Distributed Battery Management System (BMS) Design, Optimisation, and System Integration for an Electric Solar Vehicle

Final Report - Final Year Research Project (ENG40002)

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Abstract

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I. Introduction

The field of Solar Powered Electric Vehicles (SPEV) is a steadily growing industry, offering a renewable alternative to conventionally powered vehicles.

As the technology has grown over the past half a century, so has to the complexity of the vehicles. Solar cars typically make use of a battery system as a buffer for periods of low solar activity. As more energy dense battery technology has been introduced, predominantly with a lithium ion based chemistry, there has been a need to monitor the health and safety of the pack.

Poorly maintained lithium ion cells have a tendency to develop crystalline structures at low battery voltages, which is dense cylindrical cells pierces the membranes separating layers, leading to a uncontrollable short circuit condition, resulting in fires [1]. Lithium cells are also sensitive to over temperature, usually resulting from higher than allowable continuous discharging; in many Lithium Iron Phosphate (LFP) based 18650 sized cells, as little as a 5C discharge rate over the course of several hours resulting in an uncontrollable thermal runaway state, usually resulting in fire. Over voltage cells also pose a risk to batteries, typically resulting in fire as well. As such there is a requirement for a system that can monitor the safety of each of these cells, and ensure that there is not risk posed to occupants of the vehicle.

A Battery Management System (BMS) is typically used to perform this vital task. A BMS monitors the state of charge of the battery pack (*Accumulator*), relaying the voltage and temperature of each cell to a controller, providing a way to shut off the accumulator in case of failure. This usually incorporates some form of meaningful feedback, such as the state of charge of the accumualor. A good BMS typically also integrates a solution to equalise or balance each series unit of the accumulator to maximise run time, usually achieved through the use of passive bleed resistors that discharge cells until they are equal, or with the use of an active balancing system which is able to redistribute a cell's excess energy throughout the pack.

The project aims to design an actively balancing battery management system, and the larger electrical architecture of a potential solar car vehicle developed by Swinburne University for the Cruiser Class of the World Solar Challenge. The BMS will feature a distributed architecture, whereby more BMS modules can be added with a single interface to a centralised ECU. In order to optimise capacity of the pack, the use of an active balance system shall be explored. The BMS design must also accommodate the use of a MPPT (Maximum Power Point Tracking) charger, a standard Type 2 electric vehicle charger, be able to negotiate the maximum discharge current with the throttle and motor controller system, and provide a discharge and precharge mechanism to avoid damage to the inverter. All of these features must integrate into the vehicle's control and management systems.

A. World Solar Car Challenge Background

Since 1987, the World Solar Challenge (WSC) has provided a platform for universities and corporations to fuel the development of solar vehicles. The competition runs over seven days, with vehicles crossing the 3022 kilometre long road between Darwin and Adelaide [2].

There are two competitive classes of vehicles in the competition; Challenger Class - small lightweight single pilot vehicles which evoke the typical image of the solar challenge, and the Cruiser Class a more practical, consumer focused offering, for vehicles with 2-4 seats. There is a third additional class, Adventurer offered for entries that meet safety requirements, however not the constraints of the Challenger or Cruiser class, as a non-scored event. The Swinburne Solar Team (SST) aimed to produce a vehicle in the Cruiser class, and as such, this project will focus on the regulations surrounding this requirement.

The cruiser class allows for the use of Type 2 vehicle chargers at controlled points on the road between Darwin and Adelaide (Currently at Tennant Creek, NT, and Coober Peedy, SA), with regulations as to what hours the vehicles may charge. The chemistry of these packs affects the total points penalty incurred by the accumulator size, a smaller accumulator being favourable. *There is no restriction as to the size of the accumulator in the Cruiser class.* Additionally, the more energy that is fed into the pack by means of these stationary chargers rather than solar, the greater the penalty at the end of the race; as such, energy conservation is a priority.

The rules for the competition are available from the following URL: https://www.worldsolarchallenge.org/the-challenge/regulations [3].

B. Task Allocation

The scope of the project was split evenly amongst the two project members. All other sections of this report were developed in tandem. These roles will translate into the development phase of the BMS system, with the expertise and leanings being applied directly on the final product.

The following sections are handled by Ethan Suter:

- Section II-A: Conventional Cell Monitoring Methodologies
- Section II-B: State of Charge Calculation
- Section II-E: Active versus Passive Cell Balancing
- Section II-F: Driver and Vehicle Feedback Mechanisms

The following sections are handled by Patrick Curtain:

- Section II-C: BMS Architecture and Scaleability
- Section II-D: Solar and EV Charger Integration
- Section III: Methodology

C. Available Market Solutions

There are many already existing BMS solutions already available on the market. The majority of these solutions are designed mainly for various lithium-ion and lithium-polymer cell chemistries, due to the widespread prominence of these types of cells across a wide spectrum from the automobile and power generation industries to personal hobby use.

This projects differentiate itself by providing a significantly wider cell voltage range, an active balancing system, and a more modular system that will scale as the Swinburne Solar Car project evolves.

II. Literature Review

A. Conventional Cell Monitoring Methodologies

The main functions of a BMS are dependant on its ability to monitor certain characteristics of the cell under its care. Given the measured capacity and discharge characteristics of a cell, a state of charge (herein abbreviated with SoC) scale can be decided upon to determine the maximum desired level of charge and the lowest desired depth of discharge that the cell will experience. As explained in the introduction, poorly maintained lithium-based cells that are allowed to overcharge or over-discharge beyond their typical operating range can cause irreversible chemical damage and affect the capacity, performance, reliability and safety of the cell.

Different types of cells/chemistries offer different methods of monitoring and calculation of properties such as State of Charge. The most accurate method possible for cells with a liquid electrolyte (e.g. Lithium variants, Lead Acid) is to measure the pH of the electrolyte since that is directly linked to the amount of potential energy present in the cell. Unfortunately lithium chemistries are too delicate and volatile to allow for such an invasive method of monitoring. More robust chemistries such as Lead Acid that can be left unsealed prove more conducive to this method. As such, non-invasive methods of cell monitoring have to be employed.

