Interim Report

Project Title:	**Battery embedded wind turbine**
Project type:	**Final Year Undergraduate Project 2019/20**
Student name:	**Raymond Zhen**
Programme of study:	**BEng FT Electrical & Electronic Engineering 4 year with IE**
Email:	**r.zhen@se16.qmul.ac.uk**
Project Supervisor:	**Dr Kamyar Mehran**

Abbreviations

Abbreviation	**Definition**
BMS	Battery management system
EES	Embedded energy storage
SOC	State of Charge
SOH	State of Health

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1 Introduction

Wind is unpredictable due to natural characteristic which contains both properties wind speed and direction, these affect the integration with the network grid during abnormal wind conditions, in such case, there will be an imbalance with both voltage and frequency generation of the converters. These converters used in wind turbines transform mechanical energy to electrical energy which must match the electrical requirements of the grid, if there is any mismatch, this will lead to destabilisation of wind turbine with the grid, essentially becoming physically disconnected. The nature of wind causes variation in power generation which causes an increase in I^2R losses in wind farm cables, in extreme cases, $\approx 50\%$ of power generated from a wind turbine can be lost in cables [1].

There is a steady growth in recent years in the production of medium to large size wind turbines, the average sized wind turbine being manufactured is typically 2.5-3MW which can power 1500 average EU households [2]. To enable high penetration of wind energy we reduce the occurrence of destabilisation with the network grid. Wind power has contributed to 12% in 2016 and 18% in 2018 to all electricity consumed in the UK [3], this source shows that this trend will continue to rise due to the movement towards greener energy and security of supply.

During times where there is a high supply of power being generated and low demand from the population, it is clear that this energy needs to be stored for times where wind power generation is low and demand is high.

A solution to enable high penetration of wind power and security of supply we can introduce Embedded energy storage (EES). EES has been a rising trend in the past decade, EES is a type of device where we can store energy produced by a source and use it at a later time, this is a general form of a battery. It is widely used throughout the world on many devices, for example, mobile phones, we are not limited to small scale storage there has been interest in energy storage for electrical power systems such as storage for renewable energy.

It is possible to realise a rechargeable battery bank within a wind turbine, they may be used with generators such as a permanent magnet synchronous generator (PMSG) or Asynchronous induction generator. Majority of the wind turbines deliver suitable voltage at low wind speeds to charge battery banks, one such example includes the Vestas-V90 which outputs 690V before it is stepped up to match grid voltage [4].

1.1 Background

To understand the context of the project, background information is required. The fundamental backbone of an EES is the battery, we will discuss two core components which make up an EES which include re-chargeable batteries and an battery management system.

1.1.1 Re-chargeable batteries

Re-chargeable batteries work on a simple concept where electrical energy is converted into chemical energy and stored, which can later be retrieved when connected to a load. With many varieties of battery cells to look at they come with different characteristics, some include capacity(mAh), shape and charge/discharge lifecycles. The following common types of cells are as listed:

1. **Lithium-ion** - a popular choice of energy storage in the current trend used in electric vehicles, prices of lithium ion cells have been rapidly decreasing. The price in 2012 is \$600 per-kilowatt-hour and in 2016 is around \$145 per-kilowatt-hour [5], this makes it an attractive choice for building battery banks for high voltage electric vehicles. Lithium-ion is used where high-energy density and lightweight is the most important attribute in a system.

2. **Nickel-metal hydride** - which abbreviates to Ni-MH, offers higher energy density when compared to Nickel Cadium cells but at a comprise of reducing charging/discharging cycle. This cell is used in a variety of industrial application such as medical instrument and hybrid cars [6].

3. **Nickel Cadmium** - which abbreviates to Ni-Cd, these cells have been understood quite well as they have been in the used extensively, these cells offer long service life and can discharge a large amount of current, they can withstand extreme temperature and suitable environmental challenges. The application for these cells makes them great for power tools, aviation and uninterruptable power supply (UPS).

4. **Lead Acid** - The lead acid battery is one of the oldest rechargeable battery which was invented in 1859, typically used in automotive applications such as cars as these batteries are rugged and can withstand accidental short circuits. Lead acid brings up environmental concerns as the toxins within the battery cannot be disposed of in landfills. In situations where systems require low cost, robustness and weight not being of importance, the lead acid battery can be considered.

