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Optimization of the Electrical Motor Generator in Hybrid Automobiles

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Abstract

The development of internal combustion engine vehicles especially automobiles, is one of the greatest achievements of modern technology. However, the large number of automobiles in use around the world has caused and continues to cause serious problems for the environment and human life. Air pollution, global warming, and the rapid depletion of the Earth's petroleum resources are now problems of paramount concern. Automobile hybrid systems combine any two or more motive 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 shortcomings, resulting in highly efficient driving performance. The hybrid automobiles have many problems in electrical motor generator, such as low power and low charging to hybrid vehicle battery.

Keywords: hybrid systems, electrical motors, generators, batteries

1 INTRODUCTION

There are many types of hybrid arrangements: series and parallel, in series arrangements: the engine drives a generator, and an electric motor uses this generated electricity to drive the wheels. This is called a series hybrid system because the power flows to the wheels in series. As shown in **Figure 1**, series hybrid system can run a small output engine in the efficient operating region relatively steadily, generate and supply electricity to the electric motor and efficiently charge the battery. It has two motors a generator (which has the same structure as an electric motor) and an electric motor. This system is being used in the Coaster Hybrid. [7, 5, 4]

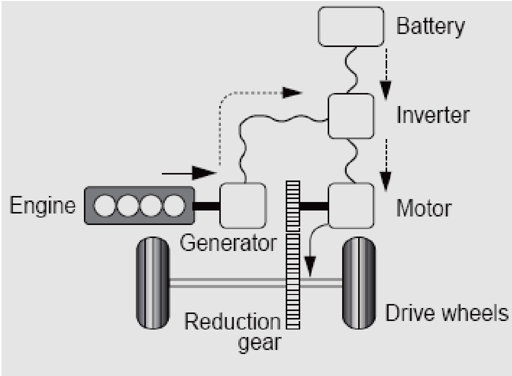

Fig. 1: Series Hybrid Drive Construction

-Parallel Hybrid System

In a parallel hybrid system, both the engine and the electric motor drive the wheels, and the drive power from these two sources can be utilized according to the prevailing conditions. This is called a parallel hybrid system because the power flows to the wheels in parallel. As illustrated in **Figure 2**, the battery is charged by switching the electric motor to act as a generator, and the electricity from the battery is used to drive the wheels. Although it has a simple structure, the parallel hybrid system cannot drive the wheels from the electric motor while simultaneously charging the battery since the system has only one motor. [7, 5, 4]

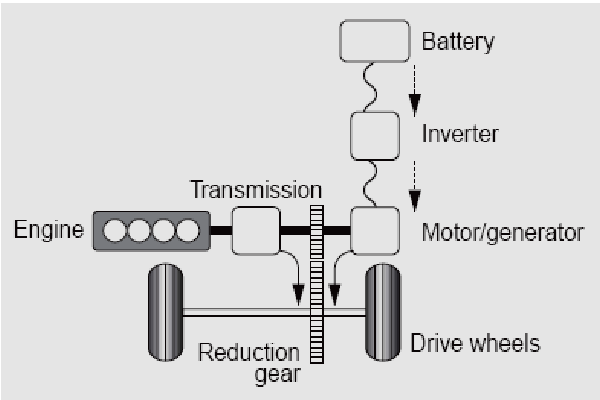

Fig. 2: Parallel Hybrid Drive Construction

-Series/Parallel Hybrid System

This system combines the series hybrid system with the parallel hybrid system in order to maximize the benefits of both systems. **Figure 3** shows that the parallel hybrid system has two motors, and depending on the driving conditions, uses only the electric motor or the driving power from both the electric motor and the engine, in order to achieve the highest efficiency level. Furthermore, when necessary, the system drives the wheels while simultaneously generating electricity using a generator. [7, 2, 3]

