actuation mechanism, therefore there is need to provide an assistant in the form of an electromechanical actuator. In this type of CVT actuation, the two pulleys are equipped with electromechanical actuators (Fig 2.13) attached to each moveable sheave. A kinematic analysis was done for clamping forces of the actuator, while a fuzzy logic controller simulated was used to predict the current corresponding to the actuation needed (Rahman *et al*., 2014). A model of this actuation method is shown in Fig 2.14, where all major driveline components, electromechanical actuation proposed and the servo motor were incorporated (Klaassen *et al*., 2004). The CVT has the capability of choosing engine speed irrespective of the vehicle speed. An electromechanical actuator was designed to overcome the power loss by hydraulic actuators. Only one electric motor actuates the two moveable sheaves while a second motor controls the clamping force (Meerakker *et al*., 2004). Optical Operation Line (OOP) is a stepped ratio control for electromechanical CVTs, which is the most efficient transmission for fuel economy compared to continuous ratio change (Bonsen *et al.,* 2005b).

CVTs have contributed immensely to reducing fuel consumption in scooters to the minimum. A scooter transmission was investigated and the brake specific consumption recorded. Then, an electromechanical actuation was introduced into the CVT which helped to isolate the engine revolution from the gear ratio change (usually the ratio change depends on engine rev). This method reduced the fuel consumption by over 40% (Grzegozek, 2016).

2.10.3.3 **Toroidal CVT**

These type of CVTs are also referred to as Roller based CVTs or Extroid CVTs. They can replace belt and pulley making use of discs and power rollers. The

Milner CVT does not need complicated external pressure for shifting (De Rijk, 2016). The various gear shift levels for a toroidal CVT are presented in Fig 2.16.

The first use of the toroidal CVT for vehicles was in 1999. A 390 N-m, 4.33 ratio half-toroidal CVT Power train unit was fitted into the transmission line of the vehicle as illustrated in the Nissan Extroid Toroidal CVT in Fig 2.17. A wider ratio, higher torque, higher efficiency and compact half toroidal CVT was reported (Shinojima *et al*., 2004). The torque transmitted and efficiency of chain drive CVTs depends on the friction forces and slip between the chain and the moveable pulleys (Tenberge, 2016)

2.10.4 Magnetic variable transmission

An electrically controlled magnetic variable-speed gearing machine (EC-MVSG) for Hybrid electric vehicles was proposed by Liu and Chau. The design adopts a magnetic gearing structure and a memory machine flux-mnemonic concept capable of both gear shifting and output variations in terms of speed and torque as illustrated in Figs 2.18 and 2.19 (Liu and Chau, 2014). Also an electroniccontinuously variable transmission (E-CVT) for power split Hybrid Electric Vehicles (HEVs) which integrates two permanent magnet motor/generators together with a rotatable coaxial magnetic gear and achieved both power splitting and mixing was designed and analysed by Jian and Chau (2010).

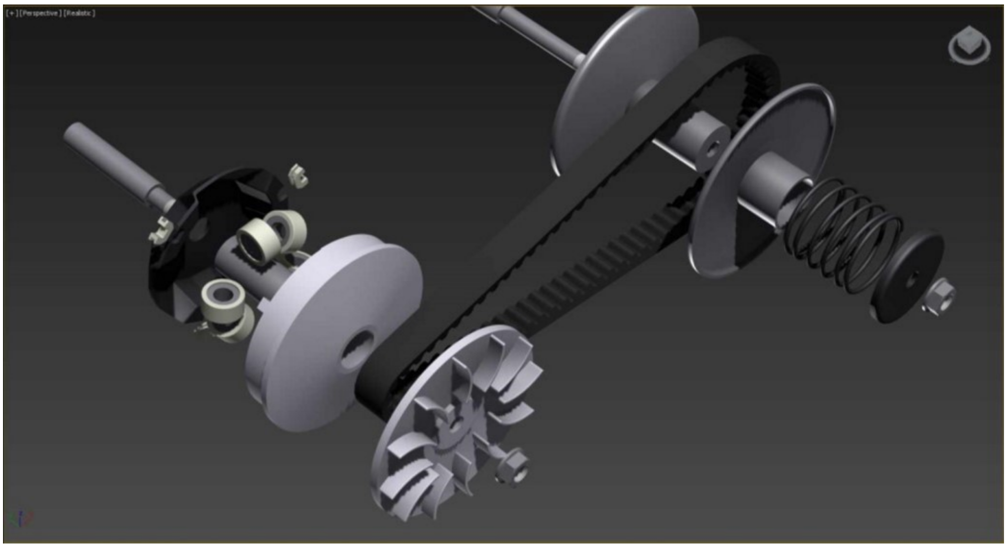


Fig 2.12: Exploded view of a CVT

Fig 2.13: An Electromechanically Actuated CVT System (Rahman *et al.*, 2014)

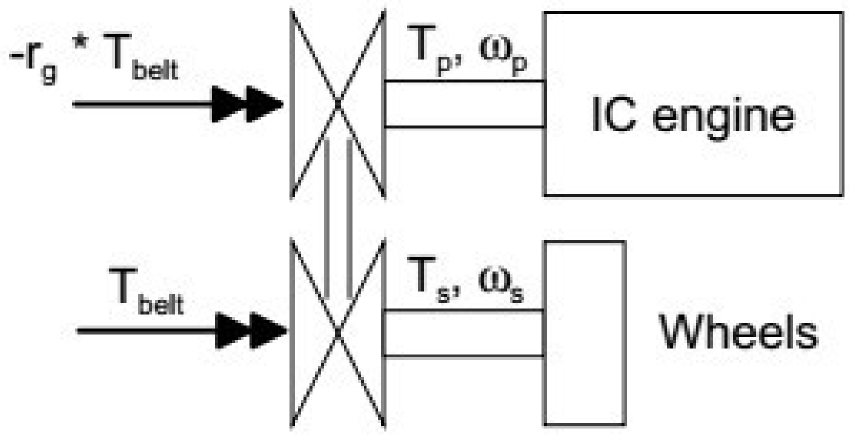


Fig 2.14: Variator Implementation (Klaassen *et al.*, 2004)

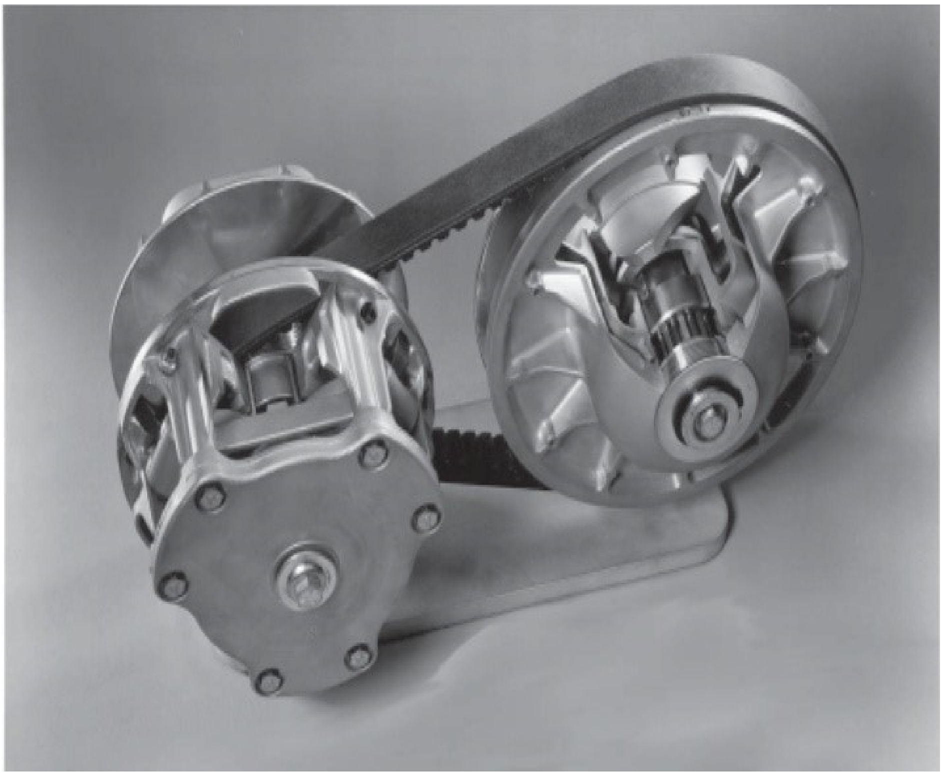


Fig 2.15: Engine Braking CVT (Hilliard Corporation, 2017)

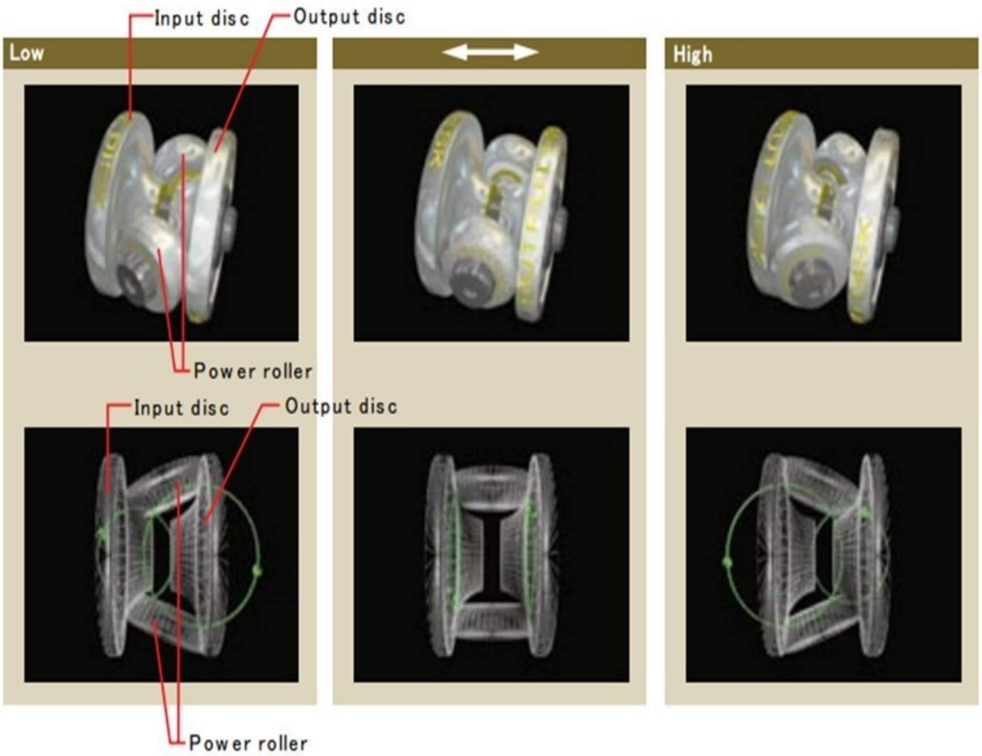


Fig 2.16: Toroidal CVT stages (Nicolas, 2013)

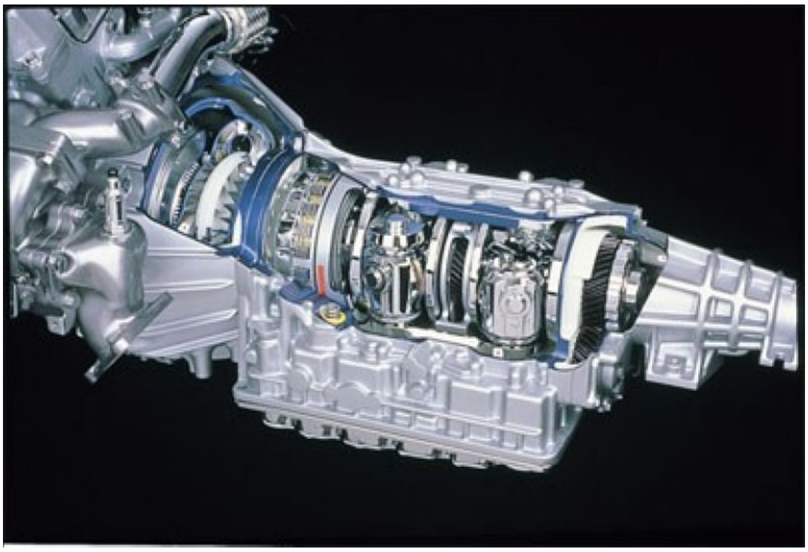


Fig 2.17: Nissan Extroid Toroidal CVT

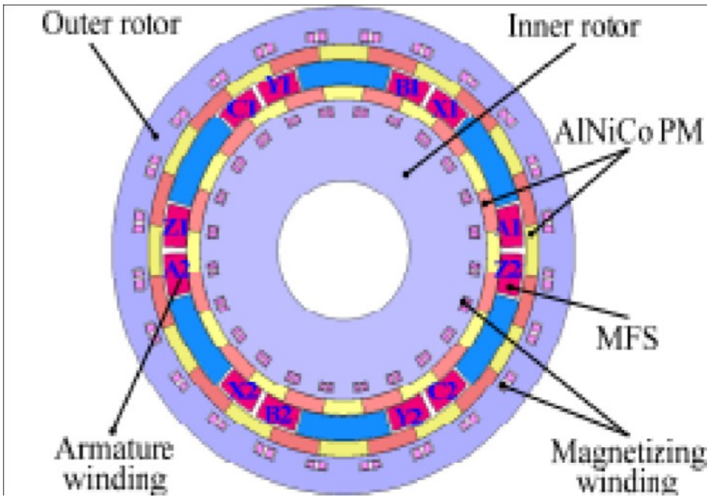


Fig 2.18: Structure view of an EC-MVSG (Liu and Chau, 2014)

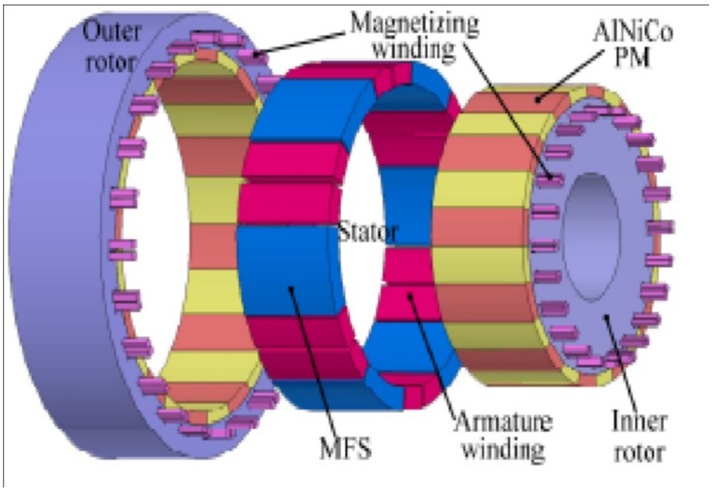


Fig 2.19: Component view of the EC-MVSG (Liu and Chau, 2014)

2.10.5 Hydrostatic power-split CVTs

Hydrostatic power split transmission has been defined to be the energy translation device in which mechanical energy at the input is converted into mechanical and hydrostatic energy and then reconverted into mechanical energy at the output (Kress, 1968). The hydrostatic power split CVT consists of the following ((Schulte and Gerland, 2011; Sun, 2010);

a) Input shaft
b) Output shaft
c) Planetary gear train
d) Internal mechanical transmission
e) Control variation unit

Power Split CVTs have been proven to be suitable for off-road vehicles, due to the sharp variations in speed and torque requirements (Schulte and Gerland, 2011). A control-oriented modeling approach based on Takagi-Sugeno fuzzy model for sensor-fault detection was developed for a power split CVT. This method has been approved to help in selecting measureable variables like hydrostatic pressure under varying load conditions (Schulte and Gerland, 2011)

The need for low fuel consumption, low emission and high performance warrants optimization of vehicle drive train. Sequel to this, a feedback and analysis was conducted to find out the working cycle suitability and power range suitability of the power-split hydrostatic CVTs shown in Fig 2.20 (Sun, 2010).

2.10.6 Ratcheting CVTs

It is also known as ‘Crank-CVT’ or ‘Variable-Stroke CVT’ as shown in Fig 2.21. It operates by converting uniform motion to reciprocating motion and then rectifies it back to an ‘almost’ uniform motion. The mechanism that produces the reciprocating motion allows adjustable reciprocating stroke and is rectified to a unidirectional rotational output by another mechanism such as a one-way clutch or a free-wheel. The speed of the output is adjusted by adjusting the reciprocating stroke (CVT, 2008b).

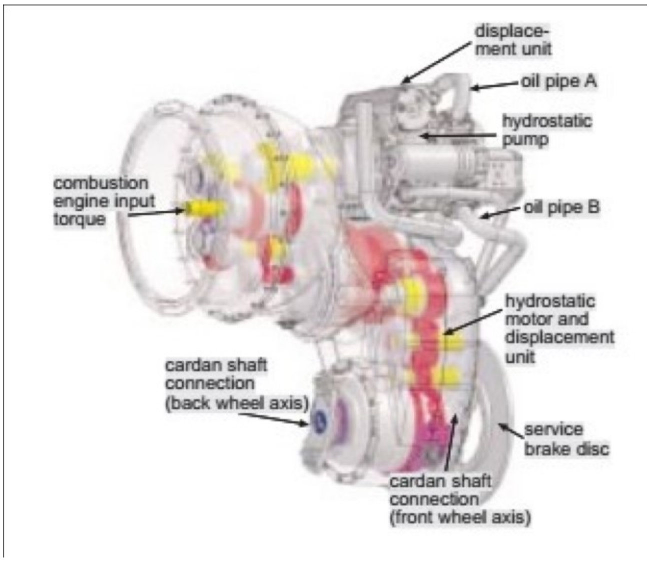


Fig 2.20: Hydrostatic power split CVT (Schulte and Gerland, 2011)

Fig 2.21:Ratcheting CVT (Ratcheting CVTs, 2008)

2.10.7 Applications of continuously variable transmissions

- CVT could be used in a wide variety of applications (Hilliard Corporation, 2017) such as;

a) Aircraft engines
b) Drill presses
c) Milling machines
d) Sport cars
e) Go carts
f) Earth moving vehicles
g) Cars
h) Motorcycles
i) Utility vehicles
j) Golf cars
k) City cars

2.10.8 Other researches on CVT

Yukawa, (2011) proposed a Quadric Crank chains and Ratchet CVT named L-CVT because it consists of 'Links'. This CVT is not based on friction conduction, so noise and slip are absent with higher transmission efficiency. Developments in automotive technology, especially in internal combustion engine technology, have seen large improvements in fuel efficiency over the last 40 years (Schafer *et al*., 2006).

CVTs provide a continuously smooth ratio progression which results in low noise, greater fuel efficiency, and increased speed with a smooth ride. Early belt type CVTs highlighted the potential of this technology but was never widely implemented due to material limitations and inherent design flaws that limited their torque capacity and durability (Kluger and Fussner, 1997). Kumar *et al.* (2016) developed a data acquisition system to be used for a CVT. The purpose was to plot the engine revolution against the gear ratio change. The ratio change is measured through the sheaves displacements which give the diameters of each sheave at any given time. The outcome would help to understand and subsequently optimize CVT response to gear ratio change.

An effort was made to improve the efficiency of a shaft drive CVT by using a combination of the torque and velocity components. The torque components were deduced from torque loss at bearing while velocity component was deduced from shear model of traction oil (Narita *et al*., 2005). A powered parallelogram arm CVT transmission was designed for a cobot which can effectively replace the usual steerable wheels. This was done by connecting a CVT to each of the three rollers which permits reduction in inertia (the rollers are usually characterized by much redundancy) and allow for larger transmission ratios (Moore *et al.*, 1999).

Until 1995, most CVTs developed usually have torque lower than 300Nm, when there was a record of developing CVT components for torque above 300 Nm. The peculiarity includes; Precise control of the minimum clamping force for proper transmission and high efficiency, excellent adjustment dynamics at low pump capacity and greater spread of gear ratios; sturdy design and optimized acoustics in power transmission elements (Faust and Linnenbrugger, 1995)

2.10.9 Comparison between automatic and continuously variable transmission

CVTs operate always on the optimum speed regimes and throttle positions as against the manual transmissions. It easily adapt to varying road conditions and power demands (CVT, 2008a). CVTs provide only positive ratios; that is it does not take into account engine speed reduction used in reverse drive. Therefore, a separate reverse gear and clutch is added to the drive train for this purpose. A comparison between a five-speed automatic transmission and a continuously variable transmission is presented in Fig 2.22;

2.11 CVT for Wind Turbines

Mihailidis *et al*. (2009) reported their findings on the experimental evaluation of the efficiency of a CVT system for wind energy converters (Fig 2.23). A new closed power loop test rig was used to test two scenarios; constant ratio gearbox (Fig 2.24) and a variable transmission gearbox (Fig 2.25). Using a constant ratio gear box means, a constant generator speed as well as constant power output. This negatively affects the aerodynamic efficiency of the wind turbine (rotor blades).When the variable transmission system was incorporated, the generator speed was now responding to the varying speed at the rotor blades, thereby resulting in increased power output. This thus translates to an increased annual power generation for the user.

Lee *et al*. (2009) carried out an experiment that gave a model for CVT drivetrain system for wind turbine applications as seen in Fig 2.26. NuVinci CVT invented by Fallbrook Technologies shown with its gear ratios in Fig 2.27 was used for the experiment, because it was specifically designed for wind applications. The CVT operates on two basic principles:

a) A traction based variable radius spherical design
b) A shifting rod manipulates the contact radius of the sphere.

Table 2.1: Comparison of hydraulic control systems for 5-speed step automatics and CVT (Faust and Linnenbrugger, 1995)

5 AT	**CVT**
Start-up device	Start-up device
Reverse	Reverse
1st Gear	Clamping load
2nd Gear	Ratio control
3rd Gear	
4th Gear	
5th Gear	
~ 6 solenoids ~ 20 valves	LuK-CVT 3 solenoids 9 valves

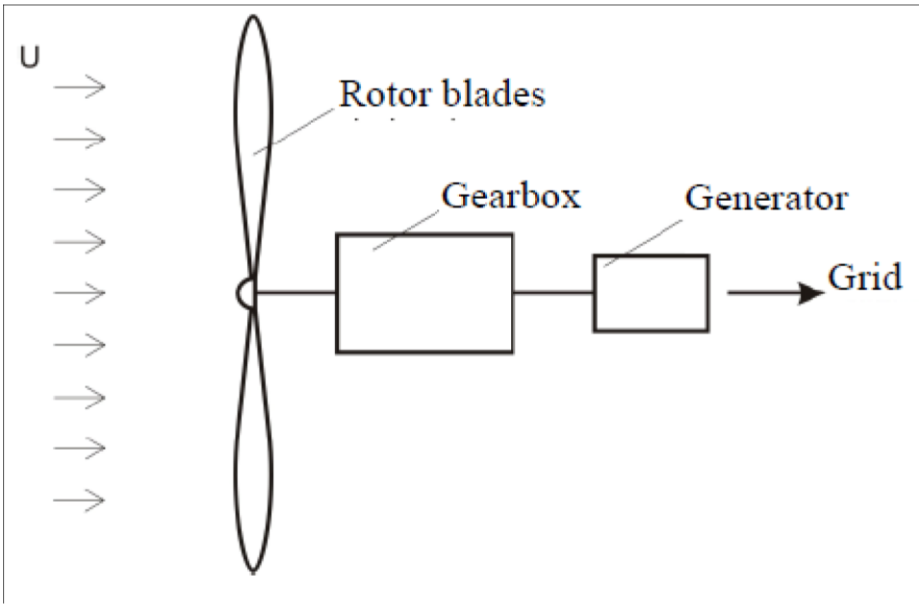


Fig 2.23: Schematics of a CVT wind turbine transmission (Mihailidis *et al*., 2009)

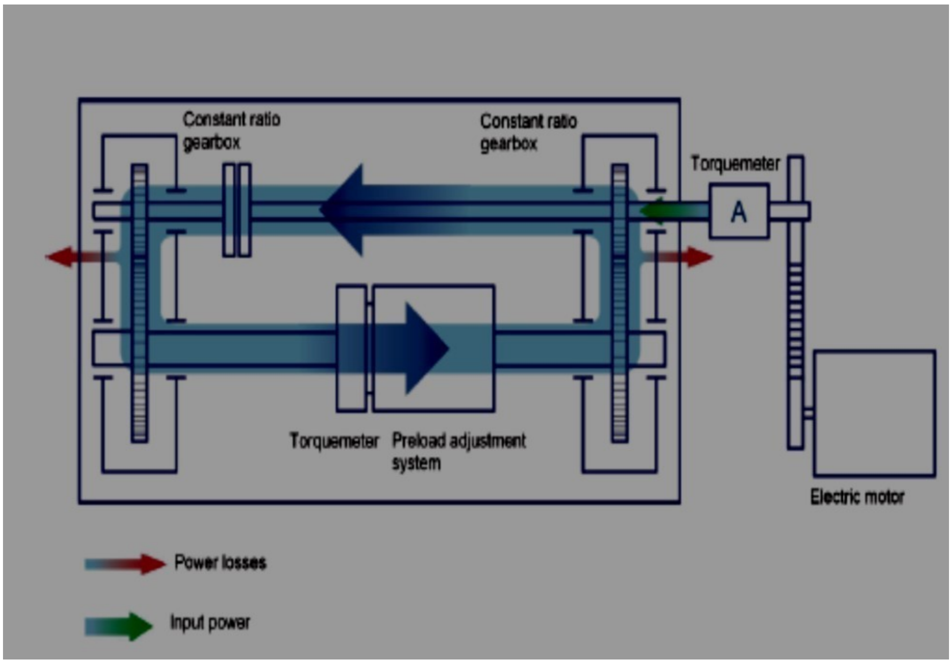


Fig 2.24: Wind turbine with constant gear ratio (Mihailidis *et al*., 2009)

