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DC-DC Converter Topologies for Electric Vehicles, Plug-in Hybrid Electric Vehicles and Fast Charging

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Abstract: There has been a rise in oil and gas use in the 21st century, which has led to issues including global warming, climate change, and a lack of crude oil. As a result of these factors, automakers have been investigating ways to make solar technology more practical. This means that solar electric cars can make good use of rapid chargers. In terms of carbon emissions, electric vehicles (EVs) are regarded as a viable alternative to internal combustion (I-I) motor vehicles. In any event, their true advantages have yet to be clearly shown, but there are several ways to boost their vitality efficiency. When utilizing energy generated by fossil fuels to charge electric vehicles, a significant amount of power is lost. There are a lot fewer benefits to using electric cars than there are to using renewable sources of power.A rapid charger battery/super capacitor is employed in this dissertation. When the super capacitor voltage drops below the battery voltage, the battery may provide power. As a result, the storm's weight is given a rather uniform distribution. As a result, the necessary power has been delivered to the load using these two energy sources. A super capacitor is employed to give power to the motor at fast speeds because of the coding in these input sources, which selects the requirement for authority at a certain moment for the motor. The output power is often provided by a battery. Solar energy is the primary source of power for this function. Fast charging of Li-ion battery cells may be achieved by delivering continuous current to charge the batteries such that they charge faster than conventional constant voltage charging. To maximize battery charging efficiency, the fast-charging method makes use of the battery management system. Additionally, PWM is regulated using a MOSFET to control the output voltage.
Keywords: DC-DC converter, EV charging, Fast Charging, On-grid EV station,

1. Introduction

Since CO2 emissions contribute to climate change, the use of electric cars in transportation has become inevitable. Battery electric cars (BEV), plug-in solar electric vehicles [PHEV], and fuel cell electric vehicles (FCEV) are all types of EVs (FCEV). Because of the expensive expense of hydrogen production and the inherent hazard of storing it, automobiles powered by fuel cells are now relegated to the research stage. These two types of cars, namely electric and solar-powered, are becoming more popular. More quickly than previously thought, the shift from internal combustion engines to electric cars is expected. Major challenges to mass-market adoption of electric vehicles (EVs) include the size and weight of the batteries themselves, charging times, inefficiency of the power conversion process because of several steps, and grid instability as a result of higher power use during peak hours. The problems stated above may be alleviated by using a solar charging station that is independent of the grid. Because of these new developments, they are now more interested in SPV-EVCS with a battery backup.

Solar charging stations for electric vehicles (EVs)

Humans can substantially reduce our reliance on fossil fuels by combining solar energy with EV charging. To power electric automobiles, all that is needed to use electricity from a variety of sources. With the increasing popularity of electric vehicles, solar energy system owners may anticipate seeing an increase in the number of people installing solar charging stations at their residences in the future years. Refueling automobiles and the natural growth of energy infrastructure need a fundamental shift in perspective. [6]

1.1 What is the change in thinking that is needed?

Plug-in electric vehicles (PEVs) and plug-in hybrid electric vehicles (PHEVs) are widely believed to be able to recharge in 2-4 minutes, similar to the time it takes to fill up a car with petrol. Even if Tesla's superchargers are attempting to exactly do that, electric charging will be different from what customers are accustomed to. Most individuals will use their home solar charging station to power their electric vehicles when they are sleeping or working. To "top up" an electric car, solar charging stations will be employed. This will allow the owner to return home and recharge the EV to its full capacity.