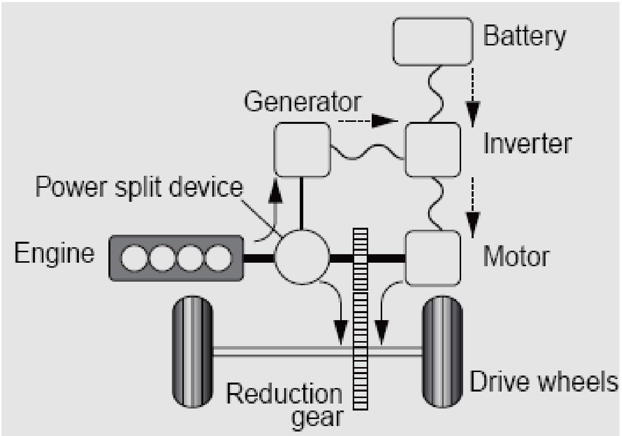

Fig. 3: series/parallel hybrid drive construction

Many researches discuss the issue of hybrid generation systems, C. Boccaletti, et al. (2006), focused on the modeling and simulation of Solid Oxide Fuel Cell (SOFC) and Gas Turbine (GT) hybrid systems for Distributed Generation. Independent dynamic models of the main components of the systems have been realized and implemented in the Matlab-Simulink environment. The models have been used to simulate the behavior of two plant configurations. Control methodologies have been analyzed and numerical results are provided, [5]. Yuliang Leon Zhou, (2007), two hybrid vehicle power train technologies were studied, a fuel cell - battery hybrid and two internal combustion engine - battery/ultra-capacitor hybrids. Power train performance models were built to simulate the performance of these new designs, and to assess the feasibility of a fuel cell hybrid power backup system for a special type of vehicles, elevators in high-rise buildings, using the ADvanced VehIcle SimulatOR (ADVISOR) first. The model was then applied to evaluate the two-mode hybrid power train for more common vehicles - commercial trucks, showing potential fuel consumption reduction. To improve modeling accuracy, a new and more flexible tool for modeling multi-physics systems, Modelica/Dymola, was used to carry out the modeling and analysis of next generation hybrid electric vehicles, exploring the potentials of new hybrid power train architectures and energy storage system designs. The study forms the foundation for further research and developments[2].

Modes of Operations

A typical full hybrid drive system has five basic modes of operation:

1. Start and low to mid-range speeds.
2. Driving Under Normal Conditions.

3. Sudden Acceleration.
4. Deceleration.
5. Battery Recharging.

-Start and Low to Mid-Range Speeds

The engine stops when in an inefficient range, such as at start-up and in low to mid-range speeds. The vehicle runs on the motor alone. See (Figure 4). [6]

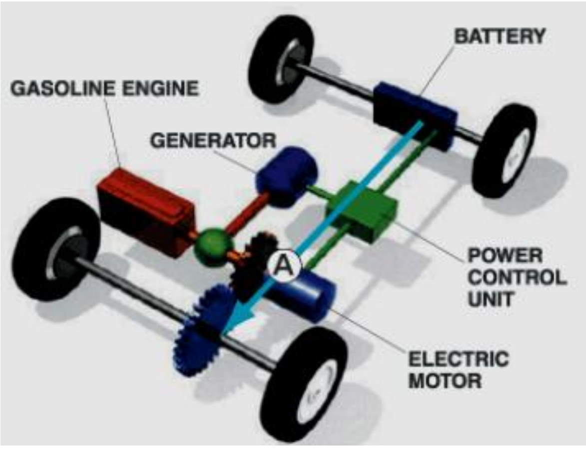

Fig.4*:* Start and Low to Mid-Range Speeds Mode

- Driving Under Normal Conditions

Engine power is divided by the power split device. Some of the power turns the generator, which in turn drives the motor. (B), the rest of the power drives the wheels directly. (C) Power allocation is controlled to maximize efficiency. See **(Figure 5)**. [8,6]

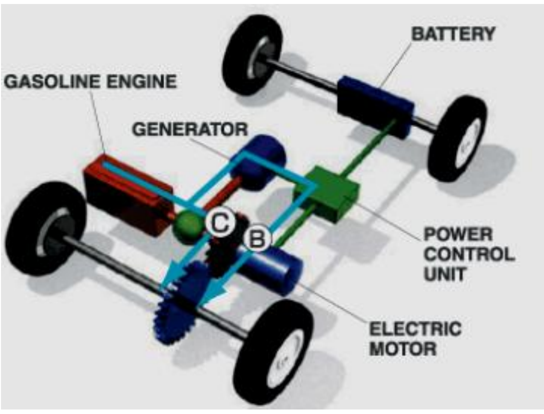

Fig.5: Driving Under Normal Conditions Mode

- Sudden Acceleration

Figure 6 shows the Sudden Acceleration mode, Extra power is supplied from the battery (A), while the engine and high-output motor provide smooth response (B+C) for improved acceleration characteristics. [8,6]

