A Review of Converter Topologies for Sustainable Lighting Systems

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***Abstract* – The global current interest is to include renewable energy systems in as many applications as possible. One area where the implementation of renewable energies is feasible is within various lighting systems, whether they are public or private. These lighting setups typically consist of multiple components. Firstly, there is the renewable energy generation system, with solar panels and windmills being the most prevalent options. Secondly, a storage method may be employed. Additionally, LED lighting fixtures are essential. Lastly, a conversion system is required to interconnect these elements, notably utilizing an LED driver at the load input to power it. Throughout this project, a comprehensive analysis of the primary converter system topologies has been conducted, exploring their common applications, suitability, and integration with renewable energy systems.**

***keywords* – LED driver, Bidirectional Converter, Isolated Converter, Non Isolated Converter, Solar Panel, Windmill.**

I. Introduction

In recent times, there has been a global inclination towards integrating renewable energies into an increasing array of applications. This trend stems partly from the escalating demand for energy observed in recent years, driven by advancements in transportation, technology, and year-round energy consumption. The surge in energy demand is fueled by endeavors to enhance the quality of life for citizens worldwide. Consequently, both energy consumption and infrastructure development have experienced steady growth over time [1]. Today there is a growing emphasis on promoting public transportation as a part of ongoing efforts to transition towards ecologically sustainable personal vehicle options. Concurrently, initiatives are underway to introduce clean energy solutions in households and explore clean energy alternatives for lighting purposes [2].

This paper focuses specifically on the latter point. Presently, there is a significant interest in enhancing the quality of life in both developed and developing nations, which encompasses improving existing lighting systems [3]. Proper street lighting systems are being examined as a means to significantly reduce road accidents and curb criminal activities in urban areas [4]. Whether illuminating roads or urban spaces, lighting systems are indispensable, with a particular emphasis on Light Emitting Diode (LED) lighting systems.

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In order to merge renewable energy systems with LED lighting systems, it is essential to use a bi-directional conversion system that allows renewable energy sources to be connected to a power supply system, usually a battery, and the battery to be connected to the LED load.

The reason why this type of system uses a bidirectional converter is because on the one hand the renewable source will directly feed the power system, and through the same converter, once the renewable system stops charging the battery, it will feed the LED load. The remainder of this paper is organized as follows. In Section II a brief introduction of the different topologies that exist for renewable energy and street lighting is made.

In Section III an analysis of different possible configurations is carried out. In Section IV, the different non isolated topologies that can be found are analyzed. In Section V, a similar analysis is made with isolated topologies. Finally, in Section VI, the conclusions are presented.

II. Converter Topologies Overview

The variable and intermittent nature of renewable energy sources poses challenges in effectively harnessing and utilizing their power output. To address these challenges and optimize the utilization of renewable energy, efficient power conversion technologies are essential. Power converters serve as critical components in renewable energy systems, facilitating the conversion, conditioning, and management of electrical energy among renewable energy sources, energy storage systems, and electrical load.

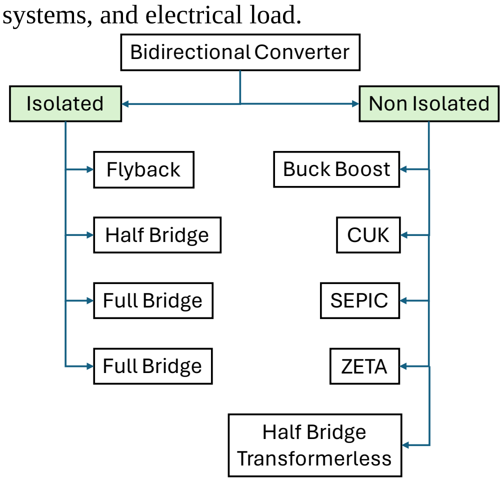

Fig. 1. Classification of the different bidirectional converters.

Different converter topologies offer unique advantages and functionalities suited to various renewable energy applications. These converter topologies play a pivotal role in maximizing energy efficiency, enhancing system reliability, and enabling seamless integration with the existing electrical infrastructure.

Fig. 1 shows a simple diagram representing the different topologies that can be used for this purpose. These topologies have been divided into 2 well-defined blocks. On the one hand, the topologies of converters with galvanic isolation between their input and output are highlighted. On the other hand, converters without any type of isolation are represented.

