International Journal of Engineering & Technology, 7 (3.17) (2018) 85-89

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Experimental Investigations on Hybrid Vehicle

Khalid G. Mohammed

University of Diyala, Iraq
**Corresponding author Email: khalid_alkaisee@engineering.uodiyala.edu.iq*

Abstract

Electric driving is one of the main courses in energy science. It represents the relationship between an electric motor as a tool to convert electrical energy into mechanical energy and between a managed or mechanical device that drives it through belts or gears. In the current research, a three-phase synchronous motor 1200 Watt was used to drag an electric vehicle with a rated load of 150 kg and at a speed of up to 40 km per hour. Transmission from the electric motor to the vehicle's tires is done through a gear to rotate the wheels of the vehicle. Batteries are used to store continuous electrical power from a 220-volt alternating power source using the DC/AC inverter. Solar energy 150 Watt has also been used by using a solar panel placed on the roof of the vehicle. Mechanical energy has also been used by mechanical pedal. The vehicle was tested on a flat and sloping road in Baquba / Diyala province / Iraq. The efficiency tests proved the acceleration and balance of the car are good and matched with the theoretical calculations.

Keywords: *Electric Vehicle; Hybrid; Solar and Mechanical.*

1. Introduction

The model of an electric vehicle is very complex as it contains many different components [1]. Transmission, electric machine, power electronics, and battery. Each component needs to be modeled. The design or rating of each component is a difficult task as the parameters of one component affect the power level of another one. There is therefore a risk that one component is rated inappropriate which might make the vehicle unnecessary expensive or inefficient. In this research a method for designing the power system of an electric vehicle is presented. The method insures that the requirements due to driving distance and acceleration is fulfilled.
The general electrical mechanical properties required for the traction motors are a large torque during the start of the movement and acceleration have been needed by electric locomotive to power large traction for acceleration required [2]. In addition to the traction force necessary to overcome the resistance to the movement of the train, while being only during the starting traction required at a constant velocity traction force necessary. During the movement on the highest slope levels, it is needed to extra traction to overcome the influence of gravity in addition to the additional powers which are bound to make a great motor torque during the start to get the big traction power required during the period of the start of the movement.There are several types of electric motors used in electric traction [3], at least three recommended types: Direct Current Motor (DCM), Induction motor (IM) and Synchronous Motor (SM). These motors have distinguished features depending on the nature of voltage supplied source, performance, the method of installation.

2. Design of Vehicle

The required torque for moving one or two vehicle ride persons by means of vehicle gear box assembly is subjected to many rules. Some of these rules are linked with tires, friction, wind resistance, weight and level inclination [4]. Fig.1 explains the design flowchart of the vehicle.

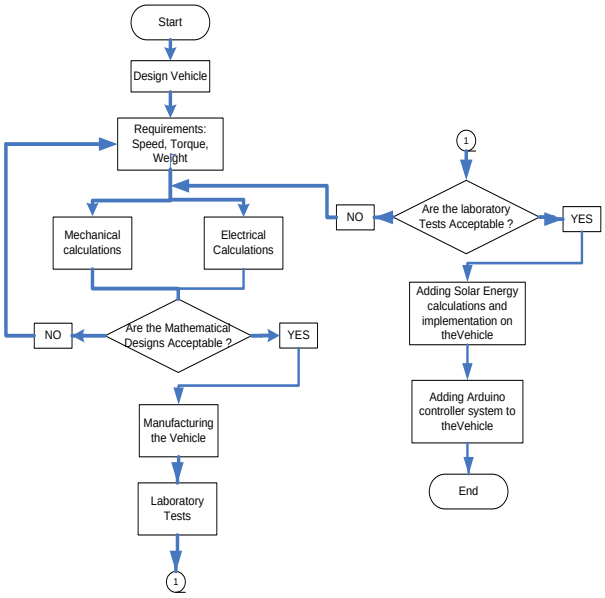


Fig.1: Flowchart of the vehicle design.

A tire under load will deform and flatten till the contact area with the ground will accept a force equal to the load on same wheel. When the wheel rolls the resulting force at contact is not any more centered but placed at a distance: this is the lever arm required to compute the needed torque on the wheel to overcome the resistance by rolling (it is not the wheel radius). The friction coefficient between rubber and ground is only needed to determine the maximal torque before sliding. This could occur in case of a very high torque at start when the vehicle inertia plays an important role. Tires deformation requires energy and tires have an internal friction (hysteresis) which you can feel after drive tires heat up.

