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Buck converter topology for fuel cell hybrid vehicles

***Abstract**. Fuel cell hybrid vehicles are electric vehicles with energy conversion technologies that combine fuel cells and batteries. The Energy Management System is crucial to the fuel cell hybrid system's operation since it lowers the system's hydrogen usage. This study looks into how to best manage the fuel cell hybrid vehicles' connected DC/DC converter topologies. The results of the simulations run in Matlab-Simulink show that the suggested buck converter is efficient and a better option for use in electrical vehicle applications. Due to its lower emissions and increased fuel efficiency, fuel cell-powered hybrid electric vehicles (HEV) are being developed by many automobile firms. Power electronics is the important technology for the development of fuel cells for propulsion. This document details various DC/DC converter topologies that are employed to link HEV motor controllers to fuel cells. The objective is to offer a straightforward and useful boost converter topology with a coordinated control that can simultaneously control both the output voltage and input current. The outcomes of simulations run under various dynamics are used to assess the buck converter's performance.*

Streszczenie**. Pojazdy hybrydowe z ogniwami paliwowymi to pojazdy elektryczne z technologiami konwersji energii, które łączą ogniwa paliwowe i akumulatory. System zarządzania energią ma kluczowe znaczenie dla działania hybrydowego systemu ogniw paliwowych, ponieważ zmniejsza zużycie wodoru przez system. W badaniu tym zbadano, jak najlepiej zarządzać topologiami połączonych przetwornic DC/DC pojazdów hybrydowych z ogniwami paliwowymi. Wyniki symulacji przeprowadzonych w programie Matlab-Simulink pokazują, że proponowana przetwornica jest wydajna i lepiej nadaje się do zastosowań w pojazdach elektrycznych. Ze względu na niższą emisję i zwiększoną oszczędność paliwa, wiele firm motoryzacyjnych opracowuje hybrydowe pojazdy elektryczne (HEV) napędzane ogniwami paliwowymi. Energoelektronika jest ważną technologią dla rozwoju ogniw paliwowych do napędu. W tym dokumencie wyszczególniono różne topologie przetwornic DC/DC, które są wykorzystywane do łączenia sterowników silników HEV z ogniwami paliwowymi. Celem jest zaoferowanie prostej i użytecznej topologii przetwornicy podwyższającej napięcie ze skoordynowanym sterowaniem, które może jednocześnie kontrolować zarówno napięcie wyjściowe, jak i prąd wejściowy. Wyniki symulacji przeprowadzonych przy różnej dynamice służą do oceny działania przetwornicy buck.* (Topologia przetwornicy buck dla pojazdów hybrydowych z ogniwami paliwowymi***)

Keywords: Buck converter, DC–DC converter; Fuel cell, Wireless charger; Hybrid vehicles.
Słowa klucz\owe: przekształtnik buck, pojazd hyvtydowy

Introduction

Air pollution and global warming are thought to be caused by the production of power and transportation. Since the majority of power plants are located outside of cities, traditional gasoline vehicles are thought to be the main source of smoke and other dangerous pollutants in metropolitan areas [1-2]. Every year, traditional automobiles contribute significantly to air pollution. The electrification of transportation is a result of the negative effects of pollution. As a result, the development of electric vehicle technology is a significant and promising answer to this problem [3-4]. This approach leads automakers to change their strategy and increase their investment in the creation of electric drive vehicles.

It is necessary to look into the problems associated with EV penetration because the market for EVs is expanding quickly. As a result, this time, a topic of consideration is the integration of plug-in electric vehicles (PEVs) into the power grid. The majority of consumers require immediate battery charging for their PEVs when they arrive home from work. The distribution transformer would be overloaded, the power quality and reliability of the entire system would decline, and utilities' machines (like three phase induction machines) as well as customers' equipment could potentially be damaged if all batteries started charging at once, assuming that they were in a fully discharged state.

Utilities must strengthen their infrastructure for generation, transmission, and distribution in order to resolve these problems. The utilities should also use EVs' smart charging, which permits communication between utilities and vehicles to adjust charging patterns [9], or offer financial incentives for off-peak charging.

