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A FINAL YEAR PROJECT REPORT

ON

DESIGN OF DOWNSIZED HYBRID POWERTRAIN FOR THREE-WHEELER VEHICLE

BY

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CERTIFICATION

This is to certify that this project was carried out by **IGBOMEZIE MICHAEL DUBEM** with matriculation number **U2013/3025005** in partial fulfilment of the award of Bachelor of Engineering (B.Eng.) in Mechanical Engineering.

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DEDICATION

This project is dedicated to the Almighty God, the University of Port Harcourt, the department of Mechanical Engineering, and to the Higher Education Partnership in Sub-Saharan African region.

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ABSTRACT

In recent times, there has been a global awareness of increased carbon footprint caused by continuous use of fossil fuel for vehicle propulsion. For sustainability of transport, there is urgent need to seek alternative propulsion system. This project addressed this challenge by using a hybridized downsized internal combustion engine (I.C.E) and battery electric (B.E) capable of massively improving the powertrain efficiency by about 8% and reducing the carbon (CO_2) emission from 134g CO_2/km to 103g CO_2/km, when the design is put into production. This project was focused on just the Auto-Rickshaw type of three-wheeler, and the hybrid type that was implemented was just the series type hybrid. By hybridizing the three-wheeler, the major operation cost was also reduced, which in some ways served as a consolation for the high cost of purchase.

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CHAPTER ONE

INRODUCTION

1.1 Preamble

An automobile is a self-propelled vehicle used to transport people and goods from one location to another location. This can be two, three or four wheels and are commonly powered by a water or air cooled piston-type internal combustion engine. The common fuel used in the internal combustion engine are petrol and diesel.

In recent times, pollutants from automobile operation have become a great challenge to the environment. It has been estimated that 70% of the carbon monoxide, 45% of the nitrogen oxides, and 34% of the hydrocarbon pollution over the globe can be traced directly to automobile exhausts (Lewis and Goldstein, 1983). Because of the high amount of petroleum and how heavily the internal combustion engine contributes to air pollution, other types of fuels and nonconventional engines are being developed, such as the ATV and Hybrid vehicles.

Hybrid Vehicles are vehicles that utilizes more than one form of powertrain to achieve propulsion, such as internal combustion engine and electric motor. There are different types of hybrid vehicles.

- **Series hybrids:** This is the oldest hybrid type. In a series hybrid car, electric motors alone turn the drive wheels, so the motors must be large and powerful. But a series hybrid is not a "pure" electric vehicle. It has a dedicated engine that burns fuel and expels emissions. The engine powers a generator to produce the electricity onboard the vehicle. In the series type hybrid, there is no direct connection between the gasoline engine and the transmission system (Reddy and Tharun, 2013).

- **Parallel hybrids:** Here the output of the engine and the electric motor are blended together upstream of the transmission. An electric motor provides an extra boost, and if it's large enough, it may be the car's only source of propulsion for short distances. In this hybrid type, there is a connection between the gasoline engine and the transmission system (Trushar, 2015).
- **Series-parallel hybrids:** As the name implies, these cars contain elements of both types. Conceptually, the engine and the electric motor feed into the transmission via separate paths, enabling fully independent propulsion via the engine or electricity. In parallel fashion, the motor-generator can either bolster the engine's output or provide battery charging via regenerative braking. Series-parallel motor-generators are sizable, so electric-only operation (at low speeds for a couple miles) is a standard feature. The engine can still power the car, but it can also be reassigned to battery charging duty while the electric motor drives the vehicle: the classic series operation. In a series-parallel hybrid vehicle, a computer monitors driving conditions and the state of the battery to decide which mode is most efficient at any given moment. The seamless blending of these modes is then carried out by a unique continuously variable transmission (CVT) that uses a planetary gear set as opposed to a system of variable pulleys and belts. Series-parallel hardware is more expensive, but the payoff in efficiency is huge: To date, these hybrids offer the largest gains in mpg, the highest electric-only speeds and the longest electric-only run times (Vinay and Raju, 2017).
- **Plug-in hybrids:** These are not really a fourth type of hybrid because a plug-in could conceivably be based on any of the above layouts. Plug-in hybrids (also called PHEVs) began appearing in the market at the end of 2010. Their distinguishing characteristic is a significantly enlarged battery that permits the electric driving range to swell beyond the mile or two possible with regular hybrids. It also provides a way to plug the battery

into an electrical outlet for recharging while parked. The benefit of the plug-in hybrid is its ability to travel in all-electric mode for short trips, reserving the gasoline engine for longer drives.

Some hybrids have more power than others. There are:

- **Mini hybrids:** This is a class that adds a modicum of electric assist to the stop-start system. Because these cars don't offer full hybrid capabilities, they can be built using very small and relatively inexpensive nickel-metal hydride or lithium-ion batteries to help keep costs down.
- **Mild hybrids:** These usually are parallel hybrids without sufficient power to propel the vehicle in all-electric mode more than a handful of yards. The gasoline engine essentially operates all of the time and is augmented by the electric motor when more power is needed for accelerating or climbing hills.
- **Strong hybrids:** These can be parallel, series or series-parallel vehicles. They have large enough electric motors and powerful enough batteries to provide some degree of all-electric mode, along with stop-start, regenerative braking and gas engine assist. The Toyota Prius was the first strong hybrid in the market and remains the best-selling of all the hybrids.
- **Vehicles with stop-start systems:** This is another class of hybrid-inspired vehicles coming into the market, making use of the stop-start systems that were perfected for hybrids. They are not hybrids because they don't have two power systems (although some in the industry call them micro-hybrids). Instead, they use a beefed-up starter motor and battery or capacitor to provide the stop-start function but have no electric assist for acceleration and no other aspects of a conventional hybrid.

The series type hybrid is not as complicated as the other types. The most important thing to note is that in this type, there is no direct connection between the internal combustion engine (I.C engine) and the transmission. An electric motor powered by a battery which is charged with a generator is connected to the transmission. Since the internal combustion engine is not connected to the transmission, the power rating of the engine can be smaller than that of a regular vehicle.

1.2 Problem Statement

The emission of CO and CO_2 from gasoline engines are harmful to the environment and it has to be reduced to create a greener friendly environment. Also the cost of owning, operating and maintaining an automobile is relatively high for the average Nigerian.

1.3 Aim and Objectives

The aim of this project is to downsize and hybridize the powertrain of the three-wheeler which is fast becoming the common means of commercial transportation in rural, sub-urban and urban areas. The hybridization and downsizing of the three-wheeler will reduce the amount of carbon emission and create a greener friendly environment, as well as reduce the overall cost of maintenance and operation.

1.4 Scope and Limitation of Study

This project is limited to the hybridization of the Piaggio Ape City Auto Rickshaw. All values and procedures contained in this project is peculiar to the Auto Rickshaw. The result of the research that led to the commencement of this project was obtained using Port Harcourt City as the case study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Early Developments

The concept of hybridization of vehicles date back to the late 1800s. Hybrid electric vehicles (HEV) emerge from a concept, which is aimed at capturing the advantages of the presently available vehicle technologies, while trying to avoid disadvantages. Furthermore, these are designed to bridge the gap in time between the first encouraging results of electric vehicle technology, and its future mature status and significant contribution to the overall reduction of transportation emissions (Cholakov, 2009). The first hybrid vehicle was invented by a young Austrian engineer named Ferdinand Porsche and Jacob Lohner in 1898 (Kamper and Wang, 2008). It was the brainchild of the Viennese coach builder named Jacob Lohner, he complained that the already existing internal combustion engines were causing too much pollution and produced a foul smell, he then turned to Ferdinand Porsche. In 1896, Ferdinand Porsche invented the electric wheel-hub motor, a battery-operated motor that fits inside the hub of a wheel (Jennifer, 2012). The in-wheel motors were combined with one of Jacob Lohners coaches and the result was the Lohner-Porsche Elektromobil (Berman, 2011). Initially, the Elektromobil was a purely electric vehicle but after they were faced with the problem of keeping the batteries charged, Ferdinand Porsche added an internal combustion engine that ran a generator which was responsible for charging the batteries thus converting the vehicle into the first ever hybrid vehicle (Watts et al, 2010). In 1900 at the World's fair in Paris the 'System Lohner-Porsche' was debuted (Watts et al, 2010). The Lohner-Porsche Elektromobil could achieve a top speed of 61.2 kilometers per hour, a speed record set in Austria (Watts et al, 2010).

The fuel source of the automobile has changed a couple of times over the years, the first self-propelled vehicle was built by Nicolas-Joseph Cugnot (1725-1804) in 1769, It used steam as its fuel source, it was a three wheeled military tractor meant for the French army. It moved at a speed of 2.5mph (Bruno, 1997). In 1885, Karl Benz developed a petrol or gasoline powered automobile, this is considered to be the first automobile. At that time, gasoline was the preferred source of fuel, even though it was noisy and produced foul smell, it was affordable and the batteries of electric vehicles were solely lacking in both energy density and durability. The limited range and high cost of early electric vehicles and hybrids such as the Lohner-Porsche prevented them from gaining mainstream acceptance (Abrams, 2013). But with the improvement of battery technology and the danger in which gasoline engine posed, more and more people began to go for the electric vehicle. In a poll conducted at the first National Automobile show in New York City in 1900, patrons favored the electric as their first choice followed by the steam engine. However, in 1904, Henry Ford (1863-1947), founder of the Ford Motor Company, overcame the challenge posed by gasoline powered cars (noise, vibration and odor). He began an assembly line production of low-priced lightweight gas-powered vehicles. Within a few years, the electric vehicle companies failed. Liquid hydrocarbons had all the desired traits with the main downside being emissions, including carbon dioxide, and supplies that became increasingly concentrated in unstable parts of the world (Abrams, 2013). While gasoline has been the dominant transport fuel, even it has evolved. Different modifications have been made to produce purer forms of gasolines but the problem of causing emissions harmful to the environment has remained over the years (Aravind, 2016).

