Engineering Management
Field Project

Converting a Motorcycle to Electric Power

By

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Executive Summary

Research was conducted to determine how simple and practical it would be to convert a standard gasoline powered motorcycle to electric power. The research involved background investigation of useful concepts in electric powered motorcycles, conversion methods, and available components, as well as an actual "hands-on" conversion experience and analysis of the newly converted motorcycle.

This research report includes a review of literature relating to electric power conversion and associated topics, as well as a detailed presentation of information related to the conversion undertaken. The conversion process involved designing a step-by-step conversion project, acquisition of all required components for building an electric powered motorcycle, and execution of the build.

Research results show that conversion of a standard gasoline powered motorcycle to electric power is practical for an average person with minimal engineering knowledge, with needed components being readily available. The reported results include a detailed explanation of a conversion process, highlighting alternatives and needed attention to safety concerns, comparative operating characteristics of the pre- and post-conversion motorcycle, and recommendations for improvements in the conversion process and further needed research.

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Chapter 1 - Introduction

With fuel prices gradually on the rise and a seasonal increase typically seen every summer in the United States, alternative fueled vehicles are becoming more and more popular. Many of the major automobile manufacturers already offer hybrid versions of their most popular models; and many more are promising all-electric vehicles to soon be on the market. This is great news for the eco-conscious person who wants to contribute to a cleaner environment, decrease their dependency on fossil fuels and, most importantly, start saving money by going to the fuel pump less often. However, one market segment that is not being addressed with such publicity is the motorcycle rider.

There is an extremely limited choice of electric two-wheeled vehicles available to the consumer market. Despite this, there is a small but devoted community of motorcycle enthusiasts willing to be early adapters of this new and unproven concept. The good news is that the technology does exist to create an electric motorcycle; the electric components are not nearly as efficient as their gasoline powered counterparts, but nonetheless have advanced well past the prototype stage. Because of this, one question for a potential rider wanting to jump into the electric motorcycle arena is whether to buy one of the limited models available or convert their own. The author chose to pursue the latter approach while setting out to prove the practicality of such a conversion.

To define "conversion", it will be understood as taking an existing motorcycle and changing its power source from gasoline to electricity. This includes purchasing and installing already manufactured parts and components that are obtainable by the typical consumer, without any special wholesale or commercial access required. This does not mean creating a motorcycle from the ground up or "from scratch" in local parlance; this would require custom design and fabrication work that most people would not be familiar with unless they worked in that type of industry.

1.1 Research Purpose

There were three main topics that the author set out to address with this research. First was the financial aspect of conversion; that is, whether converting an existing motorcycle from gasoline to electric power was financially reasonable compared with purchasing an electric powered motorcycle. The second topic of research was the practicality of conversion; that is, whether an average person with the right parts, tools and knowledge can perform a conversion. The third and final topic involved in research was the performance of a converted motorcycle; that is, whether keeping the cost of a conversion low would have a substantial impact on acceleration, top speed and range. All of the main components that comprise an electric motorcycle are available to retail consumers and are easily obtained through standard methods such as online auction sites and direct distributor stores (a listing and description of these components will follow later in this report as the author discusses the "hands-on" conversion experience). This helped to confirm one of three things that the author identified as required to performing a conversion, these were: parts, tools and knowledge which will all be expanded on later in this report.

1.2 Report Structure and Content

This report is divided into four main parts. A literature review, the procedure and methodology of the research and design process, the build process and finally, results and usage of the converted motorcycle. The literature review covers printed material, as well as online sources of information that are pertinent and valid in the motorcycle conversion process. The research and design process that the author undertook is then discussed and presented to the reader. This includes the selection and acquisition of the motorcycle and all of the required components. The term “build” that is used throughout this report, refers to building the motorcycle back up from being stripped down to a skeletal state to remove all ICE (Internal Combustion Engine) parts. The build process does not refer to actually building, constructing or fabricating any major components of the motorcycle as that would be beyond the ability of the author and conflict with the conversion emphasis of this research. While describing the author’s unique approach to this conversion, the terms and concepts are kept general enough to apply to other conversions so that the reader can visualize how this idea can be adapted across a wide spectrum of motorcycles. The build process is covered next, this includes explaining the three requirements that were previously mentioned (parts, tools and knowledge). The final section covers the use of the completed motorcycle, its specifications, a comparison to its original factory configuration, differences in riding style and operation compared to a regular motorcycle, licensing and registration issues, and performance issues. This report concludes with a section devoted to suggestions for further research that the author felt would be of benefit to the electric motorcycle conversion community.

To further define the question of practicality, with regard to an average person with minimal engineering knowledge, the author will discuss the potential candidates for undergoing this conversion process. First, the author defined the "average person" as one who is a high school graduate because this is the first formal education threshold in the United States. In 2008 there were 192.6 million people from the group aged 18 years and older who obtained a high school degree showing that this is clearly a majority of the population. (U.S. Census Bureau, 2008) When taking into account a person's more specific interests beyond the general education provided in high school, it is assumed that the question of conversion practicality is more appropriately aimed at the 6.3 million people who have achieved a vocational certificate or higher in an engineering discipline. (U.S. Census Bureau, 2004) This represents a considerable portion of the population that could reasonably be expected to have the knowledge and interest to do a conversion. The author fits this category by having a bachelor's of science degree in electronics engineering technology. This helps to partially meet the requirement of having the knowledge to do a conversion.

Because it was beyond the scope of this research, this report does not cover electric automobile history, development, conversion processes or consumer available solutions. Electric automobiles have a much broader and detailed history than electric motorcycles and would warrant much more research to adequately cover. This report does not cover any topics involving other types of alternative fueled vehicles or alternative fuel sources such as propane, ethanol, hydrogen or fuel cells. This report also does not cover the technology or concepts involved in hybrid vehicles or technologies. Because practicality was being investigated in the conversion process, the author does not attempt to go into specific technical details of a resolution that the common person would not care to learn or understand. As an example, when discussing components, the author keeps the comparisons to a generalized level using standard electrical formulas rather than explaining in detail the specific electrical behavior of their internal designs. The reader should also consider that this research was not an optimization exercise, therefore some design features and components of this project were not the most optimal or efficient solution with regards to aerodynamics, friction principles, electrical efficiency or design utility.

Chapter 2 - Literature Review

The author began the research process with a review of existing literature on the topic of converting motorcycles to electric power. The author was in search of any scholarly journal articles or whitepapers written on the subject and any literature documenting the step-by-step conversion process. It was found that there were only a handful of books available covering the topic of conversion with regard to automobiles, and even less literature on the subject of converting electric motorcycles.

2.1 Book Sources

One of the few electric vehicle (EV) conversion books available that the author reviewed was *Build Your Own Electric Vehicle* by Seth Leitman and Bob Brant. This book was in its 2nd edition in 2009, which was long overdue considering its first edition date of 1993. The authors did an excellent job of covering all of the basics of EVs, and the components required for them to operate. The first four chapters alone were devoted to explaining the benefits of driving an EV, the history of EVs, and choosing the right one for your lifestyle. These chapters had minimal relevance to the conversion process. The remainder of the book explained all of the main components found in every EV such as the motor, batteries and motor controller. It was surprising to find only 40 pages out of 329 actually devoted to the conversion process, with most examples in the book being older vehicles (pre-2000) and not a single mention of motorcycles. Fortunately, all of the concepts presented in this book directly relate to a motorcycle conversion, so it was still a valuable resource. Despite a few mentions of the modern Tesla Motors and their popular electric sports car, the book projected an out-of-date feel with its black and white photos and lack of any modern conversion examples.

Another recently published book solely on the subject of motorcycle conversions was titled *Build Your Own Electric Motorcycle* by Carl Vogel. Vogel used generally the same format as Leitman and Brant and used a lot of their references and diagrams for all of the generic electrical information that was not motorcycle specific. So much so that one would assume the books came from the same author. Again, as Leitman and Brant did, Vogel only devotes one 17 page chapter to discuss the actual conversion process and used his own motorcycle conversion as the example. While using his own conversion gave him credibility with the topic, there were two reasons that this was a poor example. First, his motorcycle was more of a "home-built" style with the frame and many parts, constructed from scratch, requiring machining skills and equipment that the average person would not possess. Second, the size of the motorcycle was so large (1210 lbs.) it would appeal only to riders already used to larger bikes of that size. Cost was another impracticality that stands out when reading about Vogel's example. $4500 was spent just on the transmission which was approximately half of the price of a brand new electric motorcycle. Estimating other costs of his project, it would quickly be out of reach of what someone would reasonably want to spend on a motorcycle conversion. It was disappointing to observe that this book used a lot of reference material from simple media articles and press releases with no real "ground breaking" news or insider knowledge that one would expect from a commercially published book. Much like the first book reviewed, this one spent most of its pages describing EV facts, history, generic build practices and component familiarization with minimal space devoted to the conversion process and only a small handful of examples listed. On a final note, despite its mid-2009 release date, it presented an aged feel with its black and white photos.

2.2 Other Key Information Sources

Opposite of the two books reviewed, some great sources of literature found on this topic were in the form of online community forums where enthusiasts exchange knowledge, experience, and industry news on electric motorcycle development. One of these was the Electric Vehicle Discussion List, at www.evdl.org, founded in 1991 by EV enthusiast Clyde Visser. According to Visser, this website is, "…an active and vital source of information and help for people involved with electric vehicles…" (Visser, 2009) The EV album section is a gallery that allows users across the country and, in some cases, globally, to showcase their EV conversion by showing pictures and including relevant statistics about capabilities, the build process and costs. With hundreds of vehicles, many are motorcycles which provided an ample amount of ideas on styles and varieties available to convert.

Another community forum that was the most helpful and included members with vast expertise in this area, was The Electric Motorcycle Information Network, sponsored by Electric Vehicle Components LLC. (www.elmoto.net, 2009) This website focuses almost entirely on the conversion process of motorcycles and includes members with a vast expertise on the subject and very open and willing to share their technical knowledge. The author felt that the most useful knowledge was gathered from participating in discussions in this forum.

Still another equally valuable forum was the Electric Motorcycle Forum (www.electricmotorcycleforum.com, 2009). This website didn't seem to have as much traffic as The Electric Motorcycle Information Network; however, many of its members jointly monitor both sites for cross sharing of knowledge. Lastly, a similar source of information in this same format is the V-is-for-Voltage forum; however, much of this website is devoted to electric bicycle owners and converters. (visforvoltage.org, 2009) With little recognition, working in their free time and on minimal budgets, it's easy to see the advances these enthusiasts are making by deciding not to wait on commercial manufacturers to provide mass produced electric motorcycles.