Conventional methods of monitoring lithium cells utilise the electrically measurable characteristics of the cell. The internal resistance of the cell can help determine its overall health, as well as its ability to supply high amounts of current. The open circuit voltage across the cell's terminals can be used as a crude method of estimating SoC. The voltage across the cell while under load can be used to infer how well the cell is coping with the given load and whether it should normally operate under those conditions. The current being drawn from the cell can be used to determine how much load the cell is under.

Monitoring the temperature of the cell is of particular importance. The electrolyte inside a lithium cell is quite sensitive to temperature. Too cold and the electrolyte starts to become viscous, lowering its chemical reactivity and affecting its output ability [4]. Too hot and many chemical changes can occur in the electrolyte that cause degradation in performance over time, such as an increase in internal resistance which makes the cell less efficient. Using a heating and cooling system to maintain a window of optimal operating temperature for lithium cells is critical to their safe, effective use and their longevity.

B. State of Charge Calculation

There are various ways to calculate the state of charge of the accumulator. The simplest method that is fairly ubiquitous across many low power BMS designs is Voltage monitoring. The voltage measured across a lithium cell's terminals can be described as a function of the state of charge. The graph below illustrates what that relationship looks like.

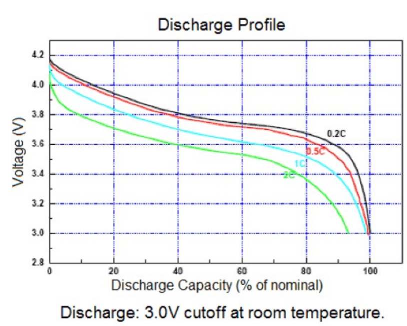


Fig. 1: The Voltage vs SoC graph aka Discharge Curve for a typical Li-Ion cell [5]

The main problem with this approach is that the voltage of a cell at any given SoC can vary greatly from what has been measured on its discharge curve. Factors such as cell temperature and the current being drawn from the cell (the different curves on the above graph are for different discharge currents) can cause the voltage to dip below what would normally be measured - a phenomenon known as *Voltage Sag*. For small scale and very low power draw scenarios, this problem is a nonissue and plenty of small scale, battery-powered embedded systems use Voltage monitoring for tracking SoC.

The second conventional method to calculate state of charge is current integration, also know as coulomb counting. The current being delivered to or supplied by the cell is measured, and integrating that over time gives the total amount of charge remaining in the cell in amp-hours or coulombs. This is a more complex approach than voltage monitoring since it requires some kind of system with memory to store and update the charge level of the cell on an ongoing basis.

There are two downsides to this method. The first one is that there is no absolute reference point for such a system. Over time, a pure coulomb counting system will drift above or below the cell's actual SoC and could lead to problems for the BMS. The second problem is that this system cannot account for inefficiencies in the cell. Say a cell is experiencing a high current draw, and thus due to having a small internal resistance is losing some energy in the form of heat as it supplies power. Coulomb counting is only monitoring the charge that ends up being delivered to the power sink, and does not see the energy/charge lost from heat. So if a cell experiences high power draw and heats up, it's losing more charge than a coulomb counting BMS recognises, possibly leading to the BMS allowing a lower depth of discharge than should otherwise be permitted in normal operating conditions.

In practice it is frequently seen that a combination and/or variation of these two methods is employed in many BMS designs. While using multiple methods in tandem further increases complexity it also addresses most of the shortcomings of both systems. The utilisation of these balancing methods in the design of the BMS controller will be considered, as well as the exploration of non-conventional and/or emerging methods of monitoring.

C. BMS Architecture and Scaleability

There are three traditional ways that a BMS is structured; centralised, whereby leads run between cells and a centralised measurement unit, and decentralised, where the BMS units are individualised to each stack. A subcategory of this decentralised unit is the modular architecture, whereby only measurement is segregated is distributed throughout the pack, a communication system linking these to a centralised management unit (CMU) [6]. Devices such as the well regarded and common Orion BMS series of BMS by Ewert are an example of a centralised BMS [7].

1) Modular Stacks

For safety reasons, a well designed accumulator will break up the accumulator into *stacks*, smaller series units that will be connected with a removable interconnect. This is done for several reasons; it allows for the isolation of faults, should a fault be detected in a stack, it can be disconnect quickly and potentially bypassed; it also ensures that those servicing the accumulator are exposed to less lethal voltages, with stacks typically having a maximum voltage under 60V. This can also be done for storage reasons, it may be necessary to stow cells in unusual places throughout the vehicle.

We can see a good example of a custom battery management solution developed for an electric motor bike that makes use of a system similar to the proposed architecture, see Figure 2. This report proposes using multiple LMU (Local Measurement Units) connected via an isolated interface to the CMU (Centralised Management Unit). This simplifies the complexity of the control interface, and allows the accumulator to be split throughout the small form factor required.

2) BMS ASICs

Large IC development companies design ASIC (Application Specific Integrated Circuits) for many different cell measurement, the most popular of these being the LTC68xx series by linear technologies. These typically feature multiple cell measurement inputs, a way to control the discharge system, and a communication interface. Alternatives to the LTC68xx series include the ATA6870 by Atmel, AD7280A by Analog (Parent Company of Linear Technologies), or the MAX11068 (Maxim now being a child company of Analog Devices) [8].