1.1.2 Battery management systems

A battery management system is an electronic device which provides protect battery from operating outside safe voltage level, monitor state of battery (State of Charge, State of Health), prompt/perform action when cell abnormalities occur (temperature, short-circuit), indicate end of life when capacity falls below set target threshold and perform cell balancing [7]. Almost all system which includes the usage of rechargeable batteries requires the use of BMS, without these place the battery may be damaged or catch fire.

There are many designs of BMS, they range from different target voltage requirements to amount of features they can have, some of these features include autonomous cell protection, cell balancing, can-bus communication (for vehicle applications) and daisy chaining for high voltage systems.

Each rechargeable battery has different chemistry which involves batteries being at a different voltage or operating threshold, caution must be taken into account when designing a BMS. For the case of lithium-ion cells, they exhibit non-linear charge/discharge curve, this can lead to difficulty in management, simply measuring voltage will not be sufficient, the BMS can execute complex algorithms which capture the SOC and SOH values of the cells.

1.2 Problem statement

Most wind turbine use similar systems to convert mechanical energy to electrical energy from the generators using either permanent magnet synchronous motor or induction motor, converters step up the voltage to match the grid. Variation of voltage and frequency in the converters are triggered by abnormal wind activity will cause the wind turbine to destabilise from the grid, this variation will also cause power losses in the cable which reduces the annual wind power output generation. Other alternatives which will discuss later have attempted to combat this issue but higher penetration of wind power can be achieved.

1.3 Aim

To design and integrate an small scale energy storage system (EES) using lithium-ion battery bank for an target commercial wind turbine with the aim of the design being cost effective when compared to ordinary wind turbine and to show benefits that the system brings to enable supply security.

1.4 Objectives

The EES embedded wind turbine must act as a single unified system where power generated from the generator needs to be distributed to both the battery and the load. Monitoring, maintenance and protection of the lithium-ion battery banks will be realised with the design of a BMS (battery management system) solution, for the prototype 3 to 5 lithium-ion cells will be used. The chosen 18650 cylindrical lithium-ion cell is one of the highest energy dense cell compared to any other battery technology today, they have an capacity of 100-256 Wh/kg [8]. The design of the BMS and the rechargeable battery bank must be targetted to an existing wind turbine, the Vestas V90 turbine will be looked at.

2 Literature Review

To understand the context of the project, we must investigate other similar systems that already exist.

2.1 Current approaches

2.1.1 Microgrids

A Microgrid is a discrete energy system which comprises of electricity generation, energy storage and electrical load. These systems collect and store energy from renewable resources such as wind and solar and provides power to the consumers, they work like miniature power grid systems.

The energy storage within the microgrids enables minimal voltage and frequency deviations. Deviations of voltage and frequency occur due to sudden unexpected variations in renewable energy generation, this can cause power shortfall or excessive generation, the storage system acts as a buffer between the generator and the consumers to provide smoothing.

Microgrids is a solution to off grid power, they can either become connected to the grid to provide support during high demand of power or they can work independently off the grid this operation is called island mode. Island mode is an attractive feature, this provides areas which are disconnected from the grid (due to geographic position) to have power since the system is powered by renewable energy sources it will be self-sufficient.

The current system of micro-grids requires multitudes to work together to reduce the occurrence of destabilisation of the grid and supply emergency power in a case of a power outage. Generated wind energy must go through several stages of conversion before being stored in the micro-grid, they take the conventional path of converting the 3 phase ac to dc, dc to ac to match the grid then converted again from ac to dc to be accumulated in the microgrid energy storage [9].

2.1.2 Academic Research

A published initial study paper by T.C Yang talks about the usage of rechargeable batteries in wind power generation with variable speed induction generators [1]. He discusses that external energy storage plants have already existed to combat challenges caused by intermittency of renewable power generation, the cost of using EES based system compared to 'external' plants will lower the costs.

The addition of the EES system within the turbine can integrate with existing AC to DC and DC to AC converters. For the following case study shows that in a wind farm of 50 wind turbine can be replaced with 10 wind turbines with EES in each of them plus 33 ordinary ones which would produce an equal amount of annual wind energy output.

