Design and Fabrication of Prototype Battery Electric Three Wheeled Vehicles

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Abstract

Significant with the increasing expense of fossil fuel and its depletion, and the impacts emission gases from petrol vehicles are having on our atmosphere, an alternative was needed. The design and fabrication of prototype battery electric vehicles is winding up progressively especially three wheel one. Three wheeled battery electric vehicles need the most ideal design conceivable to minimize the extent of energy necessary to power the vehicle. One of the paybacks of an incorporated design is a lighter vehicle, with high efficiency as a design objective focus. The lighter the vehicle, the lesser amount of energy it will necessitate to drive, therefore less greenhouse emissions. Three-wheel electric vehicle services are: university campus, clubs, hospitals, airports, residential compounds, villas, car and goods towing, trailer to haul the trash, remote area transportation etc. This work entails for investigation, design and building of a prototype three-wheeled battery drive electric vehicle with entire simple control system. A three-wheeled battery electric vehicle as an electric mobility is being developed and tested at Suez Canal University (Egypt) and Sepang International Circuit (Malaysia). The design of the three-wheeled battery electric vehicle must have many favorable characteristics such as low mass and good aerodynamics. The vehicle designed with one seat to be thrusted by brushed motor attached on the rear wheel and powered by 48V Lithium-ion battery. The numerical study is performed by MATLAB Simulink 2017 modeling and the results recorded 140km/kWh with regenerative braking system. The fabricated three-wheel battery electric vehicle total weight is 55kg. Its tested in different tracks, many attempts, with best result 100km/kWh. Vehicle maximum speed is 60km/h and the maximum efficiency is 70% at 25km/h.

Keywords

prototype, battery electric, three-wheel vehicles, lithium-ion battery, chassis.

1. INTRODUCTION

Creating people in urban regions have brought vehicle maker into another test for age of pretty much nothing and eco-friendly, anyway safe vehicles. In this vein, another period of little vehicles has late showed up. Nowadays, in perspective on their low fuel use and effortlessness of driving and halting in populated urban territories, they are expanding more thought. For instance, around three wheels have beforehand being used as a part of the open transportation structure in a couple of countries. Electric three wheels have the upside of lower fuel costs and zero releases. Despite their unmistakable quality, three-wheels, due to their typical light and limited structure, have one critical drawback: They are not by any stretch of the imagination stable in merciless moves.

Zandieh, [2014] investigated the effect of applying camber angle of a three-wheeled vehicle, which has two wheels in the front and one in the back. Effects of camber angles on stability parameter are calculated by MATLAB/Simulink. Furthermore, the forces generated on each part of the suspension system are determined using Multibody Dynamics Adams software. [Naidu et al., 2012] also studied the ride analysis of the three wheeled vehicle used MATLAB/Simulink program.

Sakamoto [2004] designed and manufactured a handmade electric motorcycle. He used Pro-Engineer and Solid Designer in design and stress analysis. The manufacturing was conducted by welding. The work included stress analysis, and manufacture. The targeted maximum velocity was 25 km/h determined from the capacity of the motor, and the obtained maximum velocity was 23 km/h. A torque-vectoring controller was also established by [Sabbioni et al., 2014] for an electric vehicle. Using this system, it was shown that the peak values of oscillation for side slip angle can be decreased. Sakhalkar et al. [2014] showed that by adding a torque vectoring control system to change the yaw rate of a vehicle, the vehicle could be kept on a desired path.

Tilting system was used with three-wheeled vehicles to improve their maneuverability during large steering angles [Kim et al., 2014]. Berote et al. [2008] has mentioned that the main problem associated with their vehicle was its weak rollover stability and a larger yaw rate was applied at the rear wheels in comparison to that applied on the front one. Anti-lock brake systems (ABS), which are able to hinder the occurrence of skidding, can be used as a controller system [Marshek et al., 2002; Bartlett and Wright, 2010].

Bharati et al. [2018] investigated the high demand use of rickshaw in the Asian countries like India, Pakistan. and how it pollutes the environment using its gasoline two or four stroke engine, so they started to make an electric prototype of this rickshaw replacing the gasoline propulsion system with an electric one.

Besselink et al. [2010] investigated the performance of the gasoline VW Lupo 3L vehicle and then converted it into an electric propulsion vehicle replacing the engine with an electric motor. They compared the results of the vehicle on both statues of the car setting the challenges for the developments on the electric vehicles. Jayesh et al. [2017] investigated Mazda suitcase internal combustion engine vehicle and made their own three wheels' suitcase electrical vehicle using a steel chassis, brush electric motor 24 volts, alkaline battery as the power source, wire braking system and finally a steering handle on the frontal single wheel with a maximum speed of 35 km/hr.

Subrahmanyam et al. [2015] fabricated a tri-wheels electric vehicle to help disabled persons. Someswara et al. [2017] investigated the design analysis of a three wheels' electric car, they run out the analysis on SOLIDWORKS for chassis and steering. An electrical three-wheel vehicle is designed for disable persons. In this a person with disable limbs uses the new technology in which the hands are used for the braking, accelerating and clutch operations. They added an alcohol detector sensor on the car for more safe driving. The chassis is fabricated using 1015 steel. Mansour et al. [2017] investigated the rollover stability of three-wheeled vehicles and the effects of road configurations. Lateral and vertical road inputs were also considered as the main causes of tripped rollovers.

