DEVELOPMENT OF PLUG IN DRIVE TRAIN SYSTEM FOR HYBRID ELECTRIC MOTORCYCLE

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Thesis submitted in fulfillment of the requirements for the award of the degree of Bachelor of Engineering in Mechanical Engineering with Automotive Engineering

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EXAMINER'S APPROVAL DOCUMENT

UNIVERSITI MALAYSIA PAHANG
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I certify that thesis entitled 'Development of Plug in Drive Train System for Hybrid Electric Motorcycle' is written by Mustika Yasti bin Yasril with matric number MH09021. I have examined the final copy of this thesis and in my opinion, it is fully adequate in terms of language standard, and report formatting requirement for the award of the degree of Bachelor in Mechanical Engineering with Automotive Engineering. I herewith recommend that it be accepted in fulfillment of the requirements for the degree of Bachelor Engineering in Mechanical Engineering with Automotive Engineering.

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We hereby declare we have checked this thesis, which written by Mustika Yasti bin Yasril, and in our opinion, this thesis project is adequate in terms of scopes and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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I hereby declare that the work in this thesis is my own, except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any other degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This thesis writing discussed about the study of Development of Plug-in Drive Train System for Hybrid Electric Motorcycle. Generally, Plug-in hybrid electric vehicles (PHEVs) use batteries to power an electric motor and use another fuel, such as gasoline or diesel, to power an internal combustion engine. Beyond battery storage and motor power, parallel drivetrain configuration is used to combine the power from the electric motor and the engine, allow them to switching between the two based on the drive profile—this is called "blended mode" or "mixed mode." The major challenges in order to complete this project is to make sure drivetrain functions very well, smooth during switching between modes, thus not damaging the engine especially during blended mode. To face these challenges, it is important to develop drivetrain configuration, thus analyze its final velocity, power and torque required for each modes. A review of literature made on the hybrid drivetrain systems outlines four different modes, namely: Electric Motor (EM) mode, Internal Combustion Engine (ICE) mode, blended mode and idle mode. The configuration shows that each mode has its own functions and characteristics depends on speed demands and also needs at certain circumstances. Mechanical coupling used to connects the engine and the electric motor to the drive shafts, and before reach final drive, there will be continuous variable transmission (CVT) component, which act as main transmission instead of going through several gears to perform gear ratio change. As final outcome, drivetrain configuration that has been finalized will be used as a benchmark to develop prototype of plug-in hybrid drivetrain system, thus works well with chassis and control system.

ABSTRAK

Tesis ini membincangkan tentang Kajian Sistem Rantaian Pemacu Plug Masuk untuk Motorsikal Elektrik Hibrid. Secara am, kenderaan elektrik hibrid plug masuk menggunakan bateri sebagai sumber kuasa Elektrik Motor, dan menggunakan petrol atau diesel untuk memberi kuasa kepada Enjin Pembakaran Dalam. Selain bateri dan kuasa motor, konfigurasi rantaian pemacu selari digunakan untuk menggabungkan kuasa dari elektrik motor dan enjin, membenarkan keduanya untuk bertukar antara dua punca kuasa berdasarkan profil pandu-ini dipanggil "mod campuran". Cabaran utama dalam usaha untuk menyiapkan projek ini adalah untuk memastikan rantaian pemacu berfungsi dengan baik, lancar semasa pertukaran antara mod, sekaligus tidak merosakkan enjin terutama semasa mod campuran. Untuk menghadapi cabaran ini, ia adalah penting untuk membangunkan konfigurasi rantaian pemacu, lantas menganalisis kelajuan akhir, kuasa dan daya kilas yang diperlukan untuk setiap mod. Satu kajian sastera yang dibuat ke atas sistem rantaian pemacu hibrid menggariskan empat mod, iaitu: mod Elektrik Motor (EM), mod Enjin Pembakaran Dalam (ICE), mod campuran dan mod lelap. Konfigurasi ini menunjukkan bahawa setiap mod mempunyai fungsi tersendiri dan ciri-ciri yang bergantung kepada permintaan kelajuan serta keperluan yang bergantung kepada keadaan tertentu. Gandingan mekanikal digunakan untuk menghubungkan enjin dan motor elektrik untuk aci pemacu, dan sebelum mencapai memandu akhir, akan ada komponen Penghantar Boleh Ubah Berterusan (CVT), yang bertindak sebagai penghantar utama, sebagai ganti melalui beberapa gear untuk melaksanakan nisbah perubahan gear. Sebagai hasil akhir, konfigurasi rantaian pemacu yang telah dimuktamadkan akan digunakan sebagai penanda aras untuk membangunkan prototaip sistem plug masuk rantaian pemacu hibrid, sekaligus, berfungsi dengan baik bersama casis dan sistem kawalan.

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LIST OF SYMBOLS

Symbols

P_{air}	Air drag
C_d	Air drag coefficient
P_c	Caloric value of gasoline
S	Displacement
e	Energy
F	Force
A_f	Frontal area
d_{gas}	Gasoline line flow
g	Gravitational acceleration
L	Inductance
m	Mass
J	Moment of inertia
P_{grad}	Power demand for gradient
P_{mot}	Power motor
r	Radius
m_{ice}	Ratio of fuel into the engine
R	Resistance
P_r	Rolling resistance
C_r	Tire rolling coefficient
W	Work

Greek Symbols

ζ	Air density
θ	Angular displacement
ω	Angular velocity
ρ	Density
η_{mech}	Mechanical efficiency
Ω	Rotational speed
τ	Torque

LIST OF ABBREVIATIONS

CAD	Computer Aided Drawing
CVT	Continuous Variable Transmission
EM	Electric Motor
EREV	Extended Range Electric Vehicles
ESS	Energy Storage System
EV	Electric Vehicle
GHG	Greenhouse Gas
HV	Hybrid Vehicle
ICE	Internal Combustion Engine
PHEM	Plug-in Hybrid Electric Motorcycle
PHEV	Plug-in Hybrid Electric Vehicle
ReEV	Range-extended Electric Vehicles
SOC	State of Charge
3D	Three Dimensional
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

In recent years, a significant interest in plug-in hybrid electric vehicles (PHEVs) has arisen gradually due to the pressing environmental concerns and increasing price of oil. Representing a revolutionary change in vehicle design around the globe, hybrid vehicles (HV) surfaced in many different ways. However, they share the hybrid powertrain that combines multiple power sources of different nature, including conventional internal combustion engines (ICE), batteries and electric motor (EM). These vehicles with onboard energy storage devices and electric drives allows braking power to be recovered and ensures the ICE to operate only in the most efficient mode, thus improving fuel economy and reducing pollutants.

Plug-in hybrid electric vehicles (PHEVs) are sometimes called range-extended electric vehicles (ReEVs) or extended range electric vehicles (EREVs), in the sense that these vehicles always have onboard gasoline or diesel that can be used to drive the vehicle for an extended distance when the onboard battery energy is depleted. Furthermore, these vehicles can provide high fuel economy during the extended driving range due to the large battery pack that can accept more regenerative braking energy and provide more flexibility for engine optimization during the extended driving range.

PHEVs have the potential to displace transportation fuel consumption by using grid electricity to drive the car. PHEVs also can be driven initially using electric energy stored in the onboard battery, and an onboard gasoline engine can extend the driving range. Plus, PHEVs can produce significant environmental and economic benefits for society. The advantages of PHEVs can be evaluated by how much fuel is displaced, as well as by how much pollution, including greenhouse gas (GHG) emissions, can be reduced (Chris Mi et al., 2011).

Lastly, drivetrain system in vehicle serves one purpose, which is to transfer engine power to the ground. Its configuration is designed according to various kinds of driving conditions and the choices of wheels to be powered by the engine or driven. Transmission and final drive components work together to make this happen. The transmission takes the output from engine and manipulates it to control speed, direction, and torque. The final drives reduce speed and increase torque.

1.2 PROBLEM STATEMENTS

Drivetrain is very important in vehicle design; this is due to its function to helps control the speed and power through gears. It also functions to transfer power from the engine to the wheels in order to propel the vehicle. Due to these purposes, it is important to determine the drivetrain efficiency before developing new drivetrain system especially in PHEV Motorcycle because it involves more drivetrain mechanism.

The vehicle engine supplies power through the combustion process. This process drives the flywheel positioned at the engine rear. The flywheel connects to the vehicle transmission system in order to adjust the power to the wheels for different applications. It also determines the power to be distributed to the other components in the drivetrain. In Hybrid System, power from two sources of drivetrain is combined which is from ICE and also EM. Thus, it is compulsory to provide proper power required so that the ICE did not damaging the EM, and vice versa. In addition, final velocity of final drive for both ICE and EM can be recorded.

Because of this, it is important to make sure that the drivetrain functions very well with other component mechanisms, such as control module. The change of mode for the drivetrain must as smooth as possible in order to reduce loss. In behalf of this, it is necessary to make a drivetrain system with a proper distribution of power from both power sources, so that it switch mode in a proper way, not damaging the engine especially during blended mode, thus, works well with other mechanisms in Plug-in Hybrid Electric Motorcycle that are going to be develop.

1.3 OBJECTIVES

a. To develop drivetrain system for plug-in hybrid electric motorcycle proper configuration.
b. To analyze proper power and torque required of drivetrain.

1.4 SCOPES OF STUDY

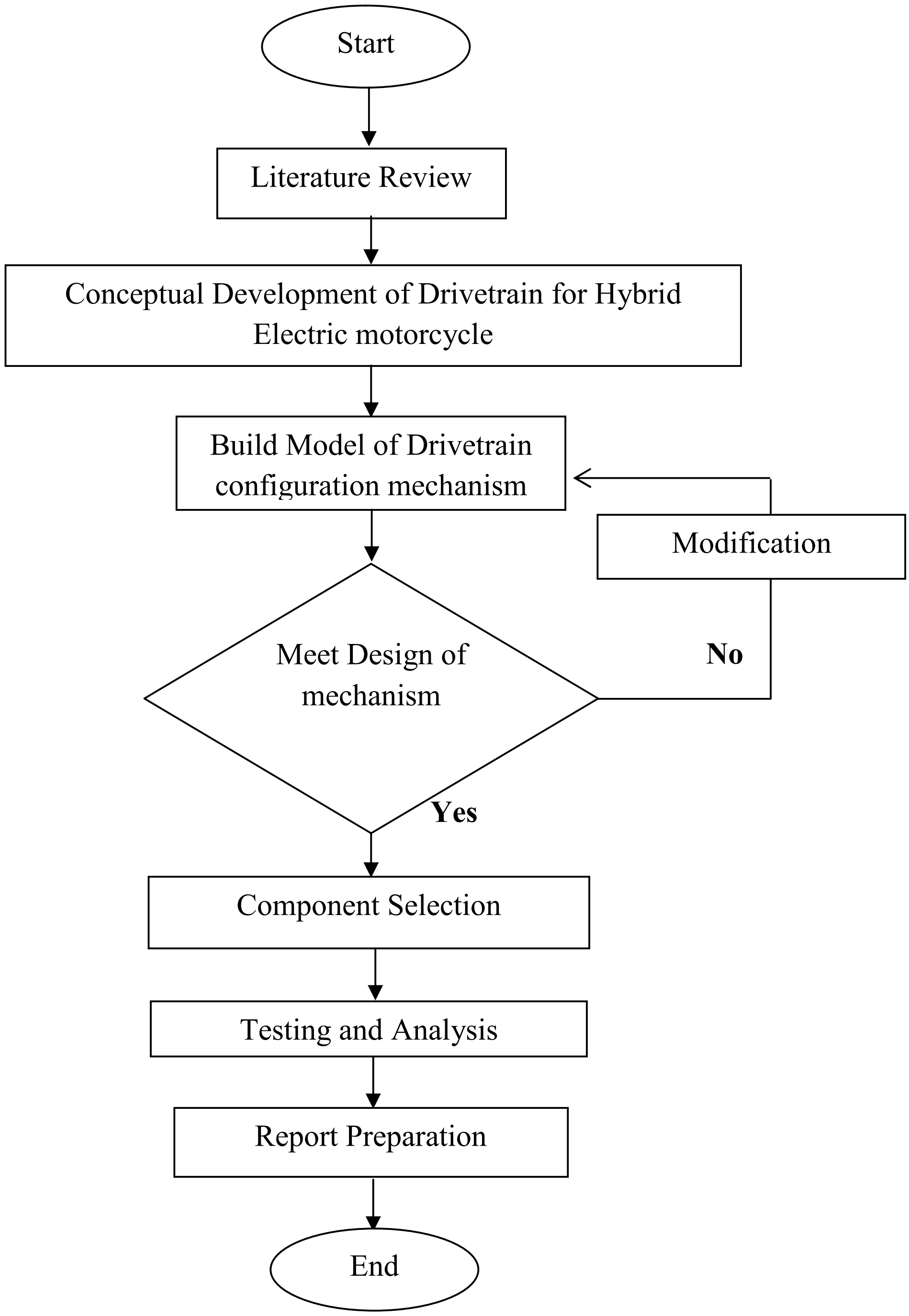
The scopes for this project are as following:

a. Conceptual Development Of Drivetrain For Hybrid Electric motorcycle
b. Benchmarking and component selection for Plug-In Hybrid Electric Motorcycle Drivetrain.
c. Development of model for Hybrid Electric Motorcycle drivetrain configuration. .
d. Experiment configuration analysis and data collection.
e. Final report preparation.

