Artificial Intelligence and Agent based Modeling for Power System Engineering

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Abstract – The fields of power electronics and fuel cells have emerged as key players in the development of sustainable power sources. The prevailing demand for fuel cells is projected to increase as they become the principal source of energy for portable electronics. A high-efficiency converter is a crucial component of the whole system and an absolute must for this specific use case. This is because the converter has a huge impact on the portability of the system as a whole in terms of size, efficiency, cost, and reliability. Choosing appropriate converter architecture is a key and important aspect of increasing the network of fuel cells for embedded systems since the converters alone accomplishes such as significant role in determining the overall efficiency of the system in this study, we take a look at the many topologies configurations of AC inverters and DC converters that are employed in the installation of fuel cells for autonomous and portable. The techniques of switching used in fuel cell energy conditioning are also analyzed in this research. The current issue with DC converters and AC inverters is also discussed at the end of this paper.

Keywords – DC Converters, AC Inverters, DC-DC Converters**,** Fuel Cell Systems, Power Electronics, Zero-Voltage Switching.

I. INTRODUCTION

The environmental and financial advantages of renewable energy systems are substantial when compared to those of conventional fossil fuel technologies, which rely on nuclear reactors and other products to create power. With its consistent power production throughout the year and the availability of fuel, fuel cells have quickly become the most popular renewable energy application. When compared to hydropower, other forms of green energy such as wind or solar power are more susceptible to the elements. While fuel cells show promise as a sustainable energy generator, their output of low voltage necessitates the use of high-phase-up DC-DC converters. The efficiency, environmental effects, and practical application of every energy source present unique difficulties. However, fuel cells' low output voltage, which decreases with increasing load current, is only one of several significant limitations to their electrical output. In addition, fuel cell stacks cannot handle surges in demand for power. Nonetheless, owing to their portability and minimal emissions, fuel cells are a promising technology with widespread potential.

The usage of renewable energy in the United States has more than doubled between 2000 and 2016, and this trend is anticipated to continue. About 10% of all energy used in the United States in 2016 came from them, and 15% of all electricity produced. There has been a 50% increase in the number of patents filed for environmentally friendly energy sources over the past five years [1]. Government incentives and regulations for renewable energy, as well as the desire to convert to cleaner fuel in order to safeguard the environment, have all contributed to a rise in global renewable energy consumption. In the present day, numerous forms of renewable energy are being utilized. Some of the most popular forms of renewable energy and the tasks for which they are best suited are presented in **Table 1**.

Table 1. Forms of Renewable Energy	
Solar Energy	Solar panels on rooftops for building structures, utility-built solar farms, and local solar projects, which generate solar for energy consumers in a specified region, have all contributed to the yearly 68 percent growth of the U.S. solar business over the last decade. There was a record installation of 3.5 million solar panels in Australia in 2016. The number of solar panels installed was highest in Queensland. Solar photovoltaic panels are able to directly catch sunlight and convert it into energy, which can then be used to power anything from a tiny item like a watch to being put into the grid and redistributed to utility consumers.

Wind Energy	Windmills have been used for centuries to harness the wind's energy, but modern wind turbines are far more efficient in converting the wind's kinetic force into usable power. Nowadays, the United States is home to over 53,000 wind turbines. Wind turbines harness the wind's kinetic energy and consist of a tall tower (often more than 100 feet) and a number of blades. The rotation of the blades is transferred to the shaft, which in turn spins a generator. In the same way that solar energy may be utilized for a variety of purposes, wind power can be used locally for things like pumping water or running a farm, or it can be fed into the electrical grid.
Biomass Energy	Renewable energy sources like biomass are becoming popular. Wood, plant matter, landfill gas, and even municipality solid trash are all examples of biomass since they contain solar energy that has been stored for later use. The energy is liberated when such things are burnt, and it may be utilized for things like heating or power. It is also possible to convert biomass into a usable liquid or gas biofuel. Ethanol, biodiesel, and other bioliquids are being employed as transportation fuels. Nowadays, biofuels consume up around 40% of the maize harvested in the United States. Alternative use for biomass and potential novel materials for biomass power are the focus of current research.
Hydro Energy	In the United States, hydropower accounts for 6.5% of all utility-scale electricity output and 44% of all renewable energy generation. Hydropower is generated by the movement of water. We harness this power by connecting generators to rivers, waterfalls, and other sources of flowing water to create electricity. Man-made hydropower stations are possible via the construction of structures like dams. Reserviors constructed by humans to store water often rely on dams to do so. After being discharged, the water flows through a turbine, producing power.

Incorporating power electronics technologies into fuel cell installations is the solution that paves the way for broad adoption of fuel cell technologies. A fuel cell technology may be used everywhere appropriate power semiconductor circuits are installed. While designing a power electronics circuit, there are a variety of switching topologies and switching components that could be used, each with its own set of benefits and drawbacks. Improved reliability and efficiency resulted from the use of hard switching energy electronics made possible by developments in the semiconductor sector. As they shrink in size, switching components become more economical. Even so, there is still a great deal of electrical hum and buzz. The goal of using a soft-switching technique is to lessen the amount of background noise and switching frequency. In addition, ZVSs (zero-voltage switches) and ZCSs (zero-current switches) may be used to reduce switching losses.

In this study, we take a look at the power electronics utilized in fuel cell systems, which typically consist of portable or stand-alone configurations that employ AC inverters and DC converters with a variety of topologies. The research also examines the switching methods implemented in fuel cell power conditioning. The rest of the paper is organized as follows: Section II presents a critical survey of the present technology underpinning the BC converter main topology. In Section III a detailed survey of the DC converter application within the systems of fuel cells has been provided, while Section IV focuses on the key limitation of the present DC converters. Section V focuses on discussing recent developments in DC to DC converters and LEVs. Lastly, Section VI draws a conclusion to the research, and recommends directions for future research.

