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Understanding Electric Vehicles Battery, Charging & It's Impact on Power Quality

Sushant Subhash Kamble[1] and Dr. Anwar Mubarak Mulla[2]
[1]Research Scholar, GCE, Karad & Lecturer, Walchand College of Engineering, Sangli (MS), India
Email: sushant1wce@gmail.com
[2]Principal, Daulatrao Aher College of Engineering, Karad (MS), India
Email: ammaitp@rediffmail.com

***Abstract*—Battery is a device that converts chemical energy into electrical energy and vice versa. The use of battery in automobiles started in early 1900's. In initial stages, battery was used for energizing automobile accessories like head lamps, indicators, horn etc. The recent advances has put battery for use in staring IC engine with electric start, integrating music system in automobiles, mobile charging and even in some of the high end vehicles custom inverters are build on battery that makes the vehicle suitable for camping purpose. Now a day's the battery operated electric vehicles are becoming popular which addresses the key challenges in reducing pollution. Likewise the use of battery in automobile sector has advanced through the years. The cycling of battery is done in terms of charging and discharging. Depending upon the size and specifications, the time taken to charge battery differs. This charging time layoff hampers the performance of electric vehicles. Various strategies, battery charging methods, charging stations are proposed and developed by researchers leaving behind critical issues related to the power quality to be addressed. This paper focuses on advancements in battery usages and charging in Electrical Vehicles. The power quality issues arising as a result of non linear load are presented.**

***Index Terms*— Battery, Electric Vehicle, Battery Charging, Power Quality, Harmonics.**

I. INTRODUCTION

Conventionally power systems are designed for unidirectional power flow. Recently PV systems and wind turbines are gaining popularity as alternate energy source. Being accepted as a clean energy source, it helps ecological system in reducing CO2 emission. They also offers many advantages like reducing burden on grid, flexibility in installation and capacity extension and decrease dependency on fuels.

Batteries have been commercially accepted as energy storage device. Until recent developments, high installation cost, short life time, low efficiency, long charging time were setbacks for installation of battery systems. However, developments in lithium ion battery have somehow overcome some of the limitations in battery usages.

II. BATTERY SYSTEMS

A battery converts chemical energy into electrical energy and vice versa. A battery is composed of cells. These cells are assembled in series and parallel combination so as to bring it to the required specifications. The

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technical specifications of battery are mentioned in terms of nominal voltage, capacity in Ah, nominal energy, life cycle, maximum discharge current, charging voltage, charging current and internal resistance [1].

Batteries are of two basic types: “primary” batteries that are discharged once and then discarded and “secondary” batteries that are recharged many times [2]. Another useful distinction is between “consumer” batteries as purchased by individuals, and “industrial” batteries as used in industry and commercial applications. Most consumer rechargeable batteries are small, single-cell devices, whereas industrial batteries tend to be much larger, multi-cell modules [3].

The processes taking place in the so-called "active materials" of the electrodes are very complicated in a battery, but they can typically be represented by simple electrochemical equations at first approximation. The equations describe a reduction phase during discharge with electron uptake at the positive electrode and an oxidation process with electron release at the negative electrode. In the external circuit, the electrons move from the negative electrode to the positive electrode. Recharging a secondary battery is essentially a reverse of the discharge-related processes [4].

Rechargeable batteries come in several different types, ranging from small consumer cells found in toys and hand instruments, to large cell banks or systems used in some standby control applications and in submarine propulsion. The batteries are often based on various chemistries, some of which are classical and well known, while others use modern electrode materials and/or electrolytes of more recent origin. However there are current growth projects for all sorts to improve efficiency and quality, as well as to reduce production costs. For eg, as used in nearly all internal combustion engine automobiles, the classical lead-acid battery is now better in efficiency, is lighter in weight, lasts longer, and cheaper than it was some years ago. [5].

Although numerous types of batteries have been invented, but the commercially available batteries are lead acid battery, Nickel Cadmium (Ni-Cd) battery, Nickel Metal Hydride (Ni-MH) battery, Lithium ion (some times called Lithium Iron) battery and Lithium Polymer battery. The selection of battery for any application is based broadly based upon energy density, power handling capability, charge efficiency, cycling capability, lifetime and initial installation cost. Batteries are improving day by day to meet the never ending needs of applications with adapting new technologies [6].

The most popular form of storage battery is the ubiquitous lead-acid battery, patented in 1859 by Planté and greatly improved in 1881 by Faure. Over 90% of the world market for medium-to-large rechargeable batteries is still met by lead-acid; most of the rest is satisfied by nickel-cadmium. For small-sized batteries, traditional nickel-cadmium cells are being rapidly replaced by nickel metal- hydride and lithium-ion cells on account of their superior performance [7].