The improvement in air quality that electric automobiles may offer to cities is their main advantage. Since pure electric cars don't have exhaust, they don't emit carbon dioxide while they're traveling. As a result, there is considerably less air pollution. [6]

Any road vehicle with the capacity to store electricity in its internal rechargeable battery packs, fuel an electric motor, and assist in tire propulsion utilizing an external power source (such as a wall outlet connected to the power grid) is referred to as a plug-in electric vehicle (PEV). Industry, transit, housing, and commerce are the top four energy-intensive industries in the world. For the United States of America (U. S.), the amounts for each industry in 2017 are as follows: 29%Transportation, 20% domestic, 18% business, 32% industrial, and 1% other [1]. The administrations look for various resources is driven by worries about the decline of fossil fuels and how that will affect global warming. Since transportation accounts for over 30% of global energy consumption, switching from gasoline-powered cars to electric, hydrogen, etc., has gained more attention. The majority of cars used for mobility today consume fossil fuels. It is clear that petroleum accounts for 90% of transportation energy. Therefore, the electrification of transportation may significantly decrease the demand off fossil fuels.

The following is how the paper is set up: A review on fuel cell hybrid vehicles and the model of a fuel cell system is proposed in section 2. The Buck DC-DC converter design for the EV-charging system and the modelling of buck converter for EVs charger are the main topic of Section 3. The experimental pulse width modulated (PWM) switching tests, the interface driver card design for the IGBT switches is shown in Section 3. The wireless charging system for EVs is covered in Section 4. Finally, the Section 4 gives the conclusion and suggestions.

Design Fuel Cell Hybrid Vehicles

A mathematical representation of the system reflects both its dynamic and static behavior as well as its attributes. It offers a clear and concrete explanation of the procedures used to operate the system.

Although there are many distinct kinds of fuel cells, they all operate on the same principles. An anode, a cathode, and an electrolyte are required for the operation of a fuel cell. The electrolyte will vary depending on the type of fuel cell; in fact, fuel cells are grouped according to the type of electrolyte they employ. Hundreds of separate cells can make up one fuel cell. A fuel cell's individual cells are made up of an electrolyte, an anode, and a cathode. Between the cathode and the anode, the electrolyte was basically sandwiched by the cell.

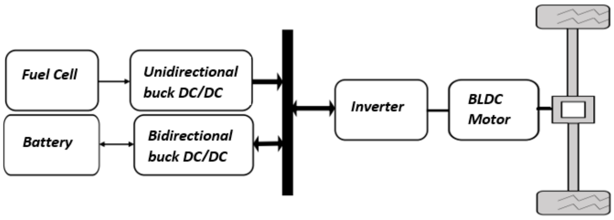

Fig. 1. Vehicle Block Diagram for a Fuel Cell

Model of A Fuel Cell System

A fuel cell is an electrochemical device that produces direct current power as long as fuel and oxidant are provided to the anode and cathode, respectively. An un-rechargeable battery is a more straightforward way to define a fuel cell. Fueled by hydrogen, practical fuel cells presently only produce electricity and water for drinking [25]. Thus, it is frequently referred to as a "zero emission engine". Power management, the fuel processor, the fuel cell and stack, and other subsystems make up a fuel cell system. A polymer exchange membrane (PEM) serves as the electrolyte in the fuel cell design that has the best chance of success for usage in automobiles. The PEM fuel cell has the advantage of a low operating temperature of roughly 80°C.

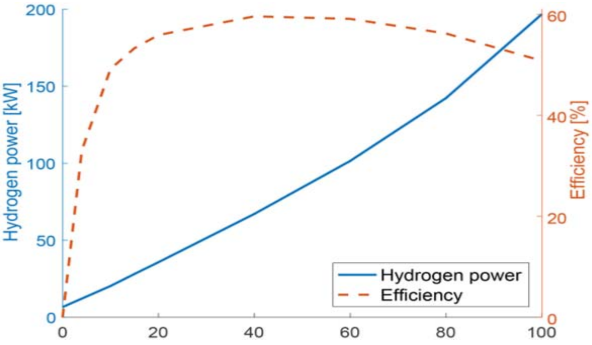

Fig. 2. Fuel cell power and efficiency vs. hydrogen power [10].

Using an online graph extractor tool, for an accurate mathematical representation, the mapping between hydrogen power and net output fuel cell power is extracted.

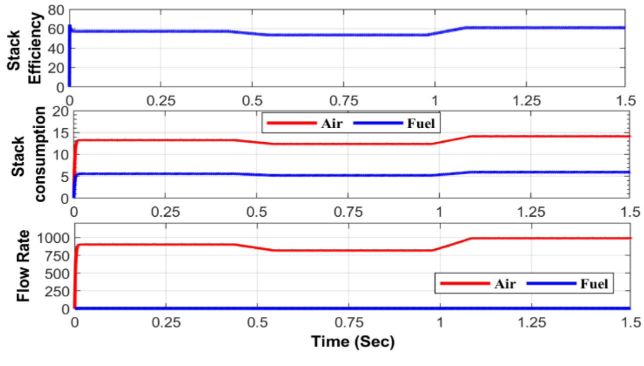

Fig. 3- Fuel cell flow rate

In all three examples, the stack efficiency of a fuel cell is presented with the air and fuel consumption of the stack. Figure 3 shows the many ways in which the FC input changes as a function of input temperature with assumed temperature.