2.1.3 Domestic wind turbine

Those who are looking to produce energy from a greener source or who live off grid may consider in investing a domestic/micro wind turbine, they are more suited to areas of greater wind than sun. Generally, these systems are equipped with 1kW to 2kW turbines, one example by a company photonic universe which produces a 2kW 48V wind turbine which targets medium to strong winds [10].

Most of these systems are required to work with the rechargeable battery bank as a supplementary part to increase surplus energy as well as providing safety for electrical and electronic devices. The domestic wind turbines are usually pole mounted and must be stored in a protective environment such as homes, these are easier to realise than that of microgrid systems where it is stored outdoors.

3 Progress and project milestone

3.1 System block diagram

An block diagram was created to represent my proposed system, figure 1 illustrates the power circuit and figure 2 represents the BMS block which will control the power circuit. Majority of the power circuit will be designed and simulated except the DC to AC converter, the generation from wind turbine will be rectified and converted into suitable DC voltages to charge the lithium ion batteries. To increase safety of the system there are several features which will disconnect the battery from the charging system and the load which will be discussed below, some of these features include fuse and emergency disconnect button.

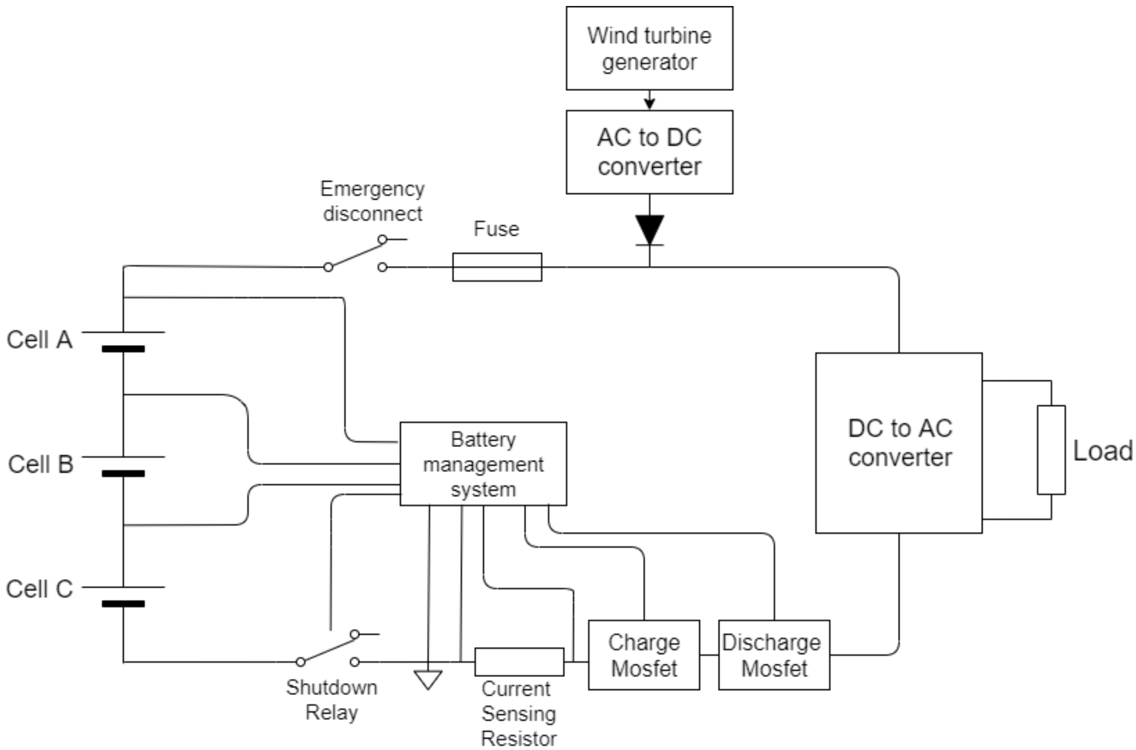

Figure 1: Power circuit block diagram

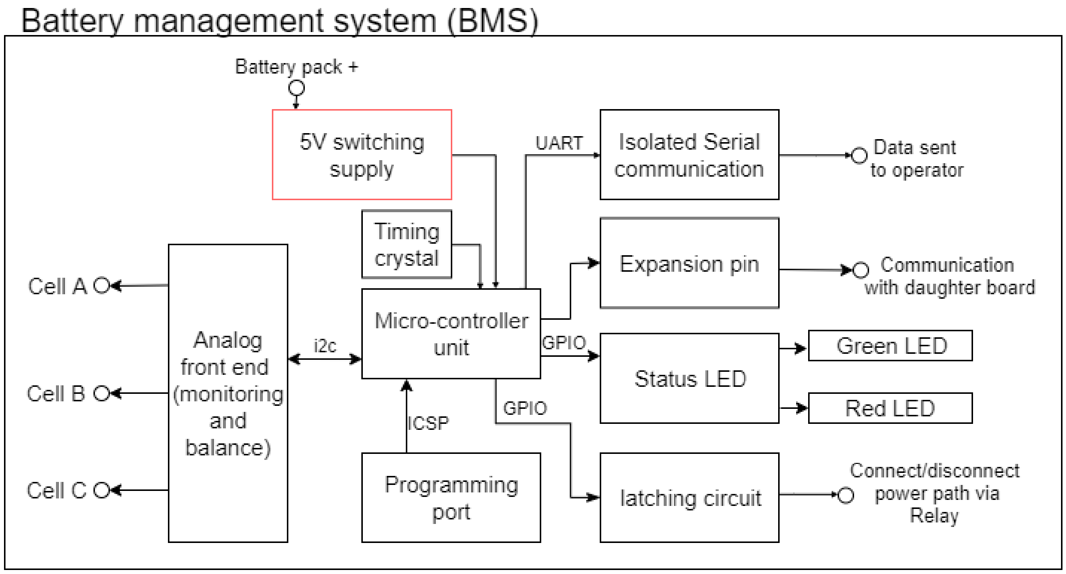

Figure 2: Battery management system block diagram

The BMS will provide control and protection for the batteries, a micro-controller host will communicate with an analog front end cell monitoring chip designed by TI instruments, the chip is BQ76920 [11]. The in-cooperation of an micro-controller brings advantages to the system such as flexibility and additional safety features.

Analog front end cell monitoring and balancing, BQ7690 features:

1. Communication to host controller via i2c protocol