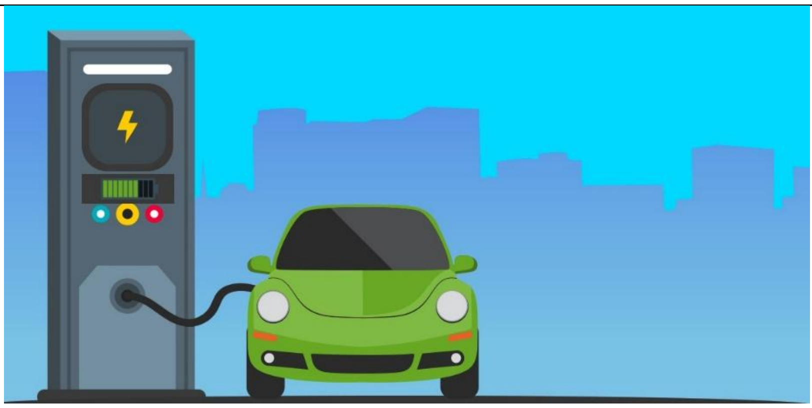

Figure 1 Charging for electric vehicles

1.2 On-Grid charging stations

The easiest approach to charge an electric automobile with solar energy is to use a grid-tied solar energy system. Grid-tied systems will supply power even if the residence does not require it at the time. **[9]**

1.3 Off-Grid charging station

"Electric Vehicle Autonomous Renewable Charger" is another moniker for an off-grid electric vehicle charger. There is no necessity to connect to local utilities. Batteries are employed as the major source of power for this system, which is provided through the converter. Because they are not linked to the grid, off-grid electrical vehicle chargers may be set practically anywhere. [10]

Table 1 Characteristics of various sources used in EV,s

Characteristics	Battery	Super capacitor	Fuel Cell
Power density (W/Kg)	100-3500	>4000	≈1600
Energy density (Wh/kg)	High,8-200	Low, 1–5	Very high, 400
Operation Temperature (◦C)	0-45	−40 to 65	−35 to 40
Cost per kWh	$125–$215(large system)	$10,000 (typical)	$17,000 (typical)
Efficiency	90% at low loads and 50% at high loads	95% at high loads	50% at rated power
Maintenance	Low, batteries only need to be replaced in vehicle lifetime	Not required	The reservoir needs a routine check-up

1.4 Components needed for a charging station

1. EV charger
2. Battery energy storage system (ESS, in case of an Off-Grid Solar energy charging station)
3. Solid foundation, in case of a stand-alone system if a hybrid setup is employed (Often used: a steel base plate that functions as ballast, so no foundation is required, simplifying the installation).
4. Intelligent software.

1.5 Overview of DC-DC Converter Topologies

This section highlights in green the advantages and disadvantages of various DC-DC converter topologies for BEV and PHEV powertrains. The converters are switched by power transistors, which are categorized based on the principles they operate on, how they operate, how much power they produce, and which way the power flows. Automobile batteries generally have a voltage between 250 and 360 V, while the SC is normally 150 to 400 V. This fall short of the 400 to 750 V needed to power a typical vehicle's load (EM). This section concentrates on step-up DC-DC converter designs since step-up converters are used in BEV and PHEV powertrains. [11]

2 Literature Review

Around a quarter of the world's greenhouse gas emissions come from transportation, with 70% of these emissions coming from road transportation, according to the World Resources Institute (WRI). The use of ultra-low carbon emission automobiles, such as battery electric vehicles, is one of various governments' sustainable mobility initiatives aimed at reducing emissions from transportation (BEVs). According to the Paris Declaration on Electro mobility and Climate Change, 100 million electric cars will be in use worldwide by 2030 [21]. Only 1.26 million electric vehicles are now on the road globally, indicating a major market increase is needed. The low market share of BEVs has persisted for some time because of the high cost, restricted driving range, and lack of charging infrastructure. Electric vehicles (EVs) have taken off in several nations because of these regulations. Incentives such as bus lanes, free or dedicated parking, and education on electric vehicles are just some of the measures that have been implemented to encourage the use of electric vehicles. [21]