EV World, an online only publication started in 1998, provides a portal experience to direct visitors to many different EV subject areas as well as to multiple EV subtopics on the site. These include owner journals, buyer guides, tutorials, conversion processes, industry news, and a vast white paper database in PDF file format covering a variety of EV topics. This site is very thorough and provides resources directly on the site or it can direct you to the appropriate site. While EV World's database articles are primarily focused on electric automobiles, the majority of information on the site is transferrable to an electric motorcycle design. This site was very professionally organized and offers expertise and credibility in the information that it provides including relevant media releases and video clips of electric and hybrid vehicle industry leaders. (EVWorld.com, 2009)

2.3 Summary of Findings

In summary, the literature review concluded that despite the minimal number of books on the topic of converting electric motorcycles, there were multiple other sources of literature that reside on the internet. These forums contain vast amounts of knowledge in semi-formal organizations with some containing geographic chapters, member dues and media event representation; not unlike many professional organizations.

Chapter 3 – Research Procedure and Methodology

The information from the literature review was used to develop a research procedure to determine the necessary steps to take in the conversion process. The intent of this research was to develop a design with compatible components that would provide a workable platform to assess the capabilities and limitations of a converted motorcycle that were expected. The various stages of the research process are outlined below.

The first stage of the research procedure was to discover what was already on the market for commercial use. The largest motorcycle manufacturers in the world were first studied. Research included reviewing current press releases in search of future offerings, and any pertinent technology breakthroughs they might be working on. Smaller manufacturers that solely produce electric motorcycles were studied next. Studying these offerings, their capabilities, limitations and price points gave the author an understanding of typical parameters to follow in the design process. The first stage was concluded with research into current information covering electric motorcycles in the media and public events.

The second stage of research was to delve deeper into the community of electric motorcycle home builders and converters through various forums and websites. By doing this, the author was able to gain enormous amounts of component knowledge with regard to compatibility and practicality. Eligible components would then be reviewed and queried for information concerning their quality and reputation among current and past users. These forums contained a wealth of expertise on individual technologies such as batteries, motors and motor controllers of an electric motorcycle as well as the entire conversion process.

The next stage was the design process. Design of the conversion centered on selection of a preferred motorcycle chassis type and the components that would be used. The chassis type was selected first and then appropriately sized components were chosen based on subject matter expert recommendations, application appropriateness and budget, with the latter being most important in the process. Component cost was minimized by purchasing used components whenever possible. A budget was set in order to stay consistent with the practicality aspect of the conversion process. Various vendors supplying the chosen components were reviewed, and chosen based on price and availability.

The next stage was the conversion process. This consisted of preparing the motorcycle chassis to accept the components and installation of the components. The order followed was to install the motor, then batteries, then motor controller, then charger and finally lesser components. During the design and conversion stages, meeting the following major objectives ware desired.

- Utilize a "sport bike" style motorcycle for the conversion, with fairings in good condition and little or no frame damage.
- Keep the total conversion cost to under $2000.
- Utilize the highest voltage system possible that the budget will allow.
- Utilize as much of the factory wiring and switching system as possible.
- Have the factory key switch act as the primary enabler of the system.
- Make little or no modifications to the factory look of the motorcycle.
- Have an on-board charging system.
- Keep the original direct drive chain system.
- Ensure it passes inspection so it can remain street legal.

Below is a listing of minor objectives. These were not as important as the major objectives and were dependent upon budget and time constraints.

- Change out all incandescent bulbs with LED bulbs.
- Install an LED daytime running light in conjunction with the existing headlight with a way to switch between the LED light for daytime use and the original headlight for nighttime use.
- Utilize unused ICE indicators on the dashboard gauges to monitor new electric functions.
- Utilize the factory "kill switch" connected to the side stand.
- Improve the look with a more "eco friendly" paint scheme and decals to bring attention to its alternative fuel source.
- Install LED accent lighting.

Chapter 4 – Results

4.1 Results of Existing Market Research

The author concluded after multiple visits to showrooms, that it was evident there were no electric motorcycles being produced in mass quantities. Attention was then turned to the four top motorcycle manufacturers in the world, Honda, Kawasaki, Suzuki and Yamaha, with the assumption that there would be information about upcoming plans, prototypes or designs. Given the current state of alternative fuel popularity in automobile markets at the time, it seemed logical that motorcycle manufacturers would want to capitalize on the good publicity already being generated. After researching educational and industry databases as well as the internet concerning these manufacturers, very little was found in regards to electric motorcycle development. Honda had the most discussion on the subject, although very brief. In their 2009 annual report, Honda's CEO stated: "In the field of motorcycles for traveling relatively short distances, we are proceeding with the development of an electric powered motorcycle that will run on batteries, and, taking advantage of special features of this power source will have zero CO2 emissions. Our goal is to introduce these electric-powered motorcycles in about two years". (Ito, 2009) This was nearly identical to the year-end speech that the previous CEO of Honda gave when he said: "Honda is currently developing a battery-powered electric motorcycle which emits no CO2 during operation, because the characteristics of a battery can be better utilized in the area of motorcycles, which are often used for short distance travel. Honda is aiming to introduce this electric motorcycle to the market about two years from now." (Takeo, 2008) Supporting this claim was a press release by Honda stating that they will establish a joint-venture company with Japan's GS Yuasa to manufacture, sell, and conduct R&D for high-performance lithium-ion batteries. (JCN Newswire, 2009) Recently, the only alternative fuel vehicles that Honda has released (neither of which can be classified as electric motorcycles) have been an electric moped prototype in 2004 for city driving, (Honda, 2004) and in 2009 they began selling a flex-fuel motorcycle in Brazil. (Honda, 2009) According to a Reuters report, Yamaha "aims to launch electric motorcycles by 2010 with a range of 60 miles on a single charge." (Reuters, 2008) This is a full year ahead of Honda's forecasts; however, it should be noted that the article later says these motorcycles will be comparable to those with engines of the 50cc size (a typical scooter size engine). KTM, the maker of a large variety of motocross style motorcycles, has also publicly announced plans for releasing an electric dirt bike in 2011 of a design that is similar to that of Zero motorcycles, which is discussed later in this report.

In an attempt to gain insight into possible future innovations and models, the author sent letters of inquiry to the Honda, Kawasaki, Suzuki and Yamaha home offices, an example of which can be seen in Appendix E. Yamaha was the only one that sent a reply; however, no useful information concerning the topic was contained in it. With no offerings available from the "big four" motorcycle producers, attention was turned to some smaller companies that are making strides in manufacturing electric motorcycles. These small companies in no way compare to the size, finances or R&D capability of the previous four companies, they are simply early adaptors breaking new ground with enthusiasm and limited budgets. They are serving a very small niche market in what the author believes will one day become mainstream transportation methods. One of the most popular models among them is the GPR-S, seen in Figure 4.1, from Electric Motorsport in California. Electric Motorsport was founded in 2001 and makes Zero Emission Vehicles available to the general public. In addition to the GPR-S, they also produce electric scooters, ATVs and boat motors. The GPR-S is a 285 lb street legal motorcycle that is a follow-on model to the original GPR which is no longer in production. It has a 14.2 kilowatt motor that produces 19 peak horsepower. The top speed is 60-70 mph which is adjustable by the sprocket gearing that is chosen. Its range is claimed to be 35-60 miles,depending on how you ride, via a 3.3 kilowatt-hour lithium battery pack. The battery pack can be recharged in approximately four hours with the onboard charger using a standard wall outlet. While Electric Motorsport claims it is two-person capable, at its small size (smaller than a comparable 250cc sport bike) with two riders, performance would undoubtedly be significantly reduced. While it is considered a production electric motorcycle, the numbers have been very limited with the first run in

2008 consisting of 30 units and the 2009 production estimate to only be 100. Price for this model is around $8800 with lithium batteries and $5800 with SLA (Sealed Lead Acid) batteries which keeps it well within the range of an average income person looking for a second vehicle. When compared to a comparably sized gasoline motorcycle however, you quickly realize there are few similarities in top speed and range, thus significantly limiting the possible uses for some riders. One key benefit of the GPR-S is that portions of it are modular making it possible for someone to upgrade the motor, controller and battery pack by simply swapping them out with no frame modifications. (Electric Motorsport, 2009) While this feature benefits the mechanically inclined person, it will have minimal appeal to many riders.

Figure 4.1: Electric Motorsport's GPR-S model
(www.electricmotorsport.com, 2009)

Figure 4.2: Brammo's Enertia model
(www.brammo.com, 2009)

Brammo Inc., in Oregon, makes the Enertia electric motorcycle as shown in Figure 4.2. This motorcycle is very similar to the GPR-S, with a similar sized motor at 13 kilowatts and a 3.1 kilowatt-hour lithium battery pack providing a claimed range of up to 42 miles depending on riding conditions. (Brammo Inc., 2009) Brammo claims a top speed of over 60 mph which should be adequate for most roads and state highways; however, it may not be sufficient to maintain interstate speeds. This motorcycle's price is slightly higher at approximately $10,800. One advantage that Brammo possesses is that they have teamed up with Best Buy to offer their motorcycles in select Best Buy stores along the west coast (Bustillo & Wingfield, 2009). This is advantageous to Brammo for many reasons; particularly, in eliminating the need to have its own storefront, and being able to harness the massive advertising power of the retail electronics giant. Another interesting feature is that they've put a configurable sound chip in the motorcycle so that people can hear it coming. (Fuller, 2009) As humorous as it sounds, the issue of "quietness" in EVs is actually gaining a lot of attention, with a bill currently in Congress asking them to consider the possibility that certain EVs could be dangerous to pedestrians. The H.R. 734: Pedestrian Safety Enhancement Act of 2009, if approved, would direct the Transportation Secretary to study and establish a motor vehicle safety standard that provides for a means of alerting the blind and other pedestrians of motor vehicle operation. (H.R. 734, 2009) A study published last year by the University of California-Riverside, financed by the National Federation of the Blind, evaluated the effect of sounds emitted by hybrid and internal-combustion cars traveling at five miles per hour. People listening in a lab could correctly detect a gas-powered car's approach when it was 28 feet away, but could not hear the arrival of a hybrid operating in silent battery mode until it was only seven feet away. (Motavalli, 2009) This reverse trend to make certain vehicles louder has spurred Nissan, Toyota, BMW and plug-in hybrid maker Fisker Automotive to consider the addition of sounds that would more prominently announce the presence of their cars on the road. It can certainly be argued that this risk is even more dangerous with an electric motorcycle, as both pedestrian and rider would be injured in a collision.