For lead acid batteries, diluted sulphuric acid is used with 3:1 water to acid ratio as an electrolyte. In this electrolyte, molecules of the acid split into positive hydrogen ions (H+) and negative sulphate ions (SO4- -). The hydrogen ions when reach at PbO2 plate, they receive electrons from it and become hydrogen atom which again attack PbO2 and form PbO and H2O. This PbO reacts with H2SO4 and forms PbSO4 and H2O [8].

The lead acid battery is characterized by following overall chemical reaction

$$PbO_2 + 2\,H_2SO_4 + Pb \; \overset{\text{Discharging}}{\underset{\text{Charging}}{\rightleftarrows}} \; 2PbSO_4 + 2H_2O$$

Lead Acid batteries are manufactured in wide variety of capacities ranging from 1 to 3000Ah for domestic, commercial and industrial applications. It is the most successful and widely used battery in the world. Lead acid battery manufacturing has faced many challenges since its invention. The key issues addresses are high cost, short life cycle and considerable maintenance. Hence It manufactured to suite the desired purpose in wide range of varieties like tubular battery, flooded lead acid battery, sealed lead acid battery, starting battery, deep cycle lead acid battery, AGM lead acid battery, valve regulated lead acid battery, standby and marine specific battery etc. Further more, other issues like environment and safety and material recycling are becoming more critical [9].

In vehicle starting, lightning, ignition (SLI) and industrial motion control batteries, the lead-acid battery finds a wide variety of uses including large stationary batteries for standby power, including small sealed cells for portable applications. Other rechargeable devices are unmatched by their rare combination of low cost, chemical and physical durability, and rechargeability. A lot of businesses are driving the market for improved batteries. For consumer electronics, industrial and stationary storage applications, rechargeable lithium ion batteries have emerged as the dominant energy storage source. The truth of cars is affordability. The cost of the battery system significantly affects electric vehicles. Use of solid state electrolyte in lithium ion battery gives improved energy density. It also has advantages of improved performance over temperature rage and improved safety [10].

Fundamental development on lithium-ion batteries goes back to the 1970s, and since the 1980s, notable progress has been made. In 1991, the first consumer lithium-ion battery was introduced, allowing for a relatively brief time between experimental study and mass development. Michel Armand has played a key role in the production and growth of lithium-ion battery cathodes, anodes, and electrolytes among the people who contributed to this progress from this start until now [11].

Lithium ion batteries are made up of one or more generating compartments called cells. Each cell is composed of three components: a positive electrode, negative electrode, and a chemical called an electrolyte in between them. The positive electrode is made from chemical compound named lithium cobalt oxide ($LiCoO2$) or lithium iron phosphate ($LiFePO4$). The negative electrode is made up of carbon (graphite) and the electrolyte varies from one type of battery to another. All lithium ion batteries more or less work in same manner. During charging the battery, lithium based positive electrode withdraws some of its lithium ions, which move through the electrolyte to reach to the negative electrode and remain there. The battery stores energy during this process. When the battery is discharging, the lithium ions move back across the electrolyte to the positive electrode, producing the energy that powers the battery. In both the cases electrons flow in the opposite direction to the ions around the outer circuits. Electrons do not flow through the electrolyte as it tends to be an effective insulating barrier, as far as electrons are concerned. The movement of ions (through the electrolyte) and electrons (around the external circuit, in the opposite direction) are interconnected processes and if any one of them stops and the other also stops. If ions stop moving through the electrolyte because the battery completely discharges and the electrons can't move through the outer circuit either, so the power is lost. Similarly we switch off whatever the battery was powering, the electron flow stops and so does the flow of ions and the battery stops discharging. Unlike other batteries lithium ion batteries have built in electronic controllers that regulate the charging and discharging in them. They prevent the overcharging and overheating that can cause lithium ion batteries to explode in some unusual circumstances.

The good amount of combination in the lithium iron phosphate and lithium cobalt batteries can be used in today's world, with one (Lithium Cobalt) supplying tremendous power for heavy applications and longer life, and another (Lithium Iron Phosphate) offers good protection with less power relative to lithium cobalt batteries. Though lithium cobalt batteries are equipped with safety electronic devices along with the safety shell on its body, still they are not fully used in cars and other vehicles because of the safety concerns as they can catch fire or explode due to the extreme heat, overcharging or thermal runway, But we have very few cars which has started experimenting such batteries to power their vehicles up to certain extent whereas lithium iron phosphate batteries are widely used in all types of small devices including laptops, mobiles, IPods, digital cameras and many more and In some cases they are also used in HEV's and EV's. Technological research has made it possible for us to hit the point where research is being carried out to discover advanced electric vehicle battery technology and use it as a replacement for gas-powered cars and other vehicles. If we continue to advance the way we have done in the area of battery technology development in the last 10 years, then we will have high potential batteries in the near future that would take time to charge as little as it takes to recharge the car today. Also if we come up with such amazing technology, it will also help us minimise the impact of global warming and noise emissions [12].

