Applications of Automotive Technology for the Electrification of Rural Areas through DC Microgrids

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***Abstract*— Electrification of rural areas is an ongoing problem worldwide. Currently utility companies try to and extend their network to the rural areas to provide electricity after increasing their load capacity. This solution not only takes years to plan and implement but is also not cost effective or efficient. Therefore, there is a need for a new electrification solution. This paper proposes that a DC microgrid is used for the electrification of rural areas. The microgrid configuration was selected due to its promising expansion results, which has enabled many developed countries to expand their network capacity in an environmentally friendly as well as smart manner. The DC topology was chosen because of its high efficiency and cost effective installation characteristics. In order to maximise the storage within the microgrid, nanogrids are proposed for individual households, meaning that each household will have its own supply as well as storage cells. The supply speculated by this paper is Solar PV; chosen because of the location of the population in question. In order to manage any excess power a localised storage system is proposed. This will act as a backup power supply when any of the lighting storage cells run out of capacity. This paper proposes that the for lighting purposes ultra-capacitors are used while for general appliances recycled 18650 cells are used. Using the recycled 18650 cells not only reduces the cost of the total system but also provides a recycling method for all the old 18650 cells which are expected to enter the market through the sales of Electric vehicles. The process of recycling old Electric Vehicles battery banks for cells has many advantages. One significant advantage, excluding the positive environmental impact, is that the community can constantly increase their own capacity and hence easily expanding their own network. Further research in implementing this solution will occur.**

***Index Terms*- 18650 Cells; DC microgrids; Distributed Generation; Nanogrid; Rural Electrification; Solar PV**

I. INTRODUCTION

Ever since the discovery of electricity some 140 years ago, peoples' dependency on it has increased significantly and machines and systems have been electrified wherever possible. Electricity has become so important in our day to day lives, that now it is included in the human rights legislation of many countries [1]. However, it was estimated that in 2016, 1.2 billion people still had no access to electricity [2], not to mention the millions of individuals who have unreliable energy sources [2]. Traditionally, the problem to supply electricity to an area would be solved by extending an existing network into the rural areas. However this approach is only viable in more developed countries, where the supply is stable and can handle the additional loading. If an underdeveloped country attempted to implement this solution, their electrical network is likely to become unreliable, hindering their development even more. Furthermore since 95% of those living without electricity are in underdeveloped countries [2] this is not a solution. A more viable solution, which has been mentioned repeatedly in literature [3]–[6], would be to use a microgrid for the specific rural area. Microgrids are not only being used in developing countries for electrification but also in developed countries to expand their network capacity [7]. The expansion projects in developed countries have primarily been focused on creating 'smart grids' with the inclusion of renewable energy sources for increased capacity. There are three main topologies which have been implemented: AC microgrids, DC microgrids and hybrid system microgrids. Currently the most common microgrid topology in use is the AC variation. This is due to its compatibility with current grid structures [8],[9]. However, electrification systems in buildings are slowly moving towards hybrid systems that can take advantage of the high efficiencies of the DC system, while still being able to power regular AC appliances [10]. DC microgrids are significantly more efficient than its AC counterpart, due to the lack of energy conversion links within the system and lower line losses [11]. Another significant advantage of the DC micro-grid is that it "does not need to track the phase and frequency of the voltage, which greatly improves the controllability and reliability of the system" [12]. The lack of frequency monitoring also allows for additional sources to be easily integrated into the system. One organisation which is at the forefront of implementing hybrid systems in large buildings, is EMerge Alliance [13]. EMerge Alliance focuses on running a dual AC and DC system in buildings, where the DC system is used to power the lighting throughout the building and the AC system powers the regular office loads. The mission of EMerge Alliance is to improve the stability as well as the efficiency of the electrical grid both on the micro and macro scale through the implementation of standards which promote the use of DC microgrids.

II. DC MICROGRIDS

The implementation of a DC microgrid offers many advantages for first-time customers. The advantages for an urban and rural customer will differ slightly due to the appliances which the customer already owns. In general, DC microgrids offer the following advantages to their customers over their AC counterparts.