2.2 Recent Developments

The rate of Carbon Dioxide (CO_2) and Carbon Monoxide (CO) emission suddenly increased to a dangerous level at the beginning of the 21st Century. This increase has impacted negatively on the ecosystem. This is the key reason for global warming and some health related issues.

This has lead ICE developers, researchers and policymakers to develop greener technology which can reduce the global warming effect. This lead the automotive ICE sector back to the Hybrid electric vehicle.

Toyota vehicles led the way in the recent development of hybrid vehicles. In 1995, Toyota debuted a hybrid concept vehicle at the Toyota motor show, with testing following a year later. In the late 1997, the first Toyota Prius, model NHW10 was launched in Japan, followed by the Honda Insight in 1999 (Liu, Peng and Filipi, 2005). The first generation Toyota hybrid system consisted of two models, the NHW10 and NHW11. The mileage for the first generation Prius was 5.7L/100km. The second generation used the Hybrid Synergy Drive. The Hybrid Synergy Drive adds a DC to DC converter boosting the potential of the battery to 500V or more. This allows smaller battery packs to be used, and more powerful motors. Overall, the mileage for the second generation Prius was 5.1L/100km (Prajapati, Patel and Sagar, 2014). The third generation improved the hybrid synergy drive even further. It has a significant reduction in weight and size, contributing to the overall improvements in fuel economy. The need for the advancement of the tools needed for hybridization of vehicles arose thereby causing improvements in batteries, electric motors and generators, inverters, etc. Electric motors began to reduce in size and increase in power output. The rechargeable batteries also increased in power output while reducing in size thus increasing fuel efficiency and speed.

Today, the hybrid vehicles are still costlier than the gasoline engine vehicles but they are relatively cheaper. The speed of the gasoline engine vehicle is still higher than the hybrid vehicle but it has significantly improved over the years as there are hybrid vehicles running at 214mph (Porsche 918 spyder).

A growing necessity in the automobile sector is replacing bigger engines with smaller capacities, thereby reducing some resulting parameters like the fuel consumption and carbon emission. (Patil, Varade and Wadkar, 2017). Due to the fact that these greenhouse gases have become a serious concern to the environment, one major way to go about this through engine downsizing. This is considered as one of the most efficient ways to improve both the performance and environments efficiencies of engines (Lang, 2004).

2.3 Knowledge Gaps from Literature Reviewed

The hybrid vehicles have become more in use and it is now relatively highly accepted even though it is still costlier and produces less speed than the gasoline engine vehicles. The dangers of the gasoline engine vehicles are far costlier than the hybrid but still, the gasoline engine vehicles are found more readily than the hybrid because people still prefer speed and cost and they overlook the damages posed by gasoline engine vehicles.

The Auto Rickshaw, a three wheeled vehicle common in Asian and African countries, is commonly used for short distance transportation. In Nigeria, the Auto Rickshaw is commonly used. It uses the conventional gasoline engine even though it doesn’t require speed and long distances. Because of how common it is, it causes serious damage to the environment, this environmental hazard can be reduced by hybridizing the Auto Rickshaw and further downsizing its powertrain to improve parameters like the fuel consumption and carbon emission.

As the Auto Rickshaw doesn’t really require speed, hybridizing the vehicle and downsizing its powertrain will help reduce the emission to the environment. With the development of battery and electric motor technologies, hybridizing the Auto Rickshaw is fuel efficient and generally more efficient than the gasoline engine Auto Rickshaw. The series connection hybrid type wass used in this project because it isn’t as complex as other hybrid types.

CHAPTER THREE

ANALYTICAL SIMULATION OF THE HYBRID SYSTEM

3.1 System Description

The main aim of this project is to electrically hybridize and effectively downsize the powertrain of the three wheeler (Auto-Rickshaw). It's not enough to just reduce the capacity of the powertrain and not account for performance, so the results from the sensitivity analysis of the gasoline driven three wheeler were compared to the those gotten from the hybrid electric three wheeler and the **modified** hybrid electric three wheeler, in order to deduce the percentage change in annual economic effect, as well as the annual CO_2 emission of the three models.

For there to be a sensitivity analysis, there first of all has to a hybridization. The main target of the hybridization was to model a hybrid electric system that was capable of approaching the capacity of the traditional (non-hybrid) three wheeler, while containing all the additional components (as a result of the hybridization) without needing any compulsory geometric expansion. Therefore, the entire results gotten from this project was not only subject to the analytically results but also subject to the geometric results gotten from the 3D modelling of the skeletal portion of the traditional non-hybrid three wheeler. Every system is bound to Cause and Effect, therefore, with a known system and a known cause, one can deduce the effect, similarly with a known effect and known system, one can deduce the cause, also with a known cause and known effect, one can deduce the system. The method that was used during this hybridization was deducing an effect that will match our target capacity with a known cause and a known system, so it involved a lot of trial and error. Basically with a known capacity and known system, different causes were tested to see which cause that will give rise to the expected effect (capacity). The analytical part of this entire process was carried out using the Matlab and Simulink software, so most equations and diagrams are linked to the software. While the 3D geometric modelling part of the entire process was carried with Solidworks CAD Program.

3.1.1 Geometrical Hybridization

This was the initial part of the hybridization process, which involve advanced 3D modelling of the traditional non-hybrid three wheeler using the Solidworks software, so as to extract some of the parameters that couldn't be gotten online at the moment and were essential for the analytical simulation, like height of centre of gravity and its position for the front and rear axle, and some other intricate dimensions. This part of the hybridization also involved the check for geometric compatibility of the electrical components (i.e. those that are large enough to require attention during installation) that will be added to the traditional three wheeler, namely; the high density battery, the electric motor and generator/alternator, and gear. To put it in a layman's language, the sizes of the additional components also had to be checked to see whether they would fit into the regular three wheeler.

During this initial stage of this design, actual and extensive dimensional details were gotten from a Piaggio Ape City three wheeler model. Due to the fact that these model are quite common in most residential area in Port Harcourt, this was a relatively easy task. All other essential details like, the vehicle weight and dimensions of the electrical components to used were gotten from sales platforms like Alibaba and Ape City websites, as there were insufficient resources at the moment to facilitate attaining these remaining details physically.

3.1.2 Analytical Hybridization

A series hybrid system comprises basically of an engine, a generator, a high density battery, an electric motor, and the vehicle body. Some of the components that were used to improve the performance of the system were the gear and the transformer.

The hybrid system comprises of two separate systems, the charging system and the driving system. These two systems can function independently and are still interdependent. The charging system comprises basically of, the engine, the alternator/generator, the dc-dc converter (optional), and the high density battery, while the driving system which comprises basically of, the high density battery, the electric motor, the transmission (which will mostly be referred to as **gear** throughout this report) and the vehicle body. These two system were model separately so as to avoid interference from each other and as such have separate input data values, although they were still eventually joined at the later part of the project. It is the combination of the charging and driving system that gave rise to the complete hybrid electric system. The hybrid driving system was compared to the non-hybrid three-wheeler to check the improvement in performance.

The equations that were stated in this subsection do not constitute all the governing equations, but comprise of the major and generalized equations for most of the components that made up the systems used for analysis.

High Density Battery: The Battery block implements a generic dynamic model parameterized to represent most popular types of rechargeable batteries.

- Discharge Model ($i^* > 0$)

$$f_1(it, i*, i) = E_{Batt} - K.\frac{Q}{Q-it}.i * -K.\frac{Q}{Q-it}.it + A.\exp(-B.it) \tag{3.1}$$

- Charge Model ($i^* < 0$)

$$f_1(it, i*, i) = E_{Batt} - K.\frac{Q}{it+0.1.Q}.i* - K.\frac{Q}{Q-it}.it + A.\exp(-B.it) \quad (3.2)$$

In the equations:

- E_{Batt} is nonlinear voltage, in V.
- E_0 is constant voltage, in V.
- *Exp(s)* is exponential zone dynamics, in V.
- *Sel(s)* represents the battery mode. *Sel(s)* = 0 during battery discharge, *Sel(s)* = 1 during battery charging.
- *K* is polarization constant, in Ah^{-1}, or polarization resistance, in Ohms.
- *i** is low frequency current dynamics, in A.
- *i* is battery current, in A.
- *it* is extracted capacity, in Ah.
- *Q* is maximum battery capacity, in Ah.
- *A* is exponential voltage, in V.
- *B* is exponential capacity, in Ah^{-1}.

(MathWorks, 2017)

Electric Motor/Generator: this component was modelled using the following parameters, every other term is dependent on these basic parameters; the armature resistance, armature inductance, and back EMF. The motor and generator are both electric machines of almost identical structure, just that they are used in opposite function, so they both function with the same principles.

The permanent magnets in the motor induce the following back EMF, v_b, in the armature:

$$v_b = k_v \times \omega \quad (3.3)$$

Where:

- k_v is back-emf constant
- ω is angular velocity.

The motor produces the following torque:

$$T_E = k_t \times i \tag{3.4}$$

Where:

- k_t is torque constant
- i is motor current.

It is assumed that there are no electromagnetic losses. This means that mechanical power is equal to the electrical power dissipated by the back emf in the armature.

Mechanical power:

$$P_m = T_E \times \omega \tag{3.5}$$

Electrical Power:

$$P_e = v_b \times i \tag{3.6}$$

Equating these two terms gives:

$$T_E \times \omega = v_b \times i \tag{3.7}$$

$$k_t \times i \times \omega = k_v \times i \times \omega$$

Therefore;

$$k_t = k_v$$

For the steady-state torque-speed relationship, the armature inductance, L, has no effect.

The resulting torque is:

$$T = \frac{k_t}{R}(V - k_v\omega) - J\dot{\omega} - \lambda\omega \qquad (3.8)$$

Where:

- V is motor voltage
- J is motor inertia
- λ is damping
- $\dot{\omega}$ is angular acceleration
- R is Armature resistance.

(MathWorks, 2017)

Vehicle Body: this component represented all forms of resistance posed to the driving force of the vehicle.