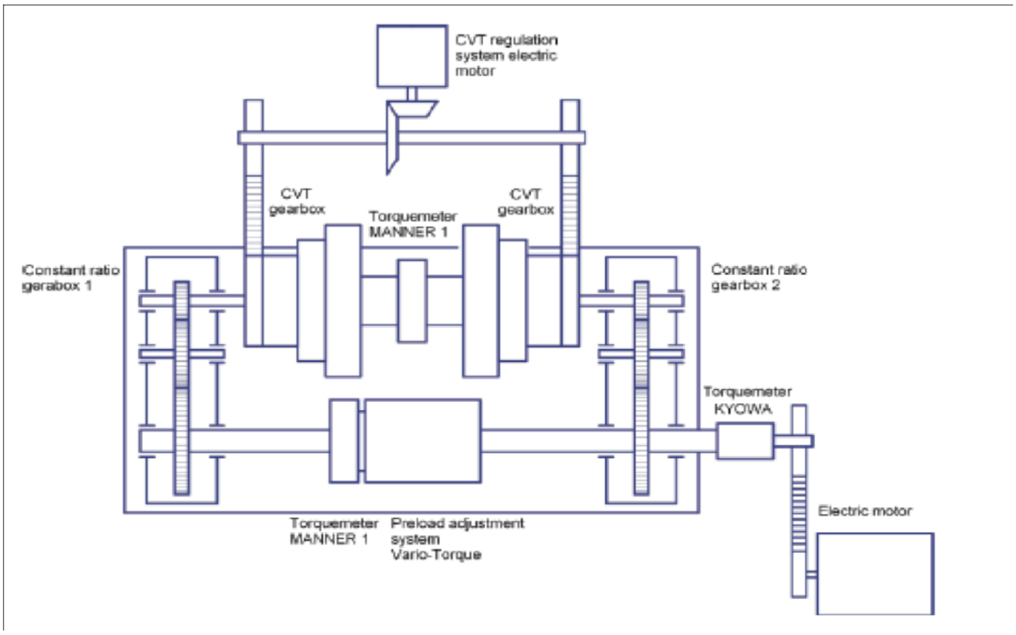


Fig 2.25: Wind turbine with CVT gearbox (Mihailidis *et al*., 2009)

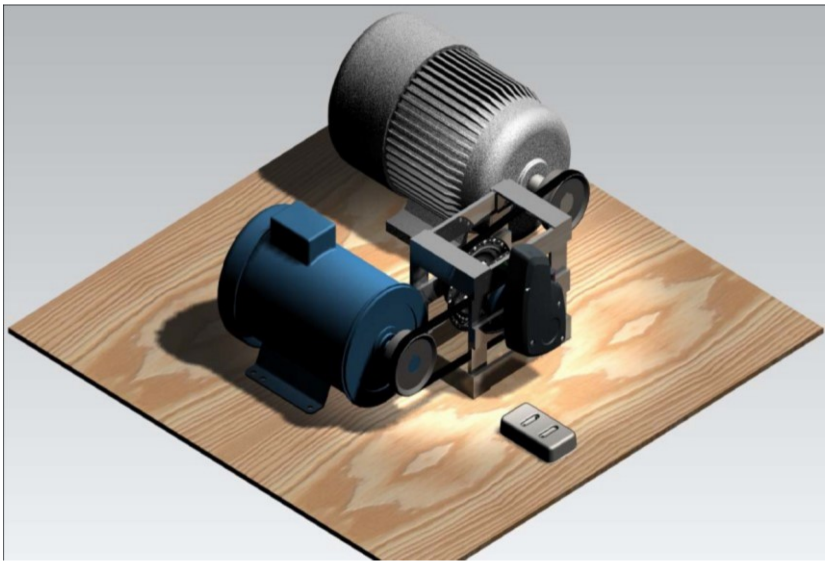


Fig 2.26: CVT Drivetrain system for wind turbine applications (Lee *et al*., 2009)

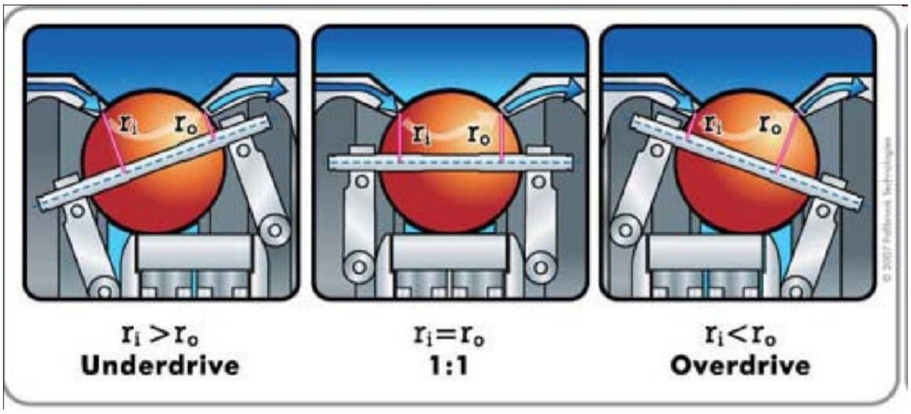


Fig. 2.27: Nu Vinci CVT gear ratios (Lee *et al.,* 2009)

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

This chapter is basically divided into five parts;

a) Preliminary Research/Information Gathering
b) Materials used for this work
c) Methods
d) Testing
e) Data Analysis

The flow chart for the work is presented in Fig 3.1

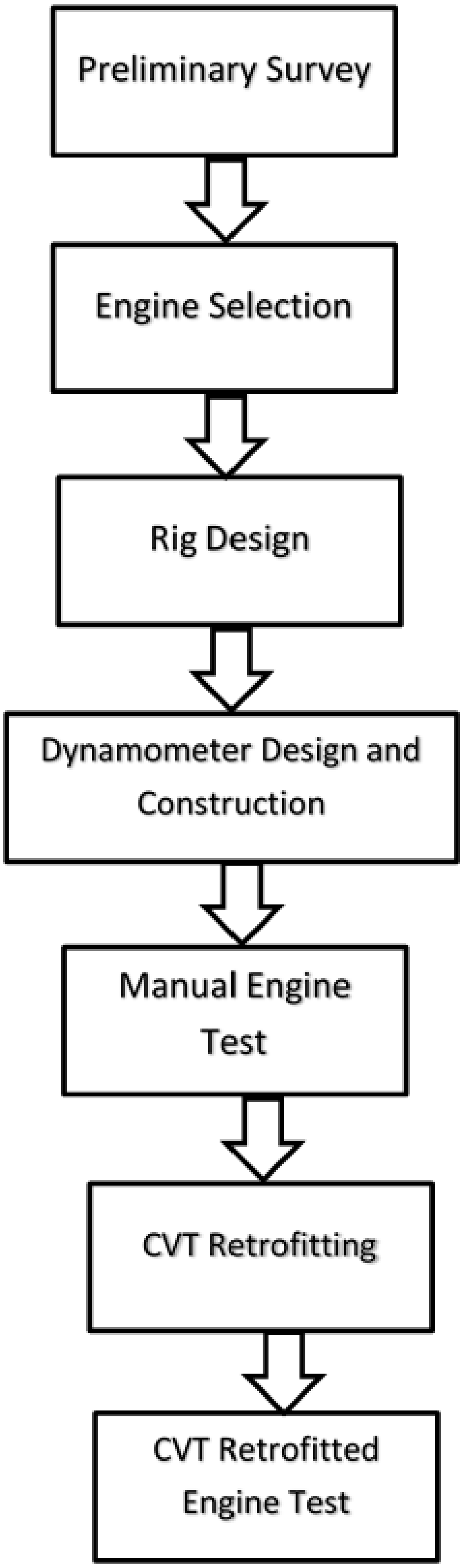


Fig 3.1: Methodology flow chart

3.1 Preliminary Research/ Information

A preliminary research aimed at extracting useful information from autorickshaw riders was carried out. This was done by administering questionnaire to autorickshaw drivers at three choice locations each in three local governments in Ibadan were selected for this survey. These locations were selected because the autorickshaw is mainly used for commercial purposes and it is at these locations we have the largest cluster of these drivers.

The questionnaire was divided into five sections with their peculiar information and questions. The five sections are;

a) General information: Information about the vehicle and the driver were requested here
b) Gear transmission: information about the transmission system which includes its serviceability, ease of maneuvering among others were requested here.
c) Drivability and comfortability: Vehicle capacity, tyre properties and other information were gathered here.
d) Accidents: Drivers experiences with accidents such as causes, frequencies etc are requested here.
e) Serviceability: Ease of servicing, frequency of routine servicing among others were requested here.

Each rider was given a questionnaire to fill and where the rider cannot fill, he was helped out by asking him the various questions presented in the questionnaire. The questionnaire used is presented in the appendix one. The questionnaires were collated and the needed information extracted. The information gathered were grouped and plot using bar charts against the two autorickshaw brand identified.

3.2 Materials

The materials used for the experiment are explained and described as follows;

3.2.1 ICE engine

Various parameters were considered for the choice of the engine used for this experiment. They are:

a) Orientation of the engine
b) Length and orientation of the output shaft
c) Ease of improvisation of cranking mechanism
d) Feasibility of Adaptation of a CVT

Based on the outcome of the questionnaires administered, it was discovered that the two autorickshaw brands are in use which are; Bajaj RE and the TVS engine models. A decision matrix based on the above criteria was used to select the most suitable engine model among these two. From the decision matrix, the Bajaj RE has the highest score of 8.08 against the TVS with 5.91. Therefore, the Bajaj RE was used for this work.

A used Bajaj RE engine was used for this experiment. It has the following characteristics and specifications;
Model: Bajaj RE ICE engine
Cubic capacity (Engine displacement): 145.45cm^3
Maximum Power: 6.6 kW @ 5000 rpm
Maximum Torque: 15.5 Nm @ 3300 rpm
Grade ability: 16.5%
Engine: single cylinder, 2 stroke
Transmission: 4 forward + 1 reverse
Fuel tank capacity:
Maximum speed:
Clutch type: wet multidisc type
(Source: RE compact, http://www.bajajauto.com/bajajre/re-compact-tech-specs.html)

Table 3.1: Decision Matrix for Engine Selection

CRITERIA			ALTERNATIVES			
	Rating	**Weight**	**Bajaj RE**		**TVS**	
			Rating	**Score**	**Rating**	**Score**
Orientation of Engine	6	0.14	5	0.7	4	0.56
Length and orientation of output shaft	10	0.23	9	2.07	8	1.84
Mountability of engine on a Rig	8	0.19	7	1.33	7	1.33
Ease of improvisation of cranking mechanism	9	0.21	8	1.68	6	1.26
Visibility of Adaptation of CVT	10	0.23	10	2.3	4	0.92
Total	**43**			**8.08**		**5.91**

Table 3.2: Gear ratio for Bajaj RE

Gear	Ratio	Gear teeth
Differential gear (forward)	1.74:1	
Differential gear (reverse)	2.28:1	
Gear 1	4.75:1	(57/12)
Gear 2	3.11:1	(53/17)
Gear 3	2.14:1	(47/22)
Gear 4	1.41:1	(41/29)
Reduction gear	3.09:1	

3.2.2 Digital tachometer

Speed measurement is a major parameter used in defining the output characteristics of an automobile engine. It is the commonest parameter known for describing automobile engine performance whether the terrain of driving is considered or not. There are various equipment and methods for speed measurement which includes the use of tachometers, stroboscopes, among others.

The tachometer has been recommended for the measurement of the speed of rotating parts especially shafts. Since the autorickshaw have an output shaft, it is easier to use a tachometer for its speed measurement.

For this experiment, a contactless tachometer was used which has a wide range of measuring distance. Thus, a tachometer shown in Plate 3.1 was purchased which has data acquisition software for online data measurement and recording which is pointed at a reflective tape placed on the measuring points.

The software also has the capacity to export recorded data into other file types for analysis of the data and further use.

The following are the specification of the tachometer;

Type: Omegaette^{TM} HHT-1500 series

Type: Hand held Non Contact

Measuring distance: 50 to 300 mm

Range: 10 to 99,999 rpm

Software: (Windows 3.1/95/98/XP Based Software)

Plate 3.1: Omegaette^{TM} HHT-1501 Contactless Tachometer

3.2.3 Dynamometer Design and Construction

The dynamometer is the most important measuring device in measuring engine output parameters because it combines various functions like speed measurement, torque measurement, power measurement, exhaust temperature measurement among others. It also adds to its function the load variations to mimic driving terrains which incorporates a braking system to the output of the engine. These various parameters are either viewed on a screen as the engine is working or stored in a removable memory on the dynamometer.

The components of the dynamometer are presented thus;

3.2.3.1 Microcontroller

Various factors are considered in the choice of microcontroller to use for a particular purpose. These include:

a) The number of digital inputs, analogue inputs. The system concerned requires; a factor which helps to determine the minimum number of inputs and outputs (I/O) that the chosen microcontroller must have and the extent of need of an internal analogue to digital converter module.
b) The size of program memory storage required
c) The magnitude of clock frequency; a factor which determines the execution rate of tasks by the microcontroller
d) The number of interrupts and timer circuits required.
e) An internal ADC stage

For this particular design, the number of computation that would be inputed is largely dependent on the amount of memory available; a microcontroller with a large memory sufficient input/output ports and analogue/digital channels such as the ATMEGA328P is quite acceptable for use.

3.2.3.2 Major blocks in the AVR MCU

The major parts of the PIC MCU (Microcontroller Unit) are the

i. program memory
ii. data memory which is also called file register

iii. the working register, and

iv. EEPROM memory section:

   a) Program Memory: 32K word length

   b) File Register Memory (Data Memory): 2K word length

   c) EEPROM Memory: 1K word length

   d) Working Register: Byte was used

The following are the features and specifications of the microcontroller used;

i. High Performance, Low Power AVR® 8-Bit Microcontroller

ii. Advanced RISC Architecture:

   a) 131 Powerful Instructions – Most Single Clock Cycle Execution

   b) 32 x 8 General Purpose Working Registers

   c) Fully Static Operation

   d) Up to 20 MIPS Throughput at 20 MHz

   e) On-chip 2-cycle Multiplier

iii. High Endurance Non-volatile Memory Segments:

   a) 4/8/16/32K Bytes of In-System Self-Programmable Flash progam memory

      a. (ATmega48PA/88PA/168PA/328P)

   b) 256/512/512/1K Bytes EEPROM (ATmega48PA/88PA/168PA/328P)

   c) 512/1K/1K/2K Bytes Internal SRAM (ATmega48PA/88PA/168PA/328P)

   d) Write/Erase Cycles: 10,000 Flash/100,000 EEPROM

   e) Data retention: 20 years at 85°C/100 years at 25°C

   f) Optional Boot Code Section with Independent Lock Bits

iv. In-System Programming by On-chip Boot Program

True Read-While-Write Operation: Programming Lock for Software Security

v. Peripheral Features

   a) Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode

   b) One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture

vi. Mode

   a) Real Time Counter with Separate Oscillator

   b) Six PWM Channels

   c) 8-channel 10-bit ADC in TQFP and QFN/MLF package

vii. Temperature Measurement

a) 6-channel 10-bit ADC in PDIP Package

b) Programmable Serial USART

c) Master/Slave SPI Serial Interface

d) Byte-oriented 2-wire Serial Interface (Philips I2C compatible)

e) Programmable Watchdog Timer with Separate On-chip Oscillator

f) On-chip Analog Comparator

g) Interrupt and Wake-up on Pin Change.

viii. Special Microcontroller Features

a) Power-on Reset and Programmable Brown-out Detection

b) Internal Calibrated Oscillator

c) External and Internal Interrupt Sources

d) Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and extended Standby

ix. Input Output and Packages

a) 23 Programmable I/O Lines

b) 28-pin PDIP, 32-lead TQFP, 28-pad QFN/MLF and 32-pad QFN/MLF. Fig 3.2 shows ATMEGA328P pin configuration.

x. Operating Voltage: 1.8 - 5.5V for ATmega48PA/88PA/168PA/328P

xi. Temperature Range: -40°C to 85°C

xii. Speed Grade: 0 - 20 MHz @ 1.8 - 5.5V

xiii. Low Power Consumption at 1 MHz, 1.8V, 25°C for ATmega48PA/88PA/168PA/328P:

a) Active Mode: 0.2 mA

b) Power-down Mode: 0.1 µA

c) Power-save Mode: 0.75 µA (Including 32 kHz RTC)

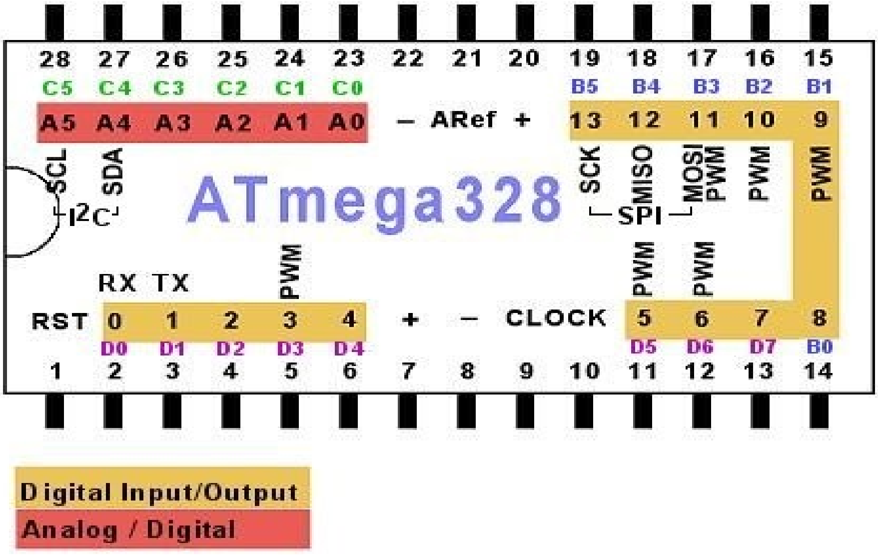


Fig 3.1: ATMEGA328P pin configuration.

3.2.3.3 Data acquisition unit

The components used in building the data acquisition unit of the dynamometer are presented in Figs 3.2 to 3.4.

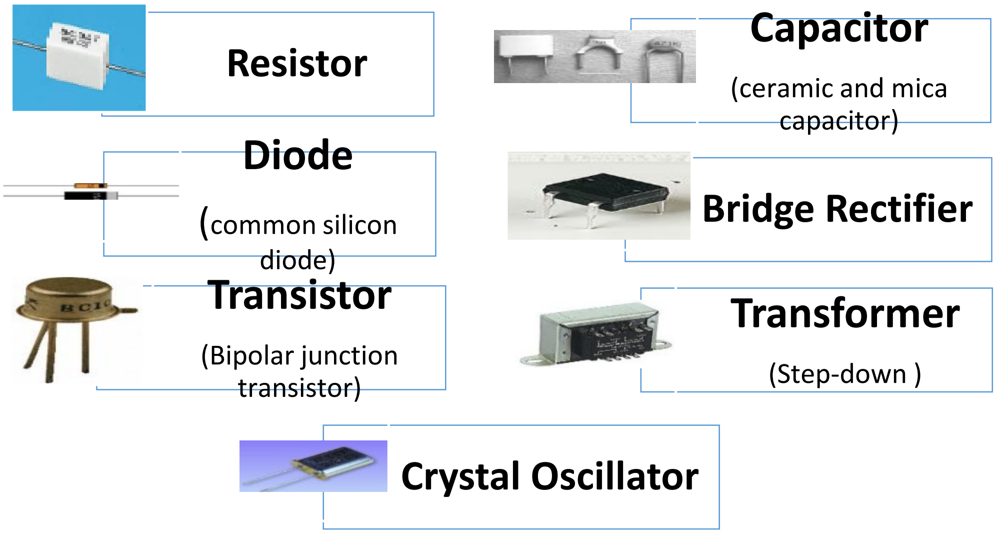


Fig 3.2: Basic building components of the dynamometer

Fig 3.3: LCD and its pin orientation

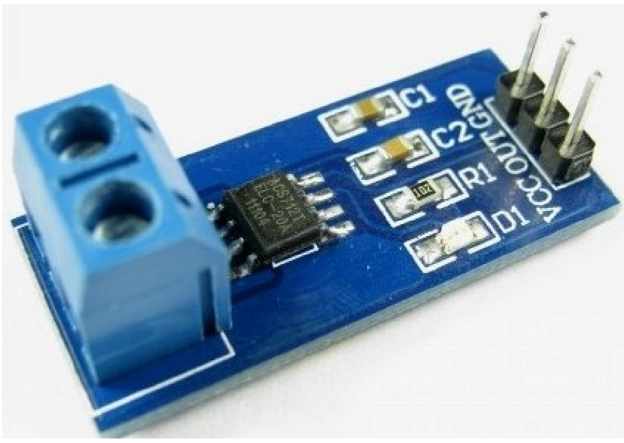


Fig 3.4: Current sensor

3.2.3.4 The Power Supply Stage

All stages in the project uses a fixed regulated +5Vdc supply except the relays that uses 12Vdc. The power supply stage is a linear power supply type and involves a step down transformer, filter capacitor, and voltage regulators to give the various voltage levels. The power supply circuit diagram is shown in Fig. 3.5 below.

The rectifier was designed with four diodes to form a full wave bridge network. C_1 is the filter capacitor and C_1 is inversely proportional to the ripple gradient of the power supply, using a 240V transformer on a 50Hz supply and transformer secondary *r.m.s* voltage output is 12V.

3.2.3.5 Principle of operation

Voltage divider stage

The Arduino can accept up to 5v on an analogue input. Voltage can range as high as 20vdc in certain situations (open circuit pv voltage), so a voltage divider that would provide 5v at 20v battery voltage, and less at various lower voltages was designed.

In other to achieve the above, Voltage Divider Calculator shown in Fig 3.6 was used. 20v was set as the input, 5v as the output, and 3k for R2. This calculates a R1 of 9K.

Because the Arduino has a 10-bit ADC, it outputs 0-1023 (1024 steps) for a 0-5v input. That's 0.00488v / step.

With a Voltage Divider with R1 = 9k Ohm and R2 = 3k Ohm,

Voltage divider for a 12v battery is calculated as follows:

12v / Ratio = 3v on the A4 pin.

3v / .00488 = 615 (ADC Reading - round up)

so A4 pin Voltage = .00488 * ADC reading (615 in this case), or 3.00 volts.

Then battery voltage = A4 pin voltage * Ratio (3 * 4 = 12)

The code to read that value is as follows is presented in the appendix seven:

Current monitoring stage

The next step is to track the current being consumed by a load, or produced by a source. ACS715 Hall Effect sensor presented in Fig. 3.7 was used to track the current being passed. The code is presented in Appendix eight and the output display interface presented in Fig. 3.8.

3.2.3.6 Construction

The physical realization of the project is very vital. This is where the fantasy of the whole idea meets reality. Here the paper work is transformed into a finished hardware.

After carrying out all the paper design and analysis, the project was implemented, constructed and tested to ensure its working ability. The construction of this project was done in three different stages;

a) The implementation of the whole project on a solder-less experiment board (breadboard).
b) The soldering of the circuits on Vero-boards.
c) The coupling of the entire project to the casing.

3.2.3.7 Implementation

The implementation of this project was done on the breadboard. The power supply was first derived from a bench power supply to confirm the workability of the circuits before the power supply stage was soldered. The circuit diagram is presented in Fig 3.15.

3.2.3.8 Soldering and casing

The various circuits and stages of this project were soldered in tandem to meet desired workability of the project. The power supply stage was first soldered before the microcontroller. The soldering of the project was done on a Vero- board, and was soldered a small size Vero-board. This unit was coupled to a plastic casing. The casing material being plastic designed with special perforation and vents and also well labeled to give ecstatic value.