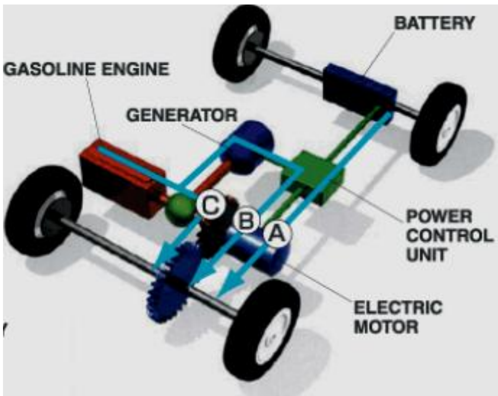

Fig.6: Sudden Acceleration Mode

- Deceleration

The high-output motor acts as a high-output generator, driven by the vehicle's wheels. This regenerative braking system recovers kinetic energy as electrical energy, which is stored in the high-performance battery. See (**Figure 7).** [6, 2]

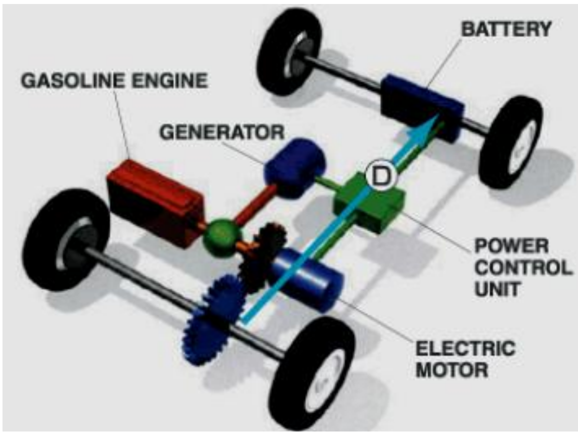

Fig.7: Deceleration Mode

- Battery Recharging

Battery level is managed to maintain sufficient reserves. See **(Figure 8)**, the engine drives the generator to recharge the battery when necessary, [6].

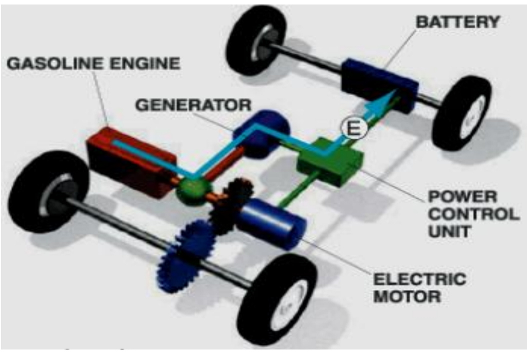

Fig.8: Battery Recharging Mode

-Motor Generator of Hybrid Vehicle

Type of motor generator in hybrid vehicle:

1- Motor generator one MG1.
2- Motor generator two MG2.

MG1 and MG2 function as both highly efficient alternating current synchronous generators and electric motors, MG1 and MG2 also as sources of supplemental motive force that provide power assistance to the engine as needed. Both the MG1 and the MG2 are compact, lightweight, and highly efficient alternating current permanent magnet synchronous type. [10]. Serving as the source of supplemental motive force that provides power assistance to the engine as needed, the electric motor helps the vehicle achieve excellent dynamic performance, including smooth start-offs and acceleration. When the regenerative brake is activated, MG2 converts the vehicle's kinetic energy into electrical energy, which is then stored in the HV battery. [10]. MG1 recharges the HV battery and supplies electrical power to drive MG2. In addition, by regulating the amount of electrical power generated (thus varying the generator's rpm), MG1 effectively controls the continuously variable transmission function of the transaxle. MG1 also serves as the starter to start the engine. A cooling system via water pump for the MG1 and MG2 has been added. See (**Figure 9)** A and B. [10]

Fig. 9 A: MG1 generates electrical power and starts the engine.

Fig. 9 B: MG2 drives the vehicle.

Electrical Model

Synchronously rotating reference frame can be used in design optimization and evaluation. In this model the flux distribution in the air gap is assumed to be sinusoidal and the iron loss and magnetic saturation are not considered.