Adoption of electric vehicles (EVs) has been found to be influenced by political processes. Importantly, to understand how different populations (such as early adopters and mainstream customers) respond to policy measures, it is necessary to conduct tailored interventions. While free parking and bus lanes may be a cost-effective alternative to costly subsidies, these incentives must be in place for a short time to avoid congestion (e.g., several autos in the bus lane) that can make these policies less tempting and may also have undesirable side effects (e.g., encourage driving instead of using public transport). The researchers say people need to be educated about the discrepancies between what they believe and what they actually do when it comes to their travel habits. According to [33], policy interventions are more effective when implemented collectively than when done in isolation. This shows how the use of professional mystery shoppers to collect data may help policymakers understand the critical role that market intermediaries like car dealerships play in encouraging people to choose electric vehicles. Go Ultra Low is a new public awareness campaign launched by the UK government and the automotive industry in the UK (GUL). One of GUL's goals is to raise awareness about the benefits, savings, and features of current electric car models among potential purchasers [3]. Uncertainty about the cause-and-effect relationship exists, even though multiple studies show a positive association between EV adoption rates and the availability of public charging infrastructure. Public charging infrastructure is a big concern, according to a recent study [26] that looked at aspects driving the uptake of electric cars. In 2012, research by [14] evaluated 30 different countries. There was a direct correlation between EV market share and the presence of charging infrastructure. According to [29], Norway has the largest percentage of electric vehicles on the market, and financial incentives and expanded charging station availability may be the best strategies to promote EV sales, according to [30].

Figure 2 EV vehicles used before in Literature

3 Methodology

3.1 DC-DC topologies and formulation:

DC-DC topologies may be explained in terms of their design and concepts is the most significant aspect of this thesis to arrive at the conclusion that in general, Chargers for electric vehicles (EVs) rely on DC-to-AC power converters with high power densities and efficiency. DC to DC converters use buck/boost or switch-mode converters, whereas AC to DC converters is used for DC to AC conversion. H-bridge inverters and three-leg inverters are the most popular types of DC/AC converters for single-phase and three-phase systems, respectively. Digitizing the process of charging and discharging is done using a high-performance CPU or an FPGA (FPGA).

DC-DC Topology implementation: This part represents the implementation of all five topologies that are:

- *Boost DC-DC Converter*

- *Interleaved 4-Phase Boost DC-DC Converter (IBC)*
- *BCRC (Boost DC-DC Converter with Resonant Circuit)*
- *FBC (Full Bridge Boost DC-DC Converter)*
- *ZVS DC-DC Converter Isolated (ZVSC)*

3.2 MATLAB Model of Boost DC-DC Converter:

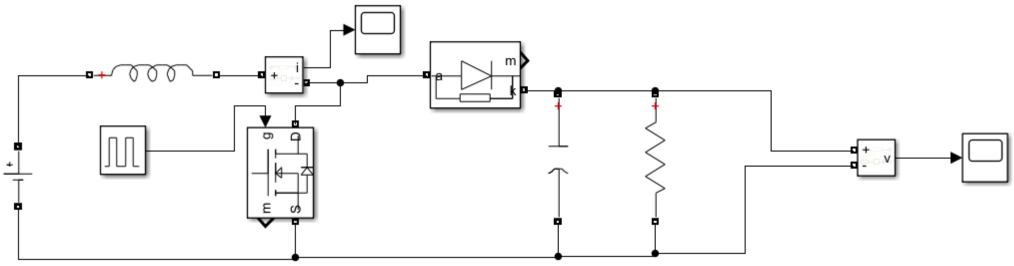

Figure 3 Model of DC-DC converter

In this circuit it was observed that the inductor is there to oscillate the voltage and produce a backup voltage provider when battery voltage is reduced or glitches. The MOSFET is available to produce switching and is used to produce PWM.

