# The integration of second life EV battery and vehicle-to-grid charging into a micro-grid environment

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The global push to reduce the effects of global warming and climate change due to an increase in greenhouse gasses has forced governments worldwide to legislate stringent emission controls in various commercial sectors that includes the transport sector. The transport sector is one of the biggest contributors to air pollution and governments have implemented emission regulations that encourage OEMs to shift towards cleaner mobility in the form of e-mobility. This would be done at first, towards hybrid and plug-in vehicle systems, and then ultimately towards full electric vehicles (EV).

The introduction of EVs and their increase in the consumer market can be seen as a contributing factor to the increase in the electricity demand during peak time, which will further increase the imbalance between the grid's peak and off-peak demand and in turn shift the pollution effect to a different segment of the energy supply chain. However, by using smart holistic management of the integration of EVs, one can decrease the difference between the base load and peak load demand on the grid, thereby ultimately increasing the efficiency of power supply to the grid mainly supplied by coal power stations. This can be achieved by not only controlling the time of energy usage to the vehicle during charging, but also to see the EV as having the potential to serve as a power source to the grid with vehicle to grid (V2G) capability.

The uYilo micro-grid project hosted by the Nelson Mandela University in Port Elizabeth focuses on the integration of EVs into a micro-grid environment with a range of embedded generation systems that include solar energy (PV) as well as energy storage in the form of a second life EV battery. The growth of EVs within the market will result in a surplus of battery packs that reach their end of life due to capacity loss that has resulted from frequent cycling during the vehicle usage. The reduced capacity will result in shorter driving ranges for vehicles and the Lithium-ion (Li-Ion) battery pack would be considered as no longer being fit for mobility purposes. Even though the battery has reached the end of life for vehicle application, it still has the potential to be utilised in second life stationary storage applications where the size and weight design criteria are less crucial and its peak power demands are far less frequent.

The study will cover the aspects of using second life EV battery in an application within a micro-grid system, where the integration of the communication, control and hardware integration factors associated with it are shown. As well as how these factors need careful consideration in integration within an energy management and battery management systems to optimise the balance requirements between the various electrical generation systems and the effective utilisation of the second life battery. The project serves as a proof of concept of a pilot project that illustrates the feasibility of using V2G functionality whilst also incorporating the second life battery application to explore the application with the use of renewable energy.

The global shift towards e-mobility in markets worldwide will affect the South African market landscape as well with a sharp increase in the number of EVs on our roads expected within the next decade. These EVs are fitted with large Li-ion battery packs to provide the necessary energy for the vehicles usage. The average life expectancy of these battery packs are estimated to be between eight to ten years with current battery technology.

The Li-Ion packs used within mobility applications will be considered to have reached their end of life when the state of health (SoH) has reached 80% of original capacity. Although no longer fit for mobility applications due to the decrease in range, the end of first life battery pack still has its majority capacity left that can be utilised in an alternative stationary application where there are no size and weight constraints, typically micro-grid applications.

The article will look at integration factors and impacts of secondary life applications for EV batteries specifically within a micro-grid environment.

Second life EV batteries have the potential to play a big role in energy storage but the EV battery within the vehicle itself can be additionally utilised earlier in its life time with vehicle-to-grid functionality. Vehicle-to-grid technology enables EVs to discharge energy from the vehicle to power loads enabling all EVs capable of bidirectional energy flow, to improve the electricity landscape significantly.

**Second life EV batteries**

*Lithium Ion EV battery packs*

Li-Ion battery chemistry is the preferred choice for EVs due to their high energy density that suits the mobility criteria of light weight and space well.

Li-Ion battery packs require intelligent control to manage the collective pack, this function is fulfilled by the battery management systems (BMS) [1]. The BMS fitted to the battery packs ensures the safe, reliable and optimal operation of the pack. The BMS monitors cell voltage and temperature as well as ensuring that the bidirectional energy flow is within the safe parameters of the pack. The BMS also monitors the charging process ensuring cell balancing as well providing feedback on the performance parameters of the pack.

Apart from cell temperature and voltage, the two main feedback parameters associated with Li-Ion battery packs are:

- State of charge (SoC)

  The state of charge is the percentage of charge left in the battery, 100% indicating full capacity and 0% indicating that no more charge is left in the battery. The SoC parameter feedback is continuously used by the user to monitor the batter capacity level.