The main objective of this work is to carry out an exhaustive study of the different converters that are used for lighting systems and that are integrated with any type of renewable energy. The aim is to create a guide that allows the designers to know more easily the classification of these converters, under which circumstances they are used, and which are their advantages and disadvantages.

III. Performance Requirements

There are several elements to consider when implementing a lighting system together with renewable energy systems, such as energy efficiency, reliability, lifetime, and adaptability. However, there is a common feature in all of them and that is the way of assembling the lighting system.

The possible elements that can be involved in these systems can be solar panels, windmills, of course a lighting load, mainly an LED load, a connection to the grid to power the LED load if the renewable systems cannot work and finally a storage system, usually a battery. However, it will not always be necessary to use each of these elements, and the way to connect them can also vary. Through a theorical study, it is possible to conclude that there are two ways to integrate renewable energy systems with lighting systems.

A. Connection on a DC bus

One of the simplest methods is the use of a DC bus. This bus can be considered as integrated in the lighting system itself and the different components that make up the system are connected to it. A typical example of a DC connection is shown in Fig. 2.

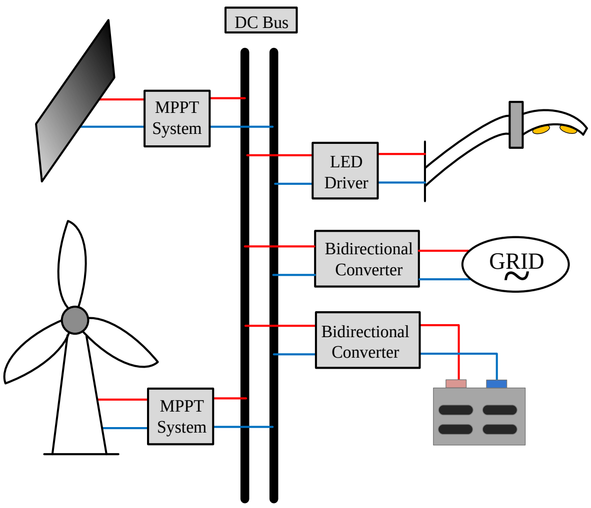

Fig. 2. Schematic of a DC Bus Connection

However, there is a major drawback to this type of connection. As can be seen in Figure 2, each element would need a converter or a specific system to be connected to the DC bus. In the case of renewable sources, an MPPT system is necessary to optimise their operation. The LED will need its own converter, which does not need to be bidirectional, but the converter in the battery will power the LED if necessary. Similarly, it is very common to find grid connections in this type of configuration. All of this makes the cost of assembly very high as each element will need its own system to be integrated into the whole.

B. Standalone Parallel Connection

On the other hand, there is a much simpler connection method where fewer elements are involved. This system is generally used when the grid is not available, where renewable energy sources are the only ones to provide the energy needed to power the LED load. An example of a typical representation of this kind of system can be seen in Figure 3.

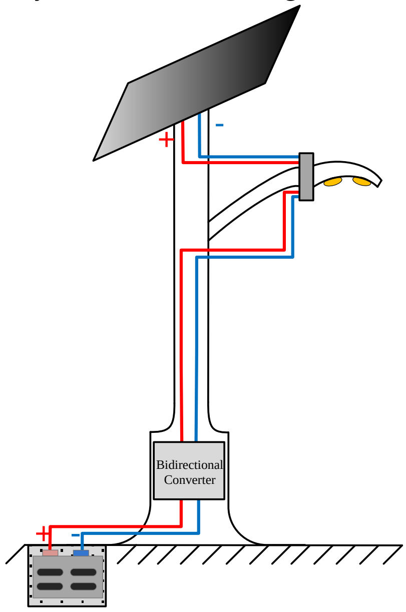

Fig. 3. Schematic of a Parallel Connection with no grid

This system is based on the use of a single converter to integrate all the components of the system. The renewable energy source, usually a solar panel, would be connected in parallel with the LED load. By means of a bi-directional converter, these two components would be connected to a battery. During the day the panel would charge the battery. At night, the battery would power the LED load. The bidirectional converter connected to the battery, the LED driver and the bidirectional converter used in parallel connections, will be the object of study of this work analysing the different topologies that can be used.