II. CURRENT TECHNOLOGY UNDERPINNING THE DC CONVERTER MAIN TOPOLOGY

Electronic converters that are really useful use switching mechanisms. With a switched-mode DC-to-DC converter, the DC voltage may be changed from one level to the other by initiating a temporal storage of energy input and emitting it to the throughput at a specific range. Components that generate magnetic fields (such as inductors and transformers) or those that generate electric fields (such as capacitors) could be used for the storage (capacitors). This voltage converter may be used to either boost or decrease the voltage. Although linear voltage control wastes energy as heat, switching conversion may increase efficiency by as much as 98%. In order to be efficient, semiconductor devices need to have quick rise and fall periods.

Nevertheless, when combined with layout parasitic effects, these fast transitions may make circuit designing challenging. Because of its greater efficiency, a switched-mode converter reduces the amount of heatsinking necessary and ekes out more use from portable devices' batteries. Since the late '80s, power FETs have been used to replace power bipolar transistors because of their superior switching efficiency reduced switching losses, and higher switching frequencies, as well as their simpler driving circuitry. Substituting a power Field Effect Transistor (FET) for the flyback diode in DC-DC converters is a significant advancement since the power FET has a considerably lower "on resistance," hence lowering switching losses. Low-power DC-to-DC synchronized converters used to be made of an electromagnetic vibrator, a frequency step-up transformer, and either a vacuum tubes or semiconductors rectification, or connectors for the rectifier on the vibrator, before energy semiconductors were widely available.

Most DC-to-DC adapters only allow electricity to flow in one direction, from inputs to outputs. When different diodes are replaced with active rectifications that can be regulated separately, however, any switching regulator topology may become bi-directional and able to shift energy in either way. A bidirectional converter is helpful for applications requiring vehicle regeneration braking, which means that the wheels receive power while driving but provide it while stopping.

Switching converters are technological marvels despite their simplicity in terms of the number of components needed. Components in high-frequency circuits must be precisely defined and physically positioned for reliable operation and low switching noise (radio frequency interference). In voltage-dropping applications, their price is greater than that of linear regulators, although it has been reducing as chip design has improved.

Many DC-to-DC converters are now available as ICs that require only a small number of additional parts. There are also converters available as fully functional hybrid circuit modules, all set to be plugged into an electronic system. Literally speaking, linear regulators are DC-to-DC converters because they convert DC power from a greater but less sustainable input into DC power with the same consistency regardless of the input voltage or the load, but this is not how they are typically referred to. (This is also true for a basic voltage dropper resistor, regardless of whether or not a subsequent Zener diode or voltage regulator is used to stabilize the voltage). In addition, diodes and capacitors may be used to create basic Dickson multiplier and capacitive voltage doubler circuits, which double a DC voltage by an integer number while only using a negligible amount of current.

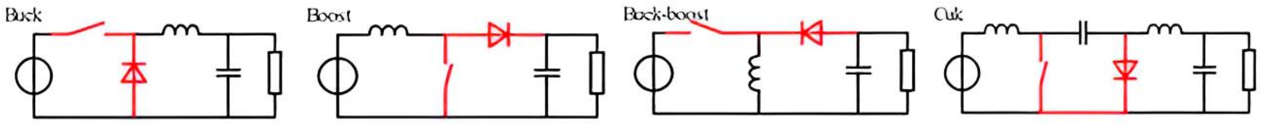

Fig 1. The buck, buck-boost, boost, and Ćuk topologies of switching DC-to-DC converters

At the left (in **Fig 1**) is the input, and to the right is the loaded output (rectangle). The transistor that acts as the switch is a MOSFET, BJT, or IGBT. Several DC converters exist on the market, each with the ability to alter the DC voltage by either increasing or decreasing its magnitude or switching its polarity. In this case, power MOSFET and the diode are employed to apply switches, even though alternative switches for semi-conductors such as BJTs, thyristors, or IGBTs could be employed instead. In addition, there are a plethora of semiconductor switchers on the market that drastically cut down on transmission loss, e.g., ultra-fast 1200V IGBTs that is capable of minimizing switching and conduction losses, and are especially useful for renewable energy technologies that aim to provide the highest possible levels of dependability and effectiveness. The1200V Trench IGBTs have been developed for lowest transmission loss and fastest turn-off at higher frequency, so they can fulfill the most stringent of performance requirements in any system. Solderable Front Metal (SFM) technology has recently seen some significant advancement that have substantially increased its power cycling capabilities and reduced power dissipation by using dual-sided cooling. SiC-based power electronics, made from Silicon Carbide (SiC), can cut down on power network size and switch losses by half, making them ideal for use in high-power electric applications such as those located in power firms, high-power corporate drives, microgrids, and renewable panels of energy.

DC-DC Boost Converter

The main parts of a boost converter are shown in **Fig. 2**: a diode (D), switching element (M), switching controller (S), and inductor (L). The controller alternates between "on" and "off" on the switching element to multiply the input voltage by the set output value. By storing energy in the inductor, the switching element can then supply current to the load and the diode while in its "on" state. When the diode is switched off, energy is released from the capacitor and used to power the load. The current waveform through the inductor determines which of two modes that are operational by the boost converter i.e. the discontinuous-conduction or the continuous-conduction. Whereas the switch is engaged, current through the inductor remains constant, but when it is disengaged, it gradually decreases until it is at zero at the end of each switching period. Because of its constant input potential, low input rippling current, and effective clamping of outputs diodes, the boost converter is particularly well-suited for use in applications involving fuel cells. The boost converter is now the most popular option for energy storage applications, and there have been several efforts to increase its efficiency at low voltage sources. The transformer design has been optimized for extremely low leakage inductances, switching in current power electronics has been used, and the necessity for a voltage clamp circuit has been removed.

