Implementation of Power Electronics in Hybrid Electric and Plug-in Hybrid Electric Vehicles

Sarath M[1]

[1]UG Scholar, Dept. of Electrical and Electronics Engineering, Rajiv Gandhi Institute of Technology, Kerala, India

---***---

Abstract - *Due to the shortage in fossil fuels and with the necessities for lessening outflows and improving fuel economy, car companies are creating electric, hybrid electric and plug-in hybrid electric vehicles. Power electronics is an empowering innovation for the improvement of these environmentally friendlier vehicles and executing the progressed electrical models to meet the request for expanded electric loads. Hence, it is basic that the automotive electrical control system will experience a drastic change within the next 5-15 years. Within the case of future HEVs, power electronics converters and related motor drive, which controls the stream of electrical energy inside the HEV control framework, guarantee to be the keys to making HEVs more fuel effective and emit lower hurtful pollutants. Power electronics play an important in the development of electric, hybrid electric, plug-in hybrid electric vehicles, and fuel cell vehicles. The article discusses the basic structure and circuit setup of EVs, PHEVs, HEVs, FEVs, and the power electronics system, power electronics solutions for HEVs, future trends in vehicular power electronics were also investigated.*

Key Words: Hybrid Electric vehicles, Fuel cell vehicles, Plug-in hybrid electric vehicles, Power electronics system, Future trends.

1. INTRODUCTION

With the increasing demand for environmentally friendlier and higher fuel economy vehicles, automotive companies are centering on Electric Vehicles, Hybrid – Electric Vehicles (HEVs), Plug – in Hybrid Electric Vehicles (PHEVs), and Fuel Cell Vehicles (FCVs). The most advancement in this sector happened only because of the advancement in power electronics and electric drive technologies. Through this improvement in power electronics, the size of converters and other electronic device get diminished which make an incredible footstep within the headway of electric vehicle technologies. In steer – by – wire and brake – by – wire application, a quick – reaction engine, inverter, and control system are fundamental and must be able to operate in unfavorable natural conditions, besides, the integration of actuators with power electronics not only improves the overall system reliability but also decreases the fetched, size, etc[1].In addition to power electronics, the innovation of the electric motor plays a major part within the vehicle's dynamics and the sort of power converter for controlling the vehicle working characteristics.

2. ANALYSIS OF HEVs, PHEVs, FCVs

By the time the commercialization of the next-generation car comes around, progressed power electronics and engine drives will have already established themselves as prime components of progressed vehicular drive trains. Progressed power electronic converters and traction motor drives will be dependable for a major portion of the vehicle's vitality utilization. As of presently, car advertising is making fast improvements in case of the hybrid electric vehicles (HEVs). Commercially accessible HEVs incorporate the Toyota Prius, Toyota Highlander Hybrid, Toyota Camry Hybrid, Lexus RX 400 h, Honda Insight, Honda Civic Hybrid, Honda Accord Hybrid, and Ford Escape Hybrid. Within the case of future HEVs, control electronic converters and associated engine drives, which control the flow of electrical energy inside the HEV power system, guarantee to be the keys to making HEVs more fuel productive and transmit lower harmful pollutants. As is well known, within the first half of the past century, the 6-V electrical system in automobiles served the reason for ignition, cranking, and a fulfilling few lighting loads. Since that point, there has been a steady rise in vehicular power requirements. Performance loads, such as electric steering, that were traditionally driven by mechanical, pneumatic, and hydraulic systems, are presently progressively being supplanted by the electrically driven systems, to extend the performance and efficiency of operation. Besides, luxury loads have moreover increased over time, forcing a better demand for electrical power[2]. It must be pointed out here that the rate of increment of automotive loads is expected to be approximately 4% per year.

2.1 Hybrid – Electric Vehicles [HEVs]

Hybrid vehicles have two or more sources of energy and/or two or more sources of power onboard the vehicle. The sources of energy can be a battery, a flywheel, etc. The sources of power can be a motor, a fuel cell, a battery, an ultracapacitor, etc. Depending on the vehicle configuration, two or more of these power or energy sources are utilized. Hybrid vehicles save energy and minimize contamination by combining an electric motor and an internal combustion motor (ICE) in such a way that the foremost alluring characteristics of each can be utilized. Hybrid vehicles are generally classified as series hybrids and parallel hybrids. Hybrid vehicles are also partitioned into mild hybrids, power hybrids, and energy hybrids, according to the part performed by the engine and the electric motor and the mission that the system is designed to achieve[1].

