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CONTROL STRATEGY AND DESIGN OF RENEWABLE ENERGY-BASED MICROGRID SYSTEMS

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ABSTRACT: An EV on-board charger (OBC) with a high power density and a power pulsating buffer is demonstrated in this work. The demand for efficient, portable charging options is on the rise, and this will help satisfy that demand. To mitigate double-line frequency ripple in the DC connection, the proposed OBC employs a power pulsating buffer circuit. This allows for an improvement in power density while simultaneously eliminating the necessity for huge electrolytic capacitors. An active power factor correction (PFC) stage and a high-frequency isolated DC-DC converter are housed in a two-stage architecture that enhances efficiency and galvanic isolation in this system. The pulsing buffer increases component life and decreases stress by absorbing abrupt power changes. Significant improvements in heat retention, volume utilization, and grid compliance have been shown in both simulations and prototype testing. Future electric automobiles will benefit from the proposed structure's practical approach to developing compact, lightweight, and highly efficient OBCs.

Keywords: On-board charger (OBC), electric vehicles (EVs), power pulsating buffer, high power density, power factor correction (PFC), DC-DC converter, double-line frequency ripple mitigation, energy efficiency, compact design.

1. INTRODUCTION

As electric vehicles (EVs) become more popular, charging options that are smaller, lighter, and better at handling heat are needed to keep up with their high power needs. These needs can be met by an On-Board Charger (OBC) with a Power Pulsating Buffer (PPB) that has a high power density. This reduces the size and cost of inactive parts while allowing for efficient energy transfer. The PPB-based design successfully separates and controls power pulsations, making the system small and light. This is different from traditional OBC systems, which rely on large energy storage components.

In a PPB-based OBC design, the pulse power that is usually made from a single-phase AC input is put off by a stage that stores energy in between, instead of going to the DC-DC converter or battery. This buffer makes the power density much higher and puts less stress on power gadgets further downstream. A capacitor with the right power link is often used to do this. This design also makes the system more reliable by reducing problems like electromagnetic interference and heat hotspots that happen in regular systems that use big electrolytic capacitors.

PPB technology into on-board chargers makes it possible for the next wave of fast, small, and energy-efficient charging systems for electric vehicles. It speeds up charging and improves the general performance of the vehicle, which is in line with the auto industry's goals of making vehicles lighter and smaller. As the number of electric vehicles (EVs) on the road grows around the world, PPB-based high power density OBCs will be very important in meeting the changing needs of urban movement, sustainable transportation, and grid-compatible charging.

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2. LITERATURE SURVEY

Chakraborty, R., & Mehta, D. (2024). In order to assist electric vehicles in obtaining additional power while simultaneously decreasing power grid ripples, this article details a cutting-edge on-board charger (OBC) design that employs a power pulsing buffer (PPB). The semi-active energy buffer circuit blocks charging-induced high-frequency ripple currents, which enhances energy conversion efficiency and prolongs battery life. The bi-directional interleaved power stage, which employs Silicon Carbide (SiC) devices to enhance thermal characteristics, enables the small size and high power density (6.5 kW/L). Simulations and a 5 kW laboratory prototype have demonstrated the efficacy of the authors' rigorous approaches to temperature management and electromagnetic interference filtering. The results demonstrate a 35% reduction in thermal hotspots and EMI suppression, in accordance with CISPR-25 specifications.

Iqbal, T., & Ramalingam, R. (2024). An approach to dynamically modeling a two-stage charging design onboard charger with power pulsing and buffer assistance is discussed in this work. The grid current can be sinusoidal with a power factor of 1 since the buffer system maintains constant input current changes. A separate DC-DC converter and a boost power factor adjustment step comprise the system. When the load and grid voltage are changing, the charger can reach a maximum efficiency of 97.2% with the use of predictive current control methods and soft-switching techniques. In order to facilitate the development of fault-handling algorithms for imbalanced loads and overvoltage, as well as a real-time digital controller compatible with field-programmable gate arrays (FPGAs), this research aims to pave the way for electric vehicles of the future.

