DEVELOPMENT OF A LAB-SCALE HYBRID VEHICLE SYSTEM FOR SMALL GASOLINE ENGINE

ZAINUL AMEERUL IKHSAN BIN ZAINUL ABIDIN

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Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

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For my beloved wife, Nur Miza Liyana Bt Md Latef,
mother, Che Norma Binti Che Din,
and father, Zainul Abidin Bin Ismail,
and also for all family members.

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ABSTRACT

In a theoretical engine, during the combustion process, oxygen from the intake air would convert all the hydrogen and carbon contents in the fuel into water and carbon dioxide to prove it is in complete combustion. However, this situation never happens in the actual combustion then the usage electricity can solve the global warming issues contributed by the emissions produced from the IC engine by reducing the dependence of the operating system on fossil fuels. Electric vehicles, via electric motors (EM), give a high efficiency compared with internal combustion engines but at a lower average top speed. Combining these two types of systems will produce a hybrid electric vehicle (HEV) system that is able to produce higher efficiency and a moderate average top speed, as well as consuming less fuel. Thus, a hybrid vehicle system will reduce the emissions released, hence reducing the greenhouse effect. The development of a hybrid electric vehicle system, especially for a small gasoline engine. The process involved in the development of a small hybrid system is similar to other larger hybrid vehicle systems. However, the system is more compact in size and has no external gearing system or gearbox system. When developing this type of hybrid system, the drivetrain structure and the Implementing a hybrid system in the vehicle system today will contribute to the environment by decreasing the emissions released into the air. The small gasoline engine in this research refers to a single-cylinder internal combustion engine with capacity below 150 cc. The developed lab-scale hybrid system showed common properties that provided it with some advantages relative to conventional IC motorcycles. Lab-scale setup is design to mimic real-world development system and control perspective. This setup expected to improve overall process control education process because of the hands on experience on modelling, system identification, control design and implementation on an equipment which is closed to real world application. In this study, the performance of the electric motor was under rated. The hybrid system only can be tested in the small range of between 1500 rpm up to 3000 rpm. By using a higher-powered electric motor, better performance and emission characteristics can be obtained, hence showing a bigger picture of the performance of the hybrid system.

ABSTRAK

Pentingnya untuk mengkaji kecekapan sesebuah kenderaan agar mempunyai prestasi enjin yang lebih baik dan tahap pelepasan gas yang lebih rendah. Kebiasaanya, kenderaan sub-kompak dikuasakan oleh enjin pembakaran dalaman (ICE). Kebanyakan ICE bergantung pada bahan bakar fosil, seperti petrol dan diesel. Kebiasaanya, produk sampingan hasil daripada pelepasan gas pembakaran adalah karbon dioksida (CO2), nitrogen oksida (NOx), hidrokarbon tidak terbakar (UHC) dan air (H2O). Kenderaan elektrik, melalui motor elektrik (EM), memberikan kecekapan operasi yang tinggi berbanding dengan ICE tetapi pada kelajuan serata yang lebih rendah. Dengan menggabungkan kedua-dua jenis sistem pemacu ini, ia akan menghasilkan sistem kenderaan elektrik hibrid (HEV) yang mampu menghasilkan kecekapan yang lebih tinggi dan kelajuan tertinggi yang sederhana, kadar pelepasan gas dan penggunaan minyak yang rendah. Oleh itu, kajian ini akan membincangkan Pembagunan Sistem Operasi Kenderaan Elektrik Hibrid Khusus Untuk Enjin Petrol Berkapasiti Kecil Berskala Makmal. Proses yang terlibat dalam pengembangan sistem hibrid kenderaan kecil serupa dengan sistem kenderaan hibrid yang lebih besar. Namun, sistem operasi ini lebih ringkas dan tidak mempunyai sistem kotak gear tambahan untuk operasi pemacuan. Penyediaan skala makmal adalah reka bentuk menyerupai perspektif sistem pembangunan dan kawalan sebenar. Penyediaan ini diharapkan dapat meningkatkan proses pendidikan proses penegendalian secara keseluruhan kerana pengalaman langsung mengenai pemodelan, pengenalan sistem, reka bentuk kawalan dan pelaksanaan pada peralatan yang hampir dengan aplikasi sebenar. Enjin petrol kecil dalam kajian ini merujuk kepada enjin pembakaran dalaman satu silinder dengan kapasiti di bawah 150 cc. Keputusan kajian prestasi enjin hybrid, kadar pelepasan gas dan kadar pengunaan bahan bakar dapat dicapai melalui kajian ini. Perbandingan kuputusan keupaayan enjin diantara enjin pembakaran dalam dan gabungan sistem hibrid akan dijalankan untuk melihat dengan lebih mendalam.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Nowadays, hybrid technology is one of the technological solutions for fuel economy and for reducing harmful exhaust gas emissions. This technology provide the combination of two sources of power for the vehicle [1], which are the electrical power from the battery and the kinetic power from the combustion of gasoline inside the combustion chamber [2], [3]. It will operate alternatingly at certain levels of operation, such as using the electrical power at lower rpm and kinetic power at medium to high rpm. Hybrid electric vehicles provide higher fuel efficiency and lower emissions through the combination of the conventional internal combustion engine with electric motors [2]. Hybrid vehicles have become increasingly popular in the automotive marketplace in the past decade.

