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A Review on a Wide Input and Output Voltage Range Battery Charger Using Buck-Boost Power Factor Correction Converter

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Abstract

The Electric Vehicles (EVs) primarily is the process by which the charging of the batteries should be done and secondly the growing appeal of power required due to the quick demand of electric power necessitated by EVs, Hybrid Electric Vehicles (HEVs) and Plug-in Hybrid Electric Vehicles (PHEVs). There has been a detailed, critical evaluation of converters that are being used for the charging modules of electric vehicles. For electric vehicle battery charging better converters needs to be used for reduced ripple in voltage and current. The conventional buck-boost converters are replaced with novel PFC converters for improving the power factor of the source. As the large capacity batteries need more power to charge which impacts the quality of the source.

Keywords: *Electric Vehicle; Conventional Buck-Boost Converter; PFC Converter; MATLAB Software; PI and Fuzzy Controller.*

1. Introduction

There has been a gradual but steady infiltration into mainstream transportation of electric cars because of electric vehicles' enormous beneficial influence on the environment. However, despite the fact that a lot of EVs are being produced, the number of EVs on the road is rather low. Lithium-ion batteries are the most often used sort of EV battery. Despite the fact that electric and plug-in hybrid cars are the most fuel efficient, they have not been extensively embraced. Batteries, pricing, and charging issues have all been cited as significant reasons for not implementing these cars on the grid. Another issue with PHEVs as compared to traditional fuel stations is the absence of suitable and appropriate charging infrastructure and regulatory support for energy storage solutions. Hybrid cars employ lithium-ion batteries that are quicker and less efficient than those used in typical electric vehicles. In addition to battery life, plug-in electric and hybrid cars have a slew of additional drawbacks as compared to pure electric vehicles. For example, the HEV's fuel economy is much lower than that of an EV. Bi-directional AC-DC converters and DC-DC converters of the same origin are the most widely utilised power converters for these vehicles.[1]

Because PEVs are a relatively new technology, there aren't many charging stations around. In addition, PEV's bidirectional converters don't employ conventional architecture; instead, they're often unidirectional bridge rectifiers. As a result of the facts acquired, it can be concluded that EVs are more efficient than HEVs or PHEVs in nature due to their zero emissions, high efficiency, reduced noise, safety, and smooth operation, as well as their independence from petroleum fuel. During braking, the electric motor acts like a generator and recharges the battery as the kinetic energy is completely transformed to potential energy. This is the primary benefit of EVs. [2]

1.1 General configuration of an EV charging system

The fundamental DC of the AC power converters is used to create the EV battery chargers, which must be very powerful and effective. Unregulated or regulated rectifiers are used in AC-DC converters that use Buck / Boost or switch mode technology. In most cases, DC-AC converters are built around single-phase H-bridge inverters or three-phase inverters.

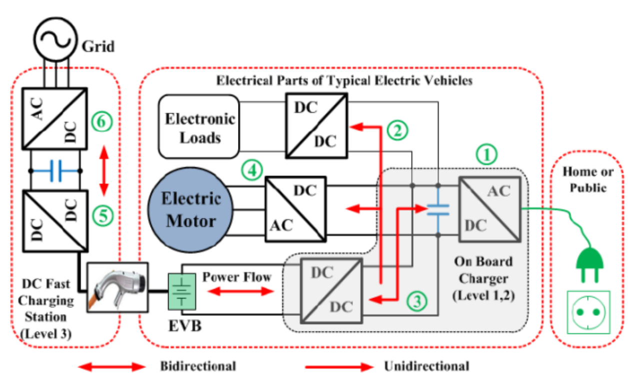

Figure 1: General topology of EV charging panel

There are many different ways to charge an electric vehicle, and this diagram displays the most common setup. Figure 1 depicts the many types of power converters that may be utilised to achieve the various effects shown (numbered from number 1 to number 6).

EV batteries may be recharged with either an onboard or an off board charger (levels 1, 2, and 3). EV battery chargers may be integrated into a vehicle, either as an on-board charger or an isolated outboard charger. The EV batteries and the grid may have a one-way or two-way power flow.