1.5 HYPOTHESIS

Drivetrain served as one of very important mechanisms in Plug-In Hybrid Engine Motorcycle development, which consist of engine, clutch, transmission, driveshaft, differential, axles and wheels. By the end of progress development, all of the component of drivetrain must be assemble; functioning well with no problem to switch between modes, having proper power distribution which means did not damaging power sources, thus works well with other mechanism in order to make sure the prototype model is successful.

1.6 FLOW CHART



1.7 GANTT CHART

The Gantt chart is referred to Appendix A

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORICAL DEVELOPMENT OF DRIVETRAIN

The history of drivetrain systems is closely linked to the history of the vehicle. Major changes in vehicle system have often been initiated or accompanied by advances in drivetrain systems.

Getting power from the engine to the wheels of an automobile has provided a seemingly endless challenge for rear-wheel-drive, front-wheel-drive, 4-wheel-drive, front-engine, rear-engine, and mid-engine cars, longitudinal, transverse, vertical, slant, and flat engines, plus an amazing array of hardware in between. George Selden's notorious 1877 patent was for a front-drive carriage with a transverse 3-cylinder engine, anticipating the Chevy/Suzuki Sprint by over a century. When it comes to car designs, there are very few new ideas, just progressively successful adaptations of old concepts (John Barach, 2011).

The heart of the drivetrain is the transmission. Because gasoline engines develop their torque over a very narrow speed range, several gears are needed to reach useful road speeds. (Steam engines and electric motors can be used in cars with no transmissions). Table 2.1 below shows timeline of transmission development progress (John Barach, 2011).

Table 2.1: Manual Drivetrain Timeline

Year	Inventor/Innovator	Description
1877	George Selden	Front-drive carriage with a transverse 3-cylinder engine
1894	Louis-Rene Panhard and Emile Levassor	Multi-geared transmission theory (engine problem during demo)
1895	Louis-Rene Panhard and Emile Levassor	Vertically mounted engine in the front of the vehicle that drove the rear wheels through a clutch, 3-speed sliding gear transmission and chain-driven axle
1898	Louis Renault	-Connected a vertical engine with transmission to a "live" rear axle by means of a metal shaft. -Additional • Rear axle • Driveshaft Compared to Panhard, Levassor (1895)
1908	T Ford	Planetary transmission; it had a central gear, called the "sun" gear, surrounded by three "planet" gears
1928	Cadillac	Synchromesh transmissions • Synchronizing system that permits drive and driven gears to be brought into mesh with each other smoothly without gear clashing. • This system allows both sets of gears to reach the same speed before they are engaged •
1930	Walter Wilson	Wilson Preselector • Four individual planetary gear sets, allowed the driver to preselect one gear ratio by moving a small lever on the steering column

Source: John Barach, (2012).

Table 2.2: Automatic Drivetrain Timeline

Year	Inventor/Innovator	Description
1904	Sturtevant brothers	Two forward speeds that were engaged and disengaged by the action of centrifugal weights without need for a foot-operated clutch
1934	Reo	Reo Self-Shifter; two transmissions connected in series • The first transmission much the same idea used by the Sturtevants • The second transmission was shifted manually and was used only when a lower gear was needed •
1937	Oldsmobile	Four-speed semi-automatic transmission called the "Automatic Safety Transmission" (AST)
1938	Buick	Five-speed semi-automatic transmission in the Special, but it was so prone to trouble that it was dropped the following year.
1939	Oldsmobile	GM Hydra-Matic transmission • three planetary gearsets that were operated hydraulically • A fluid coupling was used to connect the engine and transmission •
1941	Chrysler	Chrysler Fluid Drive transmission • A fluid coupling was used to connect the engine and transmission • Perfecting the fluid coupling •
1948	Buick	-Evolved automatic transmission into the hydraulic torque converter (today coupled to a planetary geartrain) - known as Dynaflow fully automatic transmission
1980	Fuji heavy industries Owned by Subaru	Continuously variable transmission, or CVT, • The transmission (or the driver) shifts gears to provide the most appropriate ratio for a given situation: Lowest gears for starting out, middle gears for acceleration and passing, and higher gears for fuel-efficient cruising.

Source: John Barach, (2012).

2.2 PLUG-IN HYBRID ELECTRIC VEHICLES (PHEVs)

Plug-in hybrid electric vehicles (PHEVs) had been growing interest among researchers due to its potential to reduced operating costs, oil displacement, national security, and environmental benefits. PHEVs might be cost more to purchase compared to ICE and HEVs in term of battery costing, but for long term, this technology will benefit consumers due to its long term savings potential (Oak Ridge National Laboratory, 2010).

Table 2.3: Comparison between Hybrid Electric Vehicle and Plug-In Hybrid Vehicle.

PHEVs	HEVs
Infrastructure: • Home recharging will be a prerequisite for most consumers; public recharge infrastructure may be relatively unimportant, at least to ensure adequate driving range, though some consumers may place a high value on daytime recharge opportunities.	**Infrastructure**: • Greater need for public infrastructure to increase daily driving range; quick recharge for longer trips and short stops; such infrastructure is likely to be sparse in early years and will need to be carefully coordinated.
Economies of scale: • Mass production levels needed to achieve economies of scale may be lower than those needed for EVs, for example if the same model is already mass-marketed as a non-PHEV hybrid; however, high-volume battery production (across models) will be needed.	**Economies of scale**: • Mass production level of 50 000 to 100 000 vehicles per year, per model will be needed to achieve reasonable scale economies; possibly higher for batteries (though similar batteries will likely serve more than one model).
Vehicle range: • PHEV optimal battery capacity (and range on grid-derived electricity) may vary by market and consumer group. Willingness to pay for additional batteries (and additional range) will be a key determinant.	**Vehicle range**: • Minimum necessary range may vary by region – possibly significantly lower in Europe and Japan than in North America, given lower average daily driving levels. 100 km (62 miles) to 150 km (93 miles) may be a typical target range in the near term.

Source: Peter Taylor et al. (2011).

On the other hand, Journal Technology Roadmap; Electric and Plug-In Hybrid Electric Vehicles (Peter Taylor et al., 2011) states that PHEVs retain the entire ICE system, but add battery capacity to enable the extended operation of the EM. PHEVs have an advantage of being less dependent on recharging infrastructure and possibly less expensive (depending on battery costs and range) than EVs.

2.3 DRIVETRAIN

The drivetrain of a vehicle is composed of the components that are responsible for transferring power to the drive wheels of your vehicle. Propulsion energy of an HEV comes generally from two types of sources; one of them must be an electric source.

In addition, integrating an EM with an ICE is the most practical means of realizing an HEV arrangment, before the pure EV eventually becomes commercial. Based on different combinations of electric and mechanical traction, HEV drivetrains are divided into three basic arrangements (Chirag Desai, 2010):

a. Series hybrid
b. Parallel drivetrain
c. Power-split or series-parallel hybrid.

2.3.1 Series Drivetrain.

A series HEV typically consists of an ICE directly coupled to an electric generator. The electric motor provides all the propulsion power. The configuration of a series HEV is shown in Figure 2.1 (Chirag Desai, 2010).

In a series HEV, because of no mechanical connection between the ICE and drive wheels, it is possible to operate the ICE very close to maximum efficiency. The ICE works in its optimal operation range as an on-board generator, maintaining battery state of charge (SOC) (G. Maggetto and J. Van Mierlo, 2005).

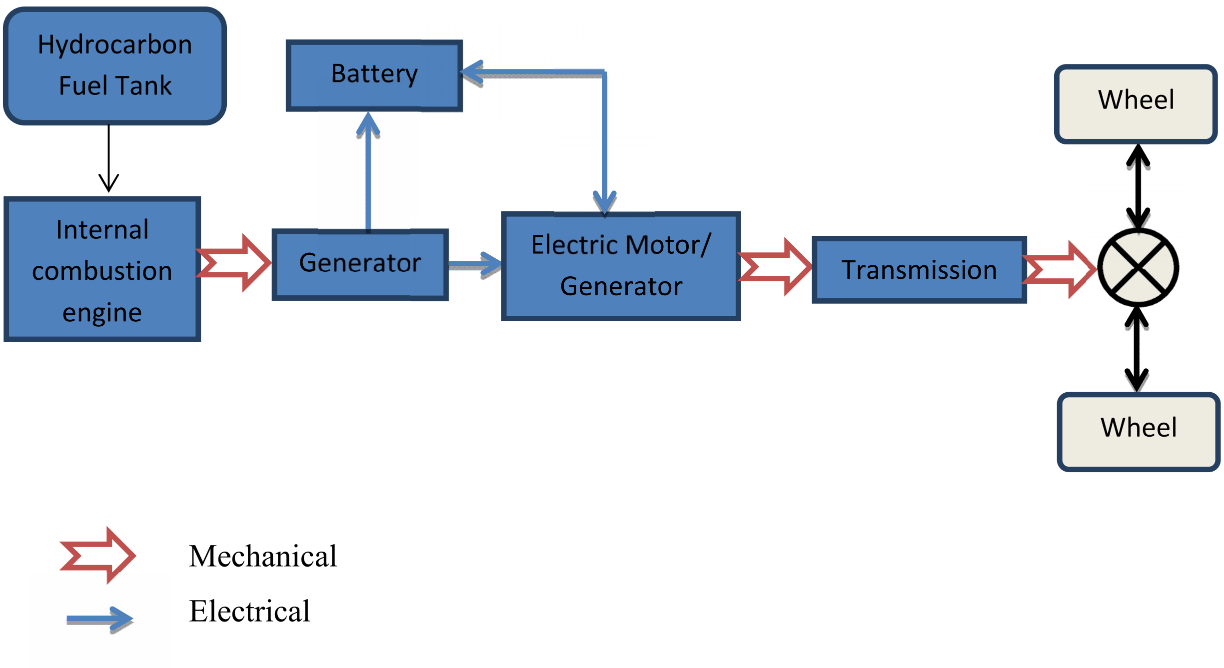


Figure 2.1: Series Drivetrain

Source: Chirag Desai, (2010)

2.3.2 Parallel drivetrain

In a parallel HEV, both the ICE and the electric motor deliver power to the wheels. A parallel HEV configuration offers freedom to choose a combination of traction sources. By merging the two different traction sources, a relatively smaller, more efficient ICE can be used. The configuration of a parallel HEV is shown in Figure 2.2 (Chirag Desai, 2010).

Since both the ICE and the EM directly supply torques to the driven wheels, no energy conversion occurs. Thus, the energy loss is low, which increases overall drivetrain efficiency. Moreover, the parallel HEV drivetrain is compact, due to the absence of an electric generator. The small size of Energy Storage System (ESS) and EM also makes the parallel HEV an attractive option. However, the control of parallel HEV drivetrain is more complicated than a series HEV (Chirag Desai, 2010).

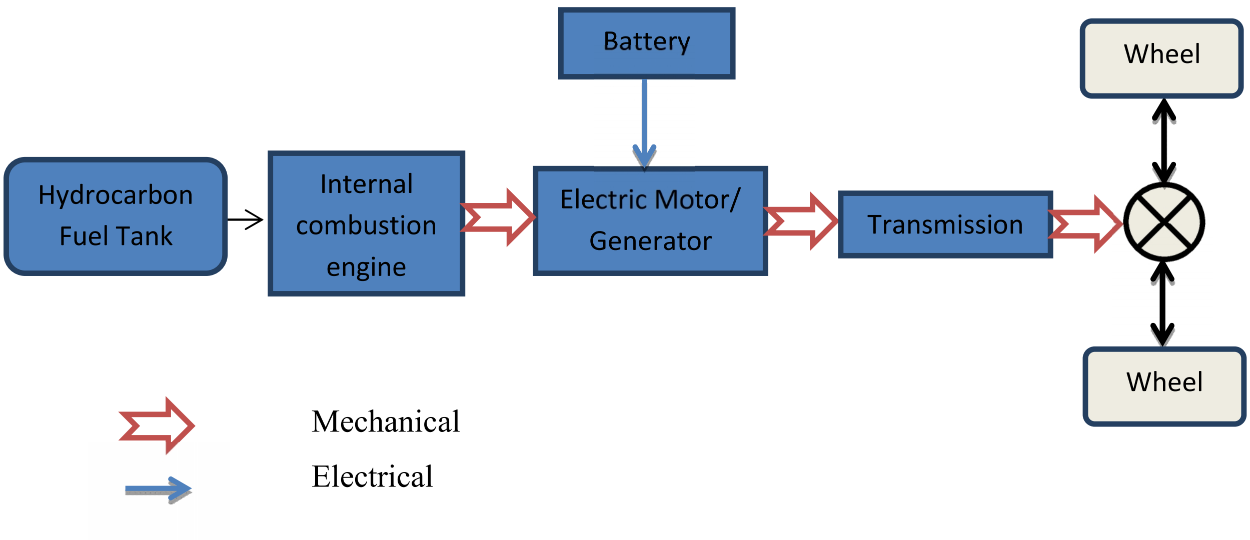


Figure 2.2: Parallel Drivetrain

Source: Chirag Desai, (2010)

2.3.3 Power-Split or Series-Parallel Hybrid.

By adding a power split unit between the generator, the EM, and the ICE, the series-parallel hybrid HEV combines the features of a series HEV as well as a parallel HEV, as shown in Figure 2.3. Although it has the advantages of both series and parallel configurations, it also has the drawbacks of these two configurations. In addition, the technical complexity of the general design and development of the combined HEV drivetrain and its precise control strategy is a major challenge (Chirag Desai, 2010).