- State of health (SoH)

  State of health indicates the amount of charge the battery can store normally stated as ampere-hours (Ah). When a battery is new, the SoH should be close to the manufactured specification, i.e. SoH=100% but as the battery ages the SoH will start to drop. For example, a 100 Ah battery that is only able to produce 50 Ah is deemed to have 50% SoH.

A battery with SoH=50% can still be charged to a SoC=100% with only the amount of charge that the battery can store being reduced.

EV battery packs are deemed to have reached its end of life when the SoH falls below the 70%-80% threshold making the battery pack no longer fit for e-mobility purpose due to the reduction in the vehicle range which means the battery be either recycled or repurposed for other applications [2].

Recycling is currently a costly exercise and industry is looking to extend the usage of the pack by repurposing the pack for other applications.

Typical secondary battery applications where the space and weight criteria is of less importance are:

- Grid-based stationary application to assist peak shaving for utilities as well as optimising the integration of renewables.
- Off-grid stationary applications such as micro-grids fully utilising renewable energy.
- Other mobile applications such as recreational.

*End of life battery process for second life application*

EV Li-Ion battery packs that have reached their end of life need to be assessed first before the second life application can take place. The assessment process entails dismantling the pack to cell level and testing the cell by fully discharging it followed by a full charge to establish its capacity as well as establishing the impedance of the cell. The assessment of the cells within a pack ensures:

- Defective cells are removed from the pack to ensure safe operation of the pack for its next application.
- Ensuring the cells in the pack has the same capacity to optimise the battery performance as it is important to have similar capacity cells in a battery pack configuration.
- Upscaling or down scaling to take place with similar capacity cells, building smaller battery packs or adding cells to build a larger pack.

The second life application can be done with the existing BMS fitted from the manufacturer or in the case of a scaled application a new BMS will have to be fitted impacting the cost of battery as the new BMS will need to be designed and fitted to the pack in the case when the original pack has changed characteristics such as its series or parallel connections or cell and capacity amount.

*Second life application factors and implementations*

Applying the battery packs to a secondary application has the following advantages:

- Reduced cost of EV ownership, the owner can now sell the old battery at the end of EV battery lifespan.
- Business case for second life battery assessment and re-fitment.
- Using less new batteries reduces impact on environment.
- Battery storage could be cheaper, enabling mass roll out benefiting various industries as per above.

Factors to consider for second life battery applications:

- Second life batteries will be competing with other battery chemistries that will not be first life.
- Second life battery performance and reliability still being assessed for feasibility which can impact the value of the second life battery applications.
- Cost of assessment and possible customised BMS fitment in the case of scaling the battery.

*Second life application within a micro-grid environment*

The following integration factors needs to be considered during the second life implementation of the EV battery pack especially within a micro-grid environment:

- Battery pack high DC bus voltage interface to the inverter and DC bus.
  Traditional micro-grid systems utilises lead acid storage systems that are typically configured to 48 V and most inverters available on the market cater only for low DC voltage inputs on the battery DC bus. The integration of a second life battery requires a high DC voltage typically between 300 V and 900 V and only a limited amount of inverter manufactures are available when using an EV pack with existing BMS and configuration.
- BMS functionality to the energy management system via CAN bus.
  The energy management system controlling the storage process needs to be able to communicate with the BMS of the battery pack and must be integrated. CAN bus integration is necessary in the event of existing BMS from an EV being utilised.
- Specified charging philosophy.
  EVs typically have an on-board charger fitted in the vehicle which rectifies and controls the energy flow to the battery pack whilst communicating with the BMS ensuring safety parameters are in check.
  The fitment of the EV pack into a stationary application is without the charger and the grid-inverter is required to control the energy flow during charging events ensuring optimal battery operational and performance.
- Battery pack balancing.
  Cell balancing within such a large series string configuration will occasionally be required to be balanced [2]. This is due to the variation found in cell capacities and internal resistance as a result of tolerances within the manufacturing process. The unbalanced nature of Li-Ion cells is compounded by the series string configuration of the pack as the cells age differently depending on factors such temperature and capacity.
  The battery pack will need to be balanced on a weekly basis to ensure optimal performance which is controlled by the BMS during charging events.
- SOC/battery level indication.