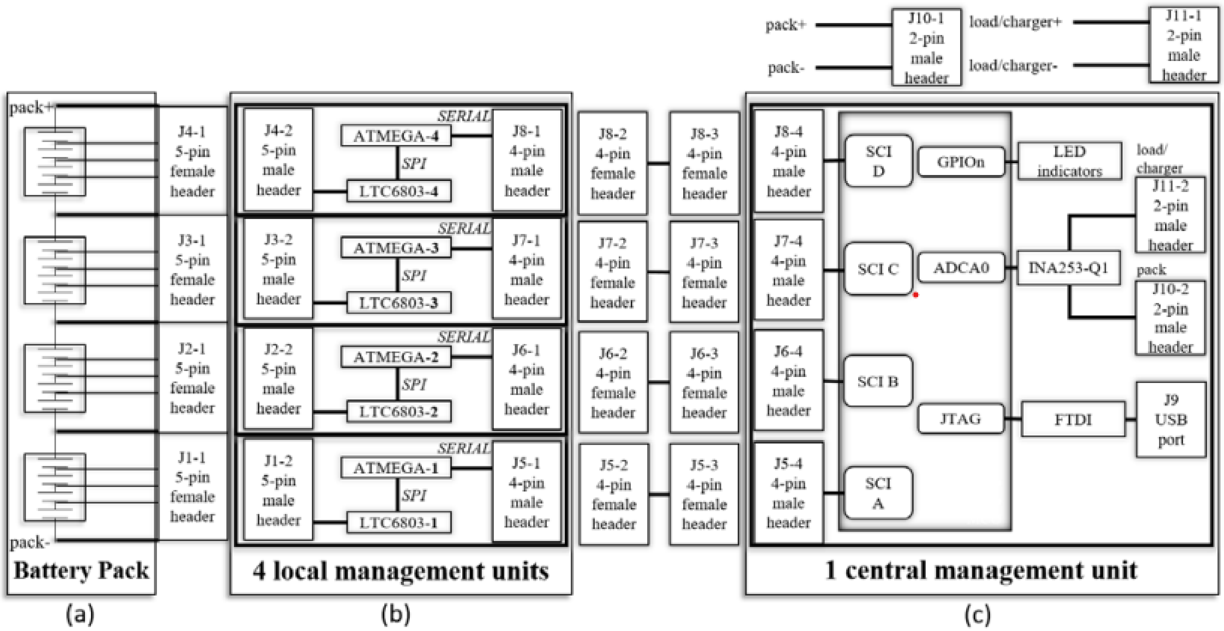


Fig. 2: The BMS system Designed by Henar, Cailang, Caliwag, and Wansu [6].

To focus on the LTC6811 IC, this ASIC makes use of an integrated ISO-SPI interface; a serialised, differential pair, version of SPI that uses galvanically isolated transformers to bridge the gap between stacks [9]. This is important as within the accumulator, there are high voltage potentials that pose a risk to life. This also features a daisy chain interface that allows for multiple ICs to behave as a single unit.

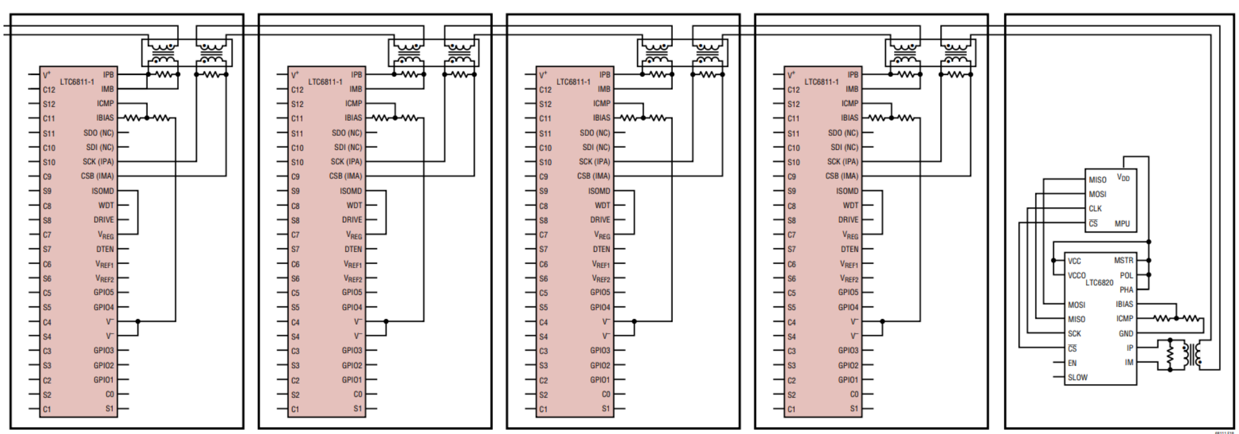


Fig. 3: The suggested daisy chain (Series) network of an LTC6811 BMS ASIC.

Using an ASIC BMS has several key advantages and disadvantages:

- They provide an integrated solution to the issue at hand, and offer a single interface with minimal external circuitry [8].
- As they are ASIC, there should not be a need to program these devices.
- They are typically more complex than using an ADC based or analogue BMS. With unusually usually poorly documented communication protocols usually reserved for B2B (Business to Business) projects [9], [8].

In any case of the BMS method, a master and slave architecture to that described by Figure 3 will likely be used.

D. Solar and EV Charger Integration

The battery this BMS will be fitted to will have three charging methods; the EVSE conventional charger, the solar charging array and MPPT, and the active balancing system, a form of charging. Each of these function exclusive to each other; the flow of current this must be controlled.

Some vehicles on the market such as PHEV (Plug-in Hybrid Electric Vehicle) make sure of further energy buffering. A 2017 project by Toyota to develop a solar assisted hybrid Prius integrated a secondary battery that would be charged during phases where the hybrid power train was active, preventing the additional waste made by DC-DC converter further in the powertrain system. A simple relay being used to disconnect this mechanism [10].

1) Vehicle Charge System (EVSE)

EVSE (Electric Vehicle Supply Equipment) is the technical term for what the lay would consider a ”charger”. These are in fact not actually a charger, but rather the charger and rectifier are kept internal to the vehicle and this station simply provides a source of electricity for this charger [11].