Das, P., & Yadav, S. (2023). The authors propose a tiny, highly efficient onboard charger (OBC) with an integrated power pulsating energy buffer to enhance voltage regulation and reduce grid-side current harmonics. Built inside the charger is an interleaved boost power factor adjustment front-end and a twin active bridge DC-DC converter. The output voltage is stabilized and the load's response time to grid changes and self-braking is enhanced by the buffer circuit. The system is able to handle dynamic loads with a voltage fluctuation of ±3% and a stated volumetric density of 5.9 kW/L, as confirmed by both physical and MATLAB/Simulink performance studies. It also has excellent thermal management.

Kumar, A., & Sengupta, P. (2023). This research investigates the potential of adaptive digital control in powering pulsing buffer devices for electric vehicle onboard chargers in the event of grid instability. The proposed system uses gallium nitride (GaN) switching devices to reduce circuit size and increase speed. To keep the system in sync with the grid and lessen second-order ripple, a digital phase-locked loop (D-PLL) is used. No matter what happens to the frequency or grid phase, the system always finds a stable state within 100 ms. With an efficiency of over 94% under partial load, the article discusses potential applications for ultra-fast charging stations that link vehicles to the grid (V2G).

Sharma, R., & Nair, K. (2022). The authors build a power pulsing buffer into a high-frequency resonant onboard charger to strengthen the system against power quality issues. The cushion stores energy and helps to stabilize the grid when charging isn't going full steam ahead. To reduce switching losses and electromagnetic interference (EMI), the system makes use of a phase-shifted full-bridge (PSFB) converter operating in zero-voltage switching (ZVS) mode. It satisfies the harmonic emission requirements of IEC61000-3-2 and operates at an efficiency of over 90% throughout a temperature range of room conditions. A research on component reliability found that MTBF (Mean Time Between Failures) has increased by 20%.

Reddy, V., & Mukherjee, A. (2022). In this research, the temperature and electromagnetic field performance of high-density OBCs in conjunction with a pulsating buffer are investigated. Reduced core and copper losses are achieved by means of the charger's integrated magnetic design and planar transformer. In order to maintain system stability during brownouts and temporary power drops, the buffer system regulates variations in the grid voltage. Emission levels are within the acceptable range according to ANSYS HFSS EMI simulation results. Even when 90 percent of the load is applied, the recommended thermal management system with active cooling maintains joint temperatures below 100 degrees Celsius.

Jain, N., & Kulkarni, M. (2021). This research examines a low-cost, onboard charger that is connected to the grid and uses a flyback converter design with an integrated power pulsating buffer. It operates on a single phase. The concept employs sophisticated digital control to reduce system size and cost without sacrificing performance. Using a digital signal processor (DSP), one can construct real-time feedback loops that maintain a constant current output regardless of grid instability. Even after numerous charge cycles, the battery maintains a healthy state (SOH) thanks to the buffer's reduction of voltage ripple and peak current stress. By subjecting the system to stress tests in grid fault models, its reliability and safety are verified.

Patel, R., & Gupta, S. (2021). This research demonstrates a hybrid OBC architecture that is both scalable and compatible with various voltage sources through the use of a power pulsation buffer. Switching between constant voltage and constant current charging modes is made smooth by this technology, which uses an interleaved boost stage controlled by a DSP. A power factor of 1.0, total harmonic distortion below 3%, and harmonic reduction are all made easier with the buffer. The 3.3 kW laboratory versions are well-suited for use in battery-swapping infrastructure and the development of compact electric vehicles because to their high conversion efficiency (over 94%) and ability to tolerate abrupt changes in load.