Hybrid vehicles have been in development since the start of the 20th century [4]. Major developments took place in the 1990s after Audi unveiled the first generation of the Audi Duo experimental vehicle, based on the Audi 100 Avant Quattro, which had a 12.6-hp electric engine that drove the rear wheels instead of the propeller shaft. The front-wheel drive was powered by a 2.3-litre five-cylinder engine with an output of 136 hp [5]. Two years later, Audi unveiled the second-generation Duo, also based on the Audi 100 Avant Quattro. From 1997 onwards, manufacturers such as Toyota and Audi started volume production of hybrid cars for commercial use.

The most common type of hybrid vehicles is the electric hybrid vehicle, which consists of an internal combustion engine (ICE), a battery and at least one electric motor (EM). Hybrids are built in several configurations, which are series, parallel and series-parallel configurations [2]. An excellent overview of this area was thoroughly discussed and well presented about Hybrid vehicles are characterised by multiple energy sources by S. Grammatico [2], and the strategy to control the energy flow among these multiple energy sources is termed “energy management”, which is crucial for good fuel economy as reviewed by Kumar et al. [6].

The hybrid system has become the subject of intensive study in the past few years by both the control- and the computer-science communities. A hybrid vehicle (HV) runs using the power from an internal combustion engine and an electric motor. The engine provides most of the vehicle’s power, and the electric motor provides additional power when needed, such as during acceleration. The hybrid vehicle operates on the principles of gasoline and electrical energies. A hybrid car features a small fuel-efficient gasoline engine combined with an electric motor that assists the engine when accelerating. The electric motor is powered by batteries that are recharged automatically during the driving process [2].

There are five main components that make up the hybrid vehicle system, which are the battery, ICE, generator, power-split device and electric motor [2], [7]. When comparing between gasoline-powered vehicles and electric vehicles (Evs), Evs are considered to be 97% cleaner by producing no tailpipe emissions that can emit particulate matter to the environment [2], [8].

1.2 Problem statement

As most vehicles today run on fossil fuels and the availability of fossil fuels is limited, there is a need to find an alternate source of energy. Electricity provides an answer to the limited fossil fuel resources but the availability of electricity on the vehicle itself is a question. As a vehicle is mobile in nature and its path is random, it cannot be provided with a continuous power supply as in the case of locomotive trains. So, the electrical power source in a vehicle is limited to batteries only. However, batteries discharge with use and need to be recharged before they can be used again.

Traditionally, a small gasoline engine employs only the internal combustion engine as its sole prime mover [2]. The demand for small-capacity engines with high power-to-weight ratio, low emissions and less fuel consumption is well known. There is also limited existence of hybrid systems for small gasoline engines to satisfy the aforementioned market demands. It is therefore desirable to have a hybrid system for small engines that offers all those advantages.