Modern commercial on-board chargers use unidirectional power flow because it is simple and reliable in both topology and function. Electric vehicle batteries may be used to generate electricity by controlling bidirectional charges. It's possible to think of an EV battery as a highly efficient distributed power source that may be used in a variety of ways. AC-DC converters and DC-DC converters are featured in all on/off board loaders, as seen in Figure 1.1. Nevertheless, the topologies and power ratings of the converters differ entirely within each category of chargers. [3]

1.2 PHEV

Overconsumption of fuels, depletion of these resources, a decrease in greenhouse gas emissions and a rise in oil costs have led to the emergence of the plug-in hybrid HEV (PHEV) alternative in recent years. It is only necessary to add more battery capacity, connect to an electrical outlet for charging, and alter the power electronics of a PHEV in order to make it a hybrid. As PHEVs can already travel 30-60 miles on electricity alone, they have the potential to become a new energy storage resource for the grid. [4]

Charge-depletion strategy is used in a PHEV, where the car's batteries are constantly used to enhance fuel economy, and the level of charge is generally as low as 30%. While the automobile is not in use, it will be linked to the power grid in order to deliver energy to the batteries and/or assist the grid in the event of a power failure. The plug-in car more than doubles the typical home load while it is charging. Because PHEVs may be plugged in at any point in the distribution network, the influence on the grid is a big worry. The PHEV will always be near to the energy demand, and the efficiency of stored energy in the EV's batteries is theoretically substantially better than the energy stored in hydrogen and in fuel cells hydrogen vehicles. To add insult to injury, hydrogen cars have a limited potential to provide the grid with additional services, as opposed to electric vehicles.[5]

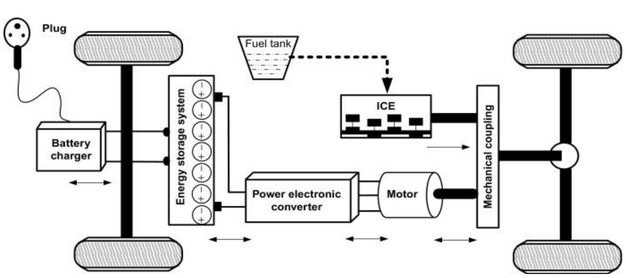

Figure 2: basic diagram of PHEV

1.3 DC-DC Converter

To connect the FC, battery, or super capacitors module to the DC-link, at least one DC/DC converter is required, as can be seen from the various EV power supply configurations. Power converters in electrical engineering, referred known as DC to DC converters, are used to convert direct current (DC) from one voltage level to another by temporarily holding the input power and then releasing that power at another voltage.

Either magnetic or electric field-based storage components (inductors and transformers) may be used (capacitors). Only one direction of power may be transferred by DC/DC converters, and that is from the input to the output. In reality, bi-directional DC/DC converters are possible with almost any topology. When regenerative braking is required, a bi-directional converter comes in handy since it can flow power in either way. [6]

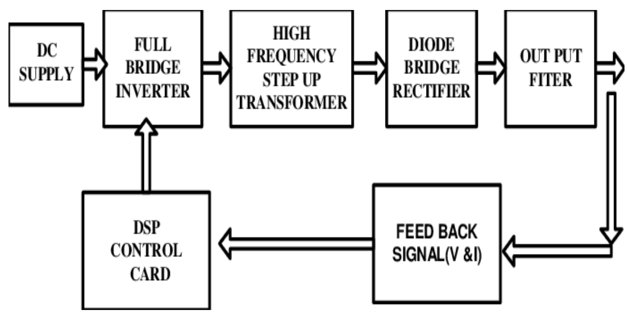

Figure.3: Basic diagram of DC-DC Converter

It is possible to regulate the input/output power flow by varying the duty cycle (the switch's on/off time ratio). Typically, this is done to regulate the output voltage, the input current, the output current, or to maintain a steady power. Isolation between the input and output may be achieved using transformer-based converters.

In addition to complexity, electrical noise, and expensive topologies, switching converters have a number of downsides. Proposals for DC/DC power converters abound in academic literature.

2. Literature Review

(Sanguesa et al., 2021) [1] As the cost of electric vehicles (EVs) decreases and people become more conscious of the effects they have on the environment and the climate, EV sales are on the rise. Battery technology, charging techniques, and research difficulties and potential for EVs are discussed in this study.. It is precisely determined how the global EV market is now doing and what the future holds for it. For starters, the battery is one of the most important components of EVs, hence a comprehensive discussion of the various battery technologies is included in the study. The numerous standards for charging EVs, as well as power control and battery energy management approaches, are also examined. Additionally, Finally, we provide our view for the near future of this sector, as well as the research areas that are still available for both business and academic groups to investigate.