Zero Motorcycles is a third, up-and-coming company that is securing part of the electric motorcycle market. They offer three models: the Zero X and MX for dirt racing, the Zero S--as can be seen in Figure 4.3--for street use and the Zero DS for both dirt and street use. As with the other two companies, Zero's motorcycles have similar specifications, and are somewhat smaller in size looking more like motocross dirt bikes than street motorcycles.

Cost is approximately $9950 and, with a claimed 31 hp motor and a 4 kilowatt-hour lithium battery pack, they too are comparable to a 250cc gasoline motorcycle in size but not performance. Again, while riding through town or smaller streets this size is fine, but it lacks the power to keep up with interstate speeds. (Zero Motorcycles, 2009)

Figure 4.3: Zero Motorcycles' Zero S model
(www.zeromotorcycles.com, 2009)

Figure 4.4: Mission Motors' Mission One model
(www.ridemission.com, 2009)

On the higher end of the budget spectrum is Mission Motors of Southern California. They produce the Mission One superbike--as shown in Figure 4.4--that exceeds the performance of all other electric motorcycles listed, albeit at a cost of $68,995. (Mission Motors, 2009) If a reader is lucky enough to be able to reserve one of the 50 they will produce in 2010, they will get an electric "sport bike" style motorcycle capable of riding 70 mph wheelies with a top speed of 150 mph and a 150 mile range. In addition to actual sport bike performance you would get a recharge time of less than 2 hours (using 220 volts), a wireless interface to its computer system and data acquisition to track most of the bike's parameters. Performance comes from a liquid-cooled, 3-phase AC (Alternating Current) induction motor and a proprietary high energy lithium-ion battery pack plus adjustable regenerative braking to capture wasted energy for battery recharging. If successful, they will truly live up to their self coined phrase: "Ducati experience with Silicon Valley imagination". (Mission Motors, 2009)

4.2 Current Electric Motorcycle Events in the Media

A recent event worthy of mention because it helped to boost the publicity of electric motorcycles was the 2009 Isle of Man TT Motorcycle race held in Ireland. This 37 ¾ mile race around the Isle of Man has been run since 1907 and stands as one of the most premier courses for racers and manufacturers alike. It is run in a time trial format on public roads around the hills and flats of the island; this makes it an ideal proving ground for testing new motorcycle engines and designs. (Isle of Man TT, 2009) What made the 2009 race so special was that it was the first year they offered a class for alternate fueled motorcycles. This race was called the TTXGP (Time Trials eXtreme Grand Prix) consisting of a pro class for teams with larger budgets and an open class that restricted the motorcycle cost to 35,000 British pounds sterling. Azhar Hussain, the TTXGP founder, believes that the event's emphasis on speed is what sets it apart from other alternative energy competitions that have typically concentrated on endurance. (Excell, 2008) Typically, racing events and competition have always spurred developments in more advanced technologies with regard to internal combustion engines and now there is hope that it will do the same for electric motor and battery technologies. Despite the race's futuristic image, statistics from the race were less than impressive. Out of 16 total bikes entered, all of which were electric powered, there were 9 finishers, 4 non-finishers and 3 non-starters. Of the finishers, the top lap time was 25:53 with an average speed of 87.43 mph. (eGrandPrix.com, 2009) When compared to the top gasoline powered lap time and average speed of 17:38 and 128.28 mph, respectively, it can be seen just how far electric motorcycles have to catch up. (Isle of Man TT, 2009) As mentioned before, this race has served to enhance this type of vehicle development, allowing their technologies to gradually work their way down to mainstream markets just as the races in the 1960s contributed to Japanese motorcycle development.

Another publicity outlet for promoting electric motorcycles and other EVs is NEDRA (National Electric Drag Racing Association). NEDRA "exists to increase public awareness of EV performance and to encourage through competition, advances in electric vehicle technology. NEDRA achieves this by organizing and sanctioning safe, silent and exciting electric vehicle drag racing events." (NEDRA, 2009) Of particular interest to the author was the Killacycle, shown in Figure 4.5, owned by Bill Dubé; an electric drag racing motorcycle that consistently sets speed records--with the latest being a 7.864 second quarter mile reaching 169 mph. It is the quickest and most powerful electric motorcycle in the world and can go 0-60 mph in under 1 second with its 500+ hp. (Killacycle.com, 2009) With statistics that are nothing less than remarkable, this machine shows just how far electric motorcycle technology can be pushed. While these statistics are not realistic expectations for a home conversion, it certainly gives inspiration to the home converter.

Figure 4.5: Bill Dubé's Killacycle
(www.killacycle.com, 2009)

Battery technology is the key to these phenomenal speeds. Charles Murray, the senior technical editor of Design News Journal explains the basics of this battery technology in his article titled "High Voltage". (2009) What sets the Killacycle apart is its special lithium-ion battery pack that slams huge amounts of current into its two motors. These batteries, made by the company named A123 and slated to power the upcoming Chevy Volt, are difficult for the public to acquire and would be very costly as well, limiting their use to commercial and custom applications such as the Killacycle. Murray also explains the trade off in energy, which is the key to understanding the difference between drag bikes and street commuting motorcycles. For the high torque requirements of drag racing, a higher power density is desired so that the maximum amps of current are available, but in return, range is sacrificed. To increase range, a higher energy density is required but eliminates the 100+ mph speed and rapid acceleration. In another article, Murray sums up the dilemma that is most at fault for holding back EV development: battery density.

> "The issues facing EV batteries of a decade ago were the same as those of today: Energy density, recharge time, cost, durability and safety were the big challenges. Energy density was prime among those, mainly because it directly translates to vehicle range: the higher the energy density, the greater the range between recharges…" (Murray, 2008)

4.3 Results of Component Research

Research initially focused on required components to purchase for an electric conversion. Below is a list of all necessary components.

- Electric motor
- Motor controller
- Batteries
- Charger(s)
- Throttle
- DC voltage converter
- Contactor (electro-mechanical switch)
- Main fuse
- Large diameter battery cable
- Cable termination lugs

This list formed the basis of future research that supported the purchase of the best components that the budget allowed. The author's design research began with reviewing various makes and models of existing motorcycle conversions that others had attempted. An excellent source for this was the electric vehicle album section of the Electric Vehicle Discussion List. Research was also performed on other discussion forums. The "hands on" conversion was to show the feasibility of converting a gasoline powered motorcycle to electric power, so cost was a key factor to consider. In keeping this practical for a majority of people, the author decided to set a generic budget of $2000 for the project. This figure was decided upon by researching stores with an internet presence that sold EV components and reviewing costs other's had published on the previously mentioned forums. This budget was kept for the purpose of determining the minimal "cost of entry" into the converted motorcycle arena. The budgeted breakdowns of costs, as well as actual costs, are found in Appendix B. Since this conversion was to show practicality as opposed to optimal solutions, costs versus benefits were analyzed after project completion rather than in the design stage. Given the $2000 budget, a top-down approach was used to allocate funds for each component based on examples, past research, and recommendations of subject matter experts.

There are many categories of companies to find the electrical parts needed for a conversion, a listing of them is found in Appendix D. Some stores cater specifically to EV converters and because of this will typically carry the broadest selection of components. In addition, they sometimes demand the highest prices for those components. Some companies sell EV components but not for conversion reasons; they cater to customers repairing golf carts, forklifts and other originally manufactured electric vehicles. Many of these components work well for EV conversions but may not be optimized for EV conversion performance since not all electric vehicle requirements are the same. Other companies sell components catering to electric bicycle converters and owners. These companies typically will have severely limited selections of components needed for EV conversions because electric bicycles require much smaller motors, controllers and batteries than electric vehicles. Finally, there are companies that sell components to a generic market of electric needs. These are typically general electric parts companies specializing in bulk purchases, with a vast inventory including everything from light bulbs and switches, to wire, connectors, plugs, and batteries.

When starting to research and purchase components for a motorcycle conversion project, the author discovered that it was advantageous to follow a prescribed order due to the physical space and weight limitations of the chassis. The motorcycle should be the first item purchased so that there is a known platform with known space and weight limits to design around. After choosing the motorcycle to convert, the first components should be the motor and motor controller as they will need to be appropriate for the motorcycle size. The next component should be the battery pack as this will be dependent upon the available mounting space after the motor and controller are installed. After the battery pack--made up of multiple batteries--is chosen, the rest of the components may be purchased in no particular order as they typically will take up minimal additional space and weight.

4.4 Component Purchasing

Purchasing the motorcycle to convert, referred to in the EV community as a “donor chassis” was a fairly easy step as there were many used motorcycles for sale in all parts of the country. The only difficult part was finding the preferred model and style. In the author’s case, it was desired to depart from the lightweight “dirt bike” style bodies that some electric motorcycle companies were using, and choose a sport bike body style. The frame was required to be straight with no prior damage, and the plastic fairing pieces in good condition. This is an important point to consider in any conversion project, as it is desirable to start with a mechanically sound donor chassis, since this will save time and cost by not requiring extra work to get it to a running condition. A damaged motorcycle in need of many repairs will soon become a restoration project rather than a conversion project. The author found a suitable motorcycle on a local internet classifieds website advertising motorcycles for sale; it was a 1990 Kawasaki Ninja ZX-6 for $400. This was already without an engine, which eliminated some of the teardown process. The author was able to sell the remaining ICE components that were still attached to the motorcycle including the exhaust system, radiator, oil cooler and various electrical components related to the engine. This recouped approximately $50, bringing the actual donor chassis cost to $350, which was under the budgeted amount of $500.

