Conversion of a Gas Combustion Engine to an Electric Motor in a Porsche 924

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ABSTRACT

This paper is a walk-through of converting a gasoline Porsche 924 to and electric engine. The paper begins with steps on how to remove the gasoline engine. It then goes into setting up the electrical system for the new electric vehicle and then follows up with the motor installation. The end of the report discusses the testing and results of the electric vehicle and finishes up with recommendations to anyone who attempts a similar project.

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INTRODUCTION

In today's world one major global problem is the dwindling supply of oil reserves and the long term increase in gas prices. Although gas prices in the US have dropped recently National Geographic states that this will not last for two main reasons. One reason is because the shale oil reserves in the US are considerably smaller than the oil reserves in the Middle East, and the second reason is that the process to take the oil out of the ground in the US, fracking, is very expensive and each well will only last a few years (Dimick, 2014). The International Energy Agency (IEA) report speculates that the oil supply in the US will begin to decline in 2020 and then the US will be back to high oil prices (IEA, 2014). According to the US Energy Information Administration (EIA), California has the highest gas prices. There are three regions, out of 7, that have the highest gas prices in California and one of them is along the central coast, including San Luis Obispo (EIA, 2015).

Since oil supplies are dwindling and gas prices will be on the rise again soon, many Americans are on the search for vehicles that use renewable energies as a source of power. There has been a 93 percent increase in electric car sales from January of 2011 to January of 2015 (EDTA, 2015). Currently new electric cars range from $24,000 for the Mitsubishi i-MiEV to $93,000 for the Telsa Model S (Green Car Reports, 2015). It is too costly for some people to go out and buy the new electric cars so another alternative is to refurbish your existing car and turn it into an electric car, usually ranging from $5,000-$10,000 (Marshall, 2002).

The objective of this project is to replace a gas combustion engine in a Porsche 924 with an electric engine. The result of this project will be to show how useful and inexpensive it is to convert a gasoline powered car into an electric powered car.

LITERATURE REVIEW

A search was initiated to see if there were any tips or research done on converting a gasoline engine to an electric engine. An article from How Stuff Works was found to have a very useful step by step procedure list:

1. Marshall states that the first step in converting a manual gasoline powered vehicle into an electric vehicle is to decide what voltage system to run.
    a. Usually the voltage system is somewhere between 96 and 102 volts
    b. This decision controls the type of motor, the type of controller and the number of batteries needed.
2. The next step is to pick which type of batteries to use, the four main types are lithium-ion, nickel-metal hydride, lead-acid and ultra-capacitors.
    a. According to the U.S. Department of Energy the most common type of battery in electric vehicles is the lithium-ion batteries because they produce a high energy level relative to their mass, they have a high energy efficiency and they have a low self-discharge (U.S. Dept. of Energy, 2015).
3. Next all the parts that will no longer be needed from the donor vehicle including the engine, exhaust system and the gas tank need to be removed.
4. The assembly of the new engine now begins.
5. The adapter plate is attached to the transmission bell housing
6. The motor is attached to the adapter plate
7. A controller is then attached to the motor
8. Battery racks are installed somewhere in the engine compartment
9. The batteries are then placed in the battery racks
10. After the engine is installed it is time to re-connect the disassembled pieces including power steering, air conditioning/heater and power brakes (with a vacuum pump).
11. The next step is to install a charging system along with a volt meter.
12. The final step is to install a relay that will connect and disconnect the controller to and from the battery and then rewire the ignition switch so that the new engine will turn on (Marshall, 2002).

Potential Problems

An initial hope was that 2 or 3 of the GEM car motors could be connected in series similar to that of forklift motors. Upon further research GEM car motors only have the female connection piece whereas forklift motors have a female connection on one end and a male connection piece on the other end, see Figure 1.

