CHEEVC Software Configurable Battery

Executive Summary

CHEEVC, a start up company based in Scotland, has developed a software controlled battery system which increases battery lifetime by up to 35% or more while at the same time permitting variable power delivery under software control – a world first. It provides dynamic control of series cell chains making up medium and high voltage batteries eliminating the need for inefficient and expensive power controllers. In addition, dynamic redundancy provides immunity from single cell failures, essential in mission critical applications. The battery is suitable for a wide range of applications ranging from power tools to electric vehicles.

The lifetime improvement is achieved by providing rest periods for the battery cells during both charging and discharging by means of a switching matrix. An extra cell in the battery string provides redundancy and the redundant cell is bypassed and rested while remaining cells carry the load. Sequential cycling rests each cell in turn so that all cells in the battery age at the same rate.

As a bonus, this switching matrix can be used to provide major enhancements in the battery functionality, simply through software, without adding any hardware. The system is particularly suitable for motor control applications such as powering Light Electrical Vehicles (LEVs) which will be the company's first product offering.

A summary of all the product benefits includes

1. Increase in cycle life of up to 35% or more.
2. Cost per cycle reduced by 15%.
3. Variable coarse and fine power output from the battery avoiding the use (and cost) of a separate power controller.
4. Lossless cell balancing during both charging and discharging. (Provides further lifetime improvement)
5. More accurate State of Charge (Range) estimation.
6. The extra (redundant) cell provides extra usable capacity (Range).
7. Higher reliability providing immunity from single cell failures. Gets you home under full power. Suitable for mission critical applications.
8. Short term emergency power boost of 30%.
9. The technology can in principle be applied to any cell chemistry, but is particularly suitable for the many variants of Lithium chemistries.

The cost to provide all of these benefits is an increase of only 14% in the cost of the battery.

The initial product will be produced in the UK using sub-contract manufacturers and will sell to *OEM* customers for between £140 to £180, depending on the specification, with a gross margin of around 30%. Production will start in August 2012 with unit sales volume rising to 36,000 units in year 3 generating a revenue of £5.75 millions with an after tax profit of £467,000.

Product Description and Business Opportunities

CHEEVC has developed some innovative battery technology providing a unique range of features and benefits with wide ranging application possibilities.

1. **The Product - Features, Functions and Benefits (Unique Selling Points (USPs))**

1.1. **Extended battery life of 20% to 35%.**
Achieved by the use of a switching matrix to provide rest periods during both charging and discharging. It uses an extra cell to enable cyclic redundancy of the individual cells in the battery chain. The use of rest periods in this way is unique technology for which a patent application PCT/CN2010/079125 was filed in November 2010. (The principle on which this depends is explained below)

1.2. **Reduced costs of 15% per cycle during the lifetime of the battery.**
A direct consequence of the extended life from the cells.

1.3. **Software controlled power output.**
Without any additional hardware, the switching matrix can be programmed to provide a variale voltage and current from the battery. No other battery has such a capability. This is also a unique technology which is also covered by the above noted patent. This facility can be used to replace the power control function normally required in motor control applications thus eliminating the need for bulky, costly and inefficient DC-DC converters or lossy rheostats.

1.4. **Immunity from single cell failures.**
The cyclic redundancy provided by the switching matrix dramatically improves reliability. This is very useful for mission critical applications. In electric vehicles (or aviation applications) it will always get you home.

1.5. **Lossless, dynamic cell balancing.**
Improves cell and battery lifetime by maintaining all cells at the same state of charge so that the weaker cells are not overstressed. Another unique feature is that it is applied constantly at all levels during both charging and discharging, not just at the end of the cycle.

1.6. **Improved accuracy of State of Charge (SOC) Estimation.**
The cell voltage, which is one of the main parameters from which the SOC is derived, can be measured when each cell is in the open circuit condition and the chemical transformation in the cell has stabilised at the end of the rest period. This results in a more accurate measurement.

1.7. **Increased battery capacity.**
The capacity of the extra cell in the chain, the so called “redundant cell” is actually used to increase the capacity of the battery.

1.8. **Short term power boost**
As above, the redundant cell can also be used to provide an emergency power boost of 30% by switching off the cyclic redundancy and using the power of all the cells in the chain. The cyclic redundancy is of course switched off during this boost.

1.9. **Works with any cell chemistry.**
While this is technically possible. Only applications using various variants of Lithium Ion chemistry are considered.

1.10. **Does not require a special charger**

Works with any standard charger designed for Lithium batteries.