IV. Non-Isolated Topologies

The non isolated converter topologies play a crucial role in efficiently converting, controlling, and managing electrical energy. Unlike isolated converters, which provide galvanic isolation between input and output, non-isolated converter topologies are characterized by their direct connection between input and output circuits. This direct connection offers advantages such as simplicity, compactness, and cost-effectiveness, making non-isolated converters highly suitable for a wide range of applications in renewable energy systems.

Non isolated converter topologies encompass a diverse array of configurations. From buck and boost converters to buck boost, Cuk, and SEPIC converters, these topologies offer versatile solutions for voltage regulation, power conditioning, and integration with renewable energy sources such as solar panels, wind turbines, and battery storage systems. Throughout this section, an analysis of the main converters which are used in lighting systems integrating renewable energy systems will be carried out.

A. Buck Boost Converter

One of the most used converters is the buck boost converter. This converter is a bidirectional converter that combines the topology of a boost converter and a buck converter. As stated in section II, the assembly of these converters can vary depending on whether it is a connection where different elements are connected through a bus, i.e., the batteries on one side, the generation system on the other side, and the lighting system on the other side [8]. Fig. 4 shows a typical implementation of a buck-boost converter.

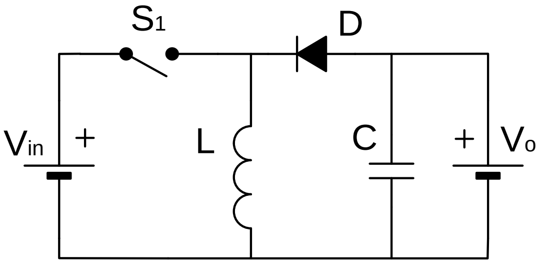

Fig. 4. Buck-Boost Topology

Examples as in [5], [7], [10] and [11], are practical cases where a connection of buck, boost or buck-boost converter systems connected to a bus network has been carried out. On the other hand, and focusing attention on another connection mode, it is possible to appreciate how in [6], [9], [12] and [13], the systems do not depend on a bus connection but by modifying the topology it is possible to connect in parallel the energy generation system. Another difference between these elements also lies in the control mode. In some cases, such as in [7], the aim is to manage the energy stored in the batteries, while in cases such as in [8], the aim is to reduce the number of passive elements in order to introduce new active elements. The simplicity and the high efficiency make this topology ideal for a wide range of input and output power systems.

B. CUK Converter

The Cuk converter offers several advantages over other DC-DC converter topologies. It provides continuous input and output currents, which results in reduced output ripple and improved efficiency. Additionally, it offers a high degree of voltage regulation and is capable of handling both step-up and step-down voltage conversion [14].

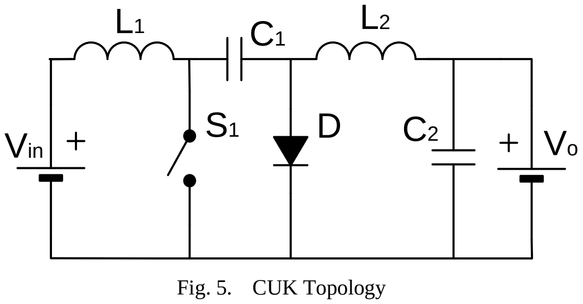

Fig. 5. CUK Topology

The main characteristic for the use of this type of converters is their use under different control modes, the most important being those presented in [15], [16], [17] or [19]. The choice of control technique for a Cuk converter depends on factors such as the desired performance specifications, system requirements, and complexity constraints. Each control technique has its advantages and limitations, and the selection should be made based on the specific application and design considerations. Due to their simplicity, these converters are often used in renewable energy systems such as [20], [21] and [22]. In these 3 cases, the connection mode is based on a connection to a DC bus, whereby each required element has its own independent converter. The main problem of this topology is its complexity and the high manufacturing cost.

C. SEPIC Converter

The SEPIC converter offers advantages such as continuous input and output currents, low output ripple, and efficient voltage regulation, making it suitable for a wide range of applications in power electronics and renewable energy systems like [25], [26], [27] and [28].