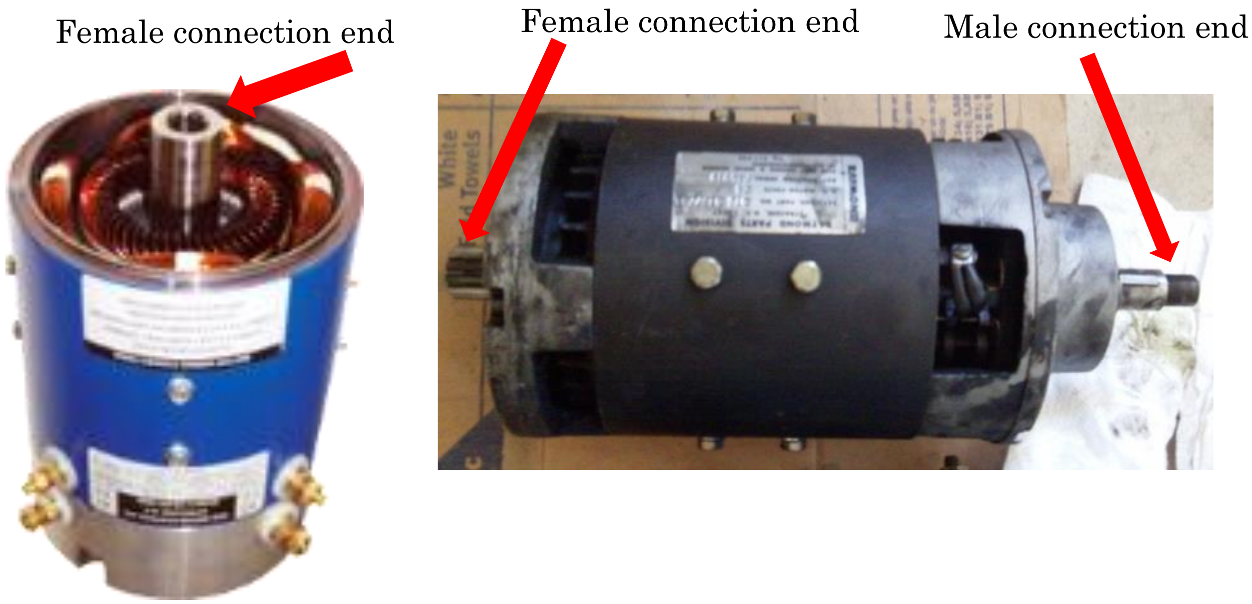

Figure 1. GEM car motor on the left compared to a forklift motor on the right. (mzmotorsport.com)

While it is unfortunate that the motors cannot be connected together it does allow the controller that came with the GEM car to be used for initial testing. If the initial testing is a success and the sponsor wants to continue on with the project a new controller will need to be built to be able to handle a larger motor with a higher voltage.

A problem that may come up in the building process is in the making of the coupler. Nelson welded a Lovejoy coupler, that he lathed a step in, and the middle splined center out of the clutch plate (with the rivets grinded off) together to make his coupler, Figure 2.

Figure 2. Finished coupler (Nelson, 2009).

He later states that the drive train system failed after a few weeks, although he does not think it was due to the coupler he does recommend putting the drive

train system together and tightening it before installing it in the vehicle (Nelson, 2009).

Another potential problem that may arise in the conversion process is the brakes and steering. Before the conversion the Porsche had powered brakes and powered steering. Nelson states that if you don't want to have to push very hard every time you use your brakes then it will be necessary to buy and add in an aftermarket vacuum pump (Nelson, 2009). Roland describes a way to use one electric pump to power a hydraulic brake booster and the power steering, meaning no vacuum pump is needed. This method will also require purchasing a fill reservoir and high pressure lines to connect to the power steering rack to the steering pump (Roland, 2011).

GEM Cars

Global Electric Motorcars (GEM cars) are the market leader in low-speed vehicle sales and they have currently sold over 50,000 vehicles worldwide (2012 Owner's Manual, 2011). Specifications on the GEM cars are shown in the following two tables. Parts for the conversion are coming out of a GEM e4 and a GEM eS, two different models of a GEM car. The motor and controller are coming out of a GEM e4 and the batteries are coming out of the GEM eS.

Table 1. Specifications 1 for GEM cars (2012 Owner's Manual, 2011).

	GEM e2	GEM e4	GEM eS
Performance			
Motor	GE Heavy Duty 5 HP, shunt DC electric motor		
Motor peak	23 HP Peak (17kw)		
Controller	Flight Systems, T4, 350 amp DC Controller		
Battery pack	Six 12-volt flooded lead acid batteries (12-volt gel optional)		
Maximum speed	25 MPH (40 km/h)		
Range	30 miles (48.3 km) (will vary with conditions)		
Drive System	12.44:1 Single speed		
On-board charger	120 volt, 15 amp, 60 Hz AC input; 72-100 volt, 12 amp DC output		
Accessory power supply	12 volt, 30 amp DC/DC converter		
Brake System			
Brakes	4-Wheel hydraulic brakes, disc front, drum rear		
Park Brake	Console-mounted lever-activated mechanical park brake		

Table 16. Specifications 2 for GEM cars (2012 Owner's Manual, 2011).

	GEM e2	GEM e4	GEM eS
Dimensions			
Curb Weight	1120 lbs. (508 kg)	1280 lbs. (580.6 kg)	1160 lbs. (526.2 kg)
Length	99 in. (251.5 cm)	128 in. (325 cm)	108 in. (274.3 cm)
Width	55 in. (139.7 cm)	55 in. (139.7 cm)	55 in. (139.7 cm)
Height	70 in. (177.8 cm)	70 in. (177.8 cm)	70 in. (177.8 cm)
Wheelbase	72 in. (183 cm)	102 in. (259 cm)	72 in. (183 cm)
Turning Circle/Radius	24 feet (7.3 m)	32 feet (9.75 m)	24 feet (7.3 m)
Load Capacity			
Payload Capacity (occupants, cargo, options)	730 lbs. (331 kg)	920 lbs. (417.3 kg)	690 lbs. (313 kg)
Gross Vehicle Weight Rating (GVWR) (page 22)	1850 lbs. (839 kg)	2200 lbs. (998 kg)	1850 lbs. (839 kg)
Gross Axle Weight Rating (GAWR)	Front 1023 lbs. (464 kg) Rear 1317 (597.4 kg)	Front 1023 lbs. (464 kg) Rear 1317 (597.4 kg)	Front 1023 lbs. (464 kg) Rear 1317 (597.4 kg)
Seating	2	4	2

PROCEDURES AND METHODS

Converting a gasoline combustion engine into an electric engine requires several steps. In this section the disassembly of the gasoline engine, the design and fabrication of the new mounts, and the installation of the new electric motor will be discussed.