2.1.1 Series Hybrid Vehicles

A series hybrid vehicle is an electric vehicle with an onboard source of power for charging the batteries. In common, a motor is coupled to a generator to deliver the power to charge the batteries. It is additionally conceivable to plan the framework in such a way that the generator seems to act as a load-leveling device that gives propulsion power. In this case, the size of the batteries can be decreased, but the sizes of the generator and the motor ought to be expanded. The power electronic components for an ordinary series hybrid vehicle framework are: 1) a converter for converting the alternator output to dc for charging the batteries and 2) an inverter for converting the dc to ac to power the propulsion motor. A dc-dc converter is required to charge the 12-V battery within the vehicle as well. In expansion, an electric air-conditioning unit needs an inverter and related control systems.

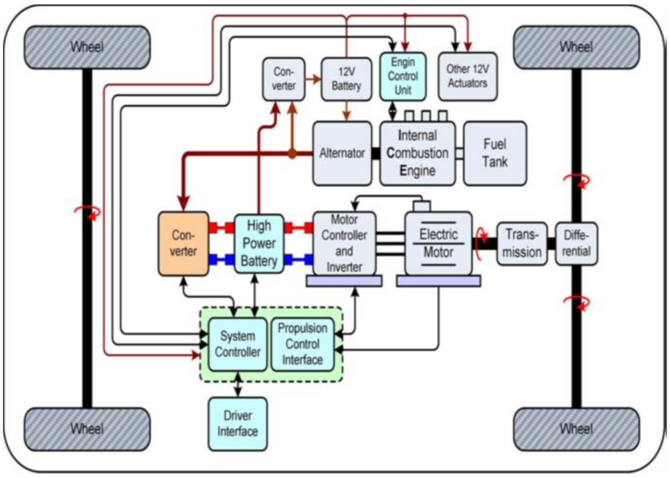

Fig-1: Series hybrid vehicle propulsion system

2.1.2 Parallel Hybrid Vehicles

Parallel hybrids can offer the most reduced cost and the choice of utilizing the existing manufacturing capability for motors, batteries, and engines. Be that as it may, a parallel hybrid vehicle needs a complex control framework. There are different setups of parallel hybrid vehicles, depending on the parts of the electric motor/generator and the engine. In a parallel hybrid vehicle, the engine and the electric motor can be utilized independently or together to impel a vehicle. The Toyota Prius and the Honda Insight are a few cases of parallel hybrid systems, which are commercially accessible. A commonplace configuration of a parallel cross breed drive framework is outlined in Fig-2

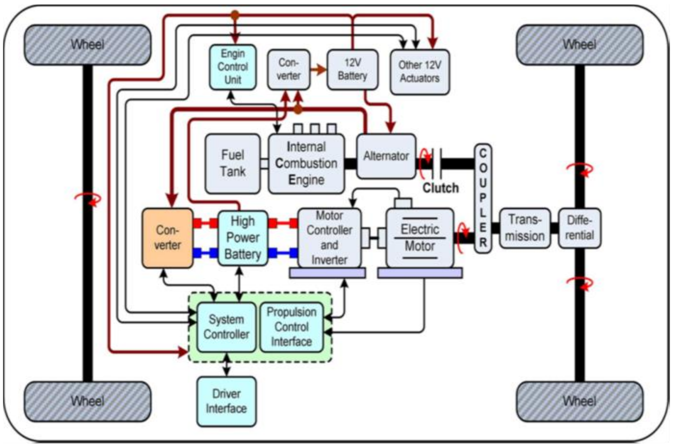

Fig-2: Parallel hybrid vehicle propulsion system

2.2 Plug – in Hybrid Electric Vehicles [PHEVs]

PHEVs have been considered as a significant progression of the hybrid vehicle technology in both the industry and the scholarly world and indeed by different government organizations around the world. PHEVs have a battery pack of high energy density that can be externally charged and, thus, can run exclusively on electric power for a run longer than normal HEVs. The battery pack can be recharged by a neighborhood ac outlet charger or within the garage. PHEVs progress the utilization of utility power since the charging of the batteries is done during night time.