1. Lower raw material costs, as fewer conductors are required [14].
2. Lower installation costs due to reduced planning. Primarily caused by [14]:
   a. A lack of complex numbers in the analysis.
   b. A lack of susceptance and reluctance present in the system.
   c. No frequency or synchronisation problems with multiple sources.
3. Reduced system size. Caused by a lack of synchronising equipment and transformers needed for traditional AC systems [15].
4. Increased appliance efficiency. Avoiding the AC-to-DC conversions can save as much as 30% on a user's total energy bill [16].
5. Increased compatibility with renewable resources, therefore, reducing the environmental impact of a DC microgrid while at the same time allowing for more types of sources.

However, with that being said the implementation of a DC system in an already urban environment is challenging due to its effect on the customer's lifestyle. Urban customers are affected far more than their rural counterparts as they will have to repurchase almost every appliance in the household. Rewiring is an option. However, this requires some technical know-how and thus cannot be expected from the average individual.

The construction of a DC microgrid can be done in three possible configurations: two-wire, three-wire and ring-shaped. Each configuration exists to serve a different sector in industry, however the two-wire variation is most commonly installed configuration [17]–[19]. The reason for this is due to its lower line losses and reduced installation cost [17]. However for DC microgrids with high capacity requirements, a three-wire system is recommended but balancing issues do exist [20].

I. Energy Sources

Distributed Energy Resources (DERs) are used in microgrids as power sources due to their size, controllability and mobility advantages [21]. Typical examples of DERs include diesel generators, micro turbines, photovoltaic (PV) systems, fuel cells and wind turbines. The use of PV solar systems in microgrids is not uncommon. Developed countries have opted for their installation not only for their reduced environmental impact, but also because the implementation times of PV systems are significantly less than coal and nuclear fired power stations. These factors, along with the decreasing cost of solar PV panels as well as advancements in battery technology and power electronic devices make solar PV technology highly suitable for any microgrid, especially DC microgrids.

According to the International Energy Agency (IEA), "95% of those living without electricity are in countries in Sub-Saharan Africa and developing Asia" [2]. The potential for using PV solar systems in African countries is extremely high as the number of hours of sunshine in Africa is higher than any other continent. North-eastern Africa holds the world record for the highest number of hours of sunshine a year, 4300 hours. This is in fact 97% of the total maximum hours possible [22]. Utilising this energy effectively would be impossible without some sort of energy storage device. The need for a storage device is not only there for night time usage but also to provide a buffer for heavy loading. In larger power grids, this storage is provided by the inertia of the generators. When a new load is connected to the system, the initial energy balance is satisfied by the system's inertia. The result of this loading causes a very slight change in the system frequency [21]. In microgrids the storage can be provided by batteries, ultra-capacitors, flywheels and in some instances water reservoirs. The batteries used can either be stand-alone banks, or the batteries found in modern Electric Vehicles (EVs). In urban environments the use of EVs is becoming more popular. Vehicle-to-Grid (V2G) technology has a great potential to improve the electrical stability of a country, however buy-in from the owners is required. The basic premise of a V2G system is to use the vehicle as a storage device; charging it when the overall demand on the grid is low and using the vehicle as a source when supply is low. The concept of using EVs as a storage device in a microgrid introduces a new topology or scale to the microgrid. The placement of energy storage devices within every home through the use of EVs essentially makes each home its own microgrid or nanogrid within a microgrid [23]. This configuration maximises the number of energy storage devices as well as capacity present in the grid. In rural areas the use of EVs is not possible. However, the concept of creating many nano grids within a microgrid should be investigated. Fig. 1 represents a generic nanogrid configuration which can be used within the rural community.

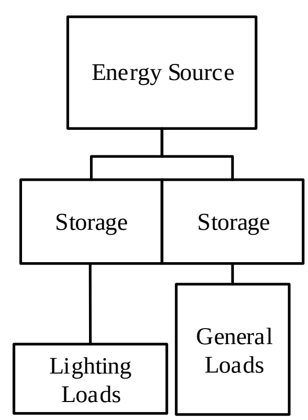

Figure 1: Nanogrid Configuration

It can be noted that the storage within the nanogrid is split into two separate units. The purpose of this to ensure that there is a dedicated supply for lighting at all times. This storage will take priority and charge first, ensuring that lighting is available every night. The proposed microgrid layout is shown in Fig. 2. A localised storage unit will be used to store any excess charge which is available during the day. This will act as a backup power supply in the instance where one or more of the lighting storage banks need additional power.

