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Review article

Review of solid-state linear transformer driver technology

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Abstract

This paper is a review of recent developments in solid-state linear transformer driver (SSLTD) for applications to pulsed power generation. It summarizes the technological advances reported by previous publications and interprets the experimental progresses. The application of solid-state LTDs has been proved to be an attractive approach to make compact and repetitive pulsed power generators that have been sought by a variety of industrial applications and scientific researches. Their advantages and disadvantages compared with their alternatives are reported and analyzed in this paper. Future technical trends of solid-state LTDs are also discussed.

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Keywords: Pulsed power; High voltage; Power electronics; Power semiconductor; Discharge

1. Introduction

Power adding using linear transformer driver (LTD) is a relatively new scheme of pulsed power generation, which is an alternative to the traditional concept of pulse compression. The difference between them is illustrated in Fig. 1. Pulsed power generation based on pulse compression achieves high power of short pulse by reducing the time interval during which a certain amount of energy is released [1–8]. In contrast, an LTD generates pulsed power by adding many low-power short pulses together in order to reach the required output power.

An LTD-based pulsed power system consists of many circuit units, each of which is capable of generating a short pulse. The output pulses of all units are added with each other both current-wise and voltage-wise, leading to power multiplication and impedance conversion. The current adding is usually obtained by direct parallel connection while the voltage adding is typically realized by inductive accumulation. An example of LTD equivalent circuit is shown in Fig. 2. Each circuit unit consists of a capacitor and a switch. A number of such units (n units) are connected in parallel to form a module and a number of such modules (m modules) are added in series inductively to form the system. If a single unit can generate an output voltage of v and an output current of i, the output voltage and the output current of the whole system become mv and ni, respectively. Therefore, compared with that of a single unit, the output power of the system is multiplied by nm and the output impedance is converted with a factor of m/n.

The most noticeable advantages of an LTD scheme, over the traditional pulse compression scheme, are in its stress distribution and modular structure. In a pulse compression system, there must be an output switch which handles the peak power of the whole system. This switch usually determines the maximum output power, the repetition rate, and the lifetime, hence it is often seen as the bottleneck of the pulsed power generator. However, no such component is required by LTD, which indicates a theoretical potential of indefinite power adding of LTD systems. In addition, an LTD-based pulsed power generator consists of many identical modules, allowing

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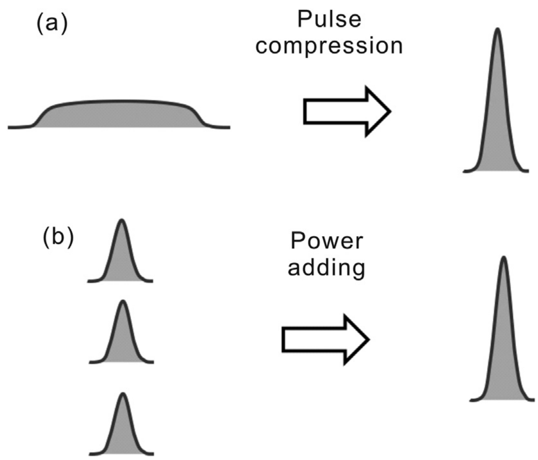

Fig. 1. Alternative pulsed power generation schemes, (a) pulse compression and (b) power adding using LTDs.

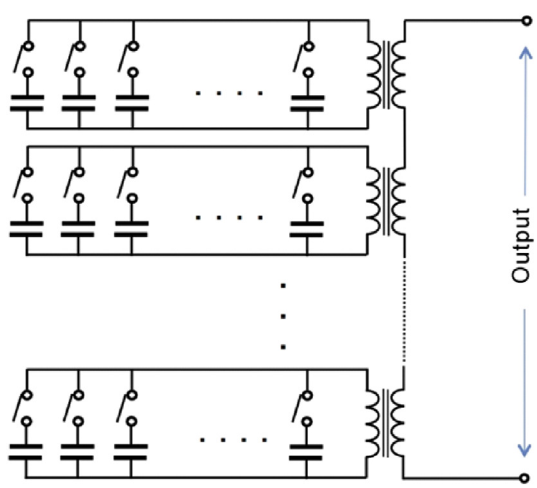

Fig. 2. Equivalent circuit of an LTD-based pulsed power generator.

the possibility of easy maintenance, module recycling, and user reconfiguration.