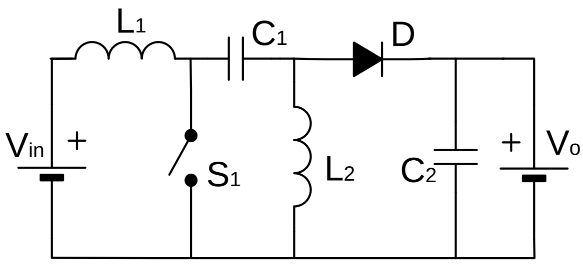

Fig. 6. SEPIC Topology

It is common to be able to use this type of converter in circumstances where, to design a standalone system dependent on a renewable system, a solar panel can be connected in parallel to the LED load as described in [23] and [29]. On the other hand, the combination of this type of converter with other non-isolated converters such as the CUK converter, as can be seen in [24] and [30], also makes it a suitable option for connecting different systems to a bus branch to obtain greater versatility. This converter may be suitable for battery and automotive application but presents a complex topology and low efficiency compared with other converters.

D. ZETA Converter

The Zeta converter is used for voltage conversion, like the SEPIC converter. It is designed to provide both step-up and step-down voltage conversion capabilities, making it suitable for a wide range of applications in power electronics and renewable energy systems like in [35] and [36].

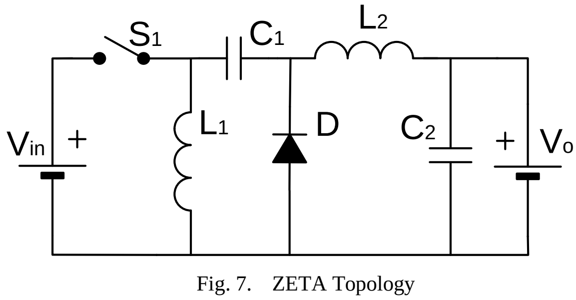

Fig. 7. ZETA Topology

Zeta converters can be effectively utilized in LED lighting systems, particularly for dimming applications. Therefore, works such as [31], [33], or [35] can be found where this type of converters is employed not only to integrate renewable energy systems with lighting systems as in [34], but also to obtain multiple outputs and thus have a greater control over the light intensity of the lighting system. As with CUK converters, it is not very common to find this type of converter in standalone systems, but they always depend on the network for their best performance. The main problem of this topology is that is complex and expensive.

E. Half Bridge Transformerless Converter

The Half Bridge Transformerless Converter distributes the workload more evenly, reducing switching losses, improving transient response, and enabling higher power densities compared to conventional boost converters. With its advanced control algorithms and seamless integration of modern semiconductor devices, this converter delivers superior efficiency and power density while maintaining robustness and reliability in diverse operating conditions.

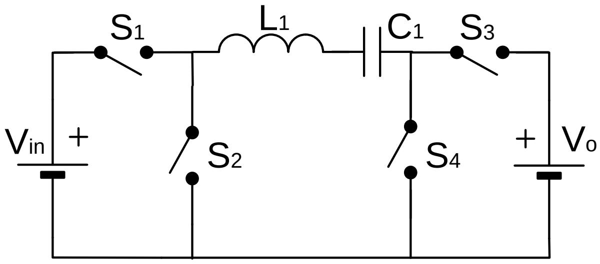

Fig. 8. Half Bridge Transformerless Topology

The main characteristic of this topology is its ease of control and optimization, so it is easy to find cases like in [38] and [39] where different control systems are integrated in lighting systems with connections to solar panels. The most common for this type of system is its connection to a DC bus as shown in [37], depending in this way on the grid for its correct operation.

V. ISOLATED TOPOLOGIES

Isolated topologies represent a crucial class of power electronic converters that play a fundamental role in various industries and applications. These converters provide galvanic isolation between the input and output circuits, ensuring safety, reliability, and versatility in power conversion systems. Galvanic isolation is achieved by utilizing transformers or other isolation techniques to prevent direct electrical contact between the input and output, making isolated topologies indispensable in applications where safety, noise immunity, and system protection are paramount.

Isolated topologies are extensively used in power supplies, inverters, motor drives, and renewable energy systems, among other applications. They offer numerous advantages, including enhanced safety, reduced electromagnetic interference (EMI), and the ability to handle high voltages and currents effectively. By isolating the input and output circuits, these converters enable the transfer of power across different voltage levels while maintaining electrical isolation, thus facilitating the integration of diverse power sources and loads.