Figure 3.1 Vehicle Dynamics and Motion

$$m\dot{V}_x = F_x - F_d - mg.\sin\beta, \qquad (3.9)$$

$$F_x = n\left(F_{xf} + F_{xr}\right), \tag{3.10}$$

Zero normal acceleration and zero pitch torque determine the normal force on each front and rear wheel.

$$F_{zf} = \frac{-h(F_d+mg\cdot\sin\beta+m\dot{V}_x)+b\cdot mg\cdot\cos\beta}{n(a+b)}, \tag{3.11}$$

$$F_{zr} = \frac{+h(F_d+mg\cdot\sin\beta+m\dot{V}_x)+a\cdot mg\cdot\cos\beta}{n(a+b)}, \tag{3.12}$$

The aerodynamic drag force is given by:

$$F_d = \frac{1}{2}C_d\rho A(V_x + V_w)^2 \cdot sgn(V_x + V_w) \tag{3.13}$$

Where:

- F_{xf}, F_{xr} are Longitudinal forces on each wheel at the front and rear ground contact points, respectively.
- F_{zf}, F_{zr} are Normal load forces on each wheel at the front and rear ground contact points, respectively.
- h is height of vehicle CG above the ground
- F_d is aerodynamic drag force
- m is mass of vehicle
- g is gravitational acceleration
- β is incline angle
- V_x is velocity of the vehicle
- a is distance of front axle from the normal projection point of vehicle CG to the common axle plane
- b is distance of rear axle from the normal projection point of vehicle CG to the common axle plane

- n is number of wheels on each axle
- C_d is coefficient of aerodynamics drag
- ρ is mass density of air
- A is effective frontal vehicle cross-sectional area
- V_w is wind speed.

(MathWorks, 2017)

Tire: this component was modelled using the tire magic formula.

$$F_x = f(k, F_z) = F_z d \cdot \sin\{c \cdot \tan^{-1}[b(1-e)k + e \cdot \tan^{-1}(bk)]\} \quad (3.14a)$$

$$R(k) = d \cdot \sin\{c \cdot \tan^{-1}[b(1-e)k + e \cdot \tan^{-1}(bk)]\} \quad (3.14b)$$

The slope of *f* at k = 0 is BCD.F_z

Where:

- $R(k)$ is Force or moment resulting from slip
- b is magic formula coefficient
- c is magic formula coefficient
- d is magic formula coefficient
- e is magic formula coefficient
- k is wheel slip

$$k = \frac{V_{sx}}{|V_x|} \quad (3.15)$$

$$V_{sx} = r_\omega \Omega - V_x \quad (3.16)$$

Where:

- V_{sx} is wheel slip velocity

- r_ω is wheel radius
- Ω is wheel angular velocity
- V_x is wheel hub longitudinal velocity

(MathWorks, 2017)

I.C. Engine: The engine is modelled using an engine power demand function g(Ω). This function provides the maximum power available for a given engine speed Ω. Maximum power, speed at maximum power, and maximum speed normalize this function to physical maximum torque and speed values.

The torque function is:

$$\tau = \left(\frac{P_{max}}{\Omega_0}\right) \cdot \left(\frac{P(\omega)}{\omega}\right) \tag{3.17}$$

Where:

- P_{max} is maximum power
- Ω_0 is speed at maximum power
- $P(\omega)$ is Power at a given value of ω
- ω is ratio of the given engine speed and the speed at maximum power.

$$\omega = \frac{\Omega}{\Omega_0} \tag{3.18}$$

$$\Omega_{min} \leq \Omega \leq \Omega_{max} \tag{3.19}$$

Where:

- Ω_{min} is Stall speed
- Ω_{max} is maximum speed

$$P(\omega) = P_1 \cdot \omega + P_2 \cdot \omega^2 + P_3 \cdot \omega^3 \tag{3.20}$$

Where:

- P_1 is Power demand coefficient 1
- P_2 is Power demand coefficient 2
- P_3 is Power demand coefficient 3

$$\omega = \frac{1}{2}\left(-P_2 \pm \sqrt{{P_2}^2 + 4P_1P_3}\right) \tag{3.21}$$

Gear: Simple Gear imposes one kinematic constraint on the two connected axes:

$$r_F\omega_F = r_B\omega_B \tag{3.22}$$

The follower-base gear ratio $g_{FB} = r_F/r_B = N_F/N_B$. N is the number of teeth on each gear. The two degrees of freedom reduce to one independent degree of freedom.

The torque transfer is:

$$g_{FB}\tau_B + \tau_F - \tau_{LOSS} = 0 \tag{3.23}$$

with $\tau_{loss} = 0$ in the ideal case.

DC-DC Converter: The ideal transformer block models an ideal power-conserving transformer, described with the following equations.

$$V_1 = NV_2, \tag{3.24}$$

$$I_2 = NI_1. \tag{3.25}$$

Where:

- V_1, V_2 are Input voltage and output voltage respectively
- I_1, I_2 are Input current and output current respectively

(MathWorks, 2017)

3.2 Powertrain Downsizing

Following the conclusion of the hybridization, the hybrid model powertrain was downsized from the regular non-hybrid model powertrain capacity to a lower capacity, so as to check the system response to being driven by a lesser powertrain, and whether this lesser capacity could actually be used in place of the regular one. After successfully downsizing the powertrain, modifications can then be added to the existing powertrain-downsized hybrid and optimization can be carried out, still using sensitivity analysis.

The downsizing of the powertrain was aimed at replacing the current powertrain with a 5kW capacity and this was carried out by duplicating the already hybridized model, dropping the engine capacity, running simultaneous simulation on the two model (non-downsized and downsized), and comparing the results.

The two main parameters that were compared from the obtained results were the percentage change in charging rate of the battery, and the percentage change in the engine fuel consumption of the downsized model in relation to the non-downsized model.

$$pc_{cr} = \frac{cr - cr_1}{cr} \times 100, \tag{3.26}$$

$$pc_{fc} = \frac{fc - fc_1}{fc} \times 100, \tag{3.27}$$

Where,

- cr is charging rate of the non-downsized hybrid model (reference model)
- cr_1 is charging rate of the downsized hybrid model
- fc is fuel consumption rate of the non-downsized hybrid model
- fc_1 is fuel consumption rate of the non-downsized hybrid model

- pc_{cr} is percentage change in the charging rate of the downsized model with respect to the non-downsized model.
- pc_{fc} is percentage change in the fuel consumption rate of the downsized model with respect to the non-downsized model.

3.2.1 Sensitivity Analysis for Model Optimization

The sensitivity analysis was carried out for three case studies, and each case study comprised of four different models; the gasoline driven (non-hybrid) three wheeler model, the charging-while-driving hybrid three wheeler model, the charging-only hybrid three wheeler model, and the driving-only hybrid three wheeler model. Due to the type of analysis being conducted on these case studies (percentage change in the annual economic effect, and the annual CO_2 emission), the comparison had to be between components in these different models that contributed to the expected output parameter (percentage change in the annual economic effect, and the annual CO_2 emission), the I.C Engine. The parameter most important for the derivation of the expected output parameter is the fuel consumption of the engine of the different models. Although the driving source for the hybrid systems is no longer the engine but the electric motor, these series hybrid models still eventually burn fuel in order to charge the battery, therefore this had to be to focal point of the comparison.

That being said, the comparison was now eventually between the annual economic and environmental effect of the non-hybrid three wheeler engine while driving, and the downsized hybrid three wheeler engine while charging the high density during operation or before operation.

3.2.2 Case Studies and their respective Models

As earlier stated, the sensitivity analysis was centred around three different case studies, and they are as follows:

-***Case 1***: Comparison between the gasoline driven three wheeler model and the basic hybrid three wheeler model without modifications/amplifiers.

-***Case 2***: Comparison between the gasoline driven three wheeler model and the hybrid three wheeler model with gear modifications.

-***Case 3***: Comparison between the gasoline driven three wheeler model and the hybrid three wheeler model with gear and voltage/current transformer modifications.

All three case studies comprised of the same four models. These four models are as follows:

-***Model** 1*: Charging-while-driving hybrid three wheeler model. The purpose of this model was to ascertain the response/performance in terms of speed, as well as the fuel consumption and the charging duration of the hybrid three wheeler model, if the operator should at any point decide to charge the vehicle while simultaneously driving it.

-***Model 2***: Gasoline-driven (non-hybrid) three wheeler model. The purpose of this model was to mimic/imitate the traditional three wheeler, so as to have a datum from which positive or negative percentage change in performance present in the other hybrid models could be discerned.

- ***Model** 3*: Charging-only hybrid three wheeler model. The purpose of this model was to ascertain the fuel consumption, as well as the charging duration of the hybrid three wheeler model, if the operator should decide to fully charge the vehicle before operating it.

-***Model 4***: Driving-only hybrid three wheeler model. The purpose of this model was to ascertain the discharge duration of the hybrid three wheeler model, if the operator decided to operate the vehicle from a complete state of charge, without simultaneously charging it.

Table 3.1 Sensitivity Analysis Case Study arrangement.

	Model 1	Model 2	Model 3	Model 4
Case Study 1	Charging-while-driving hybrid three wheeler model without modifications	Gasoline-driven (non-hybrid) three wheeler model	Charging-only hybrid three wheeler model without modifications	Driving-only hybrid three wheeler model without modifications
Case Study 2	Charging-while-driving hybrid three wheeler model with gear modifications	Gasoline-driven (non-hybrid) three wheeler model	Charging-only hybrid three wheeler model with gear modifications	Driving-only hybrid three wheeler model without modifications
Case Study 3	Charging-while-driving hybrid three wheeler model with gear and transformer modifications	Gasoline-driven (non-hybrid) three wheeler model	Charging-only hybrid three wheeler model with gear and transformer modifications	Driving-only hybrid three wheeler model with transformer modifications

3.2.3 Annual Economic and CO_2 Emission Effect

As earlier stated, the point of the sensitivity analysis was to have a reason to downsize the power train. After the different models were arranged, these test were run for some certain expected parameters; the percentage change in annual economic effect, and the percentage change in the annual CO_2 emission. What was meant by the annual economic effect is basically the amount spent on fuel daily, calculated over a year's span.

