THE UNIVERSITY OF WESTERN AUSTRALIA

School of Mechanical Engineering

Battery Management, Power Supply and Safety Systems in an Electric Drive Vehicle

Stephen Whitely

10119492

School of Mechanical Engineering, University of Western Australia

Supervisor

Thomas Braunl, Assoc. Prof. Dr. habil.

School of Electrical, Electronic and Computer Engineering

3rd November 2008

ABSTRACT

There is currently a great focus on reducing carbon emissions and fossil fuel consumption by means of alternative energy sources in transportation. An increasingly popular option is the electric vehicle (EV). One of the main criticisms on EVs is their limited range. Range is largely dictated by limitations of the batteries carried in the vehicle. Battery technology is continuously improving but in order to get the most out of current and future technologies, intelligent battery management and efficient use of the energy is required. The management of charging and discharging of the batteries can allow for increased range and extended battery life on current technology and can be applied to new battery technologies as they become available.

This paper will cover the installation and implementation of battery management, power supply and safety systems in a conventional vehicle converted to electric drive for the Renewable Energy Vehicle (REV) Project at the University of Western Australia. These systems will be based on a Lithium ion battery pack and will be predominately using currently available technologies to provide a simple conversion that could be achieved by general members of the public without access to high tech labs and workshops.

These systems will be tested and reviewed for their strengths and shortcomings. Suggestions will be made as how to improve the systems for future works by the REV Project in ongoing years.

This paper shows that while the systems are adequate, a number of improvements on battery management, efficient power distribution and safety issues can be made.

Stephen Whitely
267 Heytesbury Rd
Subiaco WA 6008

3rd November 2008

Associate Professor Carolyn Oldham
Dean
Faculty of Engineering, Computing and Mathematics
University of Western Australia
35 Stirling Highway
Crawley, WA 6009

Dear Associate Professor Oldham

I am pleased to present this thesis, entitled "Battery Management, Power Supply and Safety Systems in an Electric Drive Vehicle" as part of the requirement for the degree of Bachelor of Engineering.

Yours sincerely

Stephen Whitely
10119492

TABLE OF CONTENTS

1. Nomenclature 1
2. Introduction and Literature Review 2
   2.1. Introduction 2
   2.2. Literature review 2
   2.3. Project objectives 6
   2.4. REV Project background 7
3. Battery Management System 8
   3.1. Description of system 8
   3.2. Process 10
   3.3. Results and Discussion 14
4. Safety Systems 23
   4.1. Process 23
   4.2. Results and Discussion 26
5. Power Supply 29
   5.1. Process 29
   5.2. Results and Discussion 33
6. Conclusions and Future Work 34
   6.1. Conclusions 34
   6.2. Future work 35
7. References 36
8. Appendices 39
   8.1. Data from experiment 2 39
   8.2. Data from experiment 3 40
   8.3. Safe Installation Guide for Batteries 40

1. NOMENCLATURE

The following are some acronyms that shall be used throughout this paper.

BMS	Battery Management System
CI	Constant Current (Charging)
CV	Constant Voltage (Charging)
DPI	Department of Planning and Infrastructure (Western Australia)
EV	Electric Vehicle
ICE	Internal Combustion Engine
ICV	Internal Combustion Vehicle
NCOP	National Code of Practice
REV	Renewable Energy Vehicle
SOC	State of Charge
ZEV	Zero Emission Vehicle

2. INTRODUCTION AND LITERATURE REVIEW

2.1. Introduction

Due to growing concerns of climate change and global oil shortages, many are looking to alternate means of power for transportation. These alternatives aim to reduce petrol consumption and emissions, in the case of hybrid vehicles, or remove them completely, in pure electric and hydrogen fuel cell vehicles.

Electric vehicles (EVs) are an appealing alternative due to their relative simplicity in construction compared to hybrids and fuel cells. They offer a zero emission vehicle (ZEV) solution and can be far more energy efficient than an internal combustion vehicle (ICV). Emissions at a power station can be comparably low (compared to ICVs) due to their efficiency or power can be sourced from renewable resources. Their main disadvantages are their limited range and long times to recharge (NAUNIN, D., 1996).

Both of these disadvantages can be directly attributed to limitations of the batteries and has especially been the main hurdle in the past with the then available battery technologies. These characteristics must be improved with better battery chemistries and manufacturing processes, and better battery management systems.

Another concern regarding electric vehicles is their safety. The issues of the chemical and electrical hazards to vehicle operators, maintenance operators and others that may come in contact with the vehicle such as emergency service personnel.

2.2. Literature review

EV History

The electric vehicle actually has a history as long as internal combustion vehicles with the first vehicle appearing in 1895 (D'AGOSTINO, S., 1993). In a historical survey of the EV, D'Agostino writes that "in the year 1900, 1575 electric automobiles were produced versus only 936 [petrol] cars." However by 1905 petrol vehicles were more popular with the advent of the starter motor and availability of petrol as a cheap, high energy-density fuel.

The article goes on to show several resurgences of the EV over the next one hundred years based on a number of factors and states that at the time of publication, "never before have political, economic, and environmental issues all simultaneously served to

strongly motivate the return of the electric vehicle – until now" (D'AGOSTINO, S., 1993).

Battery technology

In the mid 1990s, before current battery technologies matured, the best available batteries for an electric conversion were still lead-acid (KEOUN, B. C., 1995). This was due to their cost and availability as other technologies existed but were not yet being produced at a cost or volume to make them available to the average do-it-yourself converter.

Oman (1994) writes of the emerging new battery technologies of just over a decade ago. Compared to today, things have come a long way and one of the technologies Oman looks at is lithium-ion but described as a new and exotic technology.

EVs have benefitted from recent rapid research and development into battery technologies brought on by recent growth in mobile telecommunication electronics as they share a number of requirements in a battery – high power, high energy density, lightweight, resistant to temperature extremes, long life and low life cycle cost (MCDOWALL, J. et al., 2001).

Numerous papers identify the lithium ion batteries for their superior characteristics. Lithium ion battery technologies are found to be attractive for an EV application as they have relatively high energy density compared to other chemistries, maintenance free as they are hermetically sealed, and, with management electronics, able to operate in a large range of temperatures, however they require battery management to realise their full potential (BRENIER, A. et al., 2004). Adapted from the same paper, Figure 2.1 compares desirable characteristics of several battery chemistry types. It clearly shows lithium ion as the best all-round performer, far surpassing lead-acid in all categories and nickel-cadmium in most.

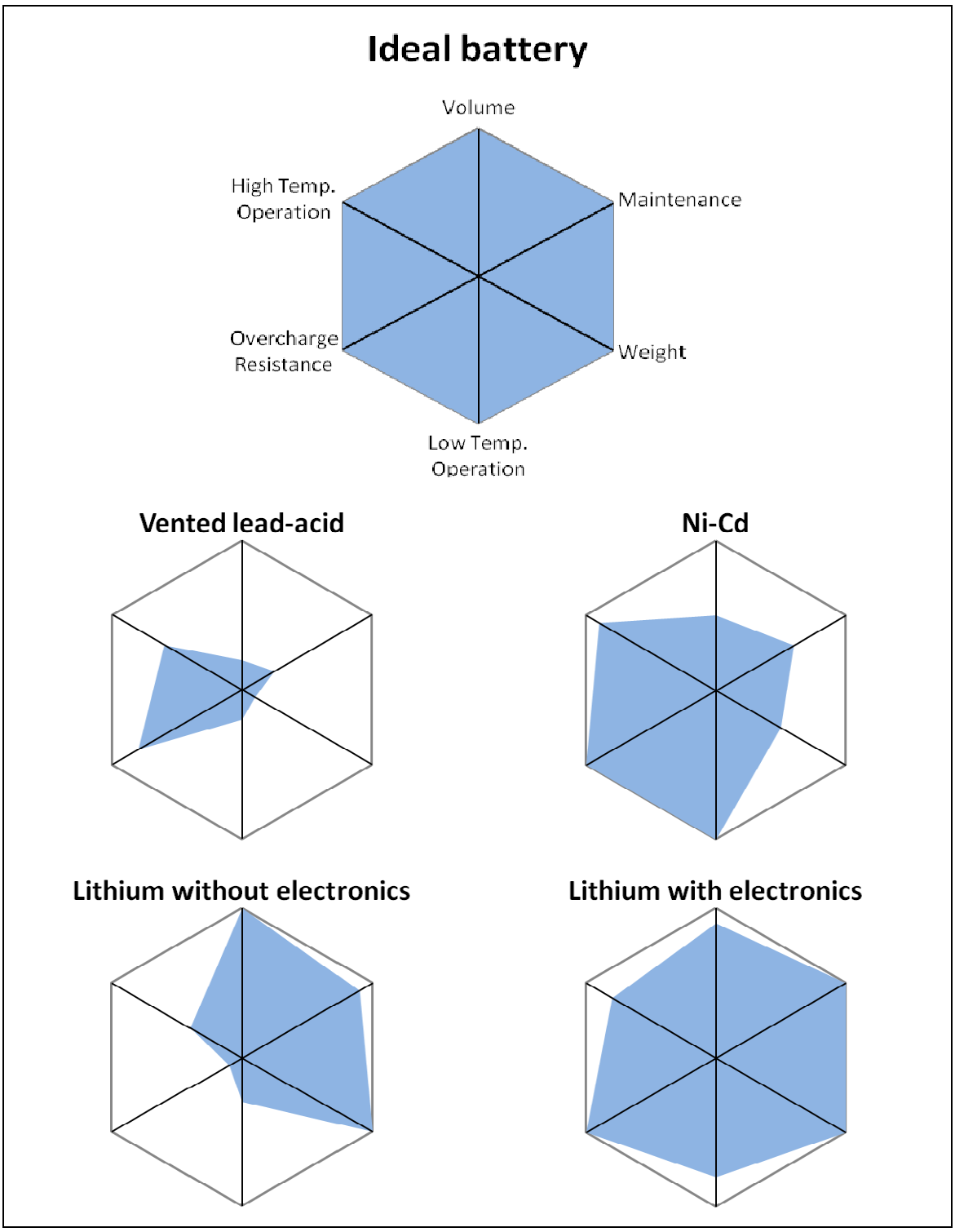

Figure 2.1 - Relative merits of various battery technologies – adapted from (BRENIER, A. et al., 2004)

Battery management

Despite benefitting by advances in battery chemistry and manufacture brought on by advancing mobile electronics, battery management in electric vehicles hasn't had such a hand-in-hand improvement as battery usage patterns in an EV are considerably different to most other application with requirements of both short high current bursts for acceleration and long periods of constant load for highway driving (MASKEY, M. et

al., 1999). This means that battery management developed for other means such as telecommunication don't necessarily suit the application to EVs.

Teofilo (1997) explains how correct charging is important to achieve maximum capacity and therefore range of the EV. Lithium ion batteries can receive 30-60% of their capacity under 'taper' charging or a constant voltage stage (TEOFILO, V. L. et al., 1997). Specialised chargers, usually microprocessor controlled, are needed that can operate in different modes in order to maximise range.

Kroeze, R. C. Et al (2008) developed a model for batteries in the paper, "Electrical Battery Model for Use in Dynamic Electric Vehicle Simulations." The goal of this model is to provide more accurate results in simulating use in an electric vehicle. Use of models like these could be used to design and simulate better battery management systems.

Haifeng, D et al (2006) have derived a model for better online estimation of the batteries state of charge. Accurate models will allow for better utilisation of battery capacity.

Galdi (2006) produces a model based on fuzzy logic by which the battery management systems can limit the vehicles performance to a degree in order to maximise the battery life when the state of charge begins to get low. This autonomous control is shown, in simulation, to increase the range of the simulated electric vehicle.

Currently there are limited commercially available implementations of battery management to suit converted EVs and systems being developed by major car manufacturers are kept in house and not available to the public. There is a great range of different power needs in converted EVs from 120V DC to 600V AC. The EVAlbum (CHANCEY, M., 2008) website shows many examples of privately and commercially converted electric vehicles ranging from twelve to two hundred batteries in a single vehicle.