Voltage graph:

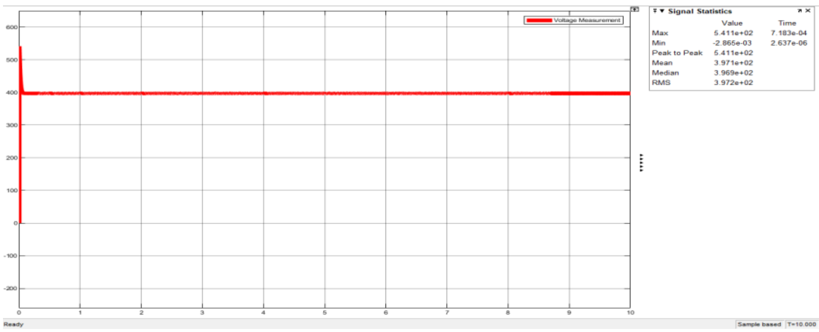

Figure 4 Output voltage of DC-DC converter

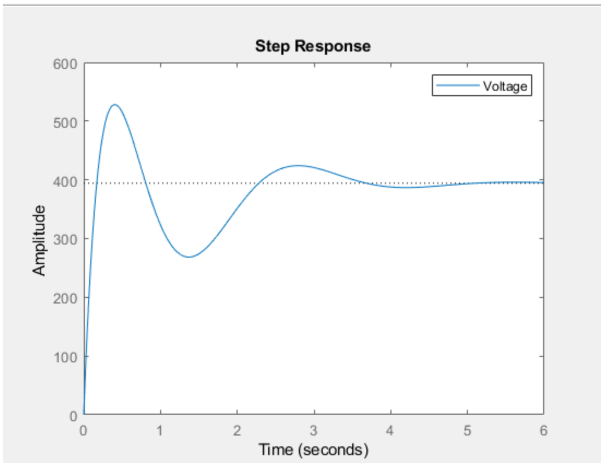

Figure 5 Step response of DC-DC converter

It can be observed at the voltage graph and observe that the applied voltage was 220V, but it has amplified and boosted the voltage to 400V. This is a very good Gain, and the system is modeled in a very efficient way. By controlling the Pulse Width Modulation (PWM), output voltage has been controlled. The voltage reaches to 400V after a slight overshoot and settles down in less than 0.1s. The peak voltage achieved is 540V and Mean voltage is 397V.

Figure 6 Current Real time graph for DC-DC boost converter

In above figure current real time graph for DC-DC boost converter has been represented at its output. The output current in the real time graph shows slight overshoot before stabilizing the system. In the following graph shown in fig.22 the current value can have been clearly seen to have maintained a content value at 1.75A.

3.3 MATLAB MODEL OF INTERLEAVED 4-PHASE BOOST DC-DC CONVERTER (IBC):

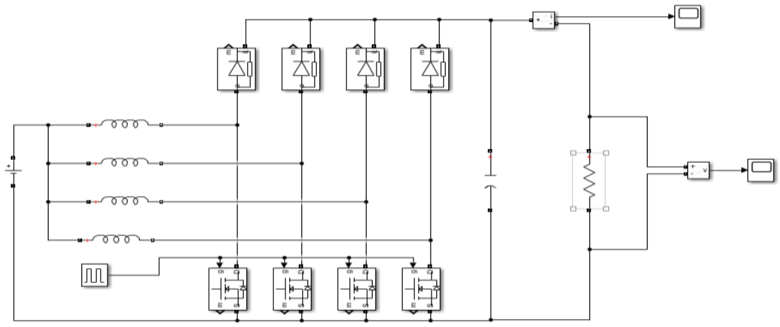

Figure 7 MATLAB Model of Interleaved 4-Phase Boost DC-DC Converter (IBC)

As shown in this circuit, the inductor helps to oscillate the voltage and provides a backup power source if the battery voltage is reduced or glitches. MOSFETs are used to create PWM. PWM stands for pulse width modulation and allows the voltage to be regulated by switching in milliseconds, thus controlling the applied voltage's duty cycle and consequently the battery supply. A diode is included in the circuit to aid in its protection from reverse emf. Finally, a filtering capacitor is added to assist in smoothing down the signal's voltage.

