Electric Conversion of Porsche 914

by

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ABSTRACT

With energy and environmental concerns becoming increasingly greater issues, electric vehicles are a promising alternative to internal combustion engine vehicles. More research and interest must be focused on battery technology and electric vehicles to make this a viable solution for the future of transportation. This project focuses on converting a 1974 Porsche 914, originally equipped with a 4-cylinder IC engine, into a full electric vehicle. The IC engine is replaced with a 50kW peak, 3-phase AC induction motor powered by twelve lithium-ion phosphate-metal cathode batteries. This paper goes through the conversion process as well as the necessary maintenance and driving techniques required to safely and efficiently operate an electric vehicle. Although the vehicle is complete it is currently in the debugging phase due to unforeseen electrical problems. The vehicle is planned to run by early June, 2007. Despite this setback, the project has been successful in starting a performance electric vehicle team, MIT EVT, and in increasing the appeal of electric vehicles in the MIT community.
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Chapter 1

Introduction

The following chapter provides fundamental facts on electric vehicles, their importance in the future of transportation and the goal of this paper.

1.1 Importance

As environmental and energy concerns are becoming larger issues, focus must be placed on alternative forms of transportation that do not rely on petroleum. Electric vehicles have a lot of potential but they are still not widely accepted. More research and interest must be placed in the field of electric vehicles and battery technology to make them viable solutions to the issues at hand.

1.1.1 Basics of an Electric Vehicle

A battery electric vehicle (BEV) is usually defined as a vehicle that utilizes chemical energy stored in rechargeable battery packs. Electric vehicles were among the earliest automobiles and are more energy-efficient than ICE vehicles. They do not produce exhaust fumes, and produce minimal pollution if charged from most forms of renewable energy. Many electric vehicles are capable of acceleration exceeding that of ICE vehicles- the Tesla Roadster has a 0-60 time of 4.2 seconds, rivaling that of Ferraris and Lamborghinis.

1.1.2 Energy Efficiency and Environmental Impact

Whereas internal combustion engines only have an efficiency of approximately 30%, electric motors can have efficiencies as high as 90%. Most of the inefficiency in electric vehicles is not from operating the vehicle but from charging the batteries.
Electric vehicles reduce dependence on petroleum, do not produce noxious fumes, and help to alleviate global warming by reducing pollution.

1.1.3 Cost and Maintenance

Electric vehicles typically cost between two and four cents per mile to operate, while gasoline-powered ICE vehicles currently cost about four to six times as much. The total cost of ownership depends primarily on the type of batteries used.

Electric vehicles have far less maintenance issues than ICE vehicles. They do not need oil changes, tune-ups, filters, timing belts, fuel pump, gaskets, etc. They also have less moving parts which are prone to wear.

1.2 Scope of Project

The goal of this project is to convert a 1974 Porsche 914 into an electric vehicle using an AC setup and lithium-ion batteries.

1.2.1 Electric Conversion of Porsche 914

The Porsche 914 was chosen based upon its stiff chassis and quality suspension parts, low-weight, and appeal. An AC conversion kit specifically for the Porsche 914 was purchased from Electro Automotive. Valence Technologies, Inc. has supplied the lithium-ion batteries to power the vehicle. Maniv Energy Capital, LLC has provided the team with funding.

1.2.2 Performance Expectations

The Porsche 914 is expected to reach a top speed of 100mph and a range of 150+ miles under ideal conditions.

1.2.3 MIT Electric Vehicle Team and Public Outreach

Through this project, the MIT Electric Vehicle Team is being formed. The goal of the team is to design and engineer high performance electric super cars- similar to the Tesla Roadster. The purpose is to show the benefits of electric vehicles and their viability as alternatives to conventional ICE vehicles.
1.2.4 Fundamental Challenges

The performance of electric vehicles is largely limited by the energy-to-weight ratio of batteries in use. Lead-acid batteries are relatively not efficient whereas batteries such as those of lithium-ion chemistries which have higher energy-to-weight ratios are expensive. Furthermore, batteries pose a different safety concern which has not been internalized by the general public (i.e. computer batteries exploding).