Deepak et al. [2014] determined that the turning radius of the wheel which was obtained by using all wheel and steering mechanism and it was relatively smaller than actual turning radius. They found the turning radius when steered on two-wheel side and one-wheel side were decreased by 83.9 cm and 26.83 cm respectively and they used 1090 Mild Steel (low carbon steel) material for chassis which is safe after using solid work stress analysis simulation. Starr [1992] presented a tutorial treatment of elementary vehicle dynamics models in order to explain how certain vehicle parameters affect vehicle stability.

Maciej et al. [2016] investigated three-wheel electric vehicle based on lithium-ion battery with electrical engine applied with spring mechanism to accumulate energy. All system assembled together by energy managing system by the mean of microcontroller to run three-wheeler vehicle with maximizing energy efficiency by minimizing of vehicle mass, minimizing wheel rotation resistance, minimizing friction force of bearing, and maximizing energy recovery from braking. Chokri et al. [2014] studied that the vehicle can be powered by single or combination of energy sources. They represent electric vehicles concept and details of power management storages, and improvement of PMC algorithms to lead to enhancement in electrical vehicles performance and saving energy. Chaofeng et al. [2019] reviewed efficiency of battery, super capacities, DC and electric motors in hybrid power system of electrical vehicles. The hybrid system which take more than source of energy can decrease energy consumption by (13.4 % to 17.6 %) by mean of (DP) dynamic programming optimization. The DP has highest system efficiency and lowest energy consumption. Cheng [2009] discussed the recent development in the electric vehicles in the Asian countries discussing the electric power battery, electric motor, braking system, steering and suspension. Sateesh et al. [2017] discussed the development achieved on the EV when using BLDC and how much energy could be saved using this motor and even how easy to control it. Sharad et al. [2016] demonstrated the advantage of tri- wheels vehicle in areas like airport, villas, universities campuses and hospitals and how to make a reliable vehicle. Pravin and Hrushikesh [2014] discussed how the aerodynamics could affect the three wheels' vehicles by explaining the parameters that affect the car drive like flow separation, vehicle shape and wake. Bako et al. [2015] investigated the use of drum braking system and how to be optimized using simulation software like SOLIDWORKS. Rony Argueta [2010] reviewed the automotive industry which directed to electric vehicles to replace gasoline vehicles. Beside that electrical vehicles are much cleaner than gasoline vehicles, it more efficient as it can convert about 75 % of chemical energy stored in battery to power wheels while gasoline vehicles can convert only about 20 %

from energy stored in fuel. Electrical vehicles much slower than gasoline vehicles, electrical vehicles top speed about 95 MPH while gasoline vehicles can go for more than 124 MPH. Electrical vehicles cover 200 miles before recharging while gasoline vehicles cover more than 300 miles before refueling.

2. VEHICLE DESIGN AND FABRICATION PROCEDURES

The general design, configuration and components of the proposed prototype three-wheel battery electric vehicle with basic dimensions is shown in Figures 1 and 2.

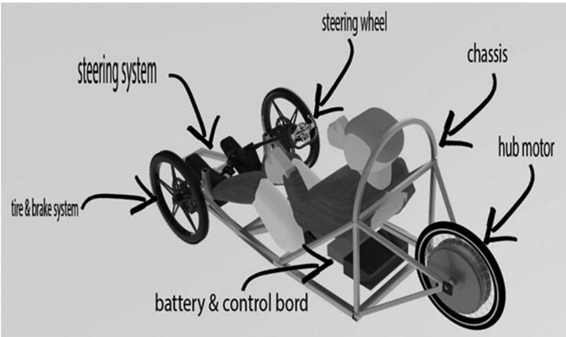


Fig. 1 Schematic of general idea of three-wheel battery electric vehicle

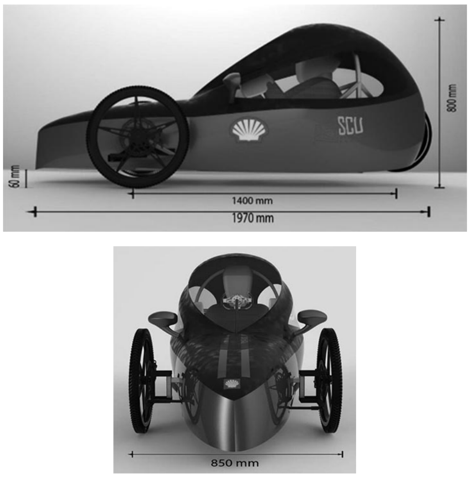


Fig. 2 CAD drawing of vehicle with basic dimensions

2.1 Vehicle ergonomics

The cockpit must be suitable for the drivers and its empty spaces can be used efficiently. The design makes all buttons in an accessible place. Also, makes the driver in a safe and comfortable position. The measurements and dimensions of the drivers are recorded to determine the position of the steering wheel and seat angle. 2D and 3D sketches of the driver are drawn to know the length of the cockpit and its height. 5-point seat belt is used to make the driver fixed and

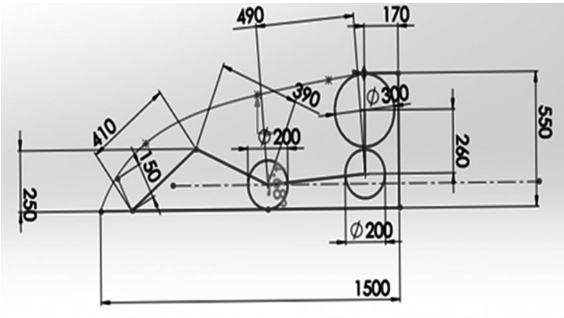


Fig. 3 Dimensions of cockpit of three-wheel battery electric vehicle

in a safer position. The waist contained the locking, it must be 90° to the floor in prototype and the belt should be in the center of the lower abdomen. The seat angle is 5° with the horizontal and the steering wheel height is 300 mm and the height of the cockpit 550 mm and its length is 1500mm as shown in fig.3. For safety, the roll bars extend beyond the driver's shoulder, so it must have a minimum 50mm gap all around driver helmet.