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The motor should supply the torque but also the energy to overcome all loses. If for instance two wheels are active, the rolling resistance and other losses are present on all four wheels even if the torque is applied only on two. Since rolling resistances are not linear their sum should consider load distribution on the different axes and wheels. All before are valid for a flat horizontal ground. If the path makes an angle the weight projection F= G*sin (angle) has to be considered as load. Here the friction coefficient between tire and ground becomes an important parameter since even if the engine is able to supply the torque (this time load x flattened tire "radius") the vehicle will only progress if the adherence limited torque is greater than wheel torque. It should be considered as well the aerodynamic resistance which is small but unneglectable even at such small speeds.

3. Mathematical Model

The necessary traction force on the wheel of the vehicle is F_t. The force F_t generated on the edge of the wheel of the vehicle is to move the tractor itself and the wheeled vehicles. The traction required for the vehicle on the ground level is given by Eqn. (1).

$$F_t=F_a+F_r \quad (1)$$

If the vehicle is moving at an inclined level can be expressed by Eqn. (2).

$$F_t=F_a+F_r+F_g \quad (2)$$

The force required for the linear acceleration of the train is F_a. Required force to overcome the strength of resistance to train traffic is F_r. Power needed to overcome the effect of earth gravity is F_r. The positive signal is used when the train goes up to the slope level while the negative signal is used if the train falls to the slope level.

3.1 Calculating the Required Force for Acceleration

The effect of the motion of F_a Newton on a mass of m kg and its weight W Newton, the value of the linear acceleration produced is determined by (3).

$$F_a = m_w * a \quad (3)$$

Since the vehicle contains rotary parts, such as pedals, axes, actuators, gearbox, etc., the equivalent mass of the m_e vehicle increases by 10% to 20% from the static mass of the train as expressed by (4).

$$F_a = m_e.\ a = (We / g)\ a \text{ Newton} \quad (4)$$

If the mass is equivalent in kilograms, F_a is denoted in Newton and the acceleration is in meters / sec^2.

3.2 Calculating the Strength Needed to Overcome Resistance of Vehicle

The strength of the resistance to the vehicle movement includes all the forces that are opposed to the movement,
Namely: mechanical resistance such as friction in the axles and in the wheels of movement, etc. It does not depend on the speed of the vehicle, but depends on the mass of the vehicle only. Wind resistance proportional to the vehicle speed box. Assuming that r is the quality resistance of the vehicle which means the opposite force to move the vehicle in (N (newton) / t (kg)) of the vehicle mass as shown by (5).

$$F_r = m\ (kg) * r\ (Newton / kg) = m*r \quad \text{Newton} \quad (5)$$

3.3 Calculating the Strength Needed to Overcome the Effect of Gravity

If the vehicle goes uphill at an angle Θ as shown in Fig.2, then the force F_g is resolved to two components and will be affected by the height axis $Sin\Theta$ as expressed by (6).

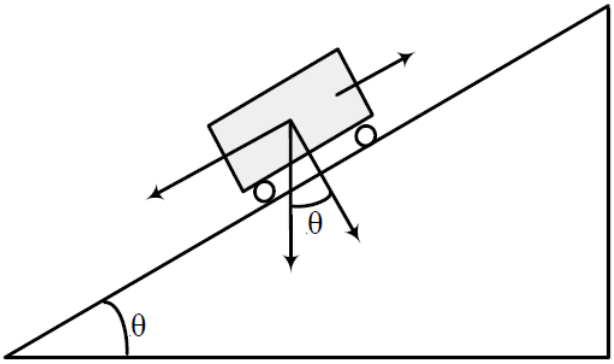


Fig.2: A vehicle climbs a sloping road.

$$F_g = W\ sin\Theta = m.\ g.\ Sin\Theta \quad (6)$$

If C is the percentage of the slope of the level is as expressed by (7), then F_g of (6) can be identified by another statement by (8)

$$C\% = (Y / X).\ 100 = 100\ sin\Theta \quad (7)$$

$$F_g = m.\ g.\ C \quad (8)$$

TOTAL TRACTION FORCE REQUIRED ON THE TIRE

$$F_t = F_a+F_r+F_g \quad (9)$$

$$F_t=m_e.\ a + m.\ r + m.\ C \quad \text{Newton} \quad (10)$$

C is a percentage of inclination, r is defined by Newton/Kg. Positive sign is used when the train is ascending to the slope level while the negative sign is allocated for the vehicle descending.