Safety

Released by the Australian Government, Department of Infrastructure, Transport, Regional Development and Local Government (2006), the National Code of Practice (NCOP) regarding the Installation of Electric Drives in Motor Vehicles sets out a number of standards, guidelines and recommendations for an electric vehicle. These

standards and guidelines must be followed in order to maintain a licensable vehicle. The document also points to a number of Australian Design Rules that must be adhered to.

Limitations of Present Work

Much of the literature currently available revolves around mobile telecommunications but applying many of the ideas could be a relatively simple matter of scaling up to suit. Only in more recent years has there been a resurgence in research and advancements that apply specifically to electric vehicles, similar to that which occurred in the early to mid nineties.

Other than the one NCOP document, there is very little official documentation about safe practices and safety systems in electric vehicles. More documents need to be produced so that standards in safety can be achieved.

2.3. Project objectives

The objectives of this project cover the installation and assessment of a battery management system, power supply, and safety and power isolation systems in the REV Project's Hyundai Getz converted to electric drive (see 2.4 REV Project background).

Some of the components used in the conversion had already been procured for use in the previous year's project. This included the motor, controller, batteries and battery management system. However, the components had never been installed or evaluated so little was known about how these systems would perform in practice.

The first stage of this project was to install the batteries and battery management systems into the vehicle and evaluate it. Then a model of an ideal management system will be derived and the real system compared to it. Suggestions shall be made for a new battery management system that could be designed in the future to perform closer to the ideal system.

The next stage is to look at what safety systems are required for isolating the electrical hazards from passengers in the vehicle and person working on the vehicle, and to ensure safe operation of the vehicle.

Lastly, power supply is looked at. This is important as there are two power rails, a range of power requirements and devices that need to be switched on and off under certain

circumstances. Different conductors and insulations need to be considered for each system's power requirements.

2.4. REV Project background

The Renewable Energy Vehicle (REV) Project is a project involving a number of students investigating many aspects of alternative propulsion vehicles. This year, the Project's focus has been on electric vehicles (EVs).

The REV Project has taken a common, cheap, internal combustion engine (ICE) vehicle, a Hyundai Getz, and converted it to an electric drive. The converted drive comprises a DC motor and controller, powered by a pack of lithium ion batteries. It also uses various systems to restore original functionality to all the cars original auxiliary systems such as power steering, brake vacuum, heating and air conditioning, which were previously powered by the original combustion engine.

The conversion of an existing vehicle has some advantages over a completely new, custom-designed vehicle. Firstly, it allows for a much simpler project that can be completed in a shorter time frame, on a smaller budget. It also allows for much simpler licensing to get the vehicle on the road, meeting the requirements of the National Code of Practice and the Department of Planning and Infrastructure (in Western Australia).

A secondary goal of the REV Project is to raise awareness and understanding of the technology amongst the general public. This is done through public exposure of the technology and producing educational materials that the public can use to do their own conversions.

3. BATTERY MANAGEMENT SYSTEM

3.1. Description of system

The main purpose of the battery management system (BMS) is to optimise the battery charging process and alert the system operator (in this case, the driver) of any errors.

The BMS that was inherited from the previous year's project, unused and untested, was an early version of the TS90 Thunder Sky battery management system from a local company, EV-Power Australia Pty Ltd (DILKES, R., 2008). Newer versions are much unchanged in regards to electrics and electronics but are now mass produced, as opposed to the handmade units shown in Figure 2.1.

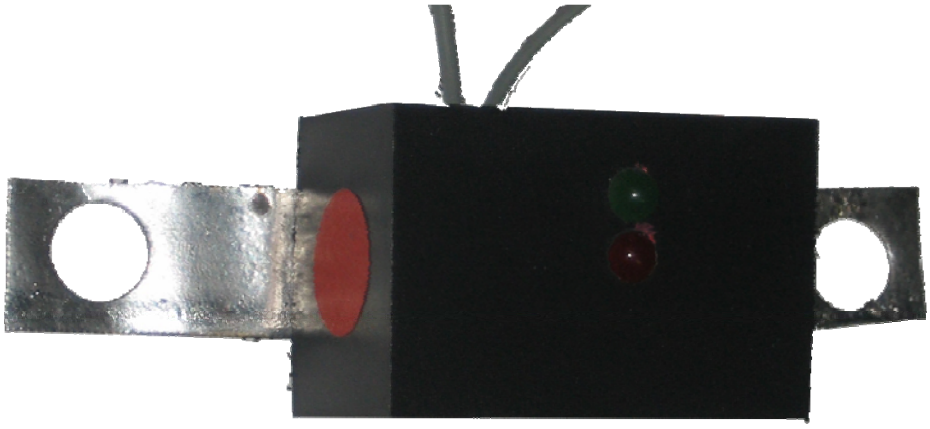

Figure 3.1 A single battery management module

The TS90 BMS is a modular system, custom designed specifically for the Thunder Sky 90Ah lithium ion batteries. With this system, each battery has a module that sits on top of it, connected to its terminals.

An error signal line daisy-chains each module to form a loop, which starts and finishes at the master control unit (Figure 3.2). The error signal is simply a relay, in each module, that is normally closed when the status is fine, so that any battery error, or a break in the signal line, will register an open circuit at the master control unit. This means that the error signal is fail-safe but the module from which the error originated is indeterminable. The states that create an error are; critically low voltage (2.5V), critically high voltage (4.25V) and being disconnected.

Figure 3.2 Master control unit (DILKES, R., 2008)

The master control unit is designed to monitor the battery error states, control the battery charger and indicate the systems state, both through LEDs for visual inspection and electronic signals.

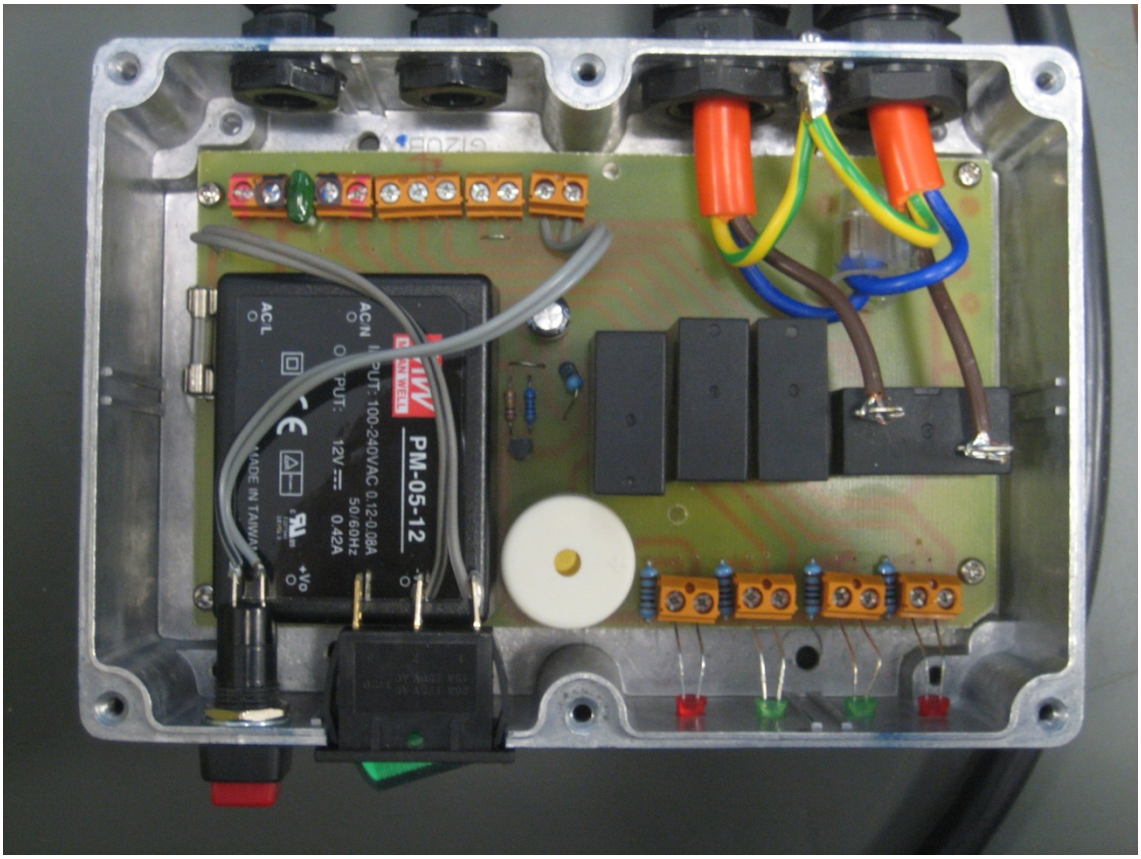

Figure 3.3 Master control unit internals

Figure 3.3 shows an internal view of the BMS master control unit. To the top-right are the mains voltage lines used to connect and control the battery charger. The top-left has connections for power (from the battery pack), error signal input (from modules), error output (to external systems) and an optional input from the charger. Along the front of the unit (bottom of the image) is the reset button, power switch, and the status LEDs; error, OK, charging and end of charge.

The battery charger to be used for this system is a Zivan NG3. It is a microprocessor controlled charger with selectable charge curves to meet the charging requirements for various types of batteries. Operating efficiency should be 85-90% (ZIVAN, 2008).

3.2. Process

Installation

The batteries and BMS were installed into a cage designed by other members of the REV project. The cage was mounted in the boot of the Hyundai Getz that was being converted. Bench testing was considered by in situ testing allowed for fast tracking of the conversion process.

The installation of the system is relatively straight forward, albeit somewhat tedious and repetitious. A guide was written for the installation of the batteries and BMS and is included in the appendices of this paper for reference.

The batteries are installed in series to give a nominal battery pack voltage of 144V from the forty five, 3.2V nominal batteries. The batteries are connected by copper straps for optimal conducting and handling the high currents, which can be up to 270A continuous and peaking even higher.

The BMS modules are installed on top of each battery in the correct orientation, as the modules are polarised. The error cables are connected up in series and terminated at the master control module.

The charger’s output is connected in parallel to the battery pack and the input is connected to the mains connector on the master control unit. The master control unit is then connected to a mains plug located in the fuel cap of the Getz, where an extension cable is connected for charging.

The remaining connectors are connected on the master control unit and the system is ready to be used and tested.

Figure 3.4 Installed battery management system in electric Getz (charger mount on left)

Experiments

There are a number of characteristics of the system that needed to be tested to see how the system performs. An ideal BMS will be energy efficient, drawing as little power as possible, effective at realising the full capacity of the batteries through effective balancing and ensure that the batteries are not being damaged by over charging, discharging or excessive current load or discharge.

The following are a set of simple experiments used to evaluate the BMS. Equipment required is little more than the batteries, BMS, charger, standard 240V mains outlet, multimeter and clamp meter.

The first set of experiments is to examine the power consumption of the battery management system, in particular the BMS modules. This was done in two simple experiments.

1. *Experiment 1*

1.1. Firstly a sample of the modules was individually tested by setting them up on a battery with an in-series ammeter.

1.2. The current draw was then measured along with the battery voltage.

The second experiment is to validate the results of experiment 1 and ensure no unexpected power drain occurs while the modules are on the batteries over an extended period of time.

2. *Experiment 2.*

2.1. With the battery management modules installed on the batteries, the voltage of each battery is recorded over a period of two weeks.
2.2. During this time, the batteries are not charged or discharged except for the modules and self discharge.

Next the BMS is tested to see how effective it is at balancing the batteries during charging. The modules aid in balancing the battery pack by bypassing current over batteries that reach a voltage of 3.9V. It is already known that the modules can bypass at most 1A.

The charger delivers 15A during the constant current (CI) stage, the first stage of charging. This means that batteries that are holding higher voltages will reach bypass stage but still be receiving most of the charging current and will rapidly reach the critical voltage of 4.25V, at which time the BMS will signal on error and the master control unit will turn off the charger.

In the second stage of charging, constant voltage (CV), the charger never delivers much more than 1A and often less than 1A. When the modules reach bypass in this stage of charging they should be effective in stopping those batteries' voltages from continuing to rise, allowing the maximum amount of energy to be stored in the batteries.