This drivetrain merges the advantages and complications of the parallel and series drivetrains. The engine can both drive the wheels directly (as in the parallel drivetrain) and be effectively disconnected from the wheels so that only the electric motor powers the wheels (as in the series drivetrain). The engine operates at near optimum efficiency more often. At lower speeds it operates more as a series vehicle, while at high speeds, where the series drivetrain is less efficient, the engine takes over and energy loss is minimized (G A Hubbard, K Youcef-Toumi, 1997).

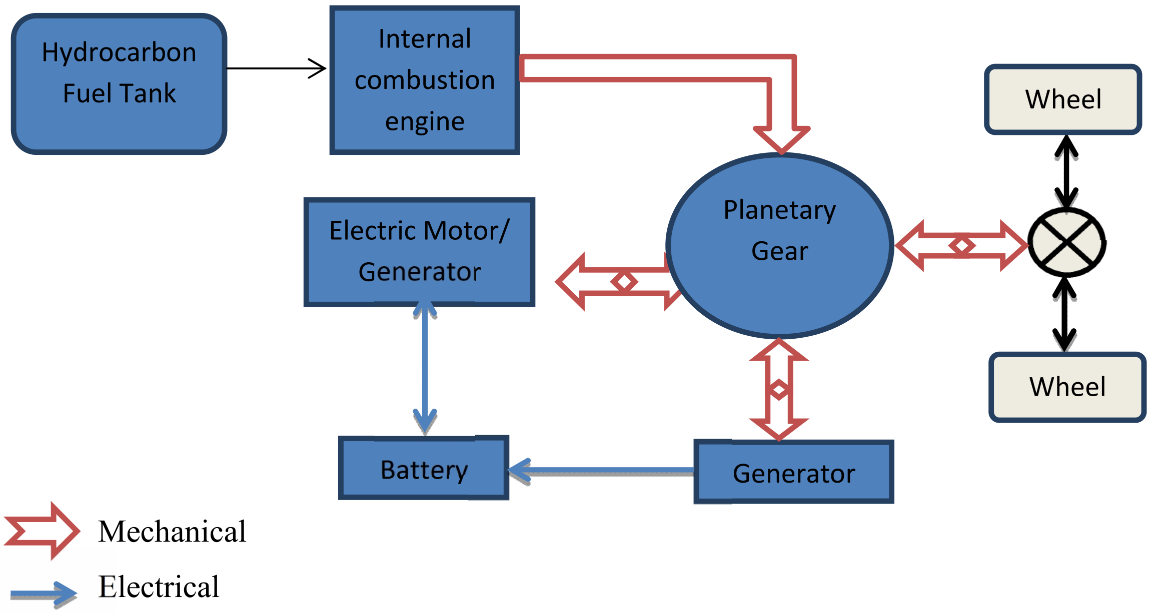


Figure 2.3: Series-Parallel Drivetrain

Source: Chirag Desai, (2010)

2.4 PARALLEL DRIVETRAIN

2.4.1 Advantages

Parallel type system contains two power sources results having higher application efficiency than the serial type. The systems can operate in various ways according to the different driving requirements due to the system can apply two power sources efficiently. The ICE and EM can output power simultaneously when the vehicle is carrying a heavy load or climbing. The two power sources then are combined through the torque integrated mechanism, generating more power to drive the vehicle. The alternator is also driven to charge the battery concurrently when the engine offers power sufficiently to drive the vehicle. The ICE does not operate in low speed driving (starting), thus the vehicle low speed power source comes from the EM (K. David Huang and Sheng-Chung Tzeng, 2004).

2.4.2 Disadvantages

Generally, the mechanism of the parallel type is more complicated than the serial type. The engine of parallel type cannot be set for its best operating range due to the outputs of ICE that employ the current parallel type are required to adjust their operation range according to vehicle loading, which means its emission and thermal efficiencies are worse compared to series type of drivetrain (K. David Huang and Sheng-Chung Tzeng, 2004).

2.5 VARIOUS TYPES OF TRANSMISSION

The transmission is a component that is connected to the engine. It transmits mechanical power from the engine to the final wheels. The transmission purpose is to reduce the revolutions of the crankshaft down to a reasonable value by using interlocking gears to reduce the number of revolutions. Thus, it makes more effective usage of the engine's torque and helps to keep the engine operating at an appropriate speed (Jegan Das Haridas, 2007).

There are 4 major types of transmission which are:

a. Manual transmission;

Manual transmission is also referred to as stick shift transmission because need to use the transmission stick every time want to change the gears. To perform the gear shift, the transmission system must first be disengaged from the engine. After the target gear is selected, the transmission and engine are engaged with each other again to perform the power transmission (Chao-Hsu Yao, 2008).

b. Automatic transmission;

Chrysler introduced the first automatic transmission system in 1941, which included a fluid coupling between engine and clutch. The gear set is the same as those in a manual transmission box; however, a vacuum cylinder or a hydraulic cylinder is used to perform automatic gear shifting (Chao-Hsu Yao, 2008).

c. CVT (Continuous variable transmission);

The continuously-variable transmission is also an automatic transmission system, which changes the diameters of input shaft and output shaft directly, instead of going through several gears to perform gear ratio change. This design can generate an infinite number of possible gear ratios. Unlike the complicated planetary automatic transmission system, a CVT only has three major parts; a drive pulley connected to the input shaft, a driven pulley connected to the output shaft, and a belt (Chao-Hsu Yao, 2008).

d. Semi-automatic transmission;

A semi-automatic transmission is a very advanced system, which still uses a clutch to perform the gear shift instead of a torque converter. Unlike the manual transmission, the computer does all of the clutch disengaging, gear shifting, and clutch engaging. This not only makes the gear shifting faster than manual transmission, but also prevents the vehicle from stalling when the car is stationary (Chao-Hsu Yao, 2008).

For this Plug-in Hybrid Vehicle Drivetrain project, the chosen transmission is continuously-variable transmission (CVT), thus it will be main focus in order to complete this project.

2.6 CONTINUOUSLY VARIABLE TRANSMISSION (CVT)

Continuously Variable Transmission (CVT) as a typical automatic uses four or five such gears, while a manual normally employs five or six. The continuously variable transmission replaces discrete gear ratios with infinitely adjustable gearing through one of several basic CVT designs. In his research, he is focusing on 3 different types of CVT which are: (M. Anand Partheeban, 2011).

a. Push Belt
b. Toroidal Traction-Drive
c. Variable Diameter Elastomer Belt

2.6.1 Push Belt

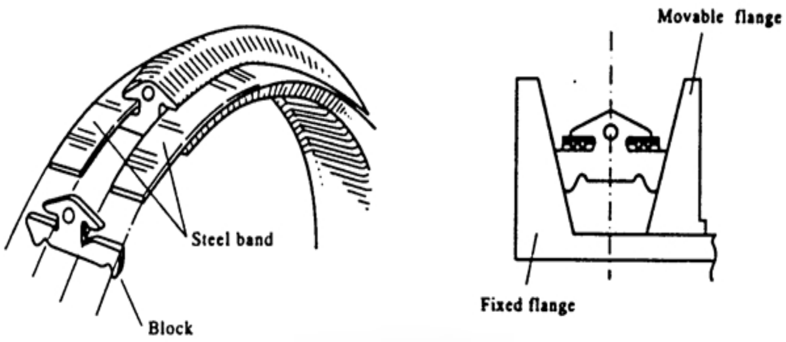


Figure 2.4: Most common type of CVT uses segmented steel blocks stacked on a steel ribbon

Source: M. Anand Partheeban (2011)

Generally, this belt transmits power between two conical pulleys, or sheaves, one fixed and one movable. A sensor reads the engine output and then electronically increases or decreases the distance between pulleys, and thus the tension of the drive belt. The continuously changing distance between the pulleys ratio to one another is analogous to shifting gears (M. Anand Partheeban, 2011).

2.6.2 Toroidal Traction-Drive

These transmissions use the high shear strength of viscous fluids to transmit torque between an input torus and an output torus. As the movable torus slides linearly, the angle of a roller changes relative to shaft position. This results in a change in gear ratio (M. Anand Partheeban, 2011).

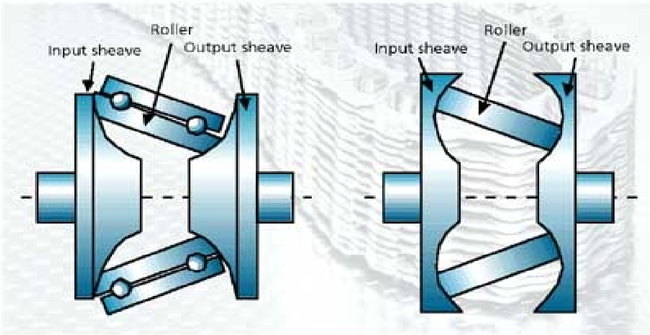


Figure 2.5: Change in gear ratio.

Source: M. Anand Partheeban (2011)

2.6.3 Variable Diameter Elastomer Belt

This type of CVT uses a flat, flexible belt mounted on movable supports. These supports can change radius and thus gear ratio. However, the supports separate at high gear ratios to form a discontinuous gear path, as seen in Figure below. This can lead to the problems with creep and slip that have plagued CVTs for years. This inherent flaw has directed research and development toward push belt CVTs (M. Anand Partheeban, 2011).

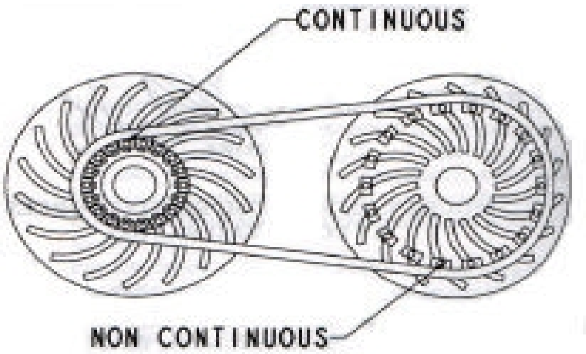


Figure 2.6: Variable Diameter Belt CVT

Source: M. Anand Partheeban (2011)

CVT constantly changes its gear ratio to optimize engine efficiency with a perfectly smooth torque-speed curve. This improves both gas mileage and acceleration compared to traditional transmissions. In his research, clearly can be summarize the advantages and disadvantages of CVT. Those are;

Table 2.4: Advantages and disadvantages of CVT

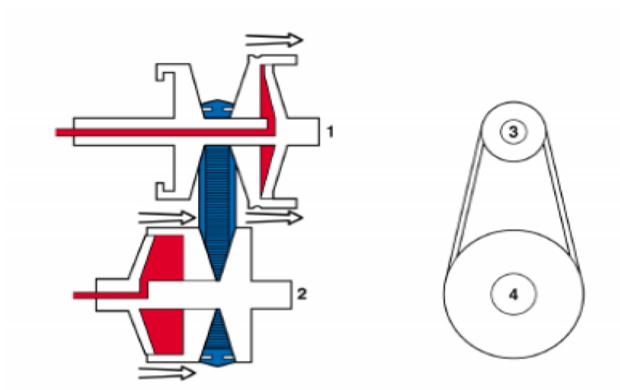
Advantages	Disadvantages
Better fuel consumption than a regular automatic transmission as the CVT is able to keep the car in its optimum power range regardless of speed. There is improved acceleration due to the lower power loss experienced	Driving a vehicle with a CVT is a very different experience and many drivers to not like it because you do not feel the engine accelerating; you do not feel any shifts instead you feel the engine racing as it would with a slipping clutch or a failing transmission which is just the CVT adjusting to provide optimal power.
Stepless transmission	Higher cost
It has the ability to allow the engine to rev almost immediately which delivers maximum torque.	Belt-driven CVTs (VDP system) have a limited amount of torque; however the technology is constantly being improved.
Provides a smoother ride than automatic transmission	Transmitting motion by friction causes greater wear. Require special oil and other materials
The hydraulic motor of the Hydrostatic CVT can be mounted directly onto the wheel hub and this allows for a more flexible suspension system and this in turn eliminates efficiency losses due to the friction from the driveshaft.	