2. Monitoring of sensor data such as cell voltages, pack current, pack temperature
3. Offers protection by controlling charge/discharge FETS
4. AFE protects against overcurrent, short circuit and overvoltage
5. Offers individual cell balancing, voltage of balance can be configured by the host controller

BMS features:

1. 5V supply - Supply voltage to power the micro-controller and sub-circuits. The usage of switching mode supply will increase supply efficiency.
2. Timing crystal - For timing critical operations. The timing crystal provides accurate pulses which is fed into the micro-controller. The micro-controller does include an internal crystal however for higher baud-rate capabilities in UART communcations the internal clock frequency does not provide the best frequency for reduction of error baud, an external timing crystal is less prone to frequency changes as it is less affect by a wide range of temperature.
3. Isolated Serial communication - Allow stream of serial data to computer via a galvanically isolated port, using opto-couplers to provide isolation from the lithium battery.
4. Expansion port - Enable communication to other external circuit boards by provide extra general purpose input and ouput pins (GPIO)
5. Status LED - LED used to communicate information to the operator about system status

6. Latching circuit - Additional safety circuit alongside the AFE FETS, the lacthing circuit will interface with an relay, this relay is connected to high current path and will disconnect the power circuit in case of abnormal battery conditions.

7. Programming port - Uses ICSP to program the chip, required for update the firmware if there are new changes

3.2 Battery management system PCB and routing

Simulation of non-battery circuit have been carried out in LT-spice (which is an free electronic circuit simulator) to test out analog circuit to determine their performance. Once tested the circuit it then placed into the schematic viewer in Altium PCB design tool. Once the schematic has been completed, routing of the circuit elements was carried out to ensure that the PCB is designed around the rules followed in the BQ76920 datasheet.