3. Experiment 3

3.1. With batteries and BMS installed, the battery voltages were measured and the charger was turned on to charge the batteries.
3.2. When the BMS cut off the charging process (because one or more batteries reach critical voltage) ten minutes was given to allow voltages to settle before measuring again.
3.3. A load was applied across the highest voltage batteries to bring their SOC down, closer to the mean.
3.4. The experiment then repeats until the charger is able to reach CV charging without pushing any batteries past critical voltage.

The last experiments are to test the charger itself. The efficiency of the charging unit should be high as minimising energy waste is high on the agenda of the REV Project in all areas.

4. Experiment 4

4.1. With the batteries in a SOC that allows the charger to operate in the first mode, constant current, the charger was turned on to charge the batteries.
4.2. Using a clamp meter, the current on the mains side of the charger was measured.
4.3. At the same time, the current being delivered to the batteries, and pack voltage are measured.
4.4. These measurements are then used to calculate the efficiency of the charger.

The charger also has to be effective in delivering the maximum charge to the batteries. The efficacy can be measured by measuring the behaviour of the charger and comparing it to the ideal charging pattern given by the manufacturer.

5. Experiment 5

5.1. With the batteries in a SOC that allows the charger to operate in the first mode, constant current, the charger was turned on to charge the batteries. The batteries also needed to be well balanced for this experiment.
5.2. Current and voltages are monitored until the charger reaches the constant voltage mode, indicated by the change of the LED on the charger from red to orange and a significant drop in current.
5.3. Monitoring of current and voltage continued until the current drops to zero and charger reaches ‘end of charge’ or ‘float charging’.

3.3. Results and Discussion

This section covers the results of the experiments described earlier and also discusses the characteristics of an ideal battery management system.

Measuring state of charge

State of charge is measure of how much charge is stored in the battery. This is a very useful measure to use in to express the results. However measuring it is not straightforward as battery voltage is not linearly proportional in relation to state of charge.

To assist in the reading of the data, equation (3.1), a sixth degree polynomial, was derived from the manufacturer's specifications of the batteries (THUNDER SKY, 2007) to approximate the relationship between the battery SOC (B_{pc}), expressed as a percentage, to the battery voltage (B_v). Note that this particular model is only valid while charging as once charging has stopped battery voltages settle back down.

$$B_v = \begin{cases} \left.\begin{matrix} -1.7449 \times 10^{-9} {B_{pc}}^6 + 4.6398 \times 10^{-7} {B_{pc}}^5 - 4.963 \times 10^{-5} {B_{pc}}^4 + \\ +0.0027 {B_{pc}}^3 - 0.0783 {B_{pc}}^2 + 1.1603 B_{pc} - 3.4323 \end{matrix}\right\} & for\ 0 \le B_{pc} < 70 \\ 4.2 \quad for\ \ 70 \le B_{pc} \le 100 \end{cases} \tag{3.1}$$

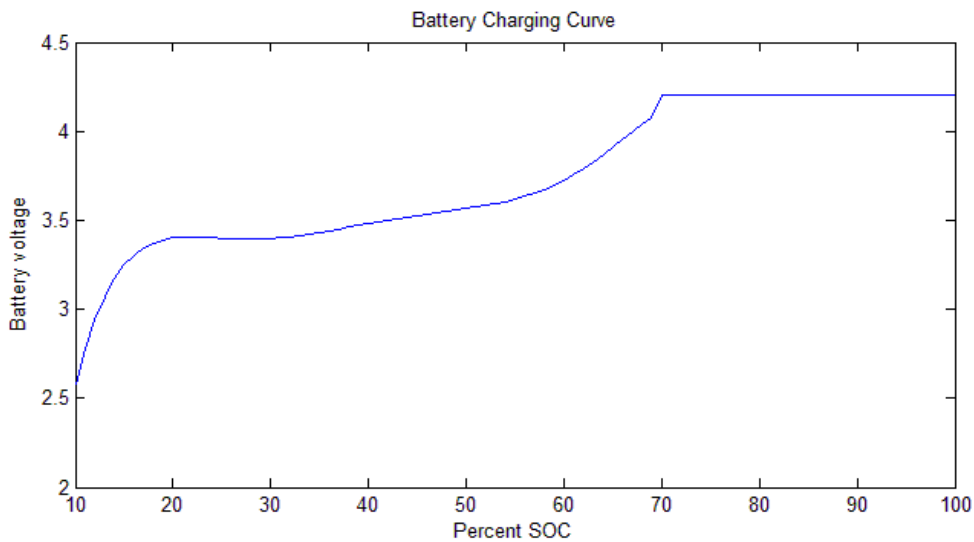

Figure 3.5 Battery charging curve Voltage vs %SOC. Adapted from (THUNDER SKY, 2007)

Experiment 1

The current draw from all but one BMS module ranged from 18.0mA to 18.3mA, whilst the battery was at 3.300V. The one odd module was drawing 44.2mA but was found to be faulty so that data was ignored.

The measurements give a power consumption of approximately 60mW. This is approximately the same power requirement for a single, standard, 15mcd, 5mm, green LED such as the one that is found on the unit. This shows that the BMS modules consume very little power and there's little room for improvement without removing the LED indicator.

Experiment 2

The data collected for this experiment showed that the voltage drop over time was very small. Unfortunately it was so small that the accuracy of the actual values is limited. The voltages were measured to accuracy of 1mV but the calculated average drop in voltage per battery per day was 0.48mV and at times the difference between measurements was zero. The raw data can be found in the appendices.

The accuracy of the data is however not very important in this experiment as the goal was to show that the BMS modules consume very little power. That fact is clearly demonstrated by the measurements.

Drop in SOC in;	
one day	0.027%
one week	0.175%
one month	0.750%
one year	9.125%

Table 3.1 Discharge due to BMS modules

Table 3.1 shows the predicted decrease in state of charge over various lengths of time. The figures suggest it would take over a month to bring the state of charge down just one percent. While the data may not be highly accurate, it's good enough to show that the energy consumed by the BMS modules is insignificant, especially given the most realistic usage model of the vehicle, where it would be charged every night

Experiment 3

Before the first charge, the batteries were very unbalanced. Figure 3.6 shows the distribution of the batteries by voltage. The distribution has a mean of 3.369V (20% SOC) but several of the batteries lie far from the mean. The difference between the mean and 3.46V works out to approximately 18% difference in state of charge. The raw data for this experiment can be found in the appendices.

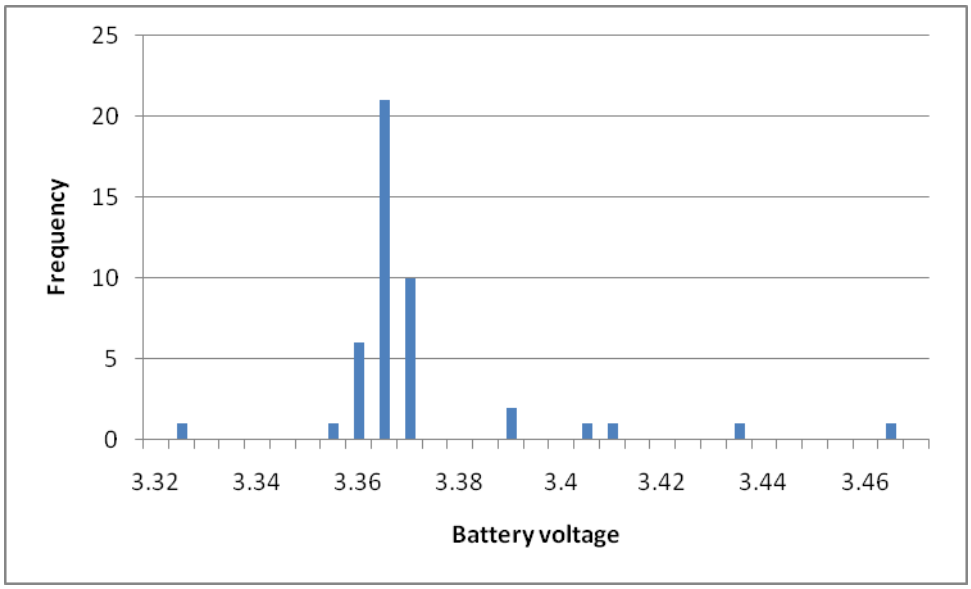

Figure 3.6 Initial battery voltage distribution

The first iteration of this experiment clearly demonstrated the battery management system's inability to deal with heavily unbalanced batteries. After charging for several hours, the first BMS module tripped at the critical voltage and the charger stopped.

The distribution of the voltage was then as shown in Figure 3.7. This clearly shows that many of the batteries are nowhere near full. In fact the mean voltage is 3.652V, which equates to just 55% of capacity.

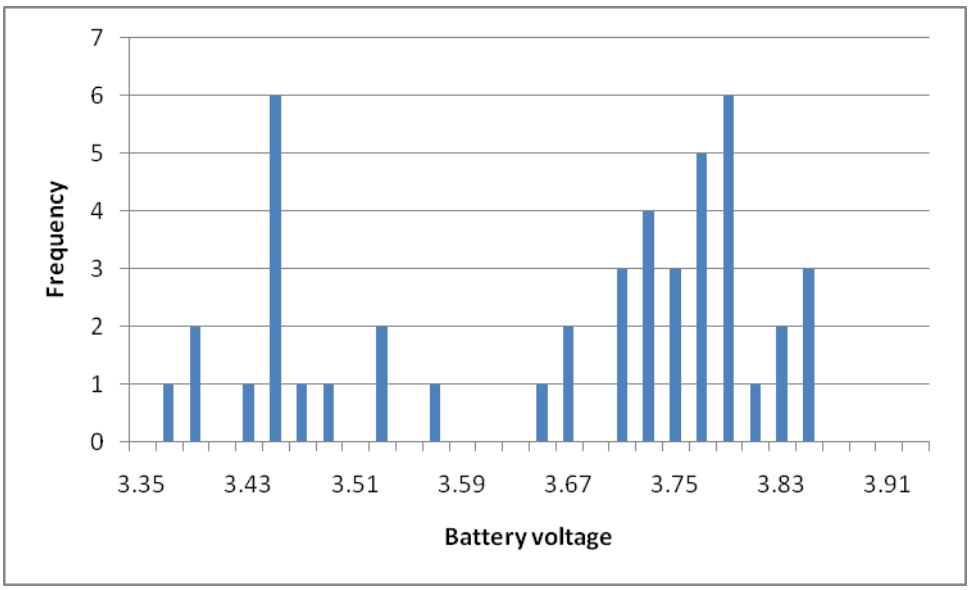

Figure 3.7 Battery voltage distribution after first charge

The difference in the two figures also demonstrates the effect of charging curve. In Figure 3.6 many of the batteries seem to be closely grouped together however Figure 3.7 shows the same batteries, after just one charge to be spread apart. The relatively small spread is deceiving as an increase of 0.1V at 3.3V is an approximately 15% change in actual charge, whereas a change of 0.1V at 3.7V is only around 3%.

Figure 3.8 and Figure 3.9 show the same data, expressed as percentage SOC instead of voltage. This shows more clearly how far unbalanced the outliers are.