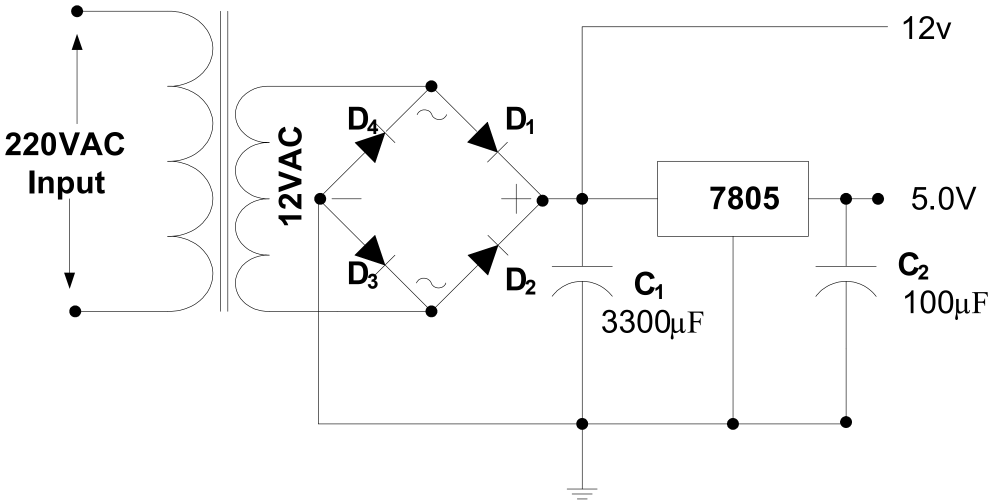


Fig. 3.5: Power supply circuit for the dynamometer

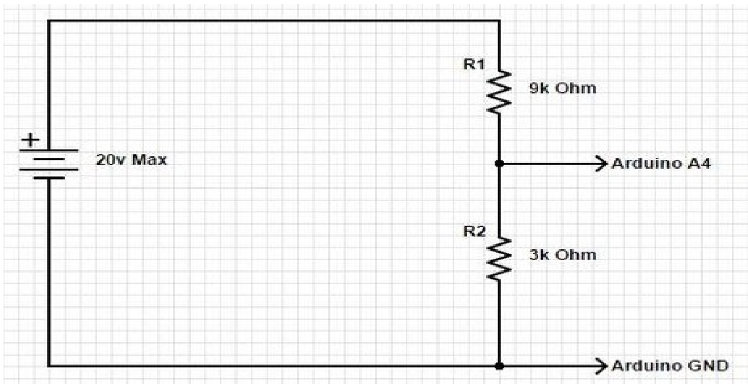


Fig 3.6: Voltage Divider

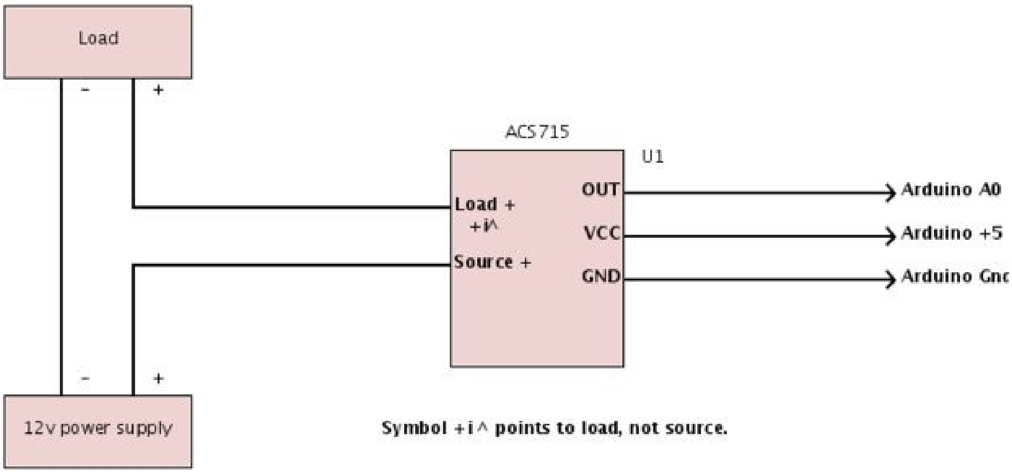


Fig 3.7: Hall Effect Sensor

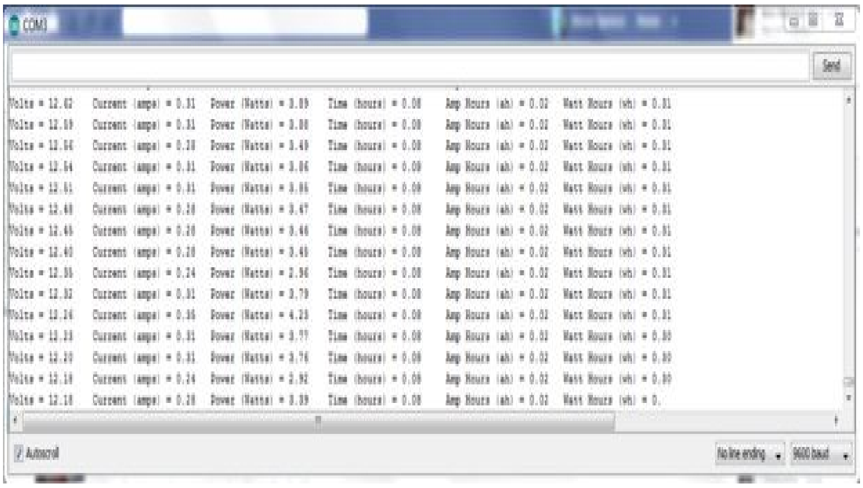


Fig 3.8: Serial Output Display

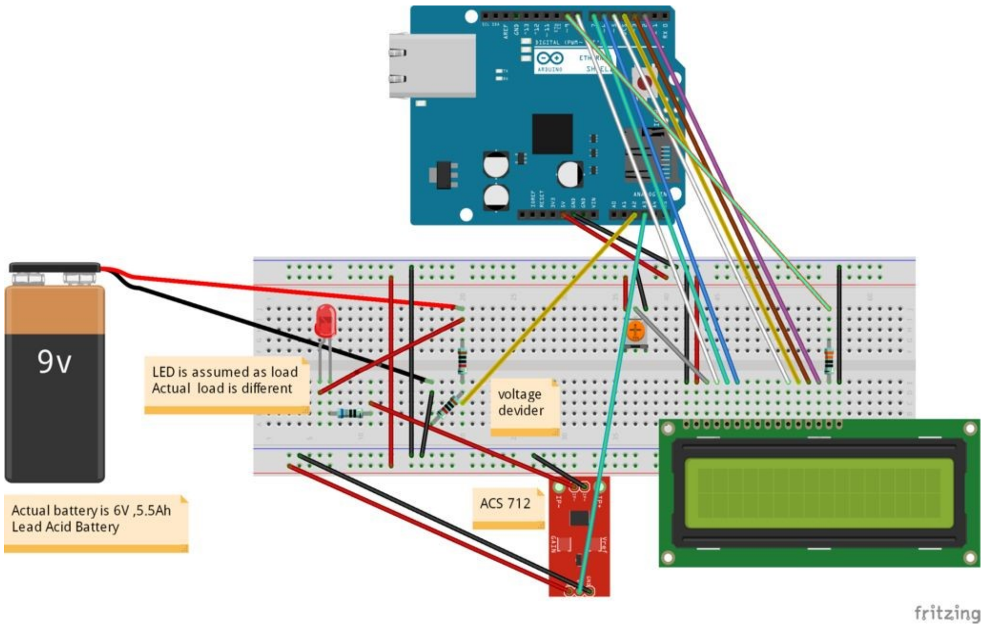


Fig.3.9: Circuit diagram for the dynamometer

Plate 3.2: Dynamometer Data Acquisition Unit

3.2.3.7 Testing

Stage by stage testing was done according to the block representation on the breadboard, before soldering of circuit commenced on Vero board. The process of testing and implementation involved the use of some test and measuring equipment stated below;

a) **Bench power supply**: This was used to supply voltage to the various stages of the circuit during the breadboard test before the power supply in the project was soldered. Also during the soldering of the project the power supply was still used to test various stages of the circuit before they were given final soldering.
b) **Oscilloscope**: The oscilloscope was used to observe the ripples in the power supply waveform and to ensure that all waveforms were correct and their frequencies accurate. The waveform of the oscillation of the crystal oscillator used was monitor to ensure proper oscillation at 16MHz.
c) **Digital multi-meter**: The digital multi-meter basically measures voltage, resistance, continuity, current, frequency, temperature and transistor h_{fe} . The process of implementation of the design on the board required the measurement of parameters like, voltage, continuity, current and resistance values of the components and in some cases frequency measurement.

The braking system is a set of resistor arranged in parallel with switch for each one so that they work independently. They are made of automobile head lamp bulbs with two types of capacities; 120W and 800W combined to form; 120W, 800W, 920W and 1600W designated as L_0, L_1, L_2, L_3 and L_4 respectively.

The data acquisition software makes use of the Arduino programming which interprets the voltage fluctuation to a Graphic User Interphase on a computer system. The other parts that make up the dynamometer are;

a) Switches (2 types: single pole, single throw and double pole, single throw)
b) Vehicle head lamp bulbs (120 W and 800W)
c) USB Jack capable: for data transfer
d) A DC motor (Bosch for Benz cars)
e) A 12V 60mAh DC Battery

f) A capacitor
g) Arduino software
h) HP Laptop (Windows 8 OS, 4G RAM, 500GHDD)

3.2.4 Laptops

The laptops were used for data acquisition and data processing.

a) Dell latitude 220 for tachometer data acquisition
b) Hp 650 for Dynamometer data acquisition

The Dell laptop shown in Plate 3.3 has the following configurations;

a) Operating system: Windows Xp
b) Hard disk: 40 G HDD
c) RAM: 2GB

The Hp laptop shown in Plate 3.4 below has the following configurations;

a) Operating system: Windows 8
b) Hard disk: 500G HDD
c) RAM: 4GB

Plate 3.3: Dell Laptop for Tachometer Data Acquisition

Plate 3.4: HP Laptop for Dynamometer Data Acquisition

3.2.5 Rig design

The factors considered during the test rig design and constructions are explained below;

3.2.5.1 Vibration:

The engine seat was made to be rigid and on the base. The design of the rig was that of the chassis of the automobile itself. This enables every part where there are supports to be adequately and firmly supported.

To avoid vibrations when the engine is working, the engine seat which is the part resting on the chassis majorly was damped using vibration dampers made of rubber cut from the truck tires. This sufficiently absorbed all vibrations that could have occurred as no vibration was observed physically.

Vibration of the engine can distort or negatively affect the measurements to be taken as well as not being safe for the measuring equipment because they are very fragile and highly sensitive. The rig was designed for the following;

a) Stability
b) Vibration damping
c) Mobility
d) Ease of attaching measuring devices and equipment as well as fuel tank
e) Easy assembly and
f) Compatibility.

The material used for the rig frame was 2 mm thick mild steel angle iron bars.

The engine seat was made rigid and it is directly on the base otherwise referred to as the 'chassis'. This made the parts that need supports to be adequately and firmly supported. The engine support was also equipped with dampers made of thick synthetic rubbers and bolted to the chassis. This sufficiently absorbed all the vibrations as no visible vibration was noticed throughout the experiments.

Vibration of the engine can affect measured data and results, because measuring equipment are very sensitive to shocks, therefore the need to prevent the vibration.

This was properly taken care of in the design of the rig. The rig was also placed on a level platform.

The frame made allowances for the various positions of fastening bolts to hold and support the engine. It also allows for the installation of the measuring devices. It also housed the improvised CVT for the transmission system.

3.2.5.2 Measuring equipment

Seat for each of the measuring equipment was also factored during the design. The base where the dynamometer would seat was fabricated, drilled so that the dynamometer can be secured to it and seated on vibration dampers made of specially designed rubbers different from the type used for the engine seat.

The speed from the engine output was increased by ratio 1:2. A belt and pulley system was designed to achieve this. The bigger pulley was attached to the output shaft of the engine output while the smaller pulley was for the dynamometer. The essence of this was to allow a significant output be picked up by the dynamometer engine. Multiplying this speed would therefore make it generate readable values.

The seat of the dynamometer was designed for adjustment so that the belt tension and center distance can be adjusted for the optimum output. The rig was also designed giving a point where the dynamometer base can be attached to the rig.

3.2.5.3 Dimensioning

The design of the rig and its construction was done to accommodate both the manual and the CVT transmission. The same rig was used to test for both transmission parameters. This was possible because the output point of both transmissions did not fall along the same axis and side of the engine. The dynamometer was attached to the output shaft for the manual transmission and also the CVT transmission where the wheels were to be attached. This made it easy for the various parameters to be measured under the various loading conditions

3.2.5.4 Design for mobility and flexibility

The rig was designed to be mobile not a bench rig. It is not bulky but compact and can be moved from one location to another by one or two people. When the engine is on it, two people can move it. The moving is possible through the wheels fixed on the base, which also serves as the ground support.

It can also be lifted when the engine is on it that is how portable it has been made. So it can be used in different laboratories and workshops. It can also be easily modified for various brands and models of the autorickshaw engines to test their operating performances.

3.2.6 Data Acquisition software (tachometer data acquisition software and Arduino)

Speed and power data collection were through data acquisition software. The purchased tachometer came with software of its own while the dynamometer made use of arduino software modified for the purpose of creating driving condition for the engine. The tachometer graphic user interface is presented in Fig 3.5 while that of the dynamometer is presented in Plate 3.6.

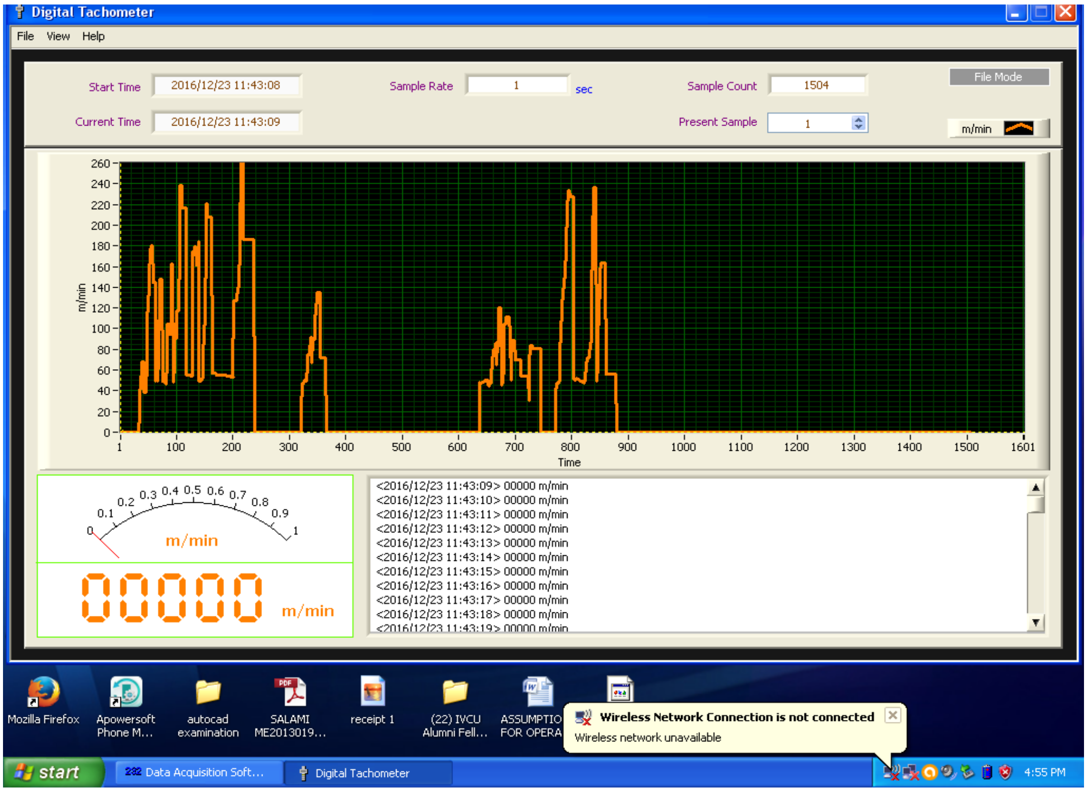


Plate 3.5: SW-U101-WIN Graphic User Interface (Digital Tachometer v5.0)

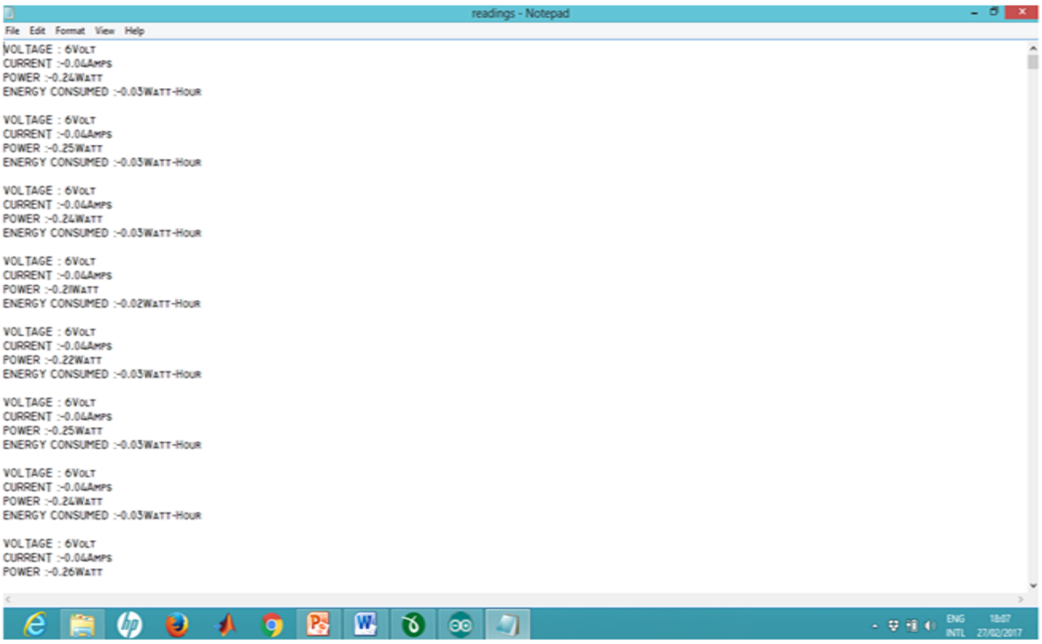


Plate 3.6: Arduino Data Output form

3.2.7 Wet cell battery

The dynamometer was powered by a 60mAh, 12 V battery shown in Plate 3.7. This battery was also used for the load variations.

3.2.8 Continuously Variable Transmission Retrofit Unit

The continuously Variable transmission unit consists of two pulleys with movable sheaves which are mechanically actuated to give desired speed ratio. The mechanical actuation was made of preloaded springs which special arrangements which responds to torque variations.

The CVT unit comprises majorly;

a) Primary Pulley
b) Secondary pulley

The pulleys are belt driven as shown in Fig 3.16
The parameters of the CVT are as presented below;
1” bore shaft, ¼ keyway for the primary sheave
6” 5/8 bore for the secondary sheave
Capacity: 250 cm^3 engine
Speed range: 1600 to 5000 rpm
Dimensions of the pulleys are presented in Fig 3.16 and the primary with the secondary pulley presented in Plate 3.8 and Plate 3.9 respectively.

Plate 3.7: 12 Volts DC Battery

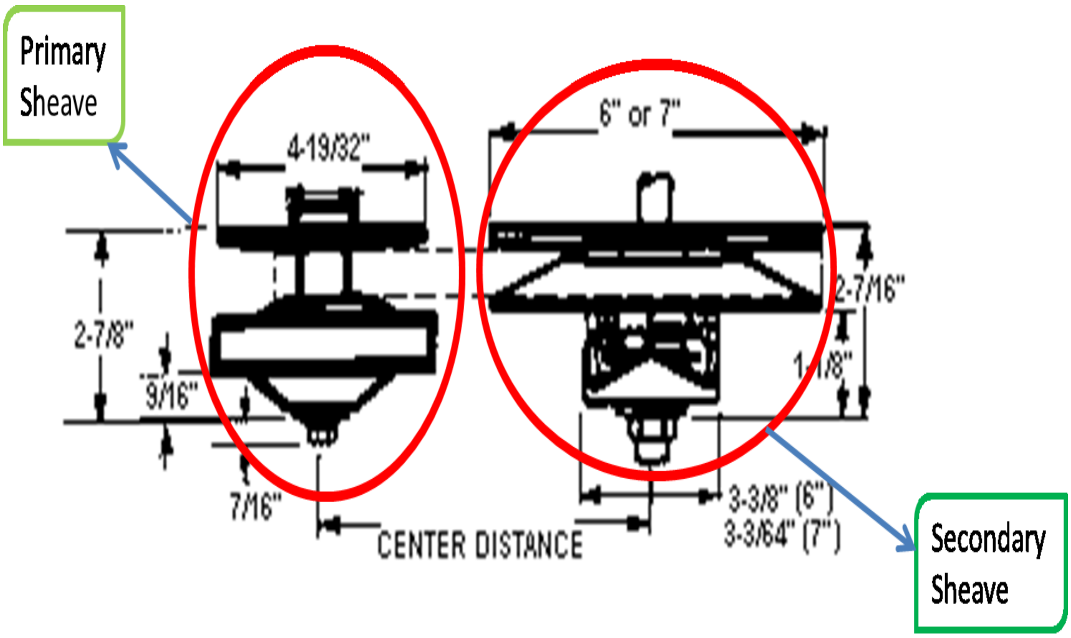


Fig 3.16: Dimensions of the CVT

Plate 3.8: Primary sheave

Plate 3.9: Secondary sheave

3.3 Methods

3.3.1 Engine modification for CVT retrofit

The Bajaj RE engine used for this work was originally designed for a manual gear transmission. Therefore it is necessary to do some modifications on the engine to allow for the CVT to be fitted to the engine. The CVT was designed to be attached directly to the crankshaft of engines. This allows it to be driven directly at output speed and torque. Therefore, the CVT was attached directly to the crankshaft of the engine.

A geared starter which serves dual purpose was originally attached to the engine;

i. To multiply the speed of the crankshaft as the engine is cranked and
ii. To also transmit the engine speed to the transmission with a ratio.

The CVT unit was fitted into the autorickshaw engine which was originally fitted with a manual transmission. The gear ratio is provided by the variable diameter pulleys which are controlled by torque. The primary pulley runs at the engine speed because it was connected to the crankshaft of the engine. The sheaves of the CVT shifts axially either side corresponding to increase or decrease speed. The ratio change is actuated by torque transmitted from the engine to the CVT unit which in turn causes the primary pulley moveable sheave to shift inwards and thus the secondary moveable sheave moves outwards as shown in Plate 3.8 . The high gear ratio shown in Plate 3.9 occurs when the primary sheaves close up and the secondary sheave opens wide. This arrangement gives the higher speeds.

3.3.2 Advantages of attaching CVT to the crankshaft

i. It allows CVT to be driven at engine speed and torque, therefore limiting speed and torque loss to a negligible point since the CVT is torque sensitive.
ii. The CVT is driven at engine speed directly which allows the engine to operate at full throttle while the CVT seamlessly changes the speed ratio delivered to the wheels.

The shaft carrying the primary pulley was attached to the crankshaft through a keyway made on the shaft. A hole was drilled on the side of the shaft which is to be attached to the crankshaft and a slot made with size of the key on the crankshaft. The key on the crankshaft originally allows the starter to be attached to it.

An improvised starter originally made for power generating sets was retrofitted to the engine. The starter is pulled by a rope wound round it to crank the engine.

3.3.3 Pulley supports

The primary pulleys were support via roller bearings on one side off the engine while the side attached to the engine had a hole drilled into it with a keyway corresponding to key dimensions on the crankshaft. A stopper screwed on the shaft was used to keep the pulley in place. The secondary pulley was also supported on the rig base with bearings on its either sides. Two bushings were used as stoppers to keep the pulley in place while the engine is working.

Plate 3.10: Starter coil removed for CVT to be attached to the crankshaft

Plate 3.11: The starter hub improvised for engine cranking

Plate 3.12: CVT retrofitted autorickshaw engine

Plate 3.13: CVT Experimental Setup

3.3.4 Manual transmission testing

The Bajaj RE autorickshaw engine was placed on the test rig. The output shaft of the engine where the axle is usually connected to was the point of measurement. It is the point where the wheels are usually attached, so this was used as the point of the gear output parameter measurement.

The dynamometer was then connected to the output shaft to measure the output power and energy outputs. The tachometer was placed with the axis of the infra-red ray intersecting with the reflective tape attached to the pulley of the dynamometer. The USB data cable was then connected from the dynamometer to the HP laptop output power and energy data acquisition. Likewise, the data cable of the tachometer was also connected to the Dell Laptop for output speed data acquisition.

An improvised starter was used for the engine cranking by replacing the engine starter linkage with a shorter one with only one linkage. This linkage was pulled like the originally fitted linkage to start the engine.

3.4. Testing

The autorickshaw engine was started on the rig. The dynamometer comprises of three parts; the tachometer (output speed measurement in rpm), the power meter (output power measurement in Watts) and the Energy measurement in Watt-Hour). The tachometer was placed conveniently and held in place close to the output shaft of the engine. A reflective tape was placed on the pulley of the attached shaft in place of the output hub of the engine output shaft. The tachometer was placed pointing the infra-red ray at the reflective tape. The tachometer cable was connected to the laptop via the RS 232 cable which has the data acquisition software.

The dynamometer was attached via a belt and pulley system. The speed of the output was multiplied by ¾ so that the output would be boosted. The measurement was read out via the data acquisition software installed on the laptop.

3.4.1 Experiment one: manual transmission testing

3.4.1.1 No load test

All the testing equipment was attached at the various points of measurement. A measured quantity of fuel was put into the tank attached to the engine. The engine was started while the gear was in the neutral position. The gear 1 was engaged and the throttle was opened gradually to full throttle which increases the output speed. The energy released (ER) from the engine, output power (OP) and output speed (OS) progressions were recorded for this gear ratio. The second gear was engaged which is the second gear ratio and the throttle was raised gradually to full throttle. The energy released, output power and output speed data were also recorded. These procedures were followed for the third and fourth gear ratios and the energy released output power and output speed data recorded as well. The data were plotted against time. The experimental flow chart is presented in Fig. 3.10

3.4.1.2 Loading test

All the testing equipment were attached at the various points for measurement.
The engine was installed on the rig. The fuel container was attached to the carburetor the power meter was connected to the output shaft via a v-belt. The tachometer was placed close to the output pulley and a reflective tape was attached to the tip of the pulley. The tachometer and dynamometer were attached to the points where they would measure the speed, power and Energy outputs of the engine.