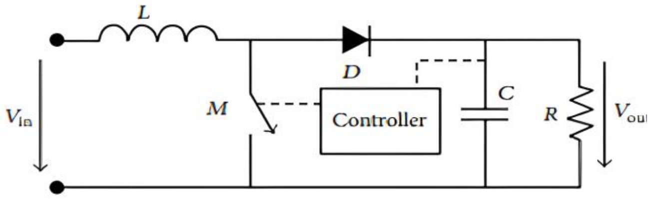

Fig 2. The DC-DC boost Converter Architecture

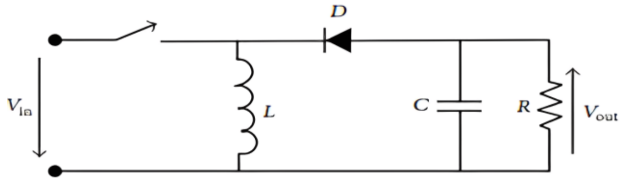

Fig 3. The DC-DC buck-to-boost Converter Architecture

With the inclusion of a capacitor-inductor-diode (CLD) cell, Chan, Chincholkar, and Jiang [2] have shown that the novel quadratic boost converters have superior characteristics to those of the traditional quadratic booster converter and are thus well-suited for applications requiring a very higher voltage step-up ratio. Lalmalsawmi and Biswas [3] examined a full-bridge (FB) DC-DC boost that makes use of a 3-mode PS-TEM control scheme and a leading-edge regulated FB cell in order to enhance effectiveness and dependability. For low-ripple applications, a research by Rudenko and Institute of Electrodynamics of the National Academy of Sciences of Ukraine [4] demonstrated how to couple a KY boost with the traditional SR (synchronously rectified) voltage source inverter, and they found that the efficiency was 90% or higher for loads greater than 50%. Ahmad, Gorla, Malik, and Panda [5] proposed a novel reconfiguration boost converter, which uses a resonant capacitance and inductances, in addition to an auxiliary switch and diodes, to reduce switching losses and increase efficiency by nearly 96%, compared to those of a conventional hard-switching transmitter. Ting, Aslay, and Sahin [6] developed a unique control strategy that makes use of loss model characteristics to enhance the effectiveness of the boost converters.

DC-DC Buck Converter

The DC voltage may be lowered by using a buck converter, which has a 1:1 conversion ratio ($M(D) = D$). Its widespread adoption may be attributed to its straightforward architecture, which has few moving parts, easy controls, and minimal/no isolation. Within the conventional buck converters, just a single active switch is employed, and the maximal voltage throughout the semiconductor endpoints is always the same as the input signal. Conventional methods are inefficient because of the large conductivity losses from rate or high-voltage electronic and the significant switching losses. The buck converter could be employed in a variety of applications, including regulators for low power and high-power and step-down processors. The DC-DC buck converter was explored and proven by Hao, Namuduri, Duan, Gopalakrishnan, and Bucknor [7], who also argued that voltage over the switching are approximately 50% lower compared to the 2-way zero-voltage switching (ZVS) buck-to-buck converter. Other features include 3-way buck clamps, active clamping, and PWM (pulse width modulation). Chen et al. [8] presented novel single-inductor quadratic converters that mitigate the effects of many power management difficulties, including its size, cost, complexity, and impact by controlling the converters in average-current mode and omitting the need for slope correction. It was postulated by Singh and Yadav [9] that DC-DC buck and boost converters may benefit from a new arrangement that makes use of two storage components to enhance output power while simultaneously decreasing ripple voltage at the converters' outputs.

DC-DC Buck-Boost Converter

The buck-to-boost converter is an energy supply, which employs the element of switching, diodes, capacitor and the inductor as its fundamental circuit components. **Fig 3** shows how buck-boost converters are differentiated from boost converters by the positioning of the switching element relative to the inductor. It is possible for the voltage of an output of the buck-boost topologies circuit to be minimal than, same as, or more than the voltage of the input. The buck-boost topology is useful for mobile systems with varying output needs and is effective whenever a larger current is present. The output of voltage is not affected by the voltage of inputs whenever the duty cycle is at 0.5. When the cycle is below 0.5, the converter of the buck-boost works in the buck mode, with a resultant output voltage, which is minimal compared to the input voltage. For the converter to operate in the boost mode, in which the voltage output is more than the voltage of input, the switching frequency should be higher than 0.5. **Fig 4** graphically represents this association.

For reduced component stress, consider the buck-boost PWM converter described by Fernandez et al. [10], which has two switches under separate control and may function as either a buck or bust converter based on the output and input circumstances. In order to create a low-voltage positive buck to boost converter, Setiawan et al. [11] presented a simple compensation scheme based on an average current control. This method delivers regulated outputs composed of maximum efficiency of 73 percent at a 1 MHz switching frequency, and it may alleviate several power management issues including cost, size, design specifications, and a straightforward compensatory design. For portable applications with low power, Boopathy and Bhoopathy Bagan [12] provided an innovative approach to creating an actual-time buck-to-boost with developed transient feedback, significantly raising efficiency from 16% to 19%. At the DC voltage level of 0.25 A, the effectiveness of the KY converters is maintained at 88% or more, solving the voltage bucking problem and expanding its range of applicability as proposed by Pham [13].

DC-DC Cuk Converter

Connecting the input and output port of the Cuk converters with an inductance creates a series circuit. The input and t output inductors are connected to a capacitor through the switch network in a cyclical fashion. M(D) is the same as the buck-to-boost converter's conversion ratio. Therefore, the converter increases or decreases the voltage while simultaneously reversing the polarity. Depending on the application, the Cuk converter may either increase or decrease the output voltages based on the input. The inclusion of inductors on both the input and output sides of the circuit allows it to invert the input voltage to a negative value. By connecting between the load and the input source, these inductors dampen the resulting current ripple. Moreover, the Cuk converter has improved dynamic responsiveness, lower EMI production, and greater efficiency. Dudrik, Pastor, Lacko, and Zatkovic [14] designed and tested a proactive snubber Cuk zero-voltage switching converters in order to accomplish symmetrical power-sharing and parallel functionalities.