The motor vector diagram is shown in **(Figure 10).** Voltage equations are expressed as follows:

$$V\ sin(\delta) = i_d\ R_1 + \omega i_q\ L_q$$

$$V\ cos(\delta) = i_q\ R_2 + \omega i_d\ L_d + E_f$$

The motor torque is then obtained as:

$$T = \frac{3P}{2}\left(\Psi_M + \left(L_d - L_q\right)i_d\right)i_q$$

Where $\boldsymbol{i_d}$ and $\boldsymbol{i_q}$ are the ***d***-axis and ***q***-axis components of the stator current vector ***Is***.

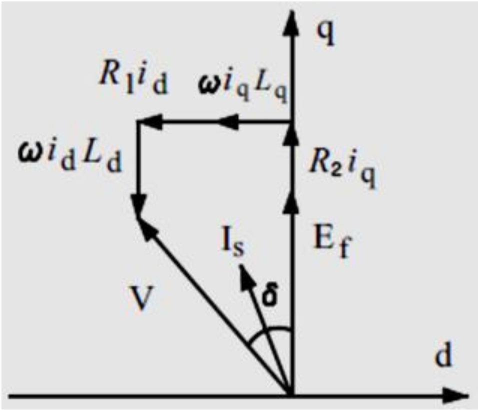

Fig. 10: Vector diagram of PMSM

Thus the magnitude of $\boldsymbol{I_S}$ is given by:

$$l_s = \sqrt{{i_d}^2 + {i_q}^2}$$

Since a PM motor torque depends on the stator current vector components as well as the motor parameters, the design optimization is carried out under the condition of maximum torque per Ampere control. This condition can be as obtained from last equations such as:

$$i_d = \Gamma - \sqrt{\Gamma^2 + \frac{{l_s}^2}{2}}$$

$$i_q = \sqrt{{l_s}^2 - {i_d}^2}$$

Where:$\Gamma = \frac{\Psi_M}{4L_s}(\rho - 1)$and

$$\rho = \frac{L_q}{L_d}$$

As mentioned above, maximum speed and cost of motor is chosen for optimization. The price of permanent magnet is very high in comparison with other material of PMSM. Therefore we can approximately use consumed magnet volume instead of motor cost.For HEV applications the case of **b** is the best case see **(figure 11).** Therefore in the optimization we should keep normalized flux linkage to normalized direct inductance close to one.

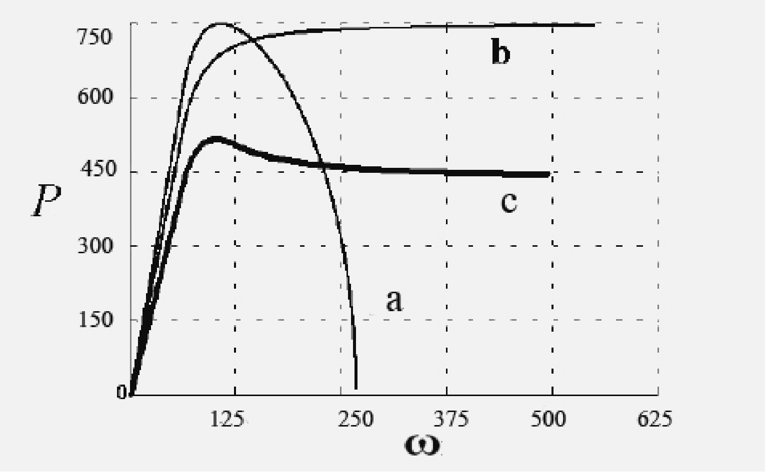

Fig.11: torque diagram for all motor generators a) $\frac{\Psi_M}{Ldn} > 1$, b) $\frac{\Psi_M}{Ldn} = 1$, c) $\frac{\Psi_M}{Ldn} < 1$

- Power Calculations

The mechanical power for the motor generator is :

$Pmec = T \times w$

where T is torque motor and w is angular velocity .The electrical power for the motor generator is :$Pelc = V \times I$

where V and I are the voltage and current motor generator respectively.

When the power is transfer from the electrical mode to the mechanical mode, the few losses occur thus the electrical power greater than the mechanical power.