Modelling of Buck Converter for EVs Charger

As seen in Figure 4, the DC/DC converter acts as the conversion interface between the DC bus and the EV battery in order to achieve energy flow between the charging station and the battery. The buck converter can be used for high-power applications and has the benefits of a straightforward structure, simple control, a small size, few components, and high conversion efficiency [9].

Consequently, the topological structure of the buck converter was chosen and designed in this study. The two-stage charge control approach of constant current first and subsequently constant voltage is used by the suggested buck model for EV charging to charge the battery pack.

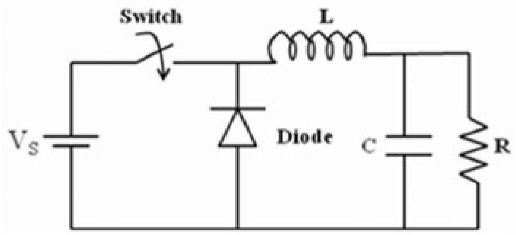

Fig 4: buck DC/DC converter.

Following are the average values for the current flowing through the load inductance and transformer leakage inductance during a half cycle of the forward operating mode as determined by the operating mode analysis.

(1) $$I_d = \frac{1}{2f_sL}D(1-D)V_o$$

According to KCL, the dynamic system's average model is given by

(2) $$\frac{dV_o}{dt} = \frac{1}{C_O}\left(\frac{V_i}{2Lf_s}\right) + \frac{1}{RC}V_o$$

The typical output voltage and shifting phase duty can be characterized as when minor signal disturbances are introduced and the signal is divided into DC and AC tiny signal components.

(3) $$\begin{cases} V_e = V_O - \tilde{V} \\ D_e = D - d \end{cases}$$

Since here does not exist a high-order term, only the steady-state DC amount is subtracted from (3), and the entire system's AC small-signal equation is calculated as:

(4) $$\frac{d\tilde{V}_o}{dt} = \frac{1}{C_O}\left(\frac{V_i}{2Lf_s}\right)\tilde{d} + \frac{1}{RC}\tilde{V}_o$$

The purpose of the buck converter is to variate the voltage respectively to the duty cycle of the PWM signal as control the N- MOSFET attached to the converter. The buck converter plays also the rule of filter because of the inductor Lb at 500µHand the capacitor Cb at 500µF included in it.

The topology of a buck converter is shown in Figure 5, with the IGBT losing power and voltage and current passing through resistor R1 at 100 ohms.

wireless charging system for EVs

The primary subject of discussion in this part will be the wireless charging system for electric vehicles based on the concept of wireless power transfer, or WPT. Wireless Power Transfer is a term that describes the transmission of electrical energy without the use of cables.

It is possible to send AC energy to batteries and other electrical devices without a physical connection thanks to wireless electricity Transfer, which is equipped to transfer electricity across an air gap.

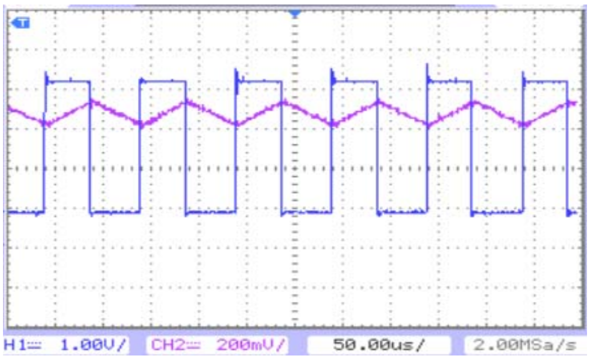

Fig. 5: Buck converter voltage and current insulation

The primary issue with WPT is how ineffective it is. Therefore, researchers are attempting to increase production using a variety of methods. Traditional WPT encounters problems like frayed cables, power outages, electric sparks, etc. WPT would thus be an excellent treatment [11]. Wireless charging uses the idea of electromagnetic induction to transmit electrical power through the atmosphere as a magnetized field. Inductive charging or cordless magnetic charging are some names for it. [10]. The finished charging circuit for EVs using the induction method is shown in Figure 6.

