A STUDY ON ELECTRIC VEHICLE BATTERY

Indukala M.P[1], Bincy M. Mathew[2]

[1]Vice Principal & HOD, Department of EEE, St. Mary's Polytechnic, Palakkad, India
[2]Faculty, Department of EEE, St. Mary's Polytechnic, Palakkad, India

---***---

Abstract - *Battery technologies are an essential catalyst to unlock growth and new advances in electric vehicles (EVs). Over the past several decades, the number of electric vehicles has continued to increase. Projections estimate that worldwide, more than 125 million EVs will be on the road by 2030. Many different kinds of batteries exist, and as new systems are developed to commercial maturity, they have been applied to the problem of electrified transportation. Early EV applications used the rechargeable Lead-Acid battery developed in 1859 by Gaston Planté. In 1899,Waldemar Jungner introduced the nickel-cadmium battery that made significant improvements in storage capacity but had some drawbacks including a voltage suppression issue that occurs as the battery aged, known as a memory effect .In 1985 the first lithium-ion (Li-ion) batteries were created and by 1991 they were commercialized. In the meantime, EVs using ZEBRA batteries and Nickel-Metal Hydride batteries were developed. The current predominant battery energy storage technology for EVs is the Li-ion battery. There is increasing interest and activity, particularly among university research laboratories, in exploring new electrochemical mechanisms that might boost the specific energy and performance of future batteries.*

Key Words: Electric Vehicles, Lead-Acid Batteries, Nickel-based Batteries, Lithium-based Batteries, solid-state electrolytes.

1. INTRODUCTION

The automotive industry's quest to limit its impact on the environment and transform automotive mobility into Electric Mobility, which is a sustainable mode of transportation, continues at high intensity. Energy Storage is an inevitable part in Electric Mobility and batteries continues to be the most preferred energy storage. Batteries are fundamentally a storage medium made up of two electrodes in an electrolyte. An electric-vehicle battery or traction battery is a battery used to power the propulsion of electric vehicles. Electric vehicle batteries are designed to give power over sustained periods of time and deep-cycle secondary batteries are used for these applications. They must be designed with a high ampere-hour capacity. Batteries for electric vehicles are characterized by their relatively high power-to-weight ratio, specific energy and energy density. Also, smaller, lighter batteries reduce the weight of the vehicle and improve its performance. Compared to liquid fuels, most current battery technologies have much lower specific energy, and this often impacts the maximal all-electric range of the Electric Vehicle.

2. CLASSIFICATION OF BATTERIES BASED ON APPLICATION

Based on application, the battery requirements vary considerably. The following are the main types of batteries based on applications:

Starter, lighting & ignition (SLI) batteries: SLI battery is used in every conventional vehicle with an internal combustion engine (ICE), and serves to start and ignite the engine, as well as to provide electricity to the rest of the car when the engine is not running. Starting an engine requires very large currents for a short period – up to 300 amperes for only a few seconds. This makes power density a key requirement for such batteries. Additionally, it needs to be able to operate reliably across a wide range of temperatures and environments, while recent advances in "start-and-stop" systems, in which the engine shuts off automatically when waiting for a traffic light, are also placing an increasing burden on the cycle lifetime of SLI batteries.