$Pelc = Pmec + losses$

Note: *Assume the losses equal zero, then the electrical power equal mechanical power.*

2 RESULTS AND DISCUSSION

Figure 12 shows relation between power and motor angular speed it can be noticed that steady state power value closes to 67.75 KW.

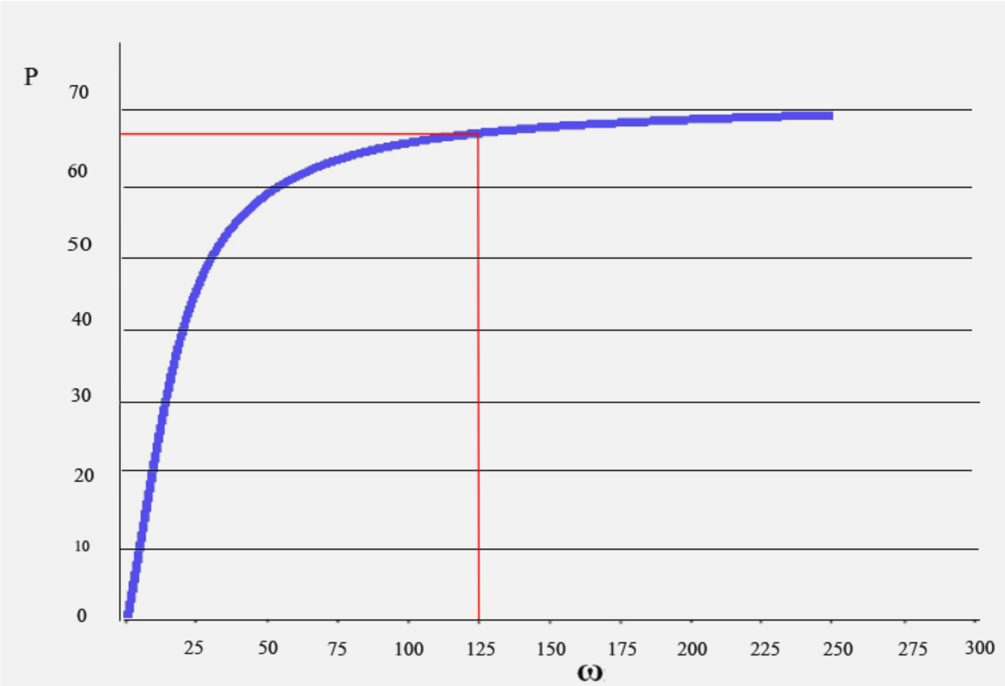

Fig.12: torque diagram for optimized motor generators

The main idea here is to make use of the mechanical motion that produces the rotational motion for the wheels, by converting this mechanical energy into electrical energy. And supply the motor generator 2 (MG2) with this electrical power. This way we raise the motor generator efficiency and reduce the work of the internal combustion engine **figure 13**.

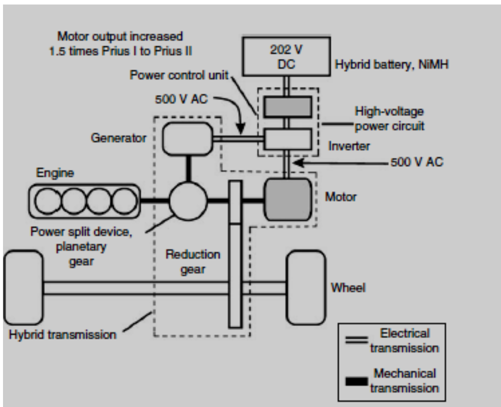

Fig.13: hybrid system

The hybrid vehicle works on two different power resources or more; in our project they are the electrical engine and the gasoline engine. Determining of which of these two different engines would be used at a given time depends on operating environment and the vehicle load. In short, when we have heavy loads, the electrical engine cannot provide enough power, so the internal combustion engine works at this time and provide the necessary power for the vehicle since the gasoline engine is capable of providing much more power see table 1.

Table 1: power and torque for engine and MG

	Engine	MG	Engine+ Mg
Torque	57 kW	50 kW	478
Power	115 N.M	400	82

The goal behind this study is to reduce fuel consumption which is non-renewable energy source, and produces pollution when burns, which negatively affect the environment. Making the electrical engine to work with higher efficiency means that it is capable of moving the vehicle in harsh working conditions without the need to activate the internal combustion engine.