Large LTDs have been studied for many years for applications to particle accelerators and fusion-related researches [9–12]. These LTDs use spark gaps as switches so that a single module consisting of 40 units can drive a current as high as 1 MA. However, since a gap switch cannot be turned off, the typical output waveform is that of an RCL circuit and, in case of impedance matching, the output voltage is about half of the capacitor charging voltage.

Recently, solid-state LTDs using semiconductor power devices have also been developed [13–15]. They have been developed specifically for industrial applications, with an aim of replacing existing solid-state pulsed power generators based on other schemes. They are characterized by compactness and high repetition rate. In addition, since the semiconductor switches can be turned off, the output waveform to a resistive load can have a certain flatness and the peak output voltage can approach the charging voltage, if the capacitors are large enough. Furthermore, it has been proved that, if the switch timings of different modules are controlled separately, the output waveform can be shaped with a wide range of variation and variety [16,17].

This paper presents a review of recent solid-state LTD (SSLTD) research and development. It provides a relatively comprehensive description for the principle and circuit structure of SSLTD. It summarizes typical experimental efforts aimed at demonstrating SSLTD characteristics. In addition, it also discusses the future development issues and trends.

2. Basic principle and structure of SSLTD

The basic principle of an SSLTD is the same as that of large LTDs, except for the fact that the switches here can be turned off before the storage capacitors are completely discharged. In the SSLTD case, relatively large capacitors are usually used so that the RC circuit behavior dominates the discharge process instead of the RCL behavior in large LTDs. As a result, the output voltage of a module equals approximately the capacitor voltage and voltage droop during the pulse can be relatively small if the capacitance is large enough.

A typical module design is shown in Fig. 3. An LTD module consists of 24 circuit units. Each circuit unit consists of a film capacitor and a power MOSFET. The cross-sectional structure of the module is shown in Fig. 4 and its equivalent circuit is shown in Fig. 5. The essential operation principle is explained as follows.

The capacitors are initially charged up to a certain DC voltage. When the MOSFETs are turned on, the capacitors discharge in the circuit loop through the MOSFETs and the upper case of the module, as shown by the solid arrows in Fig. 5. At the same time, the large inductance of the magnetic core induces a secondary current in another circuit loop through the whole outer case containing the module and the load, as shown by the dashed arrows in Fig. 5. It is important to note that, for an ideal core, the primary and the secondary currents should be nearly identical and the net current through

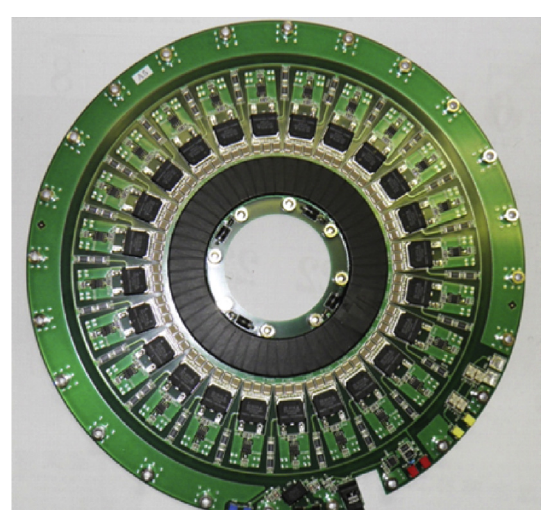

Fig. 3. An example of SSLTD module.

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