Electric vehicle batteries: The fast-growing Electric Vehicle market is made up of major groups of EVs, each with a distinct set of requirements: hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), full electric vehicles (EVs) and commercial electric vehicles (CEVs). HEVs are conventional ICE vehicles for which the propulsion systems are combined with smaller electric motors driven by batteries, which are commonly charged by regenerative braking. The smaller relative capacity of the batteries makes energy density and capital cost less relevant. However, as the battery is charged and discharged frequently and powerfully through braking, it has to have a high power density, extremely short charging time, and long cycle lifetime, which requires thousands of cycles. Compared to HEVs, a PHEV has a battery that can also be charged by plugging into an external electricity source. These batteries typically have much larger capacity, enabling the vehicle to drive fully electric for short distances. This leads to requirements for lower capital cost and better energy density, while power density and cycle lifetime are of less concern. Full EVs no longer have ICEs, and thus require much larger batteries to deliver sufficient range for drivers, which makes capital cost and energy density their most important needs. EVs also require batteries with high reliability (as the vehicle can no longer fall back on the ICE) and good cycle lifetimes of around 1,000 cycles, which enable them to last for the same mileage as the rest of the car components. Commercial EVs such as e-buses typically have increased safety needs as the battery systems are large and the impact of a thermal runaway (battery meltdown) can be severe. Cycle lifetime is also of more importance than in PHEVs and EVs, as the buses are charged at least daily. In the case of buses for which fast charging is required, they can be fully charged multiple times a day, which makes cycle lifetime even more important.

Electronic devices batteries: Batteries for electronic devices are used mainly within laptops and mobile phones, as well as for tablets, e-readers and other devices. All these applications have similar requirements, with volumetric energy density by far the most important. They need to provide the largest-possible amount of energy in the most compact form. As most applications have low drain, power density is typically not an issue. Battery costs are relatively small in comparison to the end product, and as the willingness to pay for high-performance batteries is generally high, cost is of secondary importance.

Stationary battery energy storage (BES): Stationary battery energy storage (BES) is a vital part of smoothing the supply and demand around power generated from wind and solar sources. Essentially, it ensures that electricity from renewable sources can be stored for use when the wind isn't blowing or the sun shining. Also, it ensures that peaks in consumption can be absorbed and backup is provided without having to temporarily rely on fossil fuel power plants (such as diesel generators).

Batteries for other applications: Many other applications exist, with their own sets of needs, e.g., drones, power tools, electric scooters, electric bikes, aviation, forklifts.

3. VIABLE ELECTRIC VEHICLE BATTERY TECHNOLOGIES

The viable EV batteries consist of the lead-acid battery, nickel based batteries such as nickel/iron, nickel/cadmium, and nickel–metal hydride batteries, and lithium-based batteries such as lithium polymer and lithium-ion batteries.

3.1 Lead-Acid Batteries

The lead-acid battery has been a successful commercial product for over a century and is still widely used as electrical energy storage in the automotive field and other applications. Its advantages are its low cost, mature technology and relative high power capability. These advantages are attractive for its application in HEVs where high power is the first consideration. The materials involved (lead, lead oxide, sulfuric acid) are rather low in cost when compared to their more advanced counterparts. Lead-acid batteries also have several disadvantages. The energy density of lead-acid batteries is low, mostly because of the high molecular weight of lead. The temperature characteristics are poor. Below 10°C, its specific power and specific energy are greatly reduced. This aspect severely limits the application of lead-acid batteries for the traction of vehicles operating in cold climates. The presence of highly corrosive sulphuric acid is a potential safety hazard for vehicle occupants. Hydrogen released by the self-discharge reactions is another potential danger, since this gas is extremely flammable even in tiny concentrations. Hydrogen emission is also a problem for hermetically sealed batteries. Indeed, in order to provide a good level of protection against acid spills, it is necessary to seal the battery, thus trapping the parasitic gases in the casing. As a result, pressure may build up in the battery, causing swelling and mechanical constraints on the casing and sealing. The lead in the electrodes is an environmental problem because of its toxicity. The emission of lead consecutive to the use of lead-acid batteries may occur during the fabrication of the batteries, in case of vehicle wreck (spill of electrolyte through cracks), or during their disposal at the end of battery life. Different lead-acid batteries with improved performance are being developed for EVs and HEVs. Improvements of the sealed lead-acid batteries in specific energy over 40 Wh/kg, with the possibility of rapid charge, have been attained. One of these advanced sealed lead-acid batteries is Electrosource's Horizon battery. It adopts the lead wire woven horizontal plate and hence offers the competitive advantages of high specific energy (43 Wh/kg), high specific power (285 W/kg), long cycle life (over 600 cycles for on-road EV application), rapid recharge capability (50% capacity in 8 min and 100% in less than 30 min), low cost (US$2000–3000 an EV), mechanical ruggedness maintenance-free conditions and environmental friendliness. Other advanced lead-acid battery technologies include bipolar designs and micro tubular grid designs. The specific energy has been increased through the reduction of inactive materials such as the casing, current collector, separators, etc. The lifetime has been increased by over 50% — at the expense of cost, however. The safety issue has been addressed and improved, with electrochemical processes designed to absorb the parasitic releases of hydrogen and oxygen.