(G. N. Kumar et al., 2021) [2] The fuzzy logic controller technique for an integrated PV electrical vehicle charger is used in this study to investigate a novel output from the "Bridge Less (BL) Cuk Converter (battery)." To charge the battery as cheaply as possible, this method relies on the fewest possible switch numbers. Although the EV-charger is operating under, at, or over its rated capacity, the voltage and current inputs remain stable. In addition, even with an uneven input supply, it retains steady battery properties. A robust BL-Cuk converter with fuzzy control is used. Because of the decreased switching needed by the new technology, there is no need for a DC condenser. Therefore, the condenser generates a balancing voltage above standard EV charging methods.

(Jati, 2021) [3] As the number of nonlinear loads grows, so does interest in creating power factor correction technologies. Nonlinear loads generate poor power factor and the emergence of harmonic currents, which may influence load system performance. A power factor corrector converter with a simple design and dependable performance is required, however. Because of these benefits, the "Interleaved Boost Converter" is often used as a power factor converter. With a fuzzy controller, a near-unity power factor can be achieved. Inductor design in the "Discontinuous Conduction Mode (DCM) approach" is very efficient. Simulation and hardware implementation of the suggested solution yielded considerable improvements in power factor.

(Singh et al., 2021) [4] As a beginner in the subject of power electronics, this work aims to give a critical assessment of single-phase non-isolated bridgeless power factor converter topologies. There are fewer switching devices in the converter's current route because of its bridgeless design. The inherent advantages of nonisolated topologies, such as lower cost, weight, and size, as well as higher efficiency, are taken into account in this review because systems such as on-board electric vehicle battery chargers, dc power supplies, and variable speed drives all benefit from these advantages. Boost, buck, and buck/boost converters are the ancestors of these topologies. Depending on the application, the topologies may be used in either continuous or discontinuous conduction modes. The benefits and drawbacks of each topology are discussed in detail. In addition, each group (boost, buck, and buck/boost) is compared in comparative research.

(Corradini et al., 2020) [5] An unusual set of problems confronts the designer when studying power converters that operate at much higher switching frequencies than is usually the case. The formulation and assessment of conversion topologies for high-frequency power conversion, as well as associated control and modelling methodologies and design procedures, represent crucial features that are intimately linked. In the context of high-frequency converter design, characterization and assessment procedures for active and passive components intended for high-frequency operation are also critical.

(Kalyanasundaram et al., 2020) [6] There has been an enormous shift in recent decades in the production and use of electric power. The rise of the electric power business and the transportation sector are at the heart of this transition. This shift is a significant contributor to pollution of the environment and the rise in global temperatures. As a result, governments throughout the world are actively searching for alternative energy sources in order to reduce their dependence on traditional fuels and greenhouse gas emissions. Building a more sustainable society will benefit from the development of clean and renewable energy sources. Energy use in transportation is shifting from fossil fuel to electricity-based fuel at the same time. Environmental pollution and global warming are challenges that may be addressed by implementing an electric transportation system. Two-stage charging models are used to attain high efficiency in this paper's EV battery charger. By using MATLAB simulation, the design is compared to the current model. Using simulations, it can be concluded that the suggested model outperforms the existing model.

(Dimitrov et al., 2020) [7] Analyze, develop, and perform experiments on an IGBT (Isolated Gate Bipolar Transistor)-based transformerless Buck-Boost DC-DC converter for rapid charging electric automobiles. Main benefits include a simple power stage construction, broad output voltage range, and excellent efficiency and power density for hard-switched converters in this class; this topology is a good fit for today's on-board battery packs in electric vehicles. The converter's fundamental modes of operation – Buck, Boost, and Buck-Boost – are shown to have an exact calculation of the loss that is dissipated. In the Buck-Boost operating mode, the study demonstrates a loss minimization technique based on a decrease in switching frequency. Using this method ensures that the thermal properties of the device remain steady during the battery charging cycle. As a result of the Buck-Boost mode's reliance on semiconductor properties, it might be regarded as a critical mode when Buck and Boost modes alone are unable to maintain the output voltage. The duty cycle and voltage range required, as defined by input-output voltages and power losses, will need more research in this regard. For the most adaptable silicon-based powerful IGBT modules, the tolerance of the applied switching frequencies is evaluated and experimentally validated. An experimental model was used to produce oscillograms of crucial properties, such as transients, IGBT voltage tails, critical duty cycle lengths and more.