The next component needed was the motor; this is normally a significant cost to any EV project whether it is a motorcycle, car or truck. The author budgeted $450 for purchase of a motor assuming a 48-volt motor would be the primary candidate. A motor was found for sale for much less from a member of the author's local chapter of the Electric Vehicle Association of America (EVAA), which the author had recently joined. This was a General Electric 72-volt 4 horsepower series-wound DC (direct current) motor with a nominal current rating of 40 amps and a 3200 rpm rating. It was a 6.7" diameter housing which is an industry standard size for this type of DC motor; many manufacturers produce motors in this diameter with slightly different specifications and uses. The motor had fallen into disrepair with rust and it was questionable whether it could operate properly; however, its price of $50 was well worth the trouble of investigating it. Even if it didn't run it would offer an opportunity to become familiar with the different parts of a motor while it was disassembled and cleaned. After disassembly, cleaning and reassembly, the motor operated properly causing a substantial portion of the budget to be conserved because of this. Figure 4.6 shows the condition of the motor before and after restoration. The motor satisfied the major objective of having the highest voltage system possible given the budget constraint. Research showed that motors above 72 volts typically run too large and too heavy in physical size to utilize in a motorcycle conversion. This motor weighed 57 lbs which was near the upper limit of weight that the author wanted to allocate to it. As the budgeted amount for a motor was $450, this presented a savings of $400.

Figure 4.6: Looking left to right; before and after condition of 6.7" dia. electric motor

The motor controller of an EV must be matched to the voltage and type of motor being controlled so logically, it was the next component purchased. Motor controllers essentially perform the same function to electric motors as a carburetor does for an ICE, by regulating the speed of the motor. Figure 4.7 shows the comparison of major EV components and gasoline powered vehicle components.

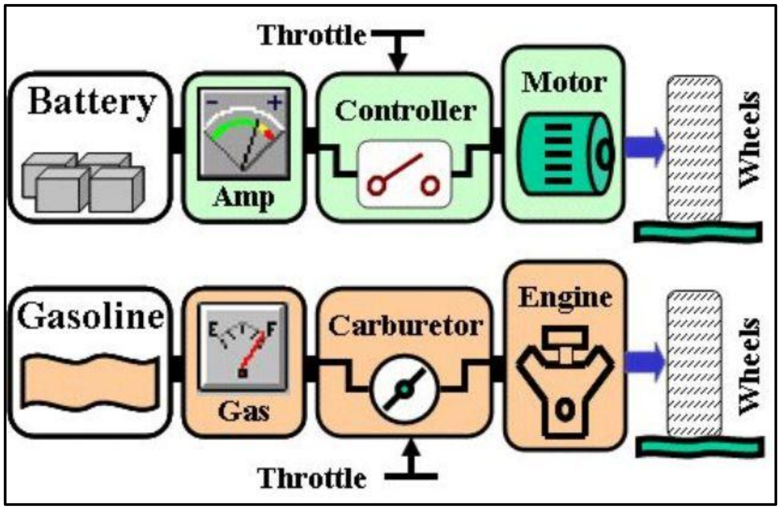

Figure 4.7: Component comparison of an EV (top) versus gasoline powered vehicle (bottom)
(www.alltraxinc.com, 2009)

The motor's speed is regulated by the amount of voltage sent to it by the controller according to input provided by the throttle mechanism. This input is then sent to the motor as a series of pulses to represent the corresponding percentage of throttle being applied ranging from 0% (none) to 100% (full) Figure 4.8 shows the graphical operation of a motor controller with an easy to understand explanation as follows,

> "A simple DC controller connected to the batteries and the DC motor. If the driver floors the accelerator pedal, the controller delivers the full 96 volts from the batteries to the motor. If the driver takes his/her foot off the accelerator, the controller delivers zero volts to the motor. For any setting in between, the controller "chops" the 96 volts thousands of times per second to create an average voltage somewhere between 0 and 96 volts." (Marshall, 2002)

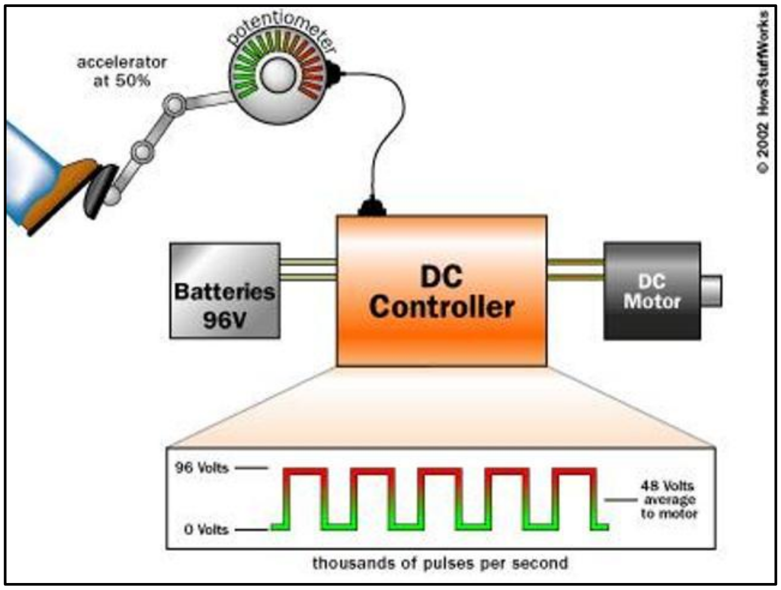

Figure 4.8: Graphical display of motor controller output
(www.howstuffworks.com)

There are three main companies that produce electric motor controllers for the EV market; they are Alltrax, Curtis and Kelly and all come in a variety of sizes and ratings. The author selected an Alltrax AXE-7245 controller based on recommendations by others, its programmability, and its ability to log usage data to a connected laptop. This will be of value later when reviewing operating characteristics of the motorcycle. This was their highest current rated 72-volt model able to handle up to 450 amps. This controller was purchased as a reconditioned model from the manufacturer for $450 which was $150 over the budget amount but significantly more inexpensive than buying a brand new one. This over-budget amount was due to originally budgeting for a 48-volt system which would have required a less expensive controller. Figure 4.9 shows the motor controller.

Figure 4.9: AXE-7245, 72-volt, 450-amp programmable motor controller by Alltrax Inc. (www.alltraxinc.com, 2009)

The battery pack was the next purchase made; this is the most critical component with regard to physical size and weight, particularly when using lead varieties. There are essentially two battery types available, lead based or lithium based. Due to budget constraints the author knew from the outset of research that one of the lead varieties was the only option considering that lithium batteries were approximately four to five times the cost of equivalent lead varieties. The first of two main types of lead-acid batteries are starting batteries, designed to deliver quick bursts of energy (such as starting engines) and with a greater plate count on the inside and thinner plates overall. Anyone who drives a car is familiar with this type of battery, they are also known as flooded or "wet cell" batteries due to their servicing needs and the water based acid inside them. The second type of lead battery is the deep cycle battery also known as marine or golf cart batteries. These have less instant energy but greater long-term energy delivery due to their thicker internal plates that can survive many discharge cycles. (batterystuff.com, 2009)

The author decided to select an AGM (Absorbent Glass Matt) style lead battery due to their inexpensive cost, depth of discharge ability and the flexibility in mounting orientation. Their mounting flexibility is due to the electrolyte being suspended in close proximity to the internal plates allowing a sealed body. When deep cycle batteries are discharged to no less than 60%, their cycle life is expected to be 300 to 400 cycles. Due to weight, it was desirable to source the batteries locally so that high shipping costs were not incurred. After many recommendations from the various forum members and consulting a local battery dealer, it was decided to use six Power Sonic PS-12350 batteries as shown in Figure 4.10.

Figure 4.10: Six PowerSonic 12-volt, 35 ah deep cycle AGM batteries
(laptop left in photo to show scale)

These batteries were chosen because they provided the most ah (amp hours) for the budgeted price of approximately $50-$60 per battery. It was also determined that the size would offer the most flexibility in mounting them in the motorcycle frame. These were 12 volt 35 ah batteries that weigh 24 lbs each. One misconception about battery specifications is that a 35 ah battery will provide 35 amps for one hour. Batteries use a 20 hour rating when advertising their ah rate, so in the above example, these batteries produce 35 ah over a period of 20 hours, which is actually only 1.75 amps per hour of discharge current as shown in Figure 4.11.

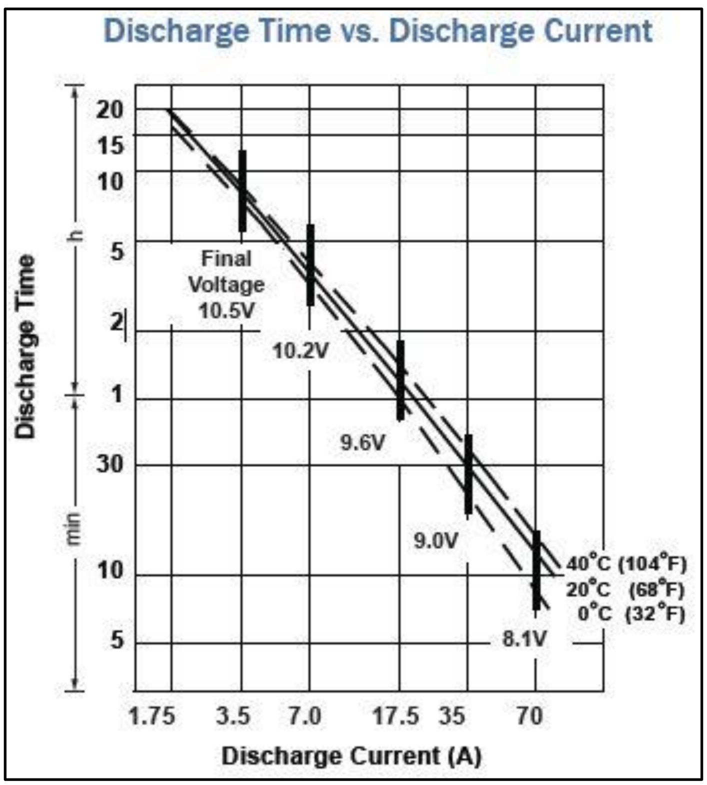

Figure 4.11: Discharge time versus discharge current of the Power Sonic PS-12350 battery
(www.powersonic.com)

The cost of these batteries were $60 each giving a total with tax of $380 which exceeded the budget by $80 however, as stated before there were significant shipping costs avoided by purchasing them locally. Utilizing these batteries would also meet the major objective of keeping the original factory look by not modifying the frame or fairings to fit the batteries.