A representative architecture of a plug-in parallel hybrid vehicle engineering is shown in Fig-3. The change of conventional HEVs into PHEVs is being attempted as a temporal technology in numerous companies to improve the efficiency of HEVs. Additionally, auto producers are considering and planning for the introduction of PHEVs into the commercial showcase. The change is accomplished either by including a high-energy battery pack or by supplanting the existing battery pack of HEVs to expand the all-electric extend. In either case, the high-energy battery pack must be able to store sufficient electrical energy from outside charging as well as from regenerative braking and must be able to supply the stored electrical energy to a traction motor framework.AC outlet charging should require a battery charger composed of an ac–dc converter with power factor correction (PFC) and a programmable advanced controller with an appropriate voltage–current profile for high-energy battery packs[2]. A bidirectional dc-dc converter and charge–discharge profile is additionally vital to exchange energy between the battery and the traction motor system.

To make PHEVs accessible to shoppers, there are a few issues to be addressed. For example, the stability of utility power to employing a great number of high-power battery chargers with PFC at the same time and the choice, safety, thermal management, and cell-balancing of high-energy batteries such as NiMH and lithium batteries for automotive applications are a few of the critical issues[3].

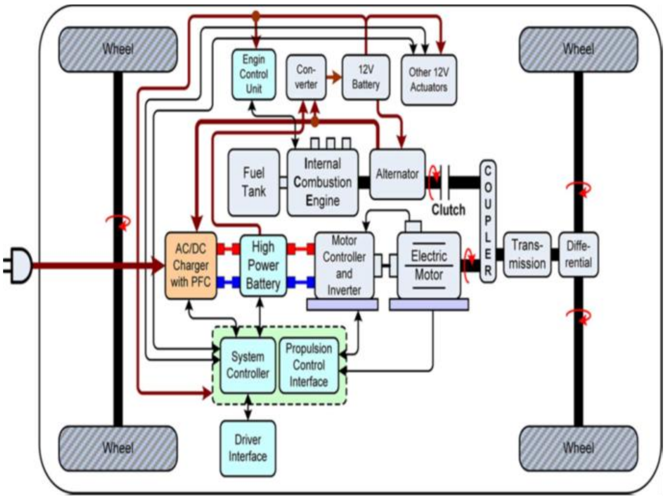

Fig-3: Plug-in hybrid electric vehicle (parallel configuration)

2.3 Fuel-Cell Vehicles (FCVs)

However, precise endeavors to realize the efficiency and emissions benefits of fuel cells within the transportation division have materialized as they were within the final 10 years. The general objective of continuous fuel cell research and development programs is to create a fuel cell engine that will give vehicles the extend of conventional cars, whereas accomplishing natural benefits comparable to those of battery-powered electric vehicles. Even though the technology is right now very costly, fuel cells offer benefits counting high overall efficiency and quiet operation due to few moving parts. Hydrocarbon fuel such as gasoline, natural gas, methanol, or ethanol is, to begin with, reformed to get the specified hydrogen using a reformer (or fuel processor). This hydrogen-rich gas from the reformer is fed to the anode of the fuel cell. It is also possible to store the hydrogen on-board the vehicle employing a pressurized barrel, rather than utilizing the reformer for converting the fuel to Hydrogen-rich gas. The oxygen is fed into the cathode fuel cell[5].

Hydrocarbon fuel such as gasoline, natural gas, methanol, or ethanol is, to begin with, transformed to get the desired hydrogen employing a reformer (or fuel processor). This hydrogen-rich gas from the reformer is fed to the anode of the fuel cell[5]. It is additionally possible to store the hydrogen on-board the vehicle employing a pressurized barrel, rather than utilizing the reformer for converting the fuel to Hydrogen-rich gas. The oxygen is nourished into the cathode fuel cell. Depending on the fuel cell stack setup, and the flow of hydrogen and oxygen, the fuel cell stack produces the dc output voltage. The fuel cell stack output is fed to the power conditioner (power electronic converter) to get the desired yield voltage and current. In a perfect world, the power conditioner must have negligible misfortunes driving to better efficiency. Power conditioning efficiencies can ordinarily be higher than 90%.