1.2.5 Thesis Outline

The following chapters will go into detail on the conversion process as well as the maintenance and driving technique unique to electric vehicles. Further testing and modifications are also proposed later in the paper.

Chapter 2

Conversion

The conversion of an internal combustion engine vehicle into an electric vehicle is not as simple as loading it with batteries and dropping in an electric motor. Much research must go into choosing the proper donor vehicle and the purpose desired for the electric car. Many vehicles are not suitable for conversion; and electric cars may not be practical in certain driving situations (i.e. long trips, towing and hauling, wet terrain or rainstorms). The donor vehicle should be lightweight (less than 3,000 lbs), have enough space for batteries, be in good condition, and have easily available OEM or aftermarket parts. Certain vehicles have special idiosyncrasies that must be known before committing to electric conversion (i.e. Honda crankshafts rotate in the opposite direction from almost any other make, Subaru and Mazda have rotary engines which present different challenges than those of the traditional piston-powered engine).
The 1974 Porsche 914 is an ideal candidate for electric conversion. It has a curb weight of 2890 pounds, plenty of space for batteries in the front and rear compartments, and has a decent market for replaceable parts. The well-maintained vehicle used in this project was carefully chosen from a caring owner in a temperate climate zone. The 4-cylinder internal combustion engine and its accessories were removed before the electrical conversion began.

2.1 Layout of Vehicle

The electric motor supplies mechanical power to the transmission and driveline that turn the rear wheels of the car. The electrical power to the motor is supplied by the front and rear batteries connected in series, managed by the controller and potbox. The batteries are recharged through the charger in the front of the car. The control system receives electrical power and information signals from various relays, terminals, and switches situated in the rear engine compartment wiring and front baggage compartment.

In Figure 2.1 the brown-colored path represents the mechanical power generation and transfer throughout the vehicle. The green-colored path represents how electrical power is stored and directed throughout the vehicle. The red-colored path represents how the controller receives information signals from both the driver and vehicle and manages electrical power to the motor. Note that the rear compartment wiring is the center of the electrical power and information signal paths.
2.2 Motor

The motor used in this conversion is the Azure Dynamics AC24- a single output, 50kW peak, 3-phase AC induction motor with 4.5k rpm nominal speed and 12k rpm maximum speed. With a peak torque of 74 N·m and a continuous torque of 30 N·m, the AC24 can provide enough torque and power to drive vehicles in the 1,000 to 1,300 kg weight-range, such as the Porsche 914. With a weight of only 38 kg it has a power-to-weight ratio of 1.32 kW/kg. The 140kg, 85 peak HP (63 kW) internal combustion engine originally equipped in the car only produced 45 kW/kg.

Other benefits of this motor include its high-efficiency brushless design (peak efficiency of 83%), ability for regenerative braking, compact design (4 kW per liter), air-cooling for simplicity in vehicle design, and its safety features (motor over-temperature protection, overspeed torque limit). Although an AC setup is 1.5x more expensive than a DC setup, its advantages outweigh the costs. AC setups have high top RPM limits, are capable of regenerative braking unlike DC setups, reduce $I^2R$ losses through high voltage/low current, and can adapt to the exact characteristics of the motor and throttle potentiometer (greater control).
The motor is installed in the rear engine compartment where the original 1.8L engine used to be. It is mounted directly to the motor mount fabricated by Electro Automotive which then sits on the original engine mount. Proper care was taken to ensure that the motor was level with the rest of the vehicle.

Power is supplied to the motor through a factory assembled, three-conductor, shielded, lugged, power cable that is connected to the controller. Feedback to the controller is sent through another cable with a factory assembled connector.

### 2.3 Transmission and Driveline

Although Azure Dynamics produces a single speed gearbox with integrated differential to be used with the AC24 motor, due to cost restraints, the stock 5-speed transmission from the Porsche 914 is reused. The transmission was cleaned and the oil replaced. The clutch, flywheel, and throw-out bearing were in good shape and so they were reused as well. The CV joints in Figure 2.0.b which join the axles to the transmission were also serviced.