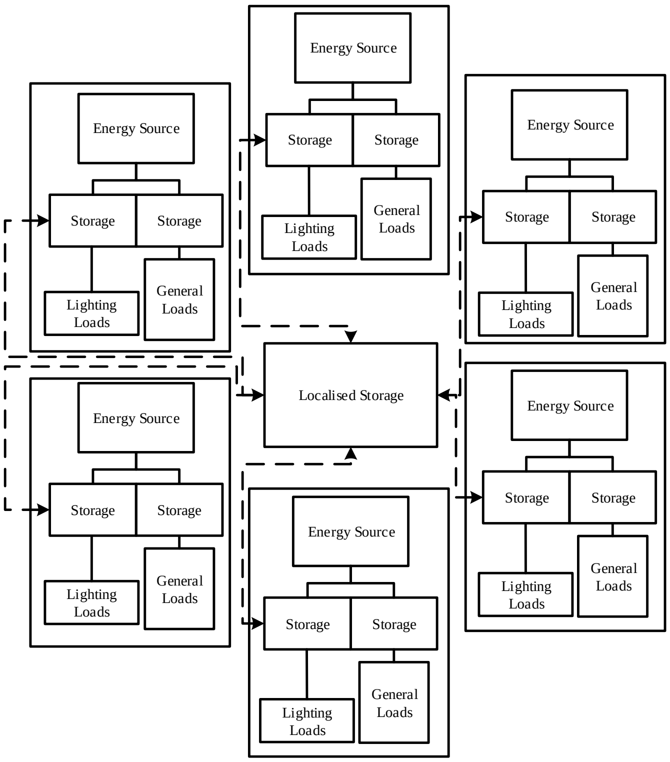

Figure 2: Microgrid Configuration

II. Storage solutions

As shown in Fig. 1 and 2 the storage used within the nanogrid is separated into two sections. The primary reason for this is so that lighting is guaranteed daily as well as in the long term plan. The storage which will be used for general loads and lighting loads will be different. The proposed storage for lighting will be ultra-capacitors[1], while batteries will be used for the general loads. The justification for using ultra-capacitors to power the lighting of a household is solely placed on the longevity of the storage device. Since no chemical action is involved in charging or discharging the ultra-capacitors, the effect is easily reversible with minimal degradation of the capacitor, even in deep discharge cycling. The typical cycle life of ultra-capacitors is in the hundreds of thousands of cycles, while still producing extremely high efficiencies (84-97%) [24],[25].

The proposed storage for the general loads is recycled 18650 cells. With the popularity of 18650 cells growing, it is only logical to recycle them in a meaningful way. The process of determining the number of 18650 cells which will need recycling has been covered by [26]. The authors used the Annual Energy Outlook data provided by the U.S Energy Information Administration (EIA) [27] to predict the number of EVs sold, shown in Fig.3. Using this data as well as their own algorithms they were able to predict the number of 18650 cells in every battery pack of every vehicle which is shown in Fig. 4 (within the figure EOL stands for End of Life). The prediction algorithms used within [26] took the following variables into account when determining the number of cells within every vehicle:

1. Vehicle electric range (R_i)
2. Vehicle consumption rate (C)
3. Battery efficiency (η)
4. Available energy of EV battery (A_i)
5. Cell energy storage ($Ecell_j$)

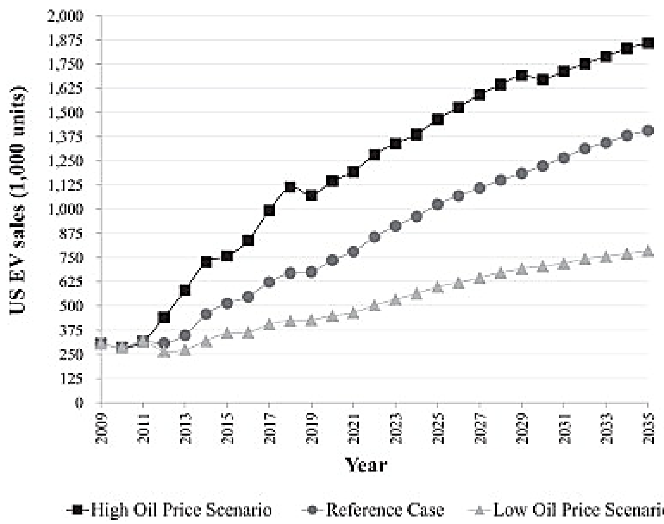

Figure 3: EV Sales forecasts for the USA, image taken from [26], but generated using [27]