Disassembly

One complete GEM e4 was disassembled, the motor and the controller were saved to use in the conversion. To access the motor and controller the entire GEM car had to be stripped down to the frame. The frame, seats and windshields were then either saved as spare parts for the other GEM cars or sold to help reduce the cost of this project. This GEM car was not functioning when it was purchased because it did not have batteries. The 6 batteries for this project came out of the GEM eS.

Before beginning the disassembly process measurements were taken to see how far off the ground the Porsche sat. These measurements will be compared to measurements taken after the new motor and batteries are installed to insure that the new system is not heavier than the gasoline engine. The front of the frame, right behind the front tire, sits 6 ½ inches off the ground. The back of the frame, right in front of the rear tire, sits 7 ½ inches off the ground. These are both shown in Figure 3.

Figure 3. The left picture shows the back of the frame measurement before removing gasoline engine and the right picture shows the front of the frame measurement before removing gasoline engine.

Figure 4 shows the engine compartment before the disassembly began. Notice how full the engine compartment is and how little extra space there is.

Figure 4. Engine compartment of the Porsche before beginning the disassembly

The disassembly began by detaching the engine from the car. This included disconnecting all of the wires, tubes, hoses and bolts that attached the engine to the frame of the car.

Figure 5, below, shows all of the wires, tubes, hoses and bolts that came from the engine no longer connected to the body of the car. The engine mounts, where the red arrows point, are still attached. The engine lift was then attached to the

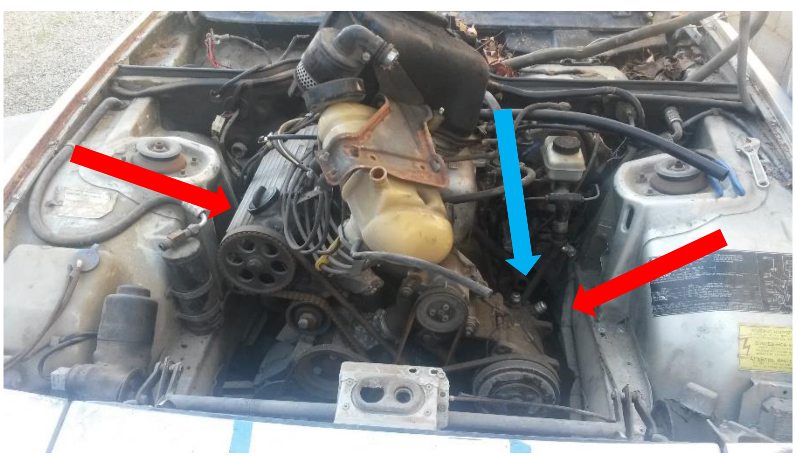

Figure 5. Engine compartment of the Porsche once the engine has been disconnected from the car frame

engine, shown in Figure 6Figure 6, shown below. Before the engine could be pulled up and out of the car the bolts in the engine mounts had to be removed.

Figure 6. Engine lift attached to the engine before disconnecting the engine brackets

The next piece that had to disconnect was the steering column, shown with the blue arrow in Figure 5. The steering column had to be disconnected because there was a piece of the engine that was sitting underneath the column. This meant that the engine would not pull straight out unless the column was moved. The steering column connection piece should have been a simple twist to release the pressure valve but because it had been so long since it had been moved it had sealed shut. A crow bar with a sledge hammer had to be taken to the valve before it finally popped off.

Once all of the mounts were disconnected the engine should have been able to slide forward to disconnect from the transmission and then lift straight up and out of the engine compartment. Because of the axle and the way it was positioned the engine was not able to slide forward. Since the engine could not slide forward the shaft connecting the transmission to the engine was not able to slide out of the engine leaving the entire engine stuck in place. To get around this problem the front axle had to be dropped, shown in Figure 8 on the next page.

Figure 8. Front axle dropped and the bottom of the engine

Once the axle was dropped the engine was able to slide forward. The engine lift was then used to slowly lift the engine up until it could clear the front end of the car frame. Figure 7 shows the engine in the lift clearing the front of the car frame.

Figure 7. Engine lift being used to move the engine out of the engine compartment in the car

Other pieces that had to come out of the car for the conversion are the exhaust system and the gas tank. The bolts holding the exhaust pipe into place where rusted and would not loosen so the exhaust pipe had to be cut with a reciprocating saw. The gas tank had to be removed because that space might eventually be used to hold extra batteries.