The first hybrid vehicle was introduced at the Paris Salon of 1899. Other hybrid vehicles, both of the parallel and series types, were built during a period ranging from 1899 to 1914. However, the greatest problem that these early designs had, was the difficulty of controlling the electric machine. Limited range of hybrid vehicle has a comparatively restricted range. Considering that an hybrid vehicle ought to generate minimal amount of energy from the ICE, the distance per charge is relatively small.

In this study, the performance of the electric motor was under rated. The hybrid system only can be tested in the small range of between 1500 rpm up to 3000 rpm. By using a higher-powered electric motor, better performance and emission characteristics can be obtained, hence showing a bigger picture of the performance of the hybrid system.

1.3 Research objectives

The objectives of this project are:

i. To develop a lab-scale hybrid vehicle system for a small gasoline engine.
ii. To validate and analyse the performance in terms of engine performance, emission release and fuel consumption.

1.4 Research scope

The scope of this research is as follows:

i. The development process was focused for lab-scale usage only.
ii. This research focused on a small 4-stroke semi-automatic engine with capacity below 150 cc.
iii. The experiment was done by using a hydraulic dynamometer to obtain all the performance data.
iv. The engine was operated at the electric motor's maximum load condition.

1.5 Significance of study

This research was conducted to develop an operating system for small hybrid vehicles and to obtain the performance data produced by the system. From this research, the obtained and analysed data can provide some insights for future researchers. The successful project can be implemented in the small-vehicle industry due to the fewer emission released and less fuel consumed.

CHAPTER 2

LITERATURE REVIEW

2.1 History of hybrid vehicle

According to Jyotheeswara and Natarajan, the study on vehicle efficiency is important in order to have better performance and lower emissions of the vehicle [9]. A sub-compact vehicle is normally powered by an internal combustion engine. Most ICEs rely on fossil fuels, such as gasoline and diesel. Johnstone et al. stated that fossil fuels are non-renewable energy that produce pollutant, such as carbon dioxide, when burned. Usually, the by-products of combustion are carbon dioxide (CO_2), nitrogen oxides (NOx), unburned hydrocarbon (UHC) and water (H_2O). CO_2 will contribute to the greenhouse effect, while NOx directly contributes to acid rain [10]. Khodabakhshian et al. found that the current powertrain control solutions in HEVs consider several factors, such as the charge of the battery and the efficiency of the engine operating at a given speed [11].

Consiglio and Delagrammatikas presented the relationship between fuel consumption and vehicle track, which can be measured by using the global positioning system (GPS) [12]. This method was also proved by Bradley and Quinn, who used a similar test to evaluate two hybrid electric vehicles both on the road and the dynamometer for the vehicles' fuel economy, battery characteristic, engine operation and overall hybrid control strategy [13].

The results enabled some realistic conditions to be simulated on a dynamometer. Bradley and Quinn studied the use of GPS technology for their measurement because of the technology's ability to accurately determine position and speed using signals from orbiting satellites [13]. Devarajan et al. found that there was a correlation between transient vehicle loads and the test on a dynamometer. Consiglio and Delagrammatikas stated that the test can be used in the future to determine the driving patterns on the road for the average passenger cars in Malaysia and their individual driving cycles [12].

Gasoline and diesel are mixtures of hydrocarbons, which are compounds containing hydrogen and carbon atoms. In a theoretical engine, during the combustion process, oxygen from the intake air would convert all the hydrogen and carbon contents in the fuel into water and carbon dioxide. However, this situation never happened in the actual combustion. The studies in [14] and [15] documented that society's concern about oil depletion, global warming, fuel economy and more stringent vehicle emissions standards has led many automotive manufacturers to produce alternative-energy vehicles, which are more fuel-efficient and environmentally friendly than the internal combustion engine.