The driver's seat must be tailored with a safety harness has five mounting points. The safety harness must prevent any motion of the driver. Any loose in the harness must be tuned by using the seat belt adjuster.

2.2 Frame design

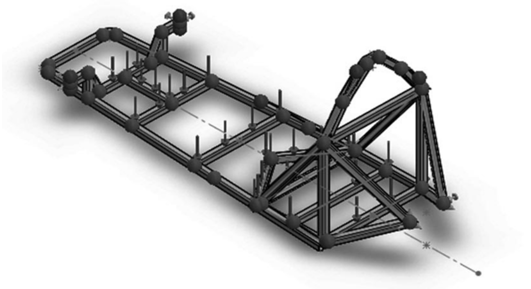
During vehicle design and fabrication, the authors must pay attention to the driver safety. Prototype vehicles must have three running wheels and 100 mm distance between the front of the vehicle body and the driver's feet (crumple zone). Vehicle bodies must not contain any external extras or sharp points. Vehicle body panels and windows must be rigid against to wind.

2.2.1 Frame description

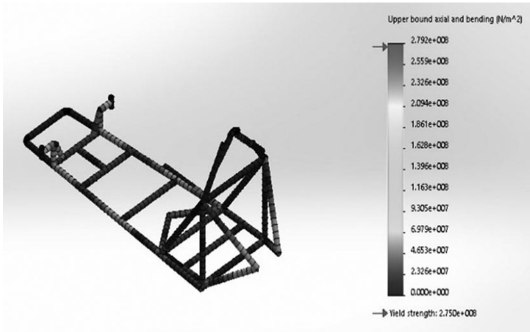
Vehicle chassis will safely protect the driver, including crumple space in the event of collision. Vehicle design assume a light weight and to be as safe as possible. Space frame design is used because it's efficient and simple, many impacts are absorbed during a collision as the tubes change all forces into tension and compression forces. Two wheels are in the front outside the body, and one wheel on the back inside the body. Aluminum 6061-Ts is used in design as it's stiff, light and have good welding properties.

2.2.2 Frame dimension

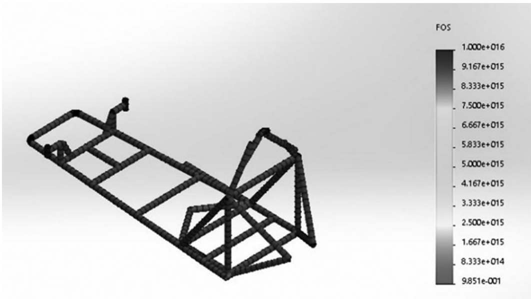
Dimensions are documented according to the ergonomics proposal to get the most weight efficient vehicle and comfortable for the driver; length 190 cm, width 50 cm, height 60 cm, wheelbase 135 cm, alu-



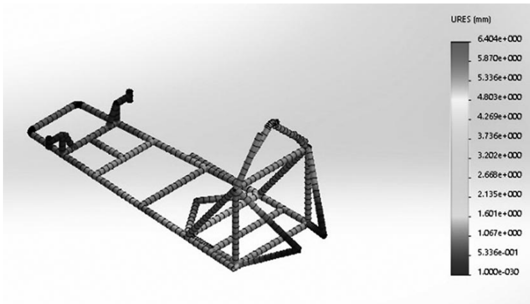
(a) Alpha frame applied forces



(b) Stress distribution



(c) Factor of safety



(d) Displacement distribution

Fig. 4 Alpha chassis stress, factor of safety and displacement distributions

minum pipes 26.9 × 3.2 mm, weight less than 10 kg.
In Egypt local market, 6061-T6 aluminum alloy and its welding is available since it has a yield strength of 275 MPa and crack sensitive, it will be a good selection. Its density is 2700 kg/m^3. It costs about 6 $/kg or 3.5 $/m. Primarily, aluminum 6061-T6 is a precipitation hardened aluminum alloy with the major content of magnesium and silicon, it's welding process must be taken by professionals as it after welding, the properties near the weld area has a loss of strength of around 80 %.

2.2.3 Frame design and simulation

Two chassis, Alpha and Beta, are proposed, investigated and simulated to select the better one according to the stress distribution, displacement distribution and factor of safety.