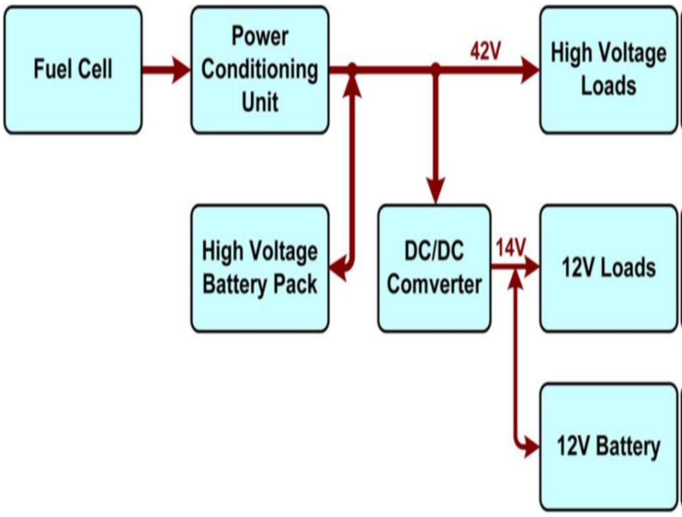

Fig-4: Typical fuel-cell vehicle system

3. Power Electronics System

Power electronics is an empowering technology for the advancement of electric and hybrid vehicle propulsion systems. The power electronics system comprises power switching devices, power converter topology with its switching strategy, and the closed-loop control framework of the motor. The determination of power semiconductor devices, converters/ inverters, control, and switching methodologies, bundling of the individual units, and framework integration is exceptionally critical for the advancement of efficient and high-performance vehicles. The challenges lie in getting a high-efficient, rugged, little size, and low-cost inverter and the related electronics for controlling a three-phase electric machine. The devices and the rest of the components ought to withstand thermal cycling and extreme vibrations. All the current EVs and HEVs utilize a three-phase bridge inverter topology for converting over the dc voltage of the battery to variable voltage and variable recurrence to control a three-phase ac engine. A three-phase hard switched bridge inverter is the topology that's being utilized in all-electric and hybrid vehicles. This topology is basic and well demonstrated and proceeds to be the technology of the future with diverse types of power devices and the related passive components for filtering, electromagnetic interference (EMI) reduction, protection, and so on. With the headway of semiconductor device technology, a few sorts of power devices with shifting degrees of performance are accessible within the showcase. The effect utilized two 3-phase inverters, each powering a front-wheel-drive induction motor. Each inverter has 24 MOSFETs connected in parallel resulting in 48 MOSFETs for each phase leg of the inverter (a total of 144 MOSFETs per inverter). These 48 MOSFETs were afterward supplanted by a single IGBT module resulting in three IGBT modules per leg. Right now, IGBT devices are being utilized in nearly all commercially accessible Evs, HEVs, and PHEVs[6]. The IGBTs will proceed to be the technology within the close future until the silicon carbide (SiC) and gallium nitride (GaN)-based devices are commercially accessible at a cost similar to that of silicon IGBTs. Significant progress is as of now made within the technology of these devices for automotive and other power applications[4]. A 3- phase dc-ac fuel cell inverter system is shown in Fig-5.

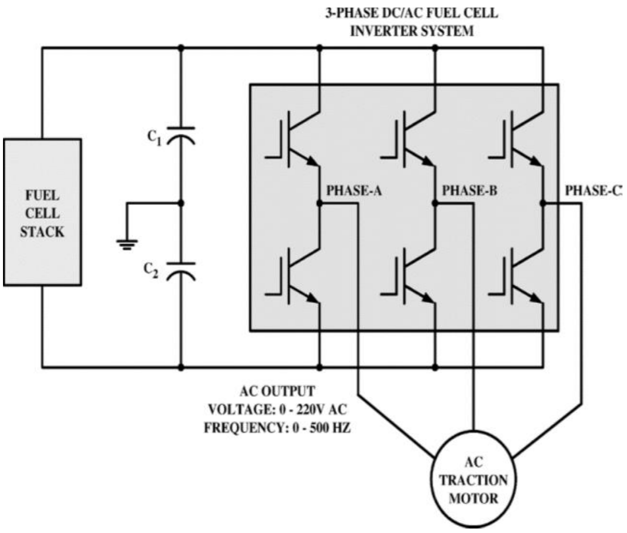

Fig-5: Fuel cell based single-stage power conversion system

SiC has ended up the choice for most of the next-generation power semiconductor devices and might replace the existing silicon technology. Progressed features of SiC devices are characteristic radiation resistance, high-temperature operating capacity, high voltage, and power handling capacity, high power efficiency, and adaptability to be used as substrate. The different properties of SiC such as more extensive bandgap, larger basic electric field, and higher thermal conductivity enable the SiC devices to work at higher temperatures and higher voltages offering higher power density and higher current density than the pure Si devices[8]. These properties permit the SiC devices such as Schottky diodes, MOSFETs, and the other devices to function at much higher voltage levels than the silicon gadgets. Be that as it may, the technology of the by and by accessible silicon carbide JFETs and MOSFETS isn't adequately developing to coordinate the reliability of silicon gadgets to be used in Evs and HEVs.These devices also have significant competition from SiC BJTs, which appear to offer more prominent reliability in terms of life tests, high-temperature operation, and temperature cycling, additionally robustness to stuns and vibrations[7].