2.1.1 Comparison between internal combustion engine, hybrid vehicle and electric vehicle

Referring to the research done by Argueta, an electric vehicle gives high efficiency as compared with the internal combustion engine but has a lower average top speed [7]. Combining these two types of systems will produce a hybrid system that is able to produce higher efficiency with a moderate average top speed and lower fuel consumption. Table 2.1 shows the comparison between ICE, HV and EV in terms of efficiency, acceleration and cost. It shown the higher efficiency shown at EV concept with 75% then followed by HV and ICE with 40% and 20% respectively.

The higher of efficiency respecting with the higher cost of the manufacturing which accessing up to RM400,000. Overall, the electric vehicle has more advantages than disadvantages. Advantages include no tailpipe emissions, which leads to a reduction in global warming and unhealthy people.

Table 2.1 Comparison between ICE, HV and EV [7]

	ICE (Internal combustion engine)	HV (Hybrid vehicle)	EV (Electric vehicle)
Efficiency	Converts 20% of the energy stored in gasoline to power the vehicle.	Converts 40% of the energy stored in gasoline to power the vehicle.	Converts 75% of the chemical energy from the batteries to power the wheels.
Speed (average top speed)	124 miles per hour (mph)	110 mph	30–95 mph
Acceleration (on average)	0–60 mph in 8.4 seconds	0–60 mph in 6–7 seconds	0–60 mph in 4–6 seconds
Maintenance	- Wheels/tires - Engine - Fuel/gas - Bodywork/paint - Electrical - Lights - Dash/instrument warning lights	Same as ICE.	Does not require as much maintenance because it does not use a gasoline engine. No requirements to take it to the Department of Environmental Quality for an emissions inspection.
Mileage	Can go over 300 miles before refuelling. Typically gets 19.8 miles per gallon (mpg).	Typically gets 48 to 60 mpg.	Can only go about 100–200 miles before recharging.
Cost (on average)	RM 56,763.00 to RM 68,926.50	RM 77,035.50 to RM 101362.50	Extensive range of RM 24,327.00 to RM 405,450.00

2.1.2 Fundamentals of internal combustion engine

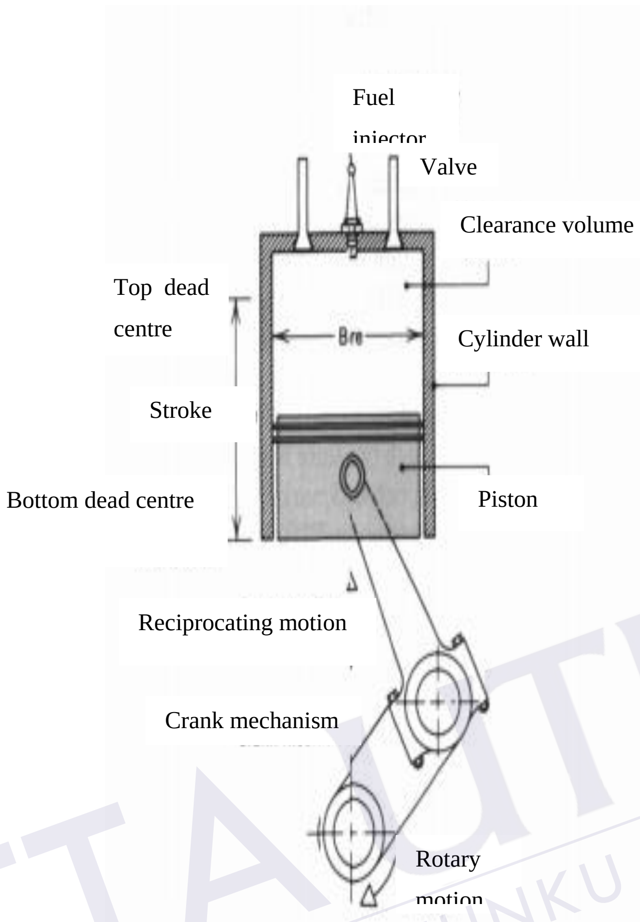

Figure 2.1 Basic components of internal combustion engine [16].