-New idea

The vehicle movement on the road is done by rotating the wheels, where the power that is produced by the electrical engine or by the gasoline engine transforms into rotational movement. We used this rotational movement to generate electrical power through the principle of electric induction **(Figure 14)**, where the electrical coils and the rotational parts on the wheel are used to generate electrical force. The type of the generated force is alternative current – 3 phases (AC-3ph).

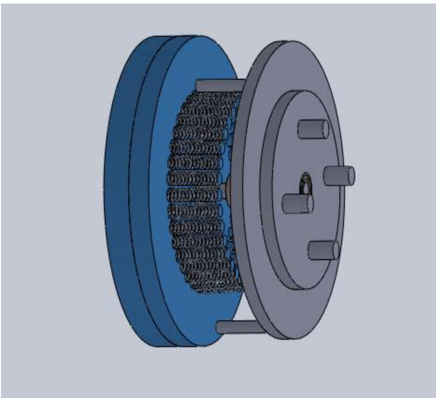

Fig.14: motor generator

The end of axial that is out of the gear box is attached to the disk. We added three small poles on the wheel flange and cylindrical plate (disk break) that have the coils - the fixed part. When adding a coil on the fixed part and other coils on the rotor part then introduced an inflammatory current to the stator coil an inductive current arises in the rotor coils. The field lines (flux) intercut and provide an alternative current in these coils – electrical principle, **(Figure 15)** the introduction of the inflammatory current to the coils is done by using slip rings with 12 volts from the auxiliary battery. And we used it for safety connection to the coils.

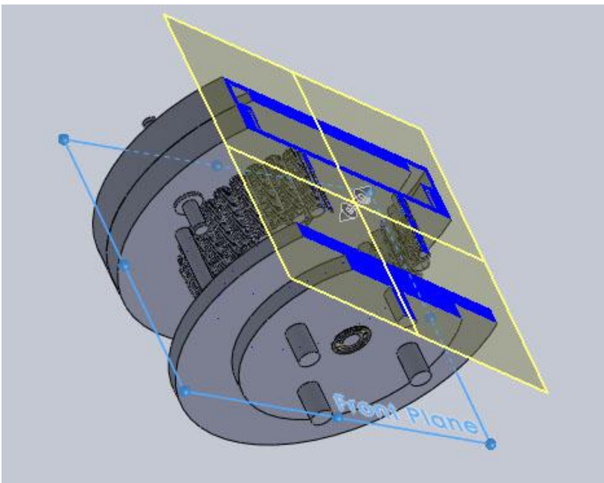

Fig.15: motor generator front section

The generated output current is directly proportional with the wheel revelation per minute (RPM). And this is alternative current 3 phase. Because the wheel rotation (RPM) is not constant, the generated current is inconstant in frequency and amplitude. So we cannot use this current to move any type of electrical motors since all the motors works on constant frequency and constant amplitude. In order to solve this problem we designed an electrical circuit (inverter) to get constant frequency and constant amplitude see **(Figure 16)**. This is done by inverting the alternative current to direct current by using diodes and then storing the new output in a storage (battery) and then return it to alternative current 3 phase, so it can be used for different purposes.

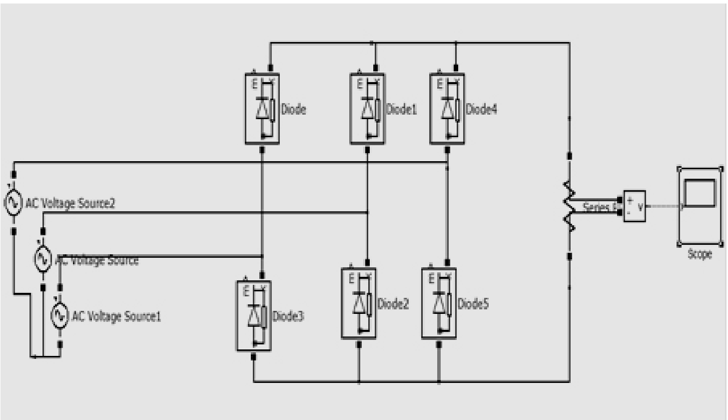

Fig.16: inverter circuit

The generated signal from the previous inverter is a square wave, and this is another problem, because the motor generator gives more efficiency if the signal is sine wave, so we designed an electrical circuit (converter), to convert the square wave into a sine wave; see **(Figure 17 A and B)**.

