بسم الله الرحمن الرحيم

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Design and construction of an experimental system of hybrid vehicles

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Dedication

To our Families · · · For their support

To our Teachers · · · For help us until the end To our friends · · ·
Who give us positive sentiment

To oppressed people throughout the world and their struggle for social justice and egalitarianism

To our great Palestine

To our supervisor Dr. Momen Sughayyer

To all who made this work is possible

Ahmed Reyad Hroub
Tariq Khaldon Qubaga
Malek Shareef Rjoub

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Finally thanks are extended to the ”Mechanical society” for the beneficial lectures provided.

Abstract

With the more stringent regulations on emissions and fuel economy, global warming, and constraints on energy resources, the hybrid vehicles have attracted more and more attention by automakers, governments, and customers. Research and development efforts have been focused on developing novel concepts, low-cost systems, and reliable hybrid electric power train.

The idea of the project is to build a laboratory experimental mod that simulates the hybrid vehicle system. This model helps the student to understand the hybrid vehicles in a practical way by identifying the components, the process and stages of each component and comparing the results with conventional vehicles.

After building the model and making the experiments on it, by running the engine in the most efficient range(2400-2800 RPM) and store the redundant power in battery and use this power when there is need for it, So we achieve the Benefit of the hybrid system by reducing the cost of (one watt) of power so the efficiency of the system increasing.

الملخص

مع تزايد اللوائح الصارمة بشأن الانبعاثات و الاقتصاد في استهلاك الوقود و الاحتباس الحراري، والقيود المفروضة على موارد الطاقة التقليدية، جذبت المركبات الهجينة اهتماما متزايدا من جانب شركات صناعة السيارات والحكومات والزبائن. وقد تركزت جهود البحث والتطوير على تطوير مفاهيم جديدة، ونظم منخفضة التكلفة، وقوة هجين موثوقة قطار الطاقة الكهربائية.

وتكمن فكرة المشروع في بناء نموذج تجريبي مختبري يحاكي نظام المركبات الهجينة. يساعد هذا النموذج الطالب على فهم المركبات الهجينة بطريقة عملية من خلال التعرف على مكوناتها والتعرف على عمل كل مكون ومقارنة النتائج مع المركبات التقليدية.

بعد بناء النموذج وعمل الاختبارات عليه، عن طريق تشغيل المحرك في مجال سرعات عمل المحرك (2400-2800) الذي يعمل فيه المحرك بأعلى كفاءة حيث نحصل على الطاقة والزائد منها يتم تخزينه في البطاريات ونستخدمه عندما نحتاج إليه، لذلك نكون قد حققنا الفائدة من النظام الهجين عن طريق تقليل تكلفة(الواط الواحد) من الطاقة وبالتالي ترتفع كفاءة النظام

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1.1 Introduction

With the increase in the world population, the demand for vehicles for personal transportation has increased dramatically in the past decade. This trend of increase will only intensify with the catching up of developing countries, such as China, India, and Mexico. The demand for oil has increased significantly [1] .

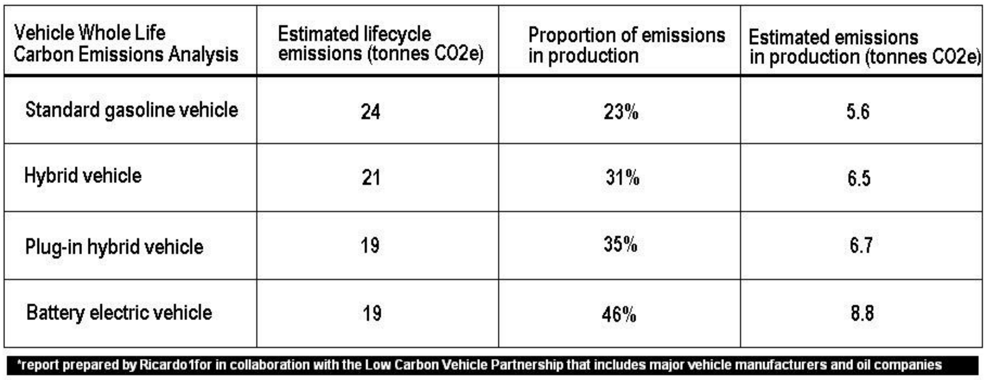
Before 2050, global warming should not exceed the value of 3.6° F (2°C) related to the earth's temperature from pre-industrial times. This goal can only be achieved by reducing emissions. The plan is to reduce the emissions per capita from the current 45 tons per year to 0.7 tons per year by 2050 [2].

When a car’s engine is running, several different types of gasses and particles are emitted that can have detrimental effects on the environment. Of particular concern to the environment are carbon dioxide, a greenhouse gas; hydrocarbons any of more than a dozen volatile organic compounds, some of which are known carcinogens; nitrogen oxides; sulfur oxides; and particulate matter, tiny particles of solids, such as metal and soot. Other emissions that affect human health and create smog include ozone and carbon monoxide [4].

Vehicle emissions can affect the environment in several ways. Cars emit greenhouse gasses, such as carbon dioxide, which contribute to global warming. Some air pollutants and particulate matter from cars can be deposited on soil and surface waters where they enter the food chain.

These substances can affect the reproductive, respiratory, immune and neurological systems of animals. Nitrogen oxides and sulfur oxides are major contributors to acid rain, which changes the pH of waterways and soils and can harm the organisms that rely on these resources, and here are a comparison between hybrid and the other types of vehicles for the amount of carbon emissions that the vehicle produce it in it’s life cycle, as shown in table 1.1 [3].

Table 1.1: Percentage of which pollutant comes from cars [3]



Vehicle Whole Life Carbon Emissions Analysis	Estimated lifecycle emissions (tonnes CO2e)	Proportion of emissions in production	Estimated emissions in production (tonnes CO2e)
Standard gasoline vehicle	24	23%	5.6
Hybrid vehicle	21	31%	6.5
Plug-in hybrid vehicle	19	35%	6.7
Battery electric vehicle	19	46%	8.8

*report prepared by Ricardo1for in collaboration with the Low Carbon Vehicle Partnership that includes major vehicle manufacturers and oil companies

Carbon dioxide also is the result of the combustion of hydrocarbons. Transportation accounts for a large share (32% from 1980 to 1999) of carbon dioxide emissions. The distribution of carbon dioxide emissions is shown in – figure 1.1[4].

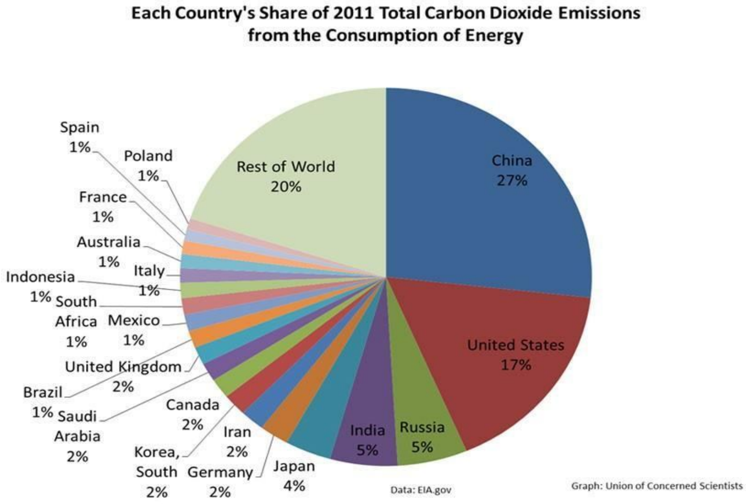


Figure 1.1: World CO2 emission by country 2011 [4]

1.2 History of Hybrid Electric Vehicles

The first hybrid car wasn't the Toyota Prius nor was it invented in the 1990s or 2000s. In fact, it dates back to the early 20th century. Still, the first hybrid car was brought into existence for reasons that will be familiar to those living in the early 21st century: Internal combustion engines were producing too much foul-smelling pollution[5].

The first hybrid car was in part the brainchild of a Viennese coach builder named Jacob Lohner, who felt that gas-driven cars were too noisy and smelly. To find a solution to this problem, Lohner turned to a young Austrian engineer named Ferdinand Porsche. In 1896, when he was just 21 years old, Porsche had invented the electric wheel-hub motor, a battery-operated motor that actually fit inside the hub of a wheel. Lohner asked Porsche to combine his in-wheel motors with one of Lohner's coaches. The result was the Lohner-Porsche Electromobility. This vehicle was first sho wn to the general public at the Paris Exposition of 1900[5].

Dr.Victor Wouk is recognized as the modern investigator of the hybrid electric vehicle movement. In 1975 he built a parallel hybrid version of a Buick Skylark. The engine was a Mazda rotary engine, coupled to a manual transmission. It was assisted by a 15 hp separately excited DC machine, located in front of the transmission [5].

1.3 Hybrid Vehicle and Conventional Vehicle

Here are a Comparison between hybrid vehicle and conventional vehicle as shown in Table 1.2.

Table 1.2: Comparison between hybrid vehicle and conventional vehicle [6].

Conventional Vehicle	Hybrid Vehicle	Item
Consumes more than hybrid by 40%.	Consumes less fuel.	Fuel consumption
Less expensive than hybrids.	More expensive than a conventional car by approximately 25%	Cost
Modern Conventional cars pollute the environment more than hybrid vehicles by 25%.	Hybrid cars are environment friendly.	Effect to environment
Conventional cars are more efficient than hybrid cars on the road because cars are designed to work on all kinds of ways.	Hybrid cars are designed to work inside the cities, and at slower speeds.	Efficiency
Conventional cars maintenance cost is less than hybrid .	They are more complex in most cases. So, the cost of maintenance is high	Maintenance

Hybrid car manufacturers are continually researching for new ways to reduce fuel consumption and better fuel efficiency. Also as more hybrid cars are being adopted, the cost of hybrid cars will reduce making it more affordable for everyone [6].

1.4 Literature Review

In this section, a broad literature survey on hybrid electric and plug-in hybrid electric vehicle research is presented. The survey emphasis vehicle modeling and simulation, power and energy management, energy storage devices, propulsion systems and influence of driving cycle that affect the overall efficiency and fuel economy.

1.4.1 Modeling and Simulation

Reza ,Mohammad and Saman (2016) presented a simulation and modeling Tehran passenger car derivation of Tehran passenger car drive cycle is described for simulation of PHEV and HEV to evaluate their longitudinal dynamic performance. and use on-board electronic equipment was used and real world traffic data were collected, covering almost all the Tehran road network for six month. Control strategy and component data are added by MATLAB/ Simulink[7].