The competition rules (Section 2.5.19) require that all Cruiser Class vehicles fit the following:

”...an on-board ac charger with an IEC 62196-2 Type 2 (male) charging inlet and be capable of charging from a single-phase ac supply (230 Vac, +10%, -6%, 50 Hz). The ac current draw must not exceed the limit indicated by the J1772 pilot signal generated by the event organiser’s Electric Vehicle supply Equipment (EVSE), which will allow charging rates up to 30 A.”

There are several things to unpack from this requirement.

1) IEC 62196 Type 2 (Male) is the requirement for the socket and pin-out. Developed by the International Electrotechnical Commission, this features 7 contacts, 2 for signalling, a protective earth, a neutral pin, and three live contacts, pictured in Figure 4.
2) J1772 is a signalling system that is used to control the most EV chargers. It uses a simple two wire system to indicate how much current the system can accept, and if there is a vehicle present.
3) A type 2 charger is any that is able to support multiple phases, Type 2 being more common in Europe and Australia [12], however as noted, this should also support a single phase connection.

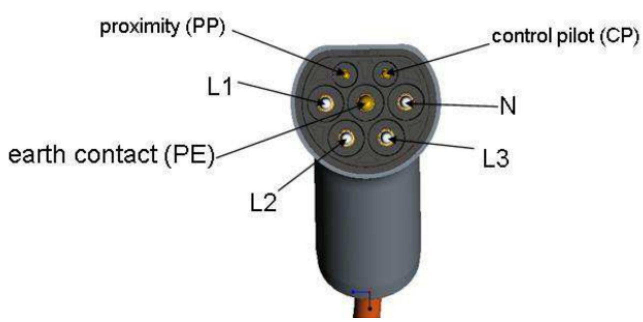


Fig. 4: Pinout of the IEC 62196 Type 2 Connector [13].

The J1772 is an SAE standard, and one of the most common signalling systems used to control the charging system in electric vehicles [12]. There are other standards defined by the SAE, that allow the connection of an off board DC charger such as J2847/2, and some that allow the vehicle to function as an off grid energy reserve such as J2847/3 [11].

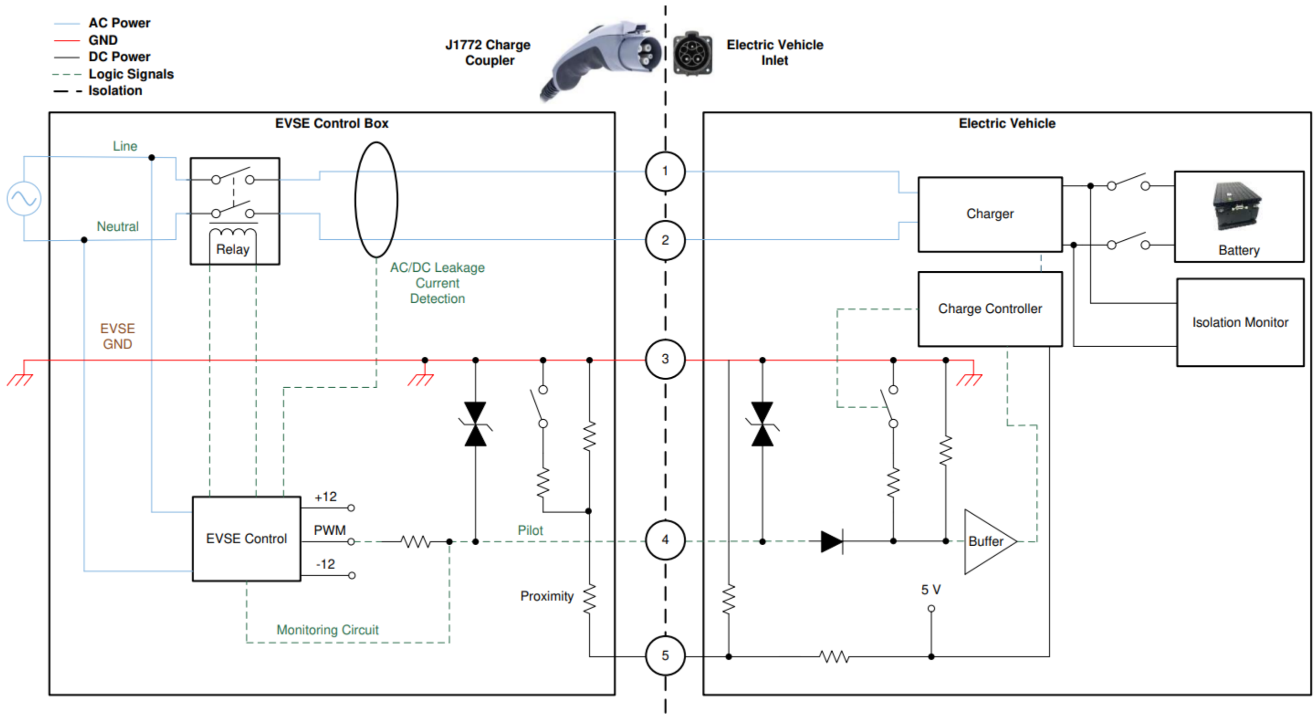


Fig. 5: A circuit diagram of the SAE J1772 interface requirement. The right half being relevant to the project [14].

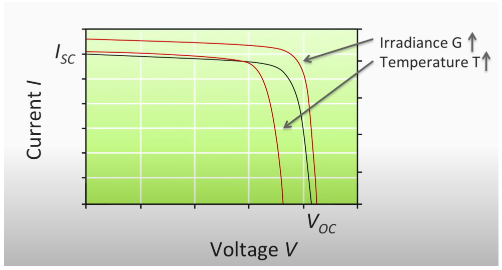
There are two pins used in a J1772 system; the control pilot, and proximity pilot. The proximity pilot is a passive circuit that acts as the safety interlock for the vehicle, using a simple resistor as the feedback mechanism to tell if a vehicle is attached. The control pilot uses a PWM signal to direct the charger as to what is available. The proximity pilot is designed to act as the physical interlock for the vehicle, usually locking the vehicle in ”Park” if detected, preventing damage to the outlet [14] [11].