With the largest components decided upon, it was then time to choose the remaining smaller ones, starting with the charger. As the author had no prior experience with any of these components, the various forums containing expertise were turned to again. Research determined that there are three main charging methods in use for electric motorcycles. The first is to have an off-board charger at home to plug into and charge from, this obviously imposes a strict range limitation since it's not possible to charge away from home. Advantages of this method are that the charger can be a large size utilizing a dedicated 110-volt home circuit or even a 220-volt circuit which equates to faster charging times. The second method is to have individual on-board chargers for charging up each battery. The advantage of this method is that the motorcycle can be charged anywhere there is a standard electrical outlet, and each battery always receives an individual balanced charge from its specific charger. A disadvantage to this is that wiring becomes more complex and more space is required on the motorcycle. The last method is to use a single on-board charger that charges the entire battery pack at once. The advantage of this system is that again, you can plug into any standard outlet; it is also easier to install because of dealing with one component instead of many. In addition, these chargers are typically cheaper per charging volt than multiple individual chargers. Disadvantages to this type are that over time, some batteries in the pack may not charge to their full capacity and require what's known as a "balance charge" to top them off once every few months with an individual charger. The author decided to weigh "ease of installation" as the most important criteria and selected a single on-board 72-volt charger. The model purchased was the HWC1B--shown in Figure 4.12--sold by Cloud Electric LLC and recommended by members of The Electric Motorcycle Information Network forum.

Figure 4.12: HWC1B single chassis, 72-volt on-board battery charger
(www.cloudelectric.com, 2009)

It was a 72-volt, 8-amp system which gave a charging time of approximately 4-5 hours depending on discharge level of the batteries. This is a good target charge time as it would allow a commuter to charge during a standard work shift or easily overnight.
It was purchased used, from a member of The Electric Motorcycle Information Network forum for $180 which was $30 more than the budgeted amount; however, it met the major objective of having an on-board charging system.

The contactor was the next purchase. This is a fairly simple electro-mechanical device that acts as a large mechanical switch for switching high current loads with a low voltage, low current signal. It is placed in line between the battery pack and the motor controller to act as a disconnect device to ensure battery pack voltage is not available to the controller when the motorcycle is in an "off" state. The standard contactor most electric motorcycle converters use is the Kilovac EV200 by Tyco Electronics in Figure 4.13.

Figure 4.13: Kilovac EV200 Contactor by Tycho Electronics
(www.evsource.com, 2009)

It is a single pole single throw (SPST) relay capable of passing up to 500 amps of current and operated with a control voltage as low as 12 volts. This was ideal for the author's major objective of having the factory key switch energize the system; the key switch provided 12-volts to close the contactor, enabling the 72-volt pack voltage to flow to the motor controller. One was purchased online for $70 which was $20 over the budgeted amount. Next, some smaller basic components were purchased with minimal research required. A simple DC voltage controller to convert the 72-volt pack voltage to 12-volts for the factory wiring system was purchased to retain all of the factory lights, flashers, horn, gauge lights and handlebar switches which were rated at 12-volts. Through forum discussions with others doing conversions, it was determined that carrying an extra battery to provide 12-volts to power the factory components would not make efficient use of weight or space, in addition, there was the risk of it going dead during a ride. Another purchase made from the same online store was the electronic throttle made by Magura. This was a standard twist-grip throttle that provides a 0-5 kohm signal to the motor controller so that it can send the appropriate amount of voltage to the motor according to the position of the throttle. Both of these were purchased for $90, $15 more than budgeted.

4.5 The Conversion Process

The conversion process began once all components were purchased. The only task left was to acquire any specialty tools needed. In the author's case, the only tool in this category was a welder for fabricating the sub frame that the motor and batteries mounted to. Welding together angle iron and tube steel was the preferred method for constructing this framework. The approach of using bolts was considered and then abandoned as the batteries posed a risk of rubbing against bolt heads. This could be a stumbling point to someone undertaking a conversion if a welder is not available; otherwise a "bolt-together" mounting frame would have to suffice. The author borrowed the use of a welder from a friend and practiced on some scrap metal to become familiar with the process. It is appropriate to note that welding is a skill requiring practice to fully perfect; poor quality welds would be an inherent safety risk to the rider. Because of the author's novice welding skills, the frame was reinforced where possible with bolts. All other tools utilized were standard types that can be found in an average garage such as drills, screwdrivers and socket sets.

Figure 4.14: motorcycle as purchased, fairings removed and engine discarded by previous owner

Figure 4.15: stripped motorcycle chassis

To begin the conversion process, the motorcycle had to be stripped down of any remaining ICE parts and thoroughly cleaned. Figure 4.14 shows the motorcycle as purchased and Figure 4.15 shows it after being stripped down to a minimal frame. This gave the author a nice clean starting point for the conversion process.

4.6 Motor installation

Mounting the motor was a straightforward method of using its base to attach it to a fabricated sub frame. Other placement options were tested using a cardboard mockup of the motor (as seen in Figure 4.16) to reduce the handling required of its 57 lb weight. The sub frame was welded together using commercially bought angle iron and tube steel and was a simple design requiring minimal skill. This was attached to the motorcycle frame at four locations for rigidity. Motor placement is important so as to replicate as closely as possible the original drive sprocket location to prevent the chain from rubbing against the swing-arm or frame. Since the motor's drive sprocket was not exactly in the original factory location, the factory chain was too short to use and a longer one was required.

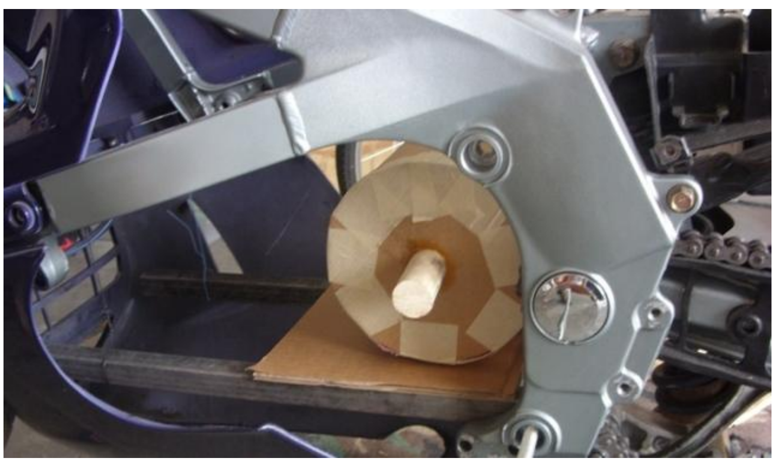

Figure 4.16: Cardboard motor mockup inside motorcycle chassis

4.7 Battery Installation

Batteries were next installed in two layers, with two resting on their sides on the bottom rails and four on the top layer in an upright position. This was found to be the optimal orientation of them while using the simple sub frame design. This layout was determined by first constructing cardboard mockups of the batteries and experimenting with their placement. Care was taken to leave adequate spacing for the battery terminals and cables. After finalizing the placement of the batteries the fabricated sub frame was welded together and painted as shown in Figure 4.17.

Figure 4.17: Fabricated sub frame with motor and batteries installed

4.8 Motor Controller and Charger Installation

With the sub frame constructed and motor and batteries mounted, it was time to select a location for the motor controller and charger. There were many locations available due to the extra space between battery levels and towards the front and top of the motorcycle. The best location was determined to be above the top battery level on a fabricated mounting board. The board provided a mounting surface as well as separation from the top layer of battery terminals to eliminate the risk of a short. (Figure 4.18)

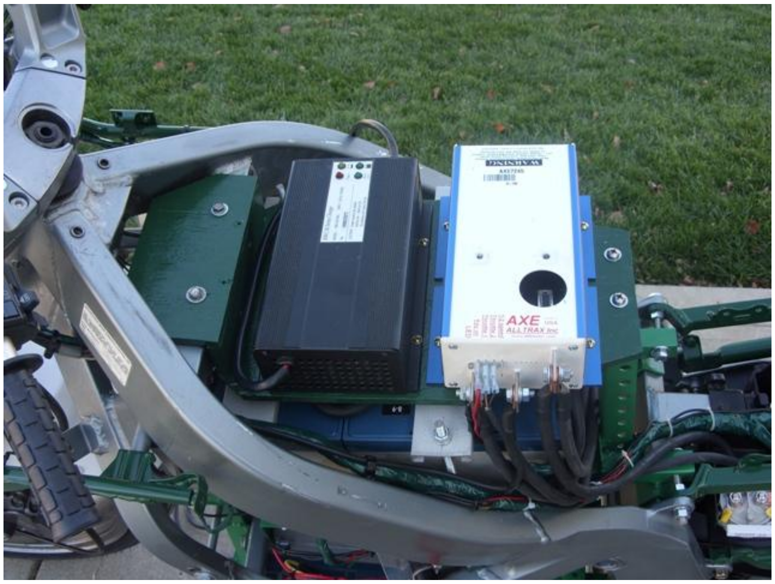

Figure 4.18: Mounting board showing motor controller and charger

To ensure there was adequate space in this location, the bottom of the fuel tank was cut out. The tank had obviously not been full of fuel in quite some time, as a safety precaution, it was filled with water while the bottom was cut out. (Figure 4.19)


Figure 4.19: Before and after: fuel tank with bottom removed to make room for components

4.9 Cable and Electrical Installation

With the main component locations finalized, cabling could now begin. Cable size was determined by using recommendations from the various forums. Forum members with similar battery and motor combinations typically used 2 or 4-AWG (American Wire

Gauge) cable. 2-AWG cable was selected to provide more of a safety margin against overheating due to high current spikes. A common practice discovered by EV converters is to use welding cable instead of battery cable. Welding cable is comprised of many more internal strands than battery cable which makes it much more flexible when routing around components and the chassis frame. Another advantage is that it costs considerably less, as the author discovered, as low as 50% of the cost of battery cable of the same AWG size. A total of 20 feet were purchased for $1.50 per foot. This was then cut to specific lengths, according to how it was routed between components. This cable was sourced locally from a welding company, which saved on shipping charges. Terminal lugs for the cable were purchased in a similar manner, by purchasing a generic type from a hardware surplus company; they were approximately 33% of the price of the ones sold by various EV component websites. These higher costs for some components were understood to be a standard advertising practice that is observed with any product when it is advertised to meet a specific need rather than a generic use. There are two methods for fastening the lugs onto the cable ends, one is to crimp them and the other is to solder them. Lacking a crimp tool, the author chose to solder the lugs which many feel creates a more conductive electrical connection over crimping. Cable size can be observed in Figure 4.20 which shows the location of the 400 amp main system fuse.