(Brenna et al., 2020) [8] Various EV charging systems are described in the literature and put into practise in real-world situations. In terms of converter topologies, power levels, power flow orientations, and charging management algorithms, this study provides an overview of the current and prospective EV charging technologies in this field. Additionally, an overview of common charging techniques is provided, with a special emphasis on a rapid and efficient charging method for lithium-ion batteries that is both effective and efficient in terms of preserving a long cell cycle life. To conclude this study, after presenting the most essential components of charging technologies and techniques and using a genetic algorithm to determine an appropriate charging system capacity, the likely future developments in this subject are evaluated.

(Bharathidasan & Indragandhi, 2020) [9] The broad overview of single-phase AC/DC-DC power electronic converter power factor correction for electric vehicle applications is completely discussed in this article. Propose the use of a variety of solid-state DC-DC converters to improve power quality in the declaration of "Power Factor Correction (PFC)." While comparing DC-DC converters, both the Uni- and Bi-Directional power flow representations are taken into account when trying to reduce "Total Harmonic Distortion (THD)" on the input and output sides. This study contains an in-depth examination of IPQC setup, design features, and selection criteria. Having a converter flow of power capability is required for an on/off-board charger for electric vehicles (EVs). Due to their high power density and efficiency, DC-DC converters are favored for medium and high voltage applications because of their ability to soft-switch. This is the most appealing attribute of DC-DC converters. Research, design, and improvement of functioning applications in the area of renewable energy and smart grids is the goal of this study.

(Vijai et al., 2019) [10] In battery charging applications, DC-DC converter performance has been shown to be a solution. Most electric bike battery chargers use a two-stage converter that includes a boost converter for power factor correction (PFC) and a dc-to-dc converter with a universal input voltage.. Because of their inefficiency and additional complexity, these two-stage conversions aren't recommended. Rather of using a DC-DC converter in this project, a SEPIC converter has been used to address the issue. SEPIC converters may reduce DC converter issues such excessive ripple, harmonics, voltage inversion, overheating, and ineffective efficiency while also achieving the highest levels of efficiency. Closed loop feedback control is used to develop and compare DC-DC converters using the SEPIC converter. PFC converter based on a single-stage switching inductor SEPIC converter is recommended as an alternative to the more common DC-DC converter because it has a higher step-down gain, lower current stress, higher efficiency, and requires fewer components. Continuous current mode is used for the operational analysis and design equations for different components of the proposed converter. The planned 48V converter is the subject of this simulation and testing. A battery charging converter with Constant Voltage and Constant Current modes of operation is also studied in terms of the broad range of supply changes.

3. Fuzzy Logic Controller

In order to create a shunt active filter control method, the DC side capacitor voltage must be monitored and compared to a reference value. There are two inputs to fuzzy processing: an error and an error change. A fuzzy controller uses a set of language rules to regulate its actions. Since no mathematical model is necessary, it may be used with erroneous inputs. [3].

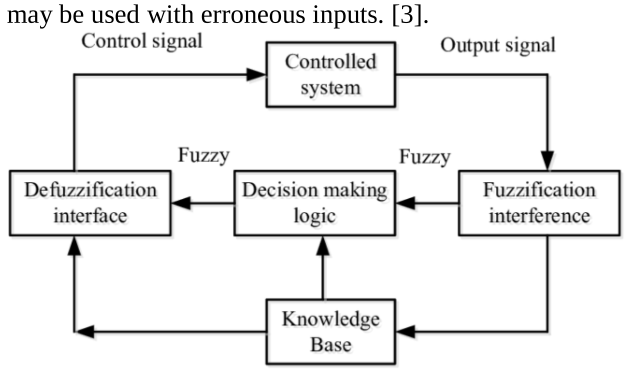

Figure 4 Block diagram of Fuzzy Logic Controller

3.1 Fuzzification

In fuzzy logic control, instead of numerical variables, linguistic variables are employed. These mistakes may be classified as either positive, medium, large, negative, or zero when compared to the reference and output signals, with the exception of zero, which is always positive. Using a triangle membership function, fuzziness is being implemented. Numerical variables are transformed into linguistic variables using fuzzification. [4]