2) Solar Charge System

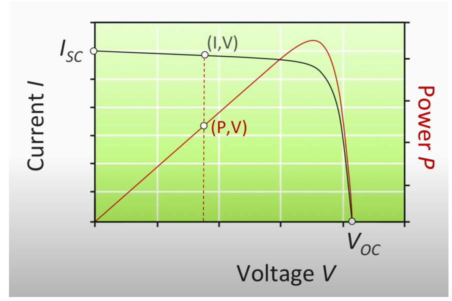
Photovoltaic cells do not produce a consistent power output, the output of which varying based on the configuration of the cells (Series and parallel units), the temperature of the cell (Which may also be influenced by any cooling effects from air flow and shaded regions), the solar intensity, and countless other factors. There must be done form of regulation in order to achieve a usable output. There are typically two methods to achieve this, a simple solar regulator, usually using some form of PWM control for the output and MPPT.

MPPT (Maximum Power Point Tracking) is a technology used to maximise the output of a solar array; it is a form of DC-DC converter, that relates voltage and current to maximise power. It is able to track the optimal voltage and current relationship in order to extract the highest possible power level from the solar array.

Solar cells are interesting in how they work; they have a typical cell voltage, however one should note that the open circuit voltage will always be higher than one under load; in this way they behave like a non-Ohmic current source. Stringing together PV cells in series increases the maximum voltage array voltage, and in parallel, the maximum discharge current. In very simple terms, An MPPT relates the voltage and current, adjusting the output voltage of the DC-DC converter relative to the required charge voltage, such that it is always drawing the highest amount of power from the panel.



(a) A standard IV curve changes depending on the environment.



(b) A PV curve, based on the IV curve..

Fig. 6: A power curve (Also called a PV Curve) can be super imposed over the I-V curve by using the power relationship $P = VI$. Any point on the IV curve can be found on the PV curve. An MPPT algorithm finds the point of inflection of the PV curve, and uses this value to find the required discharge current by varying the output voltage. Images sourced from TU Delft [15].

If we consider the anatomy of a solar vehicle, the solar cells will be affected by various conditions; cells on the front of the vehicle are subject to greater air flow, and will typically be cooler than those in the rear. In the case of a solar car travelling north-south, one half of the vehicle will be in shade for many hours of the day. This affects the way in which the MPPT system will behave, and as such there are many SPEVs that utilise multiple MPPT, managed by a centralised control plane. These feature a buck-boost DC-DC converter to control the output, such that they can be part of the same system [16]. This multi MPPT system has two advantages, the MPPT does not need to have as high of a current rating since this load is shared, and the output power can be better managed.

Much of how these MPPT behaves is invisible to the operator; it is a black box. These controllers track this point of inflection typically by using some form of fuzzy logic or analogue means to perform the required calculation [17].

It may be necessary to use a DC-DC converter after the MPPT to boost the output MPPT voltage to the DC-DC converter, depending on which MPPT unit is selected.

E. Active versus Passive Cell Balancing

Cell Balancing is the most vital aspect of maintaining the health and performance of an accumulator. An accumulator will consist of an array of multiple cells making up a parallel pack, with a number of those packs connected in series. These parallel packs will be simply referred to as *cells* in this section due to there being no functional difference in the amount of cells you have connected in a parallel pack. Balancing involves having a connection to each point between all the cells, so that each cell can be monitored without having to account for other cells in the stack.

1) Passive Balancing

The most ubiquitous form of balancing found in BMS solutions currently is passive balancing, which employs the use of a bleed resistor in line with each cell. Typically a passively balanced BMS will perform balancing while it is charging the battery. The charger connects to the top and bottom of the stack and delivers current The voltages of each cell are monitored and if an individual cell's voltage rises above the average cell voltage of the whole stack, its bleed resistor is connected via a transistor to drain a small amount of current and dissipate the energy until the cell's voltage is brought down to match the average cell voltage level.

This is the simplest approach to balancing, both in structure and in the required amount of hardware. Only a single resistor and transistor is required per cell to enable balancing. The major downside to this

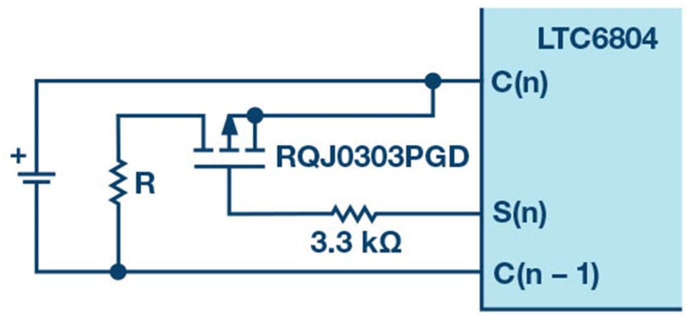


Fig. 7: The layout of a passive balancing circuit, focused on one cell, using an *LTC6804* as a balancing controller

approach is that it is inherently inefficient. Any balancing that needs to be done is power that gets wasted in the form of excess heat, which can prove problematic in the environment of an enclosed vehicle chassis where the cells are quite sensitive to temperature. The main advantage that this approach could provide in a solar powered vehicle is that balancing can take place no matter whether the accumulator is being charged, discharged, or experiencing no power draw.