In order for the AC24 motor to fit properly onto the transmission, an adaptor system is used (Figure 2.3.a). The adaptor is precisely designed, machined, and installed to ensure that the motor transmits power and torque to the transmission without issues.

![Figure 2.3: Diagram of Adaptor Plate (a) and Motor-Adaptor-Transmission Component (b).](image-url)
2.4 Control System

The motor used in this conversion is the Azure Dynamics AC24- a single output, 50kW peak, 3-phase AC induction motor with 4.5k rpm nominal speed and 12k rpm maximum speed. With a peak torque of 74 N-m and a continuous torque of 30 N-m, the AC24 can provide enough torque and power to drive vehicles in the 1,000 to 1,300 kg weight-range, such as the Porsche 914. With a weight of only 38 kg it has a power-to-weight ratio of 1.32 kW/kg. The 140kg, 85 peak HP (63 kW) internal combustion engine originally equipped in the car only produced 45 kW/kg.

2.4.1 Controller

The Azure Dynamics Digital Motor Controller (DMOC) is a traction inverter for controlling three-phase AC motors. The DMOC utilizes state-of-the-art control techniques and electronic devices, such as Space Vector PWM and Trenchgate IGBTs. The controller is also the key component in the regenerative braking aspect of the vehicle. Several safety features ensure that the motor is not damaged: overvoltage and undervoltage protection, inverter overtemperature protection, motor overtemperautre protection, overspeed torque limit, and invalid pedal signal detection. Although the controller is capable of a peak power of 78 kW, the vehicle is limited by the 50 kW AC motor.

Figure 2.4: Controller mounted in Rear Luggage Compartment (a) and closer view of power cables (b).
The controller is mounted in the rear luggage compartment onto the controller mount. In order to clear the controller height the controller mount was sunk into a hole cut out of the compartment floor. In Figure 2.4.a the input and output cables and wires are shown. Power from the batteries is transmitted through gauge 2 cables into the positive and negative terminals of the controller. The "controlled" output power is then sent to the 3-phase AC motor through the three cables from the motor. Feedback from the motor is sent back to controller through the gray motor speed sensor cable on the driver-side of the controller. The controller harness (multi-colored wires) is connected to the various terminals and relays in the engine compartment and front luggage compartment.

2.4.2 Potbox

The potbox, or potentiometer, is essentially a variable resistor (0-5kohm) that interfaces between the throttle pedal and the controller. Depending on how far the throttle is depressed, it sends a signal ranging from 0-5kohm to the controller. The controller then interprets the signal and varies the amount of power to the motor. In Figure 2.5 the potbox arm is in the full Off position. When the throttle pedal is depressed it pulls the throttle cable and potbox arm to the left. When the potbox is all the way to the left, the maximum amount of power is sent to the motor.

![Figure 2.5: Potbox with throttle cable and microswitch.](image-url)
The potbox also comes equipped with a microswitch (hidden behind plate cover) which prevents the controller from receiving power if the vehicle is started with the throttle pedal depressed. This ensures that the vehicle will not jump forward when starting the car (similar to starting a car in first gear).

2.5 Batteries

Energy is supplied to the controller and motor through twelve U24-12XP lithium-ion batteries donated by Valence Technologies, Inc. Lithium-ion batteries are used in this application because of their high energy-to-weight ratio— it takes approximately 6 kilograms of lead-acid battery to store the same amount of energy that a 1 kilogram lithium-ion battery can handle. Other advantages of using lithium-ion batteries include low self-discharge rate of approximately 5% per month, no memory effect as with other battery chemistries, and the ability to endure hundreds of charge/discharge cycles.

The disadvantages of using lithium-ion technology are: 1) their life span is dependent upon aging from time of manufacture (shelf-life) regardless of whether they were charged, 2) they are sensitive to high temperatures and will degrade much faster when exposed to heat, 3) they can go into a state of deep discharge which will cause irreversible damage. Because of these drawbacks, the batteries are stored at low charge levels and low temperatures, and are equipped with a voltage monitoring circuit (“smart” battery) that will shut down the system when the battery is discharged below a certain voltage. In addition, the circuit continuously draws a small current from the battery even when not in use so that capacity loss is minimized.