Figure 4.20: 400 amp main system fuse location and sample of the 2-AWG cabling

After the main wiring of 2-AWG cable was complete, the factory wiring harness was prepared for installation. Soon after the motorcycle was purchased, a service manual was purchased for assisting in disassembly and reassembly. This contained a wiring schematic which was of tremendous value in removing all unnecessary circuits that supported the ICE. One of the major objectives was to keep the existing wiring harness and switching components; utilizing this schematic made it possible to keep only essential wiring. (See Figure 4.21)

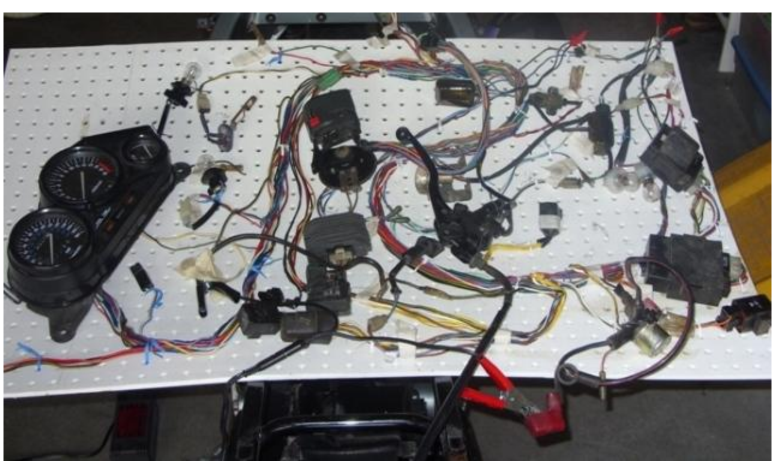

Figure 4.21: Motorcycle factory wiring harness unwrapped for testing and removal of unnecessary circuits

Once all unnecessary circuits were stripped out of the wiring harness, unnecessary electrical components were also eliminated; these included the rectifier, starter solenoid and ignition control unit. Next, the voltage converter input was spliced into the 72-volt wiring system, after the main fuse and the output was spliced into the point that originally connected to the motorcycle starter battery. This provided a 12-volt source to the factory wiring harness in place of the factory battery. Other connections required to meet the major objectives were to splice the key switch circuit into the contactor--seen in Figure 4.22--via a normally open relay and splice the side stand switch into the relay to interrupt the key switch circuit when the side stand is down, thus, preventing the motorcycle from involuntarily moving while the rider is not ready.

Figure 4.22: Location of contactor

These connections can be seen in the schematic at Appendix A. For safety, two manual disconnect switches were installed. The one on the bike's left side enabled the 72-volt circuit that turns on the motor controller and the one on the bike's right side enables the charging circuit connected to the battery pack. The same switch type was selected for both so that the same key will fit in each one. The switch key can only be removed in the open circuit position, so by using only a single key for both switches, the circuits become mutually exclusive in which they cannot both be enabled at the same time. This prevents the possibility of the system being energized while the charger is charging the battery pack. Additionally, the existing side stand switch was retained to enable the "interrupt" relay that was wired into the circuit enabling the contactor to close. This opens the battery pack circuit if the side stand is in the down position. The electronic throttle was then installed. An alternative method to achieve the same functionality would be to use the existing motorcycle throttle cable and link it to a potentiometer box with a variable resistor; however, while saving greatly on cost, it would consume much more installation time.

4.10 Safety

It should be noted that all component connections were very straightforward to understand utilizing basic knowledge of DC voltage and sizing components for appropriate current amperage. No components had to be disassembled, taken apart, rewired or modified in any way. This was not something to attempt if someone had little or no knowledge of DC electricity, nor for someone unsure of their ability to understand and interpret electrical component installation manuals. Risks involved consisted mainly of shorting circuits that would have caused arcing and extremely high amounts of current. To mitigate this risk the author chose to not utilize a chassis ground system. All circuits were grounded to the wiring harness and back to the common ground of the battery pack.

While not a typical method with automobile manufacturers, this “floating” ground eliminated the risk of an exposed “hot” wire coming in contact with the metal frame and causing a short. In addition, as can be seen in Appendix A, all circuits were fused with appropriate fuses including use of the factory fuse junction box. There were four main safety features incorporated into the motorcycle wiring. A manual disconnect switch that must be turned on to energize the motor controller and voltage converter, the key switch, that must be turned on to partially enable the contactor and the side stand switch that must close the “interrupt” relay to allow the key switch circuit to enable the contactor. The fourth safety feature is the 400 amp main fuse that will melt and open the battery pack circuit should any shorts occur in that circuit.

4.11 Functional Testing

At this point the motorcycle was ready for a functional test. The motor was still not connected to the rear wheel for safety reasons. The first test was to simply power the system on and verify the safety features. Powering the system on consists of the following sequence:

- Turn the manual key in left side switch (battery pack circuit) to enable motor controller and DC voltage converter to turn on
- Turn factory key switch to enable 12 volt system and prepare “interrupt” relay in contactor control circuit
- Raise side stand to close “interrupt” relay and enable contactor to close, providing full pack voltage to motor controller

All motorcycle functions that were left intact such as the headlight, turn signals, brake lights and horn, functioned as expected from the 12-volts supplied by the DC voltage converter. The throttle was then tested and the motor successfully ran at variable speeds determined by throttle twist amount.

4.12 Road Testing

The last key item to be installed before a road test was the drive sprocket which had to be ordered from a hardware surplus company. Sprockets of this size were inexpensive at $5 each so three different sizes were ordered, a 10 tooth, a 12 tooth and a 15 tooth; this would allow experimenting with different gear ratios. Since a DC motor has no internal gearing and is directly linked to the rear wheel via chain, and is equivalent to a single speed transmission. Because of this, top speed and acceleration characteristics must be modified by changing the gear ratio between the drive sprocket and driven sprocket. The distance between the motor shaft and rear sprocket was measured and the appropriate length of chain was ordered with the sprockets. The sprockets were installed and at this point the motorcycle was ready for road testing and data collecting via a 9 pin serial-to-USB cable that connected the motor controller to a laptop carried on board during the test rides. The appearance of the finished conversion can be compared with the original in Figures 4.23 and 4.24 respectively. This shows that the major objective of making little or no modifications to the original factory look was met. With the exception of not having an exhaust system, there is a very minimal difference in the aesthetics of the two versions. Figure 4.23 shows the initial assembly of the converted motorcycle to verify its functionality; later it was disassembled, repainted and all wiring rewrapped. Figure 4.25 shows the motorcycle with new paint.

Figure 4.23: Motorcycle fully assembled after electric conversion

Figure 4.24: Motorcycle with ICE in original factory configuration

Figure 4.25: Motorcycle with new paint scheme

4.13 Conversion Results

Using basic knowledge of electricity, simple tools, a welder, and easily obtained electrical components, the author converted a gasoline powered motorcycle to an electric motorcycle for under $2000. This motorcycle, as geared, has a top speed of 52 mph with the existing sprocket ratio of 1:4.5 (10 tooth front/45 tooth rear) and a range of approximately 15 miles. It can be charged from any standard 110 volt electrical outlet in approximately 4-5 hours, and is expected to last 300 to 400 charging cycles. For approximately 20% of the price of a new electric motorcycle the author created an equivalent vehicle with nearly 90% equal speed and 25% of the range capability. The range was limited by battery capacity, which was limited by the budget. As will be explained below; upgrading the battery size would soon exceed the motorcycles original factory weight, despite having the physical space for them. The most desirable solution to this battery energy density problem is to use lithium batteries, but despite their ability to more than triple the range while taking up the same space as lead varieties, they can cost up to eight times more. In addition to cost, they also require additional components for safe operation such as an on-board battery management system and special chargers. For long term transportation solutions however, lithium batteries would be the most beneficial choice for an energy source to get the most range for the size.

4.14 Cost to Operate

When considering the cost of operating an electric motorcycle, it must be considered that there are two types of maintenance costs outside of the actual purchase or conversion cost. The first is the electricity cost of charging the batteries. In the author's conversion, it was assumed that the batteries would never be allowed to go below a 50% state of charge; therefore charging would need to restore 17.5 ah of charge into the pack. Since electricity is sold by the kilowatt-hour (kwh), 17.5 ah must be converted to kilowatt-hours by using the standard P=IE (power = current x voltage) equation, using 17.5 for I and 72 for E, it shows the equivalence of 1.260 kwh. Given the national average cost for 1 kwh of electricity as 10.42 cents in 2009; it would cost 13.13 cents to recharge. The second operating cost is made up of the annual special fuel motor vehicle decal of $75 (explained in more detail below), and the cost of replacing the batteries spread out over their lifecycle. Assuming a 350 cycle life of the batteries, the author estimated a 3 year usage depending on riding frequency. The battery cost of $380 would be spread over the mileage span of those 3 years as shown below in Table 4.1. Other maintenance costs are for a new set of brushes for the electric motor. When compared with the equivalent costs to operate a gasoline powered motorcycle for the same number of miles in Table 4.2, it can be easily seen that it is approximately five cents per mile more expensive to operate the author's electric motorcycle than an equivalent gasoline motorcycle. It must be made clear to the reader however, that this is one unique example given the author's budget, component selection, and state regulations for Missouri. Other configurations and state regulations would provide different results.

Author's electric motorcycle operating costs (in Missouri)

Total charge cycles of batteries	x	Miles per charge	=	Total miles
350		15		5250
Total charge cycles of batteries	x	Cost per charge at 10.42 cents/kwh	=	Total electricity cost
350		$0.1313		$45.96
Special fuel vehicle decal per year	x	Estimated usage years	=	Total decal cost
$75		3		$225
				Replacement motor brushes cost
				$50
				Battery pack replacement cost
				$380
				Total operating cost for 5250 miles
				$700.96
				Cost per mile to operate
				$0.1335

Table 4.1: Cost per mile to operate the author's electric motorcycle for 5250 miles

Gasoline motorcycle operating costs (in Missouri)

		miles were kept at 5250 for comparison		Total miles 5250
5250	/	40 mpg	=	Total gallons required 131.25
Cost per gallon $2.80	x	gallons required 131.25	=	Total cost of gasoline for 5250 miles $367.50
Oil and filter and misc yearly maintenance $60	x	miles are estimated at approximately one year of riding 1	=	Total maintenance cost for 5250 miles $60
				Total operating cost for 5250 miles $427.50
				Cost per mile to operate **$0.0814**

Table 4.2: Cost per mile to operate an equivalent gasoline motorcycle for 5250 miles

4.15 Current Draw

During multiple test rides an adequate set of data was collected for examination. The logging capability of the motor controller included data on battery pack voltage, battery pack current, motor current and throttle position. Data was recorded once every second during the test rides. Table 4.3 shows a sample taken of a typical test ride. Analyzing data from multiple test rides showed that the average current draw from the motor was 77.7 amps which created a current draw from the battery pack of 51.9 amps. The average test ride was 15 miles and the average speed was 30 mph. When considered against the amp hour rating of the batteries, and assuming the batteries were discharged no lower than 50%; this results in approximately .86 miles per ah.