They also a Fuzzy Logic Controller is developed for energy management system. Then genetic algorithm is utilized for optimization of control strategy [7].

Simulation results indicate that the proposed controller reduced fuel consumption and emissions by about 14 % and 21 % respectively. Also, due to using more electric power, PHEV in comparison to HEV demonstrated better performance during Teh-car driving cycle, which saves considerable amount of energy. They also in this paper a parallel HEV and PHEV model are developed in ADVISOR [7].

Control strategy and component data are added by MATLAB / Simulink. Simulations are conducted for various driving cycle and control strategies [7].

1.4.2 Influence of Driving Cycle

Orkun, Jeremy (2012) compare the potential of hybrid, extended-range plug-in hybrid, and battery electric vehicles to reduce lifetime cost and life cycle-greenhouse gas emissions under various scenarios and simulated driving conditions. they are find that driving conditions affect economic and environmental benefits of electrified vehicles substantially. Customer vehicle purchasing decision part guided by EPA fuel economy and AER estimates based on standard laboratory test driving cycles [8].

However, diverse real-world driving conditions can deviate substantially from laboratory conditions, affecting which vehicle technologies are most cost effective at reducing GHG emissions for each driver. As such, the choice of driving cycle for testing necessarily preferences some vehicle designs over others. This effect has become more pronounced with the introduction of hybrid and plug -in power trains because factors like regenerative braking and engine idling affect there lative importance of aggressive and stop and go driving conditions on system efficiency [8].

When comparing HEVs to PHEVs under the average U.S.grid mix, it is clear that most of the GHG-reduction benefit of PHEVs comes from hybridization, and relatively little additional benefit can be achieved through plugging in.HEVs provide an optimal or near optimal economic and environmental choice for any driving cycle[8].

However, given a substantially decarbonized electricity grid plug-in vehicles could reduce life cycle GHG emissions across all driving cycles, and lower battery costs combined with high gasoline prices would make plug-in vehicles more economically competitive [8].

1.4.3 Electric Propulsion and Energy Storage Device

Karl BA. Mikkelsen (2010) make a study to convert a Chrysler Pacifica into a hybrid electric vehicle. The objective of this study was to evaluate the effectiveness of a hybrid electric energy storage system for use in a modified Chrysler Pacifica. The results show that effectiveness of a hybrid storage system depends on the size and type of the hybrid storage system, the type of driving patterns observed, and what metrics are evaluated. The results are conclusive to the extent that the model and simulation of the modified Pacifica power train are accurate [9].

Energy consumption is increased in HESS's. The increase comes predominantly in higher DC-DC converter losses, demonstrating that hybrid energy storage has implications for other components in the power train.

The power system of the battery-battery HESS was unable to fully accommodate regenerative braking demand in all cases, resulting in some current reversals for the energy batteries. This leads to the conclusion that a battery-capacitor system is appropriate for applications demanding frequent, large velocity changes. The power system of the battery capacitor HESS was very bulky, limiting space for energy batteries. This reduced vehicle range compared to the battery-battery system, leading to the conclusion that a battery-battery system is appropriate when range is the primary concern [9].

1.4.4 Previous Projects

Osama, Fadi, Menyar (2016) they are making a project to build an electric hybrid system, and the aim of this project is to prove that the power that will be stored in the batteries is a cheap power, which they are doing two experiments on the system that built, and after doing the two experiments, the numbers prove that this assumption is a fact, because the less fuel consumption was in the efficient range of the engine (2400-2800 RPM). to achieve the benefit of the hybrid system, the engine must work in the efficient range and store the redundant power in battery and use this power when there is need for it [4].

The system produced are suffers from several problems, the main problem is the not precise design, and the rest problems in the experimentation of this system, these problems because of the insufficient time for working on this project, and the other reason is the lack of the accurate experimentation devices [4].

1.5 Project Idea

The idea of the project is to build a laboratory experimental system that simulates the design and installation of hybrid vehicles. This model helps the student to identify these technologies and compare them with traditional vehicles. This is done by studying the components of the system and the function of each part, and developing the appropriate design of the model using internal combustion engine (single cylinder), an electric motor- generator, battery, to store energy from the internal combustion engine (ICE), and use this energy when we need it.

And the components of the project assembled as in Figure 1.2, to make a hybrid experimental system.

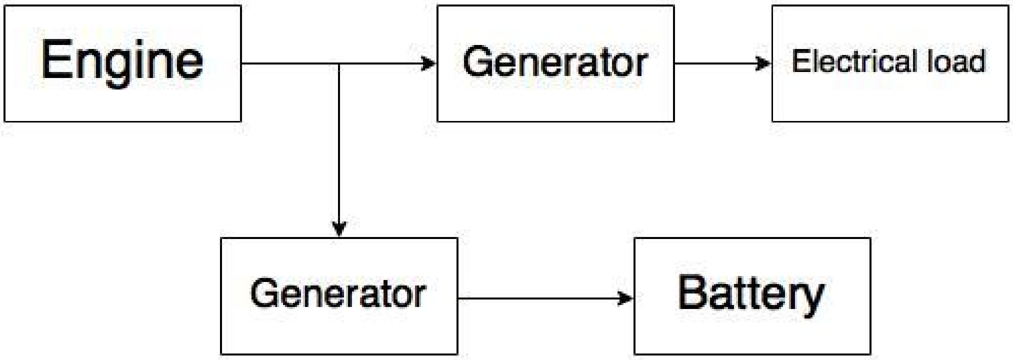


Figure 1.2: Block diagram of the hybrid experimental system.

1.7 Time Table

In this section attached the time table of the project, that distrusted on two semesters.

Table 1.3: Time table

1st semester												
	■	■	■									
Drafting				■	■	■						
Literature					■	■	■	■				
				■	■	■	■	■	■			
						■	■	■	■	■	■	■
Writing a							■	■	■	■	■	■
2nd semester												
Buying	■	■	■	■	■							
Lathing				■	■	■	■	■				
Building						■	■	■	■	■		
Testing ,									■	■	■	■

1.8 Budget

In this section attached the budget table, that show the parts needed to complete the project and its price.

Table 1.4: Budget

Cost	Pieces
600 NIS	ICE
500 NIS	Electric motor-generator
700 NIS	The Battery
300 NIS	The stand and the other parts
2000 NIS	Total

CHAPTER2

AUTOMOTIVE ELECTRIC HYBRID SYSTEMS

2.1 Introduction.

2.2 Hybrid Definition.

2.3 Types by Degree of Hybridization.

2.4 Types by Drive Train Structure.

2.1 Introduction

This chapter contains the types of hybrid systems, In the beginning hybrid vehicle consist of two types of power sources, such as an internal combustion engine and an electric motor, to take advantage of the benefits provided by these power sources while compensating for each other’s shortcomings, resulting in highly efficient driving performance. Although hybrid systems use an electric motor, they do not require external charging, as do electric vehicles.

2.2 Hybrid Definition

Hybrid electric vehicles do not change the makeup of energy supply for transportation, just as conventional motor vehicles, HEVs are powered by petroleum, only more efficiently. In contrast, in addition to potentials for further efficiency improvements, HEVs have potentials for more substantial changes in the overall energy flow by supplying energy for transportation at least in part from the electrical power grid. Briefly addressed are technical and economic challenges in HEVs.

Hybrid systems, using a combination of an internal combustion engine (ICE) and electric motor (EM), have the potential of improving fuel economy by operating the ICE in the optimum efficiency range and by making use of regenerative braking during deceleration in motive power sources for automobiles alone, we have been continuously improving conventional engines and have developed and commercialized lean-burn gasoline engines, direct injection gasoline engines and common rail direct-injection diesel engines, etc. We have also been modifying engines so that they can use alternative fuels, such as compressed natural gas (CNG), instead of gasoline or light oil, and have been installing these engines in commercially sold vehicles [6].

Toyota has also developed and has been marketing electric vehicles (EV) that use motors for the driving source; hybrid vehicles (HV) that combine an engine and a motor, fusing the advantages of these two power sources; fuel cell hybrid vehicles (FCHV) that use fuel cells (FC) to generate electricity based on a chemical reaction between hydrogen and the oxygen in the air and that supply this electricity to electric motors to produce driving power [6].

As shown in figure 2.1, The hybrid vehicle may consist of a gasoline engine combined with an M/G. An HEV is formed by merging components from a pure electrical vehicle and a pure gasoline vehicle. The electric vehicle has an M/G which allows regenerative braking for an electric vehicle; the M/G installed in the HEV enables regenerative braking. For HEV, the M/G is tucked directly behind the engine. In Honda hybrids, the M/G is connected directly to the engine. The transmission appears next in line. This arrangement has two torque producers; the M/G in motor mode, M-mode, and the gasoline engine. The battery and M/G are connected electrically [3].

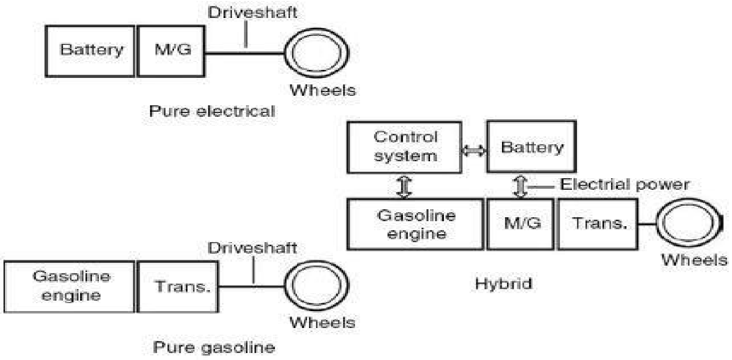


Figure 2.1: Components of a hybrid car. The hybrid is formed by combining a gasoline conventional with a pure electric vehicle [3].

2.3 Types by Degree of Hybridization

2.3.1 Full Hybrid

sometimes also called a strong hybrid, is a vehicle that can run on just the engine, just the batteries, or a combination of both. Ford's hybrid system, Toyota's Hybrid Synergy Drive and General Motors/Chrysler's Two-Mode Hybrid technologies are full hybrid systems. The Toyota Prius, Ford Escape Hybrid, and Ford Fusion Hybrid are examples of full hybrids, as these cars can be moved forward on battery power alone. A large, high-capacity battery pack is needed for battery-only operation. These vehicles have a split power path allowing greater flexibility in the drive train by inter converting mechanical and electrical power, at some cost in complexity [7].