Source: Kevin R. Lang (2000)

2.7 BASIC PRINCIPLES OF CONTINUOUSLY VARIABLE TRANSMISSION

The CVT is an automatic transmission that uses two pulleys with a steel belt running between them. To continuously vary its gear ratios, the CVT simultaneously adjusts the diameter of the “drive pulley” that transmits torque from the engine and the “driven pulley” that transfers torque to the wheels.

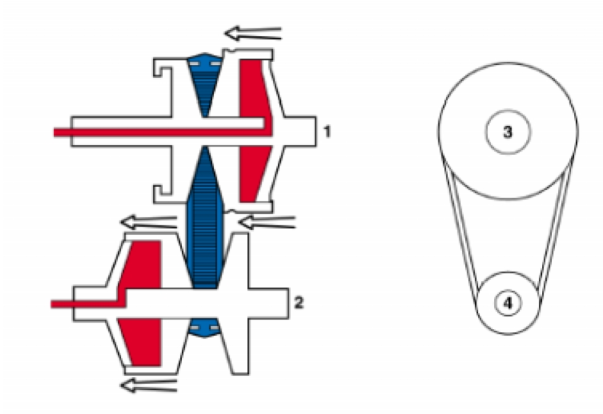
It uses a primary pulley and a secondary pulley. By comparison, the “drive pulley” diameter being relatively small, while the “driven pulley” diameter is large. Both pulleys have one fixed half and one mobile half, controlled by hydraulic pressure. The position of the drive belt on the pulleys will determine the ratio. If the mobile half of the pulley is close to its opposite half then the drive belt is forced to travel around the outer circumference. When the pulley is open wide then this circumference is reduced. The primary and secondary pulley mobile halves are diagonally opposed so when the drive belt diameter is reduced on the primary pulley, it increases on the secondary pulley (Mohammad Azlan Bin Abdul Aziz, 2010).



1 Input from the engine
2 Output to the wheels
3 Drive pulley at minimum diameter (Low)
4 Driven pulley at maximum diameter (Low)

Figure 2.7: Pulleys in low position

Source: Mohammad Azlan Bin Abdul Aziz, (2010).



1 Input from the engine
2 Output to the wheels
3 Drive pulley at minimum diameter (Overdrive)
4 Driven pulley at maximum diameter (Overdrive)

Figure 2.8: Pulley positions in high ratio (overdrive)

Source: Mohammad Azlan Bin Abdul Aziz, (2010).

The drive belt is used to transmit power and torque. To pull away, a low ratio is required. To provide this, the primary pulley is open, allowing the drive belt to sit down into the pulley and forcing it to run around the outer of the closed secondary pulley. As vehicle speed increases, a higher gear ratio is required.

To do this, the primary pulley gradually moves towards its fixed partner, increasing the pulley circumference. At the same time the secondary pulley is forced apart reducing pulley diameter, therefore creating a higher gear ratio. An overdrive ratio is obtained when the primary pulley is fully closed and the secondary pulley is fully open. The secondary pulley is now forced to rotate approximately two and a half time for every turn of the primary pulley. As acceleration takes place it becomes possible to select a higher ratio by increasing the diameter of the drive pulley while, at the same time, decreasing the diameter of the driven pulley. This degree of change can be controlled to ensure that the most suitable ratio is provided (Davy Geuns, June 2003).

HEV will have both electric and gasoline power systems. The concept explored here is to couple the two sources of power into one that is combined in a way that will make the overall system perform as a single unit that is transparent to the driver and provide comparable response to the vehicle with no additional controls. In fact, it would be advantages if the system were completely automatic except for special circumstances such as mountain ascent and descent. The chosen component for this integration is a mechanical Continuously Variable Transmission (CVT). Of course, other kinds of CVT's can be considered such as electric and hydraulic, but because of efficiency, durability, noise, simplicity, and most importantly, cost, the mechanical CVT is considered the best choice

2.8 PLUG-IN HYBRID-ELECTRIC MOTORCYCLE DRIVETRAIN

Next, as a reference for my project, study has been made on Hybrid-Electric Motorcycle Drivetrain. According to Kuen-Bao Sheu and Tsung-Hua Hsu, the proposed motorcycle hybrid system, consists of a gasoline engine, an electric motor, a transmission, a power inverter, and an electronic controller (Kuen-Bao Sheu and Tsung-Hua Hsu, 2005).

The transmission connects the ICE, the EM, and the rear wheel of the motorcycle. The transmission is made up of a mechanical type rubber V-belt CVT with a shoe-type centrifugal clutch (engine clutch), two chain drives with two one-way clutches, and a final drive consisting of two gear-pairs. The EM can function as an EM or a generator, according to the driving condition and battery power levels. The electronic controller receives commands from the driver and feedback signals from sensors to select the operating mode and to decide how much power is needed to drive the wheels and how much to charge the battery (Kuen-Bao Sheu and Tsung-Hua Hsu, 2005).

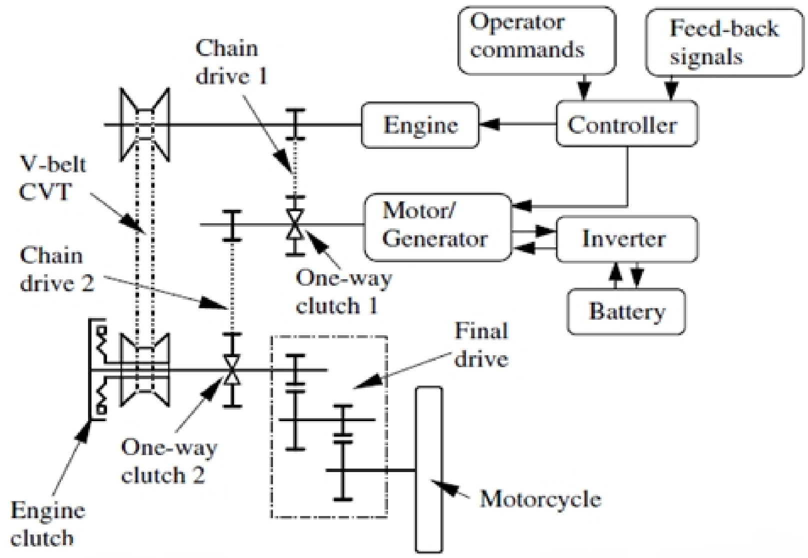


Figure 2.9: Schematic diagram of the hybrid-electric motorcycle drivetrain

Source: Kuen-Bao Sheu and Tsung-Hua Hsu (2005)

The proposed hybrid power system can operate in four different modes to maximize the performance and reduce emissions: (1) electric motor mode; (2) engine modes 1 and 2; (3) engine/charging mode; and (4) power mode (Kuen-Bao Sheu and Tsung-Hua Hsu, 2005).

a. Electric Motor Mode

As in start-up or low-speed situation, the electric motor converts chemical energy stored in the battery to drive the motorcycle while the gasoline engine is shut down to reduce emissions. As shown in Fig. 1, the electric motor transmits power via the chain drive 2 and the final drive alone powers the motorcycle by engaging the one-way clutch 2, whereas the one-way clutch 1 and engine clutch are disengaged (Kuen-Bao Sheu and Tsung-Hua Hsu, 2005).

b. Engine mode 1 and mode 2

During moderate and high speeds, the engine clutch is disengaged and both the one-way clutches 1 and 2 are engaged to operate the engine mode 1. Here, the engine alone drives the motorcycle via the chain drive 1 and 2 and through the final drive. As the engine speed increased, the engine clutch engaged and the one-way clutch 2 is automatically disengaged. Here, the engine alone drives the motorcycle through the rubber V-belt CVT and the final drive to operate the engine mode 2. If a higher speed of the shift point from the electric motor mode to the engine mode is selected, the engine mode 1 can be automatically discontinued. In addition, since the engine and the electric motor output shaft are coupled with chain drive 1, the EM can be switched into a neutral mode to allow the EM output shaft to spin freely (Kuen-Bao Sheu and Tsung-Hua Hsu, 2005).

c. Engine / Charging Mode

During moderate or high-speed cruising, both the magnetic clutch and one-way clutch 1 are engaged and the one-way clutch 2 is disengaged. Part of the engine power is transmitted to the motorcycle through the rubber V-belt CVT and the final drive, and the other part to the EM via the chain drive 1 and one-way clutch 1. If the battery power is low, the EM is switched into the generator mode for charging the battery. Since the engine can be operating under high-load conditions, by reducing the low-load driving time in this operating mode, the hybrid system has less fuel consumption (Kuen-Bao Sheu and Tsung-Hua Hsu, 2005).

d. Power Mode

When climbing hills, the motorcycle is operated in a power mode. Here, the electric motor power via the one-way clutch 2 and the engine power through the rubber V-belt CVT are coupled together to drive the motorcycle simultaneously (Kuen-Bao Sheu and Tsung-Hua Hsu, 2005).

2.9 TORQUE COUPLER / MECHANICAL COUPLING

Physically, a torque coupler are two torque sources combine their torques to provide mechanical power output to a drivetrain component such as the gearbox or final drive (Antonio Sciarretta and Lino Guzzella, 2007).

The coupling device could be a chain drive, a belt drive, or a gearbox. Occasionally, in parallel HEVs, the ICE and the EM drive separate sets of wheels. Hence, the two torques are coupled through the road. This type of parallel HEV provides all-wheel drive capability (Chirag Desai, 2010).

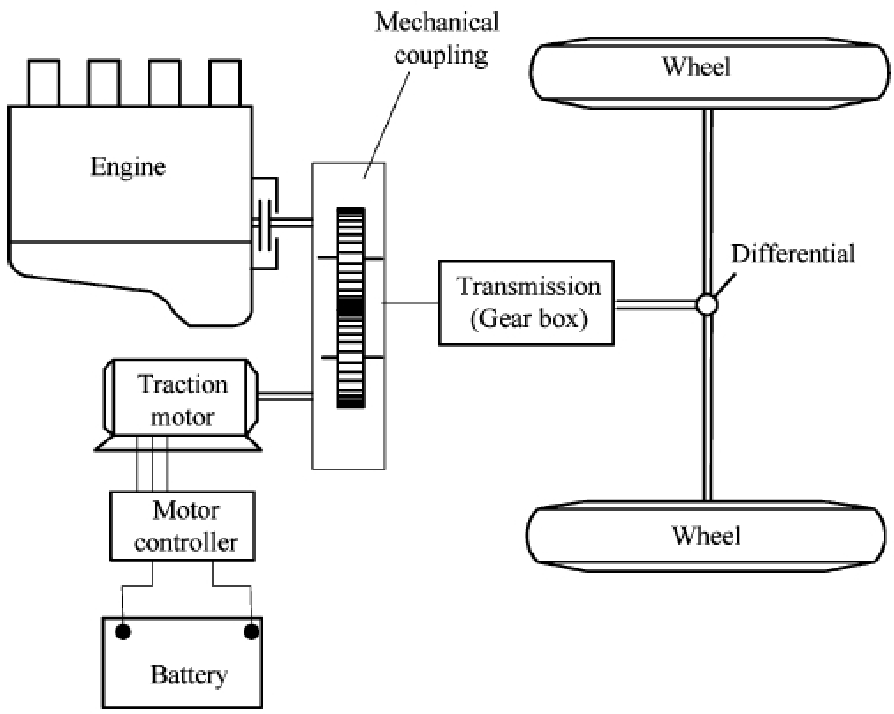


Figure 2.10: Mechanical coupling hybrid drivetrain

Source: Yimin Gao and Mehrdad Ehsani (2006)

In a mechanical coupling hybrid drivetrain, two power sources may be coupled together by either torque or speed. The typical torque coupling is a shaft-fixed gear set as shown in Figure 2.11 below.