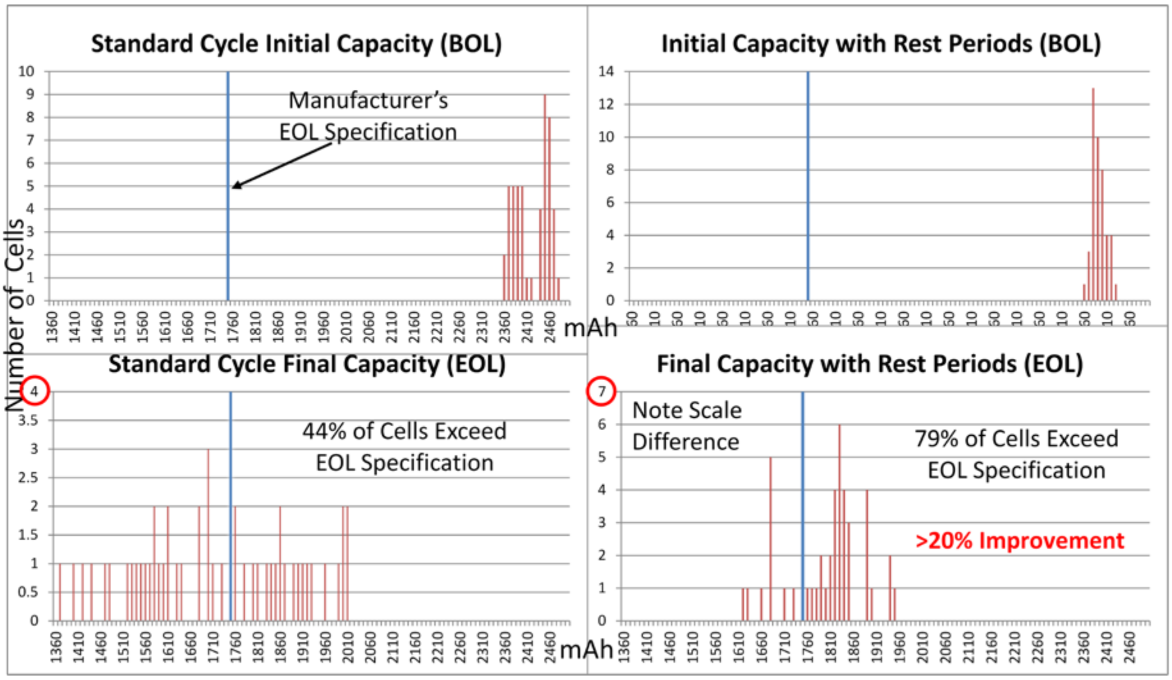
2. **The Technology**

When a battery is charged, a chemical reaction takes place in which the active chemicals take in electrical energy and are transformed from one set of compounds to a different set. When the battery is discharged, the chemicals are transformed back to their original state and energy is given out again in the form of an electric current.

The rate at which a battery or cell can be charged or discharged is limited by the rate at which the active chemicals in the cells can be transformed. Forcing high currents through the battery causes unwanted, irreversible chemical reactions to occur because the chemical transformations cannot keep up with the current demands. This damages the battery causing it to lose capacity and thus age prematurely.

Providing rest periods during both charging and discharging allows time for the chemical reactions to stabilise thus reducing the stress on the cells, avoiding unwanted chemical reactions. While this principle applies in principle to all battery chemistries and has been known for some time, nobody has applied it in a controlled way to increase the cycle life of the cells. This is the core of the CHEEVC technology for which the above patent application has been filed.

Before embarking on a new product development, the company conducted tests to prove the feasibility of the concept. The results are shown below.



48 Samples for each test of 300 Cycles with charge rate 0.5C (CC-CV) and discharge rate 1.0C

The graphs show that by applying rest periods during the discharge periods, the cycle life of the cells can be increased by 20%. Similarly, applying rest periods during charging will produce a further increase.

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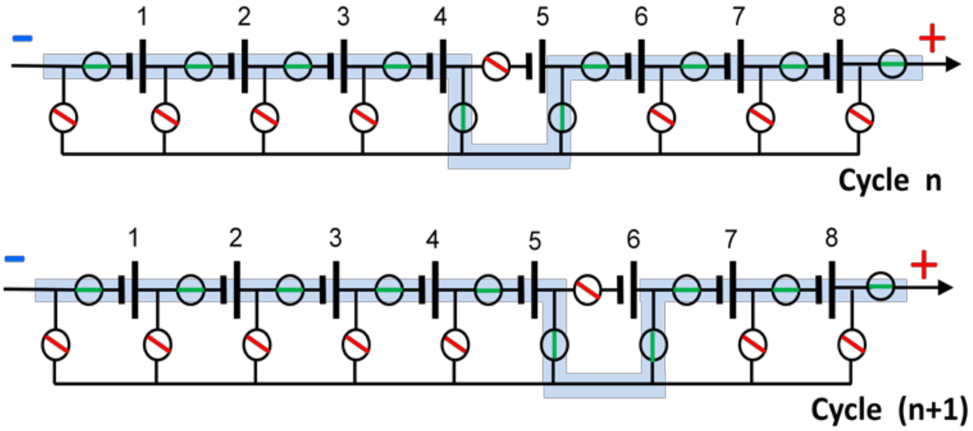
2.1. Stress Reduction by Cyclic Redundancy