2.3.2 Mild hybrid

Is a vehicle that cannot be driven solely on its electric motor, because the electric motor does not have enough power to propel the vehicle on its own. Mild hybrids only include some of the features found in hybrid technology, and usually achieve limited fuel consumption savings, up to 15 percent in urban driving and 8 to 10 percent overall cycle. A mild hybrid is essentially a conventional vehicle with oversize starter motor, allowing the engine to be turned off whenever the car is coasting, braking, or stopped, yet restart quickly and cleanly. The motor is often mounted between the engine and transmission, taking the place of the torque converter, and is used to supply additional propulsion energy when accelerating. Accessories can continue to run on electrical power while the gasoline engine is off, and as in other hybrid designs.

the motor is used for regenerative braking to recapture energy. As compared to full hybrids, mild hybrids have smaller batteries and a smaller, weaker motor/generator, which allows manufacturers to reduce cost and weight [7].

2.3.3 Plug-in Hybrid

The plug-in hybrid is the most diverted hybrid vehicle in the market. This type of vehicle uses a high-power battery (typically lithium-ion or lithium-polymer type) for operation. This battery configuration is designed to accept charge from an electrical outlet. When the battery is charged, the vehicle is capable of running strictly on electric power. If the charge on the battery gets depleted during the drive, it is then driven by the internal combustion engine. This hybrid configuration has all the advantages of a hybrid vehicle while sharing some of the benefits of an electric vehicle [3].

2.4 Types by Drive Train Structure

2.4.1 Series Hybrid

In a series hybrid system, the engine drives a generator, and an electric motor uses this generated electricity to drive the wheels. The generator both charges a battery and powers an electric motor that moves the vehicle. When large amounts of power are required, the motor draws electricity from both the batteries and the generator. Series hybrid configurations already exist a long time: diesel-electric locomotives, hydraulic earth moving machines, diesel-electric power groups, loaders [10].

In case of series hybrid system, the mechanical output is first converted into electricity using a generator. The converted electricity either charges the battery or can bypass the battery to propel the wheels via the motor and mechanical transmission. Conceptually, it is an ICE assisted Electric Vehicle(EV)[10].

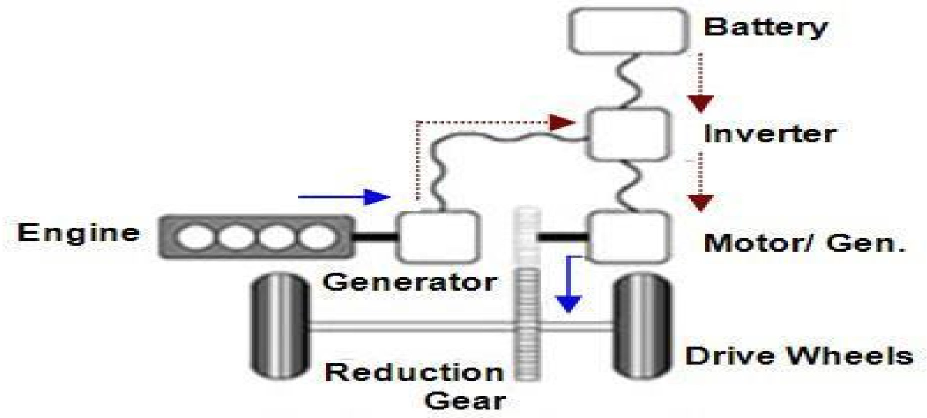


Figure 2.2: Rear-wheel-drive series hybrid electric vehicle layout.

.

In this type of system mechanical decoupling of the engine from the drive wheels allows operation anywhere on its speed-power curve – can aim for optimum operation as much as possible. Also in this type, Electric motors spin to very high rpm therefore the transmission unit requires less gears, is cheaper, and lighter. And in this type, can use one electric motor per wheel – implications for AWD, traction and stability control [10].

The disadvantage of this system the series hybrid requires a larger, more complicated battery and motor to meet its power needs. The larger battery and motor and the addition of a generator often makes the series hybrid costlier than a parallel hybrid. Series hybrids are also not as efficient as parallel hybrids for highway driving since the engine is not directly connected to the wheels [10].

2.4.2 Parallel Hybrid

The parallel HEV allows both ICE and electric motor (EM) to deliver power to drive the wheels. Since both the ICE and EM are coupled to the drive shaft of the wheels via two clutches, the propulsion power may be supplied by ICE alone, by EM only or by both ICE and EM. The EM can be used as a generator to charge the battery by regenerative braking or absorbing power from the ICE when its output is greater than that required to drive the wheels [10].

The advantages of the parallel hybrid drive train are:

1) Both engine and electric motor directly supply torques to the driven wheels and no energy form conversion occurs; hence energy loss is less

2) Compactness due to no need of the generator and smaller traction motor [10].

And the drawbacks of parallel hybrid drive trains are:

1) Mechanical coupling between the engines and the driven wheels, thus the engine Operating points cannot be fixed in a narrow speed region.

2) The mechanical configuration and the control strategy are complex compared to series hybrid drive train [10].

Due to its compact characteristics, small vehicles use parallel configuration. Most passenger cars employ this configuration.

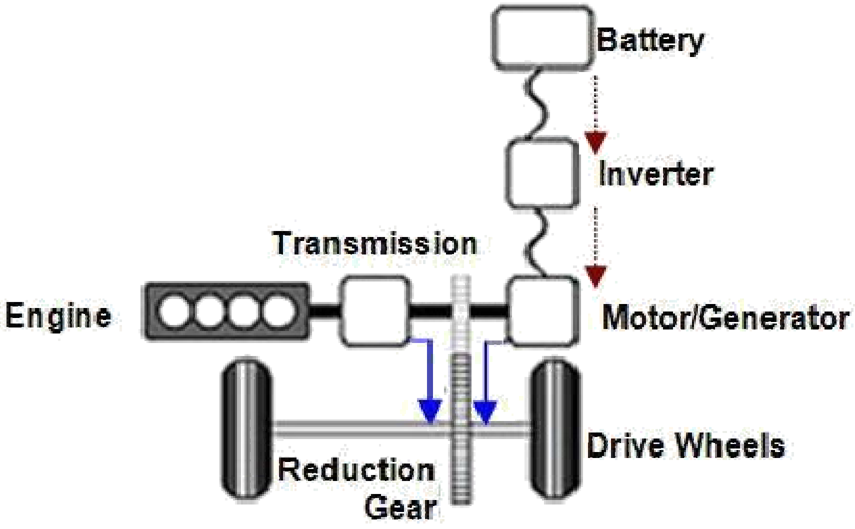


Figure 2.3: Rear-wheel-drive parallel hybrid electric vehicle layout.

2.4.3 Series-Parallel Hybrid

In a series – parallel configuration the electric motor, the electric generator, the internal combustion engine, and the wheels of the vehicle can be linked together through one or multiple planetary gear sets or other devices .Figure 2.4 shows the series – parallel configuration in which the power provided by the engine gets split and transmitted to the wheels through two paths: series and parallel [4].

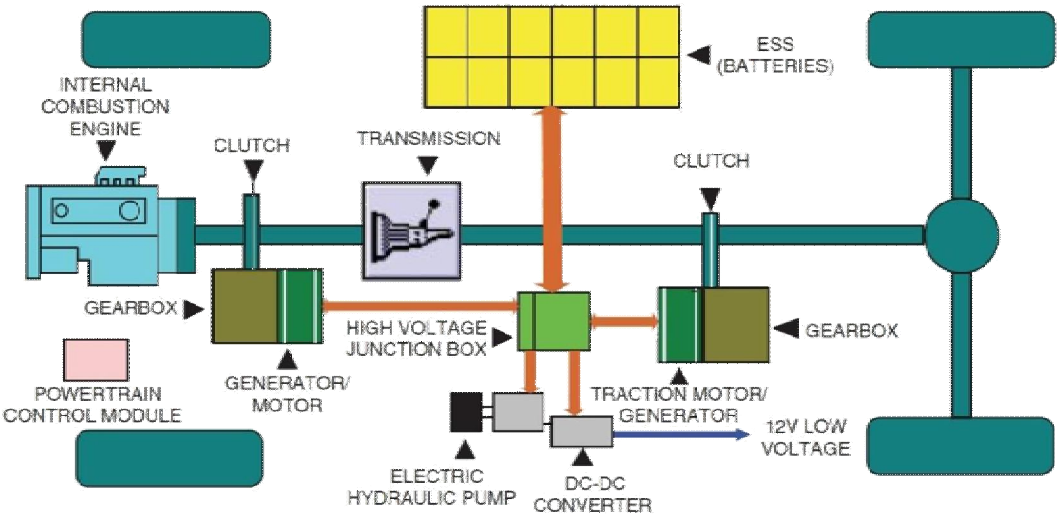


Figure 2.4: Rear-wheel-drive series - parallel hybrid electric vehicle layout.

The configuration of the series - parallel hybrid incorporates the features of both the series and parallel hybrid electric vehicles, but involving an additional mechanical link compared with the series hybrid and also an additional generator compared with the parallel hybrid. although possessing the advantageous features of both the series and parallel hybrid electric vehicles, the series – parallel hybrid electric vehicle is relatively more complicated and costly. Nevertheless, with the advances in control and manufacturing technologies, some modern hybrid electric vehicle prefers to adopt this system [4].

CHAPTER 3

HYBRID SYSTEM MODELING AND DESIGN PLAN

3.1 Introduction.
3.2 Internal Combustion Engine Parameters.
3.3 Electrical Components Parameters.
3.4 Maximum State-of-charge of Power Source.
3.5 Operation Modes of the Parallel Hybrid Vehicle.

3.1 Introduction

Design methodology for one particular configuration may be not applicable to other configurations and the design result for a particular configuration may be applicable for only a given operation environment and mission requirement. This chapter will focus on the design methodology of parallel drive trains with torque coupling, which operate on the electrically peaking principle that is, the engine supplies its power to meet the base load (operating at a given constant speed on flat and mild grade roads, or at the average of the load of a stop-and-go driving pattern) and the electrical traction supplies the power to meet the peaking load requirement.

3.2 Internal Combustion Engine Parameters

3.2.1 GEOMETRICAL PROPERTIES OF RECIPROCATING ENGINES (Compression ratio rc)

The main parameters define the basic geometry, of a reciprocating engine is Compression ratio rc .

$$\text{RC} = \frac{\text{maximum cylinder pressure}}{\text{minimum cylinder pressure}} \qquad (3.1)$$

Typical values of these parameters are: rc = 8 to 12 for SI engines and rc = 12 to 24 for CI engines [9] .