TABLE I
SUMMARY TABLE OF NON-ISOLATED TOPOLOGIES

Feature	**Buck-Boost**	**CUK**	**SEPIC**	**ZETA**	**Half Bridge Transformerless**
Complexity	Very Simple	Moderately Simple	Moderated	Moderated	Complex
Cost	Low	Low-Medium	Medium-High	Medium-High	High
Power Range	Wide Range	Medium-High Power	Wide range typically Low-Medium Power	Low-Medium Power	Suitable for high Power
Efficiency	High	Moderated due to switching losses	Moderate-High	Moderate	High due to the reduction of conduction and switching losses
Control Strategy	Simple	Moderately complex	Moderately simple	Moderately simple	Complex
Size	Compact	Large due to the components used	Large because of the use of two inductors	Compact-Medium	Multiple power stages require larger inductors
Possible Applications	**Manage and balance battery power devices, provide consistent current/voltage to lighting systems**	**Use of MPPT in solar panels or industrial power supplies**	**Provide variable input voltage on renewable energy systems**	**Power industrial equipment that requires stable voltage supplies**	**High performance power supplies and manage power from renewable energy source**

A. Flyback Converter

Flyback converters represent a widely used and versatile class of isolated DC-DC converters, playing a pivotal role in numerous power electronic applications across industries.

With their ability to efficiently convert electrical energy while providing galvanic isolation between input and output circuits, flyback converters have found extensive use in diverse applications, ranging from power supplies and LED drivers to battery chargers and renewable energy systems.

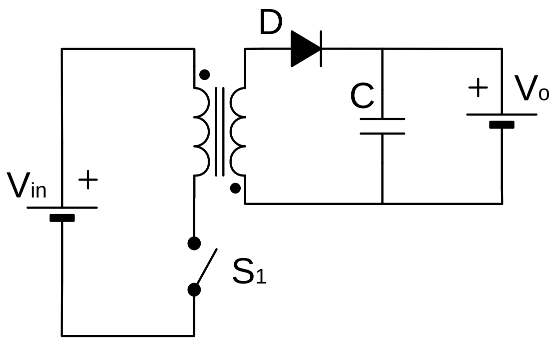

Fig. 9. Flyback Topology

This type of converter can be found in a multitude of applications. For this reason, when used to power a lighting system based on renewable energy sources, cases can be found as in [40], where it is a standalone parallel connection and therefore does not depend on the grid at any time or, on the contrary, as in [41], where the different elements are connected to a DC bus. However, the most common application is to find combinations of flyback converters with other simpler converters such as SEPIC, Buck, or ZETA converters, as reflected in [42], [43] and [44], respectively. This topology is interesting due to its low cost but is limited to low to medium power applications.

B. Half-Bridge Converter

The Half-Bridge Converter stands as a very important converter in power electronics, offering a balance of efficiency, simplicity, and versatility in various applications.

This converter topology plays a crucial role in transforming electrical energy efficiently, making it a fundamental component in numerous power systems, including motor drives, UPS systems, renewable energy converters, and voltage regulators [45] [46].

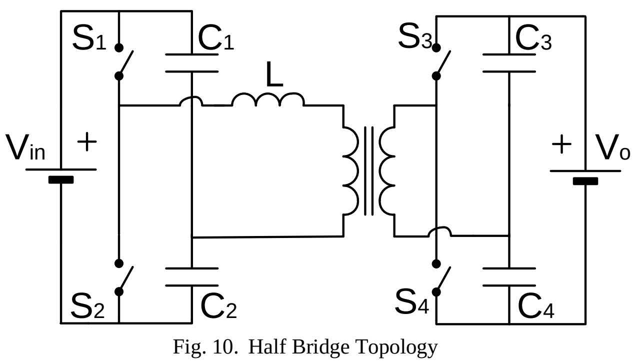

Fig. 10. Half Bridge Topology

When connected to renewable energy sources, the Half-Bridge Converter optimizes power extraction by efficiently stepping up or down the voltage levels as required, ensuring maximum energy harvest under varying environmental conditions. This type of converter is usually employed as a combination of other converters as in [47] or where different control methods can be used. The main drawback of this converter is its complexity and high cost.