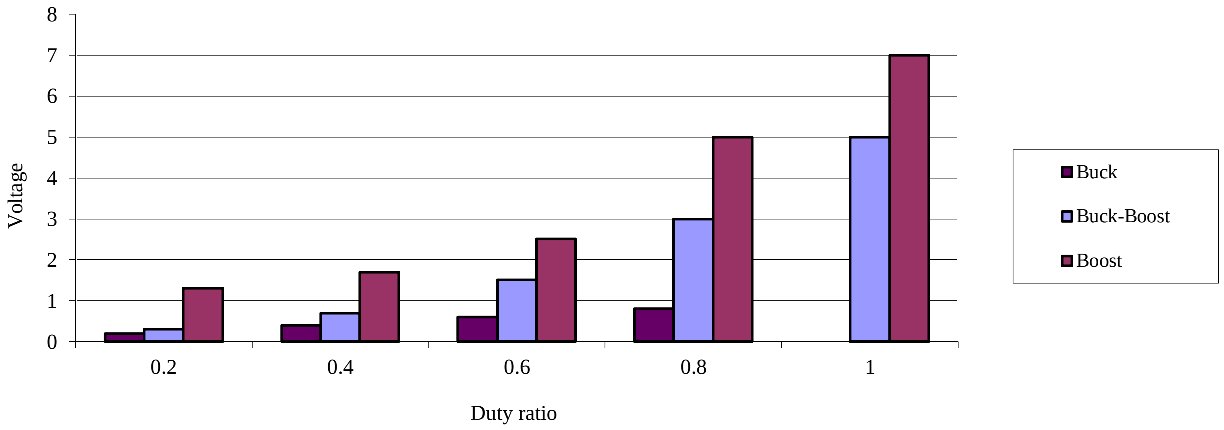

Fig 4. A comparion of the Duty Ratio Within the Buck, Buck-Boost and the Boost Convert

DC-DC SEPIC Converter

The single-ended primary inductance converter (SEPIC) may be used to boost or drop voltage. This does not, however, result in a polarity reversal. $M\ (D)\ =\ D/\ (D\ 1)$ is the formula for determining the multiplier for a given dimension. The SEPIC is capable of accepting a wider input voltage dimension, functioning in the buck-boost mode with no polarity reversal and little input power pulsation. The fuel cell's advantages as a source of energy are as follows: As it is a converter, it could be utilized in either boost or buck applications, and it gives you greater discretion when planning the auxiliary source's architecture. Unlike standard buck or boost converters, SEPIC converters can work properly even when the voltage output is the reverse polarity.

As an inductor is placed in input signals of SEPIC converters, it could attenuate pulses of the input power, and potentially and compensate for the downside of the electrical power pulses, rendering fuel cell systems easier to precisely manage. The SEPIC's versatility as a step up/down converter as well as a source of noninverting output has made it a popular component in photovoltaic systems and LED backlights. Nevertheless, because of its added inductor and capacitor, which result in significant power losses, its energy conversion effectiveness is less than that of other converter topologies, e.g., as the buck and boost converters. A re-structured SEPIC structure for a step-down or step-up converter was developed by de et al. [15] as an enhancement over the conventional SEPIC structure in continuous conduction mode. Little losses in transmission of input power to the load are possible.

III. APPLICATION OF DC CONVERTERS IN FUEL CELL SYSTEMS

As the fuel cells are known for their limitations (limited current densities, unplanned power output, and lower voltages) the DC converters has become the most fundamental element of the fuel cell model for standalone or portable usage. The typical voltage that can be supplied by a single DMFC under load is between 0.3 and 0.5 V. Combining a DC converter and a transformed power source from the battery pack may help with these issues. Numerous DC adapters have been established to supplement fuel cell frameworks, though their effectiveness is governed by both conduction and switching inefficiencies. The effectiveness of the DC converter increases as its switching and conduction losses decrease.

Minimizing the number of elements employed and their operating dimensions may effectively decrease transmission losses. A fuel cell implementation is needed because of the employment of a power controller to provide the necessary load voltage. Because of this, the fuel cell may need a nominal supply input that is greater than, the same as and lower than the voltage produced by the battery pack. The minimal supply voltage system necessitates a converter that can step upward or downward the fuel cell voltage. To efficiently raise or lower the fuel cell voltage, step-down (buck converters) and step-up (boost converters) are two typical kinds of converters utilized in fuel-cell systems, notably in low-voltage diverse applications and the single-stage level (step-down).

Singe-Stage Topologies

In order to fulfill the operational necessities of the fuel cell models, scientists established a variety of single-stage converter architectures, such as DC-AC inverters and DC-DC converters. The supply voltage may be a controlled DC voltage or an AC voltage, dependent upon whether a DC and AC load is being energized. The single-phase structure has lesser moving components and is simpler to control. Ramirez, Sipahi, Diaz, and Leyva [16] looked at many different DC converters employed in portable fuel-cell models and argued that the DC-to-DC buck converters provide the best effectiveness for a 100W fuel cell power condition by retaining the variation of the input frequency of less than 3% of the real input current and providing a well regulated output voltage. According to Rimondi et al.'s [17] comparison of the two topologies, the design of the boost converter is desirable for applications with lower voltage within fuel cells. Saha, Modal, Chattopadhyay, and Mukherjee [18] propose a two-inductor boost converters employing a single reverberating inductor, and they calculate its maximum efficiency to be 92.4% while operating in ZVS mode at Vin = 30 V.