CHEEVC's solution is to provide the necessary rest period by means of cyclic redundancy

- An extra cell in the battery string provides redundancy
- The redundant cell is bypassed and rested while remaining cells carry the load
- Sequential cycling rests each cell in turn
- All cells in the battery age at the same rate
- Resting takes place during both charge and discharge cycles
- An added benefit is that the cell voltage can be measured at the end of the rest period once the chemical reaction has stabilised providing a more accurate estimation of the State of Charge (SOC) of the battery.

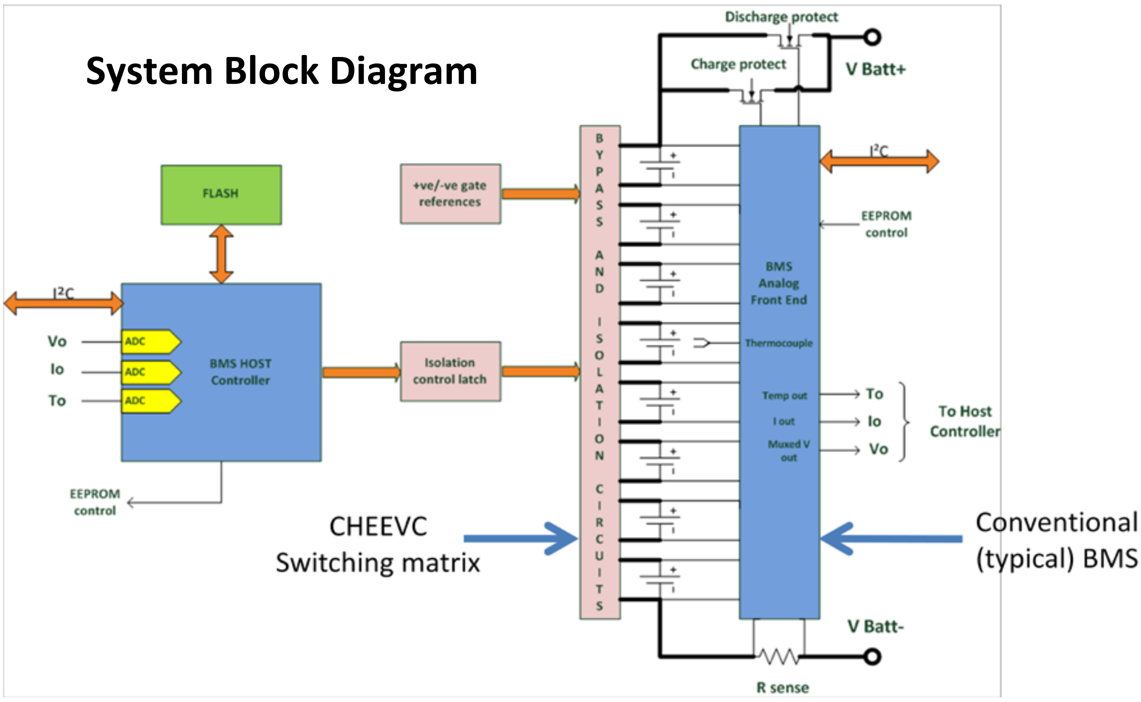
The diagram below shows the principle of cyclic redundancy. Cells are bypassed sequentially under software control using 2 or more switches, in this case Field Effect Transistors (FETs). This provides access to, and control of, individual cells.



In the example above, one redundant cell is provided for seven active cells providing 1 for 7 redundancy. The switching circuit causes each cell to be sequentially cycled out of the active cell string thus allowing a rest period for each cell every 8 cycles. The same circuit can be used to provide variable voltage and with the addition of another FET per battery cell the circuit will also provide dynamic cell balancing which also prolongs the life of the battery. The battery design uses conventional hardware and software technology and does not depend on technology breakthroughs.

2.2. **System Description**

The CHEEVC switching matrix works in conjunction with a conventional Battery Management System (BMS) to provide extra functionality and enhanced benefits to the battery. The overall system block diagram is shown below.