Design and Construction

The following will discuss the different parts of the design and construction process.

Connecting Mount.

A plate needed to be designed to connect the transmission bell housing to the motor, it would be used as one of the support pieces for the motor as well. Figure 9 shows the bell housing which the plate will be modeled off of.

Figure 9. Transmission bell housing

The plate was designed to be a circle for two main reasons, one it gave easy access to be able to mount support brackets to and two because it was easier than solid modeling all of the odd curves. The first step in making the plate was making a SolidWorks model of the piece, shown in Appendix B. The drawing was transferred into AutoCAD and was then cut out, to scale, on cardstock paper. The holes were cut out to make sure they aligned with the bolt holes in the bell housing. After a few minor adjustments and a re-print the cardstock plate fit perfectly.

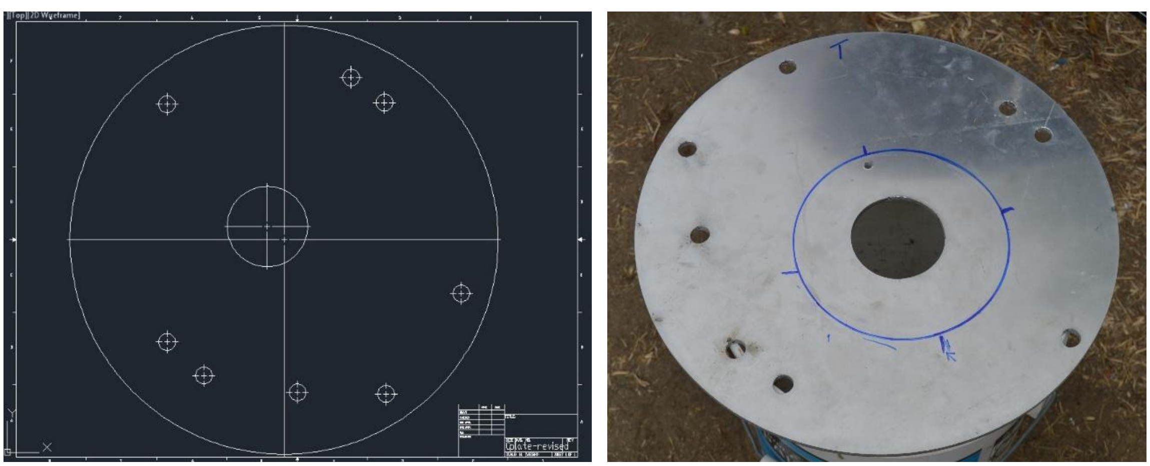

Figure 10. AutoCAD drawing of plate and the completed cut-out plate. The blue line on the finished piece shows were the motor will attach

The AutoCAD drawing was then taken to the plasma cutter in Lab 6. The plate was cut out from a ¼" thick piece of 5052 aluminum.

Figure 11. Plasma cutter right before cutting the plate

The plate was then tested to see if it matched the transmission bell housing.

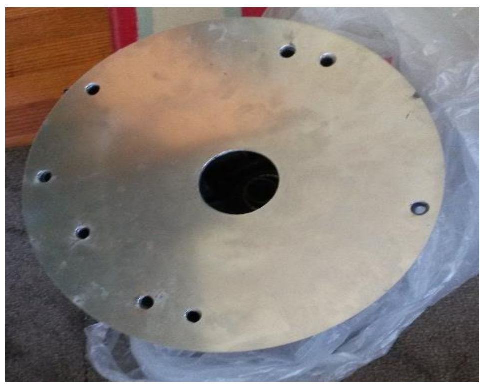

Figure 12. Plate sitting on top of bell housing.

Electrical System.

After the plate was made the next step was to test the old motor that would be used. The motor that was used in the conversion was from an old GEM car which did not drive. To make sure that the motor was not at fault for the GEM car not running the motor needed to be tested. To test the motor it was attached in place of another motor in a working GEM car. Because the motor in the working GEM car would have been difficult to remove the wires were just detached. The detached wires were then connected to the motor that needed to be tested via jumper cables, shown in Figure 13, shown on the next page.

Once the cables were in place the GEM car was turned on and the gas pedal was slowly stepped on. Because of how close the positive and negative terminals were on the motor a little bit of arching occurred. After re-positioning the cables slightly the GEM car was turned on again and the motor started spinning when

the gas pedal was stepped on. After it was determined that the motor worked the motor was disconnected and was ready to place in the Porsche.

Figure 13. Testing of the old GEM car motor, shown by the arrow.