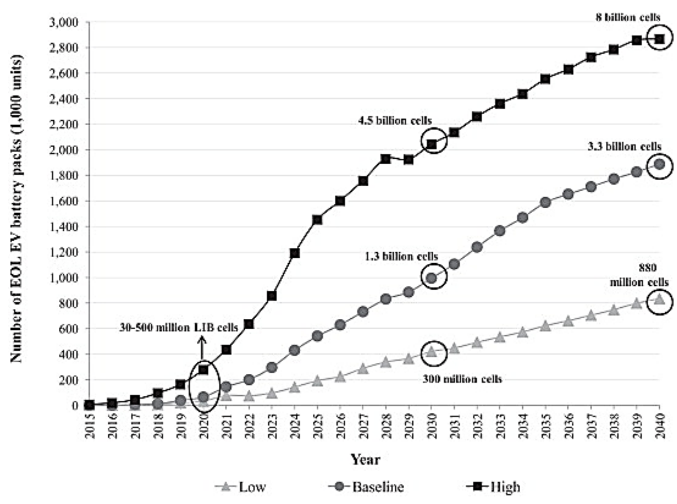

Figure 4: Number of 18650 cells generated from EV applications between 2015 and 2040 from [26]

Since the publication of [26], new predictions have been made on the sales of EVs within the USA by the EIA [28], the updated prediction is shown in Fig. 5. The new prediction is

[1] Also known as super-capacitors

significantly higher than the one made in 2012 with one noticeable change, the oil price does not dictate the number of EVs sold as drastically as it did in 2012. There are many factors which have led to this but the suspected cause is the launching and sale of EVs by Tesla and other big motor vehicle brands.

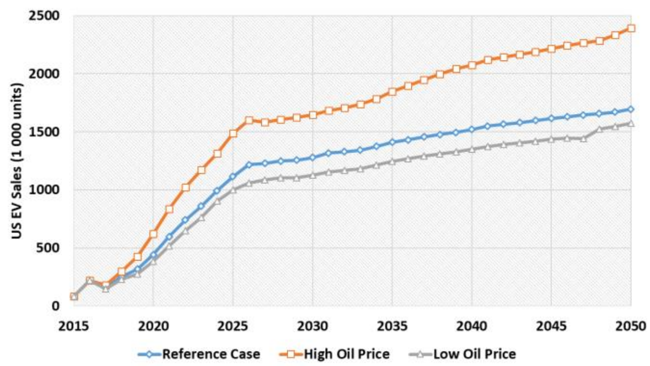

Figure 5: EV Sales forecasts for the USA from [28]

With this increased prediction, even more lithium ion cells will enter the waste streams, hence making the need for recycling plans even more critical. The predictions made in [26] estimate that between 38% and 43% of the batteries in the waste stream will be type 2 EOL cells, where type 2 cells are defined as; "Those found in vehicles that reach their end-of-lives before their batteries" [26]. These type 2 cells are not only available from EVs but also old appliance batteries like laptops and power tools and have already been used to create power walls in homes by DIY enthusiasts. The primary advantage of using recycled cells is the reduced cost as well as environmental impact. By allowing communities to create their own storage banks with recycled cells it not only solves the problem of how to recycle the battery banks from EVs but also empowers the community.

III. Discussion and Conclusion

The implementation of microgrids in developed countries has led to the building of smarter grids while at the same time expanding their network in an environmentally friendly manner. The most efficient variant of the microgrid is a DC microgrid but it has been implemented less frequently in urban environments (developed communities) due to the lifestyle changes required of customers to use them. Rural customers however do not have these problems as they usually either only own DC appliances or do not own any electrical appliances. Since the vast majority of the "non-electrified" communities live in solar rich areas, solar PV systems will be used. Low cost MPPT converters are available to ensure that all the available power is extracted from the panels.

There is a need for a new electrification solution which will provide an efficient and effective supply of electricity to rural communities. Even though this problem has existed for many decades, the body of knowledge surrounding the use of a DC microgrid as a solution, is very limited. Consequently, the development of a DC microgrid based solution is suggested. The research will focus on an implementable design which includes the high-efficiency advantages of using a DC system while at the same time evaluating the feasibility of using a dual storage system of ultra-capacitors and recycled lithium ion batteries. This type of storage solution will not only provide a use for old EV battery cells but will also empower the community in a manner which is sustainable, providing long term solutions for both electricity and sustainability.

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