Review of High Step-Up DC-AC Power Electronics Solutions Without Galvanic Isolation

Urgency of the research. Energy storage technologies are heavily related to electric vehicles. The fast charging station together with the wireless power station potentially makes the electric vehicle more attractive and user-friendly.

Target setting. The main problem in this area is the large size and low battery life, as well as the limited loading speed of electric vehicles. It is also important to optimize power density with the greatest possible efficiency.

Actual scientific researches and issues analysis. The analysis of publications shows that a lot of attention has been paid to this topic of research, there are a large number of publications by leading institutes and world-renowned scholars. Therefore, in the current article, a comparison of two main families of non-isolated converters with reference to articles and domestic scientists is also shown. The first family, based on one-step solutions, is presented and classified. Also shown is an analysis of two-stroke converters based on the intermediate DC converter with a high increase.

Uninvestigated parts of general matters defining. Many problems with the power industry should be solved to increase the implementation of technology and accelerate the transition from traditional charging to electric mobile charging stations. In the case of a simplified solution without the use of galvanic isolation and the use of low voltage batteries, the gain of the DC converter of the converter plays a very important role.

The research objective. The main task of this work is to review high-frequency DC converters without galvanic isolation to charge the battery from the network.

The statement of basic materials. In the analysis of solutions based on single-stage dc converters and the review of topologies, it was found that among the several groups of impedance networks most suitable for use are high-gain networks based on magnetic connected inductive components or a transformer. With proper implementation, this will result in an increase in the voltage gain through the rotational factor. The same circuitry based on an inverter with a Z-Source Inverter (ZSI) and a SEPIC converter, even with more modified solutions, is limited in practical implementation and operation. These circuits contain many passive components and have additional losses in semiconductors.

In the review of two-level DC converters with a high degree of amplification without galvanic isolation on the basis of high-frequency DC converters, a review and comparison of several solutions was performed. The most interesting circuit is a switched capacitor bidirectional converter consisting only of semiconductor switches and capacitors. An efficiency ratio ranges from 95 to 98.5 % over the entire download range. The intermediate concept of this solution has become quite popular in recent years, thanks to such benefits as high efficiency over a wide range of loads, reduced conduction losses, high power density.

Conclusions. High step up dc-ac converters are one of the key elements for battery charging from the grid. They provide a flexible power processing interface between energy storage device and the rest of system. Two main families of non-isolated converters are considered. The first family based on single-stage converters can be interesting because of reduced amount of elements. At the same time the complex control is a disadvantage.

Key words: high step up; converter; battery charge.

Fig.: 5. Bibl.: 10.

Problem definition. The topic of energy storage technologies strongly linked with electrical vehicles. The main problem in this field lies in the large size and low lifetime of the batteries along with limited charging speed of the electrical vehicles. The second problem relates only to power electronics issues. This topic is under investigation. The fast charging station along with wireless power station potentially makes an electrical vehicle more attractive and user friendly [1].

At the same time, many power electronics problems should be solved to increase acceptance of the technology and accelerate the transition from traditional to electrical mobility. In case of simplified solution without galvanic isolation and low voltage batteries utilization, the boost factor of dc-ac converter plays a very important role. Another issue lies in power density and efficiency optimization.

The main goal of this paper consists in overview of high gain dc-ac converters without galvanic isolation for storage battery charging from the grid. There are two types of converters that can be underlined. Fig. 1a shows the single-stage dc-ac converter, while the fig. 1b shows the general structure of two-stage the dc-ac converters.
Fig. 1. a) single-stage dc-ac converter b) two stage dc-ac converters

Single-stage dc-ac converters The first solution of single-stage solution is Active Boost Cell (ABC) At the beginning, the buck-boost two-level inverters derived from the SEPIC dc-dc converter have been successfully developed for bidirectional power conversion with special voltage boost circuitry added between the dc source and the inverter circuitry [2]. Since the auxiliary transistors are used in the boost circuit, in order to distinguish this approach from the passive impedance network application it will be called ABC.

Fig. 2a shows conventional Cuk-derived topology for single input voltage source. In this topology, a voltage boost circuit is made up of inductor $L_1$, two switch $S_1$ capacitor $C_1$. This boost cell is inserted between the dc source with reversed polarity and inverter. Besides inductive boosting, the turning ON of the switches causes also $C_1$ to act as a split dc-link capacitive bank for powering the inverter.