The equations that will be stated are simply for model 1 in case study 1, and can similarly be applied to the other models in the same case study or in the other case studies.

$$pc\_afc(1) = \frac{723680.84 - afc(1)}{723680.84} \times 100, \tag{3.28}$$

$$pc\_ace(1) = \frac{11938.24 - afc(1)}{11938.24} \times 100, \tag{3.29}$$

$$afc(1) = dfc(1) \times 356, \tag{3.30}$$

$$ace(1) = lpd(1) \times 2.392 \times 356, \tag{3.31}$$

$$dfc(1) = lpd(1) \times 145, \tag{3.32}$$

$$lpd(1) = \frac{p(4) \times 3.6 \times cd(1)}{2 \times 0.745}, \tag{3.33}$$

Note: the denominator in the above equation is only multiplied by two for model 1.

$$cd(1) = \frac{100}{p(1) \times 12}, \tag{3.34}$$

Where,

p(1) is charging rate (percentage change in state of charge per five minutes)

p(4) is fuel consumption

cd(1) is charging duration

lpd(1) is litres per day

dfc(1) is daily fuel cost

ace(1) is annual CO_2 emission

afc(1) is annual fuel cost

pc_afc(1) is percentage difference in the annual fuel cost as regard to that of the non-hybrid.

pc_ace(1) is percentage difference in the annual CO_2 emission as regard to that of the non-hybrid.

In order to successfully run this sensitivity analysis, some assumptions had to be made so as to simplify a seemingly complex analysis.

3.2.4 Assumptions

1. Vehicle is always assumed at top speed, so only top speed parameters will be used for analysis.
    - The reason for this assumption is to avoid all the irregularities in parameters that come from braking, accelerating and turning, because one can't just make a guess on how many times the vehicle operator changed speed or direction during work hours.
2. Daily work hours is equivalent to the high density battery discharge duration.
3. The only source of power for charging the high density battery is the engine.

- The reason for this assumption is to avoid the irregularities in parameters that will come from the inconsistency in the country's power supply (commonly referred to as NEPA/PHCN).

4. Charging and Discharge rate are separately uniform for all states of charge.
5. System runs continuously through Daily work hours.
   - The reason for this assumption is to avoid accounting for all the possible pit stops or breaks from work taken by the vehicle operator.
6. All system simulations (be it non-hybrid or hybrid three wheeler) were run on gear 1.
7. Aerodynamic resistance of the hybrid model is only about 20% of the non-hybrid model.
8. The sole contributing parameter to the annual economic effect is the daily expenditure on fuel. Every other parameter like maintenance (oil and other services), have insignificant effects compared to the former.

CHAPTER FOUR

SIMULATION RESULT AND INTERPRETATION

4.1 Input Data

As earlier stated, the design of the hybrid electric three wheeler was carried out with the aid of the Matlab Simulink and Solidworks computer program. There were no input parameters for the 3D modelling part of the hybridization, and all working drawing of the skeletal parts of the three wheeler can be found in the appendix.

All the systems modelled in this project, due to the similarity in purpose share most of the same input parameter with few exceptions. The General inputs cover all inputs shared by all the systems, while all other inputs are specified according to their processes.

4.1.1 General Input Data

Table 4.1 High Density Battery

S/No	Quantity	Symbol	Unit	Value
1	Nominal voltage	E_{Batt}	V	51.2
2	Rated Capacity	It	Ah	50
3	Maximum Capacity	Q	Ah	200
4	Cut-off voltage	E_{Batt}	V	40
5	Fully charged voltage	E_{Batt}	V	58.4
6	Nominal discharge current	I	A	50
7	Internal resistance	K	Ohms	0.513
8	Exponential zone (Voltage)	A	V	58.4
9	Exponential zone (Capacity)	B	Ah^{-1}	200

(Source: m.alibaba.com)

Table 4.2 Electric Motor

S/No	Quantity	Symbol	Unit	Value
1	Armature resistance	R	Ohm	0.578
2	Armature inductance	L	H	1.2e-5
3	Back-emf constant	k_v	V/rpm	0.016
4	Rotor inertia	J	gcm^2	0.0001
5	Rotor damping	λ	Nms/rad	0
6	Initial rotor speed	ω	rpm	0

(Source: m.alibaba.com)

Table 4.3 Electric Generator

S/No	Quantity	Symbol	Unit	Value
1	Armature resistance	R	Ohm	1.613
2	Armature inductance	L	H	1.2e-5
3	Back-emf constant	k_v	V/rpm	0.0306
4	Rotor inertia	J	gcm^2	0.000159
5	Rotor damping	λ	$Nmsrad^{-1}$	0
6	Initial rotor speed	ω	Rpm	0

(Source: m.alibaba.com)

Table 4.4 Hybrid Vehicle Body

S/No	Quantity	Symbol	Unit	Value
1	Mass	m	kg	500
2	Number of wheel per axle	n	-	2
3	Horizontal distance from CG to front axle	a	mm	1437.6
4	Horizontal distance from CG to rear axle	b	mm	234
5	CG height above ground	h	mm	477.34
6	Frontal area	A	m^2	2.09
7	Drag coefficient	C_d	-	0.1
8	Gravitational acceleration	g	ms^{-2}	9.81
9	Air density	ρ	kgm^{-3}	1.18

(Source: http://piaggio.co.in/product.php)

Table 4.5 Non-Hybrid Vehicle Body

S/No	Quantity	Symbol	Unit	Value
1	Mass	m	kg	394
2	Number of wheel per axle	n	-	2
3	Horizontal distance from CG to front axle	a	mm	1437.6
4	Horizontal distance from CG to rear axle	b	mm	234
5	CG height above ground	h	mm	477.34
6	Frontal area	A	m^2	2.09
7	Drag coefficient	C_d	-	0.5
8	Gravitational acceleration	g	ms^{-2}	9.81
9	Air density	ρ	kgm^{-3}	1.18
10	Vehicle Top Speed	v_{max}	ms^{-1}	19.44

(Source: http://piaggio.co.in/product.php)

Table 4.6 Tire

S/No	Quantity	Symbol	Unit	Value
1	Formula B coefficient	B	-	10
2	Formula C coefficient	c	-	1.9
3	Formula D coefficient	d	-	1
4	Formula E coefficient	e	-	0.97
5	Slip	k	-	0

(Source: Matlab R2017a)

Table 4.7 I.C. Engine

S/No	Quantity	Symbol	Unit	Value
1	Maximum power	P_{max}	W	7880
2	Speed at maximum power	Ω_0	rpm	5100
3	Maximum speed	Ω_{max}	rpm	8000
4	Stall speed	Ω_{min}	rpm	250
5	Fuel consumption per revolution	FC	mg/rev	5.79

(Source: http://piaggio.co.in/product.php)

Table 4.8 Gear

S/No	Quantity	Symbol	Unit	Value
1	Gear ratio	g_{FB}	-	5

(Source: http://piaggio.co.in/product.php)

4.1.2 Hybridization Input Data

As explicitly explained in the previous chapter, the hybridized system is separated into two sections, the charging system and the driving system. These two sections can function independently and are still inter-dependent. The hybrid driving system was compared to the non-hybrid three-wheeler, to check the percentage improvement in performance. The tables belonging to this subsection as earlier explained is a combination of the general input values for the hybrid components and these which will be specified in the table below.

Table 4.9 Non-hybrid Three-wheeler

S/No	Quantity	Symbol	Unit	Value
1	Throttle ratio	T	-	0.57

Table 4.10 Hybrid Driving System

S/No	Quantity	Symbol	Unit	Value
1	Current	i	A	26.37
2	Voltage	v	V	95.90

4.1.3 Powertrain Downsizing Input Data

Due to the nature of the simulation that was run in this subsection, it involved just the charging system of the non-downsized and downsized hybrid system, because only the charging system contains the engine amongst the two systems that make up the complete hybrid system, and our main focus is the engine. The table belonging to this subsection as earlier explained is a combination of the general input values for the hybrid components and these which will be specified in the table below.

Table 4.11

S/No	Quantity	Symbol	Unit	Value
1	Throttle ratio (non-downsized)	T	-	0.89
2	Throttle ratio (downsized)	T	-	0.7

4.1.4 Model Optimization Input Data

This part of the project involved the modification of the hybridized and downsized model and checking each systems response to the same excitation. For the purpose of having a fair comparison, the non-hybrid had to be brought down to the same speed as the hybrid system. The tables belonging to this subsection as earlier explained is a combination of the general input values for the hybrid components and these which will be specified for the different case studies in the table below.

Case 1

Table 4.12 Model 1

S/No	Quantity	Symbol	Unit	Value
1	Throttle Value	T	-	0.7

Table 4.13 Model 2

S/No	Quantity	Symbol	Unit	Value
1	Throttle Value	T	-	0.7

Table 4.14 Model 3

S/No	Quantity	Symbol	Unit	Value
1	Throttle Value	T	-	0.47

Table 4.15 Model 4

S/No	Quantity	Symbol	Unit	Value

1	Current	i	A	20.07
2	Voltage	v	V	73.46

Case 2

Table 4.16 Model 1

S/No	Quantity	Symbol	Unit	Value
1	Throttle Value	T	-	0.7
2	Gear ratio	g_{FB}	-	0.75

Table 4.17 Model 2

S/No	Quantity	Symbol	Unit	Value
1	Throttle Value	T	-	0.7

Table 4.18 Model 3

S/No	Quantity	Symbol	Unit	Value
1	Throttle Value	T	-	0.47
2	Gear ratio	g_{FB}	-	0.75

Table 4.19 Model 4

S/No	Quantity	Symbol	Unit	Value
1	Current	i	A	20.07
2	Voltage	v	V	73.46

Case 3

Table 4.20 Model 1

S/No	Quantity	Symbol	Unit	Value
1	Throttle Value	T	-	0.7
2	Gear ratio	g_{FB}	-	0.75
3	Winding ratio	N	-	1.75

Table 4.21 Model 2

S/No	Quantity	Symbol	Unit	Value
1	Throttle Value	T	-	0.7

Table 4.22 Model 3

S/No	Quantity	Symbol	Unit	Value
1	Throttle Value	T	-	0.47
2	Gear ratio	g_{FB}	-	0.75
3	Winding ratio	N	-	1.75

Table 4.23 Model 4

S/No	Quantity	Symbol	Unit	Value
1	Current	i	A	20.07
2	Voltage	v	V	73.46

4.2 Output Data

The entire analytical aspect of this project was carried out using Matlab Simscape and the following tables give the output parameters for the simulations. Just like the input data values, different aspects of the entire simulation process also have their different result and as such different output data tables.