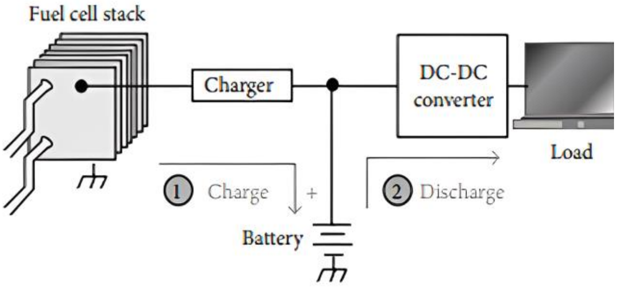

Fig 5. Battery Charger Structure

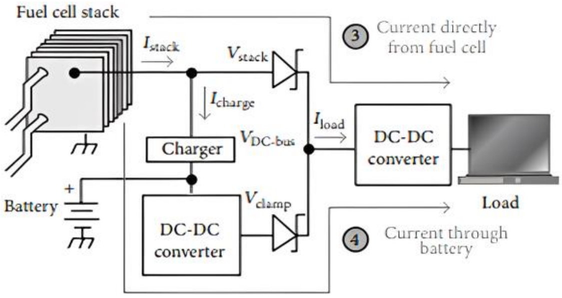

Fig 6. Charger and 2-diode Structure

In order to make the most of the benefits offered by both the fuel cell and the battery, Patrabansh, El-Sharkh, and Alam [19] designed a comprehensive hybrid dynamic DMFC structure, as shown in **Fig 5** and **Fig 6**. In this configuration, the load is shared between a a Li-ion battery and DMFC stack (see **Fig 7**). **Fig 5** shows a typical hybrid battery charger circuit, which gets its power directly from the battery. As the DMFC stack is in operation only while the battery is being charged, the fuel cell does not provide the laptop with electricity. The DC-DC converters and computer are powered by the charged battery during the DMFC stack's first operation. As can be seen in **Fig 6**, the fuel cell would have supplied either indirect or direct electrical energy to the DC-DC converters and computer by recharging the battery, which would then have been used to provide power. It was instantaneous between these two strategies. In the case of a fuel cell failure, the battery current will be utilized to augment the direct current provided by the fuel cell. This auxiliary current is processed by three converters: output regulation converter, battery output converter, and the battery charger.

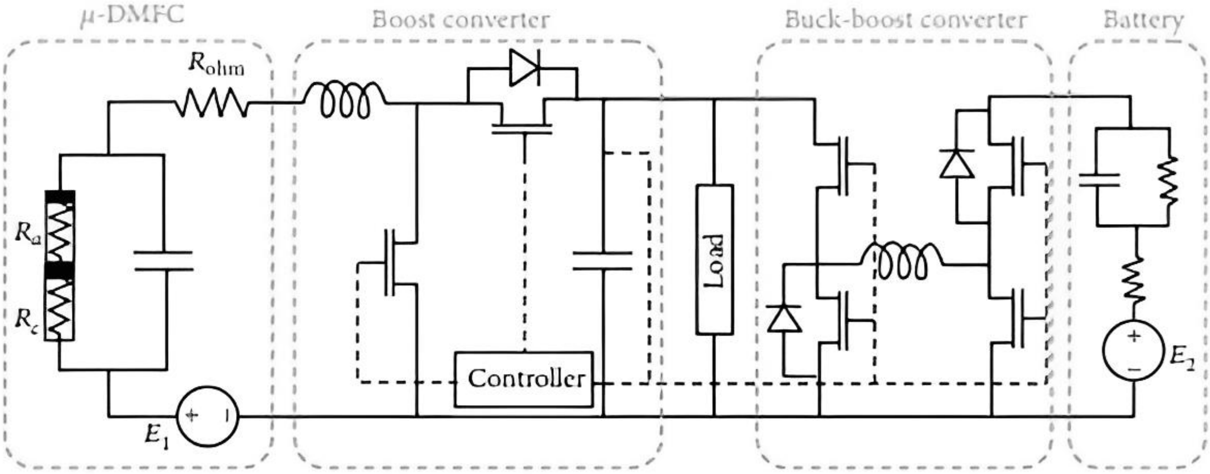

Fig 7. Hybrid Power Architecture (Li-ion battery and small-scale DMFC)

A hybrid DC-DC converter was suggested by Yuan, Peng, Liu, and Yi [25] for use in a laptop that draws power from a fuel cell. Unfortunately, a significant drop in voltage is causing issues for this power distribution system, necessitating a voltage regulator module (VRM). The hybrid converter showed that a 30 W fuel cell could accept power from several DC-links, revealing a new approach to power distribution that takes into account the flexibility of many energy inputs.

Multistage Topology

The term "multistage topology" is used to describe power conditioning setups that include numerous stages of conversion, such as several AC inverters and DC-DC converters. A DC-DC converter is employed in this construction to transform the current or voltage produced by the fuel cell. A converter, maybe a boost converter, buck converter, or some other sort, is utilized to charge an battery or ultra-capacitor. The output of this converter is then used by the inverter as a parameter to transform. At the second step of this setup, a DC-DC converter changes the voltage of DC into AC. More components are needed for a multistage architecture, which results in a greater power loss compared to a simpler design. For example, Boendermaker, Zuidervliet, and van Duijsen [21] describe a system in which a bidirectional converter and boost converter are used to connect a DMFC and a supercapacitor bank to a DC power bus. Barati and Ahmadi [22] proposed and spoken at length about a similar topology.

A supercapacitor is used to regulate the voltage level by making up for the system's lack of power during high-load situations and making use of the DMFC's excess power when the load is low. This is all done whereas DMFC is continually being checked at MPP by the MPPT controllers. By quickly charging and discharging the supercapacitor in response to varying load conditions, a well-designed bidirectional converter guarantees a steady flow of power to the load at all times. Aoun, Kunz, and Ture [23] demonstrated a transportable high-efficiency dynamic DMFC structure. This setup doubled the effectiveness of the power transformation process by using a smart batteries as a reserve for buck-boost converters and the fuel cell.

As can be seen in **Fig 7**, hybrid sources integrate the high energy efficiency of battery with the higher power density of fueling cells with the goal to lengthen the lifespan of portable electronics. Synchronization boost converters are wired in series with fuel cells to enhance the voltage to DC standard (bus) (3V for electrical device). In practical implementations, fuel cells connected in series will provide input voltages of 2 to 4 V at full-load, with power regulation of the battery pack handled by an H-bridge buck-to-boost converters. H-bridge buck-to-boost converters are analogue in design, allowing them to switch between boost and buck modes reliant on the battery's state of charge.