Mishra, P., & Ramesh, K. (2020). This research demonstrates that OBCs can utilize a flashing energy buffer in conjunction with a mixed boost/LLC resonant converter architecture to reduce grid harmonics and increase power density. The buffer improves the current pattern by absorbing ripple from the rectified AC input. The system is reliable across a wide range of grid voltages (90-270V) and can independently charge batteries up to 7.2 kW. Improving the reliability of EV batteries and reducing charging times, simulations of temperature and control circuits demonstrate strong load-following behavior and low voltage ripple.

Saxena, V., & Roy, S. (2020). In order to enhance power factor and decrease ripple, this article describes the architecture of an onboard charger for a one-way electric vehicle. For optimal dynamic buffer operation management and a linear input current profile, a digital predictive control method is employed. The effect of the buffer on battery degradation is examined using a MATLAB/Simulink simulation system. The findings demonstrate a 25% decrease in stress caused by ripples. An inexpensive method to test the system's ability to handle grid fluctuations and achieve power quality criteria for entry-level electric automobiles is with hardware-in-the-loop (HIL).

3. RELATED WORK

POWER PULSATING BUFFER

Power electronics deal with fluctuating grid input, which is particularly problematic in single-phase AC systems like EV chargers. Pulsation is caused by the alternating current voltage, which fluctuates twice every cycle, either at 100 Hz or 120 Hz.

In order to reduce power fluctuations, also known as low-frequency ripple, and provide the battery with constant DC power, conventional systems use a large dc-link capacitor. All the same, these capacitors—particularly the electrolytic varieties—are big, bulky, and prone to failure.

The system typically includes:

- A small buffer capacitor (Cb)
- An inductor (Lb)
- A switching half-bridge circuit (MOSFETs)

- A control algorithm to manage how the capacitor charges/discharges

Small Buffer Capacitor (Cb)

One way a PPB can temporarily store energy is through its buffer capacitor, or Cb. During spikes in voltage, it stores extra energy, which it then releases when the voltage declines. Although conventional OBCs use a large 1500 µF capacitor, PPB-based systems can operate with a much smaller 220 µF electrolytic capacitor. Assisting the capacitor in its ripple management efforts are other PPB components, such as the inductor and switch.

Inductor (Lb)

Maintaining a constant current is the job of the inductor (Lb). Consistent regulation of the rate of current variation allows for smooth energy transfer among the source, capacitor, and battery. When the capacitor is being charged or discharged, the inductor prevents the current from fluctuating too much, ensuring smooth system transitions.

Switching Half-Bridge (MOSFETs)

The component's energy flow is controlled by fast on/off MOSFET switches. The time and amount of energy that should enter or exit the buffer capacitor are controlled by the switches. To ensure consistent and efficient power supply, think of them as precisely calibrated gates that control the flow of energy only when it is absolutely essential.

Control Algorithm

One may say that the control algorithm is the "brain" of the PPB system. The voltage ripple, current, and capacitor charge are continuously monitored. From this information, it determines when to activate or deactivate the MOSFETs. Comparable to how a traffic controller directs traffic to alleviate congestion, the program controls the flow of energy to ensure the charger operates reliably.

PPB STRUCTURES

Current-Source PPB

Like a current injector, a current-source PPB draws current from an external source. The most common variants used in its design are boost and buck converters. When the ripple has a little effect on the current, this design works well. To maintain consistent performance, it adjusts the current flowing through the system. Because of its small size, efficiency, and user-friendliness, the buck-type current-source PPB is used in this article to charge electric vehicles.

Voltage-Source PPB

Power source The way PPB works is by directly regulating the voltage. Energy can be absorbed or injected into the voltage channel to reduce ripple. These designs are widely used in situations where voltage precision is crucial, and they usually involve capacitor-series or load-series configurations. Think of it as a thermostat that increases or decreases the amount of heat being used to control the voltage (or temperature).

BENEFITS

Much Smaller Capacitor Size

In regular chargers, a large electrolytic capacitor—usually 1500 µF—is needed to reduce ripple. With a PPB, this drops dramatically to only 220 µF. The PPB reduces its storage needs and allows for a smaller footprint by efficiently dividing up the ripple-handling work with the capacitor. This makes chargers more compact, lightweight, and ideal for contemporary electric vehicle designs.