4.2.1 Output Data for the Hybridization

In this aspect of the simulation, the only target value was the capacity of the hybrid in terms of speed as compared to the non-hybrid three-wheeler. The aim of the hybridization was to model a system that even with all the extra weight from hybridization can still approach or even surpass the capacity of the non-hybrid three wheeler.

Table 4.24

S/No	Quantity	Symbol	Unit	Value
1	Hybrid Vehicle Speed	v	ms^{-1}	21.40
2	Non-Hybrid Vehicle Speed	v	ms^{-1}	18.06

4.2.2 Output Data for the Powertrain Downsizing

The aim of this aspect of the project was to apply a lesser capacity to the same system and ascertain its response to the reduction. Therefore, only parameters like fuel consumption and charging rate were of importance in this subsection.

Table 4.25 Non-downsized Hybrid Model

S/No	Quantity	Symbol	Unit	Value
1	Fuel consumption	fc	gs^{-1}	0.381
2	Charging rate	Cr	%/s	0.0054

Table 4.26 Downsized Hybrid Model

S/No	Quantity	Symbol	Unit	Value
1	Fuel consumption	fc_1	gs^{-1}	0.3433
2	Charging rate	cr_1	%/s	0.0044

4.2.3 Output Data for the Model Optimization

The aim of this aspect of this aspect of the project is to modify the hybridized and downsized model and check the response of the different modification to the same excitation, so that the optimal model can be deduced from the analysis. The optimization was centred around percentage change in annual economic effect and annual carbon emission. the percentage change in annual economic effect and annual carbon emission of each of the models present in this section is in relation to the non-hybrid model.

Case 1

Table 4.27 Model 1

S/No	Quantity	Symbol	Unit	Value
1	Charging rate	p(1)	%/s	0.0034
2	Speed	v	ms^{-1}	17.33
3	Fuel consumption	p(4)	gs^{-1}	0.635
4	Charging Duration	cd(1)	hr	8.17
5	Litres per day	lpd(1)	lr	12.54
6	Daily Fuel cost	dfc(1)	₦	1817.51
7	Annual Fuel cost	afc(1)	₦	647033.16
8	Annual CO_2 Emission	ace(1)	kg	10673.82
9	% drop in Annual fuel cost	pc_afc(1)	%	10.59
10	% drop in CO_2 Emission	pc_ace(1)	%	10.59

Table 4.28 Model 2

S/No	Quantity	Symbol	Unit	Value
1	Speed	v	ms^{-1}	16.49

2	Fuel consumption	p(5)	gs^{-1}	0.376
3	Litres per day	lpd(2)	lr	14.02
4	Daily Fuel cost	dfc(2)	₦	2032.81
5	Annual Fuel cost	afc(2)	₦	723680.84
6	Annual CO_2 Emission	ace(2)	kg	11938.24
7	% drop in Annual fuel cost	pc_afc(2)	%	0
8	% drop in CO_2 Emission	pc_ace(2)	%	0

Table 4.29 Model 3

S/No	Quantity	Symbol	Unit	Value
1	Charging rate	p(2)	%/s	0.0048
2	Fuel consumption	p(6)	gs^{-1}	0.484
3	Charging Duration	cd(2)	hr	5.75
4	Litres per day	lpd(3)	lr	13.44
5	Daily Fuel cost	dfc(3)	₦	1948.99
6	Annual Fuel cost	afc(3)	₦	693841.61
7	Annual CO_2 Emission	ace(3)	kg	11445.99
8	% drop in Annual fuel cost	pc_afc(3)	%	4.12
9	% drop in CO_2 Emission	pc_ace(3)	%	4.12

Table 4.30 Model 4

S/No	Quantity	Symbol	Unit	Value
1	Discharging rate	p(3)	%/s	0.0036
4	Vehicle Speed	v	ms^{-1}	16.42
4	Discharging Duration/Working hours	dd(1)	hr	7.72

Case 2

Table 4.31 Model 1

S/No	Quantity	Symbol	Unit	Value
1	Charging rate	p(1)	%/s	0.0037
2	Speed	v	ms^{-1}	19.48
3	Fuel consumption	p(4)	gs^{-1}	0.516
4	Charging Duration	cd(1)	hr	7.51
5	Litres per day	lpd(1)	lr	9.36
6	Daily Fuel cost	dfc(1)	₦	1357.16
7	Annual Fuel cost	afc(1)	₦	483147.47
8	Annual CO_2 Emission	ace(1)	kg	7970.27
9	% drop in Annual fuel cost	pc_afc(1)	%	33.24
10	% drop in CO_2 Emission	pc_ace(1)	%	33.24

Table 4.32 Model 2

S/No	Quantity	Symbol	Unit	Value

1	Speed	v	ms^{-1}	16.49
2	Fuel consumption	p(5)	gs^{-1}	0.376
3	Litres per day	lpd(2)	lr	14.02
4	Daily Fuel cost	dfc(2)	₦	2032.81
5	Annual Fuel cost	afc(2)	₦	723680.84
6	Annual CO_2 Emission	ace(2)	kg	11938.24
7	% drop in Annual fuel cost	pc_afc(2)	%	0
8	% drop in CO_2 Emission	pc_ace(2)	%	0

Table 4.33 Model 3

S/No	Quantity	Symbol	Unit	Value
1	Charging rate	p(2)	%/s	0.0044
2	Fuel consumption	p(6)	gs^{-1}	0.343
3	Charging Duration	cd(2)	hr	6.31
4	Litres per day	lpd(3)	lr	10.46
5	Daily Fuel cost	dfc(3)	₦	1517.24
6	Annual Fuel cost	afc(3)	₦	540136.06
7	Annual CO_2 Emission	ace(3)	kg	8910.38
8	% drop in Annual fuel cost	pc_afc(3)	%	25.36
9	% drop in CO_2 Emission	pc_ace(3)	%	25.36

Table 4.34 Model 4

S/No	Quantity	Symbol	Unit	Value
1	Discharging rate	p(3)	%/s	0.0036
4	Vehicle Speed	v	ms^{-1}	16.42
4	Discharging Duration/Working hours	dd(1)	hr	7.72

Case 3

Table 4.35 Model 1

S/No	Quantity	Symbol	Unit	Value
1	Charging rate	p(1)	%/s	0.0032
2	Speed	v	ms^{-1}	15.64
3	Fuel consumption	p(4)	gs^{-1}	0.693
4	Charging Duration	cd(1)	hr	8.68
5	Litres per day	lpd(1)	lr	14.53
6	Daily Fuel cost	dfc(1)	₦	2107.49
7	Annual Fuel cost	afc(1)	₦	750265.52
8	Annual CO_2 Emission	ace(1)	kg	12376.794
9	% drop in Annual fuel cost	pc_afc(1)	%	-3.67
10	% drop in CO_2 Emission	pc_ace(1)	%	-3.67

Table 4.36 Model 2

S/No	Quantity	Symbol	Unit	Value
1	Speed	v	ms^{-1}	16.49

2	Fuel consumption	p(5)	gs^{-1}	0.376
3	Litres per day	lpd(2)	lr	14.02
4	Daily Fuel cost	dfc(2)	₦	2032.81
5	Annual Fuel cost	afc(2)	₦	723680.84
6	Annual CO_2 Emission	ace(2)	kg	11938.24
7	% drop in Annual fuel cost	pc_afc(2)	%	0
8	% drop in CO_2 Emission	pc_ace(2)	%	0

Table 4.37 Model 3

S/No	Quantity	Symbol	Unit	Value
1	Charging rate	p(2)	%/s	0.0060
2	Fuel consumption	p(6)	gs^{-1}	0.510
3	Charging Duration	cd(2)	hr	4.60
4	Litres per day	lpd(3)	lr	11.35
5	Daily Fuel cost	dfc(3)	₦	1645.22
6	Annual Fuel cost	afc(3)	₦	585699.14
7	Annual CO_2 Emission	ace(3)	kg	9662.02
8	% drop in Annual fuel cost	pc_afc(3)	%	19.07
9	% drop in CO_2 Emission	pc_ace(3)	%	19.07

Table 4.38 Model 4

S/No	Quantity	Symbol	Unit	Value
1	Discharging rate	p(3)	%/s	0.0036
4	Vehicle Speed	v	ms^{-1}	16.42
4	Discharging Duration/Working hours	dd(1)	hr	7.72

4.3 Result Interpretation and Discussion

From the result gotten after hybridizing the three wheeler system, we can see that the hybrid approached the non-hybrid three wheeler capacity even though it could be seen that the whole lot of extra weight, and change in driving principles took its toll on this capacity.