3. **Mechanical Construction**

The mechanical design can be adapted to work with small cylindrical cells (called 18650s) which are manufactured in very high volumes for use in laptop computers as well as the Tesla sports car, or it can work with pouch cells as used in the Chevy Volt hybrid electric car and favoured by the Chinese in electric bicycles. For this first option CHEEVC has also developed an innovative method of interconnecting the cells by wire bonding which enables the batteries to be assembled by machine, avoiding costly and potentially inaccurate manual assembly. A patent application PCT/CN2010/079121 to protect this technology was also filed in November 2010.

4. **Scalability**

Though the initial applications are for electric bikes, the design can be scaled up in 2 ways to cater for high power applications. Higher power FET switches can be used. As the power requirement increases, the cost of the cells increases more quickly than the cost of the FETs improving the cost effectiveness of the design. However the downside is that such applications will require more sophisticated thermal management to cope with the increased heat dissipation of the higher power cells and the associated electronic circuits. By using high power FETs current handling capacities of 400 amps are possible.

The alternative method of increasing the power handling capacity of the battery is to build up the battery from low capacity modules as is done in the Tesla car.

5. **The Market**

In principle, the technology can be used with any multi-cell battery of which billions are sold every year. The first generation CHEEVC products will be suitable for applications with power levels up to about 1kW and capacities up to about 2 kWh. This includes batteries used to power Light Electric Vehicles (LEVs) such as electric bikes, scooters and mobility aids, high capacity power tools, airborne surveillance drones, remote control models and motor control applications. Second generation products will be designed for higher power applications such as electric and hybrid electric vehicles (EVs and HEVs).

In practice the company will initially focus its attention on the LEV market for which the CHEEVC technology is ideally suited. This is because the market opportunities are very large and growing with many players making it relatively easy to find a suitable partner to participate in a demonstrator product from which to establish the business credibility. Typical partners are e-bike and scooter manufacturers but could also include cell makers, battery pack makers, motor manufacturers and traders selling electrification kits. There is also the possibility of online sales to this latter kit market. Licensing the technology is also a further possibility.

5.1. **The LEV Market**

5.1.1. **Total Market**

30 million new electric two-wheel vehicles per year are sold in China alone which accounts for 98% of the world demand and this is expected grow at a compound annual rate of 9.4% through 2016. The fastest growth will occur, though from a lower base, in the Middle East (54% compound annual growth rate (CAGR)) and Latin America (30% CAGR). The market for e-bikes in Europe is currently around 700,000 units per year (1.1 million according to IDTechEx) growing at over 17.3 % per year. Europe's share of the world market in 2016 is expected to increase to about 3.4% in units and 12% by value because the bikes use the more expensive Lithium Ion technology. Similarly in North America e-bike sales in the U.S. have recently been growing at a 21% annually and could reach 785,000 per year by 2016 when their share of global sales is expected to be 1.9%, representing 5.6% of the global revenue.
(Sources: Pike research, The LEV Association, Autoblog, IDTechEx and ElectricBikeE).
In India, the total market is 120,000 e-bike units per year, also growing at 5% per year.
(Source: Naveen Munjal, CEO of Hero which sells 1 million two wheelers per year).

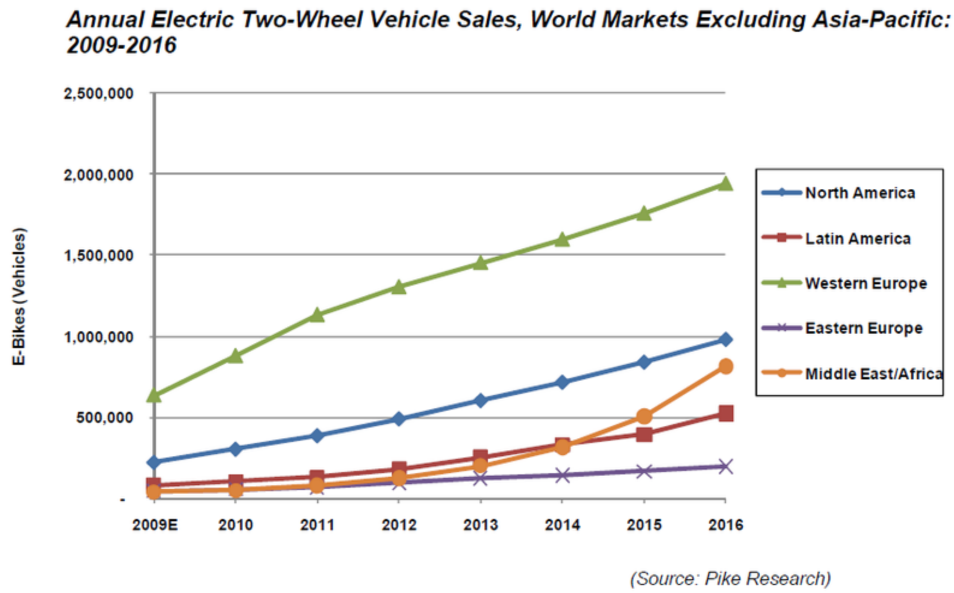
Every one of these bikes needs a battery.