3.2.2 Mean Effective Pressure (MEP)

While torque is a valuable measure of a particular engine's ability to do work, it depends on engine size. A more useful relative engine performance measure is obtained by dividing the work per cycle by the cylinder volume displaced per cycle. The parameter so obtained has units of force per unit area and is called the mean eflective pressure (mep)[11].

The mean effective pressure (mep), which is defined as the work per cycle per displacement:

$$\text{mep} = \frac{\text{work per cycle}}{\text{displacment of cylinder}} \tag{3.2}$$

The mean effective pressure can be expressed in terms of torque as:

$$\text{mep} = \frac{2\pi NrT}{Vd} \tag{3.3}$$

mep : (bar).

Nr: is the number of revolutions of crankshaft for each power stroke per cylinder (*Nr*=2 for four stroke engines and *Nr*=1 for two stroke engines).

T: is the torque in(N.m), *Vd*: the engine cylinder displacement(mm).

3.2.3 AIR/FUEL AND FUEL/AIR RATIOS

In engine testing, both the air mass flow rate ma and the fuel mass flow rate are normally measured. The ratio of these flow rates is useful in defining engine operating conditions:

$$\text{Air /fuel ratio} = \frac{\dot{m}a}{\dot{m}f} \tag{3.4}$$

$$\text{Fuel / air ratio} = \frac{\dot{m}f}{\dot{m}a} \tag{3.5}$$

The normal operating range for a conventional SI engine using gasoline fuel is 12 ≤ A/F ≤ 18 (0.056 ≤ F/A ≤ 0.083); for CI engines with diesel fuel, it is 18 ≤ A/F ≤ 70 (0.014 ≤ F/A ≤ 0.056) [11].

3.2.4 Power and Drive Train Torque Output

The practical engine performance parameters of interest are power, torque, specific fuel consumption, and specific emissions. The power (KW) of the four-stroke engine can be expressed as numerical equation:

$$P = \frac{Vd \times mep \times n}{600 \times k} \tag{3.6}$$

n = Engine speed, K = 2 for four stroke engines [11].

The torque T (N.m), is given by:

$$T = \frac{mep \times Vd}{4\pi} \tag{3.7}$$

3.3 Electrical Components Parameters

3.3.1 Battery

The batteries are made of unit cells containing the chemical energy that is convertible to electrical energy. One or more of these electrolytic cells are connected in series to form one battery. The grouped cells are enclosed in a casting to form a battery module. A battery pack is a collection of these individual battery modules connected in a series and parallel combination to deliver the desired voltage and energy to the power electronic drive system [4].

Battery Capacity

One factor rating a battery is capacity, C, with units of ampere hour (Ah). A rechargeable NiMH battery in the AA size has capacity equal to 2.5 Ah. For discussion, assume the battery current, I, is 0.5 A. The time, t, that the battery can operate before it goes dead is

$$t = \frac{C}{I} \tag{3.8}$$

C: Battery capacity(Ah). I: Battery current(A) [4].

The preceding calculation applies to a perfect battery and does not take into account the decline of terminal voltage. Cell capacity, C, is determined partially by the mass of available reactants. The capacity of a perfect battery in either series or parallel assembly of cells is derived below. Let Co be the capacity of a cell in (Ah). Let Vo be the cell voltage in (volt). The energy of a cell, E_0 in (joule), is the product [4].

$$Eo = Co \times Vo \tag{3.9}$$

Consider a battery with N cells. The energy of the battery, E,is

$$Eo = N \times Co \times Vo \tag{3.10}$$

If connected in series, that is, end-to-end, the battery voltage is

$$V = N \times Vo \tag{3.11}$$

The energy of the battery connected in series is

$$Eo = (N \times Vo)Co = V \times Co \tag{3.12}$$

When connected in series, the capacity of a battery is the same as the capacity of a cell, that is V = Vo. The energy of the battery connected in parallel is

$$Eo = (N \times Co)Vo = V \times Co \tag{3.13}$$

For a parallel connection, the battery capacity, C, is equal to NC0. Compare battery energy for series and parallel connections; the equation is almost the same [5].

3.3.2 DC Motor

The electric motor is one of the most important components in a hybrid vehicle. The brush less DC motor are widely used for this application due to higher efficiency, lower cost, less maintenance, and longer lifetime [8].

In the brush less direct-current (BLDC) motor, the mechanical brush/ commutator system is replaced by a motionless electronic controller. In a BLDC motor, current and torque and voltage and turning speed are linearly related [8].

Since DC voltage varies with battery state of charge and operating conditions in hybrid electric vehicles, BLDC motor has to work with a DC/DC converter, to convert the DC voltage to the required operating voltage level of the electric motor.

The required efficiency of the DC/DC converter is normally above 95% in hybrid vehicle applications [4].

3.4 Maximum State-of-charge of Power Source

When a vehicle is operating in a stop-and-go driving pattern, the PPS must deliver its power to the drive train frequently. Consequently, the PPS tends to be discharged quickly. In this case, maintaining a high SOC in the PPS is necessary to ensure vehicle performance. Thus, the maximum SOC of the PPS control strategy may be the proper option. [5]

3.5 Operation Modes of the Parallel Hybrid Vehicle:

3.5.1 Motor-alone propelling mode

The electric motor alone delivers its power to the driven wheels, while the engine is shut down or idling. The engine power, electric traction power, and the PPS discharge power can be written as

$$Pe = 0 \tag{3.14}$$

$$Pm = PL/(\eta t, m) \tag{3.15}$$

$$Ppps\_d = Pm/(\eta m) \tag{3.16}$$

Where Pe is the engine power output, PL is the load power demand on the drive wheels, ηt,m is the transmission efficiency from the motor to the driven wheels, Pm is the power output of the electric motor, Ppps-d is the PPS discharge power, and ηm is the motor efficiency[5].

3.5.2 Hybrid propelling mode

The engine operation is set on its optimum operation line by controlling the engine throttle to produce power Pe. The remaining power demand is supplied by the electric motor. The motor power output and PPS discharge power are:

$$Pm = (PL - Pe.\eta t.e)/\eta m \qquad (3.17)$$

$$Ppps\_d = Pm/(\eta m) \qquad (3.18)$$

Where ηt,e is the transmission efficiency from the engine to the drive wheels[5].

3.5.3 Peaking Power Source charge mode

The electric motor is controlled by its controller to function as a generator, powered by the remaining power of the engine. The output power of the electric motor and PPS charge power are

$$Pm = ((Pe - PL.\eta t.e)\eta t.e.m\,.\eta m) \qquad (3.19)$$

$$Ppps\_c = Pm) \qquad (3.20)$$

Where ηt,e,m is the transmission efficiency from the engine to the electric motor.

3.5.4 Engine-alone propelling mode

The electric system is shut down, and the engine is operated to supply the power that meets the load power demand.

The engine power, electric power, and battery power can be expressed by

$$Pe = PL/(\eta t.e) \tag{3.21}$$

$$Pe = 0 \tag{3.22}$$

$$Ppps = 0 \tag{3.23}$$

3.5.5 Regenerative-alone brake mode:

The engine is shut down or set idling. The motor power output and PPS Charge power are

$$Pmb = PL\,.\,\eta t.\,m\,.\,\eta m \tag{3.24}$$

$$Ppp\_c = Pmb \tag{3.25}$$

3.5.6 Hybrid braking mode:

The electric motor should be controlled to produce its maximum regenerative braking power, and the mechanical brake system should handle the remaining portion. The motor output power, battery charging power, and mechanical braking power are

$$Pmb = Pmb.max\ .\ \eta m \qquad (3.26)$$

$$Ppp\_c = Pmb \qquad (3.27)$$

It should be noted that for better braking performance, the front forces on the front and rear wheels should be proportional to their normal load on the wheels [5].

An electric battery is a device consisting of one or more electrochemical cells with external connections provided to power electrical devices such as flashlights, smart phones, and electric cars [5].

CHAPTER 4

BUILDING THE EXPERIMENTAL SYSTEM

4.1 Introduction

After studying the electrical hybrid system, and the benefit of using this system, and the problems that can be solved by the electrical hybrid system, the tendency of the project idea is to build an experimental system of the electrical hybrid system.

After studying the electrical hybrid systems drive train structure, it found that the parallel structure is more efficient than the series structure, so the tendency in this project to use the parallel structure.

With researching of the resources that can be used to build the experimental system, it found there is a conventional experimental system in the automotive workshop, this conventional experimental system can be used to built the experimental hybrid system.

The block diagram of the experimental system will be as shown in figure 4.1.

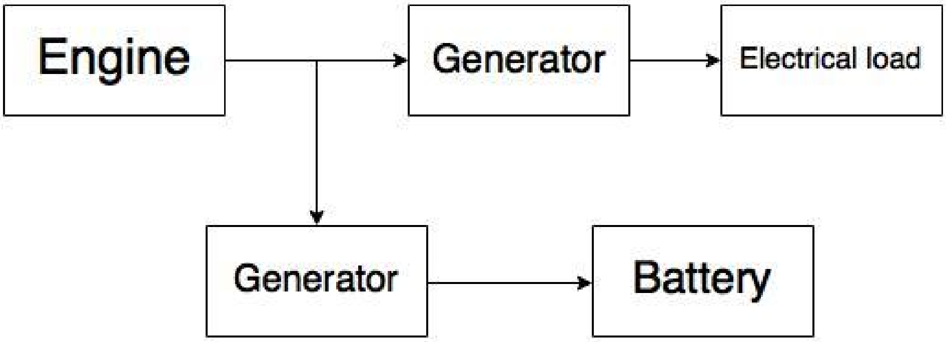


Figure 4.1: Block diagram of the hybrid experimental system.

4.2 Components of the Hybrid Experimental System

This section show the parts that used to build the experimental system.

4.2.1 Internal Combustion Engine

The internal combustion engine in this experimental system is delivering the power to the generator, at internal combustion engine alone mode , and the generator converts this mechanical power to electrical power and provides this electrical power to electrical loads, but in the peaking power source charge mode the internal combustion engine will work in high range efficiency ,and will deliver their power to the electrical load and to the generator to charge the battery.

The power of the generator can be determined by knowing the electrical voltage and the electrical current using voltmeter and ammeter devices, and put the values of the electrical volt and the electrical current in this equation :

$$P = I \times V \tag{4.1}$$

P: power (Watt).

I: Electrical current(Ampere).

V: Electrical voltage(Volt).

The speciations of the internal combustion engine are shown in table 4.1 and table 4.2.