The next step in the conversion was to get the electrical wiring all set up in the Porsche. To do this all 6 of the batteries were taken out of the GEM car. Once the batteries were removed from the GEM car a small lip was found around all of the batteries. Even though this lip added just under an inch to each battery it made it so the batteries would not fit in the initial formation in the Porsche. After some careful consideration it was determined that the batteries would not fit anywhere under the hood. Next measuring was done and a decision was made to put the batteries in a straight line in the trunk. This was nice because it allowed the control board to be placed right behind the batteries so that cables could easily be connected back to the board. Once the decision was made to put the batteries in the back of the car the trunk was cleared out of all of the fabric and padding. A ¾ in thick piece of plywood was cut out to fit snuggly in the trunk. The batteries were then lined up along the backseat with all of the positive terminals facing the front of the car. The converter and controller were then installed behind the batteries. The controller had wires to go to a 12V accessory system that ran the blinkers, lights and horn in the GEM car but since the original blinkers, lights and horn from the Porsche were being used the 12V system, from the GEM car, was taken out. After the 12V system was taken out the batteries and the controller were all connected in series, shown in Figure 14.

Figure 14. Batteries being connected in series

Due to a few short cables battery 5 had to be flipped around 180 degrees so that the positive terminal was closer to the back of the car, this allowed the batteries to be connected in series without having to buy new cables. The final electrical layout of the Porsche is shown in Figure 15.

Figure 15. Final battery layout, connected in series

The batteries were then tested to make sure that it was at least a 72V system. This is shown in Figure 16. Once it was confirmed that the system did have 72V the main electrical work for the Porsche was completed.

Figure 16. Testing the voltage of the entire system

Motor Installation.

The first step in the motor installation process was to install the transmission bell housing and then attach the plate to the front of the bell housing. The two were attached with four large bolts as seen in Figure 17.

Figure 17. Transmission bell housing attached to the plate.

Since the plate would eventually be used to support the motor a supporting bracket needed to be installed to support the plate. The supporting bracket was made out of slotted angle iron. The slotted angle iron was cut to fit snugly up against the plate and fit into the old engine mounting brackets. This is shown in Figure 18, shown on the next page.

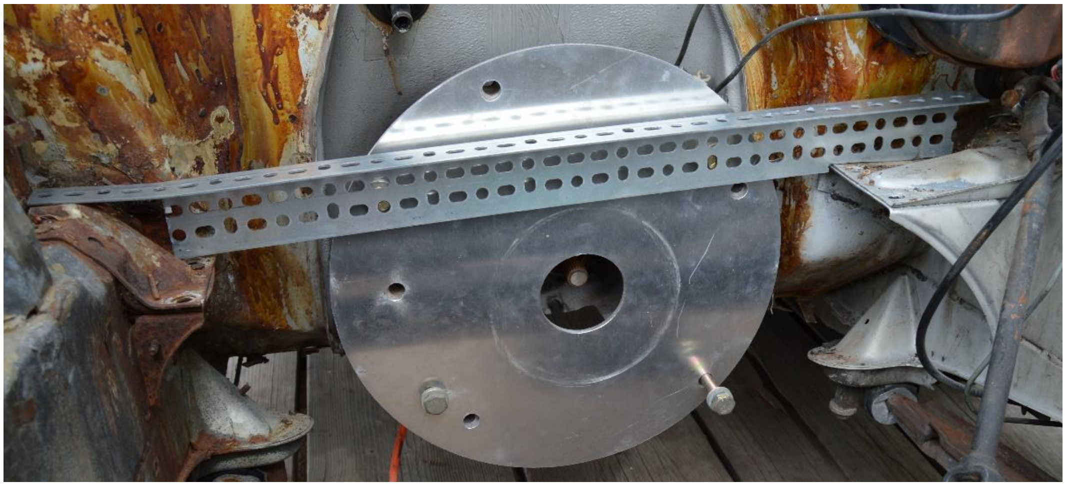

Figure 18. Mounting bracket for plate.

After the mounting bracket was installed the motor with the coupler was attached to the transmission shaft. Installation and the correct placement of the motor are shown in Figure 19.

Figure 19. Motor installation and final placement.

Four holes had to be drilled in the plate so screws from the motor could go through to attach the two together. To get the correct placement of the screws an outline of the motor was drawn onto the plate and then lines were drawn where the holes had to be. Figure 20, on the next page, shows the plate with the circle outline marked as well as the plate with the 4 - 5/16” holes.