IV. LIMITATIONS OF CURRENT DC CONVERTERS

The input current will increase until the boost converter's power lowers if the outputs power is too high. This will cause considerable losses and a decrease in efficiency. Because of this, the voltage across the diode drops significantly. If the diode is replaced with a switching element in low-voltage applications, as shown in **Fig. 8**, the resulting design is a synchronous DC-DC boost converter. During the transition from M1 off to M2 on, a shoot-through current may be generated; hence, a time delay is necessary in this circuit. This minimizes the power loss caused by the voltage drop across M2.

When PWM control was used for the higher-load situation and PFM controls were employed for low-load situation, significant efficiency gains were possible over the entire load range. To a certain extent, the load determines the amount of energy lost during conversions and switching. Boost converters have a big drawback in that they produce a lot of switching noise. As the fuel cell's voltage of the output is impacted by this noise, its performance suffers each time the switching element is activated and deactivated. A soft switching approach, which employs snubber circuit design at every switch, an extra electromechanical interface at the converter input and output, and so on, may all help to prevent this issue from occurring.

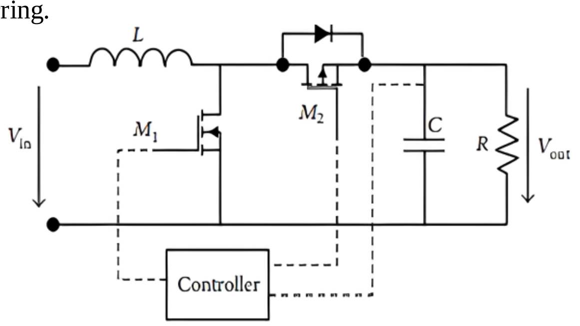

Fig 8. Synchronous DC-to-DC boost Converter Architecture

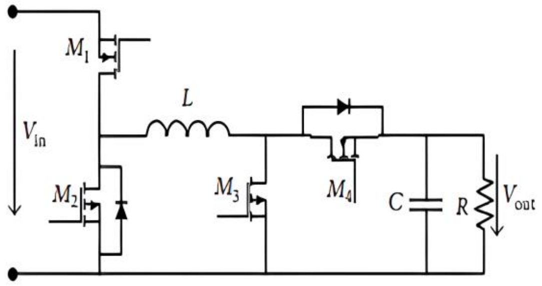

Fig 9. Non-inverting buck-to-boost Converter Architecture

To accomplish the same increment in output voltage, the converter of the buck-to-boost switching frequency must be greater than that of the power converter. However, the buck-boost converter is minimally economical compared to the power converters because higher duty periods enhance transmission and distribution losses in the frameworks. It's also not a good idea since the voltage level polarity is the opposite of the voltage at the source. One potential solution to this problem is a buck-to-boost converter with non-inverting input. It is indicated in **Fig 9** that the boost converter and the buck converter may be cascaded to form a non-inverting buck-boost design. Switches are more efficient than diodes for low-voltage applications. As with the boost multilevel inverters, this one is affected by the noise of switching. Employing the converter with higher switching frequencies improves efficiency without increasing the complexity or expense of the power cooling systems. Conventional hard-switched PWM has limitations including high transistor stress, high switching inefficiencies, and undesirable EMI. Soft-switching PWM technologies are being employed for the frequency of high-switching operation with high conversion effectiveness and larger volume-to-power percentages.

V. RECENT GROWTH IN DC-DC CONVERTERS AND LEVS

Concerns about the negative impacts of burning fossil fuels have prompted a global shift toward environmentally friendly technologies. The usage of electric cars is an area of green technology that shows promise (EVs). By the end of 2021, it is predicted that there will be around 16.5 million electric vehicles (EVs) on the roads worldwide. This includes both BEVs (battery electric vehicles) and PHEVs (plug-in hybrid electric vehicles). According to the Stated Policies contexts, the EVs number in the world is projected to reach about 200 million by 2030. Light electric vehicles (LEVs), such as scooters and mopeds, are on the rise. This is because they are convenient for public transportation and relatively small in size, both of which are important for nations working to decrease their carbon impact.

As an added bonus, such cars may be charged using a standard household AC power socket. Three-wheeled e-bikes in the Netherlands and e-rickshaws in India are two well-known applications of LEVs. Due to their slow pace, short daily travel, and huge volume, three-wheeled vehicles in India offer enormous potential for electrification. The result is an increase in the popularity of three-wheeled e-rickshaws in metropolitan areas, which were formerly dominated by autorickshaws powered by Compressed Natural Gas (CNG). **Fig 10** displays the percentage of LEV sales in different countries. This pattern makes it clear that nations like China and India have accounted for a disproportionately large number of sales of two- and three-wheeled LEVs.