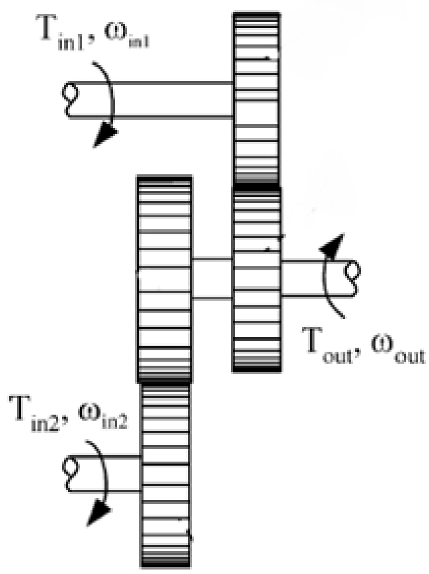


Figure 2.11: Example gear set as torque coupler

Source: Yimin Gao and Mehrdad Ehsani (2006)

In hybrid drivetrain, when an ICE is connected to input 1, an EM to input 2, and driven wheels to the output, the EM torque can be used to adjust the ICE torque to meet the wheel torque requirement. Thus, the engine can be operated with its optimal torque. Most parallel (torque coupling) hybrid drivetrains employ this principle (Yimin Gao and Mehrdad Ehsani, 2006).

2.10 GOVERNING EQUATION

2.10.1 Power Required

Theoretically, output maximum speed for Modenas Jaguh Engine that going to be used in this project is 133 km/h @ 36.94 m/s. Therefore, after having the new drivetrain system for this project, it is important for me to calculate the actual maximum speed that can be achieved, and having modification on the choosing gear diameter criteria before start with fabricating process.

To calculate actual maximum speed, the most important thing is to analyze the most accurate size for diameter of gear in drivetrain system. This is because the power distribution from ICE and EM is being transferred to the final drive through drivetrain gearing and shaft system.

Thus, power distributions also need to be calculated. The following formulas are used to estimate the power motor (Dennis Doerffel and Suleiman Abu Sharkh, 2006).

$$P_{mot}(grad,v)=\frac{P_r(v)+P_{air}(v)+P_{grad}(grad,v)}{\eta_{mech}} \tag{2.1}$$

Rolling resistance: $$P_r(v)=C_r.m_{max}.g.v \tag{2.2}$$

Air drag: $$P_{air}(v)=C_d.A_f.\frac{1}{2}.z.v^3 \tag{2.3}$$

Power demand for gradient: $$P_{grad}(gradient,\ v)=m_{max}.g.v.\sin(\arctan\frac{gradient}{100}) \tag{2.4}$$

Total Power Required (Blended mode hybrid) = Power ICE (2.5)

Based on Eq. (2.5), total power required is equal with power ICE, this is due to total power for blended mode is based on highest power supply source which is from ICE.

2.10.2 Tangential Speed Formula

Basically, this formula is used to determine final velocity for the final drive (wheel). This can be done by calculating velocity and angular velocity using transfer rotation method. Details about the calculation will be discussed in Chapter 4 (Dennis Doerffel and Suleiman Abu Sharkh, 2006).

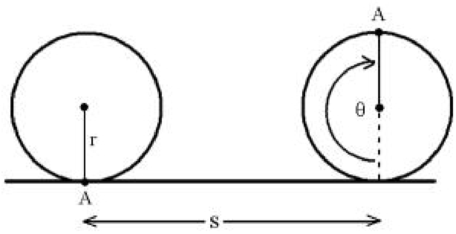


Figure 2.12: Tangential distance diagram

Where tangential distance, $s = r\theta$, (2.6)

Above equation is used and the defining equation of angular velocity to determine a relationship between linear and rotational velocity. To do this we consider a wheel rotating with constant angular velocity ω as it moves to the right with linear velocity v.

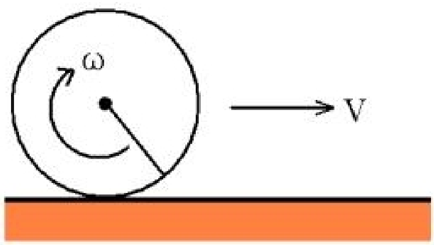


Figure 2.13: Wheel rotating with constant angular velocity with linear velocity

Define speed of any point on the rim of the wheel as the tangential speed, v_t, and clearly, all points on the rim of the wheel have the same tangential speed. Furthermore, it should be obvious that the tangential speed is equal to the linear velocity v of the wheel.

The angular velocity of the wheel is defined by $\omega = \frac{\theta}{t}$

θ, is the angular displacement in time t and it is related to the distance the wheel travels by s = rθ. Substituting $\theta = \frac{s}{r}$ into this equation we have

$$\omega = \frac{\theta}{t} = \frac{s/r}{t} = \frac{s}{t} \times \frac{1}{r} \qquad (2.7)$$

But s/t is the linear velocity of the wheel that we have seen is also equal to the tangential velocity of any point on the rim of the wheel. So

$$\omega = v\,\frac{1}{r} \qquad \text{Or} \qquad v = r\omega \qquad (2.8)$$

CHAPTER 3

METHODOLOGY

3.1 CONCEPTUAL STUDY DEVELOPMENT

Conceptual Study of Development of Plug in Hybrid Electric Drivetrain System is an important stage in my area of study. At this stage, the necessary part is to plan about the projects requirements, literature studies and schedules in order to get more information regarding this title. All the materials are collected from journal, reference book and research papers gathered from libraries and Internet.

As title for this project is Development of Plug in Hybrid Electric Drivetrain System, it is important to do research study within the boundary of the topic. Once clear with the title, next step is to find out the related component and equipment to be used.

While planning, it is compulsory to do the research about the project related, which including study about the drivetrain component such as CVT, Clutch and Alternator. The study is not just for the function of the component but the types of component available, thus searching the most suitable component for this project.

3.2 CONCEPTUAL DRIVETRAIN DESIGN DEVELOPMENT

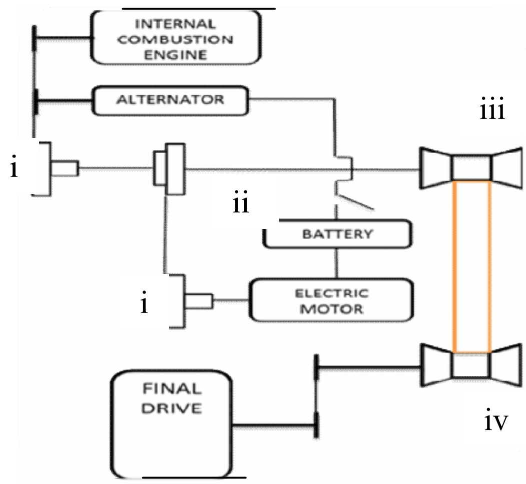
3.2.1 Drivetrain configuration

In order to achieve right configuration, several drawing has been made and discussed. Main concept need to be developed is that it must have two power sources as input, and got one output before reach final drive.

Components involved to complete a drivetrain system are two power sources which is the ICE and EM, an alternator, battery, magnetic clutch, one way clutch, gear sets, transmission, sprockets, chains and rear tire.

3.2.1.1 First configuration

Rejected due to the configuration design did not satisfy two input and an output mechanism. Other weakness of this configuration is difficulties to combine rotation from two power sources with a one way clutch. Major modification on one way clutch needed in order to make sure this configuration is a success. Figure 3.1 below shows the first configuration drawing for hybrid motorcycle drivetrain.



i. Magnetic clutch
ii. One way clutch
iii. CVT driver
iv. CVT driven

Figure 3.1: First drivetrain configuration

3.2.1.2 Second configuration

At first, this concept idea for this drivetrain configuration is accepted. This is because the configuration use mechanical coupling or torque coupler to solve first configuration problem. Mechanical coupling concept idea has been discussed in Chapter 2.9 literature review section.

But this configuration got switching mode problem for ICE mode. The magnetic clutch is not in same shaft with ICE, but at alternator. One of alternative is that the magnetic clutch needs to combine with one way clutch. Due to this issue, some modifications need to be done on both component design and also restudy the right position for magnetic clutch. Figure 3.2 below shows second configuration model.

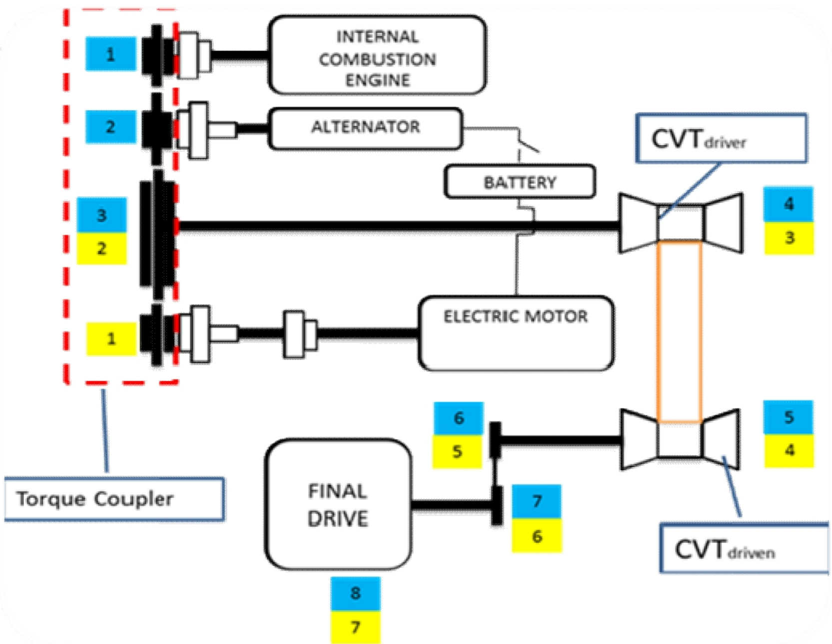


Figure 3.2: Second drivetrain configuration

3.2.1.3 Final Drivetrain Configuration

After analysing second configuration, some change has been made to ensure there will be no problem to switch between mode, especially ICE mode. The design is accepted, thus, next step is to analyse gearing diameter, find out its final drive velocity for both ICE mode and EM mode. Figure below shows final configuration for hybrid drivetrain system.

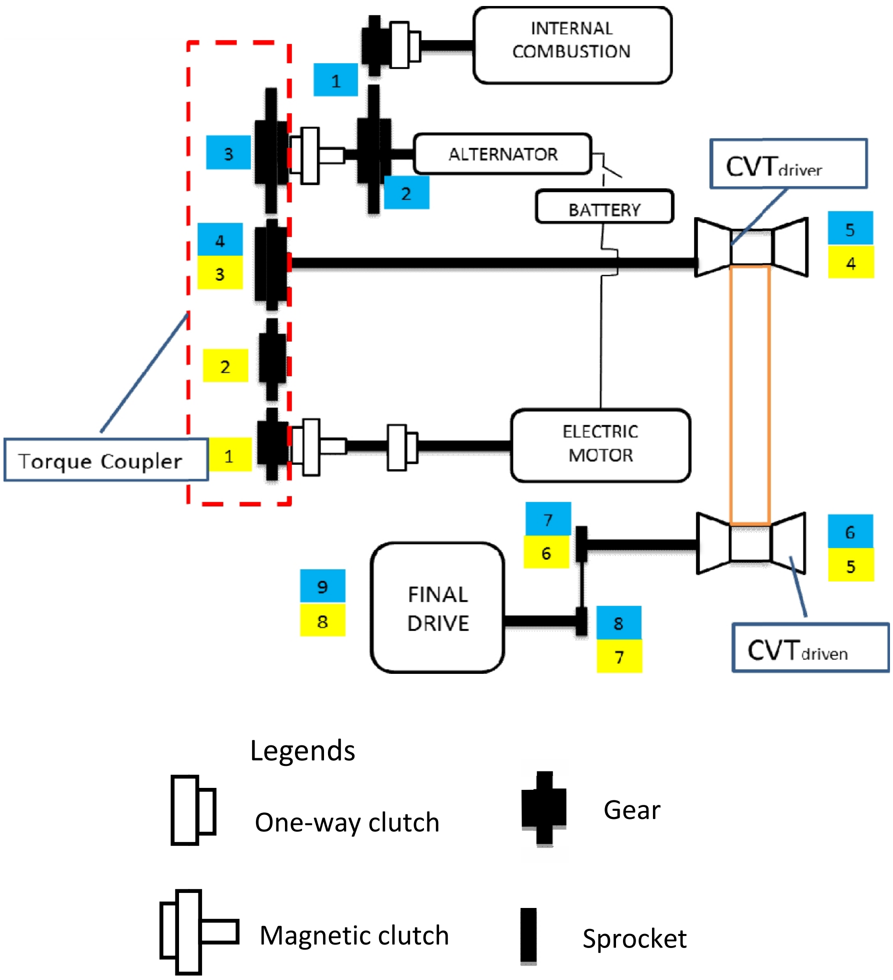


Figure 3.3: Plug-In Hybrid Motorcycle Drivetrain Configuration

The figure above shows finalizes conceptual design of drivetrain mechanism. There were two magnetic clutches, two one-way clutches, gearing act as torque coupler and sprocket. Magnetic clutch act as an actuator for operation modes changing process so that the clutch engage, hence transferring the power from ICE, or from the EM and finally to the final drive.