3.2 Nickel-based Batteries

Nickel is a lighter metal than lead and has very good electrochemical properties desirable for battery applications. The following are the different nickel-based battery technologies:

Nickel/Iron System: The nickel/iron system was commercialized during the early years of the 20th century. Applications included fork-lift trucks, mine locomotives, shuttle vehicles, railway locomotives, and motorized hand-trucks. The system comprises a nickel hydroxy-oxide positive electrode and a metallic iron negative electrode. The electrolyte is a concentrated solution of potassium hydroxide (typically 240 g/l) containing lithium hydroxide (50 g/l). Its nominal open-circuit voltage is 1.37 V. Nickel/iron batteries suffer from gassing, corrosion, and self-discharge problems.

These batteries are complex due to the need to maintain the water level and the safe disposal of the hydrogen and oxygen released during the discharge process. Nickel–iron batteries also suffer from low temperatures, although less than lead-acid batteries. Finally, the cost of nickel is significantly higher than that of lead. Their greatest advantages are high power density compared with lead-acid batteries, and a capability of withstanding 2000 deep discharges.

Nickel/Cadmium System: The nickel/cadmium system uses the same positive electrodes and electrolyte as the nickel/iron system, in combination with metallic cadmium negative electrodes. Its nominal open-circuit voltage is 1.3 V. Nickel/cadmium technology has seen enormous technical improvement because of the advantages of high specific power (over 220 W/kg), long cycle life (up to 2000 cycles), a high tolerance of electric and mechanical abuse, a small voltage drop over a wide range of discharge currents, rapid charge capability (about 40 to 80% in 18 min), wide operating temperature (40 to 85°C), low self-discharge rate (0.5% per day), excellent long-term storage due to negligible corrosion, and availability in a variety of size designs. However, the nickel/cadmium battery has some disadvantages, including high initial cost, relatively low cell voltage, and the carcinogenicity and environmental hazard of cadmium. The nickel/cadmium battery can be generally divided into two major categories, namely the vented and sealed types. The vented type consists of many alternatives. The vented sintered-plate is a more recent development, which has a high specific energy but is more expensive. It is characterized by a flat discharge voltage profile, and superior high current rate and low-temperature performance. A sealed nickel/cadmium battery incorporates a specific cell design feature to prevent a build-up of pressure in the cell caused by gassing during overcharge. As a result, the battery requires no maintenance.

Nickel–Metal Hydride (Ni–MH) Battery: The Nickel-metal hydride battery has been on the market since 1992. Its characteristics are similar to those of the nickel/cadmium battery. The principal difference between them is the use of hydrogen, absorbed in a metal hydride, for the active negative electrode material in place of cadmium. Because of its superior specific energy when compared to the Ni–Cd and its freedom from toxicity or carcinogenicity, the Ni–MH battery is superseding the Ni–Cd battery. Ni–MH battery technology has a nominal voltage of 1.2 V and attains a specific energy of 65 Wh/kg and a specific power of 200 W/kg.