2.5.1 Valence U-Charge XP Power System

The twelve lithium-ion batteries in the vehicle are of Valence’s U-Charge XP series. Whereas traditional lithium-ion technology utilizes cobalt oxide material for cathodes, these batteries incorporate lithiated metal phosphate cathodes which are much safer (less prone to explode under high temperatures) and have a longer shelf life. Although these batteries only hold 75% as much power as lithium cobalt oxide batteries, their increased safety is a major plus for electric vehicles.

Each battery weighs 15.8 kg bringing the total vehicle battery weight to 189.6 kg. The OCV of the battery was determined to be 13.35V and with all twelve connected in series the
circuit has 160.2V. Each battery has a capacity of 100 A-hr and an energy capacity of 1.36 kW-hr. Figure 2.6.b illustrates how capacity decreases as the battery is repeatedly charged and discharged under different temperatures.

Figure 2.6: Image of Valence Lithium-ion Battery (a) and its Life Cycle Performance Curve (b).

Figure 2.7 shows the charge and discharge rate performances of the U12-24XP lithium-ion battery. Note how the battery remains at a high discharge voltage until it fully discharges. Also note that capacity for the most part increases linearly with charge time. It takes approximately 2.5 hours to charge one battery and an estimated 5 hours to charge the entire system.
2.5.2 Battery Management System

Valence has provided the Battery Management System (BMS) which connects to the battery system through communication cables. The BMS monitors the state-of-charge, temperature, voltage, and current in the system. It also features battery-to-battery balance control to ensure that any single battery does not enter deep discharge during operation or becomes overcharged during charging. The BMS is a key feature of this battery system and provides another level of safety to the “smart” electronics within each battery.

2.5.3 Battery Containment and Hookup

Due to physical constraints of the Porsche 914, the batteries are distributed amongst the front baggage compartment (four units) and the rear engine compartment (8 units). The weight of the batteries is kept inboard of the axles as much as possible to ensure that handling is not compromised. Figure 2.9 depicts the welded steel racks that enclose the batteries. The front rack is bolted to the bottom of the spare tire well and the rear rack is bolted to the passenger compartment firewall and suspension mount posts.
During the installation of the rear battery rack it was realized that the AC motor and adaptor plate interfered with the proper placement of the rack. An easy solution to this problem was to extend the length of the suspension mount posts using stock steel columns (Figure 2.10). Consideration was taken to ensure that the battery height clearance would not become an issue.
The batteries are arranged and connected together using the layout in Figure 2.11. The batteries are interconnected in series using 4 gauge cables. A fusible link is installed in the front and rear sections in case of a short circuit. The front and rear battery sections are connected using 2 gauge cable fed through a heater duct the length of the vehicle. A battery pack “most positive” terminal and a “most negative” terminal are installed on the driver’s side wall of the engine compartment. The input power cables for the controller are connected in series to the batteries through these terminals.

*Figure 2.11: Battery Layout with four units in front and eight units in the rear compartment.*

The red battery in Figure 2.12.a is the auxiliary battery used to switch ON/OFF the controller, and power lights and other accessories. Note that the battery terminals are covered with electrical tape in these early pictures. The electrical tape has been replaced with polyethylene battery terminal covers. Furthermore, the entire front and rear sections
2.6 Charger

The vehicle uses the Zivan NG3 charger to recharge the batteries when depleted. This charger model is a compact state-of-the-art high frequency, high industrial unit. It has an aluminum base, ABS cover, and internal cooling fans. It is configured specifically for the Valence batteries and their charging profiles. The charger has several safety features (thermal, current, voltage sensors) and alarms when a situation occurs. It also comes equipped with a LED indicator which shows a red light when the batteries are in their initial charging phase, yellow light when batteries reach 80% of charge, and a green light when the batteries have reached 100% of charge. It should take approximately five hours to fully charge the vehicle.