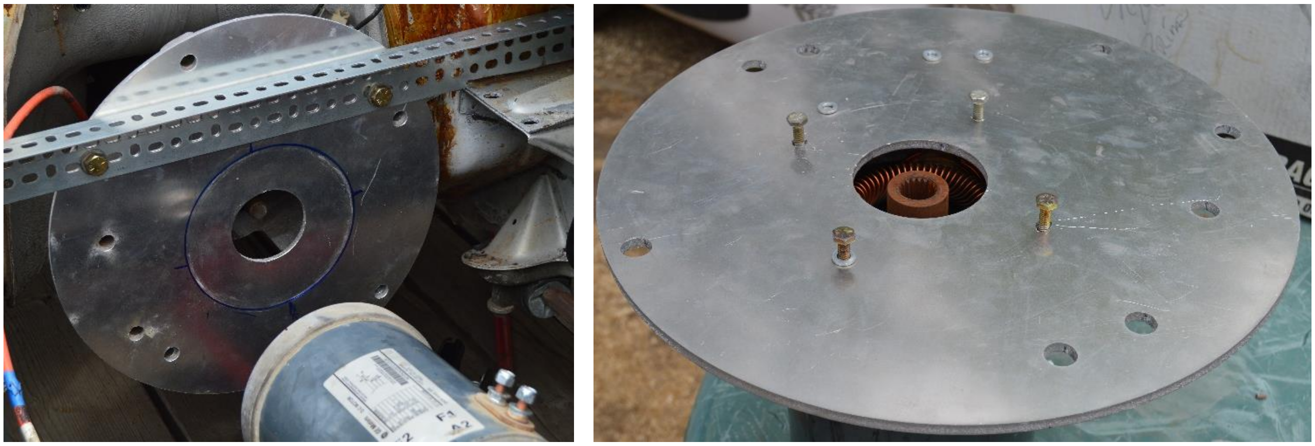

Figure 20. Plate with motor mounting screws.

Screw thread was put on the screws before they were drilled into the plate and motor to permanently link the two. Figure 21 shows the screws being drilled into the plate and motor and then the final attachment of the plate/motor to the transmission bell housing. The bolts attaching the bell housing to the plate were then tightened, completely locking the system into place.

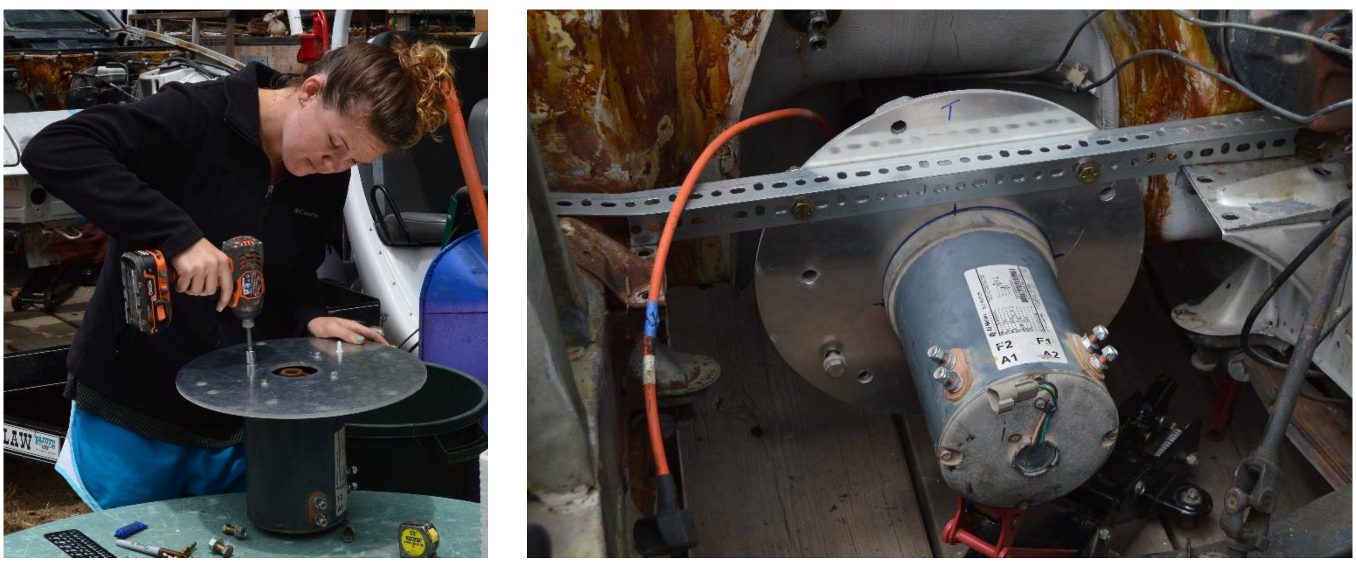

Figure 21. Final attachment of panel to motor and panel/motor to bell housing.

Two long wires had to be cut and then soldered to attach the motor in series with the batteries. Figure 22, on the next page shows the end of one of the wire ends being soldered together, after which the end cap was soldered onto the wire.

Figure 22. Tinning the end of one of the wires.

After the two wires were tinned together they were attached to the two positive terminals on the motor. The two wires were then run underneath the car, along with 4 other grounding wires, back to the batteries. The completely attached and hooked up motor is shown in Figure 23.

Figure 23. Fully attached and assembled motor.

RESULTS

Electrical System Testing Results
After the electrical system was installed tests were performed to determine if the system was running correctly. A test was done to see what the total voltage was. Since the 6 batteries were connected in series the voltage should have been equal to or greater than 72V. When all of the batteries were connected and on the voltmeter measured 84V.

The controller was tested by using a voltmeter to verify that the voltage was flowing to the correct wires. After verifying that the controller was actually sending voltage to all of the correct lights and the steering column it was tested to verify that there was a large increase in the current.