Samuel et al. stated that internal combustion engines are heat engines where the chemical energy of the fuel is converted into thermal energy, which in turn is converted into the mechanical output at the crankshaft [17]. The term "internal combustion" refers also to gas turbines, but that the term is usually applied to reciprocating internal combustion (IC) engines, such as the ones found in everyday automobiles. There are basically two types of IC ignition engines, which are those that need a spark plug and those that rely on the compression of the fluid [18].

There are two types of internal combustion engines: the 2-stroke and 4-stroke engines. The fluids converting the chemical reaction into mechanical reaction are usually gasoline and diesel.

Table 2.2 Comparison between 4-stroke and 2-stroke engines [16], [19]

4-stroke engine	2-stroke engine
4-stroke engines make less noise.	2-stroke engines are louder comparatively.
4-stroke engines are heavier.	2-stroke engines are lighter comparatively.
Engine design is a bit complicated due to the valve mechanism, which is operated through the gear-chain mechanism.	2-stroke engines have ports, which makes its design simpler.
No need of adding oil or lubricant to the fuel.	Addition of oil is required.
The top side of the piston is flat.	A bump or protuberance may be needed on the top side of the piston.
Mixture remains only in the combustion chamber.	Air-fuel mixture enters through the inlet port and travels in to combustion chamber, passing through the crankcase.
Power is produced once every four strokes of the piston.	Power is produced once after two strokes of the piston.
4-stroke engines complete two rotations of the crankshaft after completing one cycle.	2-stroke engines complete one rotation of the crankshaft after completing one cycle.

2.1.3 Working principle of 4-stroke gasoline engine

The fundamental difference between the 4-stroke engine and the 2-stroke engine is the way in which the induction and the exhaust processes take place. In the 4-stroke engine, there are separate strokes for the induction and the exhaust processes. In the 2-stroke engine, however, both the induction and the exhaust processes take place during the same stroke [20].

The process that involves both induction and exhaust is called scavenging, or a gas exchange process [21]. This type of internal combustion gasoline engine is known as a 4-stroke engine because there are four stages of movement in one complete combustion.

2.1.4 Introduction to 2-stroke engine

In a 2-stroke engine, every alternate stroke is a power stroke, unlike the 4-stroke engine, in which power gets delivered once every four strokes. This gives a significant power boost. The acceleration will be higher and the power delivery will be uniform.

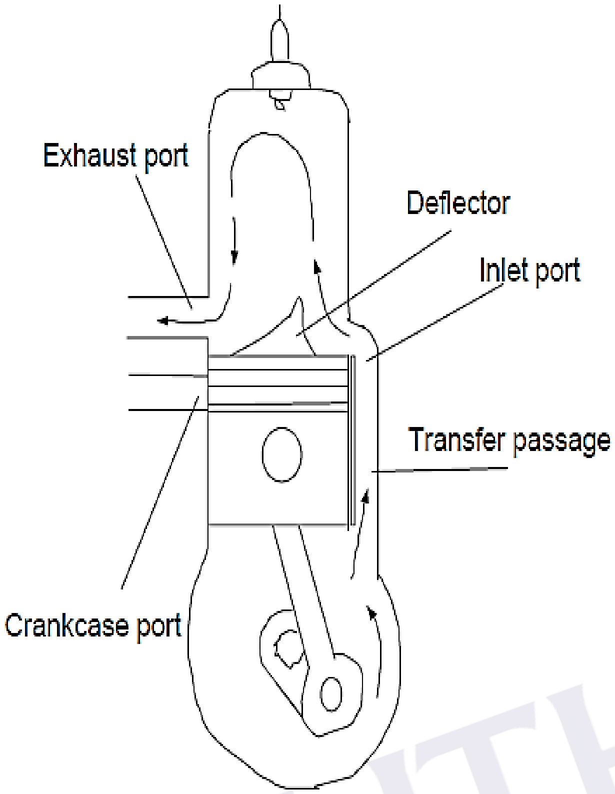

Figure 2.2 Basic components of 2-stroke engine [19]

The 2-stroke engine is mechanically a very simple operation. There are no valves or camshafts. The piston is connected by the connecting rod to the crankshaft. Lubrication is achieved by mixing oil with the fuel, and the resulting mixture then bathes all the moving parts. The complete cycle takes only one upstroke and one down stroke of the piston, so some elements of the four phases of operation must occur simultaneously [22]. Some of the important parts of this engine are the exhaust, the inlet, the crankcase port and the spark plug.