The charger is mounted in the front compartment where the gas tank used to be. Electrical power is transmitted from a wall socket to the charger input cable. The power is then routed to the most positive and most negative terminal blocks through 10 gauge wire. From these terminals the batteries receive their charge.
2.7 Rear Engine Compartment Wiring

The rear engine compartment wiring is located on the driver side wall of the engine compartment. It consists of the upper and lower interface terminal, secondary charger interlock relay, neutral start relay, and regenerative braking relay. The controller's wiring harness connects directly to this section of the car and communicates to the rest of the car.
2.7.1 Upper Interface Terminal

The Upper Interface Terminal connects the DMOC controller to the Power Rotary Switch and Regenerative On/Off Switch in the passenger compartment. It also connects the yellow wire from the State-of-Charge Voltmeter in the passenger compartment to the most negative terminal block in the rear engine compartment.

![Diagram of Upper Interface Terminal]

Figure 2.14: Upper Interface Terminal.

2.7.2 Lower Interface Terminal

The Lower Interface Terminal connects the DMOC controller to the Potbox, 12V +keyed black wire from factory fuse block, and ground. It also connects the Potbox Microswitch to the Neutral Start Relay. The factory backup light wires and oil pressure light are rewired as well.
2.7.3 Secondary Charger Interlock Relay

The Secondary Charger Interlock Relay works in conjunction with the Primary Charger Interlock Relay in the front compartment to ensure that the vehicle cannot be driven away while the vehicle is being charged. If the charger is still connected, the relays will prevent the controller from driving the motor.

Figure 2.15: Lower Interface Terminal.

Figure 2.16: Secondary Charger Interlock Relay.
2.7.4 Neutral Start Relay

The Neutral Start Relay works with the Potbox Microswitch to ensure that the vehicle
does not jump forward if the throttle pedal is depressed. If the Microswitch does not sense the
Potbox arm to be in the full Off position it will not allow the controller to drive the motor.

![Neutral Start Relay Diagram]

Figure 2.17: Neutral Start Relay.

2.7.5 Regenerative Braking Relay

The Regenerative Braking Relay activates the brake lights when the motor and controller
are experiencing regenerative braking.

![Regenerative Braking Relay Diagram]

Figure 2.18: Regenerative Braking relay.
2.8 Front Baggage Compartment Wiring

The Front Baggage Compartment Wiring included the DC/DC converter, Primary Charger Interlock Relay, Key Switch Relay, Relay Fuse Block, and Relay Terminal Interface.

![Front Baggage Compartment Wiring](image)

*Figure 2.19: Front Baggage Compartment Wiring.*

2.8.1 DC/DC Converter

In order to power the lights, horn, and certain EV components an auxiliary battery with 12 volts grounded to the chassis is required. The DC/DC converter taps off the entire battery pack at a very low amperage to recharge this auxiliary battery. The lithium-ion batteries are discharge evenly, and the current draw is negligible.

2.8.2 Relay Terminal

The relay terminal connects the DC/DC converter, auxiliary battery, keyswitch relay, and primary charger interlock relay.
2.8.3 Primary Charger Interlock Relay

The Primary Charger Interlock Relay works with the Secondary Charger Interlock Relay to ensure that the vehicle does not drive off with the charger still connected.

2.8.4 Keyswitch Relay

The Keyswitch Relay turns on the DC/DC converter and battery pack voltmeter with the ignition key.

2.8.5 Relay Fuse Block

The Relay Fuse Block is used in case a short circuit were to occur in the front baggage compartment.

2.9 Gauges and Switches

Mounted in the center console is the High Voltage Meter, Ammeter, Low Voltage Meter, and Regenerative Braking On/Off Switch. The Power Rotary Switch is currently not installed.

Figure 2.20: Gauges mounted in center console.
2.9.1 High Voltage Meter

The High Voltage Meter acts as a “fuel gauge” and measures the voltage in the battery pack. Under acceleration, the gauge will draw down to a lower voltage because higher current is required by the motor. The gauge must therefore be read without depressing the throttle.