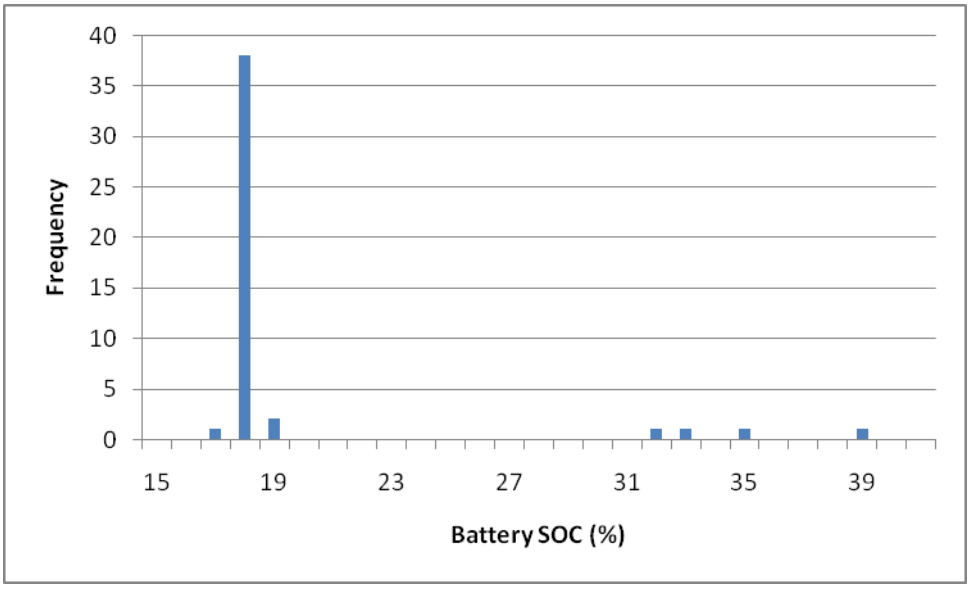

Figure 3.8 Initial state of charge distribution

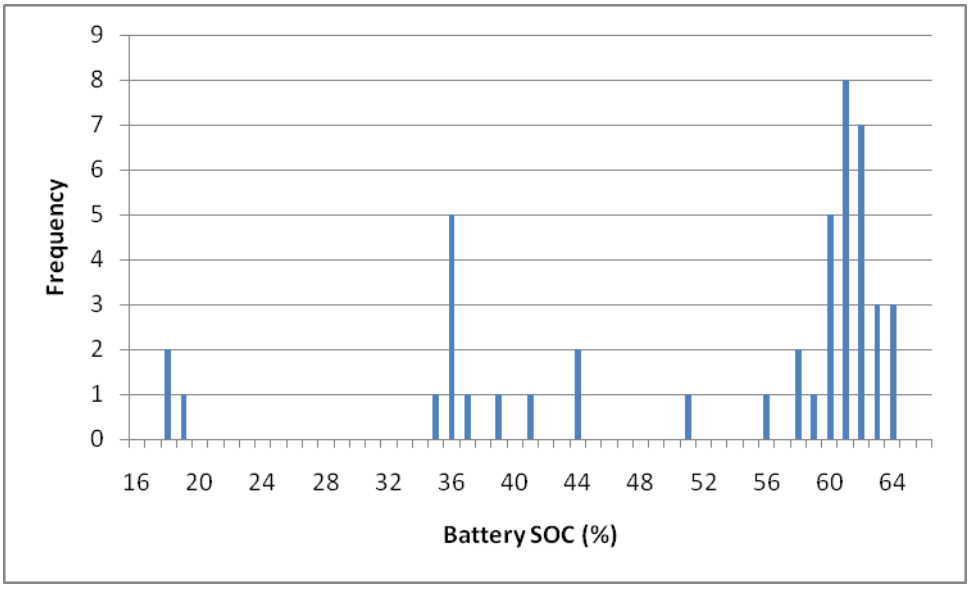

Figure 3.9 State of charge distribution after first charge

In order to be able to charge the batteries uninterrupted, the batteries that recorded high voltages were drained slightly with an adjustable load. Once the highest batteries were brought down, the batteries were measured and the experiment repeated.

Several times the experiment was repeated, manually balancing the batteries to bring down the voltages of batteries that were reaching critical voltage. When the batteries reached a state where the charger was able to charge the battery pack through to end of charge state the distribution of the battery voltages and SOC are as shown in the following figures.

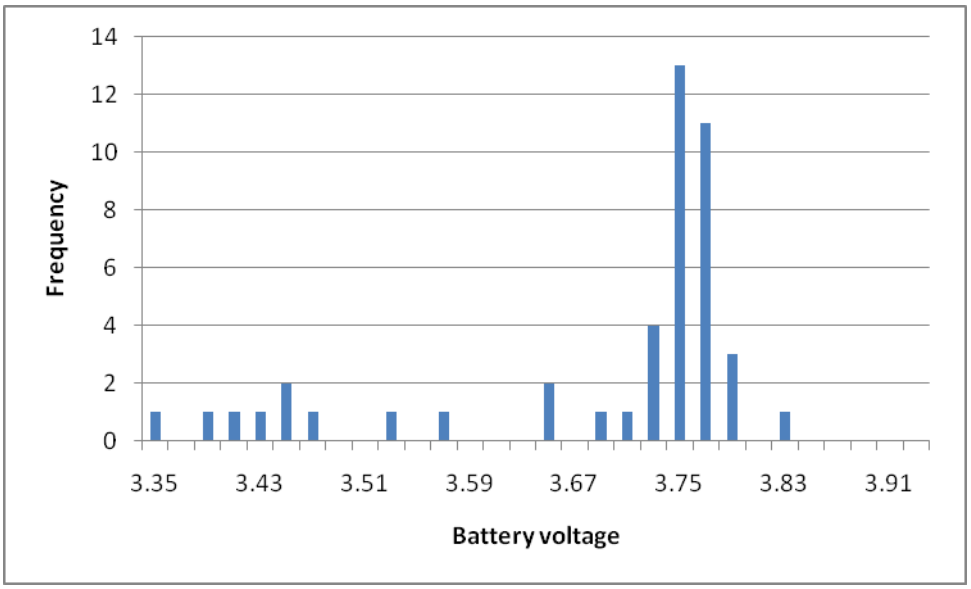

Figure 3.10 Distribution of battery voltage before final charge

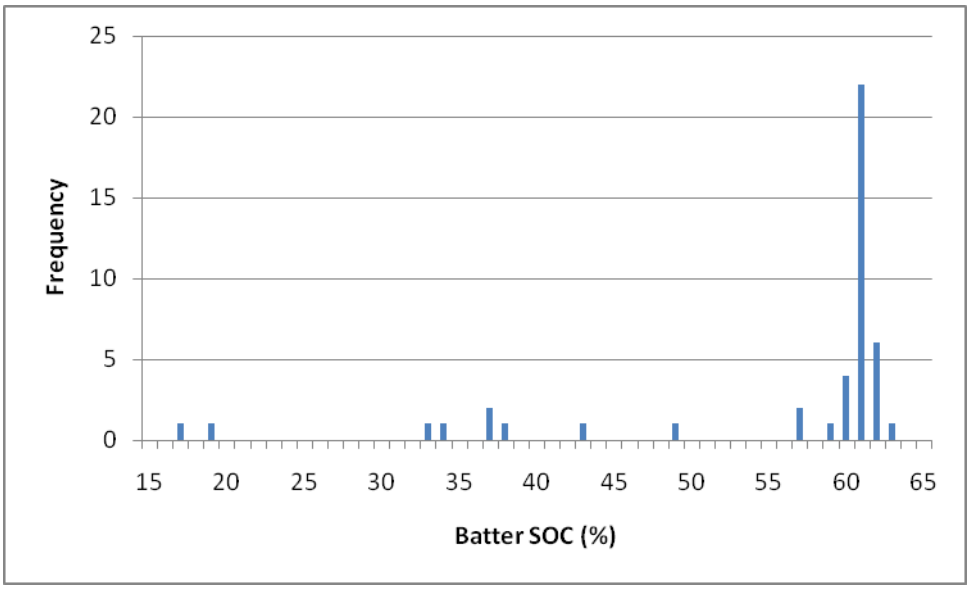

Figure 3.11 Distribution of SOC before final charge

As can be seen in the figures, there are no more high voltage batteries, causing the charger to stop prematurely. However, there are still many batteries with low SOC.

Further charging failed to bring all batteries up because the end of charge state was being reached. In this state, the charger delivers nearly no current and just maintains a constant voltage.

For a crude estimate of how unbalanced the batteries could be while still being able to be charged effectively, the batteries' state of charge can be modelled as being normally distributed throughout the pack if the sample size is large and distribution is random when they come from the factory.

If when the battery pack reaches an average of 3.75V per battery (when the charger enters CV charging), the standard deviation of the batteries SOC is less than one half of the difference between 3.75V and the bypass voltage, 3.9V, then 95% of the batteries should not have reached bypass and it is likely that the charging should be able to complete. This works out to be a standard deviation of just 2% in the state of charge.

In practice the batteries were not evenly distributed as the sample size was too small and their original state of charge may not have been truly random. However this does help to illustrate the limitations of the BMS as it is incapable of automatically balancing the batteries without assistance.

Experiment 4

The power input and output of the charger was measured and a sample of measures is shown in Table 3.2.

Input current (A)	Output current (A)	Output (V)	Efficiency
12.5	15.4	154.2	79.2%
13.6	15.5	154.8	73.5%
13.9	13.0	155.4	60.6%
14.0	12.9	155.8	59.8%
13.5	13.2	155.5	63.4%
12.4	13.1	156.4	68.8%
11.7	12.6	156.5	70.2%

Table 3.2 Charger power and efficiency

The results show a rather poor efficiency, especially as the manufacturer's claim 85-90% efficiency (ZIVAN, 2008). However, this poor performance is likely because the charger is working outside of its efficient range due to a modification.

A modification was made to the charger as it was decided that the vehicle was to be able to charge its batteries from any standard Australian mains outlet (240V, 10A). The charger was originally configured to draw up to 19A. The charger was adjusted to draw as little power as possible, which was still not under 10A. This also had the undesirable effect of making the charger very inefficient.

It is clear from this experiment that another charger is going to be needed to meet the requirements.

Experiment 5

Whilst charging, the output and behaviour of the charger was monitored.

In the first stage of charging, the charger behaves in a constant current mode. The charger supplies 15A to the batteries and the voltage increases with the state of charge.

Once the total voltage reaches 169V (3.75V per battery), the charger enters a constant voltage stage and the current decreases gradually.

Eventually the current drops off and the charger is in an end of charge (or float charge) mode. The charger holds a voltage of 169V to maintain the charge.

To determine how effective the charger is, it is compared to the charging curve in Figure 3.12.

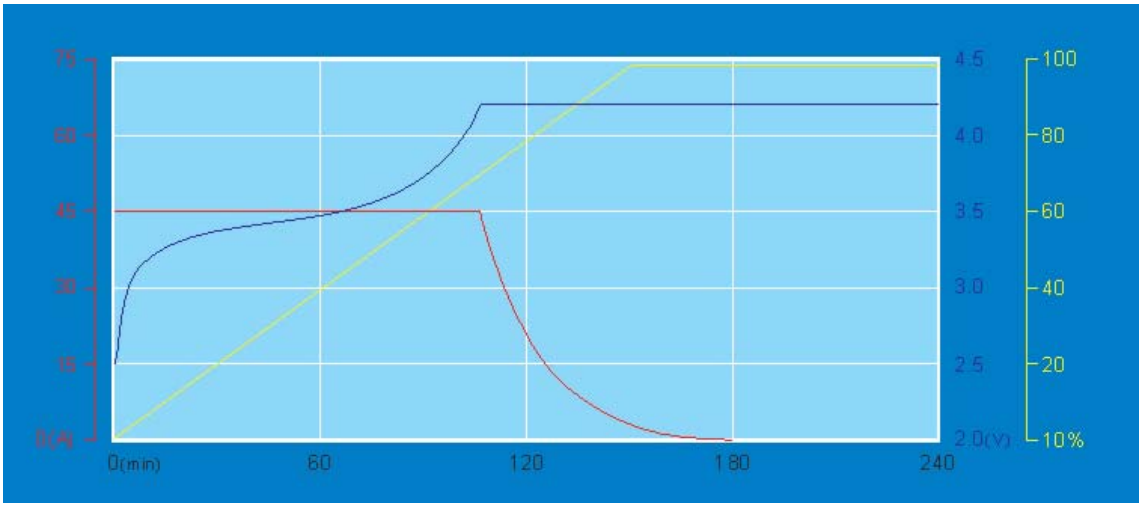

Figure 3.12 Charging characteristics chart (THUNDER SKY, 2007)

The charger delivers only a third of the optimal current in the constant current stage. This is acceptable as it is a limit that has been imposed by the requirements of using standard electrical outlets. The only sacrifice is the speed of charging.

The charger reaches constant voltage mode at 3.75V per battery. When compared to the chart, it can be seen that some capacity may be unutilised due to this as the ideal voltage to reach is 4.2V. This conservative charging may help in increasing the longevity of the batteries but means that there's 9% of the batteries' capacity that is never used.

