

솔리드 스테이트 스위치를 이용한 AC/AC 전압 변환기 설계

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요약

흔한 경우의 종래의 전력 변환기는 AC 전압을 AC 전압으로 변환하기 위해서, AC/DC 변환기를 사용하고 DC/AC 변환기를 사용하여 AC/AC 전압의 변환을 하였다. 근래 AC/AC 전압으로 직접 변환하는 몇몇의 연구가 진행되고 있다. 이 논문에서 종래의 전력 변환기를 대신하여 한 개 또는 두 개의 트랜지스터를 주요 부품으로 사용하여 자동 전압조절이 용이한 지능형 AC/AC 전압변환을 위한 디지털 제어기 시스템을 제시한다. AC 출력전압을 얻기 위해 솔리드 스테이트 스위치를 이용하여 AC/AC 전압 변환기를 설계하였다. 펄스폭 변조기용 AC 전력 스위치를 채택하여 고효율을 달성할 수 있었다. 한 개 또는 두 개의 솔리드 스테이트 스위치를 사용함으로써 고전력용 반도체 소자와 전력 분배 네트워크를 제어하기 위한 기능을 갖게 된다. 이 논문에서 제시한 변환기는 시뮬레이션 결과가 매우 효율적인 출력을 발생하였다.

Design of AC to AC Voltage Converter Using Solid State Switches

Kee-Hong Um*

ABSTRACT

Conventional power transformer adopted AC/DC and DC/AC converters in order to transform an AC voltage signal to another AC voltage signal. Recently, a few studies have been done on the direct conversion of an AC voltage to another AC voltage. In this paper, we present a digital controller system which can be applied to intelligent AC to AC voltage conversion to be used for an automatic voltage control by using only few transistors, replacing conventional electrical power transformers with solid state switches. We have designed an AC to AC voltage converter by adopting solid state switches in order to obtain an AC output power. It was possible to obtain highly efficient AC to AC converter by adopting AC power switches for pulse-width modulator(PWM). By introducing only few solid-state switches, high power solid state devices and networks of power distribution. The P-spice simulation showed the effective output of our converter we designed.

Key Words : Solid state switches, Solid state transformer(SST), Switched-mode power supply(SMPS), Buck converter

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I. Introduction

The number of renewable energy sources is constantly growing. This development results in a rising number of distributed power plants, which are principally subject to substantial energy fluctuations. The voltage sag correction and highly dynamic control of the power flow new power electronic systems are required, to easily connect the new energy sources to the grid and improve the power quality by harmonic filtering [1].

With power electronic devices rapidly developing, it is becoming possible to apply high frequency PWM converters as distribution transformers. A power electronics-based solid state switches provides an attractive alternative to a conventional transformer [2].

Compared to a conventional grid frequency passive transformer, an solid state transformer(SST) has the following advantages: (1) the bulky low frequency transformer is replaced by a compact high frequency transformer, (2) an SST can control active/reactive power flow, and (3) an SST can protect the power system against short-term voltage sag and over-current.

They can change the voltage and other characteristics of the power they produce. They can put out either ac or dc power, or take in ac and dc power from wind turbines and solar panels and change the frequency and voltage to what's needed for the grid.

They have processors and communications hardware built in, allowing them to communicate with utility operators, other smart transformers [3, 4].

A switched-mode power supply (SMPS, or simply

switcher) of the buck converter or the boost converter is an electronic power supply unit that incorporates a switching regulator [5]. It is well known that an SMPS is an electronic power supply that incorporates a switching regulator in order to be highly efficient for the purpose of converting electrical power. Like other types of power supplies, an SMPS transfers power from a source like the electrical power grid to a load (e.g., a personal computer) while converting voltage and current characteristics.

It is also known that An SMPS usually employed to efficiently provide a regulated output voltage, typically at a level different from the input voltage. Similar to other types of power supplies, an SMPS delivers power from a source, like the electrical power grid to a load while converting the characteristics of signals of voltage and current. Usually, an SMPS is used to efficiently provide a regulated output voltage, typically at a level different from the input voltage.

The input and output voltage ratio of SMPS mainly depends on the duty cycle of switches in the circuit. The resulting rectangular waveform is low-pass filtered with an inductor and a capacitor. The capacitors in the circuit reduce the radio frequency (RF) noise. Other advantages include smaller size and lighter weight (from the elimination of low frequency transformers which have a higher weight) and lower heat generation due to higher efficiency [6]. The buck converter (or the boost converter) which has bi-directional switching devices, can be used to make a solid stage transformer.

The input and output voltage ratio of buck converter mainly depends on the duty cycle of

switches in the circuit.

Few studies have been done for the AC/AC direct converter systems by using PWM rectifiers and inverters. Several (more than ten) transistors are used [7]. Just one or two transistors are employed in our design of new systems.

The new solid-state transformers are much more flexible. They use transistors and diodes and other semiconductor-based devices that, unlike the transistors used in computer chips, are engineered to handle high power levels and very fast switching.

II. Structure and Operation

In this section, the structure of the SST system we have proposed is shown. The operation is explained. Transformers are essential device of the power grid, converting the high-voltage electricity delivered through power lines to the 110/220-volt supply needed for consumers. Typically, one transformer distributes power to several homes. Although the SSTs may not look very different on the outside, they shows major advantages, most importantly in what is referred to as power quality, which is profoundly influenced by users of the grid [8].