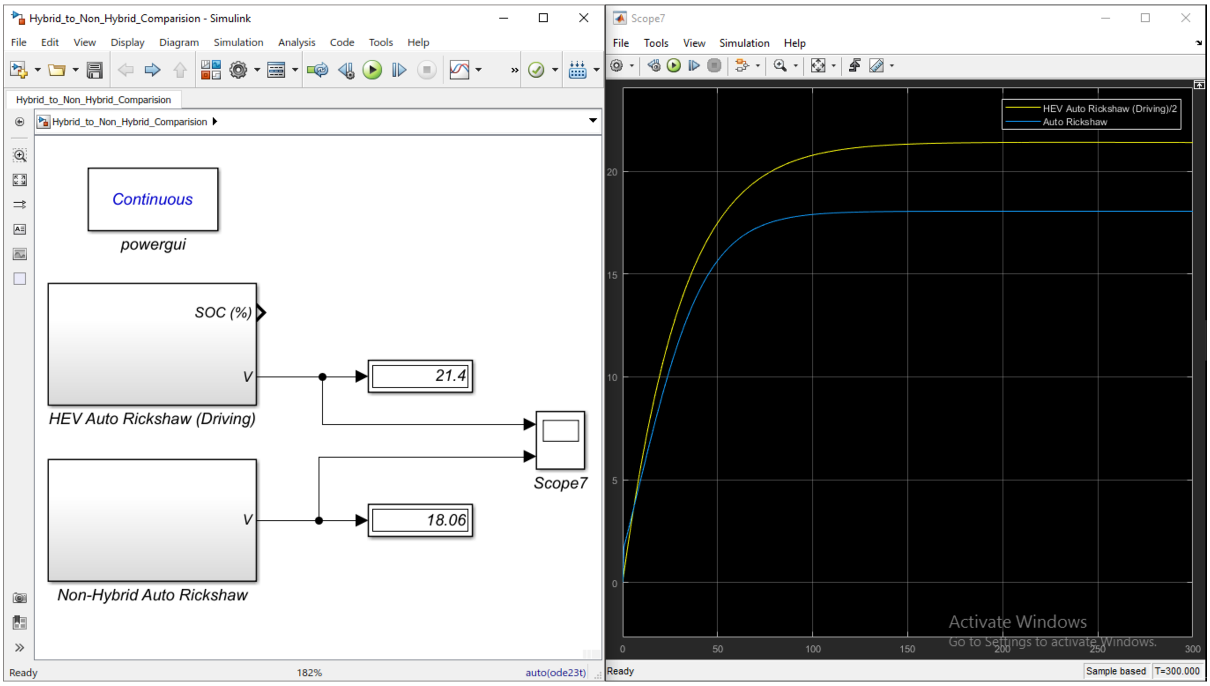

Figure 4.1 Simulation results for the Hybridized Three Wheeler.

Similarly, from the results gotten from the downsized model, it can be seen that the reduction in capacity had its effect in fuel consumption as well as the charging rate of the model, as shown in the chart below.

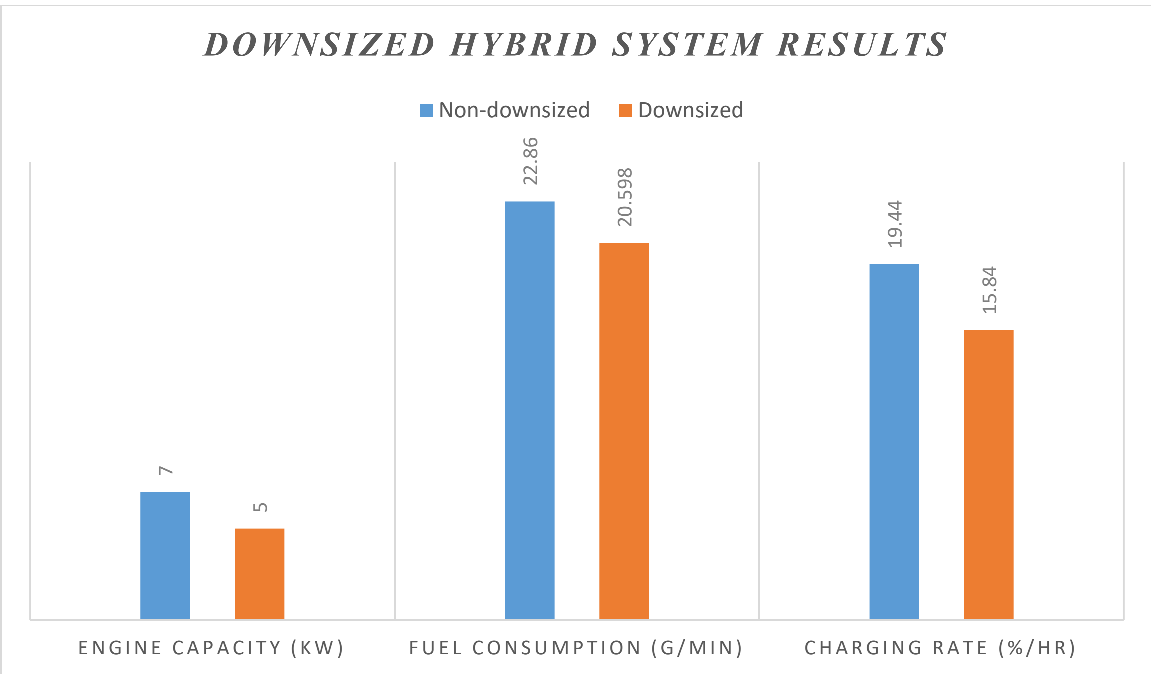

Figure 4.2 Simulation results for the Powertrain-Downsized Three Wheeler

Taking a look at the chart interpretation of the model optimization it can be seen that even without the modifications like placing gears to aid the charging process at reduced fuel consumption as implemented in Case 1, the hybrid model still showed some significant improvement in economic effect and CO_2 emission. These improvement as expected still increased with the modification to a point that could complement the initial high cost of the hybrid system.

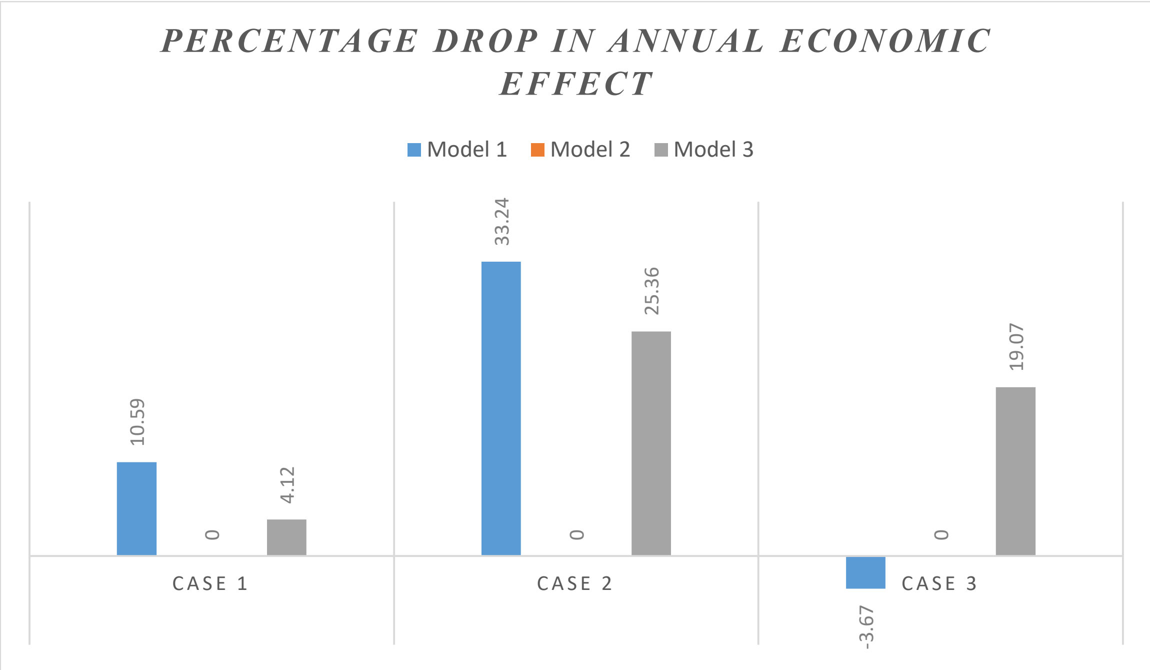

Figure 4.3 Percentage change in Annual Economic Effect.

It can be seen that the most improvement was made in model 1, which was because of the nature of the operation. If the vehicle operator should decide to charge and operate the hybrid model simultaneously as implemented in model 1, then s/he would not need to run the engine for the next day which implies that most of the calculation that were run for the models 2 and 3 over a span of one day will be run for the model 1 over a span of 2 days. This made it significantly better than the other model theoretically. While in reality, considering the time constant of the system which will play a significant role when braking and accelerating is introduced into the analysis amongst other factors then, these values will be subject to a whole wider set of parameters.