Table -1: Basic Comparison of Batteries

	Lithium Ion	Nickel-Metal	Lead-Acid
Easy Access / Inexpensive	✓	✗	✓
Energy Efficient	✓	✓	✓
Temp. Performance	✓	✗	✗
Weight	✓	✓	✓
Life Cycle	✓	✗	✓

3.3 Lithium-based Batteries

Lithium is the lightest of all metals and presents very interesting characteristics from an electrochemical point of view. Indeed, it allows a very high thermodynamic voltage, which results in a very high specific energy and specific power. There are two major technologies of lithium-based batteries: lithium–polymer and lithium-ion.

Lithium–Polymer (Li–P) Battery: Lithium–polymer batteries use lithium metal and a transition metal intercalation oxide for the negative and positive electrodes, respectively. It has a layered structure into which lithium ions can be inserted, or from where they can be removed on discharge and charge, respectively. A thin solid polymer electrolyte (SPE) is used, which offers the merits of improved safety and flexibility in design. On discharge, lithium ions formed at the negative electrode migrate through the SPE, and are inserted into the crystal structure at the positive electrode. On charge, the process is reversed. By using a lithium foil negative electrode and vanadium oxide positive electrode, the Li/SPE/V6O13 cell is the most attractive one within the family of Li–polymer. It operates at a nominal voltage of 3 V and has a specific energy of 155 Wh/kg and a specific power of 315 W/kg. The corresponding advantages are a very low self-discharge rate (about 0.5% per month), capability of fabrication in a variety of shapes and sizes, and safe design (reduced activity of lithium with solid electrolyte). However, it has the drawback of a relatively weak low-temperature performance due to the temperature dependence of ionic conductivity.

Lithium-Ion (Li-Ion) Battery: Since the first announcement of the Li-ion battery in 1991, Li-ion battery technology has seen an unprecedented rise to what is now considered to be the most promising rechargeable battery of the future. Although still at the development stage, the Li-ion battery has already gained acceptance for EV and HEV applications. The Li-ion battery uses a lithiated carbon intercalation material for the negative electrode instead of metallic lithium, a lithiated transition metal intercalation oxide for the positive electrode, and a liquid organic solution or a solid polymer for the electrolyte. Lithium ions swing through the electrolyte between the positive and negative electrodes during discharge and charge. On discharge, lithium ions are released from the negative electrode, migrate via the electrolyte, and are taken up by the positive electrode. On charge, the process is reversed. Nickel-based Li-ion battery has a nominal voltage of 4 V, a specific energy of 120 Wh/kg, an energy density of 200 Wh/l, and a specific power of 260 W/kg. The cobalt-based type has a higher specific energy and energy density, but at a higher cost and significant increase in the self-discharge rate. The manganese-based type has the lowest cost and its specific energy and energy density lie between those of the cobalt- and nickel-based types. It is anticipated that the development of the Li-ion battery will ultimately move to the manganese-based type because of the low cost, abundance, and environmental friendliness of the manganese-based materials.

4. LATEST TRENDS IN BATTERY TECHNOLOGY

Li-ion batteries have improved dramatically over the past 25 years, enabling improved performance in consumer electronics and the introduction of new applications such as drones and EVs. However, to accelerate these and other applications, new innovation is vital – a step-change in performance is required. A lot is happening in next-generation technologies. A host of battery technologies using alternative materials are being developed by ambitious start-ups, while there is increasing innovation within the Li-ion space primarily focusing on three areas: silica anodes, advanced cathodes and solid-state electrolytes.

Silica has higher energy capacity than graphite, the normal material for anodes. This is leading to it being blended through graphite anodes, with the aim of eventually moving towards full silica anodes. These can offer theoretical increases in energy density of up to 40 percent. However, for this to happen, issues in cycle lifetime have to be overcome, in which the anode pulverizes itself upon its 300 percent volume expansion while charging. Ongoing innovations use only minor silica concentrations, limiting potential density increases to 10–20 percent.

Many advanced-cathode chemistries exist that have higher energy capacities and voltages, such as lithium nickel manganese oxide (LNMO). These high-voltage cathode materials are currently facing issues with the liquid electrolyte used in common battery systems, which break down at voltages above 4.5 V.