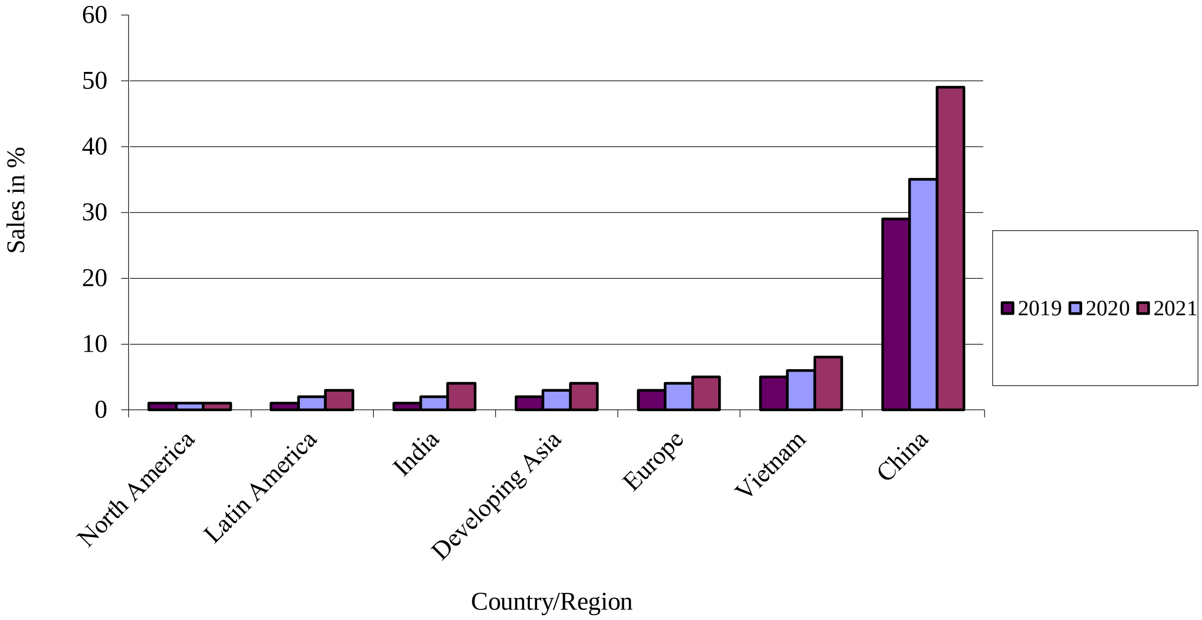

Fig 10. Trends of electric cars in Different Countries Development from 2019-2021

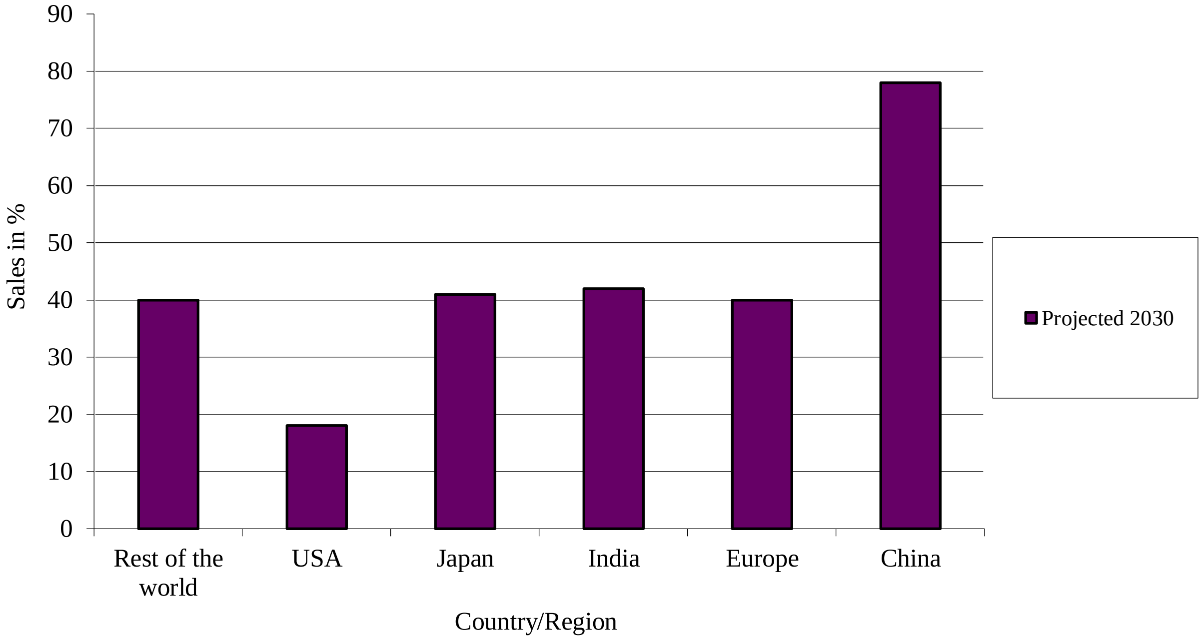

Fig. 11: Trends of electric cars in Different Countries Forecasted sales by 2030

Fig 10 shows the trends of electric cars in different countries illustrating the development from 2019-2021 **Fig. 11** shows forecasted sales by 2030. It is crucial to strengthen and expand the LEV charging infrastructure to keep up with the growing number of these vehicles. **Table 2** provides a selection of the LEVs now on the market. This table shows that the typical voltage for LEV batteries is between 48 and 72V, and the maximum available ampere-hours (Ah) is up to 180. So, unlike other types of EVs, LEVs just need a simple connection to a household's AC supply in order to be charged. As this is the case, LEVs have less complicated charging needs than conventional EVs. One other important lesson from this chart is that the majority of the cars listed have a regular charge time of 3 to 5 hours, with just a select handful able to use rapid charging. It follows that producers of two- and three-wheeled EVs need to make ready access to rapid charging a top goal. While recent publications have touched on LEV charging in some way, there is a dearth of effort that is categorically dedicated to the charging of LEV. In contrast to the extensive discussions of DC-DC converter architectures for the charging of EV seen in other papers, an overview of DC-DC converters is lacking for LEVs.

Table 2. Prevailing LEVs and Battery or Charging Specifications

Wheelers	Models	Batteries Type	Voltages	Capacities	Duration of Charge	Fast Charging
2-Wheeler	Athers 450-Plus	Li-ion	51V	3.7kWh	5 hours 50 Minutes	1 to 2 hours
	Okinawa PraisePro	Li-ion	72V	2kWh	2 to 5 hours	-
	Hero-Electrical Optima-CX	Li-ion	51V	30Ah	4 to 5 hours	-
3-Wheeler	Terra Motors Y4A	Lead Acid	48V	140Ah	6 to 8 hours	-
	Fixed Battery/Pioggio Ape E City	Li-ion	48V	8kWh	3 hours 45 minutes	-
	Mahindra Treo	Li-ion	48V	7kWh	3 hours 50 minutes	-

Fig 12 depicts a typical soft-switched boost converter consisting of a boost switch S1, a boost diode D2 and a boost inductor Ls. Nevertheless, Barote and Marinescu [24] suggested that the effectiveness of converters could be enhanced by adding an auxiliary network. A pair of inductors L1 and a diode D1 makes up the auxiliary network.