Ideal battery management system

In order to evaluate the BMS system, some characteristics of an ideal BMS system are considered.

First and foremost the BMS is there to protect the batteries. Without it, lithium ion batteries are prone to failure and short longevity. The batteries need to be protected from over charging and over discharging.

When charging, the BMS will stop the charger if any battery reaches critical voltage. When discharging, the modules similarly produce an error but it is up to other systems to use that signal to stop using the batteries. This system is adequate as long as it is used correctly.

Next, the system needs to draw the minimal amount of power. If the modules are drawing excessive power then a nontrivial amount of the battery charge could be constantly lost, even while the vehicle is idle.

The system installed has been shown not to draw any significant amount of power so, on this point, it meets the ideal system.

The BMS should be able to balance the batteries. In order to do this the system needs to be able to bypass a larger current (up to 15A) during charging or put the batteries in parallel during charging.

The system has been shown to only be able to balance batteries that are slightly out of balance. The 1A limit on the bypass is a significant deficiency.

The charging needs to be high in efficacy and efficiency both to store the maximum amount of charge in the batteries and waste as little energy as possible.

The charger has been shown to be quite unsatisfactory in this particular system. Due to artificial limits imposed upon it, it is unable to operate efficiently. The conservative charging voltages also mean that not all of the capacity of the batteries is utilised.

An ideal, but more complex system would be able to measure and log the voltages and states of the batteries. This would be especially helpful in the laboratory environment where measurements are required to be made frequently. This would also allow monitoring of the voltages while under load and driving.

Currently, the system has nothing in place for monitoring.

Compared to the ideal BMS the TS90 system comes up short. However it has succeeded to meet a number of criteria and is certainly adequate for the task. When paired with a more appropriate charger unit, the system would be considered better.

4. SAFETY SYSTEMS

4.1. Process

Safety is an important consideration in this project due to the potential hazards. Extra care must be taken as the vehicle is not limited to a controlled environment such as a laboratory but is to be taken out onto public roads where conditions and events are not always able to be controlled.

This section of this paper covers the specification, design and implementation of safety systems to isolate the battery voltage the rest of the vehicle in an emergency situation and from the motor circuit when hazards are present.

Specification

The main guide for the specification of these systems comes from the National Code of Practice for Light Vehicle Construction and Modification (2006). The first specification is for the master contactor. “A master switch for isolating the power supply to the motor and its control apparatus must be located within easy reach of the driver. The master switch must isolate all electrical connections to the power source.” Also “[safety equipment] must be supplied in preference to the traction circuit” (DEPARTMENT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND LOCAL GOVERNMENT, 2006). So under any failure or power shortage the system must still supply power to the safety equipment such as lights, windscreen wipers and brakes.

Due to the many systems involved in the vehicle, a number of conditions need to be met before the vehicle is rendered safe to drive. These conditions will need to be met before power is made available to the controller and motor circuit. The main conditions considered are;

- Charging cable disconnected
- Brake assist vacuum pump functioning satisfactorily
- Key in and in and turned to ‘on’ position (ignition signal)
- Accelerator pedal engaged (microswitch on the throttle pot box)
- Inertia switch reset (cuts power in case of a crash)

As the care shall be installed with Eyebot microcontroller (BRAUNL, T., 2008) for logging purposes, the errors need to be sent to the Eyebot as well. The Eyebot can take a digital signal up to 5V on the digital IO.

All safety systems should be simple, fault tolerant and failsafe.

Design

The first system is the primary contactor. In order to isolate the batteries from all other systems, a high voltage, high current rated, two-pole contactor with mechanical actuation is to be installed in the cabin. The actuator is a large, red, emergency stop button.

Consideration was given as to the location as it needed to be visible, simple to access by the driver and be connected to the main power rail without adding electrical hazard to the cabin.

The optimal location was found to be in a panel in the centre console, next to the cigarette lighter plug. This allowed for ease of access and the cables can be routed up through the floor without too much trouble. It is also easily visible for anyone attending the vehicle in the event of an accident.

As it is required to maintain power to safety systems at all times, the 12V battery must remain installed to supply these systems even when the main power supply is isolated.

A secondary contactor is installed to cut power to the traction circuit (controller and motor) until all the previously mentioned conditions are met. The contactor has a single input so a system is needed to read the signals from several systems and output a single logical (high/low) 12V signal. The errors also need to be input to the Eyebot microcontroller.

As the error signals are all simple switches and relays, they are simple to use. The only exception to this is the ignition signal, which is just a 12V signal. Most of the error sensors provide two or three wires to connect to. These are a common line, a normally closed line, and, in some, also a normally open line. To utilise the error signals, 12V is applied to a common line and the signal is taken from the normally closed (closed circuit when error is not present, open circuit for error). This gives a 12V logical high as a ‘system okay’ or safe signal.

As the Eyebot cannot handle 12V on the digital IO, a solution is required to provide the error signals at a lower voltage. Voltage divider circuits could have been used but instead, a simple and novel error relay box was designed as it provides a simple solution for both enabling the secondary contactor and relaying the errors to the Eyebot microcontroller.

The design can be seen in Figure 4.1 and is based on a group of double pole, double throw (DPDT) relays.

The DPDT relays allow two isolated circuits to be controlled by the same error signal. Six of the relays are used to control the secondary contactor. The other two are for non-vital errors.

The first pole of the first six relays is connected in series, with 12V on one end and a line to the contactor on the other. This is used to enable the secondary contactor. Only when all six relays close will the contactor close. Unused error signals are connected to power to close those relays.

The second pole of the relays has one side connected to a line that goes to an output from the Eyebot controller kept at a logical high (3.3V or 5V) and the other side connects back to the Eyebot's digital inputs.

The design is fail safe as if any signal wire is broken, it will be open circuit and be treated as an error, disallowing the contactor to close.

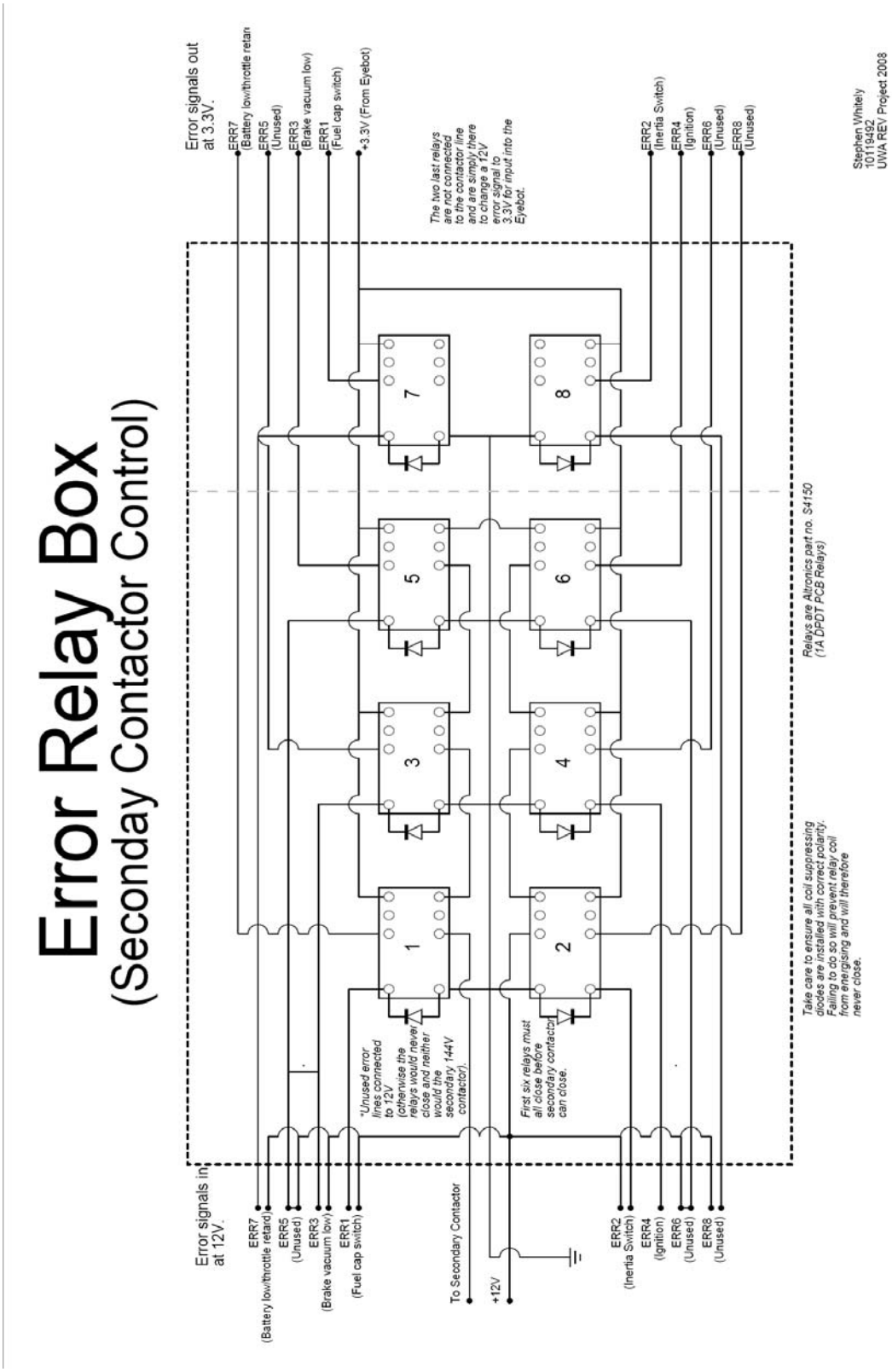

Figure 4.1 Error relay box design

4.2. Results and Discussion

The primary contactor has been installed as designed, as can be seen in Figure 4.2. It is simple to access by the driver and all high voltage connections are fully insulated and

inaccessible. It is also of rugged enough design to withstand frequent use and rough treatment.

Figure 4.2 Main contactor/emergency stop button installed

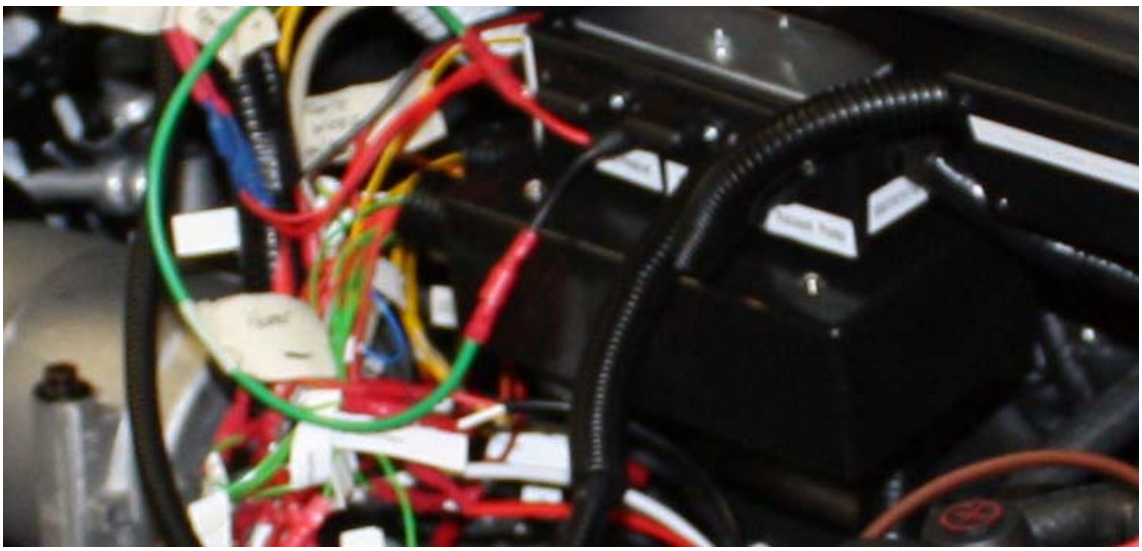

Figure 4.3 - Error relay box prototype installed

The error relay box was also built and installed. Testing shows that failure of any one error signal stops the contactor from closing and all signals giving okay status closes the contactor.