2.2 Types of hybrid electric vehicle systems

A hybrid electric vehicle can be classified based on the way in which power is supplied to the drivetrain and also on the degree of hybridisation. With many types of hybrid technologies available, there is much interest in the widespread conversion to hybrid transportation. With such a massive world population and a high dependency on transportation, a significant switch to hybrids from gasoline and diesel vehicles must be met [23].

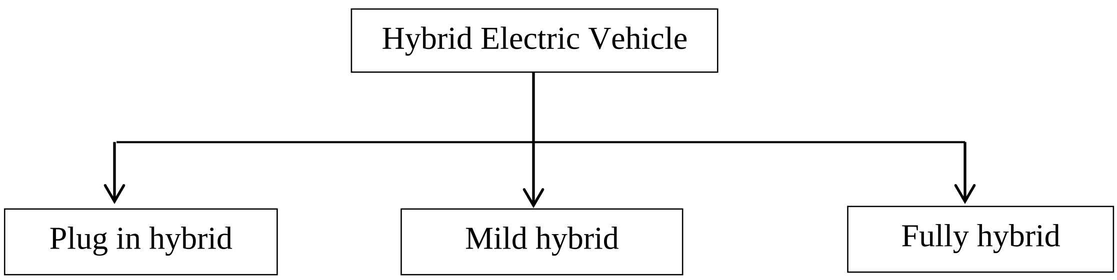

Figure 2.3 Types of hybrid electric vehicles

2.2.1 Plug-in hybrid

This type of hybrid vehicles, sometimes called plug-in hybrid electric vehicles (PHEVs), are hybrids with high-capacity batteries that can be charged by plugging them into an electrical outlet or a charging station. They can store enough electricity from the power grid to significantly reduce their petroleum consumption under typical driving conditions.

According to researcher Markel and Simpson stated that a plug-in hybrid electric vehicle (PHEV) is a hybrid electric vehicle (HEV) with the ability to recharge its electrochemical energy storage with electricity from an off-board source, such as the electric utility grid [18]. The vehicle can then drive in a charge-depleting (CD) mode, which reduces the system's state of charge (SOC), while using electricity instead of consuming liquid fuel [24].

2.2.2 Mild hybrid

A mild hybrid system cannot propel a vehicle on electric power alone. The use of the electric motor is to start the combustion engine, such as the start-stop function, thus offering a boost function during acceleration or enabling regenerative braking to recuperate energy [25]. The required voltage from the battery can be reduced compared with the full hybrid or electric vehicles, as the electric motor used in mild-hybrid vehicles has a limited power of less than 20 kW in order to reduce the cost of the components [25].

2.2.3 Fully hybrid

A fully hybrid vehicle can operate using just the battery power without using its internal combustion engine. This makes this type of hybrid system more fuel-efficient compared with other types of hybrid vehicles. At low speeds, the electric motor is used because it is more efficient than the internal combustion engine [26].

The full-hybrid configuration allows for the pure electric drive under certain conditions; hence, the ICE can be turned off even while the vehicle is moving. The ICE's on/off operation by the full-hybrid configuration contributed to this vehicle type being named as the most fuel-efficient midsize-class vehicle by the U.S. Environmental Protection Agency (EPA) in 2012 [27].

2.3 Types of hybrid drivetrain structures

In hybrid electric vehicles, there are generally two types of drivetrain structures, which are series hybrid and parallel hybrid. These two types of drivetrains are commonly used in hybrid electric vehicle nowadays. Hybrid cars do not require a change in the existing transmission and fuelling infrastructures compared with vehicles with electric, hydrogen or other alternative energy sources [28].