Table 4.1: Speciation's of the internal combustion engine of the conventional experimental system.

EH17-2D	Model
Air-Cooled, 4-Cycle, Single-Cylinder, Horizontal .T.O. Shaft, Gasoline Engine	Type
67 x 49 mm (2.64 x 1.93 in)	Bore X Stroke
172 CM^3 (10.50 cu.in).	Piston Displacement
8.5	Compression Ratio
2.6 (3.5)/3000 2.9 (4.0)/3600	(HP)/rpm KW Output (contentious)
4.4 (6.0) /4000	(HP)/rpm KW Output (Max.)
10.7 (1.09)/2600	Torque N.m Max. (kgf.m)/rpm
Counterclockwise As Viewed from P.T.O Shaft Side	Direction of Rotation
Forced Air Cooling	Cooling System
Overhead Valve	Valve Arrangement
Splash Type	Lubrication
Automobile OilSAE #20, #30 or 1OW-30 ; Class SE, SF or higher	Lubricant
0.65 L (0.17 U.S.gal.)	Capacity of Lubricant

Table 4.2: Speciation's of the internal combustion engine of the conventional experimental system.

EH17-2D	Model
Gravity Type	Fuel Feed System
3.6 L (0.95 US. gal.)	Fuel Tank Capacity
Flywheel Magneto (Solid State)	Ignition System
NGK B6HS	Spark Plug
Recoil Starter	Starting System
Centrifugal Flyweight System	Governor System
16.0 kg (35.3Ib.)	Dry Weight
299 mm (11.77 in.)	Length
3030 rnm (12.99in.)	Width
380mm (14.96in.)	Height

4.2.2 Generator

The generator that used in this project is generator for vans from man company the speciation of this generator is illustrated in the table .

4.2.3 Battery

The battery is an important part of the hybrid system, to store the power in it and restore the power when there is need for it. In this project two acid 12 volt batteries used, and connected in series to give 24 volt equivalent battery.

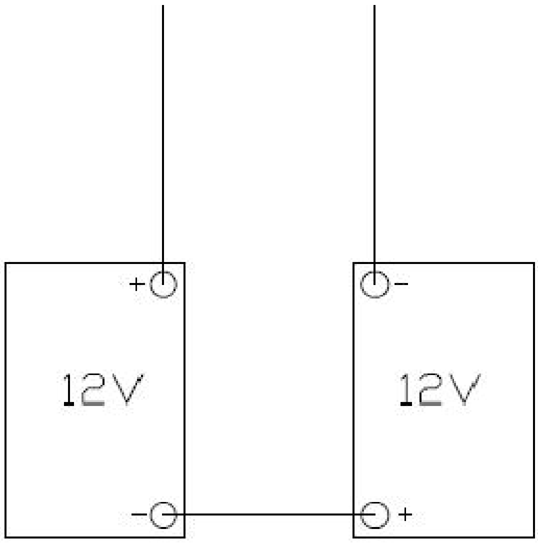


Figure 4.2: Batteries connection.

4.3 System Design:

This section show the system design, which made by using AutoCAD program to draw the views of the system as shown in figures below, then applying the design equations to make designing for the system parts.

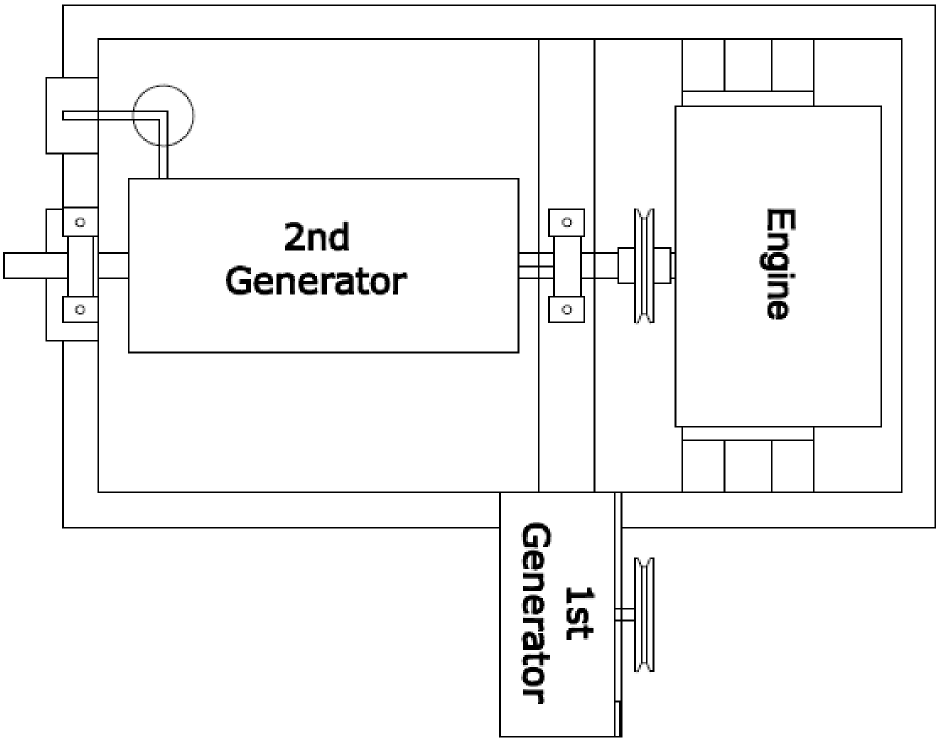


Figure 4.3: System Design Head View.

In this view we show the parts of the system, and how the arrangement of the parts on the stand.

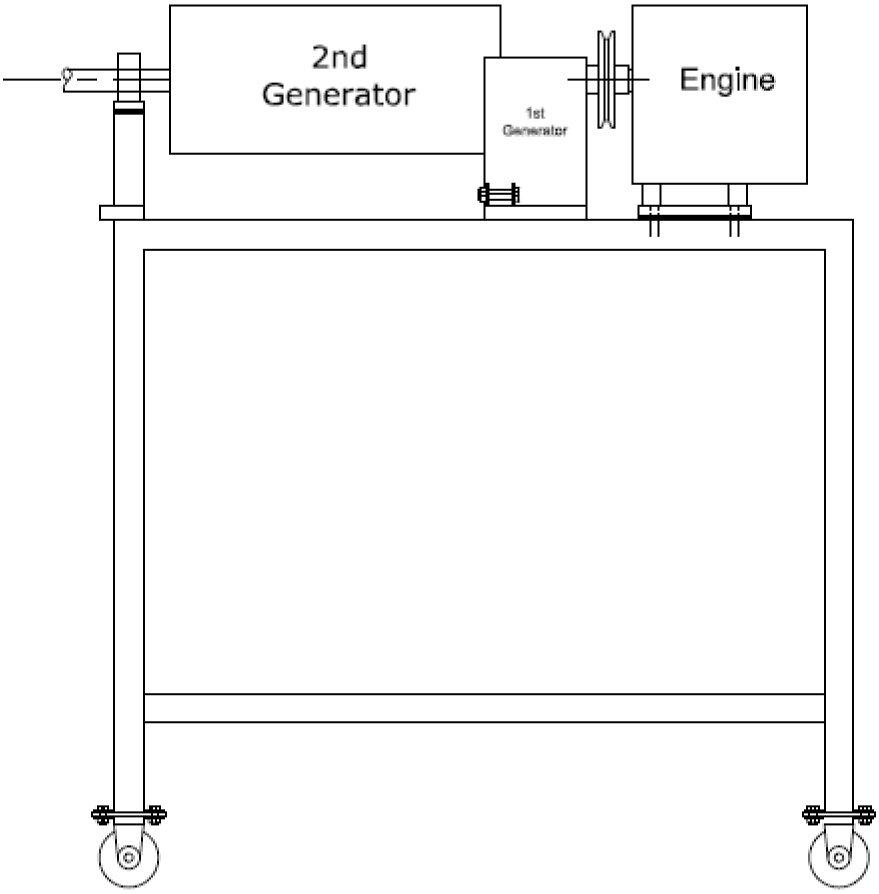


Figure 4.4: System Design Front View.

In this view we show the parts of the system, and how the parts assembled on the stand.

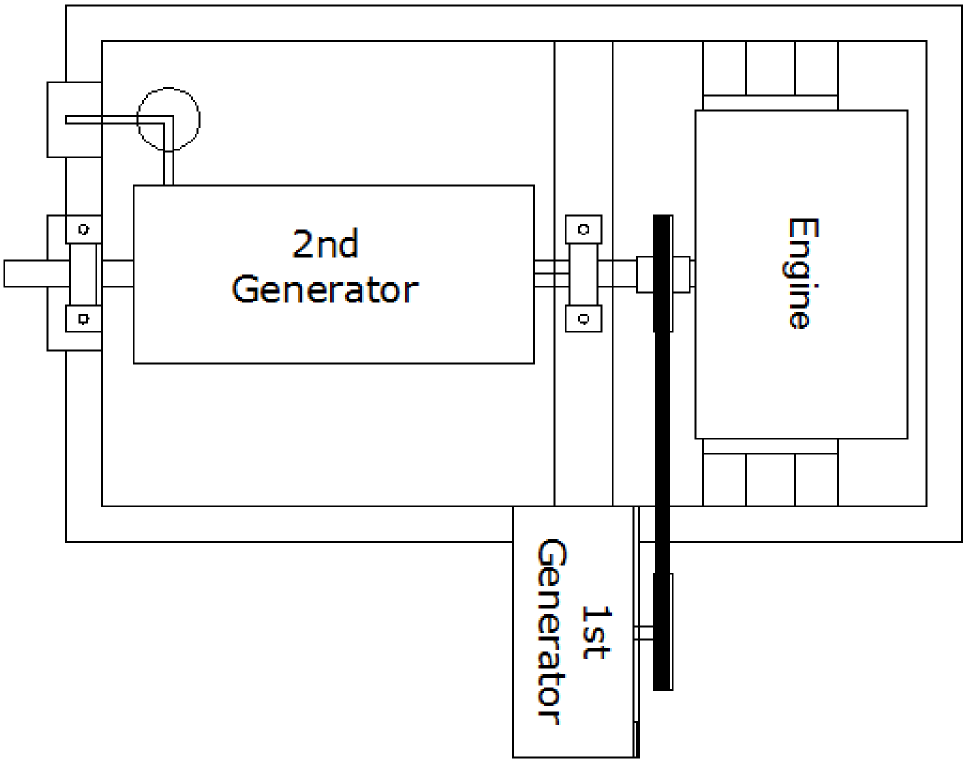


Figure 4.5 Assembled System Design.