A small change was made in the design to accommodate the vacuum low sensor as it is normally open in the safe state. This means that the brake vacuum sensor will not fail

safely if there is a wire disconnected. This will have to be a temporary fix until an appropriate replacement sensor can be sourced.

In its current state, the error relay box is likely to fail after some time due to the many weak connections in it. By design, any failure is only going to prevent the vehicle from running and not present a safety risk. As a prototype and a proof of concept it works but a better built version will be required in the near future.

Extra relays were designed into the box with the foresight that extra sensors would be added in the future. Some suggested sensors include some to protect the motor such as an over-rev error for when the motor may be spinning too fast when no load is applied, or a neutral gear sensor to prevent the motor from being run unloaded.

5. POWER SUPPLY

5.1. Process

The issue of power supply can first be looked at in regards to each system with three factors;

- What voltage does it require?
- How much current can it draw? (Peak? Constant?)
- When should it be turned on?

Once these questions are answered for each system in the vehicle, an organised approach to arranging the power management can be achieved.

All the main systems in the vehicle run on either the high voltage rail (144V) from the batteries, or the original 12V rail. All the pre-existing systems in the vehicle are already wired, fused and switched, so no changes need to be made with those systems.

Some of the systems have high current draw and special attention needs to be given to ensure they have cables capable of handling the current and that they have appropriate fuses and are not connected in line with devices that could be damaged.

Table 5.1 lists the various systems in the vehicle and their power requirements.

System	Voltage	Current draw	Powered on
Motor and controller	144V	Up to400A	Special
Primary contactor	144V	Up to400A	Manual
Secondary contactor	Both	400A/ ~1A	Special
DC/DC Inverter	Both	6A/55A	Ignition
Vacuum pump and control circuit	12V	8A	Ignition
Error relay box	12V	<1A	Permanent
Eyebot microcontroller	12V	<1A	Permanent
Heater control	12V	<1A	Ignition
Heater	144V	20A?	Special
Power steering control	12V	<1A	Ignition
Power steering	12V	50A	Special
Error signals	12V	<<1A	Permanent

Table 5.1 Individual system power requirements

Once this information is known for each system, an organised plan can be made on how to connect all the systems to power. For example, several 12V systems only require power when the ignition is turned on. To simplify the design, the vacuum pump, heater control and power steering control can all be turned on with a single relay.

From the table, cable requirements can be considered. All cables in the system can use one of the following classes of cables

- High voltage, very high current – 50mm^2 welding cable, up to 500A, 150A continuous
- High voltage, high current – 8AG, 50A
- High voltage, low current – standard 10A
- Low voltage, high current - 8AG, 50A
- Low voltage, moderate current – standard 10A
- Low voltage, low current – standard hook-up, 1A

Note that some cable is suitable for more than one class. Light gauge, multi-cored cables are also suitable for signal wires that do not need to carry much current, however terminal connections must be strong and protection from mechanical wear must be considered.

Armed with this information, a schematic can be drawn up of the electrical systems. Figure 5.1 shows the systems, contactors, relays and fuses. It shows how systems will be connected up to common nodes in the system. The schematic does not, however, take into account the physical location of components and is not an actual physical wiring diagram.

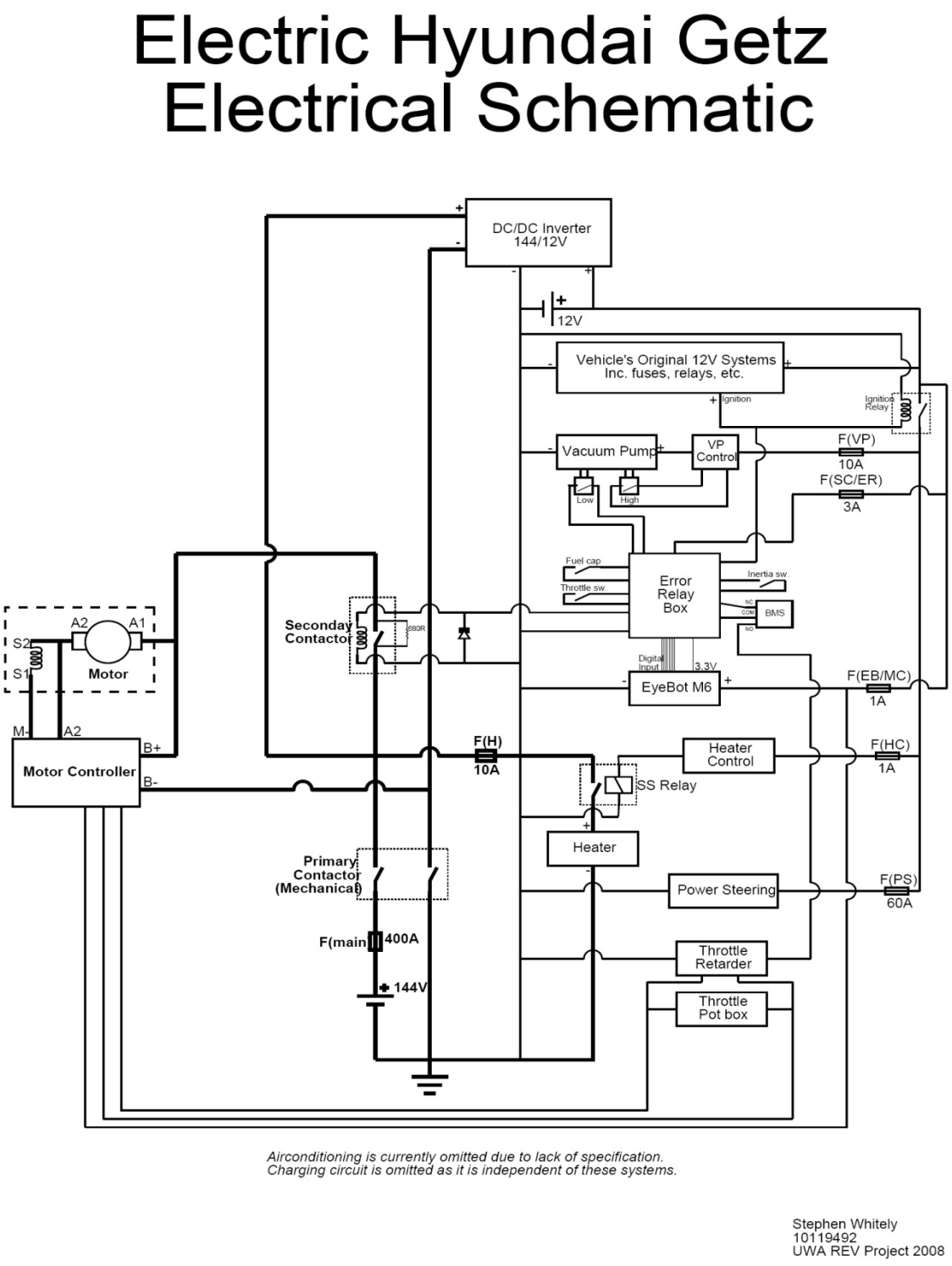

Figure 5.1 Electrical systems

From planning with this diagram, a 12V terminal box was designed. This box provides a central location where the systems connect and all the fuses can be accessed easily. The terminal box is a simple design consisting of three power rails (common ground, 12V permanent on, 12V ignition on), a relay and panel mounted fuses. This greatly simplifies the wiring requirements.

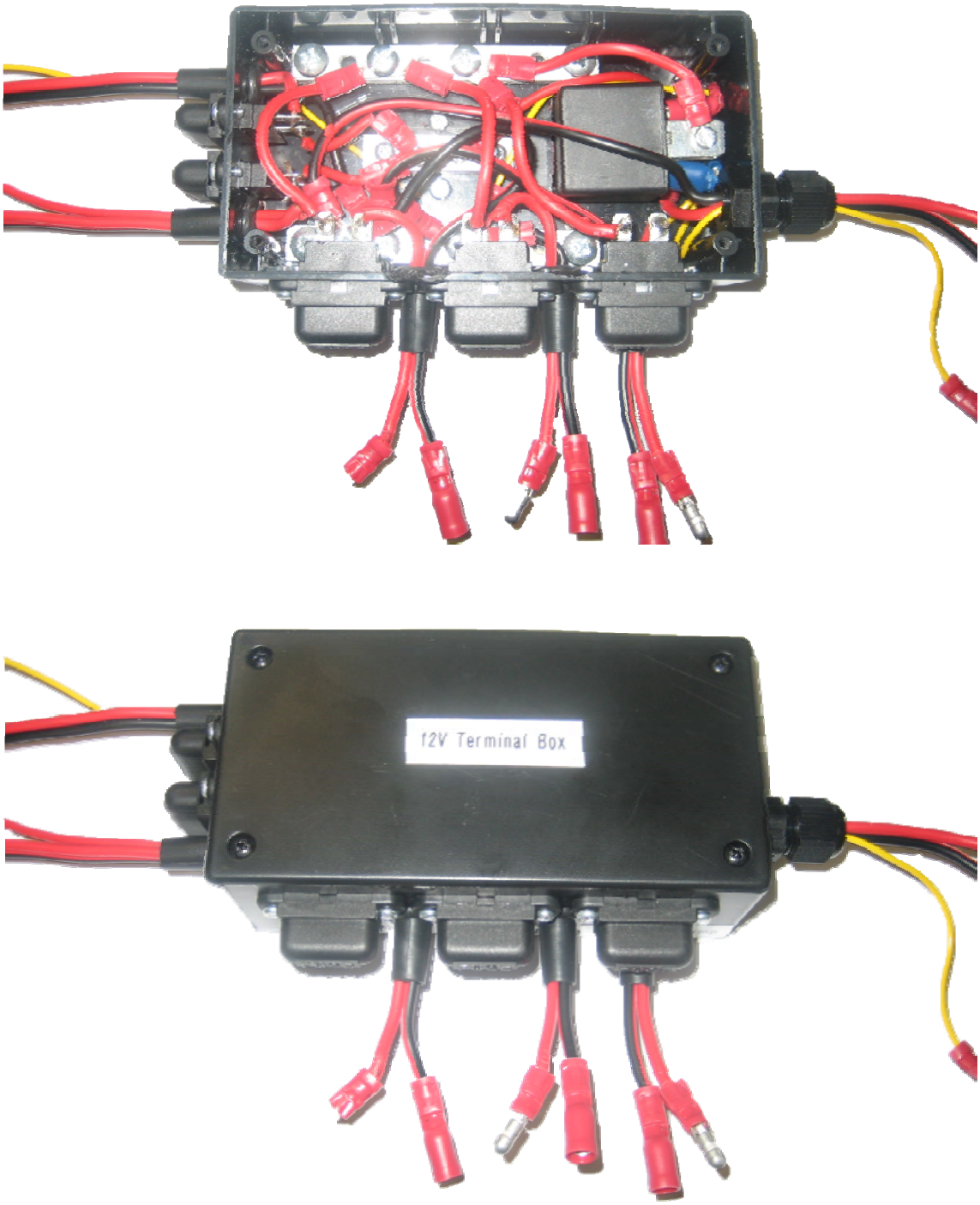

Figure 5.2 12V Terminal box internal (top) closed (bottom)

5.2. Results and Discussion

Using the schematic as a guide, all the systems have been installed into the vehicle. Testing has shown that they all act as expected.

Organised planning has allowed the system to be simplified from what initially seemed complex. By categorising all the power needs, like systems have been grouped to save on cable clutter and redundant replication of components.

As the DC-DC inverter has been found to be able to charge the battery whilst driving without any trouble, a solid-state relay has been connected to it so that it only turns on with the ignition signal.

Standard black split loom has been used to add mechanical protection and some degree of organisation to all the wires. Initially the cabling was in such a mess that a failure was inevitable if something wasn't done.

Figure 5.3 Electric systems installed in the Hyundai Getz

6. CONCLUSIONS AND FUTURE WORK

6.1. Conclusions

At the time of writing, the EV Getz had only just been licensed for legal road use. As such only limited tests were conducted on discharging the batteries and no full cycles have been achieved. In the near future full range and battery cycle tests shall be carried out.