While for the one-way clutch, it functions to prevent reverse rotation and act as a safety actuator for the EM and ICE. The one-way clutch has been designed to perform slip functions in one direction while performing engagement in the opposite direction. Thus, it protects the EM from being turned by the ICE where the revolution per minute of the ICE is actually higher than the EM, and vice versa.

Next component is Alternator. The alternator consists of a spinning set of electrical windings called a rotor, a stationary set of windings called a stator, a rectifier assembly, a set of brushes to maintain electrical contact with the rotor, and a pulley. It generates direct current for recharging the battery and for powering vehicle electrical loads.

3.3 DRIVETRAIN OPERATING MODES

There are four operating modes in between of the primary power source (ICE) and secondary power source (EM), those modes are:

3.3.1 Electric motor mode

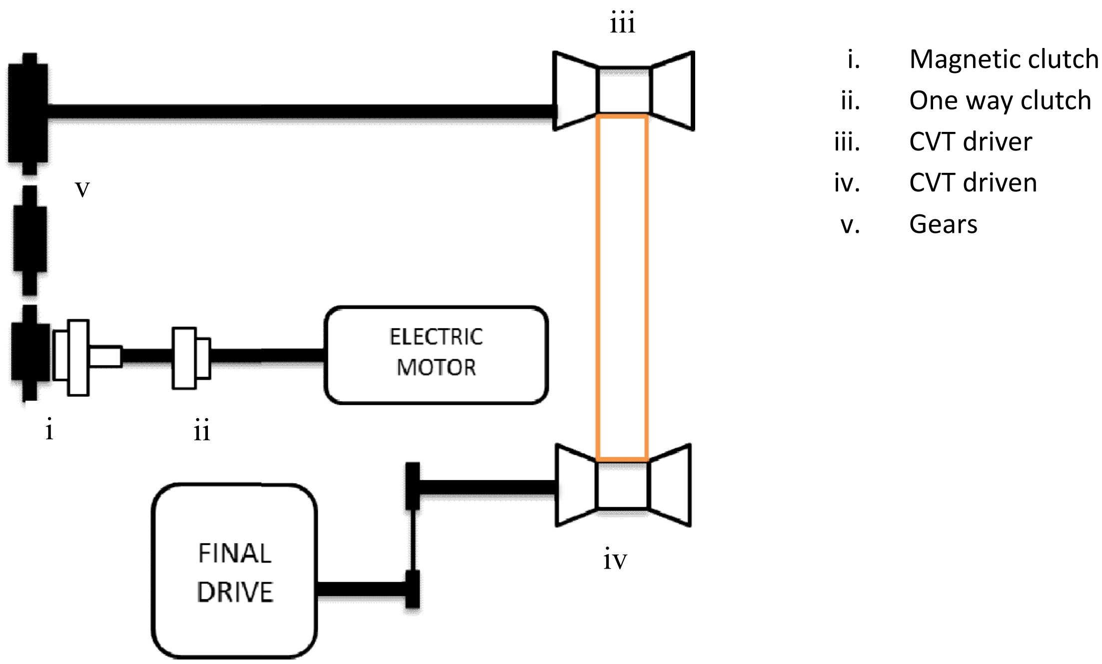


Figure 3.4: Electric motor mode mechanism

This configuration mode also called as lower operating mode. At startup, the Hybrid Electric Motorcycle will operate in EM mode. During this mode, the main power source comes from EM. The component involve during this mode are EM, magnetic clutch, one-way clutch, CVT and final drive. During this mode, magnetic clutch at EM will engage, while the ICE will be protected from EM rotation by one-way clutch.

3.3.2 Internal Combustion Engine mode

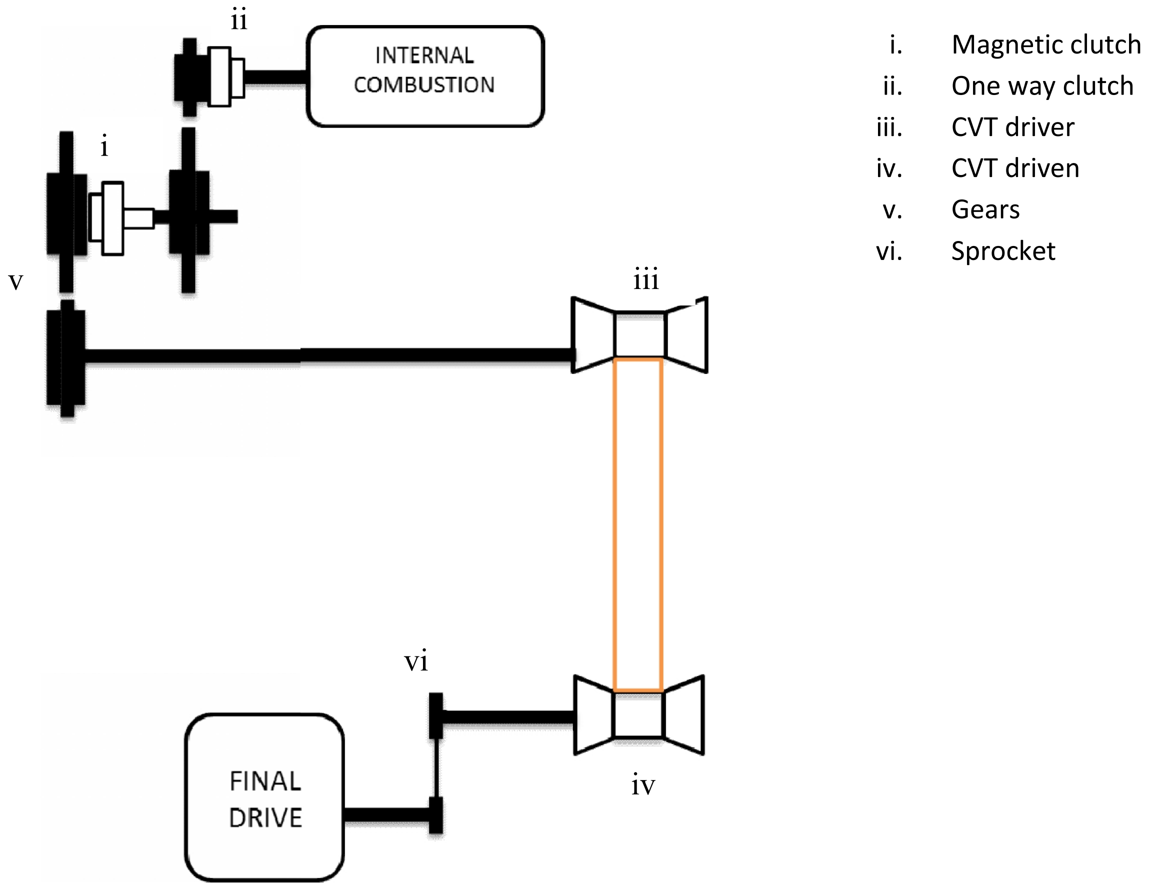
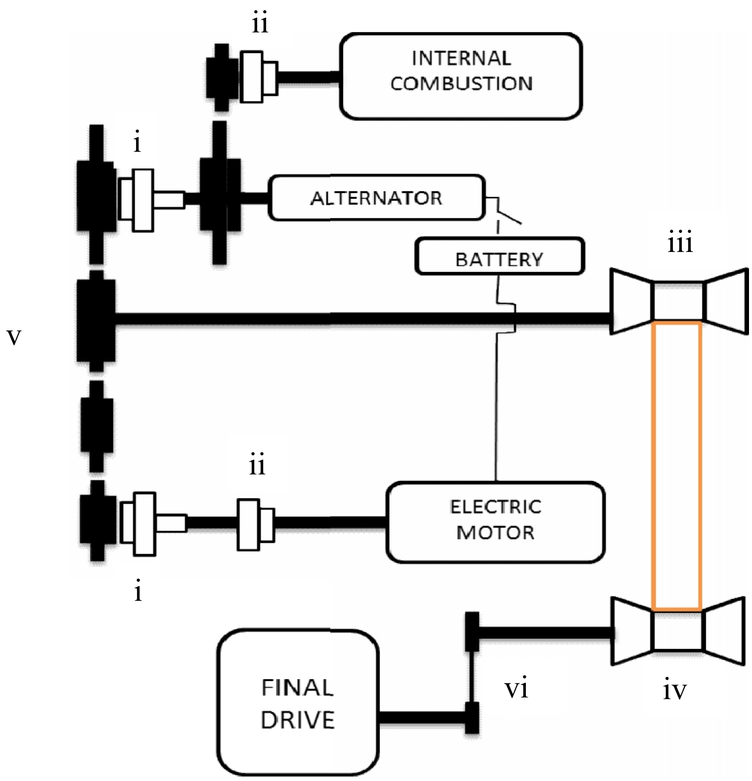


Figure 3.5: Internal Combustion Engine mode mechanism

For this mode, it will switch on at a specific speed which will be controlled by control module. Component involve are one-way clutch, magnetic clutch, CVT and final drive. The main source for this mode is ICE, thus will give more power to the motorcycle compared to EM. During this mode, magnetic clutch at EM will disengaged, thus protecting the motor from damage due to ICE rotation.

3.3.3 Blended mode



i. Magnetic clutch
ii. One way clutch
iii. CVT driver
iv. CVT driven
v. Gears
vi. Sprocket

Figure 3.6: Blended mode mechanism

Blended mode mechanism will be activated when additional torque needed in order for the vehicle to climb uphill road. During this mode, both ICE and EM will functioning and supply more power to the final drive. Both magnetic clutches will engaged the same goes to one-way clutch. Other than supplying power to the final drive, the ICE will function as a generator to charge up the battery to prevent battery running out.

3.3.4 Idle mode

During idle mode, when the vehicle is not moving, both ICE and EM are turned off so that energy will not be wasted. At this moment, only battery continues to power up the auxiliary system such as headlamp, signal lamp, dashboard display and so on.

3.4 DRIVETRAIN COMPONENTS.

3.4.1 Drivetrain Components Selection

The components for this project are based on the drivetrain mechanism diagram (Figure 3.1) where all the components related have been ready at Solar House. Picking the right components is very important. Many criteria should be taken into consideration such as function, dimension, capacity, cost and many more. This is because every part plays their own role in order to make sure the drivetrain functioning very well, changing between modes smoothly and efficiently. Below are the lists of the entire components and the other material that will assemble to complete this project

a. Continuous Variable Transmission (CVT)
b. Internal Combustion Engine (ICE)
c. Electric Motor (EM)
d. Alternator
e. Magnetic clutch
f. One way clutch
g. Sprocket

Next stage is components modification. There are some components need to modify in order to make sure the drivetrain system functions very well. Basically there are two main components need to modified which are

a. Magnetic clutch and gear
b. One-way clutch and gear

3.4.2 Drivetrain Components modification

a. Magnetic clutch + gear

This component will be assembling at two power sources which are ICE and EM. Magnetic clutch will engaged and disengaged depends on mode needed. Figure below shows assembled magnetic clutch with gear.

Figure3.7: Assembled magnetic clutch and gear

b. One-way clutch + gear

This component will be installing at ICE driveshaft where the assembled gear will connect direct with gear from alternator driveshaft. Main purpose of this component is to protect the ICE when the hybrid motorcycle runs with EM mode, and also blended mode.

Figure3.8: Assembled one-way clutch and gear

All machining process is made in faculty laboratory with help of laboratory assistant. The process to modify must be done neatly according to the dimensions and drawing in order to reduce lost in term of cost and time.

3.4.3 Drivetrain Construction

The construction part of drivetrain mechanism already started. But for my scope, will be focusing more on final drivetrain configuration, with complete drawing, some modification and mounting on chassis for the drivetrain components.

But, for the software part, Solidwork 3D modeling software is used. In Solidwork, The project using it to construct 3D drawing for each component of drivetrain system. Every dimension need to be measured, and then drawn the components in Solidwork. When some components need to be assembled, for example, assemble drivetrain component with chassis, they may not match. In this case, the work should be redone. Following are some components which are drawn in Solidwork.