The tachometer was placed to face the output pulley and axially coinciding with a reflective tape place at the surface of the pulley. This is such that the ray from the tachometer would directly intersect with the reflective tape and count the revolutions per minute. The readings were plotted and displayed on the laptop screen. The data were then exported to excel spread sheet upon completion of the experiment.

The dynamometer was connected to the output shaft of the transmission via a pulley and belt arrangement. As stated earlier, the speed was doubled, for better sensing by the transducer of the data acquisition unit. As the engine runs, the pulley attached to

the output shaft turns which inturn turns the alternator of the dynamometer twice its own speed. The data acquisition unit was connected to the laptop via a serial cable. The data were recorded per second by the arduino and displayed on the laptop screen. The data were exported upon completion of the experiment.
The data acquisition cables were then connected to the laptops and the laptops powered on. The data capture softwares were started and the required settings were made for the recording. The engine was cranked and started. At Idle position, the engine was allowed to run for a minute. The gear level was moved to the position of Gear 1 and the throttle was gradually raised. This last step was repeated for the remaining three gear ratios and the corresponding data recorded. The engine was put out. The data was then extracted and exported for further processing.

This procedure was done for the various loads using the load variator presented in Fig 3.32 a&b. The time taken (T) to complete the test (gear one to gear four) and the quantity of fuel consumed (FC) for each experiment under the various loads were also recorded.

For better results, one side of the output shaft of the transmission was stalled, that is not allowed to rotate, so that all the torque and speed transmitted were completely captured through the use of one output shaft rather that splitting the transmission into two which reduces the output parameters by a percentage.

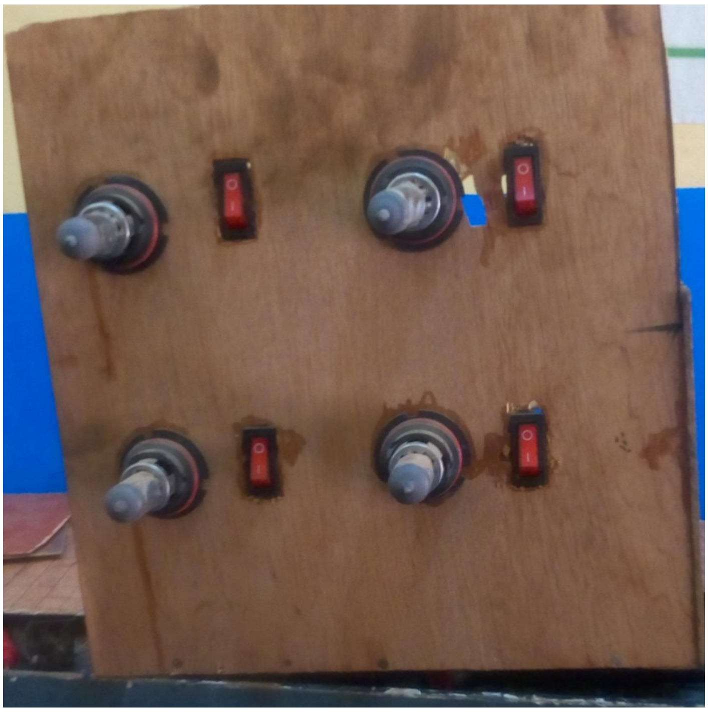


Plate 3.14a: Loading Variator 1 (60W loads)

Plate 3.14b: Load Variator 2 (800W loads)

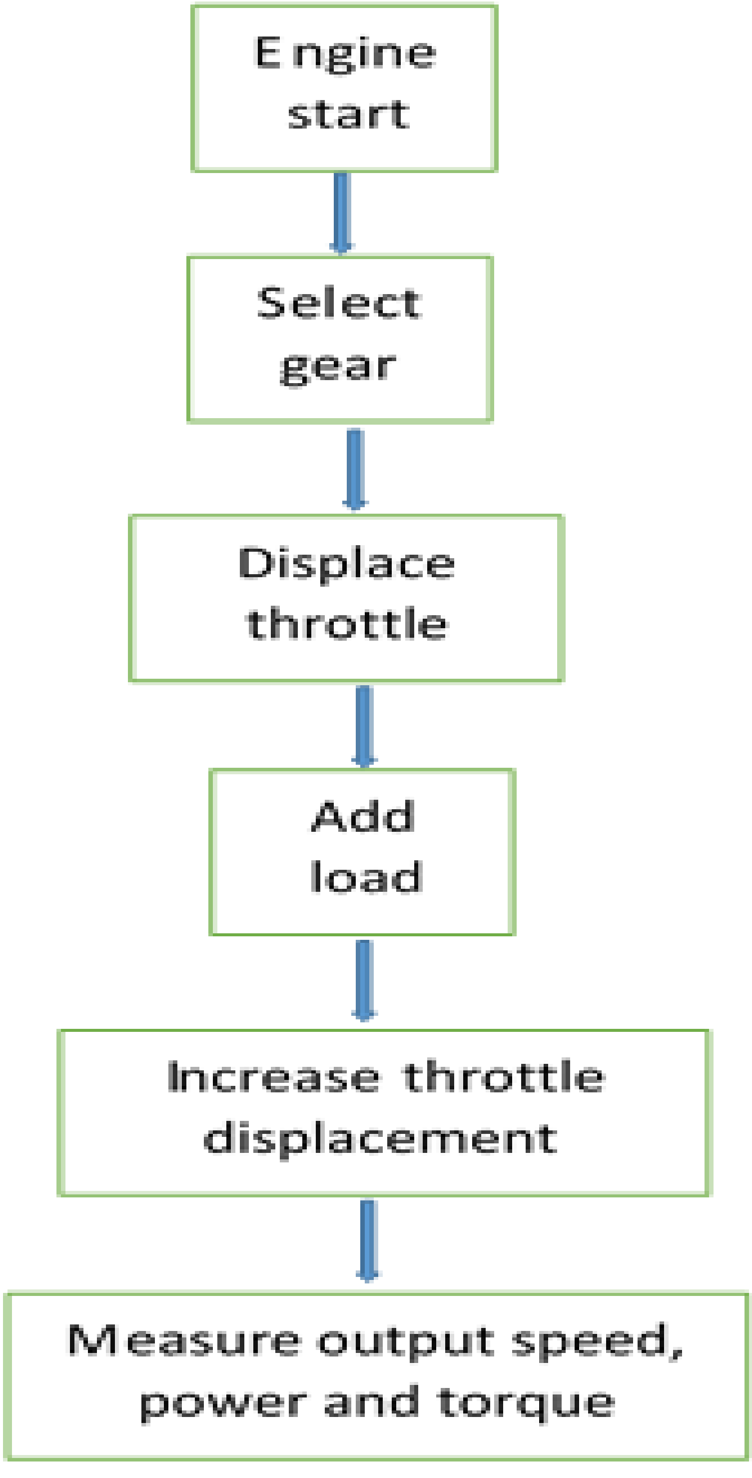


Fig 3.10: Experimental flow chart

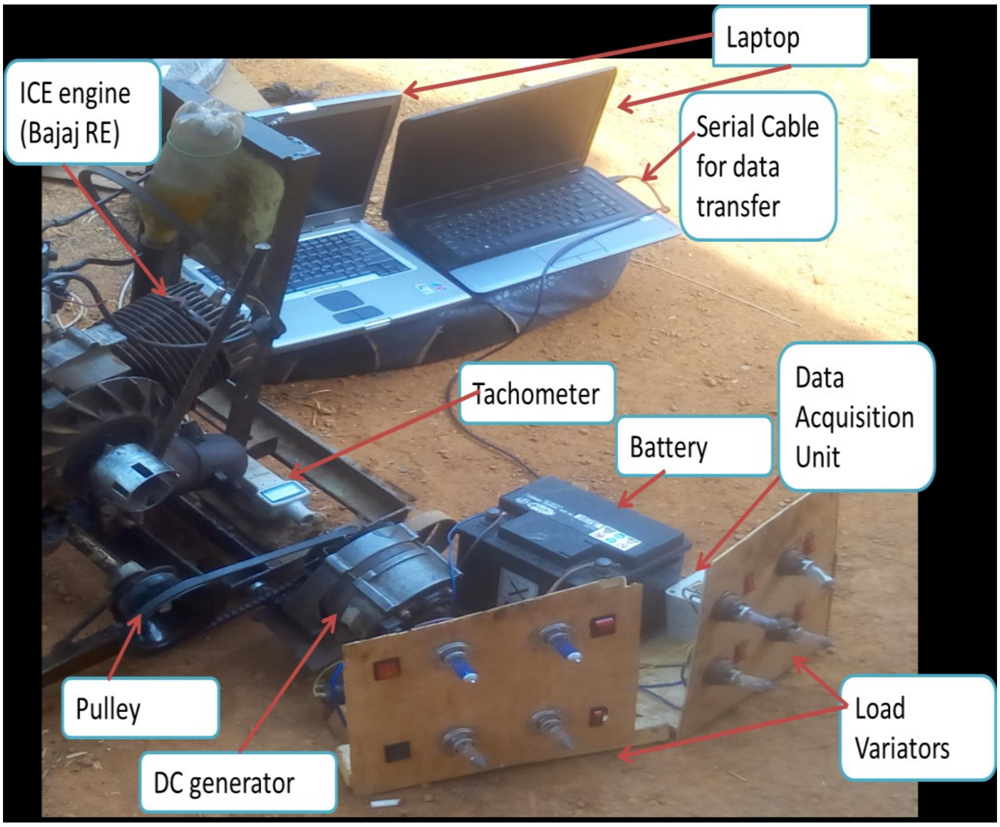


Plate 3.15: Manual experimental set up

3.4.2 Experiment two: CVT test

The starter of the engine was removed so that the primary pulley can be attached to the crankshaft directly. The engine was cranked and the engine was raised to full throttle (since there is no manual gear ratio change) for the CVT to smoothly on its own accord change the speed ratios according to the torque it received from the engine.

This procedure was done when no load was imposed by the dynamometer, and repeated for the various loadings as it was in the case of the manual transmission.

3.5 Data analysis

All the data measured were analyzed using Analysis of Variance (ANOVA), comparing the manual transmission to the continuously variable transmission. The entire hypothesis tested at $P < 0.05$ level of significance.

Plate 3.16: CVT Experimental Setup

Plate 3.17: Improvised Starter for engine fitted with CVT

Plate 3.19: CVT at idle position

Plate 3.20: CVT at lowest ratio

Plate 3.21: CVT at intermediate ratio

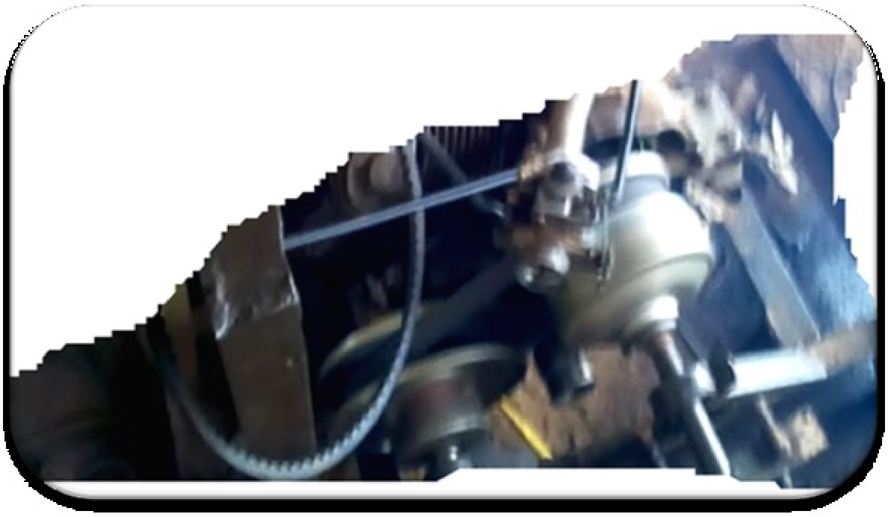


Plate 3.22: CVT at highest ratio

CHAPTER FOUR

4.0 Results And Discussion

The results and discussions of the performance characteristics of the autorickshaw manual and CVT equipped engine are presented in this chapter. The characteristics includes: speed, power, torque, energy data, time taken to complete cycles and fuel consumed for each transmission. The results of the preliminary survey were also presented.

4.1 Preliminary Survey

Information was extracted from autorickshaw drivers to ascertain some peculiarities of the vehicle which helped in determining some aspects of this work. The results are presented in Fig 4.1 – Fig 4.7.

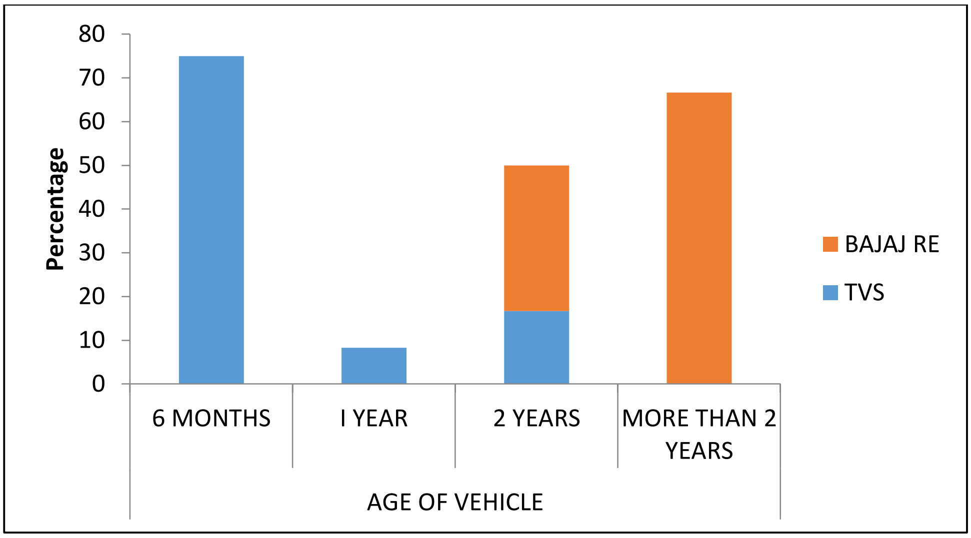


Fig 4.1: Age of Vehicle for Bajaj and TVS

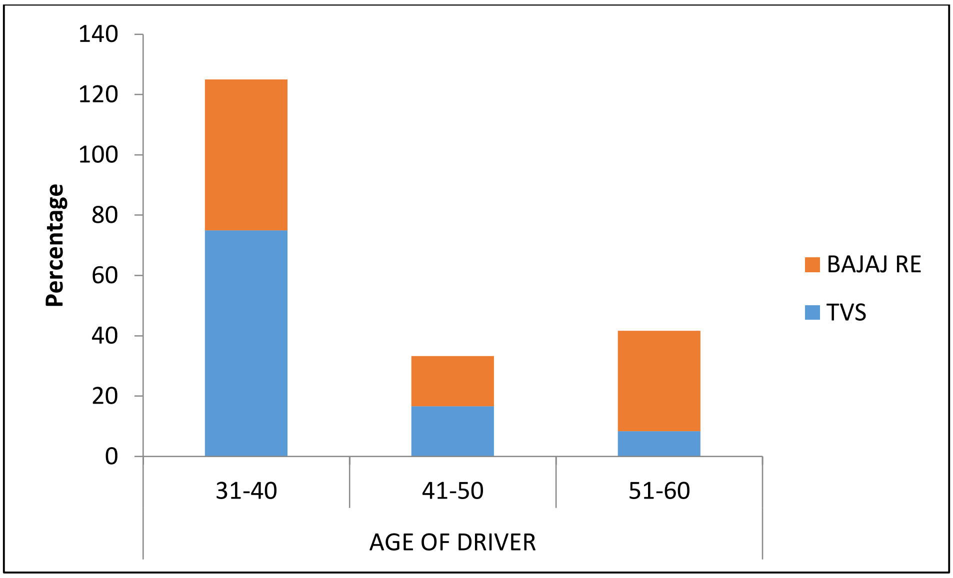


Fig 4.2: Age of Driver for Bajaj and TVS

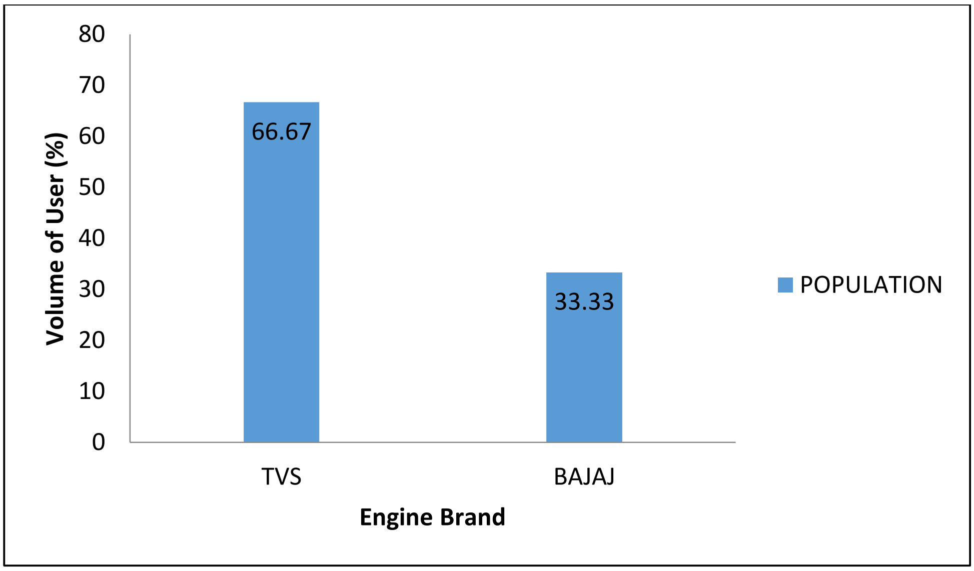


Fig 4.3: Percentage of Bajaj Usage to TVS

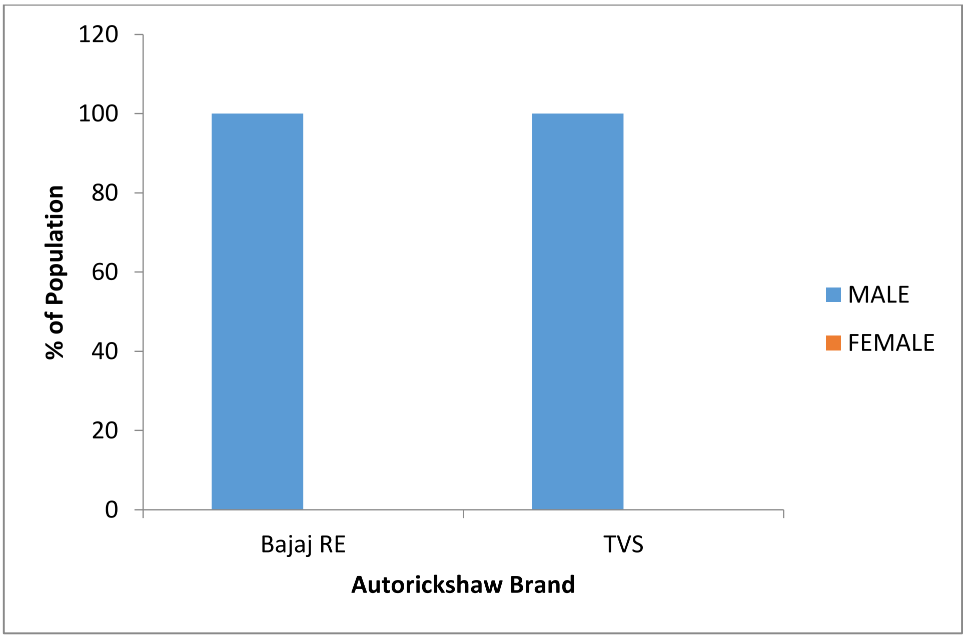


Fig 4.4: Drivers Gender

From Fig 4.1, at the time of the survey, Bajaj RE brand were the only models used over the years until recently when the TVS brands were introduced into the market. There were no Bajaj RE autorickshaws that were less than two years at that time, but we can say they are a very strong brand because almost 50% of them were more than three (3) years old at that time. Fig 4.3 showed that 66.37% uses the Bajaj brand while 33.33% uses the TVS. This can be because the TVS were a new brand at that time and it cannot immediately be at par with well-known Bajaj brand. The TVS were a more aesthetically attractive brand compared to the Bajaj brand and they also have more car room which would make the passengers more comfortable.

From Fig 4.4, all the drivers were male at the time of the survey; no female was driving the autorickshaw at that time in the areas the survey was carried out. 60% of the autorickshaw drivers were in their 30s according to Fig 4.2. 75% of the oldest (those above 40 years) use the Bajaj brand, while the rest 25% uses the TVS brand. The middle aged drivers in their 40s have the range of 52% using TVS brand while 48% uses the Bajaj brand.

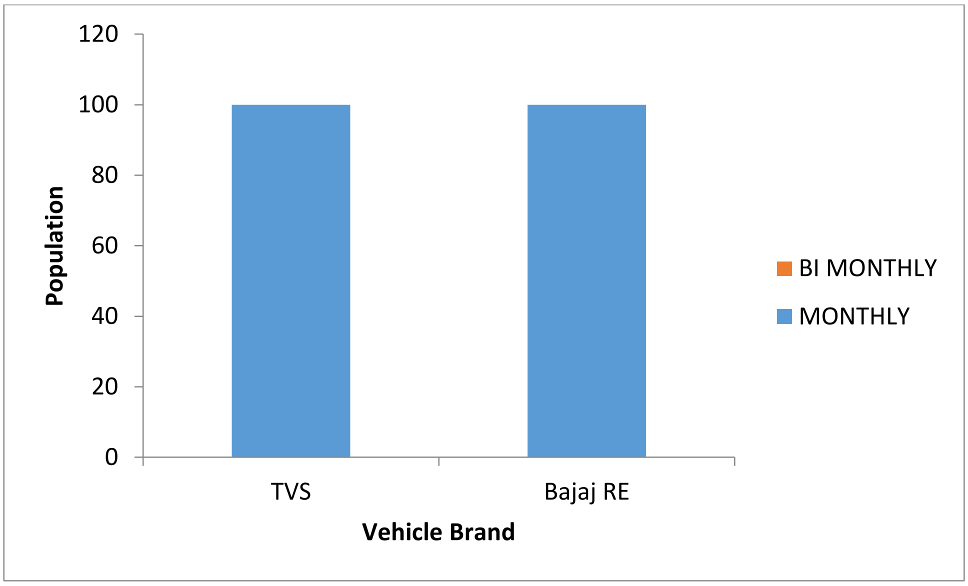


Fig 4.5: Frequency of routine servicing

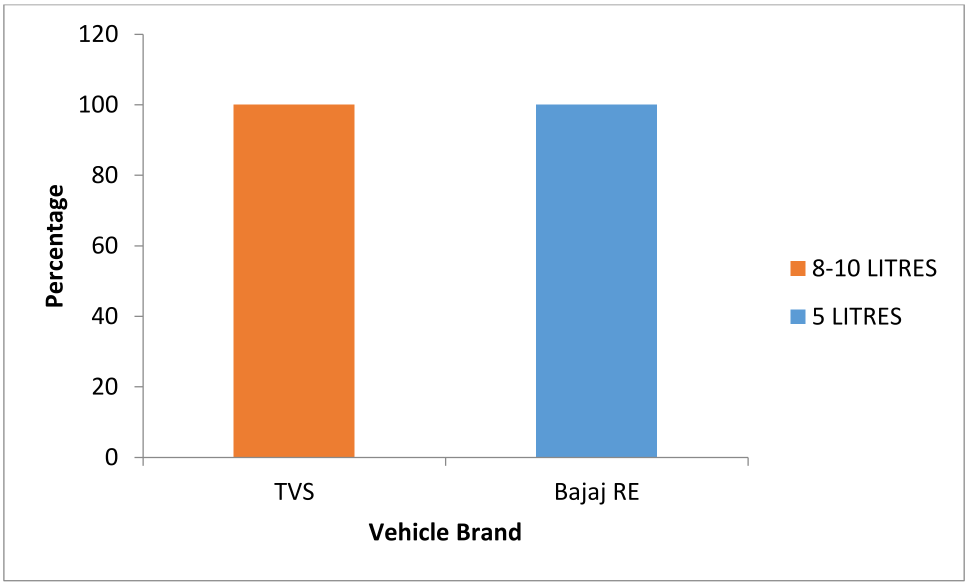


Fig 4.6: Fuel tank Capacity

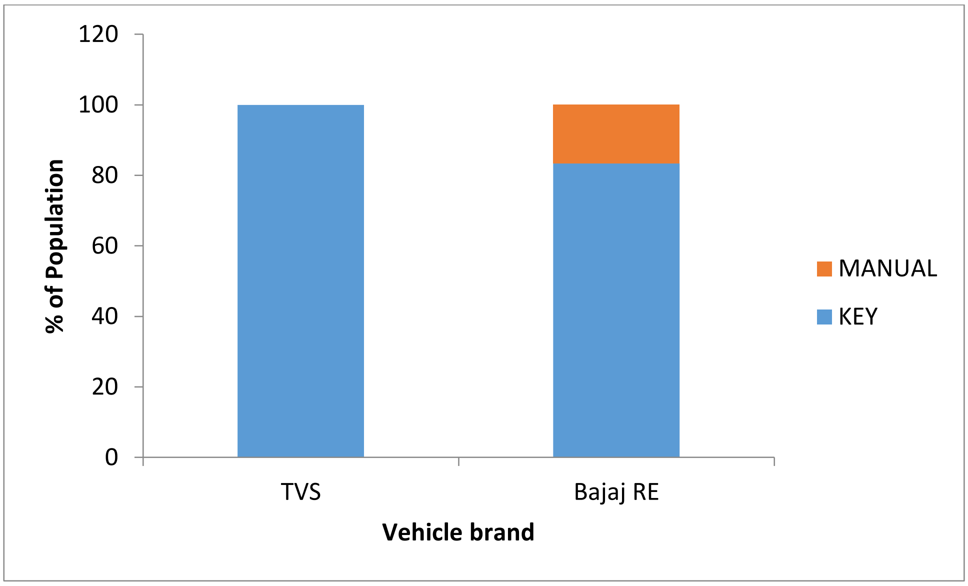


Fig 4.7: Type of Starter used by Vehicle Brands

From Fig 4.5, the servicing of the autorickshaw is done monthly for both vehicle brands. The servicing usually involves;

i. changing of the engine oil for the TVS engines,
ii. clearing carbon deposit from the exhaust pipes by heating it up
iii. changing the piston and piston ring

Since the engine uses fuel, it has fuel tank whose capacity varies from vehicle brands to engine brands. From Fig 4.6; it can be seen that all the Bajaj brands fuel tanks have a capacity of 5 litres, while the TVS brands range between 8 and 10 litres. The difference in the TVS brand was due to the modifications made to the most recent brands manufactured. The Bajaj brand users have to refill their tank more often than the TVS users because the average daily fuel consumption is 10litres.