In this view we show the parts of the system, and how the parts assembled on the stand and how they connected with each other.

4.3.1 Bolt Design:

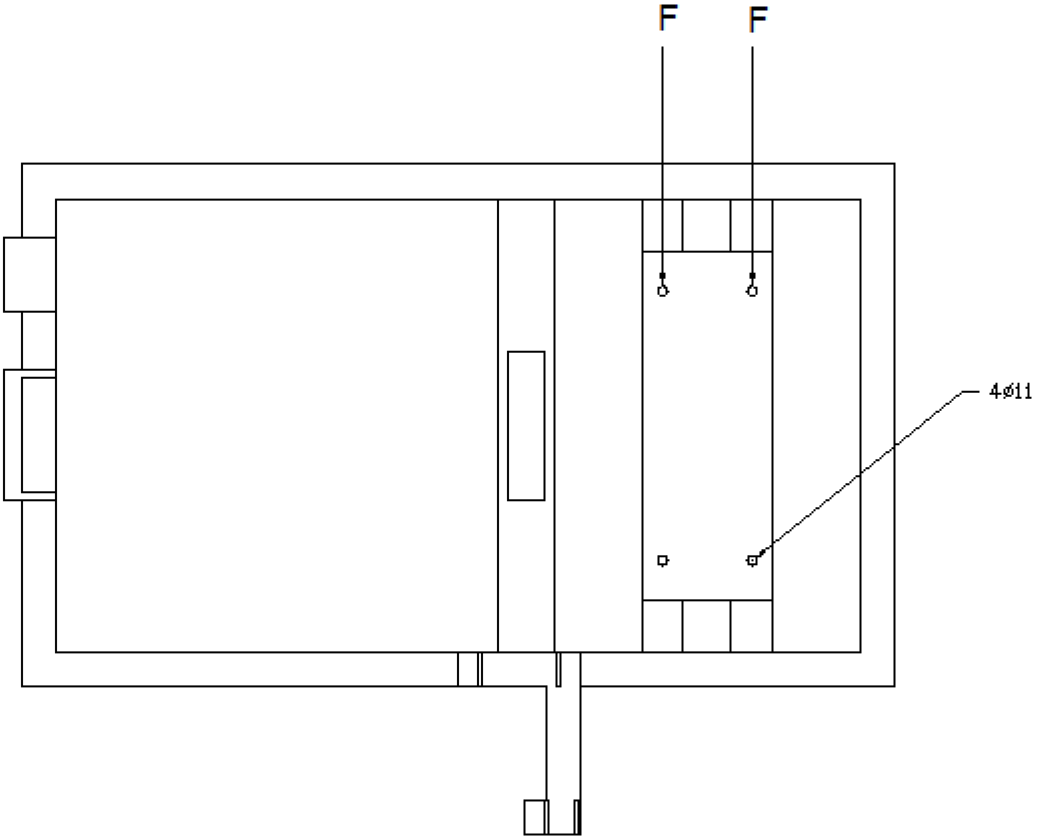


Figure 4.6: Bolt Design .

Thread length for metric-series bolts (mm):

For bolt head standards:

See tables A-29, A-30 [12]

125<L<200

$$L_T = \begin{cases} 2d + 6 & L \leq 125 \qquad d \leq 48 \\ 2d + 12 & 125 < L \leq 200 \\ 2d + 25 & L > 200 \end{cases}$$

L=36mm , d=12 mm , A_t=61.2 mm^2

$F_P = A_t S_P$

F_P=50.58KN

$F_i=0.9F_P$

F_i=45.522KN

K_b= AtE/L =484.7

$K_m = (k_1 + k_2)/k_2 k_2$

$K_m = 1.4\ 10^{\wedge -4}$

$C = kb/\ k_b + k_m$

$P_{max} = (S\ p\ At\ - Fi)/\ c$

$P_{max} = 5060N$

1)bearing in bolt ,all bolts loaded :

$\sigma = F/2td = Sp/n$

F=576Kn

2)bearing in members all bolts active:

$\sigma = f/2td = (Sy)/n_d$

F=162.24 KN

3) shear of bolt active:

$\tau = 0.577Sp/n$

3) edge shear of member:

$\tau = 0.577(Sy)_{mem}/n_d$

F=117 KN

4)Tensile yielding of member across bolt holes:

$\sigma = (Sy)_{mem}/n_d$

F=676 KN

5)Member yield:

$F = wt(s_y)_{mem}/\ n_d$

F= 1352 KN

6)Maximum shear stress in each bolt:

$\tau_{max} = F/A_t$

$\tau_{max} = 540$ MPa

7) Summarize the design in a table:

L=36mm

At= 84.3 mm^2

Fi=54.522KN.

Sp=600.

Table 4.3: Summarize design the bolts

Tensile force per bolt:	F=5.060KN
Bearing in bolt, all bolt loaded:	F=576 KN
Bearing in members, all bolt active:	F =162.24 KN
Shear of bolt, all bolt active:	F=156.6 KN
Edg shear of member:	F=117 KN
Tensile yielding of member across bolt holes:	F=676 KN
Member yield:	F= 1352 KN
Maximum shear stress in each bolt:	t max 540 MPa

4.3.2 Welding design:

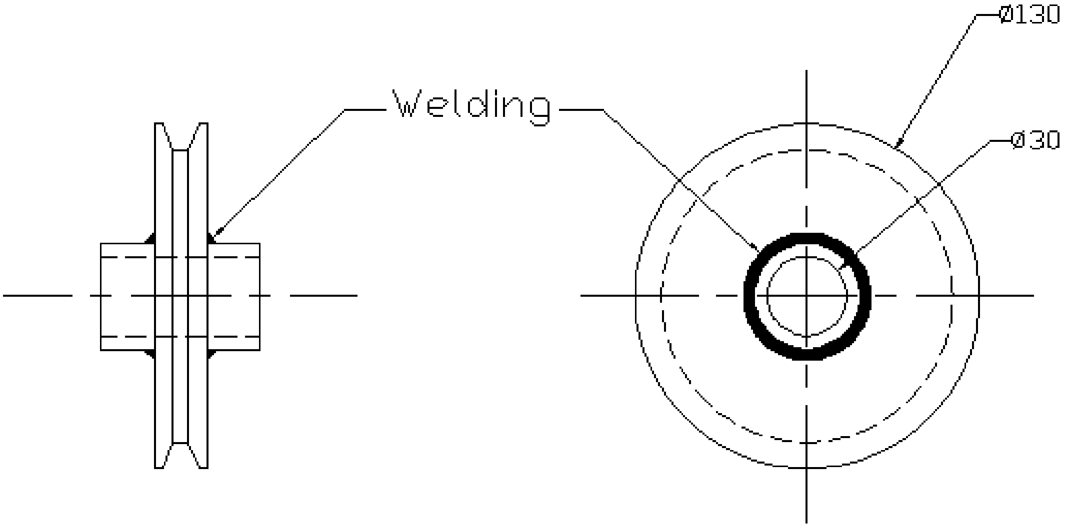


Figure 4.7: Welding Design .

Weld group geometry:

Table (9-1)[12]:

$A = 1.414\pi hr = 66.5\,h \quad mm^2$

$J_u = 2\pi r^3 = 1413.7mm^3$

$J = 0.707hJ_u \quad = 99.5h\ mm^4$

Strength of the weld :h

Table (9-3): $S_{ut} = 427$ MPa

$$\tau_{all} = 0.3S_{ut} = 0.3(427) = 128.1\ \text{MPa}$$

Load on weld group

F = 384 kN

T=10.7N.m

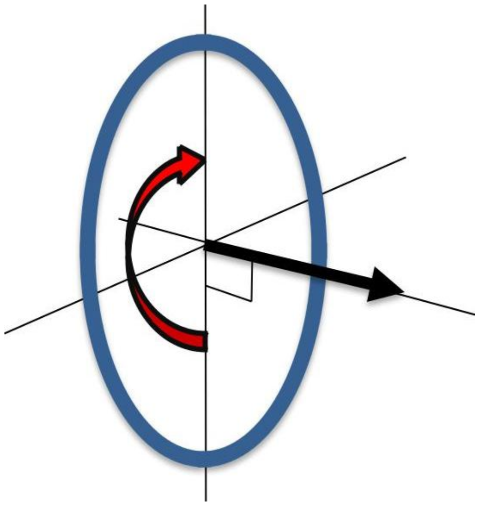


Figure 4.8: Load on Weld .

1. Primary shear:

$\tau' = F/A$

$\tau' = 774.4/\text{h}$

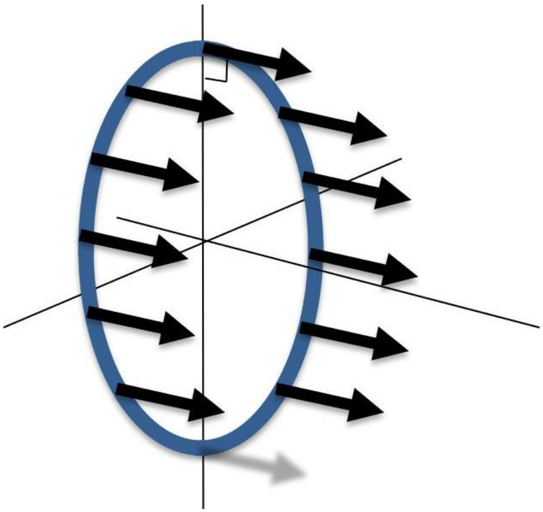


Figure 4.9: Primary Shear .

2. Secondary shear:

$\tau'' = TC/J$

$= 160.6/h$

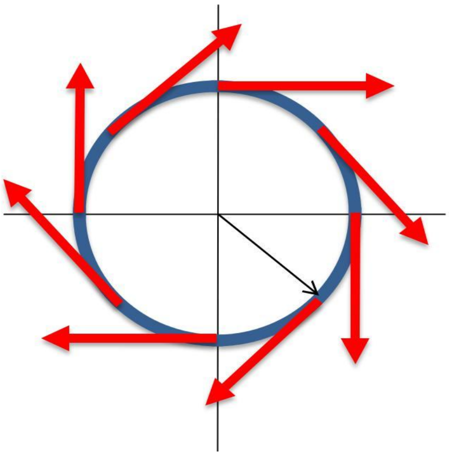


Figure 4.10: Secondary Shear .