The third and strongest contender for innovation is a solid-state electrolyte. This replaces the current electrolyte system that is made of organic solvents, dissolved lithium salts and polyolefin separators by one thin, ion-conducting membrane. It is often seen as one of the technologies with the most disruptive potential inside Li-ion, unlocking the use of new cell components and delivering four benefits:

1. A solid-state electrolyte makes the safe use of pure lithium anodes possible, readily increasing the energy density of a cell by 40 percent.
2. It unlocks new types of cathodes. The oxide-based solid- state electrolyte no longer breaks down at 4.5 V, allowing the use of 5 V cathodes and further increasing the energy density by 10 percent.
3. It enables a new class of conversion cathodes such as sulfur and oxygen, enabling even larger potential increases in energy density. Lithium-sulfur systems have long been produced by companies such as Sion power; however, they suffer from cycling issues due to polysulfides shuttling through the separator to the anode. This is one of the many possible problems that solid-state electrolytes may solve.
4. Improved battery safety – perhaps the largest benefit. Using a solid material instead of a flammable liquid electrolyte prevents the formation of dendrites (lithium slivers living in the electrolyte that can cause internal battery short circuits, which lead to meltdowns) and makes electrolyte leakage impossible (avoiding potential self-ignition). Increased cell simplicity might potentially also lead to decreased costs. Given that safety is one of the primary priorities of virtually all big players, even a slightly higher initial cost of this new technology might be worth their investment.

Because of these advantages, solid-state electrolytes are of large interest to battery manufacturers as well as users.

5. KEY TECHNICAL PARAMETERS OF ELECTRIC VEHICLE BATTERY

While choosing a battery technology for Electric Vehicles, the following six parameters are to be considered:

Safety: Safety is the most important criterion for electric-car batteries. Even a single battery fire could turn public opinion against electric mobility and set back industry development for months or years. The main concern in this area is avoiding thermal runaway—a positive-feedback loop whereby chemical reactions triggered in the cell exacerbate heat release, potentially resulting in a fire. Thermal runaway can be caused by an overcharged battery, too-high dis-charge rates, or a short circuit. Chemistries that are prone to thermal run- away, such as NCA, NMC, and LMO, must be used in conjunction with system-level safety measures that either contain the cells or monitor their behavior. Such measures include a robust battery box, a very efficient cooling system (to prevent the early stages of thermal runaway), and precise state-of-charge monitoring and cell-discharge balancing. While battery safety is indisputably a valid concern, it is useful to put this concern in context by recalling the significant safety challenges originally associated with the internal combustion engine (ICE) and with gasoline storage, which were largely overcome through improvements in design and engineering.

Life Span: There are two ways of measuring battery life span; cycle stability and overall age. Cycle stability is the number of times a battery can be fully charged and discharged before being degraded to 80 percent of its original capacity at full charge. Overall age is the number of years a battery can be expected to remain useful. Today's batteries do meet the cycle stability requirements of electric cars under test conditions. Overall age, however, remains a hurdle, in part because aging accelerates under higher ambient temperatures. It is as yet unclear how fast various kinds of batteries will age across a range of automotive-specific temperature conditions. To manage these uncertainties, Original Equipment Manufacturers (OEMs) are specifying batteries of sufficient size to meet electric cars' energy storage needs over the typical life of a vehicle. Most automotive manufacturers are planning for a ten-year battery life span, including expected degradation. For example, an OEM whose electric car nominally requires a 12-kilowatt-hour (kWh) battery is likely to specify a 20-kWh battery instead, so that after ten years and 40 percent performance degradation, the battery will still have sufficient energy capacity for normal operation. Of course, this approach increases the size, weight, and cost of the battery.OEMs can consider other options. For instance, they might choose to install smaller batteries with a shorter life span and plan to replace them every five to seven years, possibly under a warranty program. Taking this approach would allow OEMs to use smaller batteries initially, upgrading them as the technology continues to advance. Performance: The expectation that the owner of an electric vehicle should be able to drive it both at blisteringly hot summer temperatures and at subzero winter temperatures poses substantial engineering challenges. Batteries can be optimized for either high or low temperatures, but it is difficult to engineer them to function over a wide range of temperatures without incurring performance degradation. One solution might be for OEMs to rate batteries for particular climates. For example, batteries optimized for performance and endurance in cold climates would rely on heating and insulation, whereas those designed for hot climates would use electrolytes and materials that allow high-temperature storage. The differences between these two battery designs would be more substantial than the current distinction between, for example, cold-weather and warm- weather tires. However, because climate-specific batteries would hinder vehicles' mobility across regions, OEMs are likely to prefer a performance disadvantage or higher over-all system costs in order to avoid such restrictions.