From Fig 4.7, TVS brands were fitted with both kick starters and manual cranking lever to start the engine, while only 80% of the Bajaj brands have both means of the starting the engine and the remaining 20% cranked manually. The remaining 20% of the Bajaj brand uses only the manual means of starting the engine. These ones were the older ones of more than two (2) years old. The autorickshaws with kick starters uses batteries which also powers electrical system of the vehicles such as;

i. the lighting system
ii. cigarette lighter
iii. charging points for phones
iv. radios

4.2: Engine Performance Characteristics

Based on the result of the survey above, the CVT was recommended as an option to help eliminate the strain experienced by autorickshaw drivers during gear change because both clutch lever and gear levers are on the left hand of the steering bar of the manual transmission autorickshaw. This means that both clutch engagement and disengagement are done simultaneously with gear change using the left palm.

The CVT unit is the one that works to overcome the load the engine is subjected to, because the engine was set to full throttle while the CVT shifts to correspond to the ratio need. The shift is done by the compression springs, the flyweights and the ram in the pulleys. The energy stored in the springs is released in response to the speed received from the engine by the primary pulley and load experienced by the secondary pulley. If the load is much such that the primary pulley cannot transmit equivalent speed and torque to the secondary pulley, it either remains constant or retracts till it balances up because at torque is lower at higher speed and vice versa.

The manual transmission works directly with the engine. The engine supplies the torque needed to overcome load because the gears acts as torque and speed converters for the engine. This is the reason for the obvious response seen in the engine responding to loads by slowing down the vehicle.

The characteristics of the manual equipped engine and the CVT equipped engine are presented in Fig 4.8 to Fig 4.31 Both transmissions were subjected to the same conditions of load: No load, 120 W (low load), 800 W and 920 W (medium loads) and 1600 W (overload).

4.2.1 Speed Graphs for Manual Transmission and CVT transmission

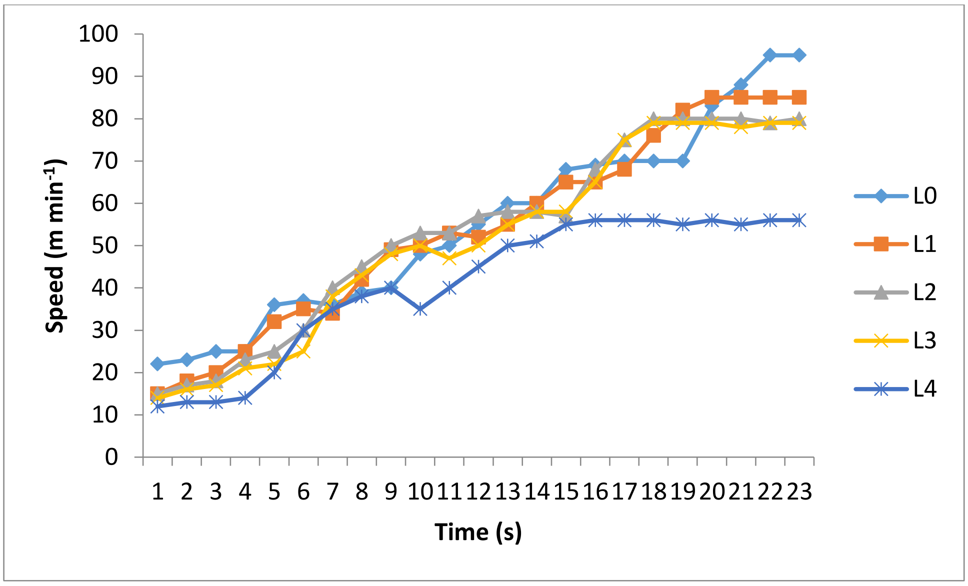


Fig 4.8: Speed for Manual Transmission (No load, 120W, 800W, 920W and 1600W)

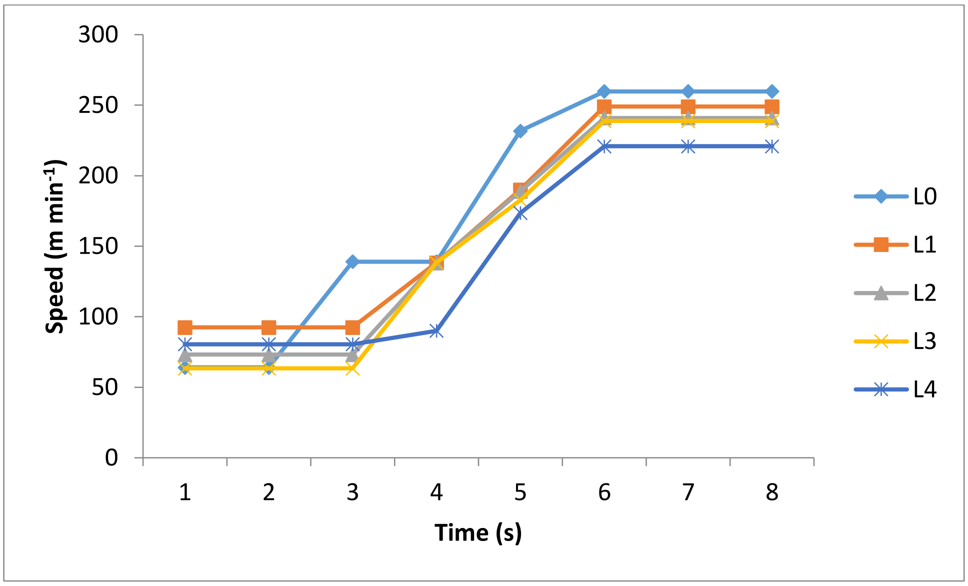


Fig 4.9: Speed for CVT (No load, 120W, 800W, 920W and 1600W)

4.2.1.1 Speed graph for manual transmission

At no load in Fig 4.8, the graph presented a lower slope than others. But there was a close match between the plot of no load and load 120W. This shows that the loading condition (driving condition) is relatively close, so there was a close behaviour in the engine output.

At load 1600W, the speed variation was rather shorter than other loading conditions. This depicts that the engine might be overloaded. The maximum speed was therefore attained in less time compared to others.

4.2.1.2 Speed graph for CVT

Considering Fig 4.9, the stepwise pattern of the graph was due to the infinite number of gear ratios within a second. The tachometer could only give the value of speed per second, meanwhile for the CVT, multiple speed change occurs within a second.

The difference in graph of L_0 and L_1 were closer than that in manual transmission. The two close loading L_2 and L_3 also have the same pattern. This was also the case in the manual transmission, showing the behaviour of the engine at medium loading. This shows that at medium load, the speed of the engine rises steady for both manual and CVT transmissions.

For the highest loading, the CVT maximum output speed was still relatively high unlike in the manual transmission with T of 81.021 against 40.383, 47.186, 38.953 and 42.376 corresponding to L_0, L_1, L_2 and L_3, respectively. $T_{critical}$ at this loading was 4.196 against 4.183 for L_0, L_1, L_2 and L_3.

Unlike in the manual transmission, the highest speed was attained in less time in the CVT as can be seen in all the speed graphs. Speed variation was low for manual transmission showing that the CVT responds better to high loads.

4.2.2 Power and Torque plots for Manual and CVT transmissions

4.2.2.1 Power and Torque for MT and CVT at L_0 and L_1

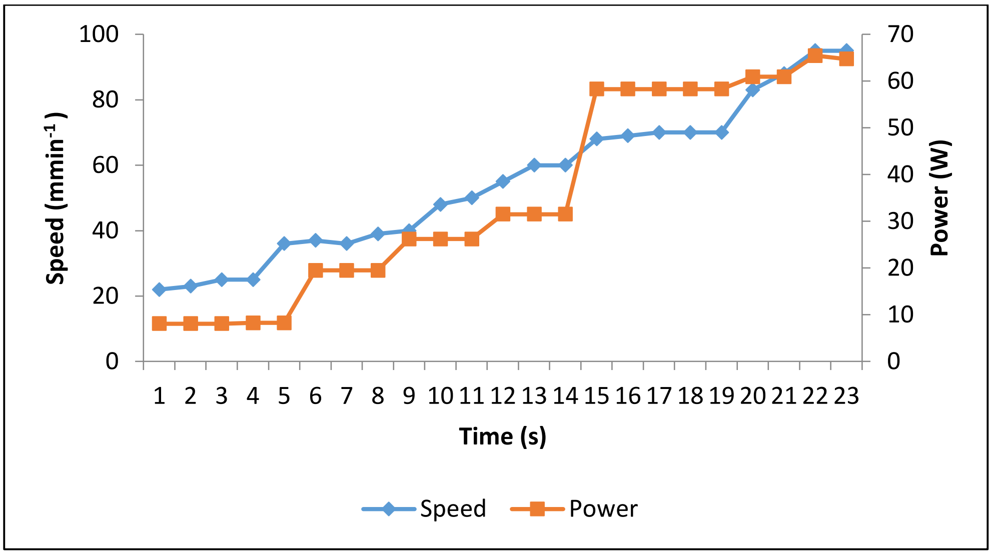


Fig 4.10: Speed vs Power (MT at No Load)

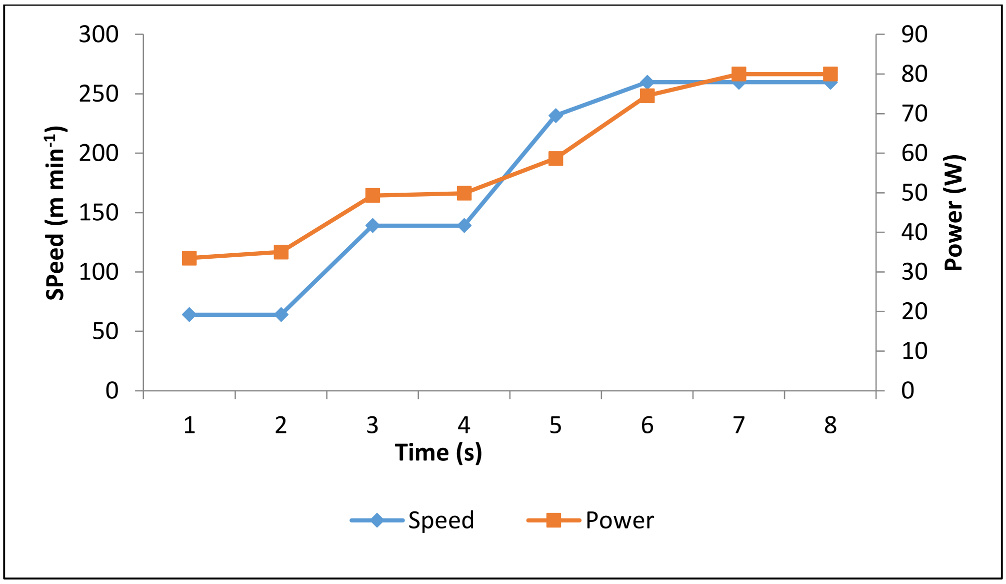


Fig 4.11: Speed vs Power (CVT at No Load)

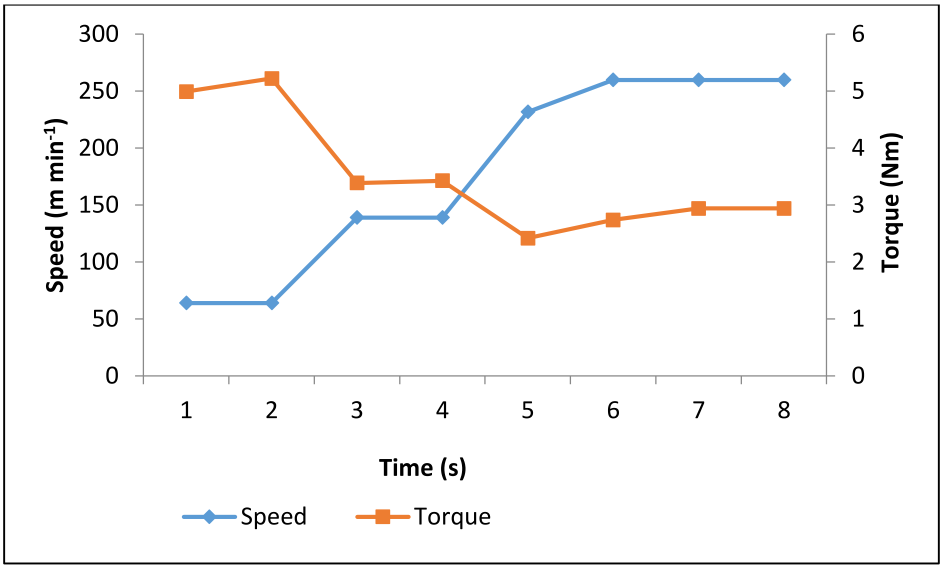


Fig 4.12: Speed vs Torque (CVT at No Load)

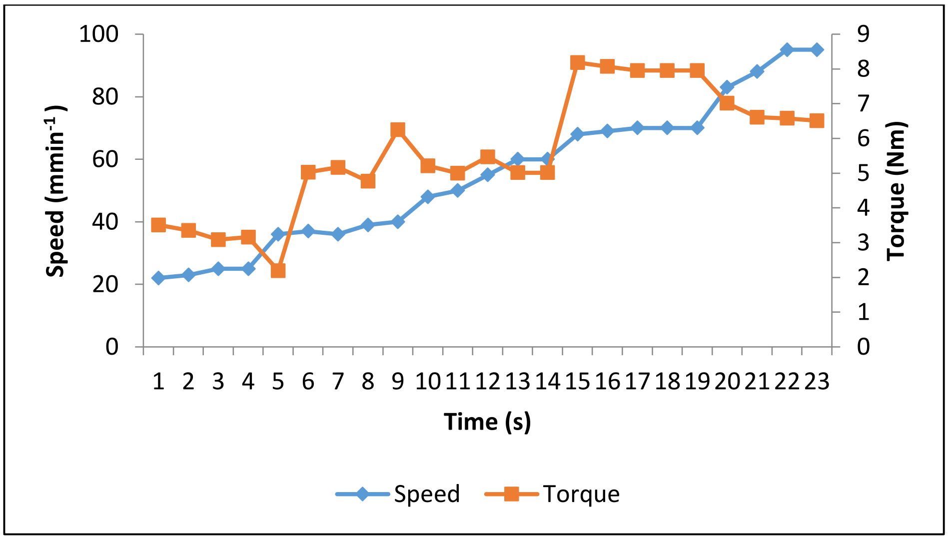


Fig 4.13: Speed vs Torque (MT at No Load)

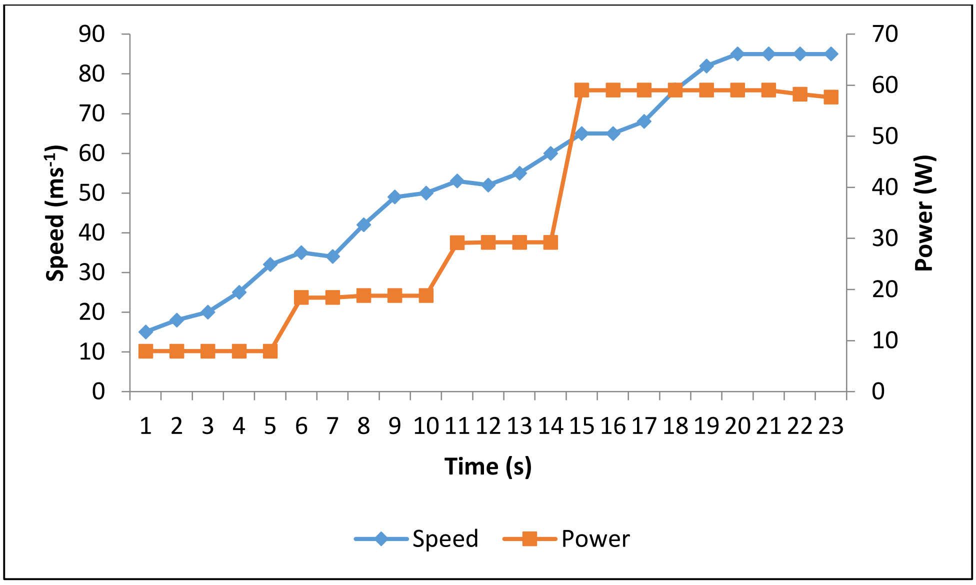


Fig 4.14: Speed vs Power (MT at 120W)

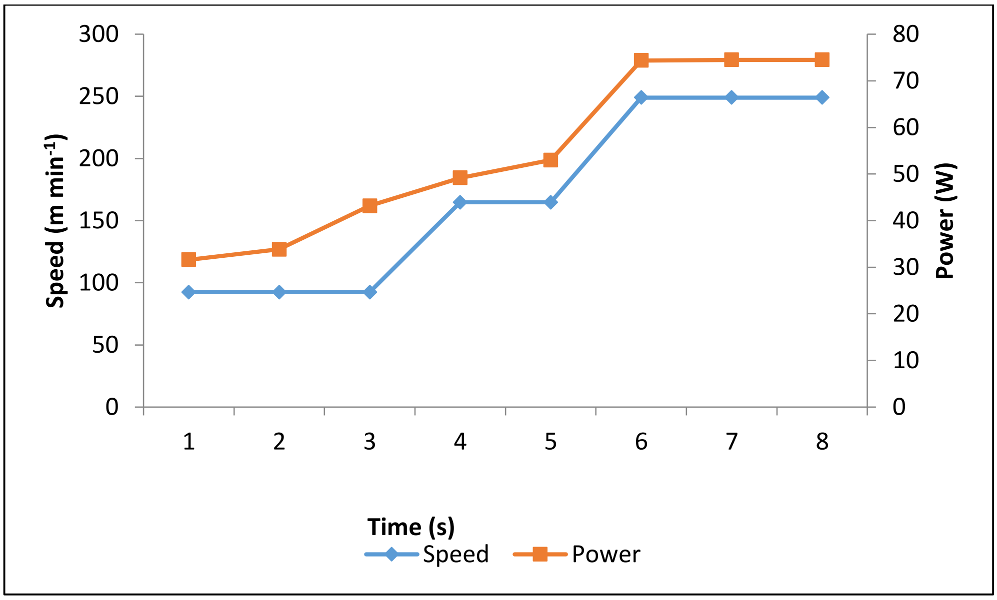


Fig 4.15: Speed vs Power (CVT at 120W)

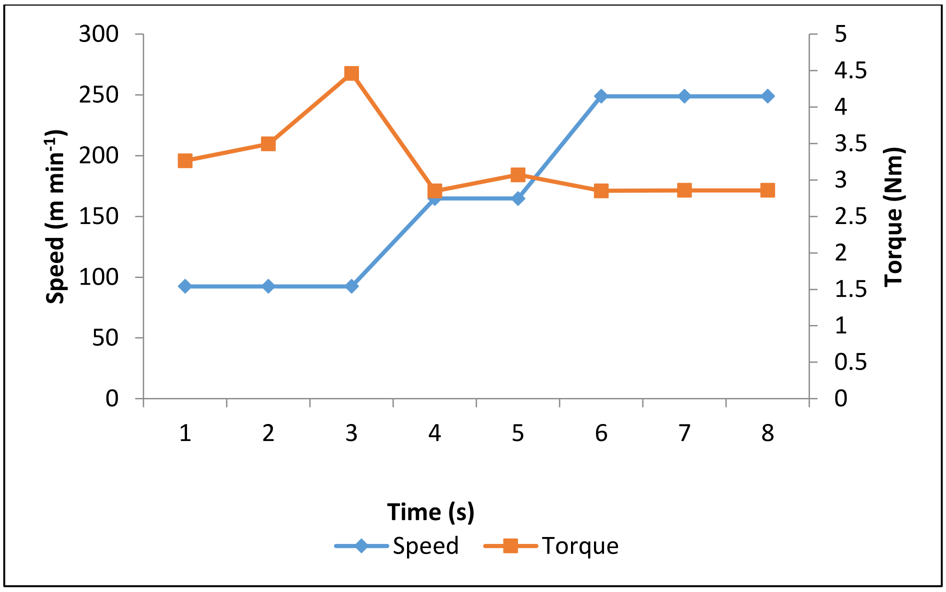


Fig 4.16: Speed vs Torque (CVT at 120W)

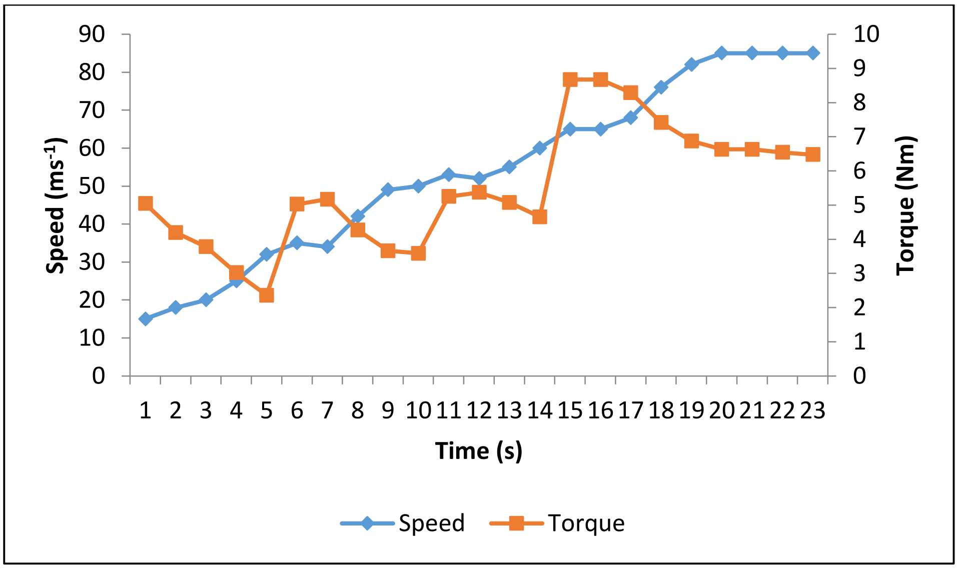


Fig 4.17: Speed vs Torque (MT at 120W)

The Power curve on the manual transmission for No load and Load 120W are similar, because the engine has not being subjected to a significant load with the application of 120W load. This is also the case in the CVT transmission.

There is a wider power range in the CVT than in the manual transmission, because the CVT has a higher inertia at start up looking at Fig 4.10 to Fig 4.17 from the Power and torque points.

The torque plots (Figs 4.12, 4.13, 4.17 and 4.18) showed a very high value at start-up which became almost constant at the middle of the travel time for the CVT, while the plots of the manual transmissions showed staggering values all along the travel time. This shows that the CVT has a much better response to torque requirement than the manual transmission even when not subjected to any load.