3.4 The Driving Power of the Movement Tires

If the train is traveling at a constant speed of V m / s, the required power P_o for movement is given by (11).

$$P_o = F_t.\ V \quad \text{watt} \quad (11)$$

If the gear efficiency is η, the required power by traction motor P_m is calculated by (12).

$$P_m = P_o/\eta = F_t.\ V / \eta \quad \text{watt} \quad (12)$$

3.5 Mechanical Vehicle Movement

The movement of the motor spindle, which makes torque rotary tires, is transmitted using a gearbox to reduce the speed from N_m to N rpm, if:

The torque resulting from the traction force on the tire T,
The traction force that drives the gears F_1
Traction force on the stirring tire F_t
Motor Rotation Speed N_m
Wheel rotation speed N
Gear conversion ratio $d_2 / d_1 = \sigma$
Diameter gear motor / diameter gear wheel stirring = d_1, d_2
Diameter of tire (Tire) D
Gearbox efficiency η

The relation between the motor torque T_m and traction torque required by the tire T, Gear conversion ratio and Gearbox efficiency η can be simplified through the equations (13) to (16).

$$T_m = F_1 . (d_1/2) \quad (13)$$

$$T = F_t . (D/2) = \eta F_t (d_2/2) \quad (14)$$

$$F_t = F_1 . H.(d_2/D) \quad (15)$$

By simplifying and representing (15) with other variables as in (16).

$$F_t = \eta . F_1 . (d_2/D) = \eta . 2T_m/d_1 * (d_2/D) = 2\eta\sigma (T_m/D) \quad (16)$$

Traction force as mentioned previously depends on many factors: weight, wind resistance and inclination. In addition, weight traction force is also increase with increasing the friction factor **μ** so that the total traction force (10) can be modified by (17).

$$F_t = m_e . a + m . r + m . C \quad \text{Newton} \quad (17)$$

3.6 Electrical Motor and Vehicle Load

Three-phase synchronous motor (3PSM) type (BLDC-YG1-ZZ-1200W) has been used in the present vehicle. The choice of this motor has depended on the speed and torque required by the tracked load. The 3PSM is supplied by AC three-phase line voltage 60-volt, 50 Hz. Its max speed is 3000 rpm. The torque of the motor can be checked by using (18). The torque is denoted by Tm, output power on the shaft is symbolled by Po and angular speed is ω. The angular velocity ω is given by (19), where n is the rotation speed in rpm unit [5].

$$T_m = P_o/\omega \quad (18)$$

$$\omega = 2\pi N/60 \quad (19)$$

Where, according to the real specification of the 3PSM, the torque of the motor can be calculated using (18) and (19).
T_m=1200 *W*/ (2*3.14*3000/60) =3.8 N. m
Fig.3 shows the three-phase synchronous motor which is used for vehicle traction and its name plate.



Fig.3: Three-phase synchronous motor for vehicle traction and its name plate.

This expected torque is considerably sufficient with 3000 rpm for the present load and as an input to mechanical gear box. The next specifications of the mechanical designed gear box will be depended strictly upon the two produced torques: torque of the 3PSM and traction torque required of the vehicle load.

3.7 Gear Box and Vehicle Load

The choice of the gear box as shown in Fig.4 subjects to many factors: Input speed, output speed, input torque and output torque required. The present vehicle has linear speed reach more than 40 km/hr. The angular velocity of the tire is given by (20). Where r is the tire radius. Practically, the tire radius is measured to give 0.135 m. The angular speed of gearbox pulley is calculated by (21).

$$V_t = 2\pi r\, \omega_t \quad (20)$$

$$\omega_t D = \omega_2 d_2 \quad (21)$$

Where, according to the real linear speed of the vehicle' tires, the angular speed of the tire can be calculated using (20).
40000/(60*60)) = 2π*0.135* ω_t
ω_t= 13.1rps
Then, the rotation speed the gearbox output pulley ω_2 is calculated using (21).
13.1 *0.27= 0.04 ω_2
ω_2=88.425rps



Fig.4: Motor gearbox.

3.8 DC/AC Inverter

The DC to three-phase inverter is designed to be as a frequency changer [6]. The real inverter designed is explained by Fig.5.