Fig. 2. a) single-stage Cuk converter b) single-stage SEPIC converter

Fig. 2b shows buck-boost SEPIC-derived topologies for single input voltage. In [2] a bidirectional buck-boost rectifier was proposed with a symmetrical passive network and a single dc switch inserted, which was derived from either the Cuk or SEPIC dc-dc converters. The boost-buck concept can be further modified with an unsymmetrical front-end structure for power inversion.

For properly controlling the buck-boost operation, the second state (when both transistors are OFF) should be inserted in the zero intervals because both generate zero line voltages, and therefore a specific modulation scheme is designed and discussed in the following chapters for this circuit.

Z-Source Inverter (ZSI) proposed by F.Z. Peng in 2002 [3]. This unique circuit has different areas of application: energy generation systems with renewables, systems without energy storage and with energy storages, grid connected systems and many other systems. These applications are possible due to the extended regulation range of the input voltage of that converter [4].

Modifications based on the above schemes are shown in Fig. 3[5]. The most common method is to use a switched inductor, as shown in Fig. 3a. This is derived by replacing the inductor $L_2$ in the qZSN by one of the switched inductors, shown in Fig. 3a Ошибка! Источник ссылки не найден. The second type of modification called capacitor assisted extended boost (CAEB) is shown in Fig. 3b and modified capacitor assisted extended boost (MCAEB) is shown in Fig. 3c. CAEB is derived by adding one diode ($D_2$), one inductor ($L_3$) and two capacitors ($C_3$ and $C_4$) to the traditional qZSI. MCAEB is derived from the CAEB qZSI by changing the connection points of the capacitors $C_2$ and $C_3$.
The third type of modification called diode assisted extended boost (DAEB) is shown in Fig. 3d, and a modified diode assisted extended boost (MDAEB) is shown in Fig. 3e. DAEB is derived by adding one capacitor ($C_3$), one inductor ($L_3$) and two diodes ($D_2$ and $D_3$) to the traditional qZSI. MDAEB is derived from the DAEB qZSI by changing the connection points of the capacitor $C_3$. These modifications can produce infinite boost. However, this cannot occur in practice due to losses. Out of the modifications, CAEB is preferable, since it requires fewer semiconductor devices. Therefore, the circuit may have lower power losses.

All of these modification types are limited in practical solutions. These schemes contain many passive components and have additional losses in the semiconductors.

Impedance networks can be subdivided into the several groups. The most suitable for high step up application are based on magnetically coupled inductive components or transformer (Fig. 4). Its implementation in the ISN can result in higher voltage boost factor due to the turns ratio. LCCT Z-source circuit is an inductor-capacitor-capacitor-transformer Z-source circuit. LCCT Z-source and quasi-Z-source circuits are shown in Figs. 4a and 4b, respectively. These schemes include a high frequency ideal transformer.

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**Fig. 3. Impedance network modifications:**
- a) switched inductor;
- b) capacitor assisted extended boost;
- c) modified capacitor assisted extended boost;
- d) diode assisted extended boost;
- e) modified diode assisted extended boost

**Fig. 4. Impedance networks suitable for high step up application:**
- a) LCCT Z-source;
- b) LCCT quasi-Z-source;
- c) Γ-Z-source;
- d) Y-source;
- e) TZ-source
Γ-Z-source network contains a transformer. The circuit is shown in Fig. 4c. T-Z-source network scheme contains magnetic components and is shown in Fig. 4d. Finally Y-source network belongs to the schemes with magnetically coupled components is shown in Fig. 4e.

**Two-stage dc-ac converters** based on the high step up dc-dc converters is the second possible solution [6]. Fig. 5 shows several possible dc-dc converters with high step up capability without galvanic isolation.