![High Voltage Meter](image)

*Figure 2.21: High Voltage Meter.*

2.9.2 Ammeter and Shunt

The Ammeter acts as an “efficiency gauge” and displays in real time how much energy is being used. When the vehicle is coasting or sitting still it should read zero. During full acceleration it should peak and then gradually fall as the motor reaches its optimum rpm level. When increasing the throttle does not cause the Ammeter needle to move up the maximum potential for the current transmission gear is reached, and it is time to shift up for more power. The ammeter assists in determining the most efficient gear for a particular speed, and vice versa.
The shunt, mounted in the rear engine compartment is required for the Ammeter. It converts the current passing through it to a calibrated millivolt signal which can then be read by the Ammeter.

2.9.3 Low Voltage Meter

The Low Voltage Meter monitors the charge level of the auxiliary battery.

Figure 2.23: Low Voltage Meter.
2.9.4 Regenerative Braking On/Off Switch

In certain situations it may be desirable to turn off the regenerative braking. For example, if the vehicle is going down a slippery slope under snow or rain conditions the regenerative braking should be disabled. The resistance in back-driving the motor may actually cause the wheels to lock, causing the driver to lose grip and control. The disable toggle is conveniently located within arm’s reach on the center console.

![Regenerative Braking On/Off Switch](image)

*Figure 2.24: Regenerative Braking On/Off Switch.*

2.9.5 Power Rotary Switch

The Azure Dynamics DMOC445 Controller allows for three levels of power selection: Economy, Normal, and Performance. The power can easily be configured through the Power Rotary Switch. However, due to unforeseen delivery issues with necessary parts, the switch is not integrated into the vehicle. The power setting is currently configured to maximum power at all times.
2.10 Suspension

Since the vehicle’s weight has been increased (approximately 83.8 kg heavier) and shifted to the rear (more batteries in the engine compartment), the suspension of the Porsche 914 must be modified. The front struts, torsion bars and control arm bushings, and rear shock absorbers and springs are upgraded to handle the increased weight.

Chapter 3

Post-Conversion Procedure

After the conversion is complete, the components must be tested to ensure that the vehicle will not pose a safety threat while driving. Also, like most complicated projects, things do not
work the first time through. Testing each of the components in the beginning is an efficient method to troubleshooting. Once testing is complete, the driver must be educated on proper driving technique and maintenance issues. The driver should become familiar with interpreting the gauges and practice driving to become more efficient. The driving experience is very different from that of an ICE vehicle.

3.1 Testing

- The grounds are checked to see if they are actually grounded. Components that should be tested for ground include the transmission, controller, relays, and terminal interfaces.
- It should be ensured that there are no potential sources for short circuiting in the wiring and especially for the batteries. Shorting in the batteries can pose a serious and dangerous situation.
- The auxiliary battery is connected and the ignition key is turned on. An audible click should be heard from the Keyswitch Relay in the front baggage compartment.
- The neutral start relay and charger interlock relays are checked to show voltage across their respective "live" terminals.
- The voltage and current across the batteries should be checked to see if they are at proper levels.

3.2 Maintenance

- When charging the vehicle, the LED indicator should be checked for the level of charge. Although the charger and the electronics built into the batteries should prevent them from overcharging, the charger should be disconnected from the batteries once fully charged.
- The voltage and level of charge of each of the batteries should be tested at regular intervals. A poorly performing battery, which could affect the performance and safety of the entire system, can easily be detected in this way.
- At regular intervals, any loose wires or cables, or signs of rubbing and wear should be searched for.
- Mounts, nuts and bolts, and any other components which may compromise structural integrity should be searched for.
- The vehicle should not be taken through a car wash.