Motor Testing and Results
Once the motor was attached in series with all of the batteries testing was done to see the difference in spinning speed of the tires. Since the car was lifted off of the ground the tires spun in all gears with 5^{th} being the fastest and 1^{st} being the slowest. A significant amount of smoke came out of the motor during testing.

Overall System Testing and Results
Once the car was off of the trailer testing was done to see if the car would move. The car was set in third gear to start, it did not move. The car was shifted into first gear and the car reached a top speed of 11 MPH.

Figure 24. Completed converted car.

DISCUSSION

Electrical System

The overall electrical system ended up working much better than anticipated. With the batteries placed in the back of the vehicle, instead of up front as originally planned, the control board was able to be placed right next to the batteries. This allowed for the use of the same wires that had been in the GEM car instead of having to make new wires. This did present a slight problem with the on/off switch and gas pedal. Because the wires for the on/off switch, forward/reverse switch, and the gas pedal came off of the control board the initial testing had to be run with the gas pedal in the back of the vehicle. Once the initial testing was completed and it was verified that the car would run, longer cables had to be made to bring these features up to the driver's seat.

One of the lessons learned was how much of a hazard testing the traction motor without the controller could be: the motor was temporarily connected directly to the full voltage of the battery pack. Upon electrical contact, the torque reaction caused the motor body to rotate abruptly, tearing the motor terminals away from the motor contacts.

A main issue with putting the batteries in the back of the car was that 4 long, thick and expensive wires had to be purchased to run up to connect to the motor in the front of the car. If the batteries were placed up front as was originally planned the extra wires would not have been needed.

Motor Installation

The disassembly of the gasoline engine seemed fairly straightforward but a few minor problems occurred along the way. The biggest issue was it was fairly difficult to fit hands down to dis-attach pieces that were lower down on the engine, this was due to how close together all of the parts were and the lack of extra space.

Another minor issue that occurred was the breaking of the windshield wiper fluid container. The container is in the bottom left of Figure 4, on page 7, and shattered when a wrench was accidentally hit the bottom of it.

An additional problem that arose was disconnecting the steering column. The steering column connection piece should have been a simple twist to release the pressure valve but because it had been so long since it had been moved it had sealed shut. A crow bar with a sledge hammer had to be taken to the valve before it finally popped off.

Marking and drilling the holes in the plate for the motor ended up being rather difficult. Since there was such a small tolerance on the holes they had to be in almost the exact location so that the screws would line up with the holes in the motor. Once the holes were drilled installing the motor was relatively simple.

The motor was not labeled very well so it took a little bit of time to figure out where each cable needed to be connected.

Overall System

The initial testing of the motor resulted in a lot of smoke. This was due to the motor sitting and not being run for so long, not because of a faulty connections. After the motor had been run a few times the amount of smoke decreased drastically.

Once the car was placed in first gear it was able to reach a top speed of 11 MPH in a dirt area. Since the car is not street legal it was not tested on the street.

RECOMMENDATIONS

Electrical System

The initial motor testing should have been done with the motor properly installed in a GEM car to avoid arching.

It would have been helpful to have run the longer cables so that the on/off switch, forward/reverse switch, and the gas pedal were up by the driver initially. This would have been less confusing for the operator of the features and the driver.

Motor Installation

A better and more precise way to find out where the holes on the plate needed to be drilled should be figured out. Outlining the motor and approximating where the holes were located was not the best solution.

The motor should have been labeled with blue tape when it was removed from the GEM car. This would have made it easier to figure out where each cable needed to be connected when installing the motor in the Porsche.

Overall System

It would have been a good idea to let the motor run for a little while, until it stopped smoking, before closing the hood of the car. The fumes made it difficult to breath inside of the car.

A vacuum pump would need to be installed before taking this vehicle on the road because the brakes currently do not work well.

Overall if this car was to be taken out onto the road it would need a much larger motor, 6 more batteries and a larger controller that could handle the increase in voltage from the 6 extra batteries. The new system would need approximately a 50hP motor with a voltage system that could handle 144V.