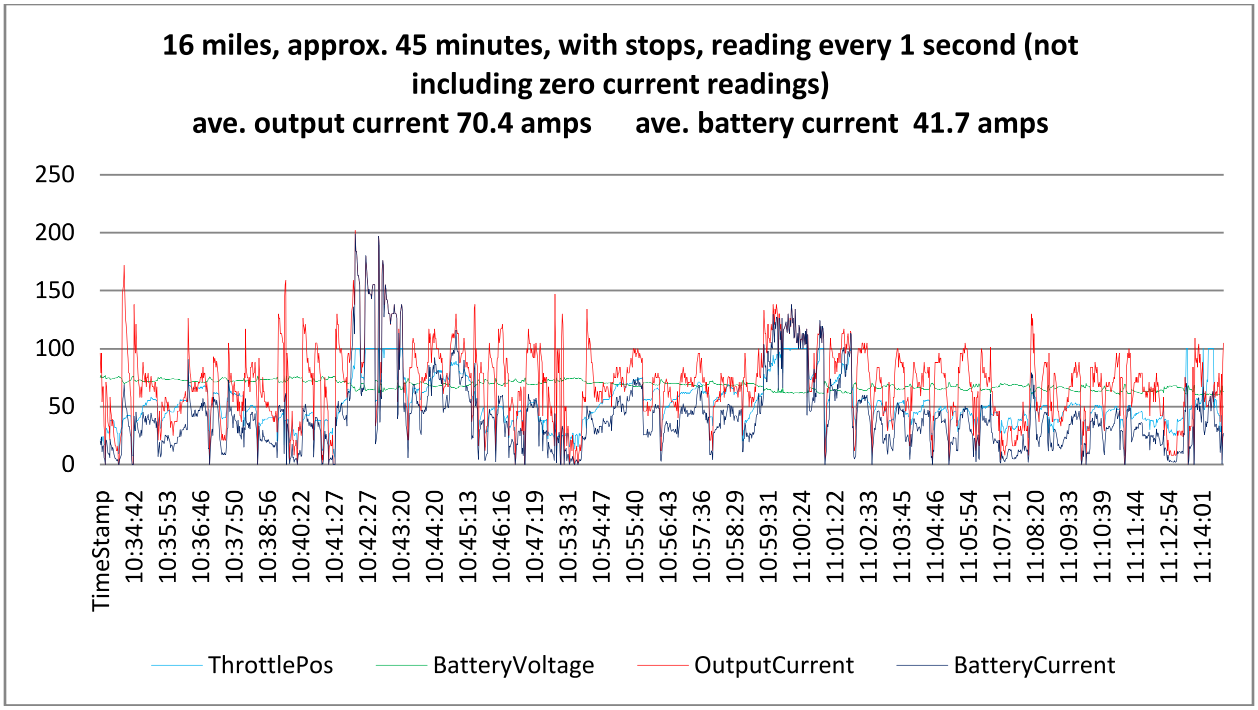

Table 4.3: Data collected during a typical test ride

4.16 Weight Comparison

There was a significant weight difference between the two versions of the motorcycle. As can be seen in Table 4.4, after the electric conversion, the motorcycle was approximately 48 lbs lighter. This delta can be interpreted as 48 more lbs of ICE weight removed versus electric component weight added. Concerning battery capacity, this equates to 8 more lbs per battery that could have been added while still staying within the factory weight limit. Further research concluded that by adhering to this weight limit, larger 40 ah batteries could have been purchased. By having an extra 2.5 usable ah of current, and using the .86 miles per amp hour range from above, it could potentially increase the range by another 2.15 miles.

	Weight		
Original dry weight of motorcycle	429	lbs	
Fuel capacity (4.75 gallons * 6 lbs/gallon)	28.5	lbs	
Oil capacity (.97 gallons * 7 lbs/gallon)	6.8	lbs	
Coolant (.66 gallons * 8.3 lbs/gallon)	5.4	lbs	
Total gasoline motorcycle weight as ridden	**469.7**	**lbs**	
Added components	Weight		
Motor Controller	6	lbs.	
Battery pack charger	4	lbs.	
Cable	6	lbs.	
fabricated sub frame	15	lbs.	
Batteries (23 x 6)	138	lbs.	
Contactor	1	lbs.	
Motor	57	lbs.	
Total Added Weight	227	lbs.	
Weight of donor chassis	195	lbs.	
Total electrical motorcycle weight as ridden	**422**	**lbs.**	
Weight difference	**47.7**	**lbs**	(lighter)

Table 4.4: Weight comparison between original motorcycle and electric version

4.17 Speed and Range Data

Since and electric motorcycle uses a single electric motor coupled to the rear wheel with a single chain, it is the equivalent of having only one gear. This means that the top speed of the motorcycle will always be a function of the motor rpm speed, the rear tire circumference, and the drive sprocket to driven sprocket gear ratio. Table 4.5 illustrates how this was computed for the author's electric motorcycle using three different front sprocket sizes. Actual measured top speed was from the factory speedometer that was cabled to the front wheel. It must be noted that while this calculation was very accurate for the 10 tooth sprocket, the 12 and 15 tooth sprockets were progressively incorrect. This was assumed to be due to air resistance greatly increasing at higher speeds.

Theoretical top speed calculator							
drive sprocket (teeth)	rear sprocket (teeth)	ratio	motor rpm	rear tire rpm	rear tire circumference (inches)	**top speed (mph)**	**actual measured top speed (mph)**
10	45	4.50	3200	711.11	77.5	**52.19**	**52**
12	45	3.75	3200	853.33	77.5	**62.63**	**55**
15	45	3.00	3200	1066.67	77.5	**78.28**	**60**

Table 4.5: Calculated and actual top speeds using three different front sprocket sizes

4.18 Riding Style Differences

When riding this electric motorcycle it was immediately apparent that it had different handling characteristics than an equivalent gasoline powered motorcycle. Coasting is more efficient as the motor was not linked to a transmission; this was equivalent to always coasting in the neutral gear on a regular motorcycle, which is not practical. There is no clutch to engage so starting off is much quicker, the rider can turn the key and go, it is immediately and always “in gear”. Because of the characteristics of DC motors, 100% torque is available at 0 rpm which gives the motorcycle a “jumpy” feel when first twisting the throttle as opposed to slipping the clutch on a normal motorcycle. Similarly, there is no warm up period for the motor, as some gasoline engines require. When riding an electric motorcycle, range is always the limiting factor and is always on the rider’s mind. To conserve battery life, braking becomes something to avoid as this wastes momentum and means additional acceleration immediately after. This tends to cause electric motorcycle riders to become more aware of their routes and plan ahead for upcoming stop signs, traffic lights and hilly terrain, all factors that are of inconsequence to the regular motorcycle rider.

4.19 Licensing and Registration

Licensing the motorcycle was a bit confusing at first and in the end, turned out to be not worth the time devoted to it. The Department of Motor Vehicle Office in the author's state of Missouri was unfamiliar with registering a converted electric motorcycle which was expected due to the lack of electric motorcycles in the community. The representative had to make many phone calls which made the process take approximately one hour, after which, it was discovered that the only requirement was to change the fuel type on the vehicle title and fill out an application for a special fuel motor vehicle decal at a cost of $75 annually. The cost of this sticker represents the state fuel taxes that are not collected at the gas pump. This decal however, is the same amount for a motorcycle, car, bus or any size vehicle up to 18,000 lbs. (MODOR, 2009) To illustrate the mismatched use of this decal cost versus actual fuel taxes, we take the current Missouri gasoline tax per gallon of 17 cents (Chapter 142 RSMo, 2009), and divide this into the $75 annual decal fee which gives us the equivalent of 441 gallons of gasoline tax. If we take a conservative mileage rate on an equivalent gasoline motorcycle of 40 miles per gallon, the 441 gallons is equivalent to 17,640 miles per year, a large amount even for a motorcycle riding enthusiast. Further, at 15 miles per charge cycle, 17,640 miles would require 1,176 charges--approximately three to four times more that the batteries are expected have. Assuming the batteries could theoretically hold up to that many charge cycles, and assuming the same 5 hour charge time, plus one hour riding time. To go 17640 miles, you would have to charge and ride the motorcycle 3.22 times every day of the year. So whether we consider miles ridden, charge capacity of batteries or charge time required, the special fuel motor vehicle decal is only advantageous for the state and gives no incentive to operate an electric motorcycle.

4.20 Objective Results

In completing the research and build portion, all major objectives were met and a portion of the minor objectives were met.

Major Objectives Met

- Utilize a "sport bike" style motorcycle for the conversion, with fairings in the best condition as can be found and little or no frame damage. --- This was accomplished by finding an adequate donor chassis meeting the budgeted price and in excellent mechanical and aesthetic condition.
- Keep the total conversion cost to under $2000. --- This was accomplished by keeping battery cost low and utilizing used components when available.
- Utilize the highest voltage system possible that the budget will allow. --- This was accomplished by using a 72 volt system to meet this objective. Any higher voltages require components too large or too heavy for use in an electric motorcycle.
- Utilize as much of the factory wiring and switching system as possible. --- This was accomplished by use of a voltage converter to change the 72 volt pack voltage to 12 volts that the factory wiring system and components could handle.
- Have the factory key switch act as the primary enabler of the system. --- This was accomplished by ensuring that the contactor with a 12 volt control voltage was purchased.
- Make little or no modifications to the factory look of the motorcycle. --- This was accomplished by selecting components and dry fitting cardboard mockups of them inside the frame and fairings before installation began.
- Have an on-board charging system. --- This was accomplished by purchasing the appropriate style charger.
- Keep the original direct drive chain system. --- This was accomplished by positioning the motor in a location that was as close as possible to the original engine output shaft.
- Ensure it passes inspection so it can remain street legal. --- This was accomplished by ensuring all factory safety devices functioned properly, this included the headlight, the turn signals, the horn, the brake lights, and the front and rear brakes.