III. Battery Charging

For lead acid battery, various charging methods are developed as – constant voltage / constant current, pulse charging, negative pulse discharge method, superimposed pulse frequency method, intermittent charging method and interrupted charge control. The comparative study of above methods reveals that there is no single perfect charging method for lead acid battery. Each charging strategy has its inherent advantages and shortcomings [13].

With constant current charging method, initial charging current is limited to an acceptable predetermined value but this add to lengthened charging time. On the other hand, constant voltage charging has higher current which also results in evolution of gas in the battery which in turn affects the performance of the battery [14].

The superimposed pulse frequency technique not only has higher efficiency than simple pulse charging but also extends the lifetime of battery. The intermittent charging method reduces grid corrosion however it adds to the risk of undercharging. It ensures full battery recharge and does not affect the temperature. It extends the battery's life by minimizing grid corrosion and protecting the battery from undercharge [15].

For lithium ion battery charging, the methods used are, trickle charge – constant voltage – constant current, stepwise charging pattern, pulse charging method and boost charging method. Constant Current Constant Voltage Trickle Charging technique is widely used for its simplicity and charging efficiency. However, the charging time is too long due to the Constant Voltage mode, which will also damage the battery and reduce its life. The five-step charging pattern technique reduces the charging time with no damage to the battery due to the suppression of the constant voltage mode. However, it is a difficult task to obtain the optimal charging pattern that will lead to the optimal charging efficiency. The pulse charge technique reduces the charging time relatively to the trickle charging technique. However, the five step charging pattern has a more significant impact on the charging time than the pulse charge technique. The boost charging method significantly reduces the charging time, a fully discharged battery can be recharged within 5 min to one third of its rated capacity [16].

Apart from the above mentioned methods, many researchers have proposed charging techniques for lithium ion batteries to improve efficiency of charging system as well as implementing the circuit protection. Such method comes with added advantages and features [17].

Lead acid batteries find wide range of applications despite of low efficiency, low energy density and shorter life cycle. The higher metal contents in it make it cumbersome for their disposal in the environment. On the other hand, lithium ion batteries provide high efficiency, high energy density and longer life cycle. This makes it as first choice in on grid, off grid and distributed energy applications [18].

Battery powered vehicles are gaining popularity on account of pollution free and silent operation. The electrical vehicle has to make a proper choice of battery. The choice of battery is determined by various factors [6]. The comparative study of various batteries has shown that lithium ion batteries are optimal choice for electric vehicles [19].

Several trends have led to an improvement in the convergence of PV with the electric vehicle (EV) charging scheme, including the steady decline in the price of PV devices, the exponential development of EVs and the concern about the impact of greenhouse gases. The EV charging stations fall into four categories as – residential charging station, charging while parked, charging at public charging station and battery swapping [20]. These EV charging stations can be energised by PV charging methods as – PV Grid charging and standalone PV charging. Standalone PV charging systems are implemented as PV to EV or with intermediately energy storage between PV & EV. This scheme requires a charge controller to meet charging voltage and current requirements of EV. The integration of PV and grid makes the charging system flexible and also increases the battery lifetime.

IV. Impact of Battery Charging on Power Quality

The penetration of battery chargers for electric vehicles (EV) in electric networks is foreseen as a potential problem for power quality. Grid connected battery chargers are rectifier based nonlinear devices that inject harmonic currents and pollute the overall power quality. The measurement of power quality is possible with power quality analyzer. The comparative study of single phase and three phase battery chargers shows that single phase circuits injects more harmonics as compared to three phase battery chargers [21]. A known harmonic component can be easily suppressed with inductor.

The grid is capable of handling the load posed by charging of EVs. With proper planning and reliable allocation, EV charging load can be accommodated by the grid. The inter-operability and stability challenges constituted by EV charging arise mostly from harmonic distortions due to increasing loads that are nonlinear. Penetration of EVs increases the load served by secondary distribution components and can cause issues under high-stress periods and high penetration [22].

The high charging loads of fast charging stations contribute to increased demand for peak loads, decreased reserve margins, voltage fluctuations, and issues with reliability. Also penalty charged by the utility for the power system's deteriorating efficiency has to be considered. The placement of charging stations plays important role in strengthening and weakening of the overall system efficiency. Thus the placement of growing charging stations shall be made with Voltage stability, Reliability, and Power loss (VRP) index [23].