REFERNCES

1. Dimick, D. "How Long Can the U.S. Oil Boom Last?" National Geographic. National Geographic Society, 19 Dec. 2014. Web. 04 Jan. 2015.
2. EIA (U.S. Energy Information Administration). January 5, 2015. “Retail Prices for Regular Gasoline”. < http://www.eia.gov/dnav/pet/pet_pri_gnd_a_epmr_pte_dpgal_w.htm> referenced January 7, 2015.
3. Electric Drive Transportation Association (EDTA). 2015. EDTA Company Homepage. < http://electricdrive.org>, referenced February 3, 2015.
4. IEA. "Energy Security Concerns on the Rise." World Energy Outlook 2014. France: IEA PUBLICATIONS, 2014. 2. Print.
5. Ingram, A. Green Car Reports. June 26, 2014. “Electric Car Price Guide: Every 2014-2015 Plug-In Car, With Specs.” < http://www.greencarreports.com/news/1080871_electric-car-price-guide-every-2012-2013-plug-in-car-with-specs>, referenced January 12, 2015.
6. Marshall, B. How Stuff Works. March 27, 2002. "How Electric Cars Work" <http://auto.howstuffworks.com/electric-car.htm>, referenced January 4, 2015.
7. Nelson, B. Instructables. 2009. “Build your own Electric Car!” <http://www.instructables.com/id/Build-your-own-Electric-Car>, referenced February 16, 2015.
8. Roland. DIY Electric Car. June 6, 2011. “EVDL List” <http://www.diyelectriccar.com/forums/showthread.php/evdl-electric-power-steering-conversion-59392.html >, referenced February 16, 2015.
9. U.S. Department of Energy. January 9, 2015. “Alternative Fuels Data Center – Batteries for Hybrid and Plug-In Electric Vehicles” <http://www.afdc.energy.gov/vehicles/electric_batteries.html> referenced February 3, 2015.
10. "2012 GEM Owner's Manual." Page 136-137. Polaris GEM Cars. Polaris, 2011.

APPENDIX

Appendix A

How Project Meets Requirements for the BRAE Major

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

Major Design Experience

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes fundamental elements as outlined below. This project addresses these issues as follows.

Establishment of Objectives and Criteria. See *Design Parameters and Constraints* below for specific objectives and criteria for the project.

Synthesis and Analysis. The project incorporates bending stress calculations of the steel angle iron used as battery supports and shear calculations on the aluminum conversion plate.

Construction, Testing and Evaluation. The electric engine has been designed and put together, and will be tested and evaluated.

Incorporation of Applicable Engineering Standards. The project utilizes AISC standards for allowable bending stresses in the motor support bar for carrying batteries under the car.

This project and its various subsystems complied with:

- ISO (International Standards Organization) Std 8715:2001 “Electric road vehicles -- Road operating characteristics”. This guided some of the analysis of the suitability of the donor car (Porsche 924) for the electric conversion.
- ASTM (American Society for Testing and Materials) standard D1079, relevant to
  Weatherproof enclosures and connectors.
- SAE (Society of Automotive Engineers) Standard J2344 “Guidelines for Electric Vehicle Safety”, Rev. 2010. Prescribes methods and metrics to be observed when designing electric vehicles for public roadway use.
- NHTSA (National Highway Transportation and Safety Administration). Regulations 301F, pertinent to crash-worthiness of modified vehicles.

Capstone Design Experience

The BRAE senior project is an engineering design project based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses). This project incorporates knowledge/ skills from these key courses.

- BRAE 129 Lab Skills/Safety
- BRAE 133 Engineering Graphics
- BRAE 234 Mechanical Systems
- BRAE 421/422 Equipment Engineering
- ME 211/212 Engineering Statics/Dynamics
- CE 204/207 Strength of Materials
- ENGL 149 Technical Writing

Design Parameters and Constraints

This project addresses a significant number of the categories of constraints listed below.

Physical. The space under the front hood limits the allowable space to put extra batteries or a larger motor. Six 12V batteries were put in the back of the vehicle due to space and weight constraints.

Economic. The cost remained as minimal as possible due to all of the in-house machining and assembly. The sponsor wanted to see the results of the tests before he was willing to put in the money for a larger motor and more batteries.

Environmental. All of the materials that were taken out of the car, including the old engine and exhaust tank, have been properly disposed of and if possible recycled. The old engine was taken to a company that repurposes old engines to put them in vehicles for low income families. Battery production and disposal is an environmental concern for this project.

Sustainability. This car will be powered by solar power so it will cut back on emissions being put into the air by coal plants. It is an electric vehicle so it no longer has the harmful emissions that a gasoline engine does either.

Manufacturability. While this is a one-time project simplicity was kept in design to make machining easier. The adapter plate was originally going to be

designed to be the same shape as the transmission bell housing but due to simplicity it was changed to just be a circle.

Health and Safety. Safety glasses have been warn whenever machining parts and rubber gloves were warn when taking out the old engine. SAE and IEEE standards for Electric Vehicle Design were kept in mind as well.

Ethical. Major ethical issues have not been encountered during this project but a goal in the future is that the energy to power this car could come from solar power not big energy corporations. It is the responsibility of this country to reduce the quantity of fossil fuels used.

Social. The intent of this project wasn't to create a social project but sustainable energy is "the new big thing" so people have been interested in this project.

Political. The car will eventually use renewable energy which will get rid of air pollution from this vehicle. Since this vehicle is powered by renewable energies it is no longer a part of the gasoline addiction in our society.

Aesthetic. Aesthetics has not been a major concern in this project since it is all under the hood of the car but all of the materials will be painted for aesthetics as well as protection of parts. And it must look cool or my Dad wouldn't like it.

Other. The whole point of switching this vehicle to an electric vehicle was to reduce fossil fuel consumption so if this vehicle is powered by electricity made from coal then there was no point to this project.

Appendix B

SolidWorks Drawing for Motor Connecting Plate