4.2.2.2 Power and Torque for MT and CVT at L_2 and L_3

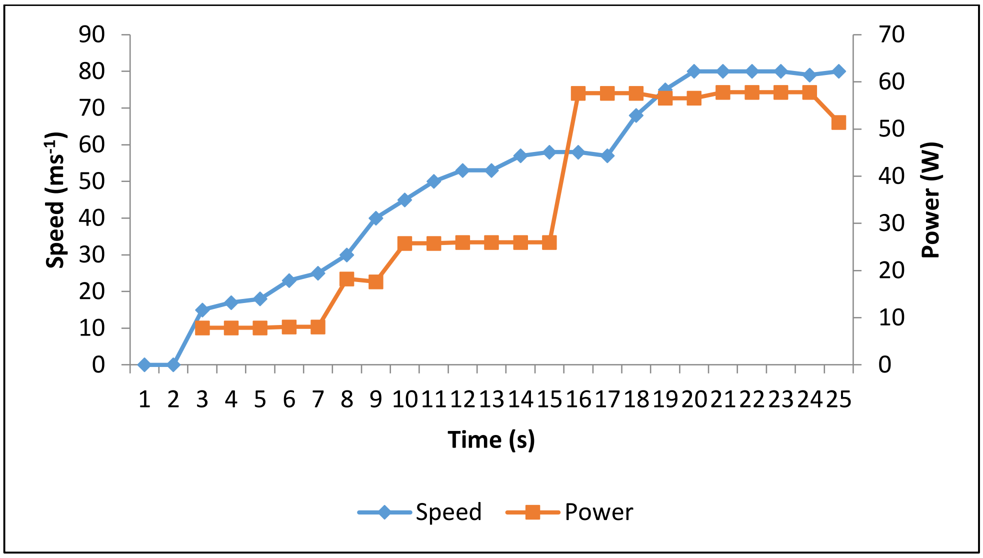


Fig 4.18: Speed vs Power (MT at Load 800W)

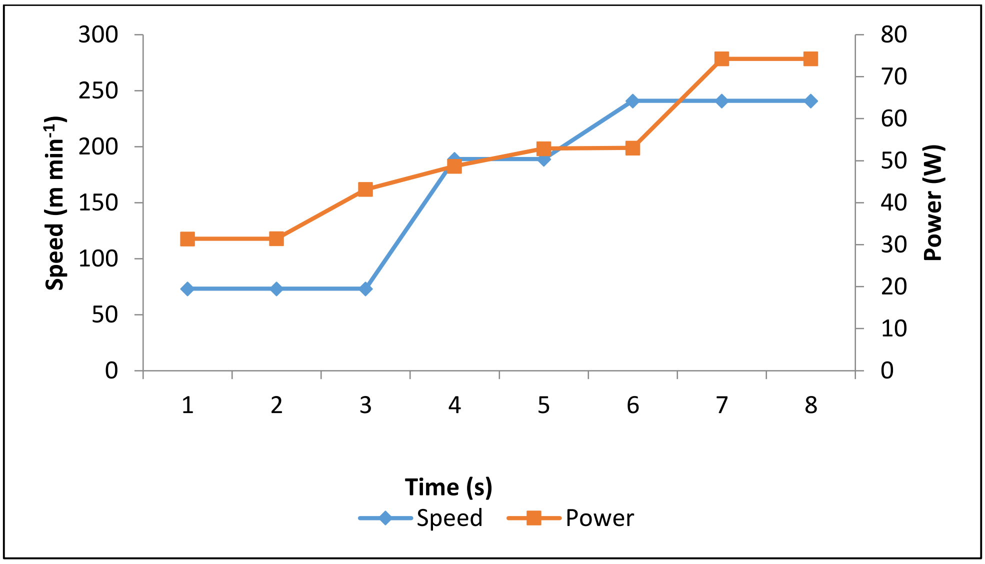


Fig 4.19: Speed vs Power (CVT at 800W)

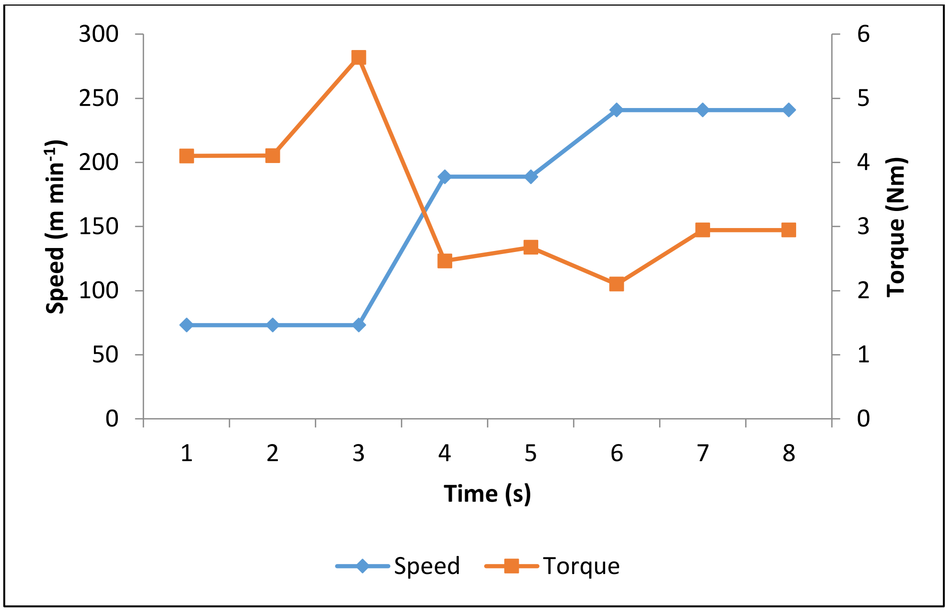


Fig 4.20: Speed vs Torque (CVT at 800W)

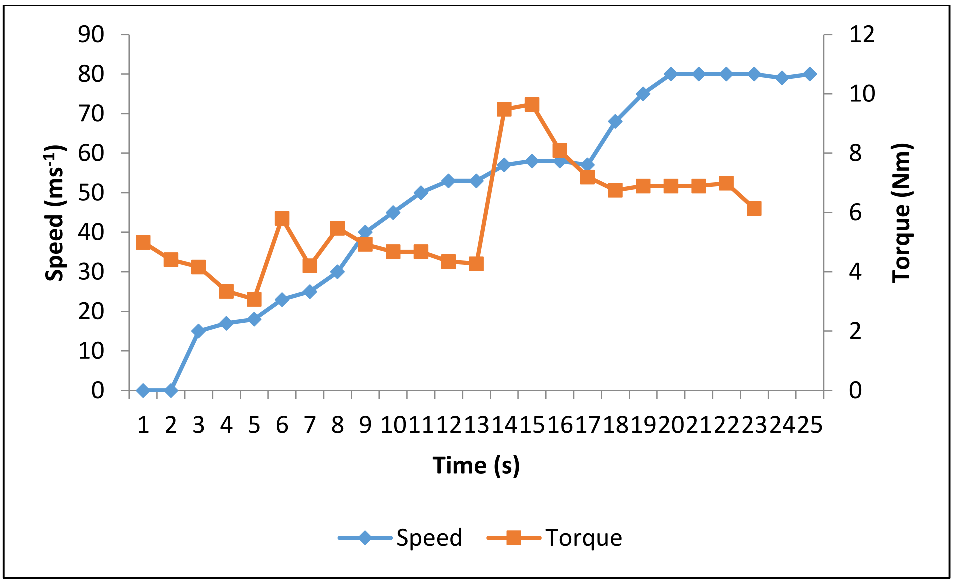


Fig 4.21: Speed vs Torque (MT at 800W)

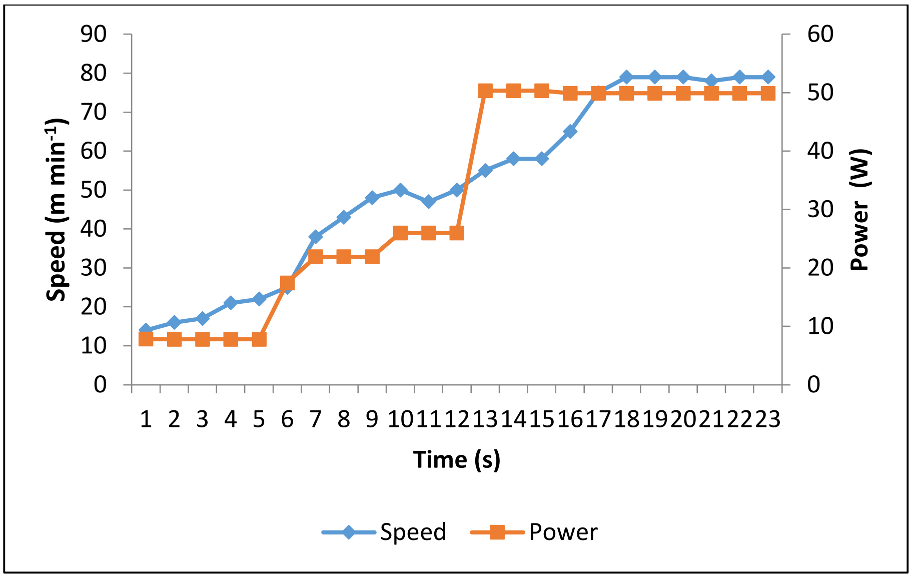


Fig 4.22: Speed vs Power (MT at 920W)

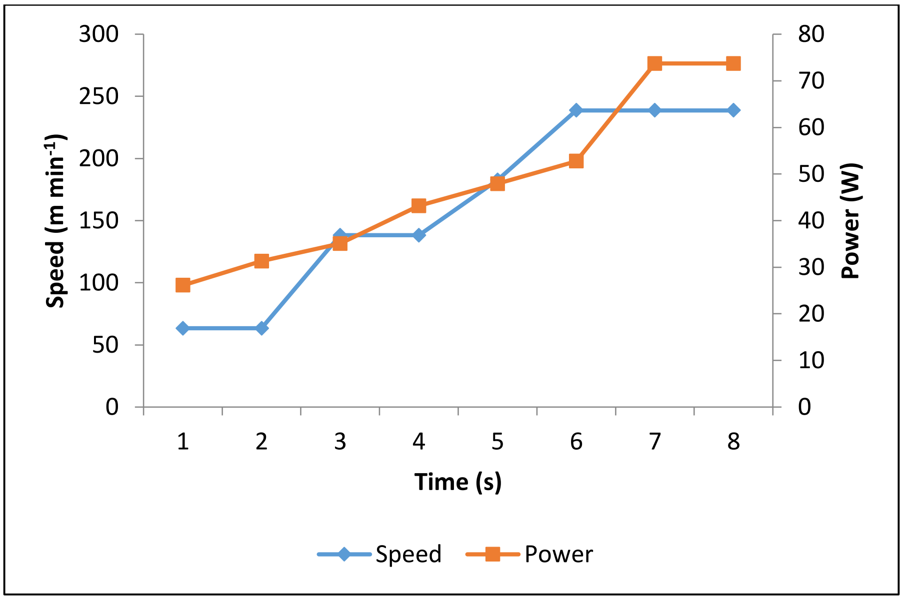


Fig 4.23: Speed vs Power (CVT at 920W)

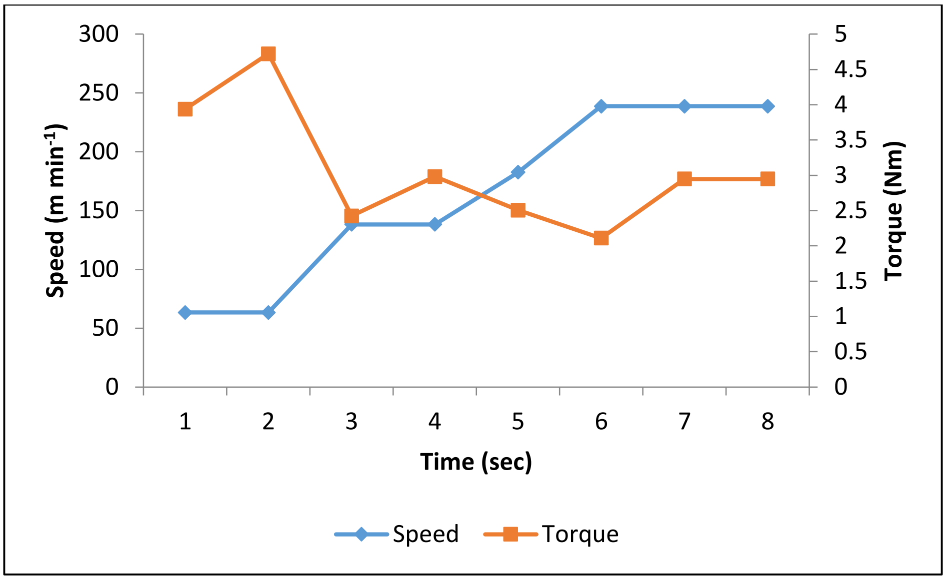


Fig 4.24: Speed vs Torque (CVT at 920W)

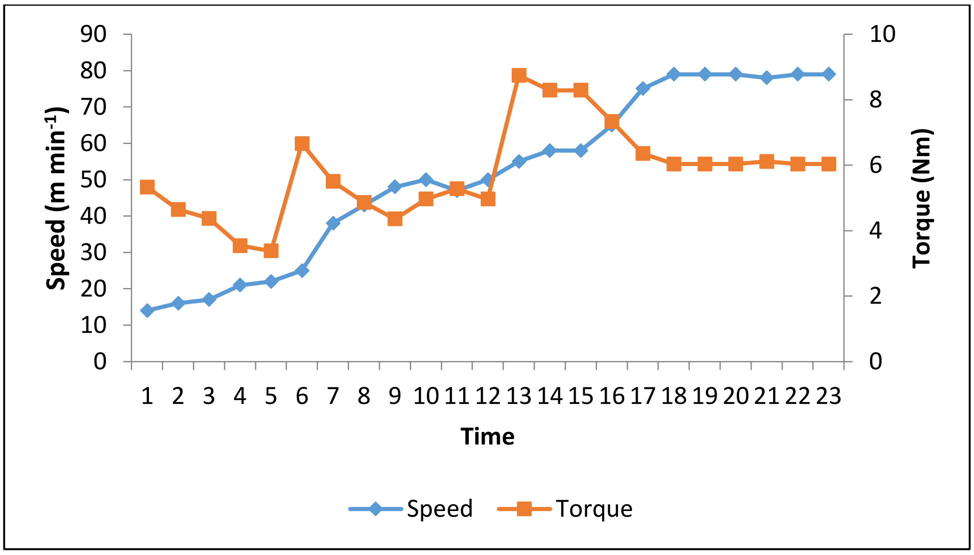


Fig 4.25: Speed vs Torque (MT at 920W)

The two loads which represent medium or average loading of the engine showed similar characteristics for each of the two types of transmission. From Figs 4.18 to 4.25; all the graphs have the same minimum and maximum values. This means the loads are within the convenient range of loads for the CVT. It can be deduced that the CVT has a wider power range.

4.2.2.3 Power and Torque Plots for MT and CVT at L_4

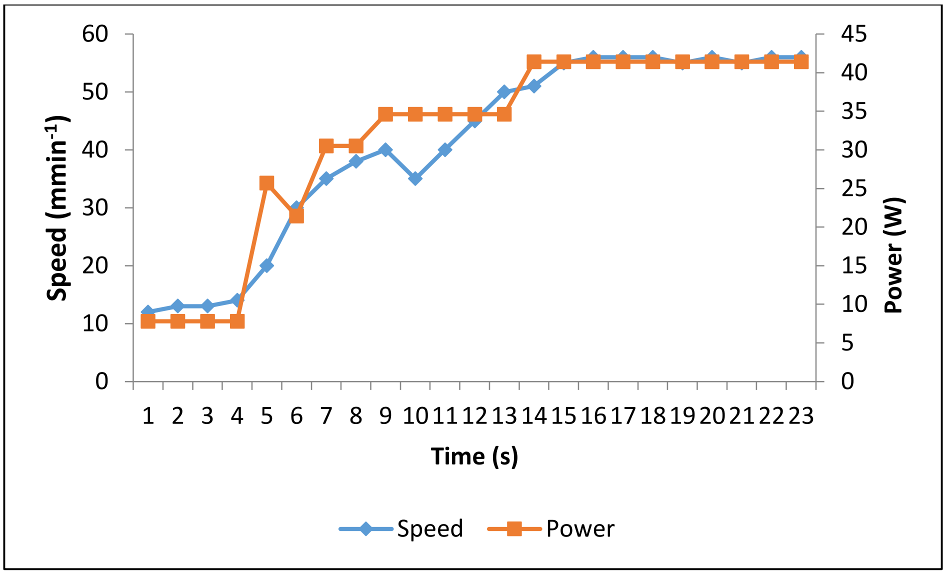


Fig 4.26: Speed vs Power (MT at 1600W)

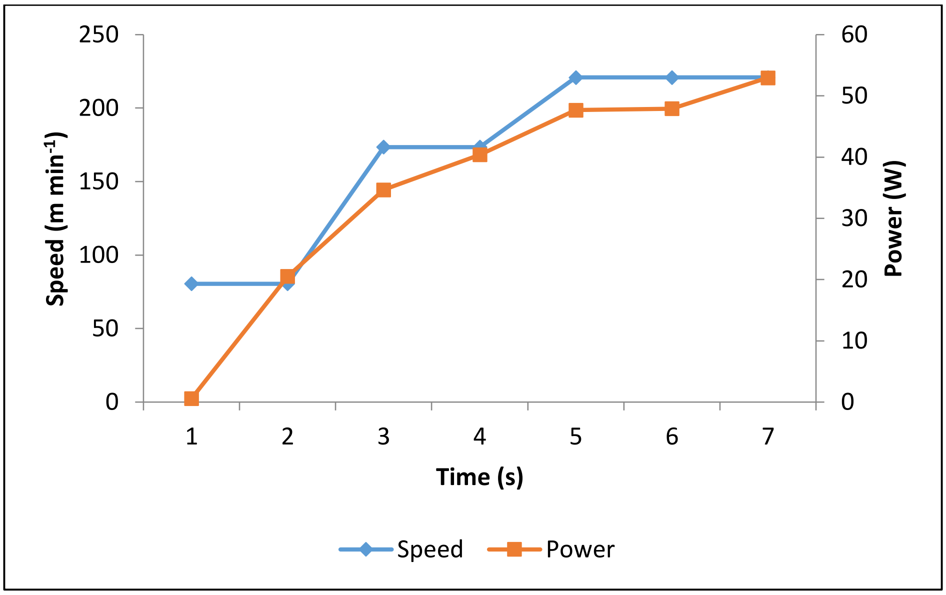


Fig 4.27: Speed vs Power (CVT at 1600W)

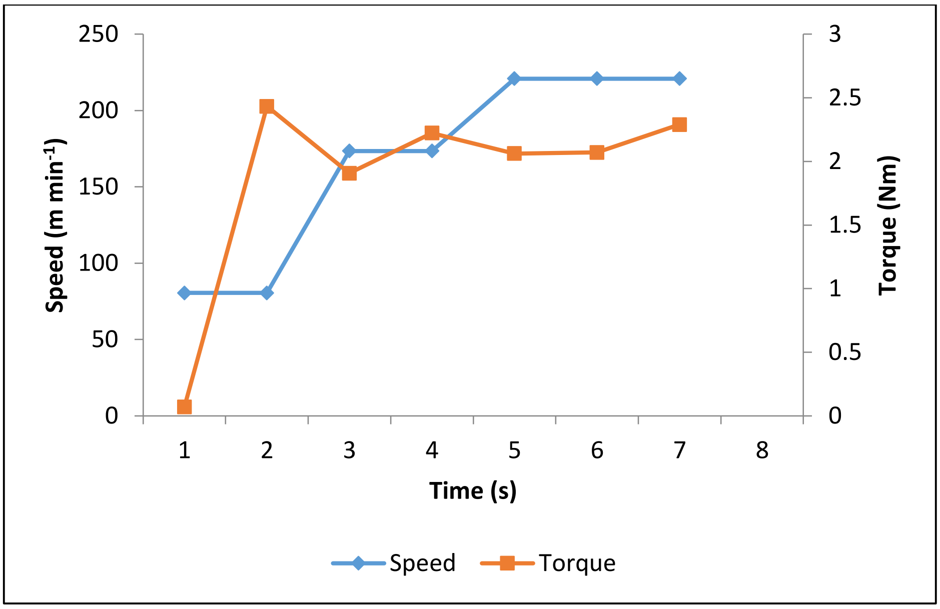


Fig 4.28: Speed vs Torque (MT at 1600W)

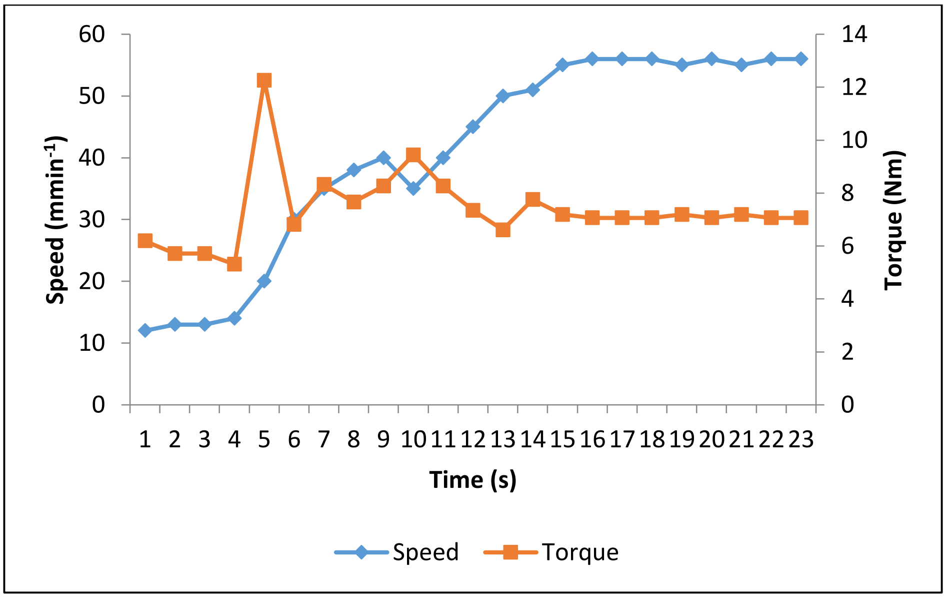


Fig 4.29: Speed vs Torque (CVT at 1600W)

The graphs in Fig 4.26 to Fig 29 reveal the response of the engine to overload for the manual transmission and the CVT. The manual transmission had a shorter range of power change and torque response than that of the CVT. The engine at this stage was vibrating and the exhaust smoke was so much for the manual transmission with sparks coming out of the exhaust pipe as the throttle was being raised around the mid-point. The CVT however exhibited a much better output; the fumes at the exhaust were much clearer, only that it was a little short of reaching its maximum speed.

From Fig 4.29, the torque was not high at start up for the CVT, but at the second phase of the journey, it short up and returned to the average point which was almost constant for the rest of the travel. But in Fig 4.28, the torque curve fluctuated about the maximum throughout the journey.

The choice of bulbs used as loads effectively loaded the engine as seen in all the graphs, because it was the reason for the various variations presented. The highest load 1600W was significant in all the readings shown clearly depicting uphill traveling.

4.2.3 Energy Plots for Manual and CVT transmission (L_0 to L_4)

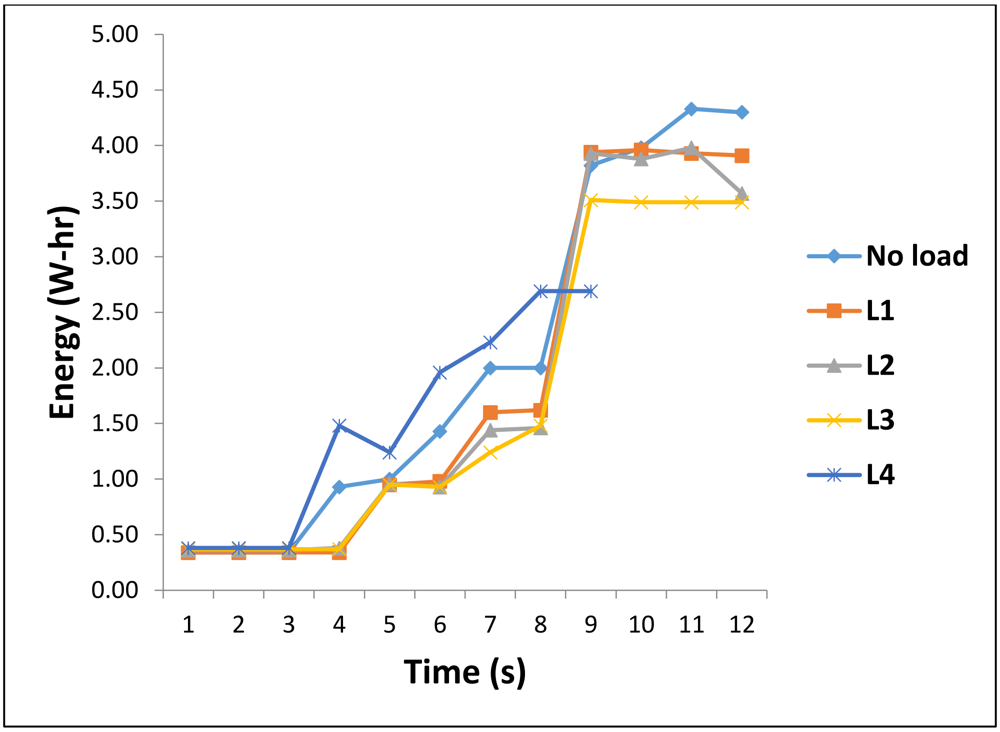


Fig 4.30: Energy Plot for MT ($L_0 - L_4$)

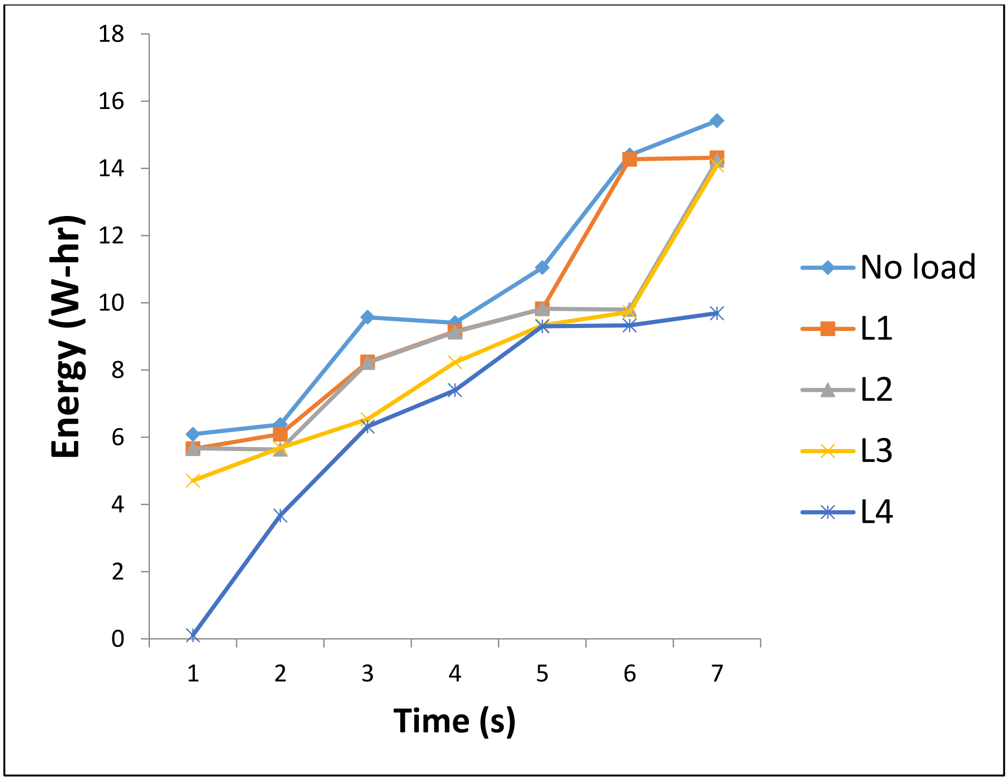


Fig 4.31: Energy Plot for CVT ($L_0 - L_4$)

The energy graphs presented in Fig 4.30 and Fig 4.31 are the same in range and pattern with the power graphs. This is according to established relationship between power and energy, because energy is the product of power and time. The energy is a cumulative property unlike the power which is instantaneous; it is a combination of the power accumulated over a period of time. This is the factor that determines the strength of the engine and transmission to overcome imposed loads or the extent to which it would carry the load.