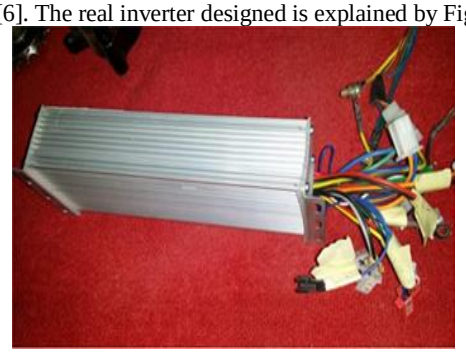


Fig.5: The DC to Three-Phase voltages inverter used.

The speed of the 3PSM is varied by using frequency changer according to its synchronous speed which is given by (22).

$$Ns = 120f/p \quad (22)$$

Hence, from the laboratory tests of the 3PSM specifications, the real number of stator slots is counted to give 18 slots. The stator is 3 phases, so 6 coils/phase is determined, for speed 3000 rpm that means 3 coils per one pole. Then according to (22) and the available data, the range of input frequency can be calculated.

3000=120*f*/6, Then *f*=150Hz, maximum frequency required and should be supplied from the DC voltage to three-phase inverter to the 3PSM to get maximum linear speed 40 km/hr.

3.9 Batteries

Five batteries are series connected; each battery is 12 VDC, 14AH as shown in Fig.6, type Sealed Lead Acid. The entire voltage is 60VDC which is supplied to the terminal inputs of the inverter. Fig.6 highlights the used battery.



Fig.6: The used battery 12VDC, 14 Amp.hr.

3.10 Mechanical Design, Bending Stress Calculations T_b

The main supports and joints of the vehicle frame are iron hollow rectangular metal with dimension 1.5 inch and thickness 2mm. the length of the iron beam 1 and beam 2 are identical, each length is 2 m. Fig. 6 shows the dimensions of the vehicle iron beams 1 and 2.
The bending stress is calculated at the centre of the beams1 and 2. The driver plus 5 batteries weight and solar panel is measured to give a weight 125 kg; hence the gravitation force by weight is determined using (23).

$$F_w = m_w * a_g \quad (23)$$

F_w= 125 *9.8=1225 Newton

The bending stress will be determined using (24).

$$\tau_b = F_b / A_b \quad (24)$$

The bending force is distributed into two beams 1and 2 as shown in Fig.7 at the middle of each, so the force F_w must be divided by 4. The length of beams is 2m, and the rectangular dimensions length of crosses sectional area of the beams 1 and 2 are 9 cm * 4 cm and its thickness is 1.5 mm. So that the τ_b calculation is implemented using (24).

τ_b= (F_b /4)/ (2(h + w) *t) = (1225l /4)/ (2(0.09+0.04) * 0.015) =78.5
N/m^2 << Bending stress of mild iron 360 MN/m^2 [3].

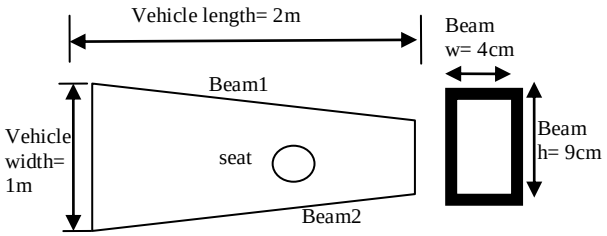


Fig.7: Dimensions of the vehicle iron beams 1 and 2

Where A_b is the cross-section area of hollow rectangular beams 1and 2 at the tires' shafts.

3.11 Mechanical Design, Axial Stress Calculations T_s

The axial total force F_s (the same as F_w) is collected by driver, 5 batteries, and the iron structure weights which it is distributed onto three tires (two in the rear and one is in front), so the force F_s must be divided by 3 tires, 2 rod sides per tire. The three circular solid rods have each cross section area A_r of 1 cm diameter. So that the τ_s calculation is achieved by (25).

$$\tau_s = F_s / A_s \quad (25)$$

τ_s= (F_s)/(3 tires * 2 sides * A_r)= (1225) / (3*2* 3.14* (0.01)^2 / 4) * 0.015) = 2.6 MN/m^2 << shear stress of mild iron 36 MN/m^2 [1].

