A review of various designs of Multi-Input Step-Up Converters for Hybrid Electric Vehicles

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Abstract- Recent regulations of vehicular emissions and the cost of conventional fuels forced the transportation industry to move towards the electrical transportation sector. This had led to a sudden increase in burden on the existing power system that is now used to charge electric vehicles. This paper briefly reviews the effect of electrification of transportation on the existing power system.
A significant research on grid-independent hybrid electric vehicles is required to tackle this. Last few years have seen extensive use of hybrid electric vehicles which uses multi-input DC-DC converters to create an interface for multiple sources to enhance the performance and reliability of the vehicle. Among different types of multi-input DC-DC converters, non-isolated multi-input DC-DC converters are suited for low and medium power electric vehicle applications. This review is intended to serve as a suitable guideline and reference for creating a judgement for multi-input high step-up DC-DC converter topologies for HEVs.

I. INTRODUCTION

In the present era, there is an immense demand for eco-friendly and energy-efficient transportation. Several types of vehicle concepts available in the current market, Most of the charging infrastructures of these electric vehicles depend on the existing power system. At present, power networks are working very close to or sometimes beyond their rated capacity. It forces frequent maintenance and also struggling to maintain power supply due to load demands beyond its design specifications. The increasing number of battery-based electric vehicles creates enormous stress on the grid. Because of the electrification of transportation using battery technology, the existing grid will be going to face technical as well as economic losses. Lithium-Ion battery is one of the major sources of battery-based electric vehicles, and it is not a renewable source. In order to avoid this dependency on the existing grid and Lithium, there is a significant need for grid-independent electric vehicle systems.

In the present scenario, fuel cell electric vehicles (FCEV) technology is improving day by day, and solar roof-top based electric vehicles are at their initial stages. It is facing economic, fuelling infrastructure and safety problems. On the other hand, solar roof-top electric vehicles cannot work independently because of the availability of space on the roof of the vehicle and sunlight. To develop a less cost grid-independent hybrid electric vehicle, there is a requirement of integration of multiple sources. The efficient combination of sources like fuel cell and solar photovoltaic cell can create grid-independent hybrid sources. Power electronic converter along with control plays a significant role in the entire process of developing efficient grid independent hybrid electric vehicles. As the number of inputs is more than one, there is a necessity for multi-input converters. Generally, an electric vehicle consists of DC-DC converter as well as DC-AC converter. As the multi-input electrical vehicle technology is soaring, the multi-input DCDC converter design and control plays a significant role in the entire system. Multi-input converters can be classified into two types, namely isolated multi-input DC-DC converters and non isolated multi input DC-DC converters. Isolated multi-input converters are mostly used in high power applications. Non isolated converters are leading the low and medium power applications. The low and medium powered EVs are very close to ordinary people, so the research and development in this area will enhance EV market.

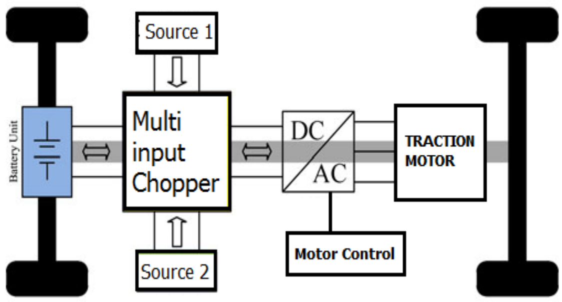

Fig 1 - General structure of the multi-powered HEV.

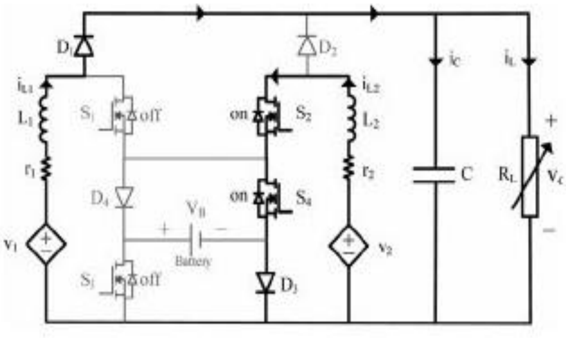

Fig 2 - Three-input dc–dc boost converter

II. EFFECT OF THE ELECTRIFICATION OF TRANSPORTATION ON GRID

The grid has a no power backup directly, so it is less sufficient to supply the loads beyond its capacity unless there is a significant generation from the peak demand power plant. However, this approach is costly. The integration and penetration of PHEV systems highlight two concerns: the capability of the network to fulfil the standards making use of load management, and ability to accommodate loads which vary with geographical location.