GaN devices are projected to have significantly higher performance over silicon-based devices, and much way better execution than SiC devices, because of their excellent material properties such as high electron mobility, high breakdown field, and high electron velocity. GaN-based power electronics highlight both low on-resistance and quick switching, driving to a considerable reduction in both conduction and exchanging losses. Because of its compatibility with high-volume silicon fabs, the GaN-on-Si technology stage can be delivered in large volume, permitting predominant performance and affordable manufacturing. It may be a higher cost than silicon, but will continuously cost less than SiC since GaN is congruous with silicon substrates. As the necessity of dc voltage rating of power devices in most of the propulsion, inverters are <1000 V, the GaN will be more pertinent for Evs than the higher voltage SiC devices. System-level points of interest, such as diminished size and weight, reduced era of EMI, and diminished system fetched can be realized with GaN power electronics, making this technology practical for future electric and hybrid vehicles. As with SiC devices, appropriation of GaN will not happen until devices have demonstrated reliability to automotive specifications. Fig-6 shows a typical propulsion system components of EV power train.

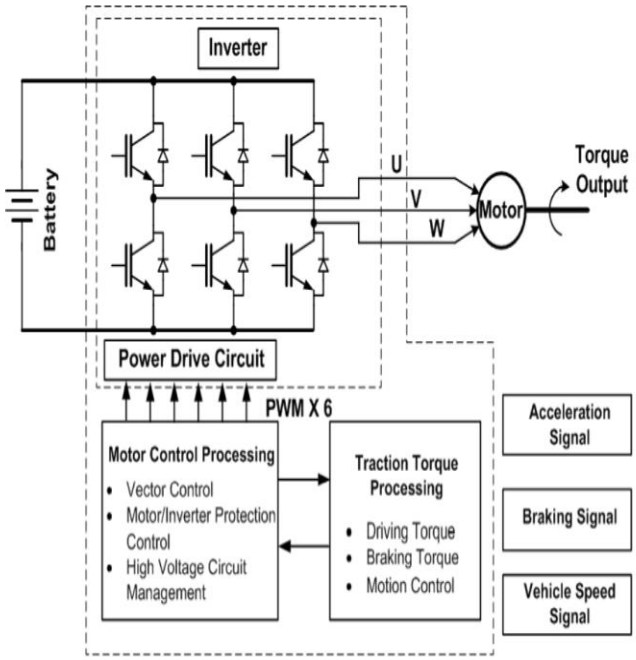

Fig-6: Typical propulsion system components of EV powertrain

4. Future Trends in Vehicular Power Electronics

The wants for advancements in consolation, comfort, entertainment, security, communication, and environmental issues require desires for improved electrical systems. This can be a modern inspiration in rebuilding the total power system in vehicles. There will be more opportunities in the following regions of automotive power systems-improved beginning, coordinated administration of power generation and demand, higher system integrity, higher efficiency, and change of the electrical environment decreasing the component cost. These are achievable by hybrid multilevel power electronic systems, a distribution system with a partitioned communication bus, and substitution of a few conventional, engine-driven, mechanical and hydraulic loads with electric loads to progress the efficiency and packaging flexibility.

Another significant change to search for is the advancement of clean diesel, diesel hybrids, diesel engine-based plug-in hybrids, and liquid natural gas-based vehicles. Clean diesel base hybrids may make it possible for automakers to extend toward the 100mpg mark in the coming years. Although there are no major automakers with a diesel hybrid within the works for a passenger car, these systems have been prevalent on passenger buses and railway locomotives for over a decade. Even though fuel cell technology had appeared an incredible guarantee, the fuel cell vehicles continue to stay as exhibit vehicles or constrained utilize vehicles.

Typically, the issues related to manufacturing, robustness of the technology, hydrogen generation, and the hydrogen infrastructure. In any case, with the progression of polymer electrolyte membrane (PEM) and strong oxide fuel cell (SOFC) technologies, the fuel cells might be utilized as range extenders rather than the internal combustion engine-driven generators in series hybrid vehicles. The prognostics and health management are presently not being executed in most of the Evs and HEVs. Integration of prognostics in the overall control system could predict the future execution of the machine by surveying the degree of its deviation from its expected ordinary operating conditions.