  The SoC is important feedback for both the user and control system to decide when to charge or discharge the battery.

  The two methods involved in establishing the SoC of the pack are:

  - Open circuit voltage (OCV):
    The SoC can be derived using the pack voltage to estimate the remaining charge that is left within the pack. The calculation is not very accurate but is reliable.

  - Coulomb counting:
    The SoC calculation is done by measuring and monitoring the energy flow in and out of the pack, enabling the BMS to keep count of the SoC. This method enables much more accuracy but has the disadvantage of

becoming inaccurate after prolonged active states where small inaccuracies in current measurements result in SoC drifting, creating false SoC feedback.

The best way to calculate the SoC is a combination of the two methods in order to reset the coulomb counting after every driving cycle [1].

- Operating environment.

  Removing the EV battery pack from the vehicle and implementing the pack in a micro-grid environment affects the battery operation and these factors should be taken into account. Most EV battery packs have closed cooling systems using liquid or gas cooling.

  - Temperature and moisture: the battery pack placement should be in a temperature-controlled environment away from direct sunlight to ensure the battery stays close to room temperature and dry as well as ensuring that the original cooling system is integrated or a similar environment for a scaled battery pack.
  - Li-Ion battery packs are well protected within a vehicle and care should be taken to ensure the new environment is free from potential items falling and damaging the pack if the pack is used in a different configuration.
  - Human safety factor: the Li-Ion battery packs fitted to the EVs have much higher voltages than conventional storage systems and persons should be made aware of dangers and access should be controlled to the second life battery pack if possible.

**Vehicle-to-grid technology integration**

The predicted rise in electric vehicle numbers in cities and towns will have the result of multiple electric vehicles being integrated into the grid and homes. The vehicle integration to the grid has the possibility to add to existing energy supply and balance problems without smart integration.

Vehicle to grid (V2G) functionality entails the bidirectional energy flow from the EV battery to the grid or micro-grid. The V2G functionality provides the capability to charge the vehicle as well as inverting the battery power to AC power to be utilised by a load.

The reverse feedback can be done on several scales:

- Vehicle to small load (V2L) discharge functionality enabling the user to power small loads in remote areas such as power tools for example.
- Vehicle to discharge to home (V2H) enabling the owner sustain the home during peak/expensive times, reducing energy costs.
- Vehicle to micro-grids (V2G), providing energy feedback into a smart system to be utilised optimally in load and energy supply demand management.
- Vehicle to grid (V2G) functionality enabling the levelling of peak demands impacting on the efficiency, cost and environmental impact of the energy utility.

The impact of feeding back energy from an EV benefits the following:

- The energy supplier/regulator due to the control challenges associated with additional feed into the grid.
- The local distribution network provider, distribution equipment can be become overloaded as well as the fear of revenue loss due to additional energy inputs.
- OEM of vehicles due to the extra cycling of the batteries shortening the expected life cycle.
- Home owners due to the extra cost involved in V2G infrastructure.
- The vehicle ownership model, battery/vehicle leasing possibilities.

V2G functionality is not fully endorsed by all vehicle manufacturers as discharging from an EV's battery more potentially accelerates ageing of the pack. However studies reveal that the V2G functionality impact on battery life is minimal [3] Therefore some manufacturers see the V2G discharge aspect as part of their strategy and with smart control of the discharge activities the cycling can be limited during the lifetime of the vehicle with the following benefits:

- Peak shaving: with proper control the power utility can benefit from the grid storage by levelling of the load demand improving grid supply efficiencies as well as driving costs down of electricity.
- Frequency control: the grid frequency is a balance between supply and demand. V2G can stabilise the grid frequency in the case of supply decrease or demand increase.

- Voltage control: phase shifts due to reactive power can be reduced closer to unity making power utilities more efficient and saves costs as well as emissions.
- Local distribution providers can balance their supply and demand with control as well as local distribution reliability with the V2G functionality being able to supply demand during a transformer trip for example.
- OEM of EVs can be benefitted by the added functionality of V2G charging for owners of EVs.
- The home and vehicle owner can supply his/her own loads during peak/high tariff periods to drive down cost of ownership as well as energy costs. The cost of ownership of the vehicle will further decrease due to lowered energy cost.
- V2G will aid in storing renewable energy for utilisation during critical times.