As it stands, the Renewable Energy Vehicle Project has been a success thus far in getting a working electric vehicle on the road that can be shown at expos and trade shows.

The current battery management system was found to be mostly adequate once manual balancing was achieved. In order to complete the balancing, each battery was charged up to 3.9V individually with a power supply. As a one of process, this is acceptable but having to do this regularly would be unacceptable. Since then the batteries have remained balanced but more testing with discharging full cycles is needed.

The only real concern would be to find a more appropriate charger so that the vehicle can be charged at any standard mains outlet and with better efficiency. It is recommended that this be replaced as it does not meet a number of the criteria set down by the REV Project.

The safety systems installed in the vehicle provide protection from high current and dangerous voltages, and ensure safe operation of the vehicle. The systems are fail-safe and designed with room for expansion of extra sensors. The quality of the build on the error relay box is, however, somewhat lacking and could lead to an unnecessary failure of the system.

The power supply part of the project was also completed successfully with all systems onboard the electric Getz able to function properly in a relatively organised system. Most importantly, the organisation makes troubleshooting much easier as the fuses are all centrally located and systems can easily be connected and disconnected.

All up, the project can be considered a successful and productive one. The project goals were met and the REV Project goal or releasing the converted electric vehicle has been realised.

6.2. Future work

There are many tasks to be considered for future work in the REV Project. Next year the group will begin work on converting a Lotus Elise to electric drive. Many things that have been studied this year will come into use with that project and many new issues will arise.

With regards to the battery management systems, much more testing needs to be done with the batteries being put through full discharge cycles and seeing how they cope under load and how they handle the voltage drop under heavy current draw.

There is already a new battery management system being developed outside of the University based on some of the findings and recommendations found during this study. When they are ready, they can be tested. Alternatively, the REV Project could develop its own system for use in the vehicles they convert.

As safety is one of the most important factors in a project like this, it is important to continue to identify and assess hazards.

One potential hazard is the limitation of the isolation from the 144V source. Whilst operating the vehicle this is not a concern as it can be adequately isolated but when working on the batteries in the vehicle, there is an unavoidable exposure to the live 144V source with the current design. A design to split the pack into easily isolatable, safe packs, without direct contact, could improve the safety to those working on the vehicle.

Now that the error relay box has been proven to work, it needs to be rebuilt as the current prototype is messy and not as rugged as it needs to be. The design would be simple to implement etched on to a two-sided PCB and this would allow the removal of many of the fragile wire connections that could potentially fail.

A formal wiring diagram is required for the vehicle. This would include the physical layout of the cables, full documentation of all connectors, wiring colour schemes and guides, troubleshooting guides for maintenance, and more. This would also be an opportunity to better organise the wiring that is currently installed and implement a proper wiring colour scheme so that maintenance would be much easier.

This is just the suggestions that arose from the areas covered in this paper. The REV Project as a whole has a lot future work ahead of it and as it continues to move forward, the scope of the group will grow and advance on to many new fields.

7. REFERENCES

BRAUNL, T. 2008. Eyebot - Online Documentation. [online]. [Accessed 1 November 2008]. Available form World Wide Web: <http://robotics.ee.uwa.edu.au/eyebot/>

BRENIER, A., J. MCDOWALL, and C. MORIN. 2004. A new approach to the qualification of lithium-based battery systems. 26th Annual International Telecommunications Energy Conference, 2004., pp.12-18.

CALWELL, C. and P. OSTENDORP. 2005. 80 plus: a strategy for reducing the inherent environmental impacts of computers. Proceedings of the 2005 IEEE International Symposium on Electronics and the Environment., pp.151-156.

CHANCEY, M. 2008. EV Photo Album: Our Electic Cars on the Web. [online]. [Accessed 21 October 2008]. Available form World Wide Web: <http://www.evalbum.com/>

D'AGOSTINO, S. 1993. The electric car. Potentials, IEEE. 12(1), pp.28-32.

DEPARTMENT OF INFRASTRUCTURE, TRANSPORT, REGIONAL DEVELOPMENT AND LOCAL GOVERNMENT. 2006. Vehicle Standards Bulletin 12, National Code of Practice for Light Vehicle Constructions and Modification, National Guidelines for the Installation of Electric Drives in Motor Vehicles. Australia: Australian Government.

DILKES, R. 2008. EV Power - Australian Electric Vehicle Specialists — EV Power - Australian Electric Vehicles sells Electric Bikes and car conversions, Electric Bicycles, Electric Vehicles, Conversion Kits. [online]. [Accessed 4 October 2008]. Available form World Wide Web: <http://ev-power.com.au/-Thundersky-Battery-Balancing-System-.html>

ELIAS, M. F. M., K. M. NOR, N. A. RAHIM, and A. K. AROF. 2003. Lithium-ion battery charger for high energy appplication. Proceedings, National Power Engineering Conference, 2003., pp.283-288.

GALDI, V., A. PICCOLO, and P. SIANO. 2006. A Fuzzy Based Safe Power Management Algorithm for Energy Storage Systems in Electric Vehicles. In: Vehicle Power and Propulsion Conference, 2006, 2006. IEEE, pp.1-6.

HAIFENG, D., W. XUEZHE, and S. ZECHANG. 2006. Online SOC Estimation of High-power Lithium-ion Batteries Used on HEVs. In: Vehicular Electronics and Safety, 2006. Conference on, 2006. IEEE, pp.342-347.

KEOUN, B. C. 1995. Designing an electric vehicle conversion. In: Southcon/95. Conference Record, 1995., pp.303-308.

KROEZE, R. C. and P. T. KREIN. 2008. Electrical battery model for use in dynamic electric vehicle simulations. In: Power Electronics Specialists Conference, 2008, 2008. IEEE, pp.1336-1342.

MASKEY, M., M. PARTEN, D. VINES, and T. MAXWELL. 1999. An intelligent battery management system for electric and hybrid electric vehicles. IEEE 49th Vehicular Technology Conference. 2, pp.1389-1391.

MCDOWALL, J., A. BRENIER, G. CHAGNON, and J. P. CITTANOVA. 2001. High power lithium ion batteries for a changing telecommunications world. In: Telecommunications Energy Conference, 2001. INTELEC 2001. Twenty-Third International, 2001., pp.187-191.

MOORE, S. W. and G. MACLEAN. 2001. Control and Management Strategies for the Delphi High Power Lithium Battery. 18th International Electric Vehicle Symposium (EVS18), Berlin, Germany. October 2001.

MOORE, S. W. and P. J. SCHNIEDER. 2001. A Review of Cell Equalization Methods for Lithium Ion and Lithium Polymer Battery Systems. SAE 2001 World Congress Technical Papers.

NAUNIN, D. 1996. Electric Vehicles. Industrial Electronics, 1996. ISIE '96., Proceedings of the IEEE International Symposium on. 1, pp.11-24.

OMAN, H. 1994. New electric-vehicle batteries. In: Northcon/94 Conference Record, 1994., pp.326-330.

TEOFILO, V. L., L. V. MERRITT, and R. P. HOLLANDSWORTH. 1997. Advanced lithium ion battery charger. Aerospace and Electronic Systems Magazine, IEEE. 12(11), pp.30-36.

THUNDER SKY. 2007. Thunder Sky Lithium-Ion Power Battery Specifications. Thunder Sky Energy Group Limited.

ZIVAN. 2008. Zivan NG3 Battery Charger. [online]. [Accessed 15 September 2008]. Available form World Wide Web: <http://www.zivanusa.com/NG3BatteryCharger.htm>

8. APPENDICES

8.1. Data from experiment 2

	Date	30-May	5-Jun	6-Jun	9-Jun	13-Jun
	Time	10:00	12:00	10:00	15:00	9:30
Battery #	13	3.317	3.311	3.310	3.309	3.308
	14	3.316	3.309	3.308	3.307	3.306
	15	3.317	3.305	3.308	3.308	3.308
	16	3.313	3.305	3.305	3.303	3.301
	17	3.317	3.311	3.311	3.310	3.309
	18	3.315	3.309	3.309	3.308	3.307
	19	3.315	3.310	3.310	3.308	3.307
	20	3.318	3.311	3.310	3.309	3.308
	21	3.315	3.309	3.309	3.307	3.306
	22	3.317	3.310	3.310	3.309	3.308
	23	3.319	3.312	3.312	3.311	3.310
	24	3.316	3.312	3.311	3.310	3.309
	25	3.316	3.311	3.311	3.310	3.309
	26	3.317	3.312	3.312	3.311	3.309
	27	3.319	3.313	3.312	3.311	3.310
	28	3.319	3.313	3.312	3.311	3.309
	29	3.317	3.310	3.309	3.308	3.307
	30	3.318	3.312	3.312	3.311	3.310
	31	3.317	3.312	3.311	3.310	3.309
	32	3.317	3.311	3.311	3.310	3.309
	33	3.314	3.306	3.306	3.304	3.302
	34	3.319	3.312	3.312	3.311	3.310
	35	3.318	3.312	3.312	3.311	3.309
	36	3.306	3.304	3.304	3.304	3.303
	37	3.317	3.312	3.312	3.310	3.309
	38	3.309	3.307	3.307	3.307	3.306
	39	3.316	3.310	3.310	3.306	3.307
	40	3.317	3.311	3.310	3.309	3.308
	41	3.316	3.309	3.309	3.307	3.306
	42	3.317	3.310	3.310	3.308	3.307
	43	3.316	3.311	3.311	3.310	3.309
	44	3.313	3.309	3.309	3.308	3.307
	45	3.317	3.311	3.311	3.310	3.309
	46	3.318	3.312	3.311	3.310	3.309
	47	3.318	3.312	3.311	3.310	3.309
	48	3.318	3.311	3.310	3.309	3.308
	49	3.315	3.309	3.309	3.307	3.306
	50	3.313	3.309	3.309	3.308	3.307
	51	3.316	3.310	3.310	3.308	3.307
	52	3.319	3.311	3.311	3.310	3.309
	53	3.319	3.313	3.312	3.311	3.310
	54	3.319	3.312	3.311	3.310	3.309
	55	3.317	3.311	3.311	3.310	3.309
	56	3.317	3.311	3.311	3.310	3.309
	57	3.316	3.311	3.310	3.309	3.308
	Avg.	3.316	3.310	3.310	3.309	3.308