- a- Alpha frame

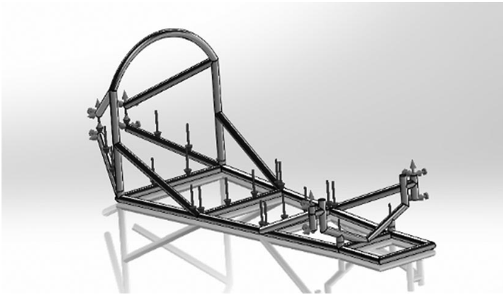
  Alpha chassis has 170 cm length, 53 cm wide, 65 cm height, wheel base of 130 cm and 8 kg weight as shown in fig.4. It's formed from ISO square tubes of 20 × 20 × 2 mm and another group of the same square tube of 30 × 30 × 2.6 mm. Stress analysis, factor of safety and displacement distributions of Alpha chassis using SOLIDWORKS simulation tool are shown in Figure 4.

  Two different loads are applied; load due to the weight of the driver and other parts in the front part of the chassis (about 70 kg) and load at the rear due to the propulsion system existence (about 20 kg).

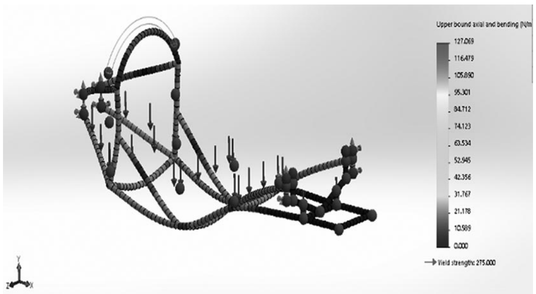
- b- Beta frame

  Figure 5 shows the CAD drawing of the Beta frame with total weight 7 kg, 180 cm length, 50 cm wide and 55 cm high. It's very good to get 1kg reduction in weight as it will safe inertia force up to 10 Newton. Stress analysis, factor of safety and displacement distributions on Beta chassis are shown in Figure 5.

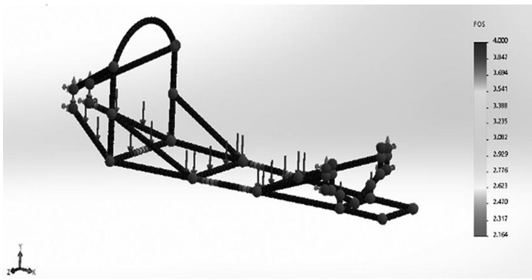
It's very clear that Beta chassis is lighter than Alpha chassis by 1kg which will safe more power. Beta chassis has 5.4 mm maximum displacement which is lower than Alpha frame maximum displacement and it has a greater safety factor of about 2 so it will be the best selection.
After Beta chassis selection its roll bar must be analyzed and simulated. The chassis must be equipped with a roll bar that extends 50 mm around the driver when seated in normal driving position. The roll bar must be able to withstand around 800 N static load that applied in perpendicular direction, without deforming in any direction. Roll bar horizontal and vertical forces effects, stress analysis, factor of safety and displacement distributions are investigated and show safety design.
From these analysis It's more obvious that the roll bar is safe when applying the load of 800 N with FOS in



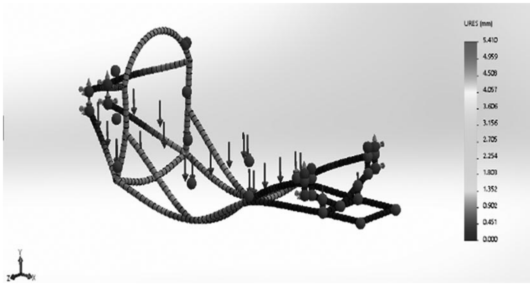
(a)Beta frame applied forces



(b)Stress distribution



(c)Factor of safety



(d)Displacement distribution

Fig. 5 Beta chassis stress, factor of safety and displacement distributions

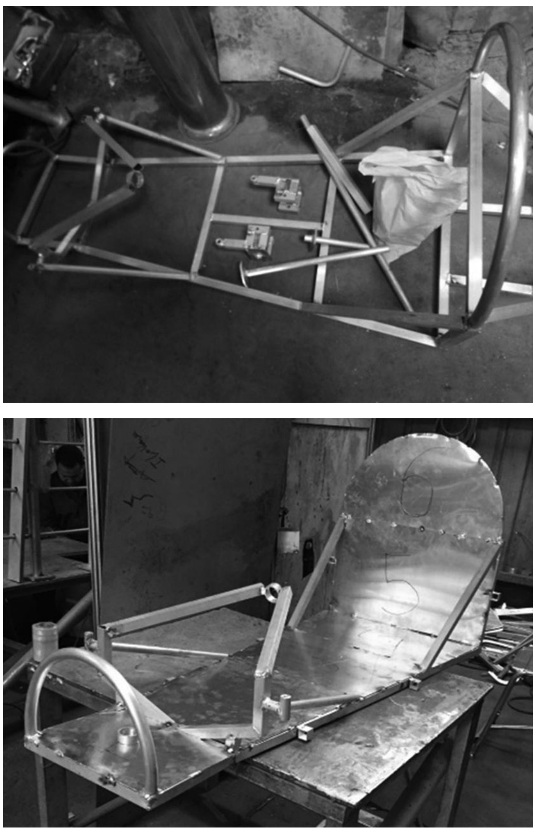


Fig. 6 Fabricated Beta chassis

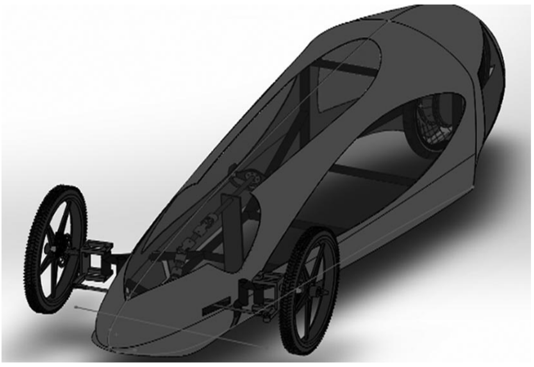
all directions nearly with neglected displacement. Figure 6 shows the photos of the fabricated Beta chassis.