Fig. 1 shows the summer and winter energy demand of South Africa during 2015. Two energy peaks can be seen with very low demand during late night and early morning.

EVs can assist in flattening the demand curve, enabling more efficiency for power utilities resulting in less emissions and cheaper tariffs. This will benefit the introduction of renewable energy which has the drawback of generation being intermittent. Storage will benefit the implementation of renewables greatly but storage is costly to implement hence the benefit of harnessing the vehicle storage application.

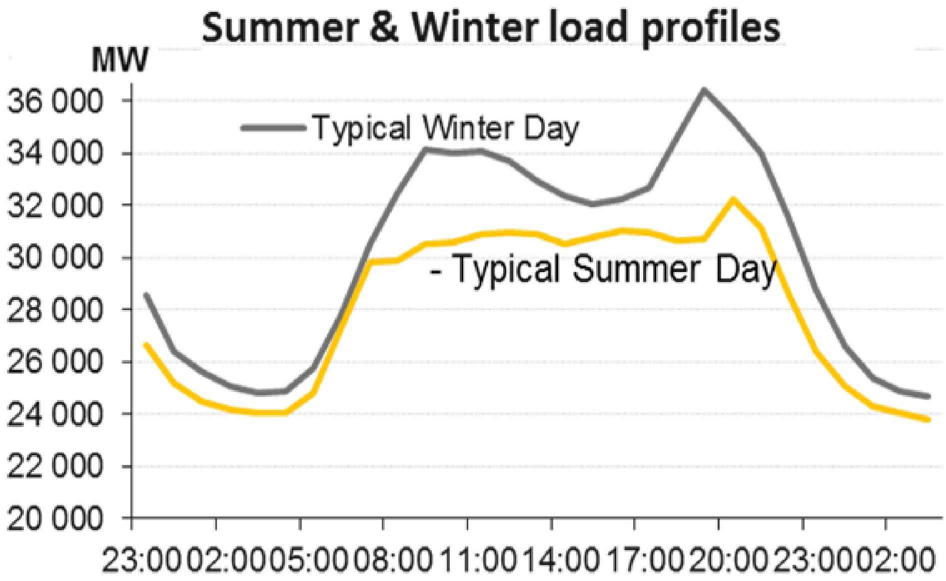


*Fig. 1: Typical South African daily demand cycle. Source: BusinessTech 2015*.

**The uYilo micro-grid**

uYilo has implemented a pilot project to showcase and demonstrate the second life battery application integration within a micro-grid with renewable energy and V2G functionality within an South-Africa context.

The micro-grid consists of the following:

- PV solar array as energy source for micro-grid.
- Second life battery storage with an aged pack from an EV with original vehicle BMS using CAN bus communication protocol.
- Hybrid inverter with two DC input channels with grid-tie and grid-forming functionality.
- Grid switch to control grid synchronisation and connection/disconnection of the system.
- Energy management system to control the interaction between the various components and systems.
- Vehicle to grid hardware capable of charging and discharging up to 10 kWh with dynamic change in direction of energy flow.
- Loads in the form of electric vehicle chargers supplying energy to the various vehicles within the programme.

Fig. 2 shows the uYilo micro-grid pilot project hardware layout with the energy management system (EMS) controlling the hardware and acting as interface for communication within the various components within the system.