2) Active Balancing

This form of balancing is not a common as passive balancing, due to its higher complexity, but it does find itself commonly used in electric vehicles due to the electric automotive industry's focus on gaining efficiencies wherever possible. Instead of passively dissipating excess energy from higher charged cells, that cell dissipates energy back into the other cells in the stack, ensuring little energy is wasted. [18]

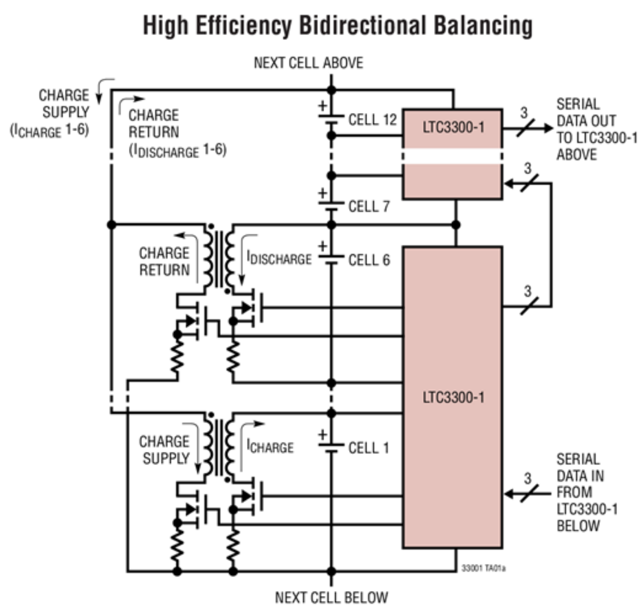


Fig. 8: The layout of an active balancing circuit, using an *LTC3300-1* as a balancing controller

One possible difficulty with active balancing is that, depending on the specific active balancing circuit, balancing may only be able to occur when the battery is not being charged. In a vehicle where there is a constant yet varying power source - solar panels - this could prove to be problematic as trying to have a cell supply excess power to the rest of the battery stack whilst the whole stack is being charged by solar panels may not be possible (one should not try to connect two power supplies together in parallel). Active balancing is the ideal method we would like to implement in our BMS design, and this is a problem that will need to be addressed, either through the circuit layout of our active balancing, or through the design of the power distribution system in the vehicle.

F. Driver and Vehicle Feedback Mechanisms

One of the most important aspects of ensuring a vehicle is kept operating in optimal fashion is ensuring the driver is provided relevant information about the state of various systems in the vehicle. The power train and power management systems are of particular interest here, given that the World Solar Car Challenge focuses on a competition that demands high performance (a vehicle race) while being severely limited by your source of energy (relative to a typical consumer combustion or electric road vehicle). This type of environment demands that every aspect of efficiency be utilised whenever possible and providing useful information on real-time relevant variables to the driver allows them to be more informed about changing the operating behaviour of the vehicle on the fly, seeking the best operation in varying conditions.

Whilst the development of a dashboard and user interface is beyond the scope of this project, the monitoring of various power systems and computation of statistics representing their behaviour should be handled by a module like the Battery Management System, with only the final results delivered to the dashboard or other devices that relay that information to the driver. By confining the main workload to the BMS it allows for more flexibility later in the design process should it be decided that some aspects of power management would be better suited to manual control by the driver, or automatic control by the BMS.

Listed are various pieces of information that should be made available to the driver as well as other peripheral systems in the vehicle:

1) State of Charge History and Projections

At the very least, current instantaneous State of Charge should be shown to the driver. Much like a fuel gauge on a combustion vehicle, this is one of the bare minimum pieces of information that needs to be available. An area this can be improved upon is in providing a visual graph of the SoC over time, with both the history of the SoC, and a rough projection line of future usage. which conveys the rate of charge/discharge for a given period in an intuitive manner. This alleviates the necessity for a driver to be constantly watching the SoC to determine how fast power is being used and/or estimate variables like time until empty.

2) Peripheral Power Usage Overview

Modern vehicles often contain many small systems in them. Giving the driver an overview of the power usage of each of these systems can allow them to better understand and adapt to the power needs of the vehicle and assist in decisions that may involve switching certain systems on or off at any given time.

3) Power-Train Overview

The biggest user of energy in a vehicle is the power-train. Providing the driver with real-time calculation on aspects like current operating efficiency (vehicle speed or output torque vs power-train energy consumption) will allow them to make better judgments about driving behaviour and reacting to different driving conditions. E.g. Wind resistance has a relatively exponential relationship to vehicle speed, so lower speeds result in better efficiency and longer range, but in a race you need to be trying to go as fast as possible whilst still maintaining good enough efficiency so you can reach the finish. Being able to track the power-train's efficiency assists greatly in finding the "sweet-spot" of operation.

III. METHODOLOGY

A. Deliverables

The result of the project is a tangible BMS that is able to balance one of the 20 cell stack to be used in the 1975 Super Beatle, and expand this to the entire accumulator.

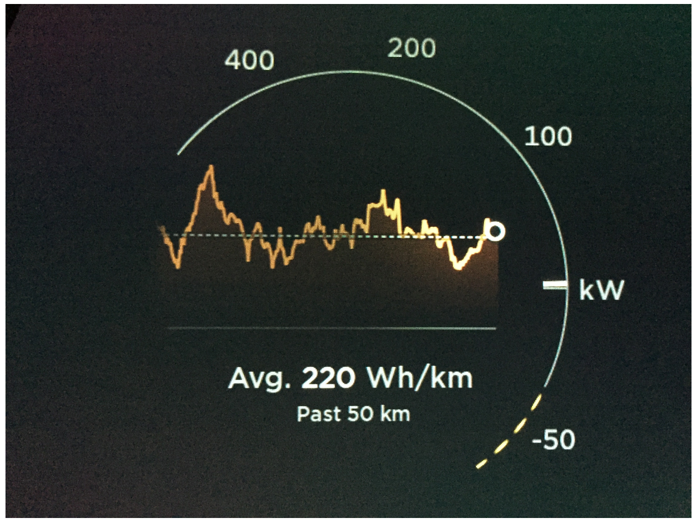


Fig. 9: The energy vs time graph found on the instrument cluster of a Tesla Model S electric vehicle, surrounded by a dial gauge that shows instantaneous power usage

The other components relevant to system integration are already available within the workshop, and are ready for use. The vehicle already features a functional drive train, motor controller with throttle control integration, as well as fuse and contactors. Testing the system will involve attaching the BMS to the vehicle.