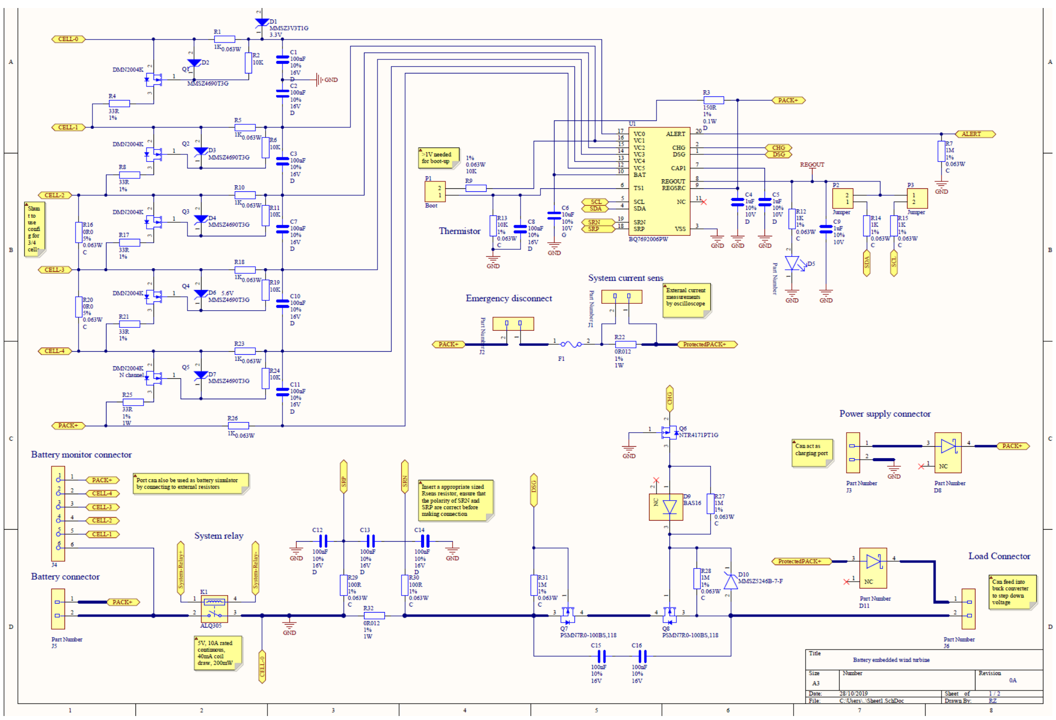

Figure 3: PCB layout in Altium

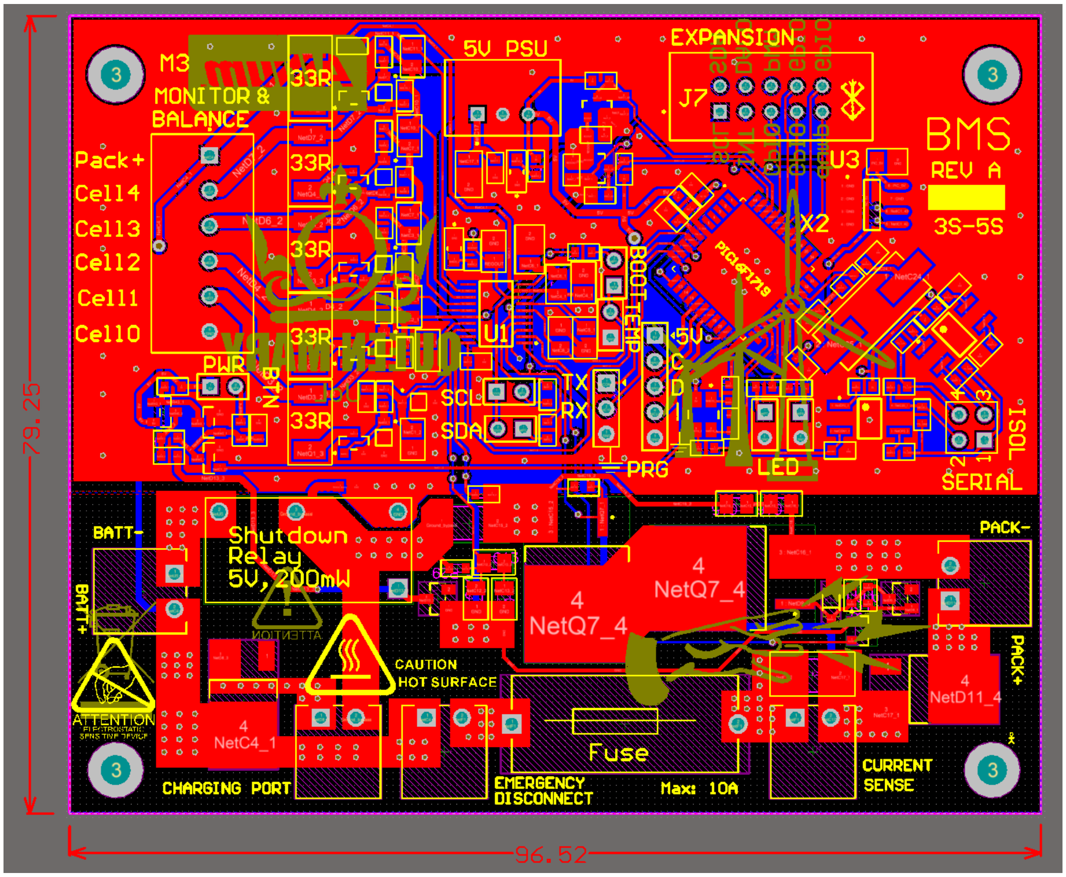

Figure 4: PCB layout in Altium

3.3 Modelling the discharge curve for target battery model

Using matlab/simulink to simulate the target cell, the Samsung INR18650 lithium ion cell [12]. An rechargeable cell element has been used with the parameters configured to match the target cell, figure 5 illustrates the discharge curve of the cell at various discharge currents.