Advantages of Fuzzy Logic Controller

The following are the benefits of fuzzy control over other adaptive control methods:

- System design can be improved since it doesn't need to know all the variables, allowing for more precision.
- The language, rather than the numerical, elements make the process resemble that of logical cognition.
- Due to their ability to handle a wide range of operating conditions, they are more robust than PI controllers.
- FLC is cost-effective.
- FLC is adaptable.
- FLC is a trustworthy company.
- FLC is more efficient.

4. Proposed System

Fast charging infrastructure is lacking; thus, automakers are relying on on-board battery chargers that can be recharged using a standard wall outlet. For electric and hybrid cars, there is a wide variety of information accessible on charger topologies, power levels and stages. As seen in Figure 5, the usual structure of battery chargers that can take a broad range of input voltages is shown here. It is necessary to have a front-end active PFC converter at the input to keep the power quality good. Boost converters, either with or without interleaved architecture, are often used in PFC applications because they give a dc output voltage larger than the peak ac line voltage. [3]

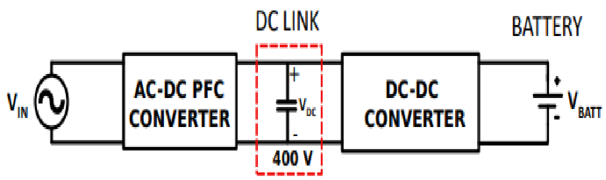

Figure 5: Two-stage layout of battery chargers

It did, however, demonstrate some gains in efficiency, but the organisation of the increase PFC category remained the same. Using a high-frequency DC-DC converter, the PFC converter's output voltage may be used to power a variety of batteries with a minimum voltage of 200 V. "There are few electric vehicles having the DC battery operating voltage less than or equal to 150 V (48 V system, 72 V,96 V,144 V)." The battery charger manufacturers use a high frequency step-down transformer in the DC-DC converters, which limits the output voltage range, transformer weight, and efficiency with restricted ZVS in such a low output voltage state.
In this research, the converter's parameters are determined and a proof-of-concept hardware setup and its results are shown. As a final step, the intended voltage range for the variable DC link PFC is tested using a Phased shifted DC-DC converter to create a universal charger.

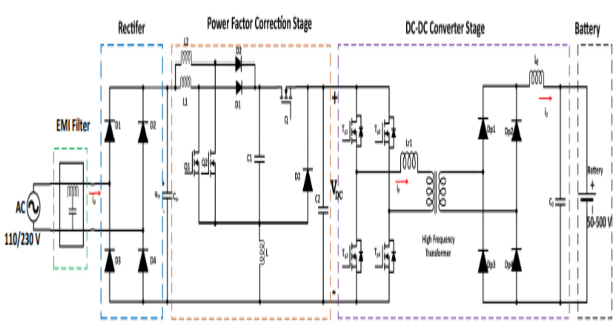

Figure 6: Proposed Interleaved boost cascaded-by buck PFC converter based on-board battery charger

Figure 4.2 is a schematic for a two-stage on-board battery charger of the kind described above. An isolated DC-DC converter and a power factor correction converter are also included. The interleaved boost and buck converters form the basis of the proposed PFC converter. Non-pulsating current from the inductors L1 and L2 at the input may be readily regulated to preserve power quality.
Reduced input current ripple is another benefit of interleaved combination at the input. Switches Q1, Q2 and diodes D1 and D2 create a boost configuration in the continuous conduction mode (CCM) of the converter. Depending on the operating mode, an LC filter is connected with either the converter's input or output to supply non-pulsating currents to the source and load. Using the input and output voltages, the converter manages the buck switch Q and diode D. When the input voltage Vmax reaches its peak, the converter's output voltage VDC may be regulated to a value either above or below that value.[4]

5. Conclusion

This paper proposes a new interleaved boost cascadedby-buck PFC converter for on-board battery chargers. The proposed PFC converters operates with wide output voltages for universal input voltages. The various modes of operation of the converter are detailed in the paper. Moreover, the converter is operated above and below the peak of the input voltage to provide a wide DC link voltage with smooth input current.

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