Specific Energy and Specific Power: The specific energy of batteries— that is, their capacity for storing energy per kilogram of weight—is still only 1 percent of the specific energy of gasoline. Unless there is a major breakthrough, batteries will continue to limit the driving range of electric vehicles to some 250 to 300 kilometres (about 160 to 190 miles) between charges. Battery cells today can reach nominal energy densities of 140 to 170 watt-hours per kilogram (Wh/kg), compared with 13,000 Wh/kg for gasoline. The specific energy of the resulting battery pack is typically 30 to 40 percent lower, or 80 to 120 Wh/kg. Even if that energy density were to double in the next ten years, battery packs would still store only some 200 Wh/kg of weight. Assuming that the battery weighs around 250 kilograms— about 20 to 25 percent of the total weight typical of small cars today— that doubling of energy density would give an electric car a range of some 300 kilometers (about 190 miles). Specific power, or the amount of power that batteries can deliver per kilogram of mass, is addressed relatively well by current battery technologies. Specific power is particularly important in hybrid vehicles, which discharge a small amount of energy quickly. In electric vehicles, specific power is less important than specific energy. Manufacturers have established design parameters for electric vehicle batteries to optimize the trade-off between specific energy and specific power. Currently, battery's performance in terms of specific power equals or exceeds that of ICEs. So researchers are concentrating their efforts on increasing battery's specific energy for given power levels.

Charging Time: Long charging times present another technical challenge and a commercial barrier that must be addressed. It takes almost ten hours to charge a 15-kWh battery by plugging it into a standard 120- volt outlet. Fast charging methods that employ more sophisticated charging terminals can reduce this time significantly. For example, charging by means of a 240-volt out- let with increased power (40 amps) can take two hours, while charging at a commercial three-phase charging station can take as little as 20 minutes. These charging systems do come at an additional cost and weight, as they require enhanced cooling systems on board the vehicle. Battery-swap methods, such as the models contemplated by Better Place, promise to provide a full charge in less than three minutes. But such approaches need OEMs to agree to pack standardization requirements and would entail additional logistical complexity.

6. THE COST CHALLENGE

Even if battery makers can meet the technical challenges outlined above, battery cost may remain above that target. Clearly, the cost of batteries will play a critical role in determining the commercial viability of electric cars. Battery costs will decline steeply as production volumes increase. Higher levels of automation will further trim costs by increasing quality, reducing scrap levels, and cutting labor costs. However, some 25 percent of current battery costs—primarily the costs of raw materials and standard, commoditized parts are likely to remain relatively independent of production volumes and to change only modestly over time

7. CONCLUSIONS

Without a major breakthrough in battery technologies, fully electric vehicles that are as convenient as ICE-based cars—meaning that they can travel 500 kilometers (312 miles) on a single charge and can recharge in a matter of minutes—are unlikely to be available for the mass market. In view of the need for a pervasive infrastructure for charging or swapping batteries, the adoption of fully electric vehicles may be limited to specific applications such as commercial fleets, commuter cars, and cars that are confined to a prescribed range of use. Of course, range-extender vehicles, which combine an electric power train with an ICE, overcome the range and infrastructure limitations of fully electric vehicles, but at the increased cost of the ICE. No single technology will dominate the industry at large. Different types of electric vehicles have very different requirements on factors such as power density, capacity, cycle lifetime, energy density and charging time. Advancement in Lithium ion battery technology with solid-state electrolyte is expected to have great potential to transform the future of electric vehicles.