PHEV causes significant variations on residential loads and increases the demand for fast response generation due to low economic dispatch efficiency. The distribution system requires additional infrastructure like Solar or Fuel cell at the residential locality to support BEV loads. This also needs replacing the customer voltage cables with high rated units, reinforcement of the second feeder and transformer, and further connects micro-generation via power electronic interfaces into the consumer voltage network.

Many studies have raised concerns about the power quality problem when an electric vehicle connected to the grid, which severely damages the connected loads, and it leads to massive economic loss. It is established that 60% penetration levels of PEVs with uncoordinated charging violate the thermal loading of feeders as well as distribution transformer. PEVs charging will raise the load on the system, so the current flow in the feeder will also increase; this will lead to severe losses in the network. Transformers that are connected to load buses are facing current limit issue when it is tested under distributed incremental increases in the load (EVs).

Name	Battery (kWh)	Time to Full Charge (Wall Connector)
2019 Nissan Leaf SV	40	6–8 h
2019 Jaguar I-Pace S AWD	90	10 h
2020 Jaguar I-Pace S AWD	90	10 h
2019 Chevrolet Bolt Premier	60	6–8 h
2019 Audi E-Tron Premium Plus	95	80% in 30 min
2019 BMW I3	22	3.5 h
2019 Volkswagen E-Golf Sel	24	6–8 h
2018 Tesla Model S P100D	100	4.5 h
2018 Tesla Model 3 Standard	50	6.5 h
2016 Chevrolet Spark 2LT	21	4–6 h
2016 Fiat 500E Esport Package	28	4 h

Fig 3– Some of the existing BEVs along with typical specifications [8]

III. FUEL CELL TECHNOLOGY FOR ELECTRIC VEHICLES

Fuel cell electric vehicle (FCEV) technology consumes hydrogen as fuel. Hydrogen can be one of the best solutions for energy storage, and later it can be instantly converted into electricity by using fuel cell. Recently, researchers developed a cost-effective platinum-nickel alloy, which can replace existing platinum electrodes and also increases the speed of chemical reaction. The extensive research and development in fuel cell technology is thriving very fast. Among all fuel cell technologies, PEM-FC is commercially well established, and SOFC technology also equally took positive inclination because of its distinctive characteristics and economic advantages. Fuel cells can replace existing batteries not only in EVs but also in other applications. Even though the fuel cell electric vehicles possessing a plethora of advantages over BEV but still the technology to be improved to reduce the cost of the vehicle. Establishing the fuelling infrastructure and production of hydrogen at low cost will lead to winning the EV race in the current market.

Weight of fuel cell stack and hydrogen tanks together less
The source is abundant in nature. **Used in long-range private cars, buses, commercial vehicles**
FCEV could provide extended range and short refilling times.
Fuel cell production generates fewer carbon footprints
Recycling of a stack is easier than a battery.
FCEVs are zero local emission vehicles
FCEV filters the air supplied into the fuel cell stack.
The FCEV creates zero noises