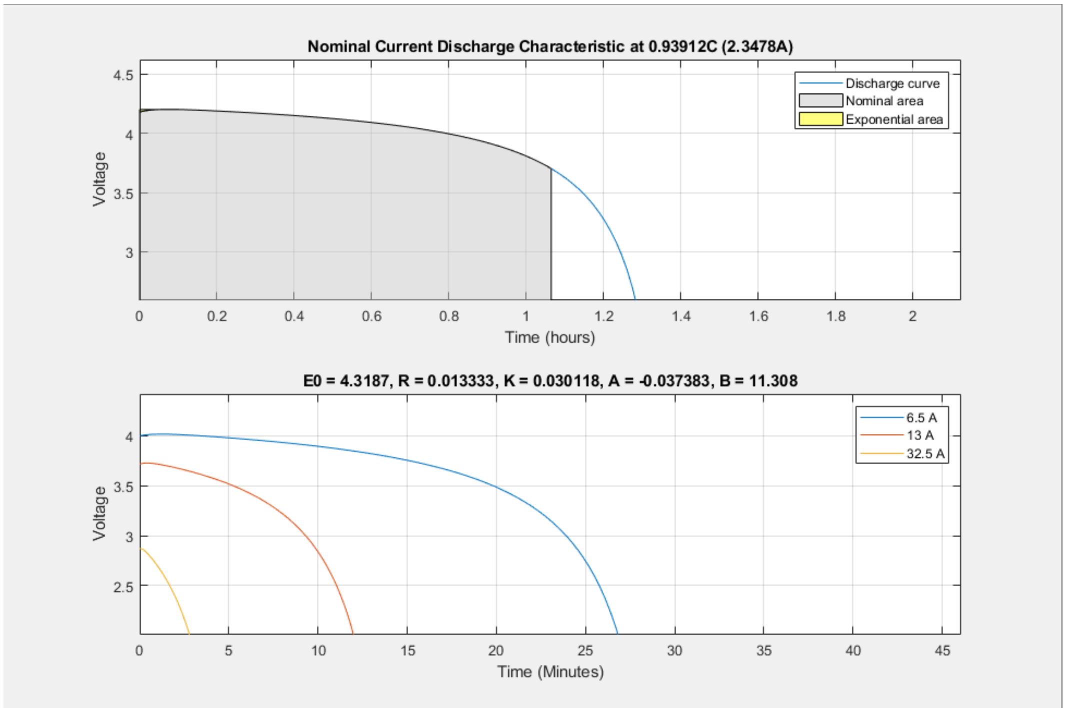

Figure 5: Samsung INR18650 parameter modelling

3.4 3D render

An royalty free model based of Vestas wind turbine [13] will be used to demonstrate that an EES system can be embedded into the mast. 3D modelling of the rechargeable banks using model in figure 7 will be designed to meet the target system specifications e.g rechargeable bank voltage, capacity.