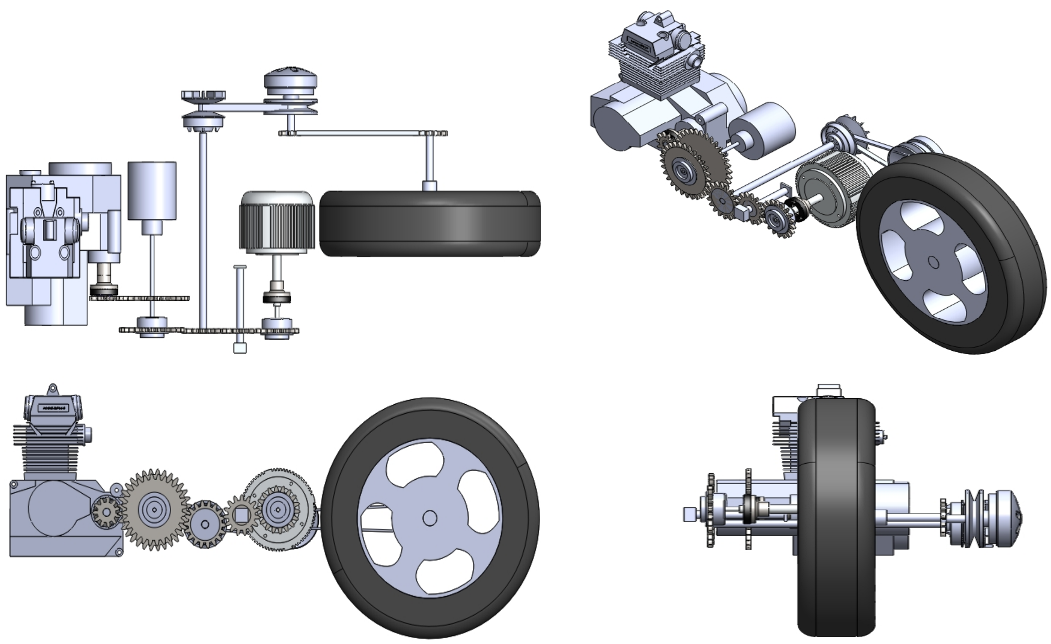


Figure 3.9: Four different view of final drivetrain configuration drawing

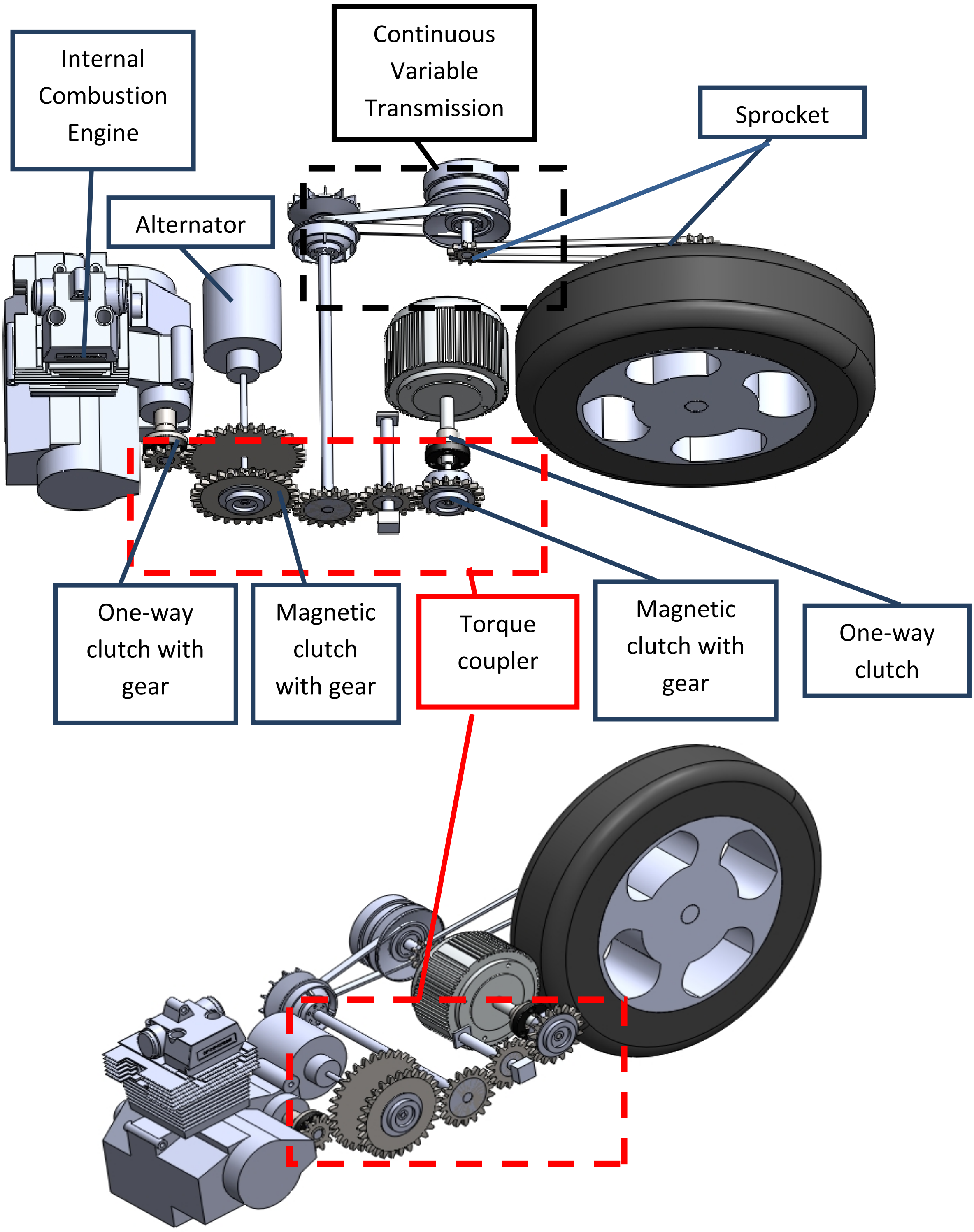


Figure 3.10: Drivetrain components close-up

CHAPTER 4

RESULT AND DISCUSSION

Before assemble the drivetrain components, some analysis need to be done to ensure it can achieve final speed requirements for each mode, and also power and torque required for the hybrid motorcycle. Next, for the final speed, comparison is made between normal calculation and results using Matlab.

4.1 Final Speed

4.1.1 Governing equation calculation

Based on eq. (2.8) from Chapter 2.10.2 which is $v = r\omega$, final speed for ICE mode and EM mode is calculated. Based on final drivetrain configuration, power value for ICE is obtained from Modenas brochure which is 8500 RPM, but after considering load from driver and motorcycle components, only take +- 38% from the total ICE power which is 3245 RPM.

Table 4.1: Modenas Jaguh 175 cc Specifications.

Items	Specifications
Max Power	16 PS (11.8 kW) @ 8,500 rpm
Max torque	13.7 N·m @ 7,500 rpm
Bore x stroke	65 x 52.4 mm
Dry weight	132 kg
Max speed	About 133 km/h

Source: Modenas.com.my

Take note that if rotation transferred through direct gearing, value for velocity, V is constant. While if rotation transferred through rotating shaft, angular velocity, ω is constant. Figure below shows full calculation of speed.

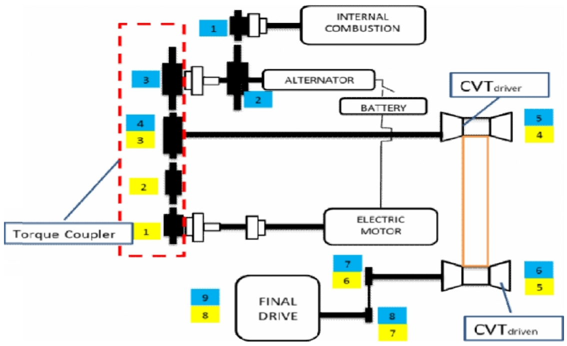


Figure 4.1: Labeled drivetrain configuration

Table 4.2: Velocity calculation for internal combustion engine (ICE)

ICE mode	No	Radius(m)	ω(rad/s)	ω(RPM)	V(m/s)	V(km/hr)
Gear + one way clutch	1	0.038	340.00	3245.45	12.92	46.51
Gear	2	0.100	129.20	1233.27	12.92	46.51
Gear+ magnetic clutch	3	0.090	129.20	1233.27	11.63	41.86
Gear	4	0.060	193.80	1849.91	11.63	41.86
CVTdriver	5	0.050	193.80	1849.91	9.69	34.88
CVTdriven	6	0.045	215.33	2055.45	9.69	34.88
Sprocket	7	0.033	215.33	2055.45	7.11	25.58
Sprocket	8	0.095	74.80	714.00	7.11	25.58
Final drive	9	0.300	74.80	714.00	22.44	80.78

Table 4.3: Velocity calculation for electric motor (EM)

EM mode	No	Radius(m)	ω(rad/s)	ω(RPM)	V(m/s)	V(km/hr)
Gear + magnetic clutch	1	0.055	157.14	1500.00	8.64	31.11
Gear	2	0.050	172.86	1650.00	8.64	31.11
Gear	3	0.060	144.05	1375.00	8.64	31.11
CVTdriver	4	0.050	144.05	1375.00	7.20	25.93
CVTdriven	5	0.045	160.05	1527.78	7.20	25.93
Sprocket	6	0.033	160.05	1527.78	5.28	19.01
Sprocket	7	0.095	55.60	530.70	5.28	19.01
Final drive	8	0.300	55.60	530.70	16.68	60.05

For the first mode of this PHEV motorcycle, electric motor mode or also known as lower operating mode final velocity value is 60.05 km/hr. This means after 60.05 km/hr, it is compulsory to switch to second mode in order to achieve more speed. The next mode is ICE mode; the value of final speed is 80.78 km/hr.

For motorcycle to travel through slope road, additional torque is needed, thus blended mode will be activated in order to supply additional torque to the PHEV motorcycle.

4.1.2 MATLAB Simulink

4.1.2.1 Selecting Models to Simulate a PHEV

Each of the equations in the overall model is detailed and explained. Parameters that are controlled inputs of the model are:

- Throttle position - torque output of both the ICE and electric motor (0 - 100%)
- Initial Battery SOC - for all batteries (%)
- Initial speed of vehicle (km/h)
- Ratio of contribution from EM and ICE (stealth mode...etc.)

Each input aspect of the model is directly controlled by the user. As a result of the input parameters and constant parameters of the entire PHEV system, the model contains vehicle speed (km/hr) as output.

Vehicle speed output, calculated by the system equations, is plotted in the Simulink programming. Next, the result of the model simulations is compared to calculated data of speed. The speed output of the driveshaft in the automobile is found by the differences of the input torque of the ICE, EM and the torque output of the driveshaft, as seen in Eq. (4.1):

$$J\frac{dW_{shaft}}{dt} + fW_{shaft} = (T_{ice} + T_{em}) - T_{driveshaft} \tag{4.1}$$

where f is the friction coefficient of the shaft and J is the moment of inertia of the shaft. The ICE of the vehicle is modeled with equations describing the engine pressure, P_{ice}, and the torque output, T_{ice} and T_{em} as seen in Eq. (4.2), (4.3), and (4.4):

$$P_{ice} = m_{ice} k_{ice} W_{shaft} \tag{4.2}$$

$$T_{ice} = m_{ice} k_{ice} d_{gas} \tag{4.3}$$

$$k_{ice} = \frac{\eta r P_c}{\Omega_{ice\_max}} \tag{4.4}$$

where m_{ice} is the ratio of fuel into the engine, Ω_{shaft} is the shaft rotational speed and d_{gas} is the gasoline line flow. Each team for the engine pressure and torque output have the term k_{ice} where η is the efficiency of the ICE, ρ the gasoline density, P_c the calorific value of gasoline and Ω_{ice_max} the maximum rotational speed of the engine (Lohmme W., 2004).

The velocity of the vehicle is modeled with an equation that represents the normal force of the car, the inclined force of gravity, and drag against the force provided by the tires. The acceleration and velocity of the vehicle is described by Eq. (4.5):

$$m\frac{dv}{dt}=mgC_r\cos\varphi+\frac{1}{2}\rho_{air}C_dA_fv^2+mg\sin\varphi-F \tag{4.5}$$

where m is the mass of the vehicle, g is the acceleration of gravity, and Cr is the road coefficient (Lohmme W., 2004). The drag of the vehicle is described where ρ_{air} is the density of air, C_d is the vehicle drag coefficient and A_f is the frontal area of the vehicle. Eq. (4.5) allows the simulation of the vehicle dynamics with supplied force, F, from the driveshaft. The DC generators/ electrical motors of the vehicle is modeled using Eq. (4.6) below,

$$L\frac{di_{gen}}{dt} + Ri_{gen} = e_{gen} - e_{out} \tag{4.6}$$

where R_{gen} and L_{gen} are the resistance and inductance of the armature windings. The change in current is defined by the difference in voltage supplied in the motor/generator with the voltage out (Lohmme W., 2004).

Each model was used to represent the PHEV model. Combining the previously discussed equations into a Simulink model allowed simulations of the system to be run. The Simulink model will be show in Figure 4.2

4.1.2.2 Matlab model

This software is used to compare results obtain from calculation using governing equation. Using Eq. (4.1) until (4.6), all data and value of components, each parameters from component model obtain from the library must be completed in order to achieve results in form of graph velocity, V against time, t.

For example is Generic Engine model. These models parameters need to be completed before proceed to another model. Figure below shows example of Generic Engine model.