Fig 4- Advantages of FCEV

IV. GRID-INDEPENDENT HYBRID ELECTRIC VEHICLES (GIHEV)

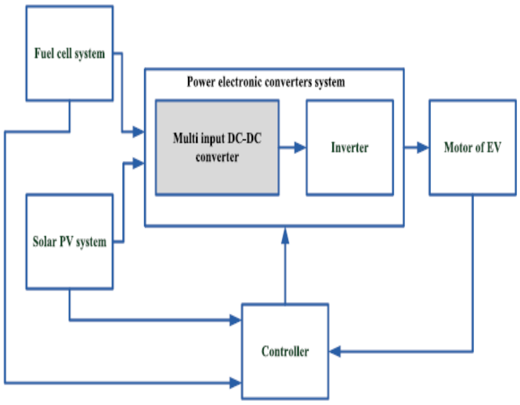

Fig 5- Block diagram of AC motor enabled grid-independent hybrid EV system

The battery, fuel cell and solar PV roof technologies have their own advantages and disadvantages. The continuous research is craved to overcome the difficulties and challenges in all three technologies in-order to meet the present and future transport requirements and to reduce the CO_2 emissions. The battery-based electric vehicles are highly dependent on the grid, so there is a necessity for developing grid-independent electric vehicle technology. Solar roof electric vehicle is less dependent on the existing grid and fuel cell electric vehicle is entirely independent of the existing grid. FCEV is consuming a significant amount of hydrogen; however, this can be drastically reduced by using a hybrid system.

One of the possible solutions is the integration of fuel cell and solar cell. This hybrid system is capable of enhancing the electric vehicle technology to the next level. It can reduce the consumption of fuel, reduce the dependency on battery technology, minimize the stress on power system networks, less usage of hydrogen fuel, and reduce the time of refuelling. In EVs, the power electronic converters such as DC/AC converters, DC-DC converters, and AC/DC converters decide the performance of the entire EV.

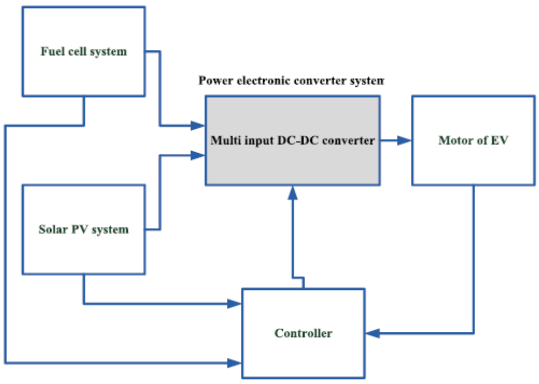

Fig 6 – Block diagram of DC motor enabled grid-independent hybrid EV system

The block diagram above demonstrates the typical block diagrams of grid-independent hybrid electric vehicle systems with AC and DC motor respectively.

V. MULTI-INPUT DC-DC HIGH STEP-UP CONVERTER

In both AC and DC traction systems, multi-input DC-DC high step-up converter undoubtedly plays a significant role in improving the performance of the entire system. It's a critical component for the proper functioning of all types of multi-input grid independent electric vehicle.
The figure above shows various types DC-DC step-up converters for various applications. There is a steady demand for high gain, efficient, reliable, small-sized, and lightweight DCDC step-up converters. A pulsating voltage source with an anti-parallel diode is called pulsating voltage source cell (PVSC). A pulsating current source in series with a diode is named as pulsating current source cell (PCSC). The development of multi-input converters typically depends on PVSC and PCSC. In order to avoid the voltage clamp across the connected branch, while developing multi input converter, PVSC should connect only in series with any one of the branches of PWM converters. Similarly, in order to avoid current clamping PCSC should connect in parallel with one of the branches of the PWM converters. PCSC with a boost converter can be best suited for multi-input high step-up DC-DC converter for hybrid electric vehicles. Now, we will see the positives and problems in various designs of DC-DC converter:

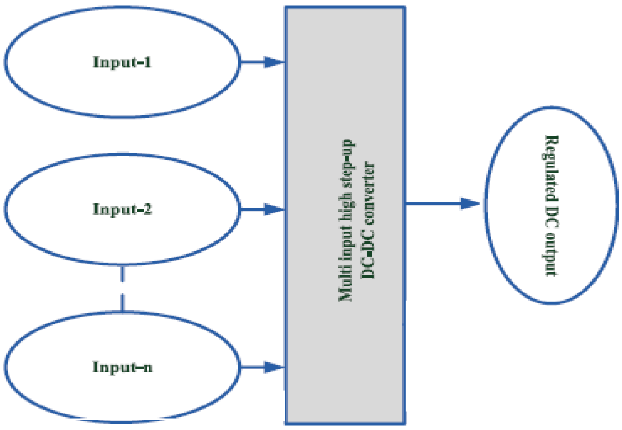

Fig 7- Block diagram of the multi-input high step-up DC-DC converter

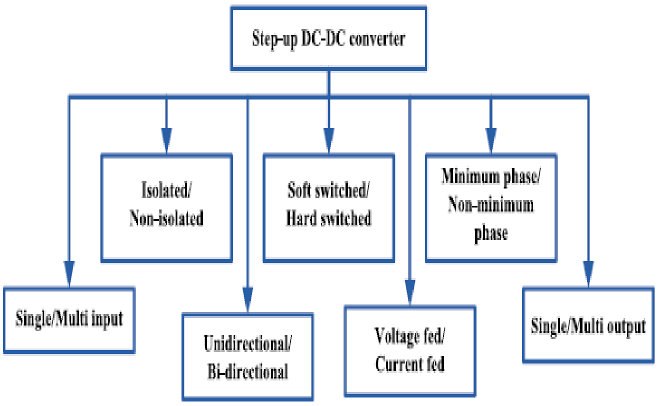

Fig 8- Different types of DC-DC step-up converters

a) Isolated DC-DC Converter

In a closed-loop isolated DC/DC converter, the feedback circuitry senses the output voltage and generates an error by comparing the sensed voltage with its feedback voltage reference. The error is then used to adjust the control variable to compensate the output deviation. Galvanic isolation between control circuitry on primary side and secondary side is also essential. Assuming the reference voltage VREF is precise and stable over temperature, regulation accuracy mainly depends on output voltage sensing accuracy

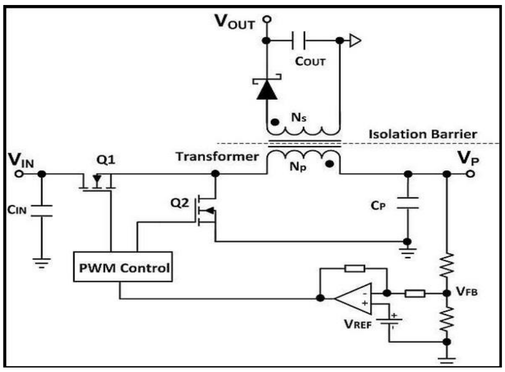

Fig 9 - Isolated DC-DC Converter

Advantages:

- Less EMI and noise problems
- Suitable for high power applications
- Maintain utility grid standards
- Positive and/or negative voltages can be generated
- Implementation of multi-output topologies is easy.
- Ground is isolated

Problems:

- Designing of coupled magnetic circuit should be more precise for high voltage gain
- More weight
- High manufacturing cost.
- Complex design
- Isolation transformer required
- The volume required is more

b) Non-Isolated DC-DC Converter

For applications requiring low power, 300W or less, a standard multiple output power supply is usually selected. Dual, triple and quad versions can be purchased off-the-shelf at cost effective prices. Models with a wide combination of 5, ±12, ±15 and 24V outputs are available. For mid to high power requirements, 350 to 1500W, modular or configurable power supplies are often chosen. Here a high power 24V module can be selected and the desired combination of other voltages satisfied by single or dual output modules.

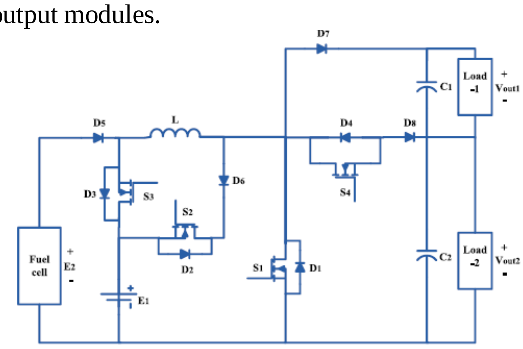

Fig 10- Non-isolated multi-input multi-output DC-DC high step-up converter

Advantages:

- Simple structure
- Less weight
- Low manufacturing cost
- Isolation transformer not required
- Ground is common

Problems:

- Input and output are electrically connected, so more safety required.
- Suitable for low and medium power applications
- Less noise filtering capability
- The volume required is more

c) Unidirectional DC-DC Converter

A unidirectional DC-DC converter which has a simple control circuit without using multiple insulated power supplies or a transformer, uses an auxiliary inductor of a comparatively small capacitance, reduces the size and weight of the converter, and has a very great capacitance without switching of supply current.

Advantages:

- Simple modulation and control
- Unidirectional power flow
- Circuit complexity is less
- Low cost

Problems:

- Because of unidirectional power flow, these are not suitable for regenerative applications

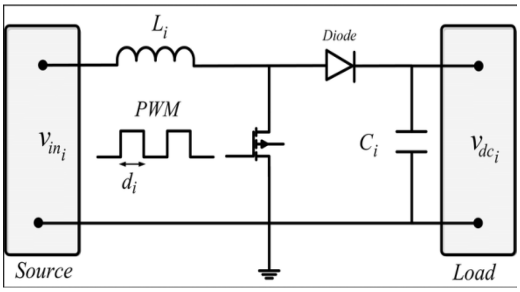

Fig 11- Unidirectional DC-DC Converter

d) Bidirectional DC-DC Converter

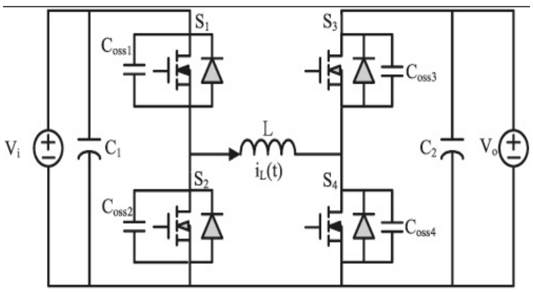

Fig 12- Unidirectional DC-DC Converter

Bidirectional DC–DC converter with phase shift control is commonly used for hybrid electric vehicle and fuel cell vehicle applications. This converter is characterized by simple circuit topology and soft switching implementation without additional devices. Despite these advantages, the efficiency is poor at light load condition because of high switching and conduction losses caused by high RMS inductor current. To achieve zero voltage switching (ZVS) for all power MOSFETs, a constant offset inductor current is maintained to conduct the anti-parallel body diodes before MOSFETs turn on.

Advantages:

- Forward and backward power flow
- Regenerative applications can be implemented

Problems:

- Complex circuit and control

In a non-isolated multi-input DC-DC converter with bi-directional power flow for EV applications. It has two operating modes, the first one is discharging mode, and the second one is charging mode. The discharging mode also called as boost mode, and charging mode also called as buck converter. Sixty percentage penetration levels of PEVs with uncoordinated charging violate the thermal loading of feeders as well as distribution transformer. PEVs charging will raise the load on the system, so the current flow in the feeder will also increase; this will lead to severe losses in the network Transformers that are connected to load buses are facing current limit issue when it is tested under distributed incremental increases in the load (EVs).

VI. CONCLUSION

The effect of electrification of transportation on the existing power system, lithium availability, and the purpose of integration of fuel cell and solar cell for HEV applications. The battery-based EV technology captured the maximum share of EV market, but it is increasing the burden on the existing power system. Because of its technical developments, the fuel cell and PV cell integrated hybrid energy system can be independent of the existing power system and lithium availability. This integrated system can be utilized as a source of GIHEVs which solve the problems related to existing BEVs, but the cost and efficiency are the two primary concerns. Each converter discussed is designed for its own application by considering some trade-off parameters like number of switching devices, size of the converter, gain, switching losses, efficiency, cost of the converter, and reliability. As there are diverse converter topologies that satisfy different trade-off parameters, so it is quite difficult to conclude that a particular topology is superior to other.

VII. REFERENCES

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