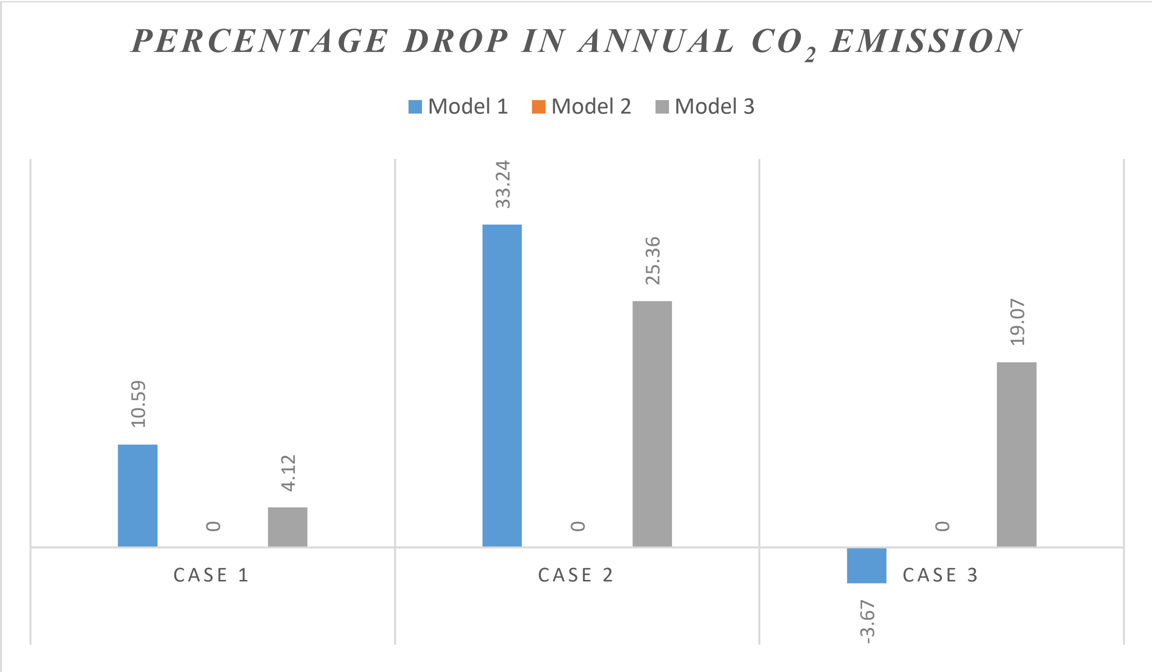

Figure 4.4 Percentage change in Annual CO_2 Emission

CHAPTER FIVE

CONCLUSION AND RECOMENDATION

5.1 CONCLUSION

In a world of depleting fossil fuel and increasing rate of global warming, the need for other efficient and dependable sources of energy while modifying already existing systems to attain higher performance or same performance with less input, cannot be overemphasized. The entirety of this project was centred around throwing light on a very prominent mode of transportation here in Nigerian and other developing countries, known as the **Three wheeler** (Auto Rickshaw). By being a prominent part of the national transportation system, it is also a prominent contributor to the country's carbon emission level.

This was implemented by using an alternative power source, in this case the electric power source. The vehicle was hybridized by integrating a series hybrid-electric connection into the already existing connection, with the regular non-hybrid capacity as a target point. After this hybridization was carried out with the use of Matlab Simulink and Solidworks computer program, the hybrid system's powertrain which is responsible for charging the high density battery was reduced in terms of output power level (downsized), and the system's response to this change was observed. This took a toll on some of the system's features like the fuel consumption and the high density battery charging time as expected. Finally, the downsized hybrid model was modified using some components in between the charging unit and driving unit, and a sensitivity analysis was run to check which of these modification yielded the most favourable result, with respect to all the assumption made before running the simulation. The sensitivity analysis consisted of three different case studies, and each of these case studies include four models, the charging and driving model, the non-hybrid model, the charging model and the driving model respectively. After these simulations were run, it was observed that the hybrid system was eventually more efficient in both the fuel consumption and in carbo emission, and that this efficiency is subject to improvement with the modification that can be added to the hybrid system.

5.2 Recommendation

In the course of accomplishing the task that was set, with the current level of expertise, a lot of assumptions had to be made in order to eliminate a lot of irregularities that actually exist in real life cases/scenarios. These assumptions even though made the system relatively easy to analyse, also confined the accuracy of the analysis compared to the actual case.

This project was limited to only a very specific type of three wheeler, which is the Piaggio Ape City Auto-Rickshaw. Due to unavailability of some essential parameters like effective vehicle frontal area, engine inertia, and so on, some of these parameters were assumed, and some software default values were used. The project didn't cover the acceleration and braking of the hybrid system, meanwhile braking is an area, if utilized properly, can really improve the actual efficiency of the hybrid system. The project also didn't cover any other alternative sources for the charging the high density battery beside the engine, which can lead to a further drop in fuel consumption. Further research on the topic could include better market survey so as to yield more accurate input parameters which will in turn lead to result much closer to the real life case.

For someone/anyone looking to further analyse this hybrid three wheeler system in future projects or research, there are a lot of areas that can pose as a very good improvement to the already existing system.

- ***Regenerative Braking:*** this is a scenario in which the energy which is regularly lost during braking of a vehicle is utilized and fed back into the battery. In some of these case the electric motor plays the role of both the motor and the alternator, thereby, saving cost on the latter component. As a result of this phenomenon, the battery discharge duration is extended with respect to number of times the vehicle experiences a braking force.

- ***Parallel Hybrid:*** this is a different form of hybrid electric system from the series type hybrid, where the engine and the electric motor both drive the vehicle simultaneously. The concept of load sharing can both improve performance in terms of vehicle speed or fuel consumption and so on.
- ***Power Transformer:*** all the converters used in the project were mainly current/voltage transformer. Just like the name implies they're just used to either supplement current or voltage, and once current is increase, voltage drops and vice versa. As a result of this link, torque is increased at the expense of speed , or the reverse is the case and both of these parameter are essential to a moving vehicle depending on the stage of operation. A power transformer supplements the entire power, current and voltage included and this could really aid the power supply and even charging requirement of the vehicle, whereby, a little power source could be amped up to drive a much larger demand.
- ***Aerodynamically Favorable Vehicle Surface:*** the current three wheeler has a very wind resistant frontal surface area, due to its height demand. If the vehicle surface area can be modelled better such that the vehicle experiences minimal resistance even on a windy day, this could really aid the vehicle speed and fuel consumption.
- ***Weight Reduction:*** there are a lot of ways to reduce weight in a vehicle system, either by changing the already existing principles of some of the subsystems, like the suspension or chassis, or even researching and manufacturing a better material for its

components, still keeping the economic efficiency of the material in mind, amongst many other methods.

- ***Turbochargers:*** another basic way of downsizing engines is through the use of turbo chargers, which improve the efficiency of engine, while reducing the fuel consumption as well as carbon emission.

So much more could be done on the already existing three wheeler to compliment what is already been/being done, or even create an entirely new approach to an old problem/system.

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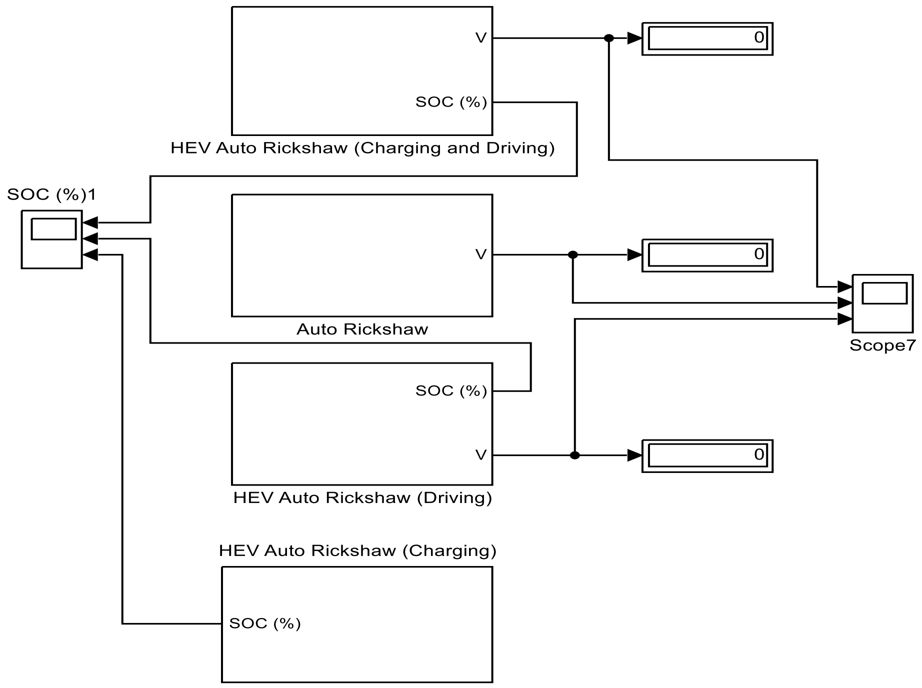
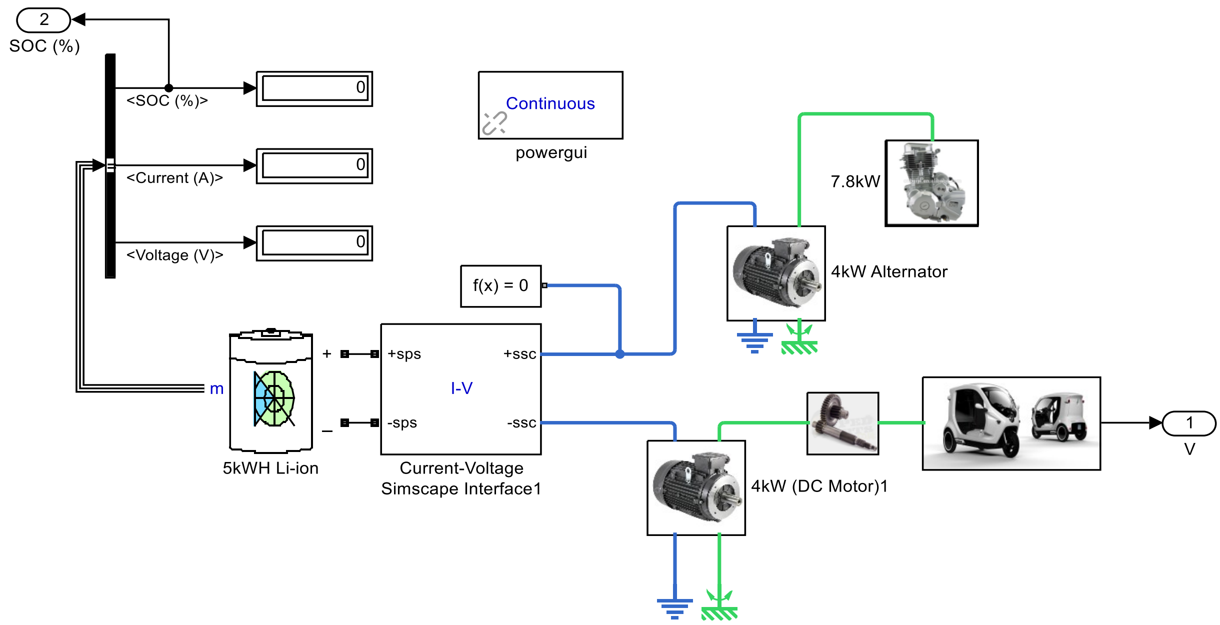
APPENDIX B