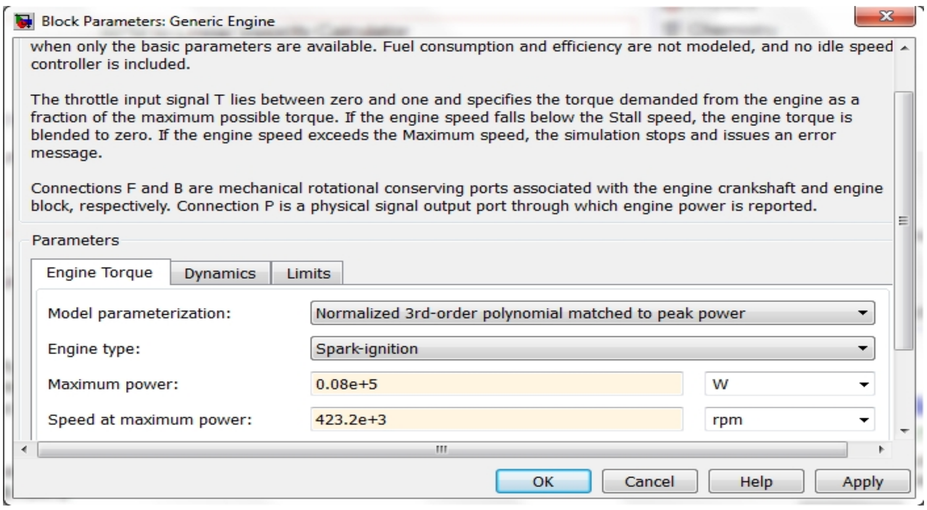


Figure 4.2: Generic Engine model parameter example

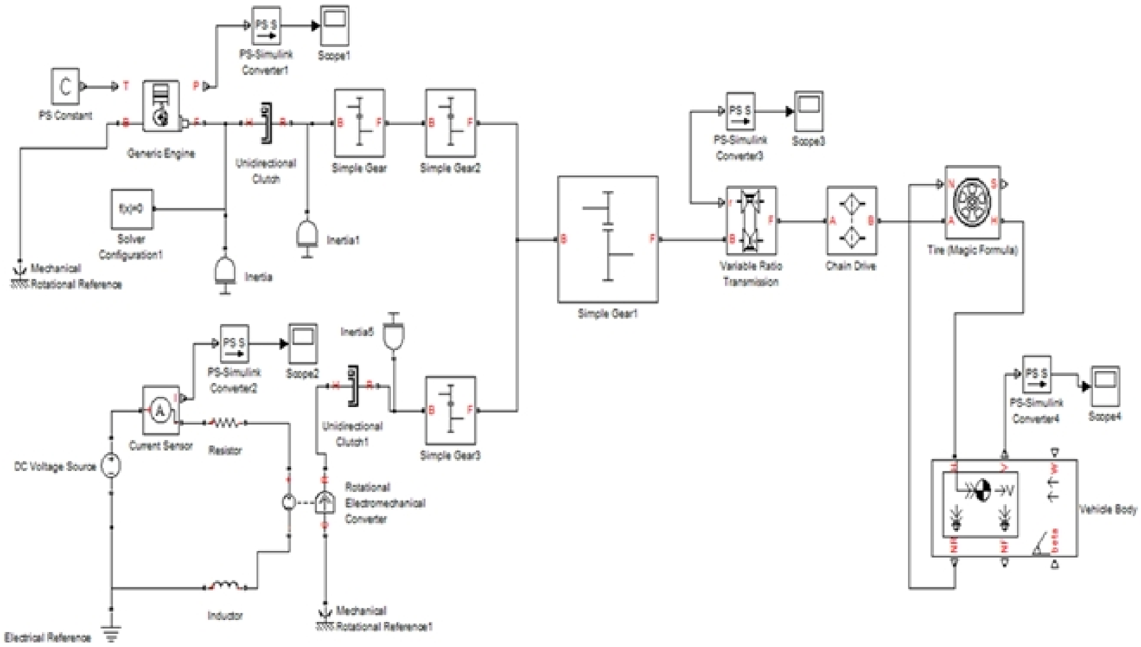


Figure 4.3: Drivetrain using MATLAB

Figure above shows complete model of Plug-in Hybrid Electric Motorcycle. It can be seen that the model having two power sources input which are EM and ICE and one output which is the final drive. In order to get result, after completing parameters needed in each model, scope at final drive will show the graph of velocity against time for EM mode and ICE mode.

Noted that if want to come out with EM mode graph, unidirectional clutch at EM must be locked while at ICE must be unlocked. The same goes if want to come out with ICE graph, unidirectional clutch at ICE must be locked and unlock the EM clutch.

4.1.2.3 Verification of Model

As previously mentioned, each individual modeling equation was verified against known data for Modenas Jaguh components. After individual verification of each component, the entire vehicle model was compared with calculated data. The two vehicle dynamic graphs show the velocity of the vehicle over a period of ten seconds for electric motor mode and nine seconds for internal combustion engine mode.

The velocity reaches nearly 60 km/hr in 10 seconds for electric motor and 80 km/hr for internal combustion engine mode which correlates pretty close to the calculated value shown previously

After done completion of all model parameters, results can be obtained from scope at final drive. Results are as shown below,

a. Electric motor mode

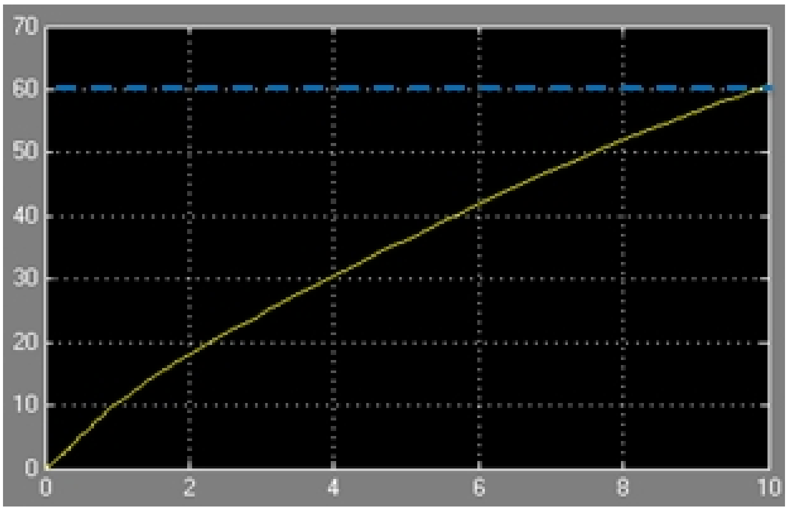


Figure 4.4: EM mode final velocity

b. Internal combustion engine mode

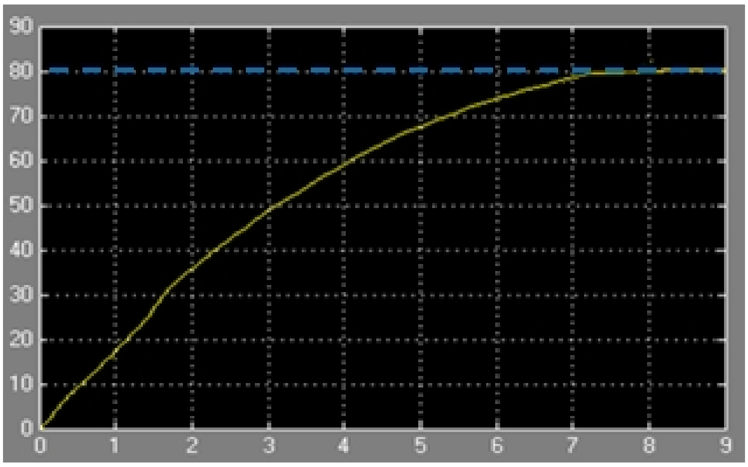


Figure 4.5: ICE mode final velocity

4.2 Power and Torque Required

4.2.1 Power Electric Motor

This can be calculated by using governing equation from Eq. (2.1), which is

$$P_{mot}(grad,v)=\frac{P_r(v)+P_{air}(v)+P_{grad}(grad,v)}{\eta_{mech}}$$

Where:

Rolling resistance: $P_r(v)=C_r.m_{max}.g.v$

Air drag: $P_{air}(v)=C_d.A_f.\frac{1}{2}.z.v^3$

Power demand for gradient: $P_{grad}(gradient, v)=m_{max}.g.v.\sin(\arctan\frac{gradient}{100})$

With constants:

Gravitational acceleration: $g = 9.81\ m/s^2$

Air density at 1 bar and 20 °C: $\zeta = 1.19\ kg/m^3$

Mechanical drivetrain efficiency is assumed to be on average $\eta_{mech} \approx 0.9$

Maximum Gradient on Malaysia Highways : Gradient = 7%

The chosen motorcycle has the following body attributes:

Air drag coefficient	$C_d = 0.5$	(Bruce Reeve, 2010)
Frontal area	$A_f = 0.6\ m^2$	(Bruce Reeve, 2010)
Tire rolling coefficient	$C_r = 0.009$	(Bruce Reeve, 2010)
Maximum mass	$m_{max} = 250kg$	

$$P_r(v) = C_r m_{max} g v$$
$$P_r(v) = (0.009)(250)(9.81)(16.67)$$
$$P_r(v) = 367.95$$

$$P_{air}(v) = C_d . A_f . \frac{1}{2} . z . v^3$$
$$P_{air}(v) = (0.5)(0.6)(\frac{1}{2})(1.19)(16.67)$$
$$P_{air}(v) = 826.88$$

$$P_{grad}(\text{gradient}, v) = m_{max} . g . v . \sin(\arctan \frac{\text{gradient}}{100})$$
$$P_{grad}(\text{gradient}, v) = (250)(9.81)(16.67)\sin(\arctan \frac{7}{100})$$
$$P_{grad}(\text{gradient}, v) = 2854.84$$

$$P_{mot}(\text{grad}, v) = \frac{367.95 + 826.88 + 2854.84}{0.9}$$
$$P_{mot}(\text{grad}, v) = 4499.63\ W$$
$$P_{mot}(\text{grad}, v) = 4.49\ kW$$

Thus, Power required for EM = 4.49kW

4.2.2 Torque Electric Motor

$$\text{Torque, } \tau = \frac{P}{\omega}$$

Where P is power required from electric motor and ω is angular velocity at final drive

Thus, $$\tau = \frac{4.49 \times 10^3}{530.70} = 8.49 \text{ N.m}$$

4.2.3 Power and Torque Internal Combustion Engine

Since engine used for the PHEV motorcycle is Modenas Jaguh 175cc, the internal combustion engine power value can be obtained from table 4.1, it can be conclude that

Power for ICE, P_{ice} = 11.8 kW and

Torque for ICE, τ = 13.7 N.m

4.2.4 Total Power and Torque required for blended mode

During blended mode, more power is needed by the PHEV's motorcycle. This is because this mode usually being activate if the motorcycle is on slope road where more power is needed. The more the power, the higher will be the torque, thus supplying more torque so that the motorcycle will ride up along the slope with no problem.

Total Power Required (Blended mode hybrid) = Power ICE

= 11.8 kW

Total Torque Required (Blended mode hybrid) = Torque ICE

= 13.7 N.m

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

For the analysis based on finalize results and analysis, the drivetrain configuration is a success and can be implement. Instead of hunting power required and final velocity, safety precautions also has been main consideration in order to make sure there will be consequences from drivetrain configuration mechanism design. For example, during blended mode, either internal combustion engine or electric motor will be protected from being damage due to unbalance shaft rotation due to different power sources output.

Finally, at the end of this PHEV's motorcycle drivetrain project, it can be concluded that all of the objectives manage to be achieve. Final velocity of final drive for EM mode is 60.05 Km/hr, while for ICE is 80.78 Km/hr. In addition, proper power required also managed to be analyzed, which are 11.8 Kw, 4.5 Kw, and 11.8 Kw for ICE power, EM power and total power (blended mode) respectively. For the torque required, value for ICE torque is 13.7 Nm, EM torque is 8.49 Nm and torque for blended mode is 13.7 Nm. Next, for fabricating process, the project will be proceed by a Master student based on finalize drivetrain configuration, and will be help by me individually. This is because it is an honor for me to see the drivetrain configuration being assembled to the chassis of Plug-in Hybrid Electric Motorcycle.

5.2 Recommendation

For recommendation, in order to achieve higher velocity for each mode, diameter of gearing at torque coupler need to be adjusted. This is because consideration taken for this analysis is fix, but can be improve.

After complete assembling drivetrain components into the chassis system, testing and data collection from DAQ system is compulsory in order to improve drivetrain system.

With the development of new technologies, new simulations and experimental procedures with PHEVs can determine the economic feasibility of PHEVs and control strategies to optimize the power flow within the drivetrain of the vehicle.

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APPENDICES

Appendix A: Gantt Chart