Resultant stress at the critical point:

All points along the weldment carry same stress with magnitude:

$$\tau = (\tau'^2 + \tau''^2)^{0.5}$$
$$\tau = 5776.5/h$$

To find the weld size, *h*, set: $\tau = \tau_{all}$

h = 4mm.

Summarize the design in a table:

Table 4.4: Summarize design Weld.

Pattern	○
Electrode:	E60XX .
Electrode:	fillet weld.
Size:	4mm.
Total length:	125.6mm.
Primary shear:	t=144.36MPa.
Secondary shear:	t= 4.015 MPa.

4.3.3 V-belt design steps

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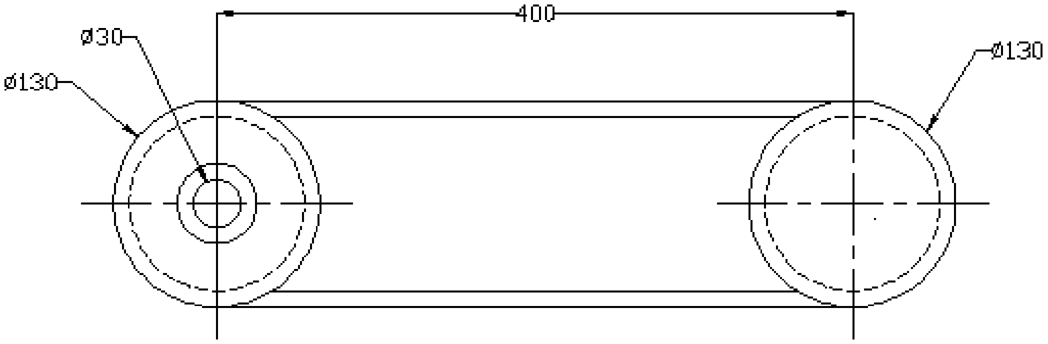


Figure 4.11: V-belt Design

Step 1. Compute the nominal speed ratio from the given speeds [12].

$$SR = \text{rpm of faster shaft/ rpm of slower shaft}$$

$$= D/d$$

$$= 1.$$

Step 2. Compute the design power H_d transmitted from the power source to the load through the belts [12].

$$H_d = K_s\, n_d\, H_{\text{nom}}$$

$$H_d = 5\text{kW}$$

Step 3**.** Select a proper belt cross section from Figures 17-1(*a*,*b*) according to the computed design power in step 1, and the faster shaft rpm, *n*.

Step 4**.** Compute the driving-sheave size limits that would produce a belt speed.

$300/\pi n \leq d \leq 1500/\pi n$

$31\text{ mm} \leq d \leq 160\text{ mm}$

Step 5. Select *standard* sheave combination (*d*,*D*) from Table 17-5

we may select : $d = 71$ mm, $D = 160$ mm

Step 6. According to the selected standard driving sheave diameter, d, and the driving rpm, n, compute the rated power, H_r of the selected belt section using Table 17-7. ($Hr = Hbasic + Hadd$) [12]

$H_r = H_{basic} + H_{add}$ =6.28 kW

Step 7. Specify a trial center distance, C, such that

$D < C < 3 (D + d)$

160mm < C < 700 mm

Therefore, let us consider , C=400 mm

Step 8. Compute the required belt pitch-length, L_p

$$L_p = 2C + \pi/2D + d) + {}^{(}D - d^{)2}/4C$$

$$=1170mm$$

$$L_i = 1170mm$$

Step 9 .Compute the ratio (D-d)/C, and enter Table 17-8 to get the angle of contact, θ, and the angle of contact correction factor, K_1. Then based on the selected standard inside length, L_i , determine the belt-length correction factor, K_2 from Table 17-9. [12]

Table 17-8: $\theta = 169°$, $K_1 = 0.97$

Table 17-9: K_2 =0.8

Step 10. Compute the allowable power per belt:

$$H_a = K_1K_2\,H_r$$

$$=4.9 \text{ kw}$$

Step 11 . Compute the number of belts, N_b, required to carry the design power:

$$N_B = H_d / H_A$$

Therefore, select $N_b = 1$ belts

Step 12. Compute the working belt tension loads; T_1, T_2, and the required belt initial tension, T_i [12].

$$T_1 = 475\text{N}.$$

$$T_2 = 36.6\ \text{N}.$$

$$T_i = 256\ \text{N}.$$

Step 13. Find the Minimum allowance; x and y for adjusting drive center distance for the belts, Table 17.3(*a*)

$$x = 15\text{mm},\ y = 15\ \text{mm}$$

Step 14. Compute the driving shaft load, F_a [12].

$$F_{a\,=}\ 600\text{N}.$$

Step 15. Summarize the design in a table:

Table 4.5: Summarize the belt design.

Input:	ICE, 4.4KW @4000 rpm.
Service factor:	1.1.
Design power	5 kw.
Belt:	AV13, 1 belt.
Center distance:	400 mm.
Belt tension:	T1=475 N. T2=36.6 N. Ti=256 N.
Minimum allowance:	X=15 m , Y=15 m
Driving shaft load:	600 N.

4.3.4 The Experiment System

The experimental system contains of the components that mentioned in the previous section, and the new generator was connected to the conventional system using v-belt, as shown in the fiugr4.3.

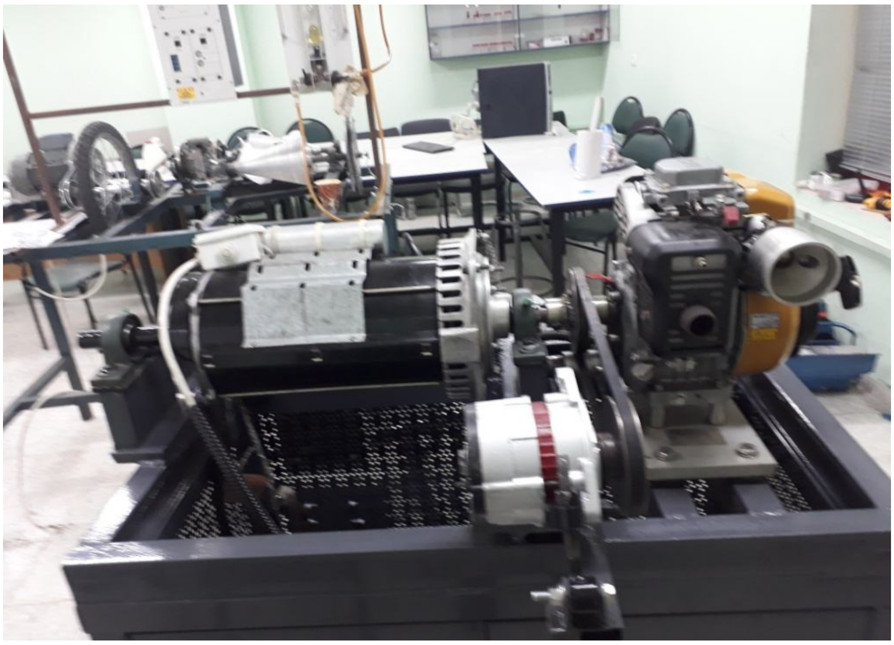


Figure 4.12: The experiment system.

CHAPTER 5

EXPERIMENTS AND RESULTS

5.1 Introduction

5.2 Experiments and Tests

5.3 Conclusions and Recommendations

5.1 Introduction

After building the experimental hybrid system, some tests and calculations done on the system, these tests and experiments are represented in the next sections, to prove the effectiveness of the hybrid system.

5.2 Experiments and Tests

There are two experiments that done ,in this section the two experiments will be shown with there's results.

5.2.1 The First Experiment

In this experiment the internal combustion engine and the generator that disconnected to the battery are working and the electrical load was three coils heater, every heater has six hundred watt power, the measurement data shown in table 5.1.

Table 5.1: Measurement Data of The Rest Experiment.

V(L) (V)	I(L) (A)	Speed of the ICE
75	3.1	2000 RPM
130	6.0	2300 RPM
170	7.5	2600 RPM
150	7.7	2800 RPM
170	7.7	3000 RPM

I(L): the input current for the load.
V(L): the input voltage for the load.

After getting these measurements, it can be calculate the output power of the input power of the load using equation (5.1).

$$P(L) = I(L) \times V(L) \tag{5.1}$$

It is necessary to know the fuel consumption in each case, to show that the cost of one watt of power in the efficient mode of the internal combustion engine, is cheaper than the one watt of power in other modes. The fuel consumption was calculated by knowing the time of using tube of 8 milliliter fuel and using this equation:

$$F(c) = (8 \times (10)^{-3})/t \tag{5.2}$$

$F(c)$: The fuel consumption (L/s).

The efficient range of the internal combustion engine used in this system is (2400-2800 RPM), this information concluded from the performance curves that shown in the previous chapter. table 5.2 show the calculations of the power and fuel consumption.

Table 5.2: Calculations of the first experiment.

Time(s)	F(c) (L/s)	P(L) (W)	Speed of the ICE
90.9	$8.80\text{x}10^{-5}$	232.5	2000 RPM
61.53	$1.30\text{x}10^{-4}$	780.0	2300 RPM
42.1	1.90x^{-4}	1275.0	2600 RPM
41.66	$1.92\text{x}10^{-4}$	1155.0	2800 RPM
40	$2.00\text{x}10^{-4}$	1309.0	3000 RPM

To calculate the cost of the one watt by fuel consumption, it can be done by dividing the fuel consumption with the total power, table 5.3 show the cost of one watt by the fuel consumption in each case.

Table 5.3: The cost of one watt by fuel consumption in different speeds in the first experiment.

The cost by fuel consumption (L/s)	Engine speed
$3.70x10^{-7}$	2000 RPM
$1.66x10^{-7}$	2300 RPM
$1.49x10^{-7}$	2600 RPM
$1.66x10^{-7}$	2800 RPM
$1.53x10^{-7}$	3000 RPM

5. 3 The Second Experiment

In this experiment the internal combustion engine and the generator that connected to the battery are working and the electrical load was via coils heater, every heater has six hundred watt power, the measurement data shown in table 5.4.

Table 5.4: Measurement data of the second experiment.

V(L) (V)	I(L) (A)	v(g) (V)	I(g) (A)	Speed of the ICE
35	0.3	27	7.7	2000 RPM
100	4.4	27	8.7	2300 RPM
130	5.7	27	8.8	2600 RPM
90	4.0	27	7.8	2800 RPM
120	5.6	27	7.86	3000 RPM

I(g): the output current of the generator. v(g): the output voltage of the generator.
I(L): the input current for the load.
V(L): the input voltage for the load.