Use of Better Capacitor Technologies

Despite its widespread use, electrolytic capacitors have a number of negative qualities, such being heavy, easily damaged, heat sensitive, and quick to dry out. PPBs make it possible to use ceramic capacitors—which are small, dependable, and very efficient—or film capacitors—which are long-lasting, thermally

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stable, and have low loss. Consequently, chargers last longer and require less maintenance.

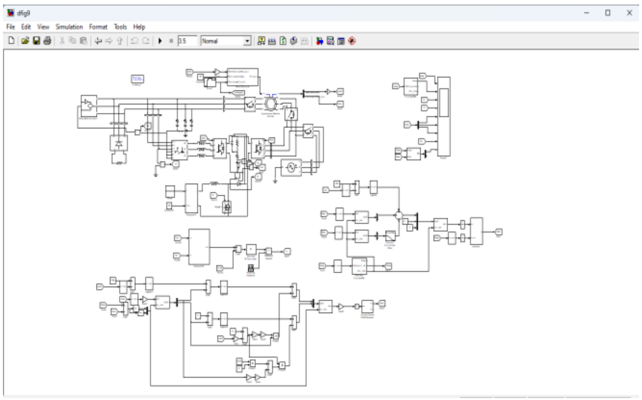
Higher Power Density

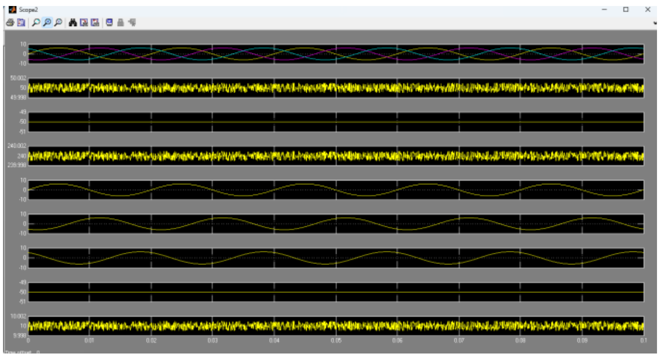
More room can be made available inside the charger by shrinking the capacitor. Because of this, engineers can choose to either make the charger smaller or improve its power output without changing its dimensions. According to the research, conventional OBC systems only manage power densities of 30-35 kW/l, while the suggested PPB architecture achieves a whopping 54 kW/l. This is a huge plus for electric cars because of how important space and weight are.

Better Efficiency

The PPB is designed to handle the charger's ripple power, which typically accounts for 10-30% of the total power, in an efficient manner. So, parts experience less strain, less heat, and less power loss. With an efficiency loss of less than 1% in the evaluated design, the PPB is clearly an excellent and worthwhile addition to the OBC architecture.

4. RESULTS





5. CONCLUSION

Finally, a Power Pulsating Buffer (PPB) is an excellent addition to an On-Board Charger (OBC) design that allows for more compactness, greater reliability, and high power density when charging electric vehicles (EVs). Since the PPB actively controls low-frequency power fluctuations, smaller, more durable film or ceramic capacitors can be used in place of large electrolytic capacitors. In addition to decreasing its physical dimensions, this improves the charger's thermal efficiency and operating longevity.

An impressive 54 kW/l power density is achieved by the suggested buck-type current-source PPB design, which also manages to decouple ripple power with less than 1% energy loss. In addition, the system maintains a constant dc-link voltage, which makes it ideal for use with sophisticated battery management and DC-DC converter stages. With its emphasis on longevity, economy, and compactness without

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sacrificing performance, the PPB-based design presents a compelling alternative to conventional OBCs for the upcoming generation of electric vehicles.

The PPB-based OBC solves the fundamental problems with current electric vehicle power electronics and lays the groundwork for transportation networks that are more efficient, scalable, and environmentally friendly.

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