C. Full Bridge Converter

The Full Bridge Converter stands as a cornerstone in power electronics, characterize for its versatility, efficiency, and suitability across a wide array of applications.

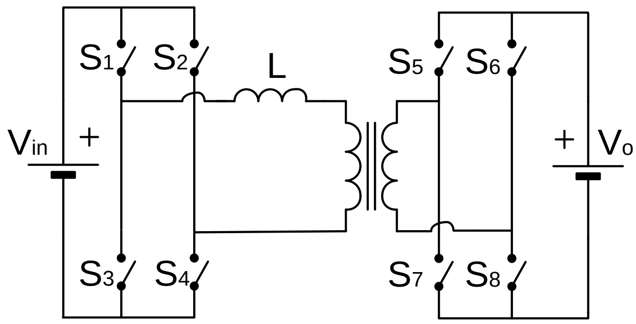

Fig. 11. Full Bridge Topology

The main advantage of this type of converter is its great versatility and the feasibility of being able to be connected in different circumstances. In the cases of [49] and [50], a Dual Active Bridge (DAB) connected to a DC bus is designed. The same principle is used in [48]. On the other hand, parallel connections independent of the network can also be used as in [51]. Finally, different control methods can be used, due to the number of switches that these topologies use. In the case of [52], a Boundary Conduction Mode (BCM) control is used. Again, this topology is not only complex but also more expensive due to the use of many components.

D. Resonant Converter

Resonant converters represent an important type of power electronic converters that offer high efficiency, reduced EMI, and enhanced power density. These converters take advantage of the principles of resonance to achieve highly efficient power conversion, making them instrumental in a wide range of applications, including renewable energy systems, electric vehicles, telecommunications, and data centers.

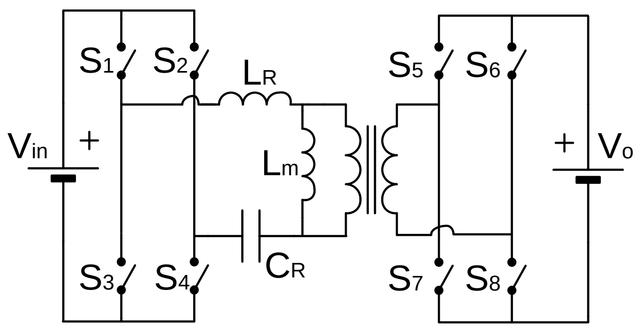

Fig. 12. Resonant Topology

Resonant converters can be of multiple types since there is no single configuration but rather it is common to combine different converters. This is the case of [54], [55] and [56] where this type of converter is integrated with a Boost, or Buck-Boost or SEPIC converter, respectively. The main characteristic of these converters compared to previously seen converters is their good performance at high power.

In cases [53] and [57], this converter is used to connect a solar panel to an LED load through a DC bus. In this case, the output on the LED has multiple channels so the power required is greater. This topology reduces switching losses but have a very complex design and a high cost.

TABLE II
SUMMARY TABLE OF ISOLATED TOPOLOGIES

Feature	Flyback	Half Bridge	Full Bridge	Resonant
Complexity	Simple	Moderated	Moderated	Complex
Cost	Medium	Medium-High	Medium-High	High
Power Range	Low-Medium power	Medium-High power	Medium-High power	High power and frequency
Efficiency	Moderate-High	High	High	High
Control Strategy	Simple	Moderate	Complex	Very Complex
Size	Medium	Compact	Compact	Compact
Possible Applications	**Low power applications and used to power supplies**	**Medium power applications like motor drivers**	**High power applications in industrial fields**	**High efficiency applications and high frequency power supplies**

VI. CONCLUSIONS

In conclusion, an exhaustive study has been carried out on the way in which renewable energies can be used for lighting systems, thus seeking to reduce polluting emissions and improve air quality in cities and towns.

A brief analysis of the different configurations that can be used for the integration of renewable systems and lighting systems has been carried out, highlighting two main ones: the connection to a DC bus and the standalone parallel connections. Finally, a rigorous analysis has been performed analysing different bidirectional topologies used, classifying them between those that are isolated and those that are not.

Among all these topologies, an extensive study of the Half bridge transformerless converter topology is expected to be carried out in the future due to its high potential as an efficient and inexpensive conversion method.

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