After getting these measurements, it can be calculate the output power of the generator and the input power of the load using equation (5.3),(5.4).

$$P(g) = I(g) \times V(g) \tag{5.3}$$

$$P(L) = I(L) \times V(L) \tag{5.4}$$

The total power can calculated by :

$$P(T) = P(g) + P(L) \tag{5.5}$$

It is necessary to know the fuel consumption in each case, to show that the cost of one watt of power in the efficient mode of the internal combustion engine, is cheaper than the one watt of power in other modes. The fuel consumption was calculated by knowing the time of using tube of 8 milliliter fuel and using this equation:

$$F(c) = (8 \times (10)^{-3})/t \qquad (5.6)$$

$F(c)$: The fuel consumption (L/s).

The efficient range of the internal combustion engine used in this system is from 2400 rpm to 2800 rpm, this information concluded from the performance curves that shown in the previous chapter. table 5.2 show the calculations of the power and fuel consumption .

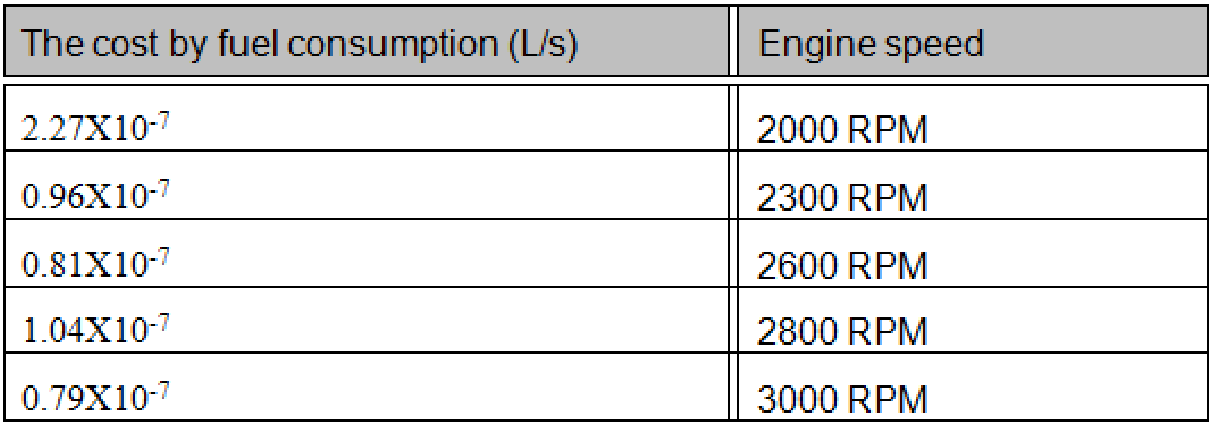
Using the output power of the generator and the input power of the load and the fuel consumption, are calculated and shown in table 5.5.

Table 5.5: Calculations of the second experiment.

Time(s)	$F(c)$ (L/s)	$P(T)$ (W)	$P(L)$ (W)	$P(g)$ (W)	Speed of the ICE
78.43	1.02×10^{-4}	218.40	10.5	207.90	2000 RPM
57.14	1.40×10^{-4}	674.90	440	234.90	2300 RPM
43.47	1.84×10^{-4}	978.60	741	237.60	2600 RPM
44.4	1.80×10^{-4}	570.60	360	210.60	2800 RPM
45.9	1.74×10^{-4}	889.22	672	212.22	3000 RPM

To calculate the cost of the one watt by fuel consumption, it can be done by dividing the fuel consumption with the total power, table 5.6 show the cost of one watt by the fuel consumption in each case.

Table 5.6: The cost of one watt by fuel consumption in different speeds in the second experiment.



The cost by fuel consumption (L/s)	Engine speed
$2.27X10^{-7}$	2000 RPM
$0.96X10^{-7}$	2300 RPM
$0.81X10^{-7}$	2600 RPM
$1.04X10^{-7}$	2800 RPM
$0.79X10^{-7}$	3000 RPM

Efficiency calculations:

$$BP = \frac{2\pi . N . T}{60000} \qquad (5.7)$$

$$\omega = \frac{N . 2\pi}{60} \qquad (5.8)$$

$$P_m = T . \omega \qquad (5.9)$$

$$\eta = \frac{P(T)}{BP} \qquad (5.10)$$

BP: The engine brake power(KW).

N: The engine speed(RPM).

T: The engine torque(N.M).

ω: The engine speed(rad/s).

Pm: The engine mechanical power(KW)

η= the system total efficiency.

Table 5.7: The efficiency value at each engine speed.

Engine speed	Efficiency(η)
2000 RPM	51
2300 RPM	55
2600 RPM	56
2800 RPM	75
3000 RPM	62

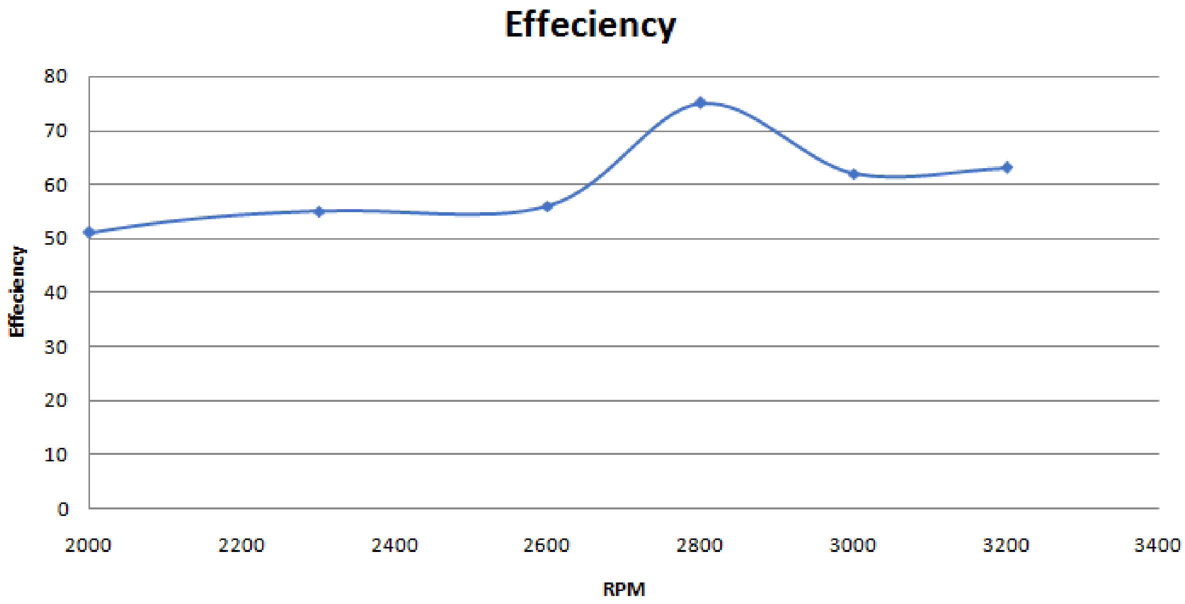


Figure 5.1: Curve of Efficiency versus Engine Speed

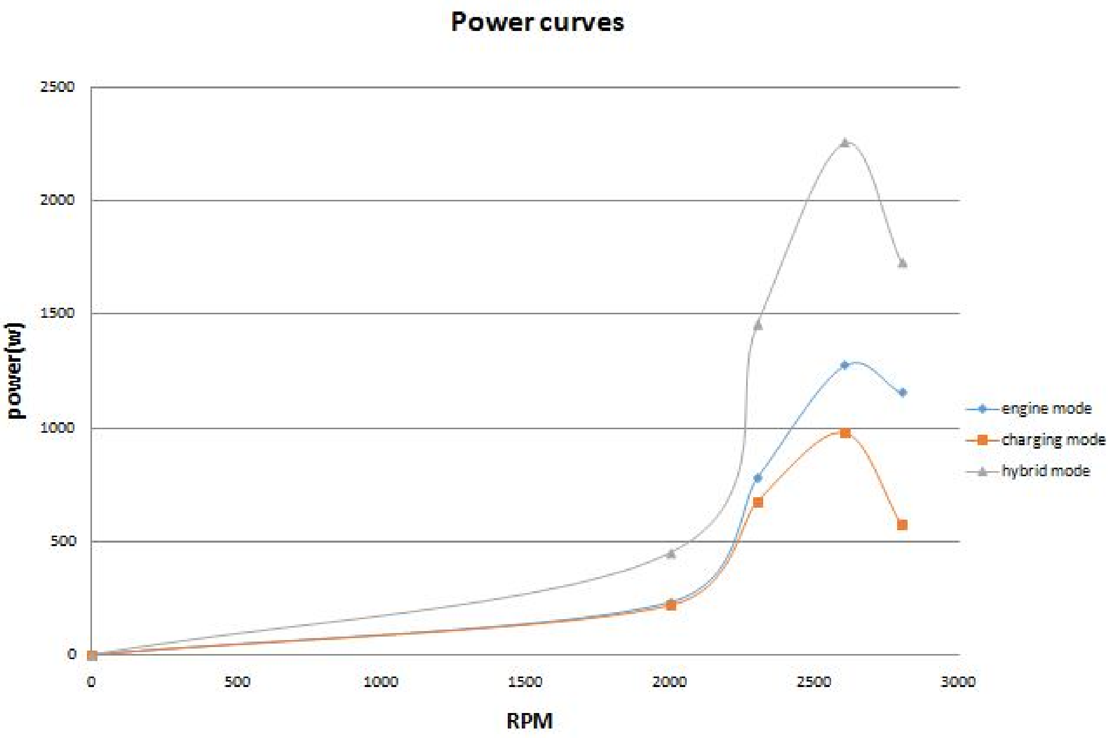


Figure 5.2: Curve of Power versus Engine Speed

5.3 Conclusions and Recommendations

The aim of this project is to prove that the power that will be stored in the batteries is a cheap power, after doing the two experiments, the numbers prove that this assumption is a fact, because the less fuel consumption was in the e efficient range of the engine (2400-2800 RPM). to achieve the Benefit of the hybrid system, the engine must work in the efficient range and store the redundant power in battery and use this power when there is need for it.

It is recommended to :

(a) Using a DC motor/generator instead of a van generator and use a suitable control system.

(b) Doing a simulation for the hybrid system using computer software like Matlab.

(c) Insert this project to course plane of internal combustion engines course .

(d) Provide a special internal combustion engine for the hybrid system.

(e) Improve the hybrid system to be plug-in hybrid system.

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