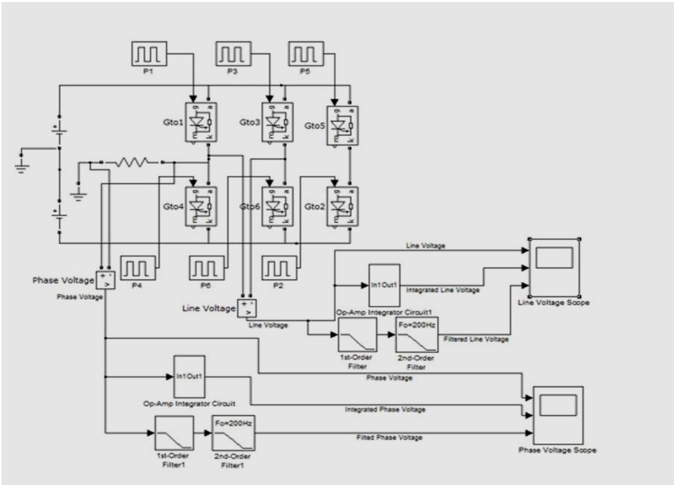

Fig. 17 A: integrator - converter circuit

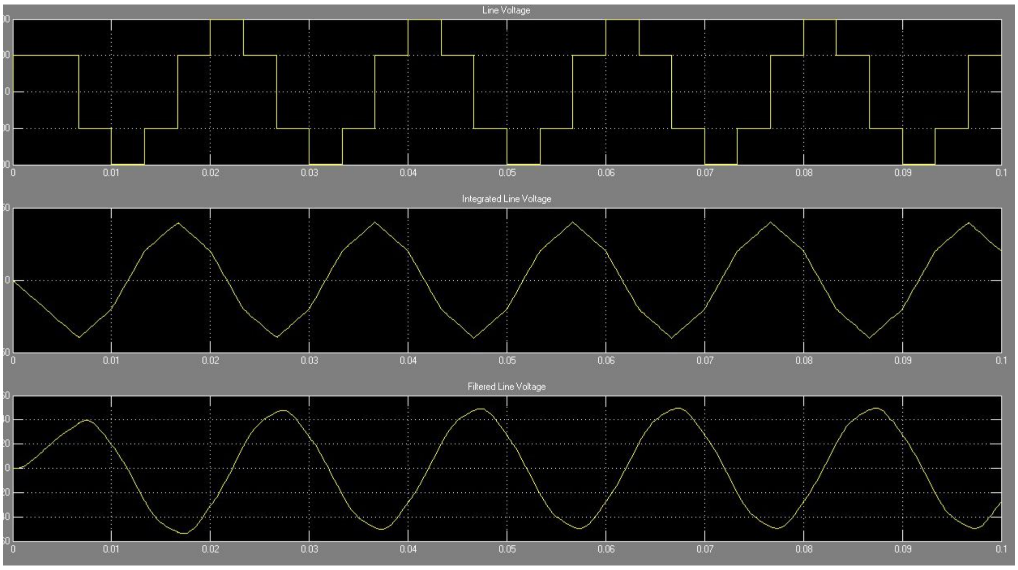

Fig. 17 B: converting from square wave to sine wave

3 CONCLUSIONS

Through the calculations on both typical and optimized, it can be noticed that the typical motor achieved the case of (c) and optimized motor achieved the case of (b) , and during our study of torque diagram, the optimized motor is the best than the typical motor , because fast and steady of responsibility. It can concluded from during applied equation on the typical and optimized motor that power, voltage and torque motor in optimized motor greater than the typical motor, thus the optimized motor better than the typical motor. Hybrid vehicles combine the advantages of the traditional and electric vehicles. The machines are fed from AC sources and can be single-phase or multiple-phase types. Single-phase AC machines are used for low-power appliance applications, while higher-power machines are always of three-phase configuration. The motor drive must be capable of handling voltage fluctuations from the source. Another important requirement of the electric motor is acceptable mass production costs, which is to be achieved through technological advancement. The primary difference between AC machines and DC machines is that the armature circuit of the former is located in the stationary piece of the structure. The major advantage of this arrangement is the elimination of the commutator and brushes of DC machines.

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