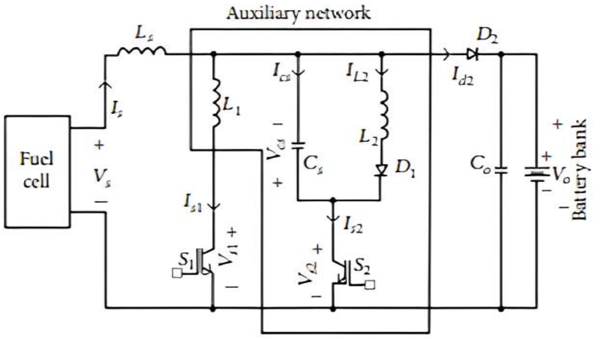

Fig 12. Novel soft-switched DC-to-DC boost converter

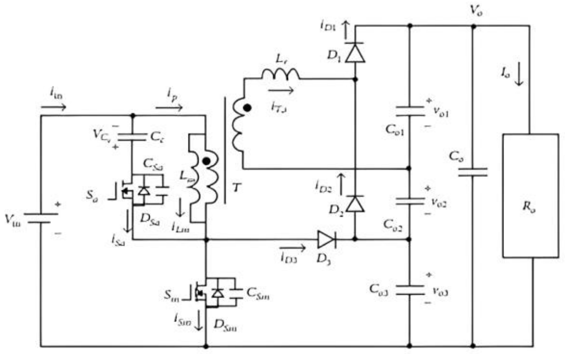

Fig 13. Novel zero-voltage switch DC-to-DC coverter

In addition to L2, a single snubber capacitor Cs is also required. This converter operates in seven different modes, with higher effectiveness (more than 95% full-load) being recorded. Adjusting the pulse width of switch S1 in the center of the converter permits users to effectively determine the voltage at its output. **Fig 13** shows a proposed unique zero-voltage switching DC-to-DC converters by Chen et al. [25] for renewable energy conversion systems, which makes use of a voltage source inverter and a doubler- voltage system composed of coupled inductor. When an active switch is employed, a voltage stress is created. An active snubber is employed to minimize this stress and emit energy that is stored in magnetizing and permeability inductances. In order to provide a high output voltage, the adopted converters in a conventional boost converter has a lengthy turn-off time. When active switches are modulated with an asymmetrical pulse-width, their inductances and output capacitance both have resonant frequencies during the transition interval. As both switchers activate at zero-voltage switching, the inefficient circuit and fast turn off time of a conventional boost converter are rendered unnecessary.

Recently, Shneen, Aziz, Abdullah, and Shaker [26] introduced a Pulse-Width Modulation (PWM) that is unique soft-switched quadratic boost converter, which operates with a DC input voltage of varying magnitude. Parasitic components in the unadventurous PWM DC-to-DC boost-converter limit the voltage gain even under extreme conditions of duty cycle, rendering it unusable in practical applications. To accommodate the broad DC input output voltages of fuel-cell systems, a novel soft-switched channel width-modulated exponential boost converter was developed. With a 92.3% efficiency rate, this converter is very effective. Vacheva, Genev, and Hinov [27] have introduced a brand new push-pull DC-DC converter that is fed by a zero-voltage switching current. Using this method, the voltage spike between the switches during the turn-off event is absorbed by an auxiliary circuit, resulting in a no-voltage switching state. With its size and weight reduced, the converter's efficiency has increased. Operating at high frequencies is needed to minimize the dimension of the inducement component and other reactive elements, which in turn reduces the converter's total size and weight. This converter is determined by the width of the pulse modulation and employs a simplified circuit. The maximum operating frequency of this converter exceeds that of a standard current-fed converter, allowing it to be used at higher frequencies. This converter employs a clamp circuit to smooth down the switching transition and eliminate [28] any harsh voltage changes that might damage the power semiconductor components. The converter's size and cost are decreased when compared to standard converters due to the use of a single input inductors and the absence of a clamp winding [29].

VI. CONCLUSION AND FUTURE RESEARCH

DC converters of different topologies have a significant contrition to the widespread application of renewable energy sources, especially in portable and self-contained applications. The review explains how DC converters might assist fuel cells more effectively transfer power to loads. A DC converter or group of DC converters may be used to remedy problems associated with unregulated voltage, poor current density, low voltage, and unstable power. When using fuel cells, it is recommended that you pair them with a composite DC converter that can steady the power conditioning from a battery, super-capacitors, or other external sources. According to this breakdown, the switching technique is what really makes a DC converter tick. By using a soft-switching technique, DC converters may increase their efficiency and density of power. The DC converter of PCU may use a single-stage design or a more complex multi-stage architecture. In single-phase topologies, DC converters are used without any further AC inverters or the DC converters, but in multi-stage topologies, they are used in conjunction with each other. In sum, the architecture of the DC converter design is crucial for fuel cell systems. Further study is needed to develop unique topologies for DC converters, which might also incorporate novel switching approaches, to accomplish a higher level of efficiency and enhance the present switching strategy. Fuel cell devices are widely sought after for certain mobile applications because to their small size and high energy density. Due to their ability to satisfy size and the standards of energy density, DMFCs (direct methanol fuel cells), DBFCs (direct borohydride fuel cells) are the focal domain of compacted fuel cell research. Fuel cells, such as DMFCs and DBFCs, are an alternative source of energy for portable electronics thanks to advances in power converter technology.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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Ethics Approval and Consent to Participate

The research has consent for Ethical Approval and Consent to participate.

Competing Interests

There are no competing interests.

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