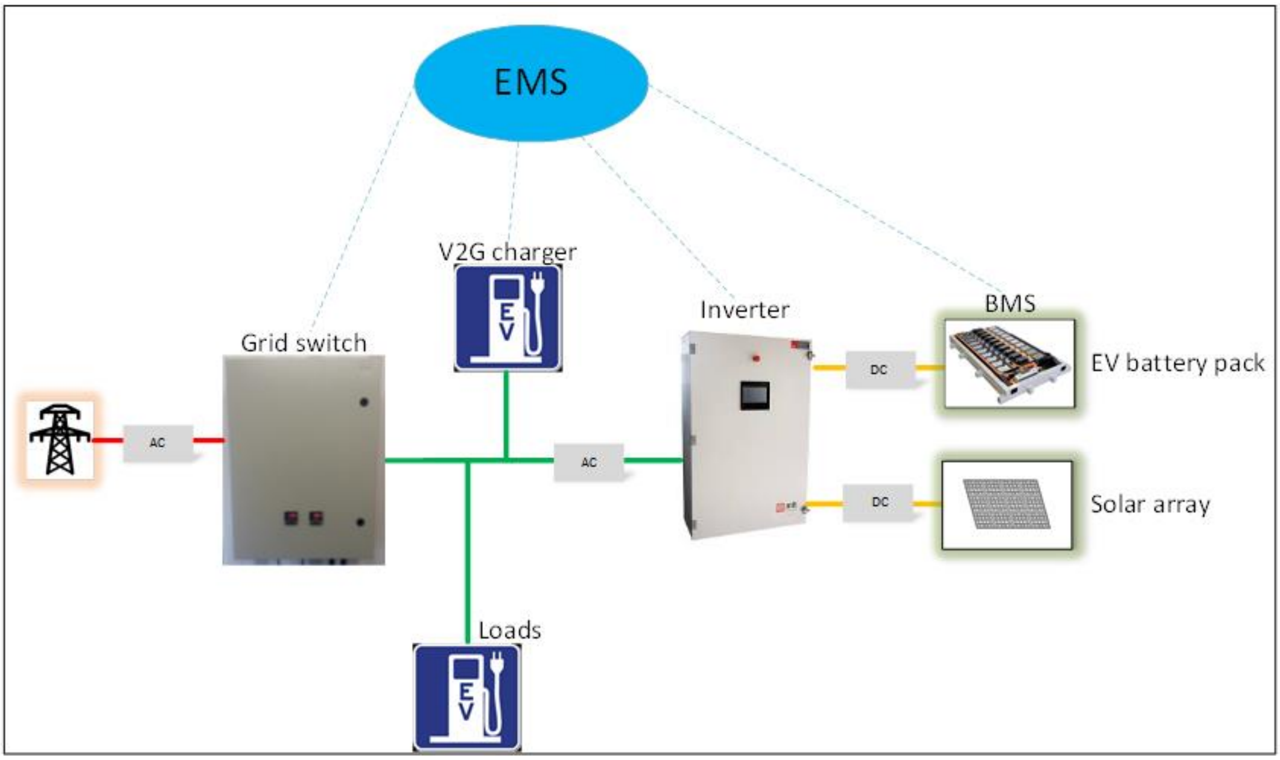


*Fig. 2: The micro-grid layout of the pilot project. The EMS controls the energy flow from the inverter, V2G charger, grid and battery.*

Factors considered during integration of second life battery application and V2G charging into the micro-grid:

- The EMS must be integrated with the V2G charger controller in order to control the charging and discharging according to the micro-grid control philosophy. The control must be able to alter the energy flow in real time with IEC 61850 communication implementation for fast operation for grid stabilisation function. The EMS will also be able to implement predictive control for demand load management implementation.
- Synchronisation between the V2G charger and inverter within the micro-grid. Synchronisation is important for both grid-tied and off-grid operations of the system. The inverter is tied to the grid switch and will control the synchronisation to the grid with the V2G charger following. The interaction between the inverter and V2G charger is important and various control philosophies will be tested and monitored between the devices.
- Anti-islanding detection protection functionality within the micro-grid. With the addition of the V2G charger, care should be taken to ensure the safety and integrity of the micro-grid with tests to be conducted to test protection functions of connected devices.
- SoC of the battery pack accuracy impacting the control functionality of the EMS. Coulomb counting found to be inaccurate due to the cycle nature within a micro-grid.
- Weekly balancing of the second life battery pack in order to keep the battery pack functioning optimally.
- The charging control settings of the second life battery needs to be set correctly to allow balancing of pack to be achieved.
- Second life battery capacity to be evaluated before and after testing period to observe ageing compared to the cycle activities captures by the system.
- Correct control of BMS states of second life battery to suit the micro-grid control philosophy best.

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