8.2. Data from experiment 3

	08-Jul 11:30	08-Jul 15:30	09-Jul 12:00	09-Jul 15:45	11-Jul 11:00	14-Jul 11:30	15-Jul 12:00	21-Jul 11:00	22-Jul 11:00	24-Jul 11:00	25-Jul 11:00
13	3.367	3.781	3.404	3.790	3.389	3.357	3.791	3.395	3.374	3.747	3.430
14	3.363	3.754	3.390	3.774	3.380	3.353	3.778	3.389	3.039	3.741	3.422
15	3.364	3.695	3.390	3.754	3.382	3.356	3.756	3.393	3.373	3.733	3.425
16	3.357	3.436	3.363	3.425	3.357	3.349	3.399	3.359	3.353	3.317	3.375
17	3.367	3.779	3.412	3.796	3.397	3.359	3.797	3.401	3.378	3.755	3.445
18	3.365	3.757	3.395	3.769	3.382	3.355	3.770	3.389	3.370	3.732	3.420
19	3.366	3.747	3.395	3.762	3.383	3.355	3.756	3.391	3.372	3.725	3.421
20	3.364	3.569	3.387	3.672	3.379	3.356	3.693	3.390	3.372	3.689	3.422
21	3.362	3.514	3.381	3.569	3.372	3.353	3.613	3.380	3.366	3.642	3.411
22	3.365	3.730	3.394	3.771	3.386	3.356	3.778	3.395	3.374	3.743	3.431
23	3.361	3.485	3.380	3.524	3.374	3.355	3.541	3.383	3.369	3.557	3.414
24	3.360	3.424	3.368	3.417	3.364	3.352	3.411	3.369	3.361	3.416	3.420
25	3.365	3.720	3.403	3.781	3.397	3.360	3.789	3.404	3.381	3.751	3.449
26	3.367	3.783	3.418	3.799	3.403	3.362	3.799	3.408	3.383	3.762	3.462
27	3.361	3.466	3.378	3.497	3.374	3.354	3.577	3.386	3.371	3.648	3.415
28	3.410	3.837	3.496	3.774	3.398	3.359	3.808	3.399	3.378	3.758	3.440
29	3.363	3.723	3.387	3.756	3.378	3.354	3.757	3.387	3.368	3.729	3.417
30	3.388	3.829	3.494	3.626	3.397	3.361	3.793	3.424	3.390	3.820	3.644
31	3.367	3.754	3.411	3.789	3.399	3.361	3.792	3.406	3.382	3.754	3.452
32	3.365	3.661	3.396	3.749	3.387	3.358	3.762	3.398	3.377	3.741	3.434
33	3.324	3.352	3.326	3.345	3.319	3.311	3.329	3.337	3.355	3.383	3.415
34	3.405	3.829	3.485	3.749	3.396	3.360	3.802	3.399	3.378	3.755	3.435
35	3.361	3.440	3.375	3.446	3.371	3.355	3.446	3.378	3.367	3.461	3.420
36	3.354	3.371	3.357	3.367	3.353	3.349	3.362	3.353	3.351	3.410	3.405
37	3.359	3.432	3.370	3.433	3.366	3.352	3.432	3.373	3.363	3.445	3.416
38	3.357	3.381	3.359	3.374	3.354	3.350	3.367	3.354	3.378	3.444	3.406
39	3.365	3.763	3.397	3.789	3.386	3.356	3.785	3.394	3.373	3.748	3.431
40	3.463	3.848	3.568	3.805	3.409	3.361	3.818	3.404	3.379	3.764	3.456
41	3.361	3.706	3.383	3.738	3.376	3.353	3.738	3.384	3.367	3.717	3.411
42	3.364	3.734	3.392	3.763	3.381	3.354	3.773	3.389	3.370	3.738	3.421
43	3.362	3.513	3.383	3.597	3.379	3.356	3.676	3.393	3.375	3.702	3.429
44	3.360	3.437	3.369	3.432	3.364	3.352	3.420	3.368	3.404	3.754	3.437
45	3.370	3.781	3.414	3.787	3.399	3.361	3.790	3.404	3.381	3.750	3.444
46	3.388	3.801	3.434	3.773	3.394	3.357	3.805	3.395	3.375	3.756	3.433
47	3.364	3.659	3.393	3.762	3.388	3.358	3.781	3.398	3.376	3.750	3.440
48	3.365	3.759	3.398	3.780	3.388	3.357	3.785	3.395	3.374	3.746	3.431
49	3.363	3.708	3.390	3.743	3.379	3.354	3.753	3.387	3.368	3.730	3.416
50	3.361	3.436	3.371	3.432	3.367	3.353	3.424	3.371	3.409	3.745	3.441
51	3.367	3.742	3.410	3.766	3.389	3.356	3.788	3.393	3.371	3.749	3.431
52	3.431	3.843	3.514	3.814	3.408	3.361	3.817	3.403	3.378	3.770	3.458
53	3.360	3.442	3.373	3.448	3.369	3.353	3.467	3.379	3.368	3.511	3.412
54	3.366	3.776	3.415	3.792	3.399	3.360	3.798	3.402	3.379	3.755	3.449
55	3.367	3.778	3.419	3.794	3.402	3.361	3.802	3.408	3.382	3.772	3.476
56	3.366	3.636	3.396	3.739	3.391	3.360	3.774	3.407	3.388	3.777	3.485
57	3.364	3.719	3.397	3.777	3.389	3.357	3.789	3.397	3.375	3.771	3.437
Average	3.369	3.652	3.403	3.668	3.382	3.355	3.682	3.389	3.367	3.681	3.435
StDev	0.0214	0.1566	0.0445	0.1559	0.0170	0.0076	0.1609	0.0167	0.0511	0.1298	0.0374
Min	3.324	3.352	3.326	3.345	3.319	3.311	3.329	3.337	3.039	3.317	3.375
Max	3.463	3.848	3.568	3.814	3.409	3.362	3.818	3.424	3.409	3.82	3.644
Spread	0.139	0.496	0.242	0.469	0.090	0.051	0.489	0.087	0.370	0.503	0.269

8.3. Safe Installation Guide for Batteries

This guide is included as a reference for future members of the REV Project. It is a guide to installing the batteries and battery management systems, specific to the Hyundai Getz electric conversion, 2008.

Instruction and Safety Guide on the Installation of Batteries in the Hyundai Getz EV

Stephen Whitely 10119492

This is a guide to assist in the safe and efficient installation of the batteries into the vehicle. It should be remembered at all times that you are working with potentially dangerous voltages and very high current, and as such all precaution should be taken. **Shorting the batteries could cause irreparable damage to both the batteries and your person**. It is advised that the installation of the batteries be done with at least one other person present. Any connection at a higher voltage (greater than 30V) should be done by, or under supervision, a technician or other qualified electrician.

1. Before you begin check that you have all the components;
   • 45 Thundersky Li-Ion 90Ah batteries,
   • 45 battery management modules,
   • 44 copper connecting straps
   • 90 bolts, flat washers and spring washers
   You will also need some tools;
   • open end spanner M8
   • ring spanner M8
   • if available, a torque wrench
   It is advised that you insulate all metal tools to avoid shorting across the batteries. This can simply be done by wrapping the tool in electrical tape or other insulator for the length of the tool.

2. First test the batteries. This can be done with a multimeter or with the battery management modules. To test with the battery management modules the **end of the module with the red circle goes on the positive terminal** of the battery (indicated by a red circle around the terminal) and the other end goes onto the negative terminal. When properly connected to the battery the module should light up its green LED. If the red LED lights up then the battery is giving a low voltage. This could be because of a problem with the battery or simply a low state of charge. Any batteries that fail should be checked and tested before continuing.

3. Install the battery cage and check that the bolts are all correctly tightened. The charger and the mounting space of the battery management etc. should be on the left hand side of the car, near the fuel cap. Check that the power cables and any other wiring are situated such that they will still be accessible after the batteries are installed. Ensure that the floor of the battery cage is in place.

4. Install the Zivan charger before the batteries as the mounting bolts will be difficult to access after the batteries are installed. It should be installed so that the terminals for charging are facing upwards.

5. For ease of installation, the left and right-most 'columns' of batteries should be installed first as they are under an overhanging lip on the cage. Likewise, it may be simpler to install the top and bottom batteries of each 'column' before filling the column.
   Extreme care should be taken when installing the batteries to avoiding shorting the terminals on the cage. Have the positive terminal insulated with tape whilst installing the batteries. It is also suggested to insulate the cage along the top edges where contact may be likely.
   Install the two 'columns' of batteries as shown in **Error! Reference source not found.**.
   Important – take note of the **numbering and orientation** of the batteries. The numbers shown in the figure represent the last two digits of the serial number printed on the battery. Keeping them in order will make testing and documentation much simpler.
   The '+' and '-' signs on the batteries indicate the positive and negative terminals. **The positive terminals are indicated by a red ring around the terminal. Incorrect orientation and connection could lead to battery damage – make sure they are laid out as in the figures.**

+ 13 -						+ 19 -
- 20 +						- 26 +
+ 27 -						+ 33 -
						- 39 +
						+ 45 -
						- 51 +
						+ 57 -

Figure 1 - First batteries to install. Note battery numbering and orientation

6. Should there be any movement when the batteries are packed in, a sheet of rubber or similar can be installed along the wall to pack the batteries tight. This will avoid vibration that could lead to physical wear of the batteries.

7. Install the remaining batteries into the cage as shown in **Error! Reference source not found.** remembering to take care in noting **numbering and orientation** and avoid shorting the terminals on the cage.

+ 13 -	+ 14 -	+ 15 -	+ 16 -	+ 17 -	+ 18 -	+ 19 -
- 20 +	- 21 +	- 22 +	- 23 +	- 24 +	- 25 +	- 26 +
+ 27 -	+ 28 -	+ 29 -	+ 30 -	+ 31 -	+ 32 -	+ 33 -
	- 34 +	- 35 +	- 36 +	- 37 +	- 38 +	- 39 +
	+ 40 -	+ 41 -	+ 42 -	+ 43 -	+ 44 -	+ 45 -
	- 46 +	- 47 +	- 48 +	- 49 +	- 50 +	- 51 +
	+ 52 -	+ 53 -	+ 54 -	+ 55 -	+ 56 -	+ 57 -

Figure 2 -Install remaining batteries

8. The next step is to install the battery management modules and some, **not all**, of the copper connecting straps. Again, the idea is to work in columns, as in **Error! Reference source not found.**. This makes each of the larger columns approximately 24V and relatively safe.
   The components should be stacked on the terminals in the following order, from bottom (first) to top (last);
   • battery management module
   • copper connecting strap
   • flat washer
   •spring washer
   • bolt
   Remember that the **end of the battery module with the red circle goes on the positive terminal** of the battery (indicated by a red circle around the terminal) and the other end goes onto the negative terminal. The module should light up green. If the module lights up red, remove the battery and test it before continuing.
   The small leads on the modules do not have to be connected at this stage but if they are not then they should be insulated to avoid damage to the modules.
   Install only the copper connecting straps indicated in Error! Reference source not found.. Be very careful not to short any batteries by dropping the connecting straps across the terminals of a battery.
   The bolt should be tightened just enough to flatten the spring washer. If a torque wrench is available, do one bolt up to the desired tension then set the torque wrench to that tension and use it to tighten the others. Some may be difficult to reach so use an open end spanner.

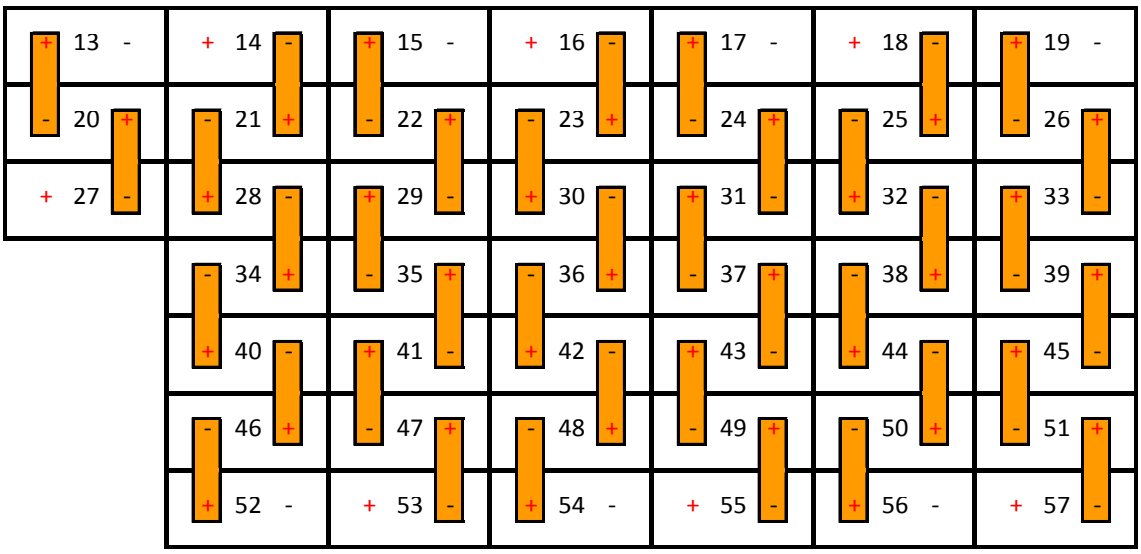

Figure 3 -Connect only the straps indicated first

The next step required the supervision of a technician as it involves hazardous voltage. After inspection, have the technician, or under technician supervision, attach the remaining copper connecting straps. Once connected there will be 144V so care should be taken.

9. Ensure the cables are open circuit (disengage safety/remove fuse) and install the power leads and charging leads. The positive (red) cables should be connected to positive terminal on battery ’27, on the left hand side. The negative or ground (black) cables should be connected to the negative terminal on battery ’19, in the forward right hand corner.

10. Finally, if not already connected, join the battery management module leads in series and install and connect the battery management box.

11. Connect up the charger and battery management. Installation is now complete. The batteries are now ready to receive their first charge.