3.4 MATLAB Model of BCRC (Boost DC-DC Converter with Resonant Circuit):

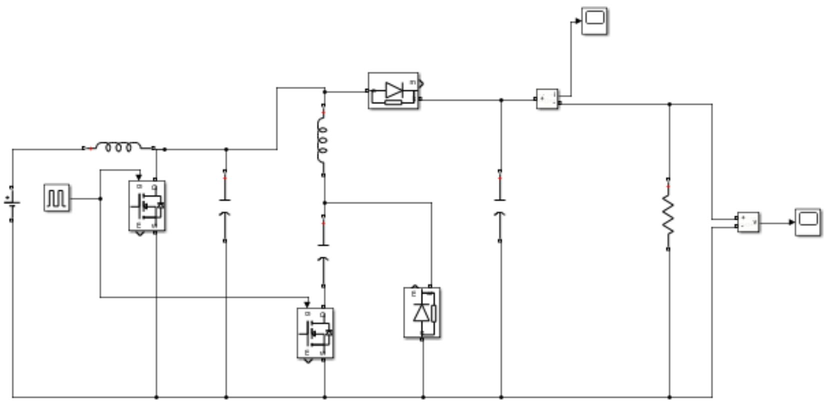

Figure 8 MATLAB Model of BCRC (Boost DC-DC Converter with Resonant Circuit)

The circuit begins with an inductor that provides more voltage when it is required. Additionally, an LC network may be utilized to increase the quality of the voltage and current and to eliminate ripples and surges. Diodes protect the circuit from back EMF and other sources of EMI. The voltage is then filtered by a filter capacitor.

Voltage Output:

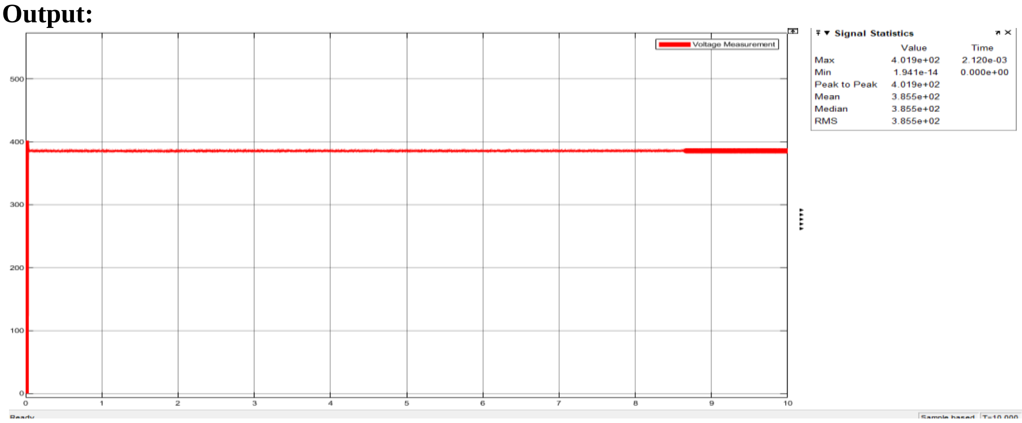

Figure 9Real time voltage output for BCRC (Boost DC-DC Converter with Resonant Circuit)

It can be observed that the voltage graph and observe that the applied voltage was 220V, but it has amplified and boosted the voltage to 385V. This is an excellent Gain, and the system is modeled in a very efficient way. By controlling the Pulse Width Modulation, the output voltage can be controlled. The voltage reaches 401V after a slight overshoot and settles down in less than 0.1s. The peak voltage achieved is 401V, and the Mean voltage is 385V. This circuit provides high voltage gains and produces a large amount of power. The voltage can be controlled by changing the PWM from the MOSFET triggering the circuit.