3. VEHICLE BODY

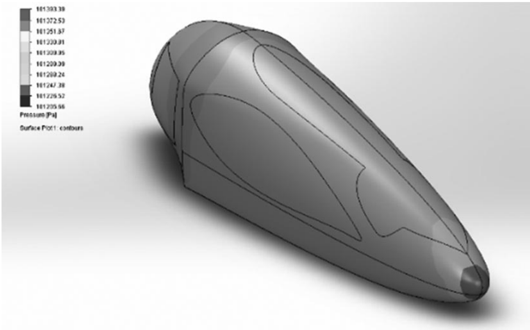
The body is very important to any vehicle due to; it's the first shield for the driver, gives the outer and the first imprison and helps in energy efficiency with a great turn. Also, the aerodynamic shape of the body affects the vehicle stability.

Several aspects were taken into concern when the vehicle body is designed; body was to be in the smallest geometry, trying to cover all the internal parts, following all of the safety rules, effective and low price materials, easy to be removed to make maintenance and for the driver to get off or on and provides good ventilation for driver, motor and all interior parts. Vehicle body details are; weigh about 15 kg, has zero angle of incidence, has a drag coefficient of 0.17 ± 0.02 and the air affects the body with a drag force that varies depending on the relative velocity between the body and the air.

Vehicle body material is fiber glass due to heat treatment process to carbon fiber sheets was impossible according to the availability in Egypt local market. Also it has low price compared with carbon fiber, easy to be found and to use it, stiff and strong in tension and compression, difficult to suffer deformation due to air. Normal glass is dangerous for the driver so polycarbonate is used as an alternative, doesn't shatter, low weight, high strength that makes it resistant to impact and fracture, readily recyclable and cost effective and high electrical and heat resistance. Figure 7 shows the full body configuration CAD drawing of the vehicle and the pressure distribution all over the vehicle body. From the pressure distribution analysis, the body is aerodynamically safe.



(a) CAD drawing of body full view



(b)Pressure distribution

Fig. 7 Vehicle body

4. VEHICLE STEERING SYSTEM

The purpose of steering system is to turn the front wheels. The steering system works to provide directional control with a comfortable amount of steering effort. The steering system consists of a steering linkage, a steering column and a steering wheel as shown in Figure 8.

Go kart steering system is the simplest system used in low weight vehicles; because it has low cost, simple and it consist of simple components. This system allows to rotate steering wheel 90° left and 90° right which produce maximum wheel angel and minimum turning radius and it contains a few parts which are characterized by cheap price and easy to manufacture and easy to control to get angles that achieve less turning radius. The design goals are; achieve neutral steering, reach to static stable factor less than 1.4 and get minimum turning radius less than 4 m.

Ackerman geometry is used to design the vehicle steering. Ackerman condition is required when the vehicle speed is too small, and slip angles are neglected. The Ackerman steering condition is used as cornerstone for the work of the steering system so velocity of fabricated car between 20-60 km/h which can determine with roll over speed calculations. From Ackerman calculations when steering wheel turned 90°, minimum turning radius 3.65 m at average wheel angels 30° and 21° is obtained.

Figure 9 shows the photo of the steering arm and the upright and the stress distribution on the upright. The upright maximum displacement is 1mm and safety factor is 1.5.

Fig. 8 Vehicle steering system

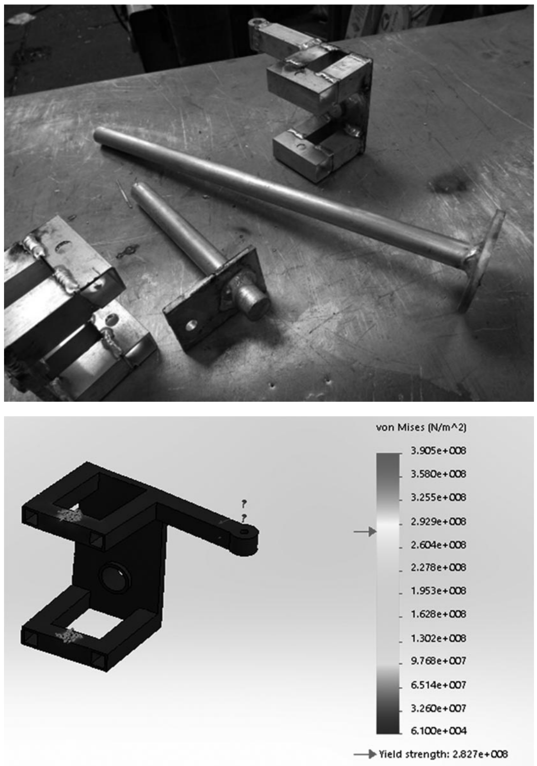


Fig. 9 Steering arm and upright photo and simulation

5. BRAKING SYSTEM

The braking system is aimed to drop the speed of the vehicle using friction force and preserve it from rolling when stopped. The induced friction slows or stops the vehicle by transferring the energy of motion to thermal energy. This heat must be dissipated by the brake system into the air.