Minor Objectives Met

- Utilize the factory "kill switch" connected to the side stand. --- This was accomplished by linking the ground output from the side stand switch to an

interrupt relay that disabled the motor controller when the side stand was in the down position.
- Improve the look with a more "eco friendly" paint scheme and decals to bring attention to its alternative fuel source. --- This was accomplished by repainting the fairings and some highlighted frame parts.
- Install LED accent lighting. --- This was accomplished by tying in an LED accent lighting system to the existing motorcycle 12 volt factory wiring harness.

Minor Objectives Not Met

- Change out all incandescent bulbs with LED bulbs. --- This was not accomplished due to available time and budget.
- Install an LED daytime running light in conjunction with the existing headlight with way to switch between the LED light for daytime use and the original headlight for nighttime use. --- This was not accomplished due to available time and budget.
- Utilize unused ICE indicators on the dashboard gauges to monitor new electric functions. --- This was not accomplished due to available time.

4.22 Concluding thoughts

The research in this report clearly shows that many factors play a part in the efficiency and financial aspects of converting an electric motorcycle. The author's budget presented a limitation, the battery type presented a limitation, and state regulations presented an unfavorable situation lack of incentive for converting a motorcycle to electric power. As reviewed before, there are companies that have created a marketable combination with capabilities consumers can use. The reader will obviously be left with the question of cost benefit when comparing the specifications of those motorcycles in their mind. Lifestyle would seem to be the primary factor in whether an electric motorcycle is right for someone. Commuting distance, climate and demographics all would be taken into consideration. As for converting a motorcycle, one important consideration the author discovered was the limitation of battery capability which is limited by budget as the overall limiting factor that determines the practicality of converting a motorcycle to run on electricity.

In summary, from a financial aspect of whether to buy or convert, one would get far more "bang for the buck" if they had the knowledge and ability to do the conversion process. As for practicality, yes, it is very practical for someone with an aptitude for electronics and mechanical engineering basics. As far as performance, lower cost seems to equate to lower performance unless lithium battery technology is utilized which brings a substantial cost requirement.

Chapter 5 - Suggestions for additional research

During this research, the author discovered multiple sub-topics that should warrant additional research for anyone wishing to further study electric motorcycles and electric motorcycle conversions. Many of these sub-topics fall in the category of optimizing components and design which was beyond the research scope of this report. Included here, are the topics that the author found would be the most beneficial in the next step of research.

Marketing and profit potential of running an electric motorcycle conversion business.

The author believes that given the right geographic location, climate and demographics, there could be potential demand by consumers to buy converted electric motorcycles. This would possibly depend on geographic factors such as mountainous or flat terrain, climate factors that affect the riding season such as temperature, rain and snow, and demographic factors such as socio-economic level, urban or rural disposition and local government support for “eco-friendly” transportation methods.

The feasibility of using other types of alternative fuel sources to power motorcycles.

The author believes that there may be other alternative fuel sources besides electricity that may possibly be harnessed to power a motorcycle. Among potential candidates are propane and ethanol that are proven sources for other vehicles, and newer technologies such as hydrogen and fuel cells. This research would be most appropriate from the standpoint of larger motor vehicle manufacturers as they have far greater finances and R&D capability for this kind of development than private citizens.

Optimization techniques of increasing the capability of electric motorcycles to make them competitive with their gasoline powered competitors.

The author believes that there is an opportunity for research into the optimization of electric motorcycle design to narrow the performance gap between electric and gasoline powered motorcycles. Areas such as aerodynamics, rolling resistance, material weights and densities, battery technology motor technology and motor controller technology all offer great potential for research and improvement. These improvements will contribute to increasing the speed, acceleration and range of electric motorcycles.

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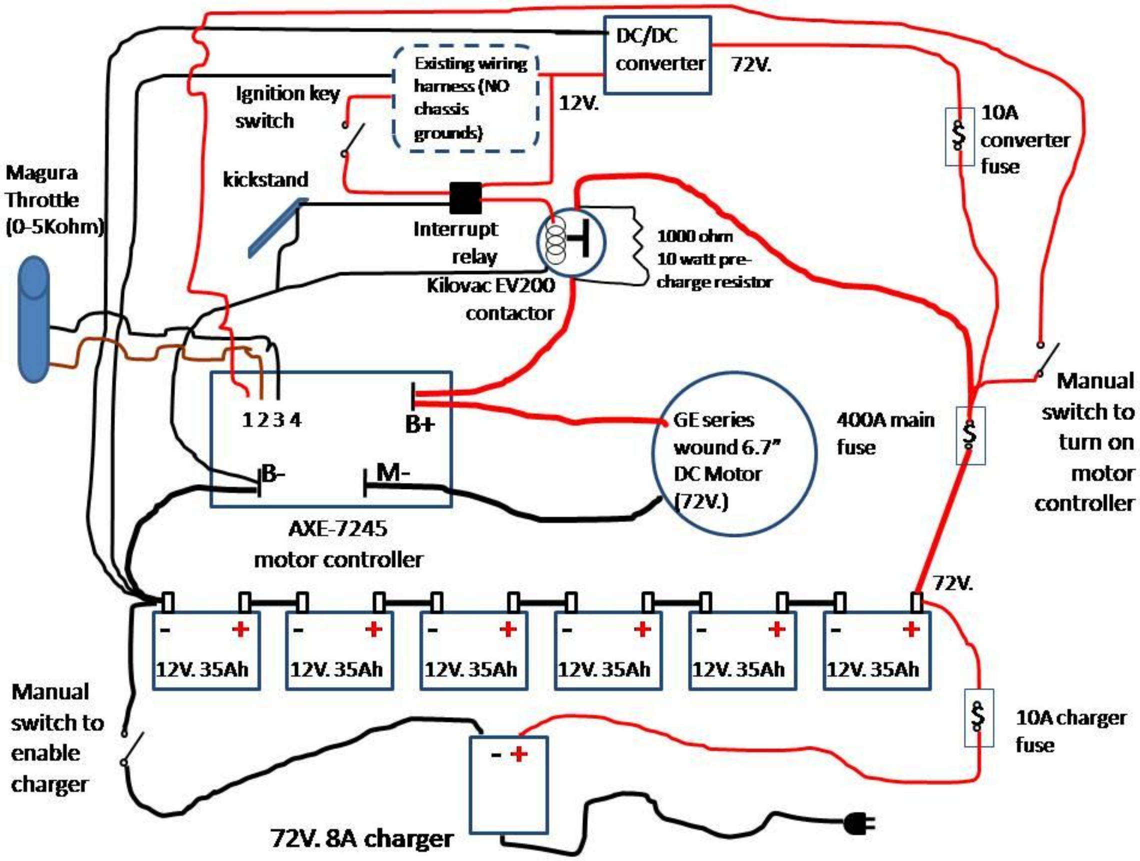
Appendix A

Wiring Diagram of Converted Electrical System



Appendix B

Conversion Costs

Component	Budget Amount	Actual Cost
Motorcycle chassis	$400.00	$350.00
Motor	$450.00	$50.00
Motor Controller	$300.00	$450.00
Battery Pack Charger	$150.00	$180.00
Cabling	$25.00	$35.00
Battery Pack	$300.00	$380.00
Fabrication Iron/steel/bolts	$50.00	$80.00
Contactor	$50.00	$70.00
Voltage Converter	$25.00	$35.00
Throttle	$50.00	$55.00
Sprockets	$15.00	$15.00
Battery cable lugs	not budgeted	$20.00
Horn	not budgeted	$5.00
Chain	not budgeted	$18.00
Chain Adjustor	not budgeted	$15.00
data cable for controller logging	not budgeted	$30.00
Paint	not budgeted	$100.00
electrical wire, connectors, switches	not budgeted	$20.00
Estimated Taxes and shipping 10% of total	$181.50	
Total:	**$1,996.50**	**$1,908.00**

Appendix C

Electric Motorcycle Manufacturers

Name	Location	Models	Cost	Top Speed in miles per hour	Range in miles	Available to the public	Website
Electric Motorsport	California	GPR-S	$8800 w/lithium batteries	60-70	30-60	Yes	www.electricmotorsport.com
Brammo Inc.	Oregon	Enertia	$10,800	60+	42+	Yes	www.brammo.com
Zero Motorcycles		Zero S	$9,950	55	50	Yes	www.zeromotorcycles.com
		Zero DS	$9,950	55	50	Yes	
Mission Motors	California	Mission One	$68,995	150	150	Yes	www.ridemission.com

Appendix D

EV Information Sources and Suppliers Consulted

Sources of information		
Mid-America Electric Automobile Association (MAEAA)	www.maeaa.org	
EV album	www.evalbum.com	
Plug In America	www.pluginamerica.com	
V is for Voltage discussion forums	www.visforvoltage.org	
The Electric Motorcycle Information Network (ELMoto)	www.elmoto.net	
Electric Motorcycle Forum	www.electricmotorcycleforum.com	
Endless-Sphere Technology Forums	www.endless-sphere.com	
Parts Suppliers		
Cloud Electric, LLC	www.cloudelectric.com	Electrical products for Evs, home, RVs, marine and industrial applications
EV Parts Inc.	www.evparts.com	Electric vehicle kits, parts and accessories for Evs
ThunderStruck Motors	www.thunderstruck-ev.com	Small R&D company that sells EV's and components
Digi-Key Corporation	www.digikey.com	Extremely large supplier of all kinds of electrical components and products
Surplus Center Burden Sales Company	www.surpluscenter.com	Provider of industrial hardware, parts and tools

Appendix E
Letter Sent to Motorcycle Manufacturers

Dear [motorcycle company] representative,

I would like to request information on [motorcycle company]'s plans for a future electric motorcycle. I am a graduate student at the University of Kansas in their Engineering Management program. I am currently working on research that involving the practicality of electric motorcycles.

This research includes an experiment to convert an existing motorcycle to electric power. This involves exchanging all internal combustion engine components with electric components. In place of the engine, carburetors and gas tank, I will be installing a DC electric motor, a motor controller and batteries.

This is an effort to show the feasibility and practicality of an electric motorcycle. Despite the popularity and media coverage of hybrid vehicles and efforts to wean ourselves of fossil fueled vehicles, there are currently no large scale manufacturing efforts to produce an electric motorcycle with a practical price tag for consumers.

Any information you can provide on this subject will greatly help me develop my research on which direction the motorcycle industry and market is heading with respect to electric power. Thank you again for your time and thank you in advance for any information or literature you can provide on this topic such as current [motorcycle company] research focus, test prototype progress, industry statistics, etc.

Chris Simcoe
Graduate student
Engineering Management program