As shown in Figure 6, the AC supply produces a three-phase voltage at a certain frequency (the network frequency 50/60 HZ), which is then converted to DC voltage by a rectifier circuit. The DC is then converted once more into an amplified AC signal by a high frequency AC invertor. The rationale for the preceding steps is that we need a high frequency for this since the AC supply only provides 50 or 60 HZ (depending on the country network frequency where you are) and we want to transfer power wirelessly. Since the high frequency AC current flows through the primary side of the coils and is alternating because it is an AC current, it naturally produces an alternating magnetic field. The secondary coils connect this magnetic field, which results in an EMF (Electro Motive Force) in accordance with Faraday's law. It is known as inductive power transmission because the secondary coils' induced EMF is brought on by electromagnetic induction. Following its passage via the secondary side, the AC current is once more rectified into a DC current that charges the electric vehicle's battery.

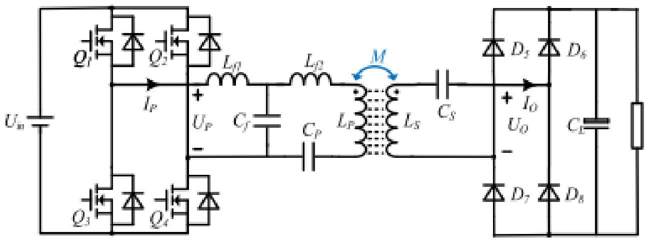

Fig.6: Circuit of wireless charging system.

The converters produce a significant step up gain using linked inductor technology. Using linked inductor and coupled capacitor techniques, a substantial voltage gain can be achieved. Unfortunately, the leaking inductance reduces conversion efficiency and spikes the voltage on the primary switch. Thus, suggested converters using coupled inductor technology have been provided. In order to increase voltage, gain, some converters also integrate output-voltage stacking and make use of several coupled inductors.

As seen in figure 7, the load and the buck converter were coupled to the secondary part of the topology during simulation.

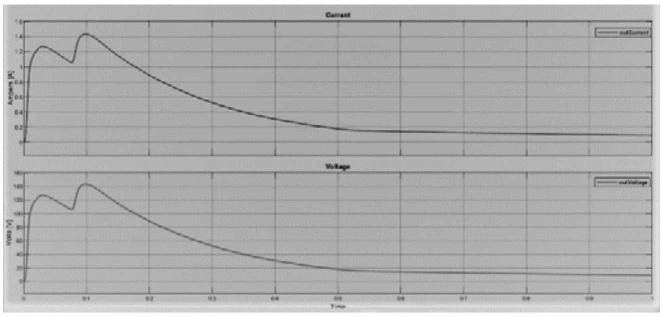

Fig. 7: The waves of voltage and current in a high Buck converter

Figure 8 of the MATLAB/Simulink plot demonstrates that the voltage and current fluctuate greatly up to a point at 100 ms before steadily dropping till 600 ms. After analyzing the circuit, it was discovered that the high output power was caused by the current in the coils oscillating for only around 0.1 seconds at a high amplitude before decreasing and achieving steady state.

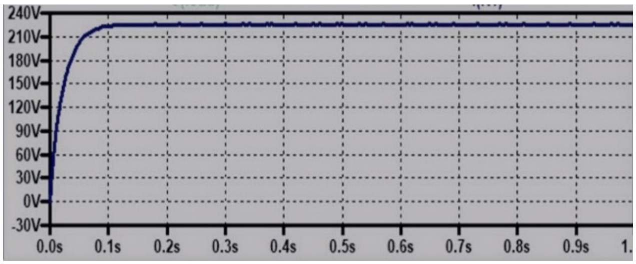

Fig. 8. Waveforms of a High-Buck converter's voltage

In addition to having a poorer efficiency than plug-in charging, wireless charging will also have a greater ripple if the same buck converter circuits and chopper switching frequency are employed. The plug-in system has an average efficiency of 70%. In comparison, less than 30% of the power is sent through the wireless charging mechanism. Losses in the inverter and the distance D between the coil are to blame for the reduced efficiency of wireless charging.

Conclusion

This study created, investigated, and experimentally validated a DC-DC converter for use in a battery charger that is based on high-voltage IGBT modules. Modeling has been done on a high dc-dc converter. The simulation outcome demonstrates that this converter technology has successfully achieved the maximum output voltage. Moreover, the use of a single switch reduces the voltage stress across the switch. In comparison to conventional dc/dc converter topologies, the suggested converter can increase efficiency with a less number of switches and results in good dependability.

Even if the study presented here is limited to the power element of the suggested converter, analysis and practical verification show that a powerful Buck converter for battery charging, based on a minimal number of modules, is a workable solution. A variable frequency switching control has the power to ensure thermal equilibrium of the IGBT modules during the full Buck modes without power reduction.

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