Vehicle has two individually actuated braking systems; each of them comprises of an activators (calipers), single command control lever and command transmission cables. One system must act on the front wheels, the other must act on the rear wheel. For the front wheels, there must be one activator (caliper) for each individual wheel, with both activators commanded by the same command control. The right and left brakes must be balanced. It must be possible to actuate the two brake systems at the same time without taking either hand off the steering system. The efficiency of the braking systems has been tested during vehicle fabrication. The vehicle with driver is placed on a 20 percent inclined to test the brakes. Each braking system has been activated separately and must keep the vehicle immobile [Rudolf Limpert, 1999]. The parts of braking system are shown in Table 1.

Table 1 Parts of braking system

Parts	Specification	Photo
Brake handle	7 mm cable travel at 20 degree lever pull	
Brake wires	Withstand master cylinder pressure, flexible and hard	
Caliper	Weight, 0.93lbs, Shimano PS1 Caliper, 2 pistons, piston Area: 0.79 in2	
Brake pads		
Disk brake BMX	Material, 420 stainless steel, dimension, 7” OD, 3/16” thick, mass, 1.22 lbs	
Wheels BMX	Shimano	

6. PROPULSION

Engines, batteries (both propulsion and auxiliary) which placed in energy compartment must be placed outside the driver’s compartment behind the rigid bulkhead. The purpose of this bulkhead is to inhibit flames from reaching the driver. If holes are made in the bulkhead to pass through wires or cables it is essential that the wires and cables are protected by a grommet or similar protective material to prevent damage.

Emergency blackout system is required to deactivate the propulsion system of the vehicle in some circumstances. The fabricated electric vehicles have an external and internal emergency blackout mechanism that must provide an isolation of the propulsion battery from the vehicle electrical system.

This type of propulsion systems which don’t need space and transports the power to the road without a part connecting between rear wheel and motor because they are connected to each other directly to reduce the amount of power wasted. This transmission system has some advantages; higher efficiency since no mechanical losses due to the frictional force between the parts, easy to install; need only two nuts from each side to install in car, more safe than chain which may fail due to vibrations, less cost, doesn’t need extra parts, reduce car length, don’t need place to install and common in lightest electrical vehicles

7. VEHICLE ELECTRICAL SYSTEM

Embedded systems (automotive embedded system) and electronics have become an increasingly integral part of modern automobiles. In this study, it’s possible to balance the common trade-offs, performance and cost, in order to realize a vehicle capable of performing and getting a high benchmark score while being a cost-effective solution for production. The goals; efficiency up to 76 %, top speed up to 60 km/h, distance range up to 100 km, Protection systems on each component and easy to reset on faults, Wire voltage drop less than 1 % of total voltage for each cable and informative clear dashboard and consume power less than 50 watt. Full vehicle electrical system, which is consisting of four main subsystems, is shown in Figure 10, as follow;

- Battery: the main source of energy to the vehicle and the crucial part for achieving maximum performance due to power to weight ratio.
- Motor Controller: controls the speed of the motor by adjusting voltage on motor terminals using Pulse Width Modulation (PWM) technique.
- Motor: converts the electric energy into kinetic energy.
- Dashboard and control system: contains embedded devices to perform specific tasks like monitoring the speed of the vehicle and the temperature of the battery and sending signals to the motor controller to change the speed of the motor.

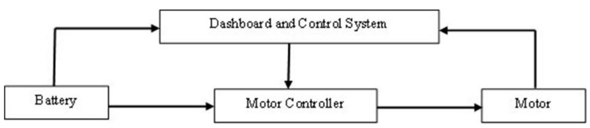


Fig. 10 Battery electric vehicle main subsystems

Battery, has nominal voltage of 48 V to be able to run the motor efficiently. A capacity of 20 Ah suitable for running the vehicle up to 100 km. Capable of supply

Table 2 Battery specifications

OSN Power Tech CO.,LTD.	
OSN-48V20AH LiFePO4 Battery Pack Specifications	
Model	OSN-48V20AH
L x W x H	265x150x145mm(optional)
Rated Voltage	48V
Rated Capacity	20Ah
Discharge Cut-off Voltage	32V
Standard Charge Voltage	58.4V
Standard Charge Current	5A
Continuous Discharge Current	2C
Charger	CC/CV (Professional Charger)
Weight	≤10KG
Working Temperature	Charge:0-45°C
	Discharge:-20°C-45 °C
Storage Temperature	-10°C-35°C
Temperature C	≥20Ah
Cycle Life	2000 cycles to 80% with 100% DOD under normal temperature

the motor with enough current, even at maximum current of 40 A thanks to its maximum continuous discharge current rate 2 C. The standard charge can fully charge the battery in 4 hours. By multiplying voltage with maximum discharge current we get 2 kw of power and its weight is approximated to 10 kg which means that the power to weight ratio is 200 kw/kg. Also its cycle life is 2,000 cycle. All technical specifications are shown in Table 2.