B. *Budget, Resources, and Assumptions*

This budget is severely limited by budget, each project receiving $70 per project member; a combined budget of $140. Given that cells and copper bus bars are freely available prior to commencement, producing and populating multiple PCBs is fully possible using a rapid, low cost PCB production house. The Linear Technologies BMS chips may prove to be more expensive than a batch of PCBs, with a single LTC6811 BMS IC costing $27 per chip as of 25/9/21. Thankfully few of these are required per module.

C. *Project Timeline*

This project aims to complete the research phase in November 2021, with the design phase taking place during the first semester of 2022. A complete project timeline is available in Section **??**.

D. *Assumptions*

Since the exact vehicle parameters are out of scope, and will likely change depending on future projects, a scaleable solution should be used in order to create the most versatile solution, however several assumptions can be made to simplify the process:

- A maximum voltage ranging between 70 V and 144 V.
- A cell voltage ranging between 0.8 and 5V.
- A CANBUS interface as the primary vehicle communication method.
- Individual stacks may be positioned at multiple points of the vehicle, with a stack voltage ranging form 20 V to 60 V.

These assumptions are based on the limitation of the motor controller available, the Curtis Curtis 1238 - E available for use has a maximum voltage of 72V - 96V, with a 60V under-voltage limit [19]. Even if the inverter were to change, there is still the practical limitation of the solar panels; modern cells with the appropriate area and efficiency typically have a usable open cell voltage of 5 V [20] and must be placed in series in order to reach the high voltage required. For an 80V system, 160 unique cells would therefore have to be used. This voltage should be as close as possible to the battery voltage in order to remove the undesirable inefficiencies of a boost converter.

We can also base some of these assumptions on existing solar challengers. A great example of a competitive challenger solar car vehicle is the 2017 Sunswift eVe, developed by UNSW. This WSC entry included a 129.6 V_{NOM}, 151.2 V_{MAX} accumulator. This is comprised of NCR18650BF cells 36S,34P with a Tritium distributed BMS. Each series unit is comprised of a single spot welded unit, [21].

E. Contingencies

It is assumed that access to the workshop will be available during the second half of this project, however, it is still possible for this to not be an option. The plan in this case is to use the manufactured PCB on an available lithium system. Vehicle system testing will be more difficult to perform, however unit testing can be performed on any generated code that is required to test this system.

In the case that an active balancing system is unable to be integrated, the passive balancing system may be used as the sole balancing method.

In the case that the support for lower cell voltages proves too complex, support for the Lithium Titanate cells may be dropped. These is very little chance that there will be used within the scope of the competition. Low cost LFP cells may be used for testing, with the possibility of using more appropriate cells in the future.

F. System Integration and Vehicle Control Architecture

SPEVs feature a system architecture similar to most other electric vehicles; they require a connection to the powertrain usually in the form of an inverter for AC induction motors, a charger, a human interface for feedback and control. This report proposes the use of the following system architecture.

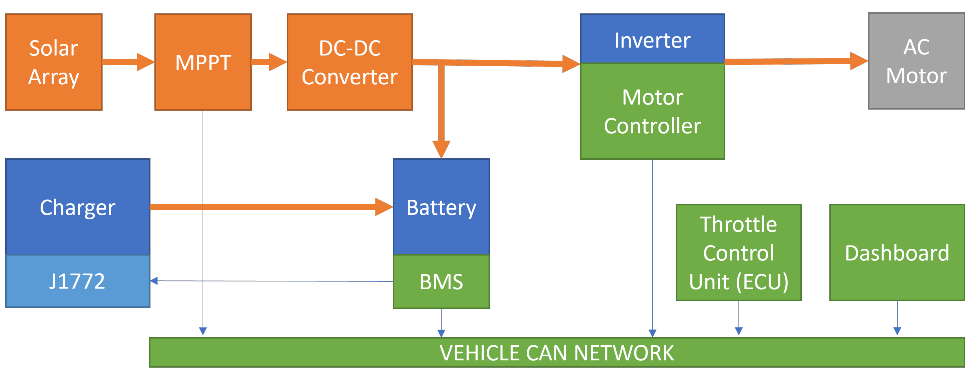


Fig. 10: The proposed high level system diagram for the Solar Car being developed.

G. Safety

Much of the vehicle's safety is stipulated by the competition rules, however not limited to these requirements. Given the danger to life possible from the failure of the accumulator, additional practices and standards must be well understood and followed. Section 2.28 of the WSC rules, Electrical Safety, defines a high voltage system as any system containing more than 60V.

As the project advances, and the outcome becomes more clear, a DFMEA (Design for Failure Mode and Effects Analysis) will be performed to ensure the safety of the system.

Several Design Standards are relevant to the application and should be kept in mind:

IPC2221B Generic Standard on Printed Board Design (High Voltage Clearance)
AS3001/IEEE 100 Double Insulation Requirements.

UL94-V0 Inflammable Material Self Extinguishment

UL1741 Standard for Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources

IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems.

1) Galvanic Isolation

In an electric vehicle, the high voltage system must be kept away from vehicle occupants, however if battery shared a ground with buttons, this would mean there is a potential circuit which in a fault condition would be closed. As such, it is typical for there be a segregation of the low voltage system and the high voltage system. Galvanic isolation is the principle that two circuits are not connected by the by the same ground reference; they are two isolated circuits. These circuits may only be coupled optically, magnetically, capacitively, or by some form of electro-mechanical interface. This is usually done to decouple electrical noise, however, if correct spacing is maintained, this can be used as a form of high voltage electrical safety.

2) Isolation Monitoring

Section 2.28.9 of the rules stipulate that a device be included to monitor that the galvanic isolation barrier is being maintained. In the case of failure, the vehicle should shutoff and return to a fail-safe state. These devices function by providing a controlled leak path. This current leak is monitored and if there is a leak of more than around 2 mA is detected, a fault flag is detected. Whilst many off the shelf BMS devices include a leak monitoring device, an IMD designed by German organisation Bender is used. Similar competitions such as Formula Student mandate use of this specific device and in fact provide these free of charge to all teams to avoid any troubles.