5. CONCLUSIONS

A few technologies are on the horizon to be implemented in the next generations of automobiles. There are still a lot of innovation challenges to overcome, especially in the region of fuel-cell vehicles. Major obstacles must still be overcome within the regions of weight, volume, and cost to achieve the expected efficiency and performance. Other issues are manufacturability, reliability, safety, and durability, and the foremost importance is the esteem to the client as a work of the cost. The boundaries to the introduction of a "More Electric Vehicle" depend on financial matters and not much on technology. The value of a hybrid or plug-in hybrid vehicle must be greater than the cost. This value condition incorporates the payback in fuel cost savings for the additional cost of the vehicle, adding to the manufacturer's corporate normal fuel economy value, vehicle execution and boost, the sum of onboard electric control for excitement features and other comforts, emissions reduction, and, finally, the image for the original equipment manufacturer.

Advance has been made within the region of control electronics and rotating machines to decrease the cost and improve the productivity of the system. The issues related to power conversion and rotating machines are comparative in electric, hybrid, and plug-in hybrid vehicles. The cost of the power electronics and the motor drive framework is being decreased more to form the hybrid and plug-in hybrid vehicles at standard with ICE-based vehicles. To universally increase the energy utilization efficiency of advanced vehicular drive trains, the rate of electrically controlled vehicular capacities is relentlessly rising. Along with this, there's currently an expansion within the number of semiconductors installed in vehicles. In addition, even higher electrical energy is required for progressed electrical loads. Hence, there's presently a solid demand for the improvement of advanced power system architectures for future EV, HEV, and FCV applications.

ACKNOWLEDGEMENT

I would like to thank my Principal Dr. Jalaja M.J., Head of the department, Dr. Manju B., Staff advisor and my guide Prof. Sreelekha V. for their valuable advice and technical assistance.

REFERENCES

[1] Ali Emadi, Young Joo Lee, Kaushik Rajashekara, "Power electronics and motor drives in electric, hybrid electric, and plug-in hybrid electric vehicles", IEEE Trans. On industrial electronics, Vol. 55, 2008, pp. 2237-2245.

[2] Ali Emadi, Sheldon S. Willamson, Alireza Khaligh, "Power electronics intensive solutions for advanced electric, hybrid electric, and fuel cell vehicular power system", IEEE trans. On power electronics, Vol. 21, 2006, pp. 567-576.

[3] Alexander Stipplich, Chistoph H. Van der Broeck, Alexander Sewergin, "Key components of modular propulsion system for next generation electric vehicle", CPSS Trans. On power electronics, Vol.4, Dec. 2017, pp. 250-254.

[4] Kaushik Rajashekara, "Present status and future trends in electric vehicle propulsion technologies", IEEE Journal of Emerging and selected topics in power electronics, Vol.1, 2013, pp. 4-9.

[5] H. Huang, J. M. Miller, and P. R. Nicastri, "Automotive electrical system in the new millennium," presented at the SAE International Truck and Bus Meeting and Expo., Detroit, MI, Nov. 1999, pp. 608-615.

[6] J. G. Kassakian, "The future of power electronics in advanced automotive electrical systems," in Proc. 27th IEEE Power Electron. Spec. Conf., Baveno, Italy, Jun. 1996, pp. 7–14.

[7] J. M. Miller, "Power electronics in hybrid electric vehicle applications," in Proc. 18th IEEE Appl. Power Electron. Conf. Expo., Feb. 2003, vol. 1, pp. 23–29.

[8] J. Shen, A. Masrur, V. K. Garg, and J. Monroe, "Automotive electric power and energy management—a system approach," in Proc. Bus. Briefing: Global Autom. Manufact. Technol., Apr. 2003, pp. 1–5.
[9] M. Kanechika, T. Uesugi, and T. Kachi, "Advanced SiC and GaN power electronics for automotive systems," in Proc. IEEE Int. Electron Devices Meeting, Dec. 2010, pp. 1–4.
[10] J. Biela, M. Schweizer, S. Waffler, and J. W. Kolar, "SiC versus Si—Evaluation of potentials for performance improvement of inverter and DC–DC converter systems by SiC power semiconductors," IEEE Trans. Ind. Electron., vol. 58, no. 7, pp. 2872–2882, Jul. 2011.
[11] H. Naik, T. Marron, and T. P. Chow, "High-low temperature performance of GaN 600 V schottky rectifiers," Phys. Status Solidi (C), vol. 8, nos. 7–8, pp. 2219–2222, Jul. 2011.

BIOGRAPHY

Final year B. Tech Electric and Electronics Engineering Student of APJ Abdul Kalam Technological University.