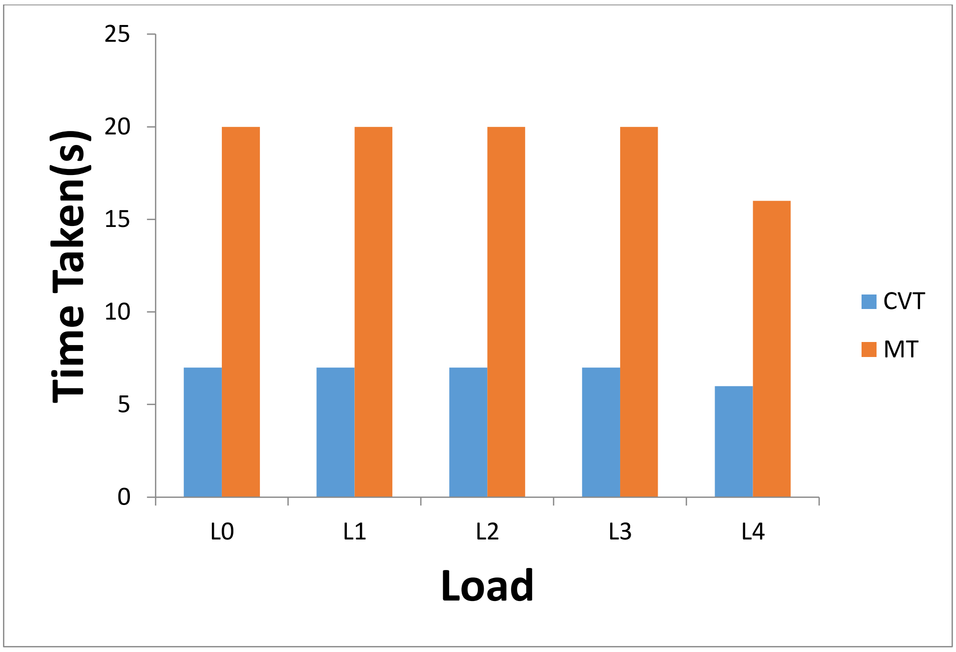


Fig 4.32: Time Taken for complete Driving Cycle under the various loadings

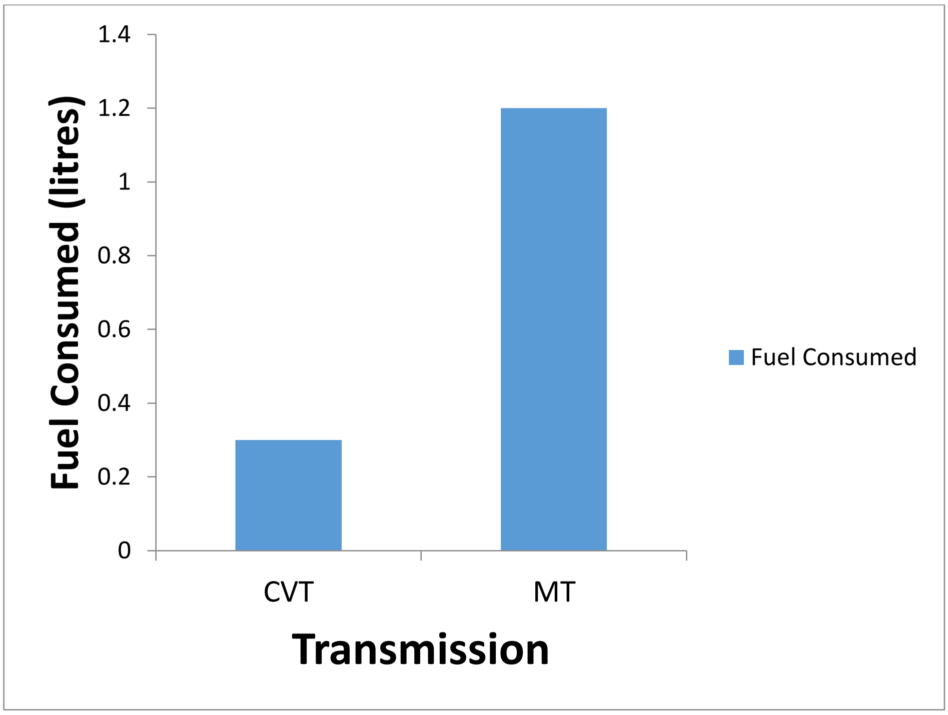


Fig 4.33: Fuel Consumed for each transmission

The time taken to complete each driving cycle was the same in the first three loading conditions for both transmission. The highest loading condition was shorter for both transmissions which depicts that the engine was overloaded by this load. The CVT transmission had a better response compared to the manual transmission.

The time taken by the CVT to complete its driving cycle is much lesser than that of the manual transmission, because the engine was set at full throttle once and for all against what is obtainable with the manual transmission. This can be said to be the reason for the fuel efficiency.

4.3 Data Analysis

Table 4.1: ANOVA for Output Speed (MT and CVT)

SPEED	mean		Variance		T	$T_{critical}$
	MT	CVT	MT	CVT		
Lo	54.96	177.15	530.77	7423	40.383	4.183
L_1	53.74	169.22	537.93	5259.14	47.186	4.183
L_2	53.09	164.97	524.17	6253.99	38.953	4.183
L_3	51.09	162.75	543.63	5526.63	42.376	4.183
L_4	40.74	167.22	268.93	3959.14	81.021	4.196

Table 4. 2: ANOVA for Output Power (MT and CVT)

POWER	mean		Variance		T	$T_{critical}$
	MT	CVT	MT	CVT		
Lo	35.47	57.6	475.33	358.67	6.503	4.183
L_1	33.86	54.26	464	329.09	5.729	4.183
L_2	34.75	51.14	433.86	274.98	4.033	4.183
L_3	32.62	47.97	323.78	327.54	4.311	4.183
L_4	31.58	34.95	155.39	345.41	0.311	4.196

Table 4. 3: ANOVA for Output Torque (MT and CVT)

TORQUE	mean		Variance		T	$T_{critical}$
	MT	CVT	MT	CVT		
Lo	5.61	3.51	3.19	1.08	9.77	4.183
L_1	5.51	3.21	3.13	0.311	12.75	4.183
L_2	5.79	3.37	3.21	1.36	12.64	4.183
L_3	5.78	3.07	2.01	0.74	25.73	4.183
L_4	7.37	1.86	1.98	0.66	95.87	4.196

Tables 4.1, Table 4.2 and Table 4.3 shows that there is significant difference in the output speed, output power and output torque of manual transmission and the CVT because for each group: T was greater than $T_{critical}$.

CHAPTER FIVE
5.0 CONCLUSIONS AND RECOMMENDATIONS

This Chapter presents the summary of this work and the recommendations for further research.

5.1 Conclusions

This work was carried out to investigate the performance of an autorickshaw engine originally fitted with a Manual Transmission (MT) and its subsequent retrofit with a Continuously Variable Transmission (CVT). To achieve this, an autorickshaw engine originally fitted with a manual transmission was acquired. The manual transmission was replaced with a continuously variable transmission unit so as compare each transmission's response to various loads. Each of the transmissions was subjected to: No load, 120W (L_1: low load), 800W and 920W (L_2 and L_3: medium loads) and 1600W (L_4:overload) respectively (downhill, level ground and uphill conditions) respectively through a dynamometer designed for this purpose.

The tests carried out revealed the following;

i. Two brands of autorickshaw are majorly used in Nigeria; the Bajaj Re which is the oldest and the TVS which were recently introduced into the market less than two years to the time of this survey.
ii. All the drivers examined were men at the time of the survey. This means that the autorickshaw drivers are dominated by men. 60% of these men were less than 40 years old, while the remaining 40% are adult and use the Bajaj RE brand.
iii. The time to attain maximum speed was shorter in the CVT with just 8 seconds while the MT was longer with 23 seconds. This shows that the CVT has better response to speed variation (almost 3 times the MT)
iv. Speed variations downhill and level ground corresponding to low and medium (intermediate) loading conditions for both MT and CVT does not show much variation for each transmission.
v. For the CVT, the torque was high at start-up and decreases with increased speed while the MT is the opposite: here the torque fluctuates about a mean. It can thus be deduced that the CVT has higher inertia at start-up.

vi. Power and Energy response in CVT was wider, while the MT has very low power range. The CVT can thus better overcome load than the MT. The value at the highest loads for the CVT was very high compared to the lower ratios.

vii. Fuel consumed for the MT and CVT drive cycles was 0.17 and 0.032 litres/m, respectively.

viii. The CVT attained maximum speed of 242± 14.35 ms^{-1} in 6 seconds while the MT attained maximum speed of 79±14.33 ms^{-1} in 18 seconds for the various loading conditions.

ix. At overload: the load corresponding to 1600W, for both transmissions, the maximum speed and power was lower than smaller loads. It was clearly seen that the manual transmission has lower load carrying capacity than the CVT, as the engine makes so much noise and increased fumes in the exhaust with sparks as the throttle is raised towards its maximum displacement.

x. There was significant different in the output speed, output power and output torque of the manual transmission and the CVT at 95% confidence level.

5.2 Recommendations

With the constant increase in the scarcity of fuel these days and the current call for reduction in global warming worldwide, the following were recommended;

i. Autorickshaws with manual transmissions should be retrofitted with CVTs. This would help reduce emission that pollutes the atmosphere and consequently contributes to global warming.

ii. A torque converter should be added to the CVT transmission which will incorporate a reverse gear for the transmission, because the CVT does not have a reverse capacity.

iii. A torquemeter should be incorporated into the dynamometer to give a direct torque measurement and compared with the calculated torque.

iv. Government and Investors should support the commercialization of the CVT driven autorickshaw, which will reduce the use of the commercial motor cycle (*okada*) that has claimed the life of many of their users.

v. For further research, an exhaust analysis should be carried out comparing the two transmissions, to determine their environmental impact especially in terms of pollution.

REFERENCES

Abu, M., Denman, B. and Surgenor, B., 2010. A Study of Fuel Cell Hybrid Auto Rickshaws Using Realistic Urban Drive Cycles. *Jordan Journal of Mechanical Engineering and Industrial Engineering*, 4(1), pp.225–229.

Adak, P., Sahu, R. and Elumalai, S.P., 2016. Development of emission factors for motorcycles and shared auto-rickshaws using real-world driving cycle for a typical Indian city. *Science of the Total Environment*, 544, pp.299–308. Available at: http://dx.doi.org/10.1016/j.scitotenv.2015.11.099.

Aher, S.S. and Shelke, R.S., 2014. Speed Variation using Cone Ring Traction Drive. *International Journal of Engineering Development and Research*, 3(1), pp.110–113.

Al-Jalil, H.F., Khdair, A. and Mukahal, W., 2001. Design and performance of an adjustable three-point hitch dynamometer. *Soil and Tillage Research*, 62(3–4), pp.153–156.

Alessandro, B., 2013. CVT Scooter Transmission. Available at: http://www.multibody.net/teaching/msms/students-projects-2013/cvt-transmission/ [Accessed February 9, 2017].

Anand, S., 2013. Who introduced auto rickshaws in India. *Quora*. Available at: https://www.quora.com/Who-introduced-auto-rickshaws-in-India [Accessed February 6, 2017].

Anyogita, S., Prakash, A. and Jain, V.K., 2004. A study of noise in CNG driven modes of transport in Delhi. *Applied Acoustics*, 65(2), pp.195–201.

Asghar, A.M., Bhatti, A. I., Ahmed, Q. and Izhar, T. 2016. Design of an Energy Efficient Electric Auto Rickshaw. *International Journal of Electrical and Computer Engineering*, 3(12), available at waset.org/abstracts/54016.

Athavankar, U.A. and Singh, S.R. 2016. *Design of Solar powered vehicle.* project III, Industrial Design Center, IIT Mumbai. Available at http://www.dsource.in/sites/default/files/case-study/solar-powered-rickshaw/introduction/file/solar-powered-rickshaw.pdf. Retrieved on Spetember 9, 2016.

Bell, C.A., 2011. Constant Power - Continuously Variable Optimisation and Simulation. *PHD thesis Brunel University*.

Bonsen B., Klaassen T.W.G.L., van de Meerakker K.G.O., Steinbuch M. and

Veehuizen P.A. 2005a. Measurement and Control of slip in a Continuously Variable Transmission. Eindhoven University of Technology. The Netherlands.

Bonsen B., Steinbuch M.. and Veehuizen P.A. 2005b. Continuously Variable Transmission ratio control strategy optimization. Technical University Eindhoven.

Casadei, S. and Maggioni, A., 2016. Performance Testing of a Locomotive Engine Aftertreatment Pre-prototype in a Passenger Cars Chassis Dynamometer Laboratory. *Transportation Research Procedia*, 14, pp.605–614. Available at: http://dx.doi.org/10.1016/j.trpro.2016.05.305.

Choudhary, A. and Gokhale, S., 2016. Urban real-world driving traffic emissions during interruption and congestion. *Transportation Research Part D: Transport and Environment*, 43, pp.59–70. Available at: http://dx.doi.org/10.1016/j.trd.2015.12.006.

Chybowski, L. 2008. Assessment Of Marine Engines Torque Load Without Using Of The Torquemeter. *Journal of Polish CIMAC, Gdansk University of Technolgy, Poland.*

Cook, G.S., 1972. An indicating tachometer for oceanographic use. *Ocean Engineering*, 2(3), pp.115–116.

CVT, 2008a. How much does CVT Benefit? *CVT-Continously Variable Transmission*. Available at: http://cvt.com.sapo.pt/performances/performances.htm.

CVT, 2008b. Ratcheting CVTs. *CVT-Continously Variable Transmission*. Available at: http://cvt.com.sapo.pt/ratcheting/ratcheting.htm [Accessed February 9, 2017].

Dawn News, 2012. *Infotainment: Tracing the history of rickshaw*. Available at: http://www.dawn.com/news/768083 [Accessed February 6, 2017].

De Rijk, M., 2016. Milner CVT. Available at: http://www.intersyn.com/index_files/page0005.htm [Accessed February 9, 2017].

De Souza, M.A., de Jesus ALves, B., Rogan, C., Baranauskes, B., Mataruco, M., Pizzeto, T.M. and Mattiello-Sverzut, A.C. 2014. Normative data for hand grip strength in healthy children measured with a bulb dynamometer: A cross-sectional study. *Physiotherapy (United Kingdom)*, 100(4), pp.313–318. Available at: http://dx.doi.org/10.1016/j.physio.2013.11.004Elektronik, E., 2017. Digital Tachometer Period measurement principle for rotational speed flow rate – ratio - proportional difference RS 422/485 interface. Available at: http://www.esters.de/en/download/ds/e180.20020626.pdf [Accessed February 8, 2017].

Faust, H. and Linnenbrugger, A., 1995. CVT Development at LuK. A LuK India colloquim. Available at https://www.schaeffler.com/remotemedien/media/_shared_media/08_media_library/01_publications/schaeffler_2/symposia_1/downloads_11/7_CVT_2.pdf. Retrieved on September 9, 2016.

Ge, Z.M. and Shiue, J.S., 2003. Non-linear dynamics and control of chaos for a tachometer. *Journal of Sound and Vibration*, 253(4), pp.773–793.

Gopinath, R., 2014. Design of a rope brake dynamometer. *Middle - East Journal of Scientific Research*, 20(5), pp.650–655. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84894680825&partnerID=tZOtx3y1.

Gore, M.M., Ronge, B.P. and Misal, N.D., 2015. A review paper on design and analysis of system of three wheeler. *International Journal of Application or Innovation in Engineering and Management (IJAIEM)*, 4(5), pp.77–80. Available at: http://www.ijaiem.org/Volume4Issue5/IJAIEM-2015-05-22-62.pdf.

Grieshop, A.P., Boland, D., Reynolds, C. O., Gouge, B., Aple, J. S., Rogak, S. N. and Kandikar, M. 2012. Modeling air pollutant emissions from Indian auto-rickshaws: Model development and implications for fleet emission rate estimates. *Atmospheric Environment*, 50, pp.148–156. Available at: http://dx.doi.org/10.1016/j.atmosenv.2011.12.046.

Grzegozek W. and Szczepka. 2016. Analysis of an employment of a gear ratio rate in CVT control system. *Scientific Conference on Automotive Vehicles and Combustion Engines.* IOP Conference Series: Materials Science and Engineering 148(2016) 012007 (KONMOT 2016).

Gyllendahl, T. and Tran, D., 2012. Development of an auto rickshaw vehicle suspension. B.Sc Project, Lulea University of Technology, p.125.

Harding, S.E., Badami, M. G., Reynolds, C. O. and Kandikar, M. 2016. Auto-rickshaws in Indian cities: Public perceptions and operational realities. *Transport Policy*, 52, pp.143–152. Available at: http://dx.doi.org/10.1016/j.tranpol.2016.07.013.

Hilliard Corporation, 2017. Engine Braking CVT Systems. *Hilliard Motion Control Division*. Available at: http://www.hilliardcorp.com/media/18142/EBS-1-Engine-Braking-CVT-Systems.pdf [Accessed February 9, 2017].

Hofman, T., Van der Tas, S.G., Ooms, W., Van Meijil, E. W. P. and Laugeman, B.M. 2009. Development of a micro-hybrid system for a three-wheeled motor taxi. *World Electric Vehicle Journal*, 3(1), pp.572–580.

ICAP. 2008. “Emission factor development for Indian vehicles” as a part of Air quality monitoring and Emission Source Apportionment Studies. *The automotive research association of India*, India.

Jian, L. and Chau, K.T., 2010. Design and analysis of a magnetic-geared electronic-continuously variable transmission system using finite element method. *Progress In Electromagnetics Research*, 107(July), pp.47–61. Available at: http://www.jpier.org/PIER/pier.php?paper=10062806.

Jin, Y., Ji., S., Liu, B and Chamarro, L. P. 2016. On the role of thickness ratio and location of axis of rotation in the flat plate motions. *Journal of Fluids and Structures*, 64, pp.127–137.

Joshi, M., D'Silva, B., Subhan, I. and Kumar, A. 2008. Autorickshaw Vehicles: A National Out-of-Hospital Care Plan for India. *Annals of Emergency Medicine*, 51(4), p.549. Available at: http://www.annemergmed.com/cms/attachment/2007887267/2030218042/main.pdf.png.

Kim, J., Lee, S. and Kim, K.S., 2017. A study on the activation plan of electric taxi in Seoul. *Journal of Cleaner Production*, 146, pp.83–93. Available at: http://dx.doi.org/10.1016/j.jclepro.2016.06.056.

Klaassen, T.W.G.L., Bonsen, B., Meerakker, K. G. O. van de., Steinbuch, M., Veenhuizen, P. A. and Vroemen, B. G. 2004. Modelling and Control of an Electro-Mechanically Actuated Pushbelt type Continuously Variable Transmission. *7th International Symposium on Advanced Vehicle Control*, pp.1–6.

Kluger, M. and Fussner, D., 1997. An overview of current CVT mechanisms, forces and efficiencies. In *International Congress and Exposition*. p. 10.

Kohring, H.J., 2012. Design and Construction of a Hydrostatic Dynamometer for Testing a Hydraulic Hybrid Vehicle. M.Sc. *project, University of Minnesota*.

Kumar A., Karmakar S., Malay N. and Lohia N, 2016. Performance Optimization of Continuously Variable Transmission (CVT) using data acquisition system. *International Journal of Engineering and Technology*. India.

Kress, J.H., 1968. Hydrostatic power - splitting transmissions for wheeled vehicles - classification and theory of operation. *Tech. Rep.; SAE Technical Paper*.

Lee, M., Schrock, D., Shidfar, S. and Weaver, R. 2009. Continously variable transmission drivetrain system for wind turbine application. Available at: https://www.scribd.com/document/177689218/Continuous-Variable-Transmission. Retrieved on September 9, 2016.

Liu, C. and Chau, K.T., 2014. Electromagnetic design of a new electrically controlled magnetic variable-speed gearing machine. *Journal of Energies*, 7(3), pp.1539–1554.

Lukic, S.M., Mulhall, P., Choi, G., Naviwala, M., Nimmagadda, S. and Emadi, A. 2007. Usage pattern development for three-wheel auto rickshaw taxis in India. *VPPC 2007 - Proceedings of the 2007 IEEE Vehicle Power and Propulsion Conference*, (December 2015), pp.610–616.

Maas, S. and Beach, L., 2009. Austin-Healey Sprite Electronic Tachometer Conversion. , pp.1–12. Available at https://www.google.com.ng/url?sa=t&rct=j&q=&esrc=s&source=web&cd=10&cad=rja&uact=8&ved=0ahUKEwjpk5ujxKDaAhUDbxQKHX8IDxAQFghYMAk&url=http%3A%2F%2Fwww.nonlintec.com%2Fsprite%2FSprite_Electronic_Tach.pdf&usg=AOvVaw3c0pax321b4vt9swloI6OW. Retrieved on March 20, 2018.

Majumdar, D. and Jash, T., 2015. *Merits and Challenges of E-Rickshaw as An Alternative form of Public Road Transport System: A Case Study in the State of West Bengal in India*, Elsevier B.V. Available at: http://dx.doi.org/10.1016/j.egypro.2015.11.492.

Manchanda, M., 2016. Auto-rickshaw: Yesterday, today and tomorrow. *Business Standard*. Available at: http://www.business-standard.com/article/beyond-business/auto-rickshaw-yesterday-today-and-tomorrow-116072500265_1.html [Accessed February 6, 2017].

Mayhew T. P., Rothstein, J. M, Finucane, S. D. G. and Lamb, R. L. 1994. Performance Characteristics of the Kin-Com® Dynamometer. *Journal of Physical Therapy. 1994;74:1047 - 1054.*

Meerakker, K.G.O. van de., Rosielle, P. C. J. N., Bonsen, B. and Klaassen, T. W. G. L. 2004. Design of an electromechanical ratio and clamping force actuator for a metal V-belt type CVT. *Information and Computation/Information and Control - IANC.*Technische Universiteit Eindhoven.

Mihailidis, A., Panagiotidis, K. and Karaoglanidis, G., 2009. Experimental evaluation of the efficiency of a cvt system for wind energy converters. *Proceedings of the 3rd International Conference on power transmission.*Aristotle University of Thessaloniki. Available at https://www.researchgate.net/publication/266458230_EXPERIMENTAL_EVALUATION_OF_THE_EFFICIENCY_OF_A_CVT_SYSTEM_FOR_WIND_ENERGY_CONVERTERS. Retrieved on March 20, 2018.

Moore A.C., Peshkin M.A. and Colgate J. E. 1999. Design of a 3R Cobot using Continuously Variable Transmissions. *IEEE Conference Proceedings on Robotics and Automation.* available at https://www.google.com.ng/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjh5viGwqDaAhWBGBQKHQNKDvEQFggnMA

A&url=https%3A%2F%2Fpdfs.semanticscholar.org%2F232b%2F86500350da7ed06b29dd07e402a5815d694a.pdf&usg=AOvVaw2win13yt9d-VXeTXbnPrJL. Retrieved on March 20, 2018.

Mulhall, P., Lukic, S.M., Wirnsingha, S.G., Lee, Y.J and Emadi, A. 2010. Solar-assisted electric auto rickshaw three-wheeler. *IEEE Transactions on Vehicular Technology*, 59(5), pp.2298–2307.

Mulhall, P. and Emadi, A. 2009. Comprehensive simulations and comparative analysis of the electric propulsion motor for a solar/battery electric auto rickshaw three-wheeler. *IECON Proceedings (Industrial Electronics Conference)*, pp.3785–3790.

Narita, Y., Yamanaka, M. and Inoue, K., 2005. *Design of Shaft Drive CVT: Calculation of Transmitted Torque and Efficiency. ASME 2005 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.* Vol 5b, pp. 875 -881.