Series hybrid are the simplest hybrid configuration as shown in Figure 2.4. In a series hybrid, the electric motor is the only means of providing power to the wheels. The motor receives electric power from either the battery pack or from a generator run by a gasoline engine. A computer determines how much of the power comes from the battery or the engine/generator. Both the engine/generator and the use of regenerative braking recharge the battery pack. Meanwhile In vehicles with parallel hybrid drivetrains as shown in Figure 2.5, the engine and electric motor work in tandem to generate the power that drives the wheels. Parallel hybrids tend to use a smaller battery pack than series drivetrains, relying on regenerative braking to keep it recharged. When power demands are low, parallel hybrids also utilize the motor as a generator for supplemental recharging, much like an alternator in conventional cars.

From Figure 2.6, series/parallel drivetrains merge the advantages and complications of the parallel and series drivetrains. By combining the two designs, the engine can both drive the wheels directly (as in the parallel drivetrain), and be effectively disconnected, with only the electric motor providing power (as in the series drivetrain).

The Toyota Prius helped make series/parallel drivetrains a popular design. Then Figure 2.7, the complex hybrid system involves a complex configuration which cannot be classified into the above three kinds. The complex hybrid is similar to the series-parallel hybrid since the generator and electric motor is both electric machines. However, the key difference is due to the bi-directional power flow of the electric motor in complex hybrid and the unidirectional power flow of the generator in the series-parallel hybrid. The major disadvantage of complex hybrid is higher complexity.

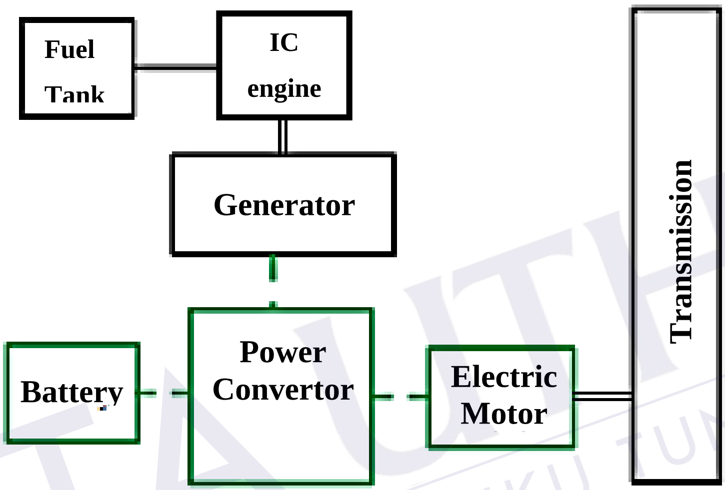

Figure 2.4 Series hybrid [29]

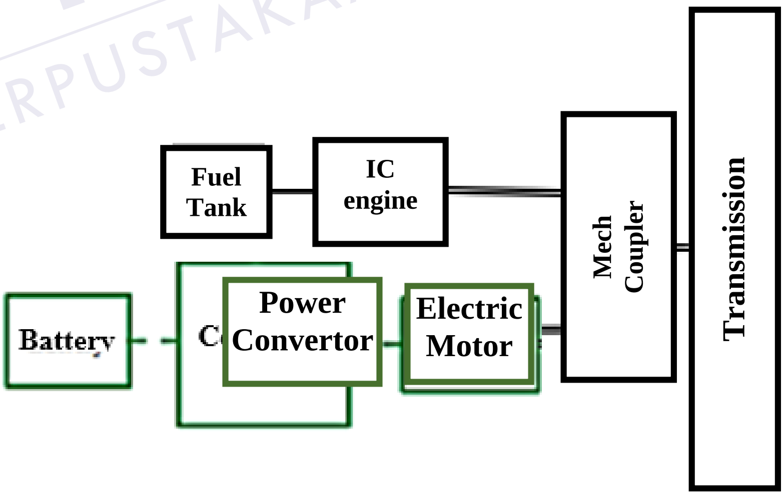

Figure 2.5 Parallel hybrid [29]

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