The EV chargers affect distributed systems with harmonics and overloads. At the micro level the effect is reflected on transformer, distribution cables and circuit breaker & fuses. The simulation studies have shown the harmonics content in the range of 25 – 30% [24, 27].

In addition to the harmonics related issues, EV charger also leads to DC offset and unbalanced load. Non linear load modelling can be used to predict possible effects of EV charge controllers on distribution system [25].

Electric vehicles cause increased demand, harmonic disturbances voltage disturbances and transformer power loss. This demand of EVs is not constant and varies with time. As maximum EVs are charged at residential connection due to the lack of charging stations, the power sector has been failed to earn the profit from this sector [26].

Various case studies on analysis of impact of EV charging solution on power quality have shown some harmonics issues towards the utility grid. Some researchers have recommended active rectification using power electronics switching devices to enhance profile of charger waveforms [28, 29 & 30]. Also, various corrective measures are suggested by researcher for mitigating power quality issues.

V. MATLAB SIMULATION AND THD ANALYSIS

To demonstrate deterioration of power quality due to non linear load of battery charger, a MATLAB simulation is done by considering single phase rectifier feeding a battery to charge it from 10% initial state of charge to 90% state of charge. It is found that the total harmonic distortion of the system is 37%.

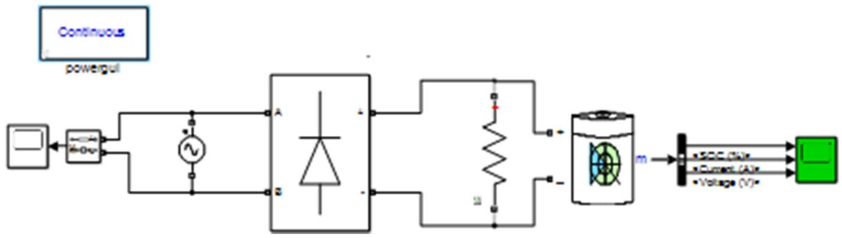

Figure 1: MATLAB Model of single phase rectifier based battery charger

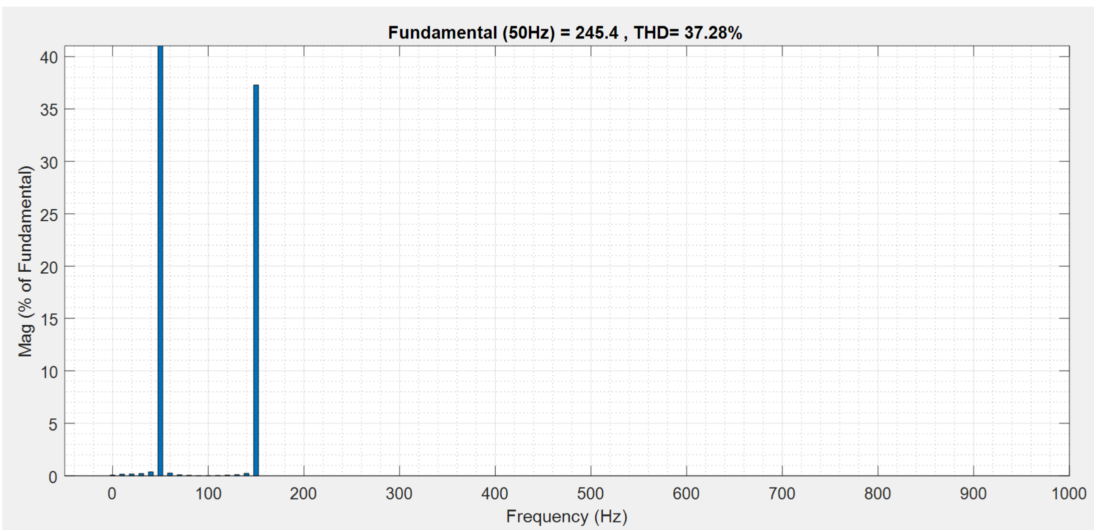

Figure 2 THD Analysis of single phase rectifier based battery charger

VI. CONCLUSIONS

The journey of battery solution in automotives is reviewed. The battery systems have developed greatly with invention and innovations in lithium ion batteries. The impact of battery charging is reflected in deterioration of power quality specifically in terms of harmonics. The MATLAB simulation shows huge amount of harmonics resulted due to non linear load of battery charger. Although different mitigations techniques are in practice for addressing power quality issues, there still exists a scope for integrating renewable energy sources with EV infrastructure.

The authors can conclude on the topic discussed and proposed. Future enhancement can also be briefed here.

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