![Diagram of high step up dc-dc converters](image)

**Fig. 5. High step up dc-dc converters:**
- a) high step-up/step-down bidirectional dc-dc converter;
- b) Cuk-based converter;
- c) The switched capacitor bidirectional converter;
- d) interleaved charge-pump topology;
- e) tapped-inductor based converter

In [7] is proposed high step-up/step-down bidirectional dc-dc converter (Fig. 5a) in which the coupled inductor \( L_c \) is used. This converter is a combination of the conventional buck-boost and a voltage doublers cell. In some region, it is possible to realize zero voltage switching. In [8] is presented the study and simulations of a new family of symmetrical hybrid multilevel inverters based on Cuk (Fig. 5b) and Zeta converters, that are able to high step up/down voltages. The switched capacitor bidirectional converter proposed in [9] and shown in Fig. 5c is composed of only semiconductor switches and capacitors. The prototype of the converter is presented in the paper, 75 kHz switching frequency is selected, the battery voltage is equal to 20 V, the output voltage is equal to 173 V and overall power is 100 W. The reported efficiency is from 95 to 98.5% in all load range. Interleaved concept became quite popular in recent years due to such advantages as high efficiency in wide load range, reduced conduction losses, high power density. The interleaved charge-pump topology (Fig. 5d) is analyzed in [10]. It has two times higher conversion ratio over conventional half-bridge topology, but because of schematic limitations duty cycle on switches \( T1 \) and \( T4 \) cannot be smaller than 0.5. Finally, the tapped-inductor based solution is shown in Fig. 5e [6]. It is compatible solution due to the turn’s ratio of inductors. It should be noted that as any similar solution it may suffer from voltage and current spikes across semiconductors.

**Conclusions.** High step up dc-ac converters are one of the key elements for battery charging from the grid. They provide a flexible power processing interface between energy storage device and the rest of system. Two main families of non-isolated converters are considered. The first family based on single-stage converters can be interesting because of reduced amount of elements. At the same time the complex control is a disadvantage.

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ОГОЛЯД DC-AC РІШЕНЬ СИЛОВОЇ ЕЛЕКТРОНІКИ БЕЗ ГАЛЬВАНИЧНОЇ ІЗОЛЯЦІЇ З ВИСОКИМ КОЕФІЦІЄНТОМ ПІДСИЛЕННЯ

Актуальність теми дослідження. Технології зберігання енергії сильно пов'язані з електричними транспортними засобами. Станція швидкої зарядки разом із бездротовою станцією передачі енергії потенційно робить електричний транспортний засіб більш привабливим та зручним для користувача.

Постановка проблеми. Основна проблема в цій галузі полягає у великих розмірах та низькому терміні служби батарей, а також обмежених вмістності завантаження електричних транспортних засобів. Також важлива оптимізація щільності енергії при значному більшому ефективності.

Аналіз останніх досліджень і публікацій. Аналіз публікацій показує, що даній тематиці досліджень приділено багато уваги, є значна кількість публікацій провідних інститутів і всесвітньовідомих вчених. Тож в поточній статті показано порівняння двох основних сімейств неізольованих перетворювачів із посиланням на статті і вітчизняних також. Представлено і класифіковано перше сімейство, засноване на однотактних рішеннях. Також показаний аналіз двохтактних перетворювачів на основі проміжного перетворювача постійного струму з високим підвищенням.

Вибір недосліджених частин загальної проблеми. Багато проблем з електроенергетикою має бути вирішено для збільшення впровадження технології та прискорення переходу від традиційної зарядки до електричних мобільних зарядних станцій. У випадку просторого рішення без використання гальванічної ізоляції та використання низьковольтних батарей, коефіцієнт підсилення постійного струму перетворювача відіграє дуже важливу роль.

Постановка завдання. Основним завданням цієї роботи є огляд високочастотних перетворювачів постійного струму без гальванічної ізоляції для заряджання акумулятора від мережі.

Висновки. В статті проведено огляд перетворювачів для зарядки аккумулятора від мережі, приведено порівняння двох основних сімейств. Високошвидкісні перетворювачі постійного струму - це один з ключових елементів зарядки акумулятора від мережі. Вони забезпечують лічковий інтерфейс перетворення енергії між пристроєм зберігання енергії та іншою частиною системи. Розглянута їх основні групи неізольованих перетворювачів. Перша група на базі одностепеневих перетворювачів постійного струму може бути зацікавленою через зменшення кількості елементів. У той же час недоліками таких систем є складний контур.

Ключові слова: високий коефіцієнт підсилення; перетворювач; заряд батареї.

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