3.12 Pedal and Gears

Two wheels of gears are used to transfer the mechanical energy produced by legs for rotating the tires and then the vehicle. It is found experimentally, the torque developed T_d by the legs is enough to move vehicle weight which is close to bicycle. To calculating the torque developed T_d, can be applied by (13) on the pedal and tire system.
T_d= 125 kg *9.8 N/m^2*(0.27/2) = 165.375 N.m, minimum mechanical torque required to move the vehicle is less than the torque required for moving the bicycle with driver is 85 kg * 9.8 N/m^2*(1/2) = 415N.m

3.13 Solar Design

The solar panel (type SK150D, 150 watt, 18V, 8.33 Amp) used is considered as additional power source has the following specifications as shown in Fig.8 through its name plate.

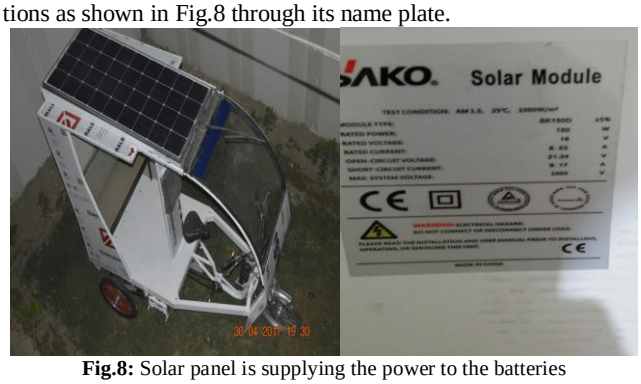


Fig.8: Solar panel is supplying the power to the batteries

The nominal produced is amplified by using power electronic chopper (low DCV /high DCV) to change the input low DC volt to required volt which is 60 DCV. The solar panel harnesses the solar energy for charging the five batteries as long as the sunlight is present.

4. Results and Discussion

The experimental test on the traction motor of the vehicle is conducted for three different speeds, the AC voltages line to line are measured and instantly the current passing through the lines. The experimental tests are shown in Table 1. Based on these experimental tests, the power input and output of the 3PSM can be calculated using the following performance equations for the 3PSM [3].

$$P_{in} = 1.73 V_L I_L \cos\theta \quad (26)$$

Table 1: Experimental Tests.

Test No.	Vehicle Speed (km/hr)	3PSM line to line voltage (volt)	3PSM Line current (Ampere)
1	20	36	5.13
2	30	47	5.59
3	40	55	6

$$Pmo = T_{sh}\, \omega = \eta m\, Pin \quad (27)$$

According to results of test1 in Table-1, by using (26), the power factor can be assumed 0.8 [5] and [7].
P_{in}=1.73*36*5.13*0.8=255.6 Watt
Corresponding to test2, P_{in}=363.6 Watt. P_{in}= 456.72 Watt for test 3. Then, efficiency of the 3PSM can be assumed 0.9 [5] and [7]. By return to (27), and using (20) and (21), the torque produced is

0.9*456.72=2π*1500/60 *Tsh

T_{sh}=2.6 N.m generated by the motor initially, to increase more through the gear box and finally will be two time the required torque for moving the vehicle.

5. Conclusion

The experimental test and theoretical calculations of the vehicle prove that there is a good validating result and fulfilled the demanding torque and speed. There is some improvement need to be applied in the future to lower the iron size of the two beams by using smaller size. In addition to that, it is possible to use four tires instead of three tires. May be using Arduino controller instead of the presented controllers in the current vehicle.
The prototype vehicle has been tested in the province of Diyala/ Baaquba / Iraq on flat and tilted lands (Al Mafraq Bridge), steady state speed reached more than 40 km/ hr with a total load was more than 125 kg. The current research was explained that the

prototype is really was tested and subjected to real electrical and mechanical engineering tests alongside using decades of applied equations on locomotives and electric vehicle to validate the experimental tests.

References

[1] Hughes, A. & Heinemann Newness (1990). Electric Motors and Drives.

[2] Grag G. C. (1988).Utilization of Electric power and electric Traction. Kanna Publishers Delhi.

[3] Theraja B. L. (2010). Textbook of Electrical Technology. Vol. 2.

[4] Subramanian, V. (1990). Electric Drives: Concepts and Applications. Mc Grew-Hill.

[5] Sawhney, A. K.(1984). A Course in Electrical Machine Design, Nai Sarak: Dhanpat raians sons.

[6] Bose, B. K. (2000). Modern Power Electronics and AC Drives, Tennessee, USA: Prentice Hill PTR.

[7] Hamdi, E. S. (1994). Design Small Electrical Machines, Chichester, UK: John Wiely and Sons