Nicolas, R., 2013. The Continously Variable Transmission. Available at: http://www.car-engineer.com/the-continuously-variable-transmission-cvt/ [Accessed February 9, 2017].

Pandey, G., Mohan, D. and Ramachandra Rao, K., 2015. Why do three-wheelers carrying schoolchildren suffer very low fatal crashes? *IATSS Research*, 38(2), pp.130–134. Available at: http://dx.doi.org/10.1016/j.iatssr.2014.12.001.

Pesgen M., Vroemen B., Veldpaus F and Steinbuch M. 2003. Control of a Continuously Variable Transmission in an Experimental Vehicle. *Drivetrain Innovations* b.v. The Netherlands.

Pesgens, M., Vroemen, B., Stouten, B., Veldpaus, F. and Steinbuch, M. 2006. Control of a hydraulically actuated continuously variable transmission. *Vehicle System Dynamics*, 44(5), pp.387–406.

Prabhu, V.N. and Manigandan, N., 2014. Design and Fabrication of Solar Transport Vehicle. *OSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 11, pp.14–19.

Radhakrishna, K., Srinivasa Rao, S. and Sudhakara Rao, B., 2015. Design and Analysis of Dump Body on Three Wheeled Auto Vehicle. *International Journal on Cybernetics and Informatics*, 4(2), pp.65–73. Available at: http://www.airccse.org/journal/ijci/papers/4215ijci06.pdf.

Rahman, A., Sharif, S.B., Mohiuddin, A. K. M., Rashid, M. and Hossain, A. 2014. Energy efficient electromagnetic actuated CVT system. *Journal of Mechanical Science and Technology*, 28(4), pp.1153–1160.

Rahman, M.M., Okura, I. and Nakamura, F., 2004. Effects of Rickshaws and Auto-Rickshaws on the Capacity of Urban Signalized Intersections. *IATSS Research*, 28(1), pp.26–33. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0386111214600893.

Ratcheting CVTs, 2008. CVT-Continously Variable Transmission. Available at: http://cvt.com.sapo.pt/ratcheting/ratcheting.htm [Accessed February 9, 2017].

Ravitega, C., Prasad, A. V and Ashitava, G., 2014. *Experimental Comparison of two different hybrid propulsion systems*, F2014 - TMH - 035. Indian Institute of Science, India.

Reynolds, C., 2009. Measuring autorickshaw emissions to inform air quality policy. *Simmple Interactive Models for Better Air Quality. SIM-air working paper Series 28*. University of British Columbia.

Reynolds, C.C.O., Kandlikar, M. and Badami, M.G., 2011. Determinants of PM and GHG emissions from natural gas-fueled auto-rickshaws in Delhi. *Transportation Research Part D: Transport and Environment*, 16(2), pp.160–165. Available at: http://dx.doi.org/10.1016/j.trd.2010.10.004.

Rhaman, M. and Ahmed Toshon, T., 2014. Solar Powered Rickshaw (SPR) can Diminish the Physical Labor of Rickshaw Puller and Improve the Power Crisis in Bangladesh. *International Journal of Engineering and Manufacturing*, 4(4), pp.26–35. Available at: http://www.mecs-press.org/ijem/ijem-v4-n4/v4n4-3.html.

Rolewicz, T.F., 1987. Design of hydrostatic dynamometers for the dynamic testing of drivetrain components, University of Wisconsin--Madison. Available at: https://books.google.com.ng/books?id=wXhqAAAAMAAJ.

Sanmugan, R. 2016. What is continously variable transmission? How does it work?. Retrieved December 15, 2016, from Quora: https://www.quora.com/What-is-continuously-variable-transmission-How-does-it-work

Schäfer, A., Heywood, J.B. and Weiss, M.A., 2006. Future fuel cell and internal combustion engine automobile technologies: A 25-year life cycle and fleet impact assessment. *Energy*, 31(12), pp.2064–2087. Available at: http://www.sciencedirect.com/science/article/pii/S0360544205001854.

Schulte, H. and Gerland, P., 2011. Control-oriented modeling of hydrostatic power-split CVTs using Takagi-Sugeno fuzzy models. *Proceedings of the 7th conference of the European Society for Fuzzy Logic and Technology (EUSFLAT-2011)*, (July). Available at: http://www.atlantis-press.com/php/paper-details.php?id=2203.

Sen, T., 2011. Noise Exposure Parameters of Auto Rickshaws Compare by Statistical

Regression Technique. Journal of Polish CIMAC (Civil Marine and Construction), 3(1),pp.9 - 13. http://www.polishimac.pl/.

Steltz, E. and Fearing, R.S., 2009. Dynamometer power output measurements of miniature piezoelectric actuators. *IEEE/ASME Transactions on Mechatronics*, 14(1), pp.1–10.

Sun, C., 2010. Hydrostatic-mechanical power split CVT. M.Sc. Thesis, Tamoere University of Technology.

Takumi Shinojima; Toshirou Toyoda, Shinji Miyata, Takashi Imanishi, Eiji Inoue, and Hisashi Machida. 2004. Development of the Next-Generation Half-Toroidal CVT with Geared Neutral and Power-Split Systems for 450 N-m Engines. NSK Ltd. Paper Number: 2004-34-2878.

Tarte, Y. and Chen, Y., 2006. Fractional horsepower dynamometer-a general purpose hardware-in-the-loop real-time simulation platform for nonlinear control research and education. ... *Control, 2006 45th IEEE ...*, pp.3912–3917. Available at: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4177998.

Tenberge, P. 2016. Power Transmission in Continuously Variable Chain-Gears A new mathematical model for the very fast calculation of chain forces, clamping forces,clamping ratio, slip and efficiency. *Power transmission in chain - CVTs.* Technische Univeristat, Chemnitz.

Valerie Mais and Michael Swift, 2009. ZERO : Non-for-Profit Organization Providing Environmentally-Friendly Auto-Rickshaw Retrofit Kits to the Third World. *International conference of usability professionals association*. University of Toronto.

Vera, B. and Nantes, L.D.S., 2015. *Displacement, Velocity, and Acceleration Transducers*, Available at: http://linkinghub.elsevier.com/retrieve/pii/B9780128007747000052.

Vezzini, A., Sharan, H. and Umanand, L., 2005. Low-pollution three-wheeler autorickshaw with power-assist series hybrid and novel variable DC-link voltage system. *Journal of the Indian Institute of Science*, 85(2), pp.105–118.

Wagner, L.E., Heber, A.J. and Harner, J.P., 1990. PC-based data acquisition program for an electric motor dynamometer. *American Society of Agricultural Engineers. 6(5)*, pp.643–646.

Weng, P.K. and Shie, J., 1990. A revolving retro-reflective marker for an optical tachometer. *Journal of Sensors and Actuators*, 24(1990) 203 - 207.

APPENDIX 1
QUESTIONNAIRE

UNIVERSITY OF IBADAN
FACULTY OF TECHNOLOGY
MECHANICAL ENGINEERING DEPARTMENT

QUESTIONNAIRE FOR KEKE NAPEP

This questionnaire is being administered for preliminary study for a research into the keke napep/marwa being used in Nigeria as shuttle within the suburbs.
Please help complete this questionnaire with utmost sincerity as no personal information is requested.

A. <u>GENERAL INFORMATION</u>
1. Age of vehicle:
2. Model of vehicle:
3. Capacity of vehicle:
4. Brand of vehicle:
5. Type of ignition: (a) key starter (b) manual
6. Type of engine: (a) 2stroke (b) 4stroke:
7. What is the fuel capacity?
8. Fuel consumption per day:
9. How much distance do you travel per day?
10. What is the cost of vehicle?
11. What is the condition of vehicle?

B. <u>GEAR TRANSMISSION</u>
1. How many gear selection does it have?
2. Does gear transmit smoothly compared with motorcycle?
3. Does gear transmit smoothly compared with cars? (a) Yes (b) No
4. How many times have you serviced the gear?
5. How often do you change the gear oil?
6. Is gear change smooth? (a) Yes (b) No
7. Does vehicle jerk during gear change? (a) Yes (b) No
8. Does the speed increase with descent? (a) Yes (b) No
9. Does the speed decrease with ascent? (a) Yes (b) No
10. What is the highest speed: (a) level ground (b) up hill (c) down hill

C. <u>DRIVABILITY AND COMFORTABILITY</u>
1. How many passenger seats are available?
2. How many passengers do you carry?
3. Do passengers complain of the number carried? (a) Yes (b) No
4. Does the vehicle look stable to you? (a) Yes (b) No
5. Is the vehicle stable while cornering? (a) Yes (b) No
6. Are the tires big enough? (a) Yes (b) No
7. How often do you have flat tires?
8. How often do you service the vehicle?
9. What parts of the engine do you; service often: repair often

10. Do you think the frames of the vehicle are strong enough? (a) Yes (b) No
11. What other features do you desire in the vehicle?

D. ACCIDENTS
1. Have you had accident with the vehicle? (a) Yes (b) No
2. Were you the cause? (a) Yes (b) No
3. Was the accident involved with (a) a car (b) bicycle (c)motor cycle (d) human (e) keke napep
4. Was it the fault of the driver? (a) Yes (b) No
5. Was it the fault of the car? (a) Yes (b) No
6. What was the cause?
7. What are the common faults you experience with the vehicle while driving?
8. What are the difficulties you experience in driving the vehicle?
9. Which parts of the vehicle do get involved in accidents?
10. Which part of the human body is usually affected in accidents?

E. SERVICEABILITY
1. Can you service the vehicle yourself?
2. How often do you service the vehicle?
3. Which part(s) do you service (a) regularly (b) subsequently
4. What is usually the cost of servicing the vehicle?
5. Do you have to replace any part while servicing?
6. If yes which part do you replace and how often?

Thank you for your time and sincerity.

APPENDIX 2
TACHOMETER

OMEGAETTE™
HHT-1500 SERIES with RS232 CABLE and SOFTWARE

TACHOMETER SPECIFICATIONS

- Digits LCD Display
- Light Reflex Measurement Technology
- Range 10.00 to 99,999 RPM
- Measuring Distance: 50 to 300 mm (2 to 12")
- Event Counter with Elapsed Time (HH:MM)
- Max/Min/Hold: True Average
- Auto Range RPM
- RS-232 Interface for Model HHT-1501
- Contact RPM and Circumferential Velocity (HHT-1502CA)
- Windows 3.1/95/98/XP Based Software
- External TTL Input: High > 4.5V (HHT-1501)
- Display 5 digits: 99999 counts
- Sampling Rate: 0.7 second (> 60 rpm); > 1 second (10 to 60 rpm)
- Time Base: 4.0 MHz Quartz Crystal
- Range Selection: Automatic
- Battery: Four 1.5 V "AA" (included)
- Auto Power-Off: 30 minutes
- Operating Temp: 0 to 50°C (32 to 122°F)
- Size: 72 L x 63 W x 36 mm D (6.8 x 2.5 x 1.5")
- Weight: 190 g (6.7 oz) (including battery)

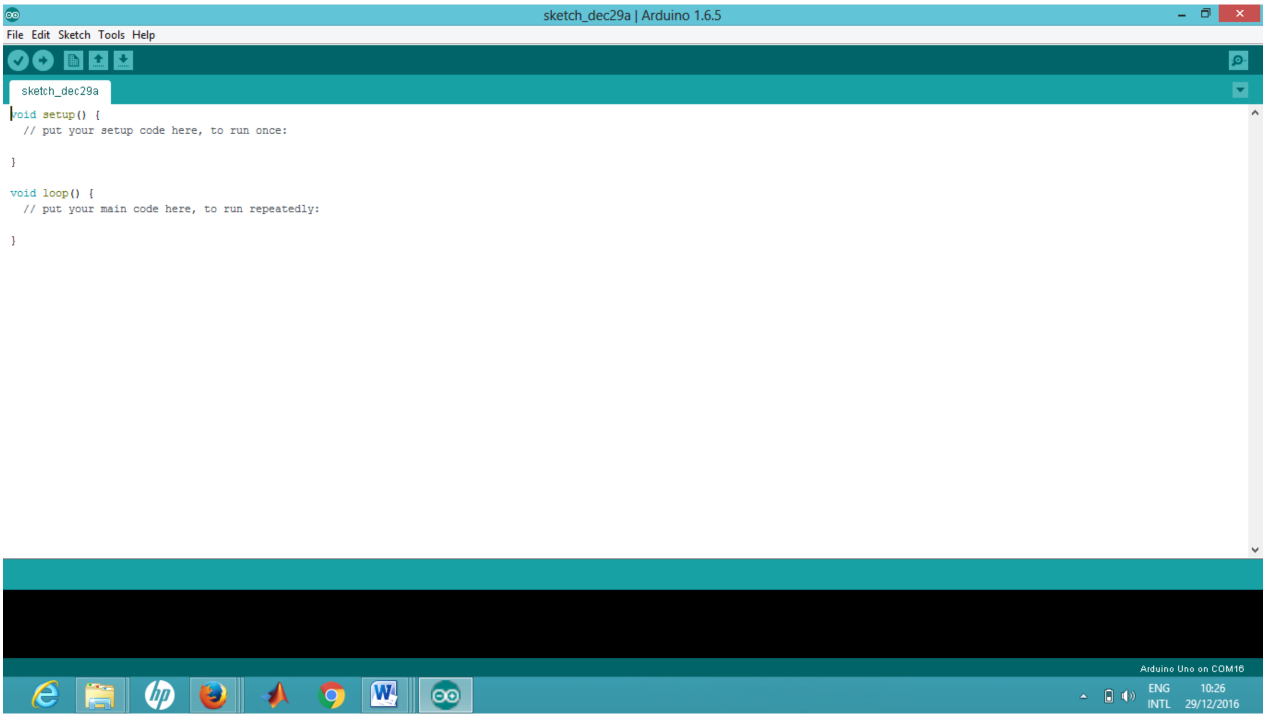
APPENDIX 3

THE CVT UNIT

40 SERIES GO KART TORQUE CONVERTER 5/8", 3/4", 7/8" DRIVEN CLUTCH Replace COMET

APPENDIX 4

ARDUINO INTERFACE



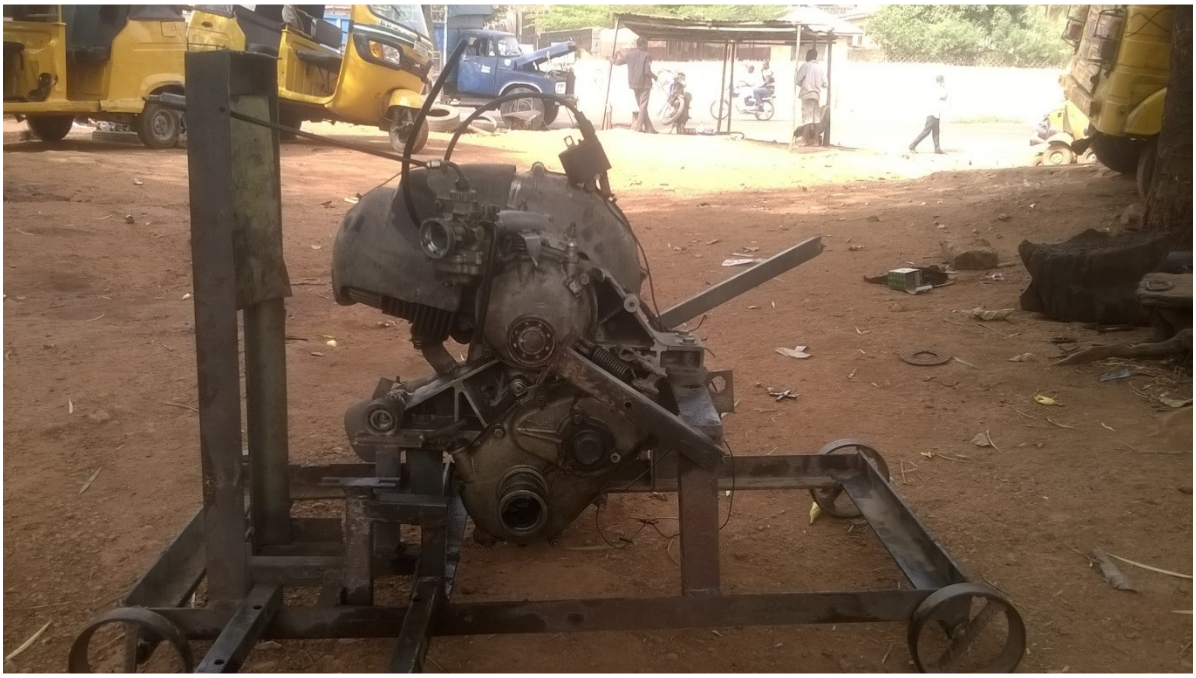
APPENDIX 5

AUTORICKSHAW ENGINE SPECIFICATION

- **Power** 9.00Kw@6000rpm
- **Torque** 16.7 N.m@4500rpm
- **Cubic Capacity** 198.88 Cm^3
- **Transmission** 4 forward + 1 reverse gear
- **Clutch** Wet multidisc type
- **Kerb weight** 337 kg
- **Wheel Base** 2000 mm
- **Overall width** 1300 mm
- **Overall length** 2635 mm
- **Overall Height** 1704 mm
- **Gradeability** 19%

APPENDIX 6

THE AUTORICKSHAW ON THE RIG



APPENDIX 7

Voltage Divider calculation and Code

R1 = 9k Ohms

R2 = 3k Ohms

V_{out} = (R1 / (R1 + R2)) * V_{in}

V_{out} = (9000 / (9000 + 3000)) * 20v

V_{out} = (9000 / 12000) * 20v

V_{out} = .75 * 20v

V_{out} = 5v

Ratio = V_{in} / V_{out}

Ratio = 4

The code to read that value is as follows:

```
ADCVal = analogRead(batMonPin); // read the voltage on the divider on pin A4
pinVoltage = ADCVal * 0.00488; // Calculate the voltage on the A/D pin
// A reading of 1 for the A/D = 0.00488mV
// if we multiply the A/D reading by 0.00488 then
// we get the voltage on the pin.

batteryVoltage = pinVoltage * Ratio; // Use the Ratio calculated for the voltage
divider
// to calculate the battery voltage, Ratio = Vin / Vout
```

APPENDIX 8

Hall Effect sensor code

```
// read the analog in value:
  sensorValue = analogRead(analogInPin);
  // convert to milli amps
  outputValue = (((long)sensorValue * 5000 / 1024) - 500 ) * 1000 / 133;
amps = (float) outputValue / 1000;
```

APPENDIX 9

ADC (analog digital converter) Math

To calculate watt (volts * amps), amp hours (amps * hours), and watt hours (watts * hours) requires tracking the time component, and performing a bit of math:

```
float watts = amps * batteryVoltage;

  sample = sample + 1;

  msec = millis();

 time = (float) msec / 1000.0;

totalCharge = totalCharge + amps;

averageAmps = totalCharge / sample;

ampSeconds = averageAmps*time;

ampHours = ampSeconds/3600;

wattHours = batteryVoltage * ampHours;
```

APPENDIX 10

Serial Output code

To output the results of the calculations to the serial port, the following code was used:

```
Serial.print("Volts = " );
Serial.print(batteryVoltage);
Serial.print("\t Current (amps) = ");
Serial.print(amps);
Serial.print("\t Power (Watts) = ");
Serial.print(watts);

Serial.print("\t Time (hours) = ");
Serial.print(time/3600);

Serial.print("\t Amp Hours (ah) = ");
Serial.print(ampHours);
Serial.print("\t Watt Hours (wh) = ");
Serial.println(wattHours);
```

Source Code

```
#include
/*LiquidCrystal lcd(7, 8, 9, 10, 11, 12);
Vcc on carrier board to Arduino +5v
GND on carrier board to Arduino GND
OUT on carrier board to Arduino A0
Insert the power lugs into the loads positive lead circuit,
arrow on carrier board points to load, other lug connects to
power supply positive
Voltage Divider
9k Ohm from + to A4
3k Ohm from A4 to Gnd
*/
int Vin = 20;
int Vout = 5;
int ratio = Vin / Vout; // Calculated from Vin / Vout
int batMonPin = A4; // input pin for the voltage divider
int ADCVal = 0; // variable for the A/D value
float pinVoltage = 0; // variable to hold the calculated voltage
float batteryVoltage = 0;

int analogInPin = A0; // Analog input pin that the carrier board OUT is connected to
int sensorValue = 0; // value read from the carrier board
int outputValue = 0; // output in milliamps
unsigned long msec = 0;
float time = 0.0;
int sample = 0;
```

```
float totalCharge = 0.0;
float averageAmps = 0.0;
float ampSeconds = 0.0;
float ampHours = 0.0;
float wattHours = 0.0;
float amps = 0.0;
int R1 = 9000; // Resistance of R1 in ohms
int R2 = 3000; // Resistance of R2 in ohms
int ratio = 0; // Calculated from Vin / Vout
void setup() {
// initialize serial communications at 9600 bps:
Serial.begin(9600);
lcd.begin(20, 4);
}
void loop() {
int sampleADCVal = 0;
int avgADCVal = 0;
int sampleAmpVal = 0;
int avgSAV = 0;
for (int x = 0; x < 10; x++){ // run through loop 10x
// read the analog in value:
sensorValue = analogRead(analogInPin);
sampleAmpVal = sampleAmpVal + sensorValue; // add samples together

ADCVal = analogRead(batMonPin); // read the voltage on the divider
sampleADCVal = sampleADCVal + ADCVal; // add samples together
delay (10); // let ADC settle before next sample
}
avgSAV = sampleAmpVal / 10;
// convert to milli amps
outputValue = (((long)avgSAV * 5000 / 1024) - 500 ) * 1000 / 133;
/* sensor outputs about 100 at rest.
Analog read produces a value of 0-1023, equating to 0v to 5v.
"((long)sensorValue * 5000 / 1024)" is the voltage on the sensor's output in millivolts.
There's a 500mv offset to subtract.
The unit produces 133mv per amp of current, so
divide by 0.133 to convert mv to ma
*/
avgADCVal = sampleADCVal / 10; //divide by 10 (number of samples) to get a
steady reading
pinVoltage = avgBVal * .00488; // Calculate the voltage on the A/D pin
/* A reading of 1 for the A/D = 0.0048mV
if we multiply the A/D reading by 0.00488 then
we get the voltage on the pin.
Also, depending on wiring and
where voltage is being read, under
heavy loads voltage displayed can be
well under voltage at supply. monitor
at load or supply and decide.
*/
```

```
batteryVoltage = pinVoltage * ratio; // Use the ratio calculated for the voltage divider
// to calculate the battery voltage
amps = (float) outputValue / 1000;
float watts = amps * batteryVoltage;
Serial.print("Volts = " );
Serial.print(batteryVoltage);
Serial.print("\t Current (amps) = ");
Serial.print(amps);
Serial.print("\t Power (Watts) = ");
Serial.print(watts);
sample = sample + 1;
msec = millis();
time = (float) msec / 1000.0;
totalCharge = totalCharge + amps;
averageAmps = totalCharge / sample;
ampSeconds = averageAmps*time;
ampHours = ampSeconds/3600;
wattHours = batteryVoltage * ampHours;
Serial.print("\t Time (hours) = ");
Serial.print(time/3600);
Serial.print("\t Amp Hours (ah) = ");
Serial.print(ampHours);
Serial.print("\t Watt Hours (wh) = ");
Serial.println(wattHours);
lcd.setCursor(0,0);
lcd.print(batteryVoltage);
lcd.print(" V ");
lcd.print(amps);
lcd.print(" A ");
lcd.setCursor(0,1);
lcd.print(watts);
lcd.print(" W ");
lcd.print(time/3600);
lcd.print(" H ");
lcd.setCursor(0,2);
lcd.print(ampHours);
lcd.print(" Ah ");
lcd.print(wattHours);
lcd.print(" Wh ");
lcd.setCursor(0,3);
lcd.print(ratio, 5);
lcd.print(" ");
lcd.print(avgBVal);
// wait 10 milliseconds before the next loop
// for the analog-to-digital converter to settle
// after the last reading:
delay(10);
 }
```

APPENDIX 11

Power supply calculations

$$Peak\ voltage, V_p = V_{rms} \times \sqrt{2}$$

$$V_p = 12\sqrt{2} = 16.97V$$

$$Supply\ frequency, f = \frac{1}{period(T)} = 50\ Hz$$

$$Period, T = \frac{1}{f} = \frac{1}{50} = 0.02s = 20ms$$

The total voltage drop,V_d for the two diodes involved in the rectification process in either of positive or negative cycles,

$$V_d = 2V_{BE}\ [V_{BE} = 0.7V\ for\ a\ silicon\ diode]$$

$$V_d = 2 \times 0.7V = 1.4V$$

Actual peak voltage value, $V_{LM} = (V_m - 2V_{BE})V$

$$V_{LM} = (16.97 - 1.4)V$$

$$V_{LM} = 15.57V$$

Change in peak voltage value over the discharge period, $\delta V = V_{LM} - V_{dc}$

$$V_{dc} = 10V$$

The filter capacitor should not discharge down to 6V in accordance with the input voltage specification of the voltage regulator.

$$\delta V = (15.57 - 10.0) = 5.57V$$

Change in time over the discharge period, $\delta t = 10ms$

Total current consumption for this design is not expected to exceed 600mA

Hence the value of the filter capacitor is obtained thus:

$$C = \frac{600mA \times 10ms}{5.57V} = 1077.20\mu F$$

To provide a safety margin, the capacitor value chosen was twice the calculated value which implies a value 2154.4µF.

The nearest available capacitor value of 3,300µF was used as the filter capacitor.