Moving to the motor, performance and simplicity for designing and troubleshooting is needed to be investigated. Moreover, motor controller circuit is designed. So for highest performance, the best selected motor is the Brushless Direct Current Motor (BLDCM) as its efficiency is near 90 %. But the cost effective of the vehicle, availability in Egypt local market, time estimated for finishing the whole system, simplicity and easy troubleshooting made the choice is changed to select a Brushed Direct Current Motor [Bektas and Serteller, 2011; Rajagopalan et al., 2007; Krishnan, 2009; Song and Choy, 2004]. The specifications of the selected motor are shown in Table 3 and Figure 11 which its performance is satisfactory as its efficiency reaches 83.26 %. With a nominal voltage of 48 V, a maximum current of 33.54 A and a rated current of 26.7 A its maximum power is at 1.6 kw and rated

Table 3 Dayton MY 1020 48 V 1000 W Motor (Brushed)

Model	MY 1020
Voltage	48 Volt DC
Output	1000 Watt
Sprocket	11T (8 mm T8F chain)
Rated speed	3000 RPM
Rated current	26.7 A
Rated torque	3.2 Nm
Weight	5.25 kg

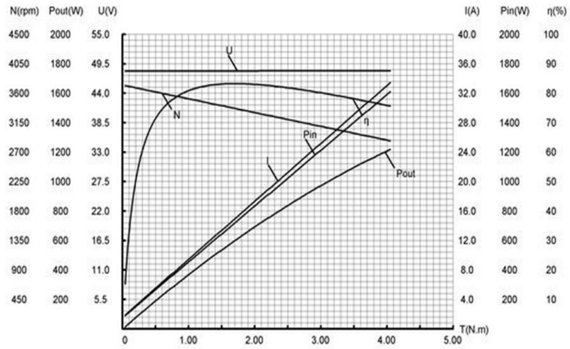


Fig. 11 Motor data sheet and specifications at different loads

power at 1.08 kw. For the mechanical specifications of the motor we have rated speed at 3,000 rpm and no-load speed at 3719 rpm which is suitable for mechanical reduction gears to increase the need torque if the track has changed to have more inclinations. This motor comes with sprocket gear 11T for T8F chain which is simple enough to change its gear ratio. At last, it has mechanical torque rated at 3.2 Nm and maximum at 4.05 Nm.

For the motor controller, ST-Electronics schematics were used for an Intelligent Power Switch for 48 V Battery Applications which was perfect for our application but needed a modification to ensure the delivery of the maximum power to the motor without losses, sacrificing additional power consumption and damaging its parts which were rated for 15 A application. Figure 12 shows the schematic of motor control.

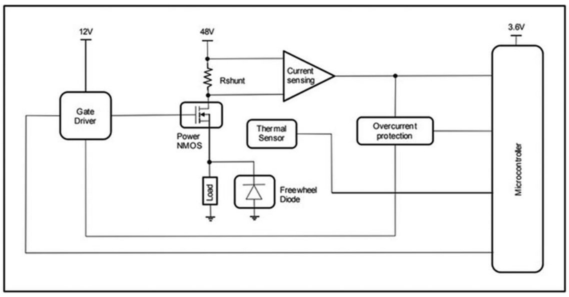


Fig. 12 Motor control schematic drawing

So three parallel switches are used to have maximum rating current up to 45 A, this ensures power delivery and system working efficiently without damaging the N-channel MOSFETs. At the dashboard, located directly ahead of a vehicle's driver, displaying instrumentation and controls for the vehicle's operation. Dashboard features a graphical LCD (128 × 64) pixel and instruments to display speed, voltage, temperature and the current of the motor and all of this was done by sensors. By using Arduino DUE as it's a microcontroller board based on the Atmel SAM3X8E ARM Cortex-M3CPU which is designed for embedded applications. Also, Linear Hall Magnetic Sensor KY-024 is used to measure the speed of the vehicle by using a piece of magnet attached to the motor and then measure the number of cycles and converting them into linear velocity. And temperature sensor DHT22 is used to measure the temperature and humidity inside motor compartment.

The full system of the vehicle has safety features for the driver. Starting with the high voltage relay which is responsible for opening the whole circuit and closing it, its coil connected to a series switches that have different functions. These switches are external emergency switch that is used for shutting-down the vehicle from outside, internal emergency switch which is used for shutting-down the vehicle from inside with the driver's side and the dead-man switch which is a push button switch opens when being released. For the dashboard power that is rated at 12 V, a DC-DC converter is used for that propose. The motor driver has its power directly after the high voltage relay. Also every branch of the circuit is fused with safety factor up to 1.5.

The field test has the following specifications and configuration in Table 4 and Figure 13.

Table 4 Track specifications

Track Detail	Specifications
Length	2.61 km
Width	16 m
Turns	8
Laps	4
Distance	10.33 km
Time limit	25 min.
Average speed	25 km/h

Fig. 13 Track configuration

After complete 4 laps in the track the fuel economy is measured using joulemeter (connected with battery) to measure the used fuel charge for 10.33 km and calculate the total covered distance for one kWh. The efficiency can be calculated using the input power to the motor measured by joulemeter and the output power. The output power is calculated from the motor rotation speed which is measured by tachometer and the corresponding torque from motor performance in Figure 11. Assuming the mechanical efficiency is 85 %, so the total battery vehicle efficiency is 70 % at corresponding speed 25 km/h. The simulation result of the efficiency is matching with experimental result.