Current Output:

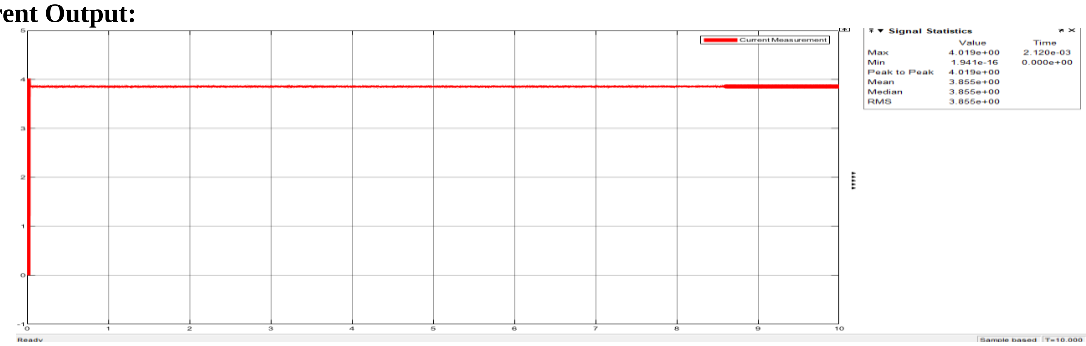

Figure 10 Current real time graph for BCRC (Boost DC-DC Converter with Resonant Circuit)

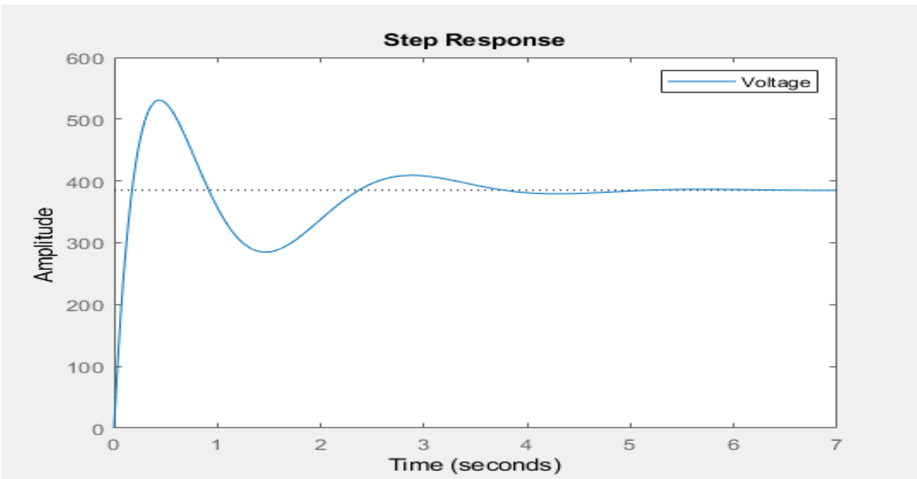

Figure 11 Voltage Step response for ZVS DC-DC Converter Isolated (ZVSC)

After a brief overshoot, the peak voltage achieved is 1056 and Mean voltage is 440V. The optimum Topology, according to the research, is an interleaved 4-Phase Boost DC-DC Converter. The voltage can be controlled by changing the PWM from the misfit that is triggering the circuit. This is a very good amplifier circuit as it produces excellent gain and is best for high voltage target boards and batteries. This circuit exhibits substantial voltage gains and generates a significant quantity of power. The voltage may be adjusted by modulating the PWM output of the MOSFET that triggers the circuit. This is a great amplifier circuit because it has a lot of gain and can be used with high voltage target boards and batteries, so it's good.