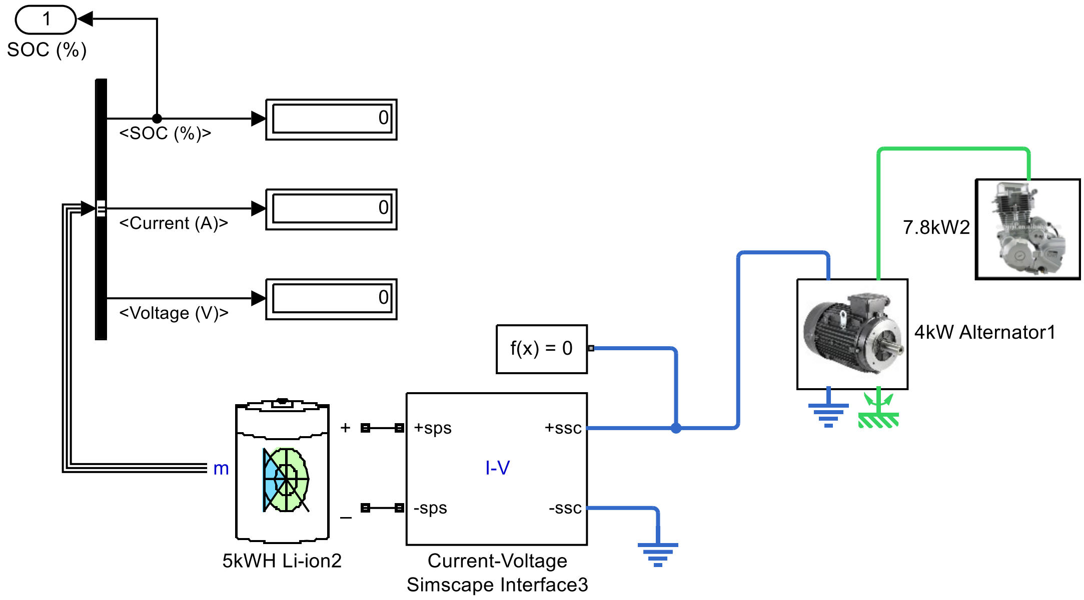
SIMSCAPE HYBRID ELECTRIC MODELS



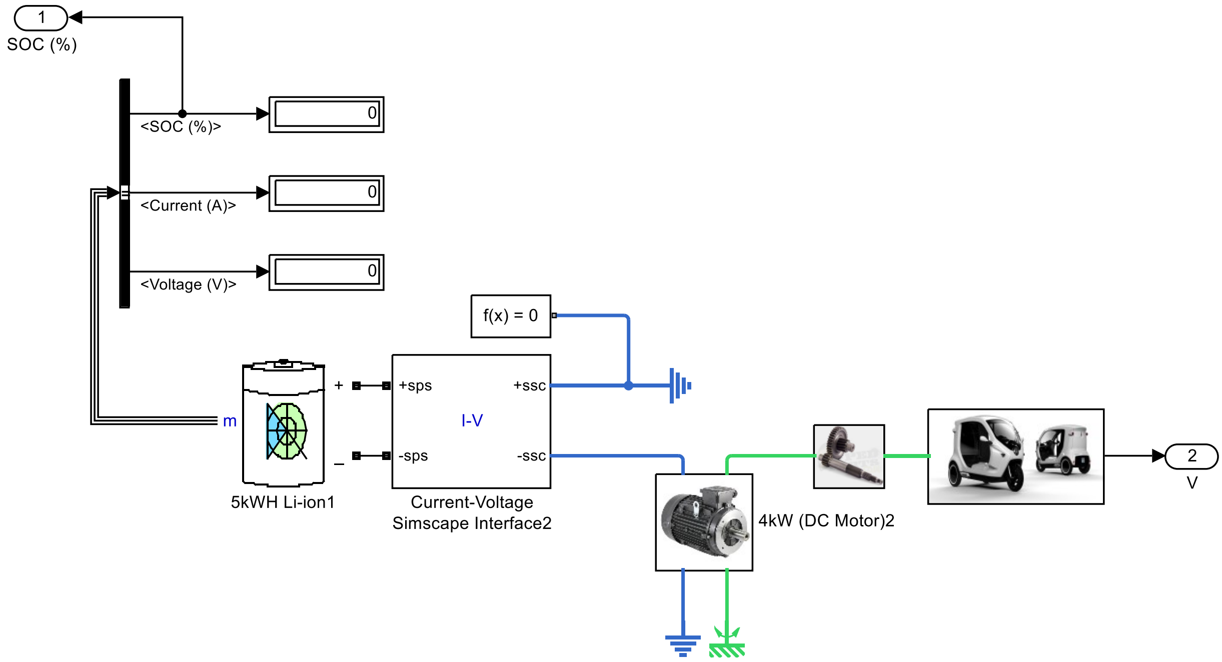
Case Study for Model Optimization.



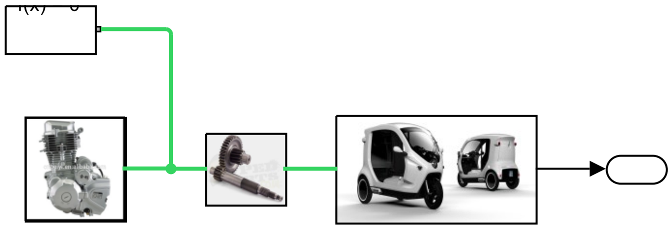
Complete Hybrid Electric System, comprising of the Charging and Driving Unit.



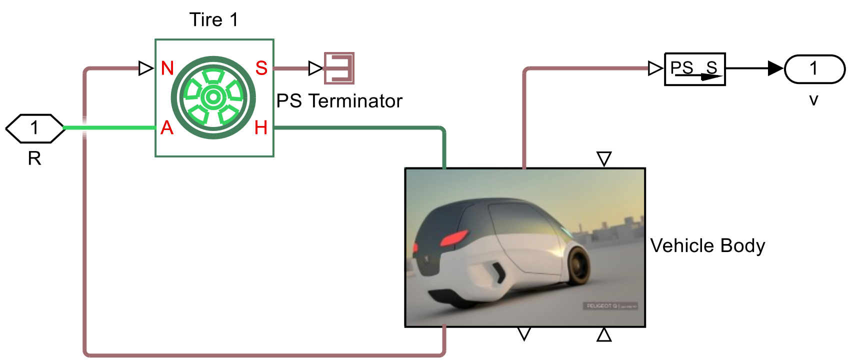
Charging Unit for the Hybrid Electric Model



Driving Unit for the Hybrid Electric Model



Non-hybrid Three Wheeler Model



Vehicle Subsystem comprising of the Tire, and Vehicle Body

APPENDIX C

MATLAB CODE USED FOR CALCULATING ECONOMIC EFFECT AND CO_2 EMISSION

```
function HEV_Analysis
p(1)=input('Charging rate of "Charging and Driving Model": ');
p(2)=input('Charging rate of "Charging only Model": ');
p(3)=input('Discharge rate of "Driving only Model": ');
p(4)=input('Fuel Consumption rate of "Charging and Driving Model": ');
p(5)=input('Fuel Consumption rate of "Non-HEV Model": ');
p(6)=input('Fuel Consumption rate of "Charging only Model": ');
cd(1)=100/(p(1)*12);
cd(2)=100/(p(2)*12);
dd(1)=100/(p(3)*12);
lpd(1)=(p(4)*3.6*cd(1))/(2*0.745);
lpd(2)=(p(5)*3.6*dd(1))/0.745;
lpd(3)=(p(6)*3.6*cd(2))/0.745;
for x=1:3
   dfc(x)=lpd(x)*145;
   afc(x)=dfc(x)*356;
   ace(x)=lpd(x)*2.392*356;
end
for y=1:3
   pc_afc(y)=((afc(2)-afc(y))/afc(2))*100;
   pc_ace(y)=((ace(2)-ace(y))/ace(2))*100;
end
fprintf('Charging Duration(hrs)\n');
fprintf('-Charging and Driving Model(%.3f)\n',cd(1));
fprintf('-Charging only Model(%.3f)\n\n',cd(2));
fprintf('Discharge Duration(hrs)\n');
fprintf('-Driving only Model(%.3f)\n\n',dd(1));
fprintf('Litre per day\n');
```

```
fprintf('-Charging and Driving Model(%.3f)\n',lpd(1));
fprintf('-Non-HEV Model(%.3f)\n',lpd(2));
fprintf('-Charging only Model(%.3f)\n\n',lpd(3));
fprintf('Daily fuel cost(#)\n');
fprintf('-Charging and Driving Model(%.3f)\n',dfc(1));
fprintf('-Non-HEV Model(%.3f)\n',dfc(2));
fprintf('-Charging only Model(%.3f)\n\n',dfc(3));
fprintf('Annual fuel cost(#)\n');
fprintf('-Charging and Driving Model(%.3f)\n',afc(1));
fprintf('-Non-HEV Model(%.3f)\n',afc(2));
fprintf('-Charging only Model(%.3f)\n\n',afc(3));
fprintf('Annual CO2 Emission(kg)\n');
fprintf('-Charging and Driving Model(%.3f)\n',ace(1));
fprintf('-Non-HEV Model(%.3f)\n',ace(2));
fprintf('-Charging only Model(%.3f)\n\n',ace(3));
fprintf('Percentage Change in Annual fuel cost\n');
fprintf('-Charging and Driving Model(%.3f)\n',pc_afc(1));
fprintf('-Non-HEV Model(%.3f)\n',pc_afc(2));
fprintf('-Charging only Model(%.3f)\n\n',pc_afc(3));
fprintf('Percentage Change in Annual C02 Emission\n');
fprintf('-Charging and Driving Model(%.3f)\n',pc_ace(1));
fprintf('-Non-HEV Model(%.3f)\n',pc_ace(2));
fprintf('-Charging only Model(%.3f)\n\n',pc_ace(3));
end
```