However they don't all use the same batteries. In the developing Asian and Indian markets, the e-bike is a workhorse for those who cannot afford cars. Low price is the main requirement and consequently almost all the electric bikes use Lead acid batteries for which the CHEEVC design is not particularly suitable. In recent months however the Chinese government has closed down a lot of Lead acid battery factories, because of concerns about the toxicity of Lead, forcing the market to move towards more environmentally friendly Lithium chemistries.

On the other hand, in Europe and the USA, users have much greater disposable income and many bikes are used for recreation. They are prepared to pay for lighter weight, higher power and longer life and for this reason most of the bikes sold in Western markets use the newer Lithium Ion technology.

5.1.2. **Addressable Market**

CHEEVC intends to concentrate its efforts mainly on the markets which primarily use the higher technology Lithium batteries namely Europe which is easier to reach and to a lesser extent the USA since the US market is more difficult to serve from the UK. Thus, from the graph below, there is a potential market of over a million batteries per year.



Though there are many brands associated with these markets, many of the products are sourced from China, though they may be specified and designed in Europe. Sales of individual brands may be only a few tens of thousands per year. CHEEVC breakeven volume is about 25,000 units per year and this should be achieved with 5 or more customers. This is about 2% of the local addressable market.

6. **Target Sales Price and Sales Margin**

The product has very strong USPs as noted above and it is not the intention to sell on price. The pricing will be similar to existing products already in the market, but the product will offer enhanced benefits.

Because batteries are available in a wide range of voltages and current capacities it is difficult to compare prices of different batteries. For this reason it is usual to compute the price per Watthour (Wh) of the available capacity to obtain a like for like comparison.
Retail prices of batteries in the UK vary between £0.59 to £2.40 per Wh with £1.15 to £1.40 being typical.

The lower price offerings tend to be imported from anonymous manufacturers by low cost retailers and offer very little warranty or service support. On the other hand, the higher cost products are associated with branded products with proper service support.
The CHEEVC battery is designed to retail at around £1.12 per Wh and will be made in the UK.

7. **The Competition**
Currently there is a wide range of batteries in the market, mostly imported from China but there are no products with the benefits offered by the CHEEVC battery. The CHEEVC battery is cost competitive but it will compete because of is enhanced functionality, not because of the price.

8. **Safety**
The CHEEVC battery uses industry standard cells and battery management electronics which provide protection both of the battery and the user. It will also be available with improved thermal management provided by encasing the cells in a jacket composed of thermally conductive phase change material which absorbs and conducts the heat away reducing the likelihood of thermal runaway. Furthermore constructing the battery from small cells reduces the magnitude of any thermal event (fire) and reduces the likelihood of the event propagating to other cells in the pack.

9. **Product Development Status**
   - The concept of using rest periods to prolong battery life works and has been proven in practice.
   - Patents for the implementation of rest periods by means of cyclic redundancy and for software control of the battery voltage have been filed in November 2010.
   - Current activity involves building a complete enhanced battery management system for demonstration purposes by integrating the CHEEVC switching matrix with a standard BMS. The target date for finishing this development and start of production is August 2012.
   - Discussions have started with several potential OEM partners with a view to establish agreed specifications for electrical and mechanical interfaces to enable the product to be incorporated into a demonstrator vehicle.
   - It is most likely that each future customer will require these interfaces tailored to their products. This will require the company to maintain a custom design activity to support these sales. This will in fact give the company a competitive advantage because customers in Europe expect local engineering support. Potential low cost competing pack makers from Asia cannot provide this ongoing assistance to the customer.

10. **Futures**
Selling into the US market has not been considered at this stage because of the difficulty of supporting the sales effort there. This is a possible opportunity for CHEEVC once it has become established in Europe.
Ultimately all overseas markets will adopt Lithium technology opening up further markets for CHEEVC existing products but they will be very competitive.

11. **Funding**
Up to now the project has been funded by Mr Ken Norton who has so far invested over £300,000 in the project. This has been supplemented by a government SMART grant of £70,000 to support the feasibility study and, following the successful completion of the feasibility study, a second SMART R&D grant of £90,000 to support the subsequent development activities.