3) Fusing and Current Protection

Each terminal of the accumulator that connects to the BMS must be fused.

Additionally a large fuse will be placed between the last series bus of the battery pack, and before the positive isolation relay.

The current clamp used to assist in state of charge calculation can be used as a way to detect over-current. There are two software based protection mechanisms that should be built in, both of which triggering an accumulator fault condition, and opening the accumulator isolation relays. They are; a hard over-current limit, a high current exceeding the current limit of the minimum rated component, aimed at preventing the main fuse from blowing, and a feedback system whereby if the discharge current limit forwarded to the motor controller is exceeded for an extended period of time, a fault condition will be triggered to prevent damage to the pack.

4) Over-Voltage and Over Temperature Protection

The battery management system will be monitoring the voltage of each cell. For each chemistry which which the BMS can support, a range must be established for the voltage which each cell is considered safe; when out of range of this range, the accumulator

5) Safety Loops and Interlocks

The power for the accumulator isolation relays must be fail safe, as such, it is sensible that the current for the AIRs pass through all interlocks within the vehicle; including the IMD, the BMS, a Emergency Stop available within reach of the driver, and the kew switch, as well as any manual service disconnects for the HV. In this way, if a fault occurs at any point within the vehicle, the accumulator will be closed and power disconnected from the system.

IV. Conclusion

As the project advances, one would expect this system to change and evolve. The distributed, active balancing system laid out in this report will address many of the issues and challenges laid out during the literature review.

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V. Appendix

A. Gantt Chart

FYRP Gantt Planner

Select a period to highlight at right. A legend describing the charting follows.

Period Highlight: 6 | Plan Duration | Actual Start | % Complete | Actual (beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Subject orientation + organising student group	1	1	1	1	100%
Applying for a project + PCF submission	1	2	1	2	100%
Initial supervisor meeting + project orientation	2	1	2	1	100%
Initial exploratory research	3	3	3	4	100%
Plan scope of research plan	4	2	5	1	50%
Main project research	4	9	5	2	20%
Resarch technical information for research plan	5	1	5	1	100%
Create supervisor presentation from current research	6	1	6	1	100%
Deliver supervisor presentation	6	1	6	1	0%
Make sure individual workbooks are up to date	11	1	0	0	0%
Create panel presentation	11	2	0	0	0%
Complete + Submit research plan	11	3	0	0	0%
Create + submit final presentation poster	12	2	0	0	0%
Deliver panel presentation (TBD in Wk 11-13)	12	3	0	0	0%
Research paper	12	20	0	0	0%
Create + submit semester progress report	13	2	0	0	0%
Finish + submit FYRP1 workbooks	13	2	0	0	0%
Review past semester	30	1	0	0	0%
Manufacturing + implementation	31	11	0	0	0%
Finish + submit research paper	38	4	0	0	0%
Begin final report	39	5	0	0	0%
Make sure individual workbooks are up to date	41	1	0	0	0%
Create final presentation / demonstration	41	3	0	0	0%
Finish + submit final report	41	4	0	0	0%
Finish + submit FYRP2 workbooks	43	1	0	0	0%
Manufactures/implemented deliverables deadline	44	1	0	0	0%
Deliver final presentation/demonstration	45	1	0	0	0%

Sem 2 2021													Exams								Su
2/08/21	9/08/21	16/08/21	23/08/21	30/08/21	6/09/21	13/09/21	20/09/21	27/09/21	4/10/21	11/10/21	18/10/21	25/10/21	1/11/21	8/11/21	15/11/21	22/11/21	29/11/21	6/12/21	13/12/21	20/12/21	27/12/21
Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Break	Wk 7	Wk 8	Wk 9	Wk 10	Wk 11	Wk 12									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

FYRP Gantt Planner

Select a period to highlight at right. A legend describing the charting follows.

% Complete (beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION
Subject orientation + organising student group	1	1	1	1
Applying for a project + PCF submission	1	2	1	2
Initial supervisor meeting + project orientation	2	1	2	1
Initial exploratory research	3	3	3	4
Plan scope of research plan	4	2	5	1
Main project research	4	9	5	2
Resarch technical information for research plan	5	1	5	1
Create supervisor presentation from current research	6	1	6	1
Deliver supervisor presentation	6	1	6	1
Make sure individual workbooks are up to date	11	1	0	0
Create panel presentation	11	2	0	0
Complete + Submit research plan	11	3	0	0
Create + submit final presentation poster	12	2	0	0
Deliver panel presentation (TBD in Wk 11-13)	12	3	0	0
Research paper	12	20	0	0
Create + submit semester progress report	13	2	0	0
Finish + submit FYRP1 workbooks	13	2	0	0
Review past semester	30	1	0	0
Manufacturing + implementation	31	11	0	0
Finish + submit research paper	38	4	0	0
Begin final report	39	5	0	0
Make sure individual workbooks are up to date	41	1	0	0
Create final presentation / demonstration	41	3	0	0
Finish + submit final report	41	4	0	0
Finish + submit FYRP2 workbooks	43	1	0	0
Manufactures/implemented deliverables deadline	44	1	0	0
Deliver final presentation/demonstration	45	1	0	0

ımmer Break								Sem 1 2022													Exams		
3/01/22	10/01/22	17/01/22	24/01/22	31/01/22	7/02/22	14/02/22	21/02/22	28/02/22	7/03/22	14/03/22	21/03/22	28/03/22	4/04/22	11/04/22	18/04/22	25/04/22	2/05/22	9/05/22	16/05/22	23/05/22	30/05/22	6/06/22	13/06/22
								Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Break	Wk 7	Wk 8	Wk 9	Wk 10	Wk 11	Wk 12			
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46

Page 2 of 2