Current Output:

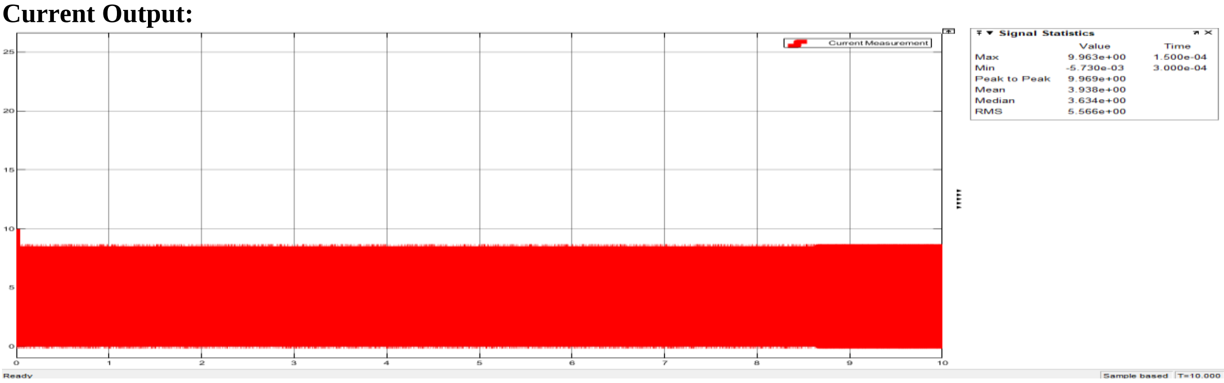

Figure 12 Current real time graph for ZVS DC-DC Converter Isolated (ZVSC)

The current reaches a high of 10.56A and then stabilizes at 4.40A. Thus, the current stabilizes within 0.1s and begins to provide enough current. Even if the current is not excessive, it is significant. The current guarantees proper battery charging, and the current is a little rippled. There are too many ripples, and as a result, the signal is extremely well filtered by the circuitry, allowing us to charge the battery without experiencing any current spikes or imbalances. For 1.3 seconds, the signal gets back to where it was supposed to be. This isn't ideal, but it could be better with more circuitry.

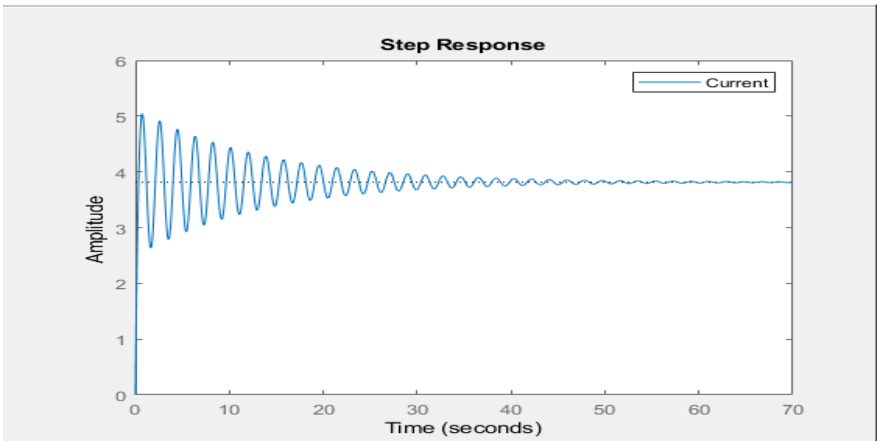

Figure 13 Current Step Response for ZVS DC-DC Converter Isolated (ZVSC)

Below given table represents the advantages and disadvantage along with components used in designing of all five topologies these distinguishing features have also been the focus of this research to along with charging capabilities that have been presented in the previous section of each of the topologies. These topologies have been implemented considering their adoptability and use in Fast Charging stations:

Table 2 Basic Comparison of topologies that have been used

Topology	Advantages	Disadvantages	Components Used
Boost DC-DC Converter	• Simple circuitry • Low cost • Simple control circuitry	• High ripple rate • Parallel devices demand high power • Voltage gains 4:1	• One Inductor • One Diode • One IGBTs • One Capacitor
Interleaved 4-Phase Boost DC-DC Converter (IBC)	• Reduce ripple current • High voltage gain, • little passive components, simple control.	• Switching losses • High component count • Duty cycle change sensitive	• One Inductor • Four Diode • Four IGBTs • Three Capacitor
BCRC (Boost DC-DC Converter with Resonant Circuit)	• Compact size • Soft switching • Low EMI	• Low voltage gain. • Not for high-power conversion	• Two Inductor • Two Diode • Four IGBTs • Three Capacitor
FBC (Full Bridge Boost DC-DC Converter)	• High voltage step-up. • 91.5% efficiency at full load. • reduced switching circuit voltage stress; galvanic isolation	• Due to HFT, •An extra clamping circuit is needed, •Has a large capacitor.	• One Inductor • Four Diode • Four IGBTs • Five Capacitor • 1 HFT
ZVS DC-DC Converter Isolated (ZVSC)	• No extra clamping circuit is needed. • Switching losses are reduced.	• High gate current rating • Low fault tolerance • Large capacitor	• One Inductor • Four Diode • Four IGBTs • One Capacitor

4 CONCLUSION

A study of battery electric cars (BEVs), plug-in hybrids (PHEVs), and fuel cell electric vehicles' DC-DC converter topologies is presented in this research (FCHARs). It is vital to note that the DC-DC converter research of the future is rife with critical concerns, such as new topologies that take advantage of the converters' high-temperatures and low-losses. Various methodologies are employed in electrical design strategies to enhance efficiency, power density, modularity, and reliability. Aside from high fidelity and multifunctionality, further mechanical design methodologies are emphasizing scalability and modularity, as well as sophisticated control and management systems. Numerous evolutionary algorithms are being used in the controller design to improve the converter's many parameters, such as model predictive control, fuzzy logic, artificial neural networks, and more. DC-DC converters are being designed, tested, and verified using high-fidelity models, which are also being created. Power handling capabilities may be scaled for a range of application needs thanks to the growing popularity of the modular design method. Over the past few decades, converters have gotten better in many ways, such as being able to work in both directions, with more than one phase, and on more than one level. During this research five DC-DC topologies were analyzed designing a system maintain input parameters and maintaining a constant load at the output that was kept constant.

The five topologies that were analyzed were namely **Boost DC-DC Converter, interleaved 4-Phase Boost DC-DC Converter (IBC), BCRC (Boost DC-DC Converter with Resonant Circuit), FBC (Full Bridge Boost DC-DC Converter) and ZVS DC-DC Converter Isolated (ZVSC).**These topologies were considered for analysis on the basis of their advantages and disadvantages that have been presented in *Table 5* of this thesis. Regarding power electronic design, dependability has become an important consideration. Keeping the parameters constant, such as temperature, is essential to maintaining the system's stability. The optimum topology, according to the research, is an interleaved 4-Phase Boost DC-DC Converter. It is very efficient, as the graphs indicate. The first thing is the ripples. The model has almost no ripples, which explains the topology's accuracy and efficiency. It also has a high voltage gain, which means it can make a lot of different voltages and use a lot of power.Furthermore, it has a large amount of current supplied, making the battery charge at exceptional speeds. The greater the current, the greater the flow of charges and, as a result, the faster the charge. It has the highest current rating with a mean current of 4.14A, but it has very high voltage surges, which should be compressed. It also has good back EMF protection and protects the circuit from different voltage and current surges. Following the output voltage and currents of all five topologies Interleaved DC-DC is the best topologies according to the analysis. To put it simply, a boost converter raises the DC voltage input. Interleaving brings additional advantages such as lower ripple currents in both the input and output circuits. Higher efficiency is gained by dividing the output current into two pathways, considerably lowering I2R losses and inductor AC losses. Although it is switching sensitive, and use of high components is implicated in design this converter but due to its charging capability it is concluded to be the best topology of the five analyzed.

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