8. SIMULATION RESULTS

Depending on the mathematical model of vehicle components and the design parameters and assumption the vehicle simulation is achieved. The simulation results are considered as a guideline of vehicle fabrication. The simulation is implemented using MATLAB 2017 (Simulink). The simulation is executed at two cases, full load and 0.8 full load. Simulation results are motor current, voltage, power and efficiency, also wheel normal force and slip. The simulation results are shown from Figure 14 to Figure 19. All figures have a transient response in the first period of time and different settling times to reach the steady state in two cases of loads. Figures 14, 15, 16 and 17 illustrate

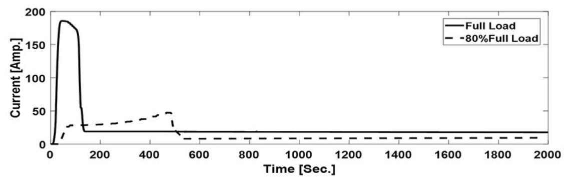


Fig. 14 Motor electrical current

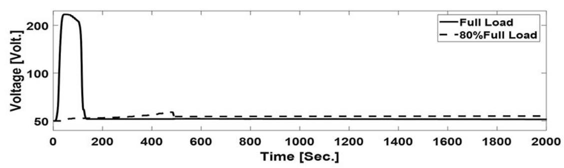


Fig. 15 Motor electrical voltage

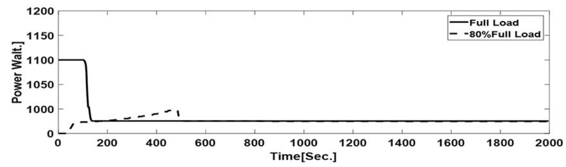


Fig. 16 Motor power

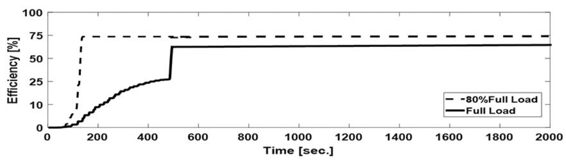


Fig. 17 Motor efficiency

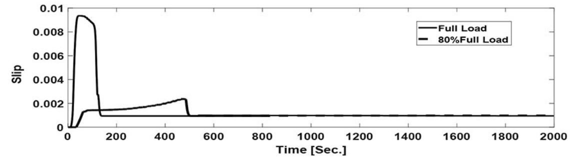


Fig. 18 Wheel slip

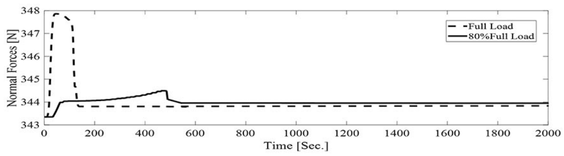


Fig. 19 Wheel normal force

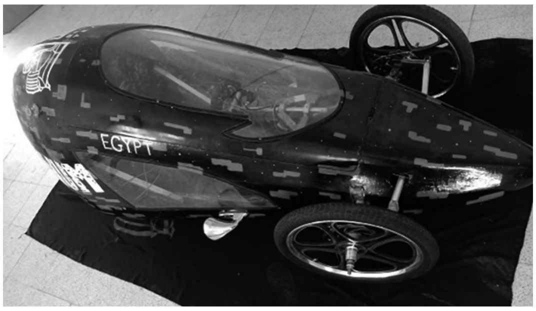


Fig. 20 Fabricated prototype three-wheel battery electric vehicle

the motor current, voltage, power and efficiency performance. Figures 18 and 19 demonstrate the slip and normal force on the wheel that integrated with motor.

After design procedures and fabrication processes the prototype battery electric three-wheeled vehicle final product is shown in Figure 20.

This project can work for experiential learning by broadcasting the steps of design and fabrication, the tests to approve the validity of the vehicle for the field test (driver control, vehicle design (mechanical), vehicle design (electrical)) and the participated competitions through YouTube channel of the team. The vehicle is assembled and disassembled once a year while people training. Organizing workshops for the recruited people to transfer the experience.

9. CONCLUSIONS

This study aimed to design and fabricate a prototype three-wheeled battery electric vehicle of highly compact to be used in several applications. An electrical three wheeler vehicle was propelled by brushed electric motors, using electrical energy stored in Lithium-ion battery. Electric motors give electric cars the required instant torque. The vehicle was made with light weight (55 kg) in order to increase its range. The vehicle was designed with special dimensions for the suitability of Egypt roads. A prototype of this vehicle was fabricated and tested in Suez Canal University (Egypt) and Sepang International Circuit (Malaysia). It has many beneficial features such as low weight, stiff frame, energy efficient. Three wheeled electric vehicle has reasonable stability and disc brakes for better braking performance. It also produces zero emissions hence reduce the health hazards and environmental pollution also reduces the global warming. The study modeled the electric car assembly in a 3D cad tool called SOLIDWORKS. The chassis analysis is carried out in SOLIDWORKS simulation tool by applying two frame analysis, Alpha and Beta frames. Beta chassis is chosen to be fabricated from aluminum 6061-T6. The numerical study is performed by MATLAB Simulink 2017 modeling. Its tested in different tracks with best result 100 km/kWh. Vehicle maximum speed is 60 km/h and the maximum efficiency is 70 % at 25 km/h.

Acknowledgement

The authors would like to acknowledge SCU racing team of faculty of engineering, Suez Canal university for providing the required facilities and environment to complete the research work. The authors would like to thank Prof. Tarek Rahmy for his support and guidance.

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(Received June 29, 2019; accepted July 11, 2019)