REFERENCES

[1] Yu Miao , Patrick Hynan, Annette von Jouanne and Alexandre Yokochi, "Current Li-Ion Battery Technologies in Electric Vehicles and Opportunities for Advancements" , Energies 2019, 12, 1074

[2] Redondo-Iglesias E.; Venet P.; Pelissier S. "Efficiency Degradation Model of Li-ion Batteries for Electric Vehicles" IEEE Trans. Ind. Appl. 2019.

[3] "Comprehensive technical analysis of second-life batteries for smart grid applications" in Proceedings of the 19th European Conference on Power Electronics and Applications (EPE'17 ECCE Europe), Warsaw, Poland, 11–14 September 2017.

[4] Horiba T., "Li-ion battery systems" Proc. IEEE 2014.

[5] M. O. Ramoni and H. C. Zhang, ``End-of-life (EOL) issues and options for electric vehicle batteries,'' Clean Technol. Environ. Policy, vol. 15, no. 6, pp. 881_891, 2013.

[6] X. Hu, C. Zou, C. Zhang, and Y. Li, ``Technologica developments in batteries: A survey of principal roles, types, and management needs,'' IEEE Power Energy Mag., vol. 15, no. 5, pp. 20_31, Oct. 2017.

[7] R. Xiong, H. He, F. Sun, and K. Zhao, ``Online estimation of peak power capability of Li-Ion batteries in electric vehicles by a hardware-in-loop approach,'' Energies, vol. 5, no. 5, pp. 1455_1469, 2012.

[8] Y. Xing, E. W. M. Ma, K. L. Tsui, and M. Pecht, ``Battery management systems in electric and hybrid vehicles,'' Energies, vol. 4, no. 11,pp. 1840_1857, 2011.

BIOGRAPHIES

Indukala M.P. received B. Tech. degree in Electrical and Electronics Engineering from Nehru College of Engineering & Research Centre, Thrissur under University of Calicut and M. E. in Power Electronics and Drives from Easa College of Engineering & Technology, Coimbatore. Since August 2011, she is with St. Mary's Polytechnic College, Palakkad as Faculty in Department of EEE and became Head of the Department in 2013 and is currently serving as Vice Principal as well. She has authored the paper Study on Extent of Utilization of Renewable Energy Sources in Kerala and A Study on Future of Electric Vehicles in India.Her current research interest includes electric vehicles, renewable energy sources and renewable energy technologies. She is a Life Member of the Indian Society for Technical Education (ISTE).

Bincy M. Mathew received B. Tech. degree in Electrical and Electronics Engineering from Mar Baselios College of Engineering & Technology, Thiruvananthapuram under University of Kerala and M. Tech. in Power Electronics and Drives from Karunya Institute of Technology & Sciences, Coimbatore. Since June 2016, she is with St. Mary's Polytechnic College, Palakkad as Faculty in Department of EEE. She has authored the paper Novel Single Phase Buck PFC Converter and the papers she has co-authored includes Modified Single Stage AC-AC Converter, Stability Analysis & Limit Cycle Behaviour in DC-DC Boost Converter, Direct AC/ AC Converter, Study on Extent of Utilization of Renewable Energy Sources in Kerala and A Study on Future of Electric Vehicles in India. Her current research interest includes electric vehicles, renewable energy sources and renewable energy technologies. She is a Life Member of the Indian Society for Technical Education (ISTE) and SPOC of NPTEL Local Chapter.