### 3.3 Driving

- The clutch should be used to accelerate out of a stop. The motor should be revved up slightly before slipping the clutch. This will give a smooth yet sprightly acceleration. Not using the clutch gives a jolting but more sluggish start.
- The motor should not be operated at high rpm with no load. This will surely damage the motor.
- On acceleration, the ammeter will peg at a maximum current and then begin to fall. It will stabilize around a certain point. At the same time, the high voltage meter will fall off sharply, then climb gradually and stabilize. This means that the maximum potential for the current gear is reached. To continue accelerating, the transmission should be shifted up.
- When shifting gears, the transmission should be shifted quickly while holding the throttle half open. The momentary rev between gears helps keep the motor rpm high for the best power and efficiency.
- On hills, it will be required to shift sooner than necessary in an ICE car. With practice, the “feel” of the car and the ammeter will teach when to shift gears.
- Climbing hills on too high a gear can damage the motor or controller. When in doubt, shift down.
- If climbing a hill and increase throttle does not increase speed, the throttle should be backed off until the vehicle responds again. That is the best performance possible in the gear and any extra throttle will waste power and heat up the motor and controller.
- The motor has sufficient torque to pull hills comfortably at low speeds. If the vehicle feel like it is losing power, the transmission should be shifted down to find the optimum throttle position for that gear.
- More throttle does not mean more speed. More throttle gives more current, which in turn decreases voltage. If half throttle has adequate torque for the job, more throttle may only waste power. Some times, a slope can be climbed faster at half throttle than at full throttle, and use less energy.
• After cresting a hill and starting down, the transmission must be shifted up. If you coast at too high a speed in a low gear, you may over-rev and damage the motor. For the same reason, the car should only be towed in neutral.

• It is not necessary to use the clutch when braking to a stop. If the clutch is used, it should be left in for several moments after the car stops. The momentum of the flywheel will keep the motor spinning for some time. If you coast to a complete stop with the clutch in, then release it before the motor stops spinning, the car will buck.

• Extra car must be used in parking lots, and around pedestrians, bicyclists, and animals. The vehicle is virtually silent and may not be noticed.

• Performance of the car does not decrease steadily with battery pack discharge. Performance remains fairly consistent throughout most of the car's range. As the pack nears total depletion, the vehicle will grow more sluggish over the last five to ten miles.

Chapter 4

Conclusion

Although the Porsche 914 Conversion is not running currently, all the aspects of an AC conversion setup have been identified and explored. The vehicle is well into the debugging process and it is expected to be on the road soon. The conversion process is summarized—noting key challenges and obstacles and guidelines for future work are stated.

4.1 Summary

The vehicle is complete but is not running. The team is keeping in close contact with Electro Automotive in this critical debugging phase. Expected date of working vehicle is within one week.
Due to the time constraints of the academic year and issues with receiving conversion components and proper instructions in a timely fashion, it has been a difficult process. There were many situations when components or instructions had to be modified for the project. Furthermore, the use of lithium-ion batteries and an AC setup are somewhat novel approaches in the automobile conversion market (due to their high cost). Nevertheless, all parties involved in the project have been very helpful and have pushed (no pun intended) the car to where it is now.

The electric version of the Porsche 914 will be more efficient than the ICE version but it will not perform better. The motor is limited to producing only 50 kW whereas the ICE could produce up to 63 kW. Furthermore, the vehicle now weighs 83.8 kg more. Although the lithium-ion batteries have some of the best energy-to-weight ratios, it still is not enough to reduce their impact on the vehicle’s total weight.

In terms of public outreach, the Porsche 914 conversion project is a success. The MIT Electric Vehicle Team is well on its way to becoming a larger presence on campus. The project is gaining interest not only amongst students and in MIT press but also in the general energy and environment conservation areas. Once the vehicle is complete it will make appearances in electric vehicle races, contests and other events. The team plans on showcasing the vehicle as soon as June 9th, 2007 at an MIT Alumni Association event focused on energy. The goal of the MIT EVT is gain support and interest in electric vehicles as a viable alternative to ICE vehicles.

### 4.2 Future Work

#### 4.2.1 Performance and Efficiency Analysis

Once the conversion is complete and the car is running without issues, the following tests and analyses should be performed:

- Range on a single charge
- Maximum speed
- Acceleration (0-60 time)
- Charging time
- Efficiency of energy conversion (electrical to mechanical)
- Heating and resulting efficiency
• Cooling methods
• Impact of regenerative braking

4.2.2 Modification and Upgrades

When funding and sufficient manpower is available the follow are possible upgrades to the Porsche 914:

• Reduce weight of vehicle by taking out Air Conditioning, audio equipment, and other accessories
• Increase range through more batteries
• Tuning of controller to handle higher power output
• Swap for a higher power output motor
• Swap transmission for more efficient gearbox
• Fans for cooling
• Brake upgrades
References