Figure 6: Vestas turbine model

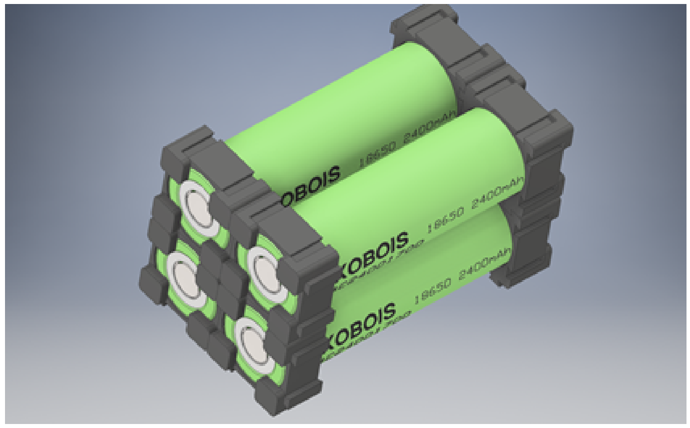

Figure 7: 4 Cell lithium-ion pack

4 Planning ahead

Reviewing all the progress that has been achieved currently to assess what work will need to carried out for the upcoming month, the Gantt chart produced in week 3 will need to be revised to reach realistic goals for next semester. The following list explains the next steps that will be carried out for this project:

1. Producing battery bank to reach target wind turbine specification

   i Currently looking into basing project on a commercial wind turbine, the model of interest is the Vestas V90

2. Design and simulation of AC to DC and DC to DC converters using either simulink or pspice circuit modelling.

   i Once simulation of the converters are complete, build a simple converter for the small scale EES prototype

   ii The simulation must be compared ot the project acquired results

3. Using the 3D model of the wind turbine and the lithium-ion cell, create a battery bank and physically embed it into the wind turbine to demonstrate that EES can be realised within the mast. Modelling will be carried out in Solid-works 2018.

4. Begin on programming in C for the chosen micro-controller

   i The micro-controller chosen is the PIC16F1719. Code will be written to allow communication between the micro-controller and the analog front end cell monitoring chip, other features will be implemented into the system to provide access to basic protection featuers such as temperature monitoring and high current sensing algorithms

5. To populate the PCB once it arrives with the components bought through the lab manager

5 Risk Assessment

No.	Description of Risk	Description of impact	Likelihood rating	Impact rating	Preventative action
Administrative Project Risk					
1	Home damaged by natural event (storm, heavy rain, fire)	Possible loss of project progress and injury	low	High	Take proper precaution and check for strong weather announcements
2	Power outage at home or university	Not able to use home desktop and/or charge laptop. Possible loss of data.	Low /Medium	Medium /High	Use public libraries for power and WIFI. Refer to offline resources for the time being which include textbooks.
3	Personal equipment not working (desktop computer, laptop, phone)	Progress of project will be stopped temporarily or worse case permanently	Medium	Medium /High	Regular maintenance of electronics and produce offline backup copy
Academic Project Risks					
4	Electric shock from equipment	Electric shock can be dangerous as with enough power can cause burns, scars and pain which may need treatment	Low /Medium	Medium	Operate variable power supply below the 50V range to prevent electric shock as these voltages cannot penetrate dry skin. Consulting the lab manager to ensure that high voltage equipment have been electrically tested before usage.
5	Injury for using lab equipment i.e burning skin from soldering	Injury can temporarily put stop to progress	Medium	Medium	Understanding proper usage of tool from lab manager, respect the equipment understanding the risk they pose
6	Handling of Lithium-ion cells can cause fire	Can cause damage to property. Probability of leading to injury/death of person	Low /Medium	High	Lithium-ion testing will be carried out under strict monitoring of lab manager, a fire-extinguishing tool is required to be nearby with the right solution to put out battery fire. Testing of BMS shall be carried out with a simulated battery bank initially that does not contain any cells.
7	Operation of project in poor environment	Electronic equipment may have unexpected interaction in high humidity and dusty environment	Low /Medium	Medium	Ensure work area is free of dust aswell as working in an dry environment
8	Risk of colleagues touching and damaging or being injured by final year project prototype	Project prototype may be damaged and action must be taken to restore the damage. Colleagues may be injured by mishandling project prototype	Low /Medium	Medium	Ensure adequate visible labels are placed on the project prototype stickers which include the warnings such as

Table 1: Risk Assessment

References

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