2.1 Solid State Transformer

SSTs would solve power-quality problems as well as lowering the current delivered to supply devices (such as electric machinery), reducing losses resulting from the transmission of electricity throughout the power grid. Furthermore, SSTs show an environmentally friendly improvement because they do not contain an insulation that can leak and

pollute the environment.

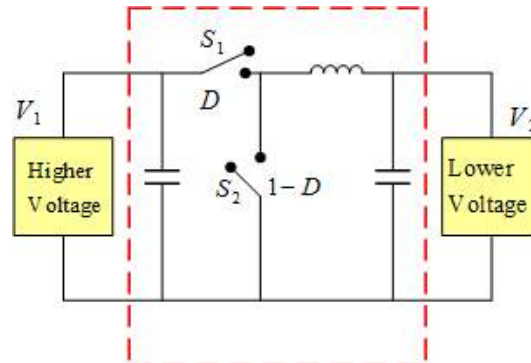


그림 1. 솔리드 스테이트 변압기의 구성도

Fig. 1. Simplified Schematic of Solid State Transformer

An example of simplified structure of a solid state transformer is illustrated in <Fig. 1>. The duty cycle D of the circuit can control the output voltage, where a duty cycle is the time that an entity spends in an active state as a fraction of the total time under consideration [9]. The term is used pertaining to electrical devices, such as switching power supplies. The circuit is a buck converter which converts high input voltage to low output voltage with active switch devices S_1 and S_2 . A buck converter is a step-down dc to dc converter. It is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that adopts two switches (a transistor and a diode), an inductor and a capacitor [10, 11]. For example, we may use this converter for input voltage to low output voltage purposes or vice versa. This makes SMPS work in a similar fashion to the operations of a bi-directional or four quadrant. When higher efficiency, smaller size or lighter weight are important factors to consider, switching regulators are used as alternatives for the linear regulators. They are, however, more complicated, their switching currents can cause electrical noise problems if not carefully suppressed, and simple designs may have a poor power factor. For a device with low power factor (PF), the solid state transformer works better compared to the

dc-linked voltage converter [12]. When the switch S_1 is on in <Fig. 1>, the input voltage is applied to the inductor, and during the rest of one cycle, S_1 is on to make inductor voltage 0 volt. Therefore, the average voltage across the inductor is equal to input voltage times the duty cycle D .

The inductor of <Fig. 1> should be chosen properly considering the input frequency and switching speed of S_1 and S_2 . Thus, the output voltage of the converter is proportional to the input voltage times the duty cycle D , which is not used for dc-operated converters. For example, if $D = 0.5$, the amplitude of output voltage is equal to 50 % of input voltage amplitude. To convert the voltage level from high to low, a buck converter can be used.

2.2 Solid State Switches

The solid state transformer system for the SST in <Fig. 1> is shown in <Fig. 2> and <Fig. 3>. Two of semiconductor switches and inductor is employed to replace the transformer.

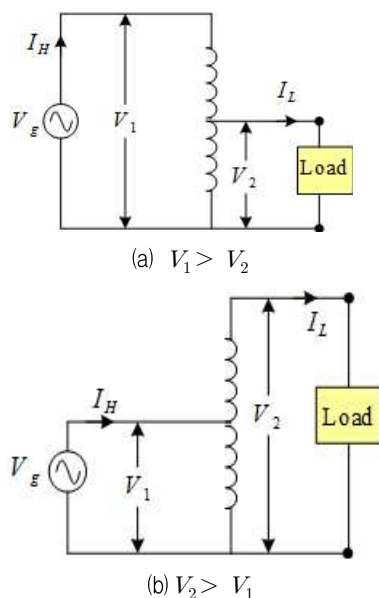


그림 2 단권 변압기
Fig. 2. Autotransformer

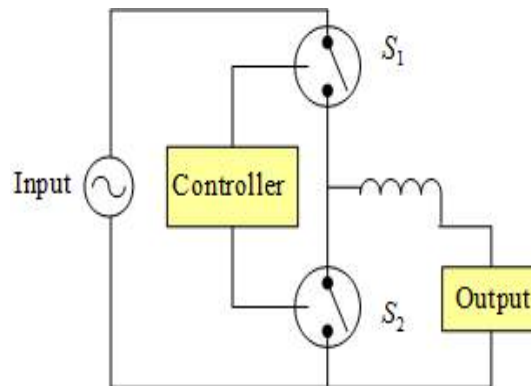


그림 3. 전자식 변압기
Fig. 3. Electronic Autotransformer

2.3 Bi-directional Solid State Switches

The semiconductor switches used in the system are required to have the bidirectional characteristics of voltages and flows of currents. The semiconductor switches that satisfy these characteristics are not commercially available. Therefore, in order to meet these requirements, semiconductor module should be assembled controlling bidirectional flows of currents and polarities of voltages. There might be several ways to design the system, one is to use using semiconductors and diodes. The system in the figure is composed of four diodes functioning to show on-off operations by on-off voltages.

We learned that the system shows an excellent controlling characteristics and stability. An important consideration to design the circuit is how to choose the switching diode to be used in high-speed switching modes. One possible choice is the Schottky Diode. But it is not suitable for the high voltage applications and two diodes should be used only in pairs. With two diode implemented, power consumption may be big.

For example, when the diode current is 10 amperes, and the voltage across the diode is 0.5 volts, the power dissipation is 10 Watts.

In high pressure situations, the Schottky Diode is not recommended. The high-speed switching diode is to be

replaced for the Schottky, but the power loss is higher by 40 %.

A high-speed switching diode can be adopted. The <Fig. 4 >,we used, shows typical bi-directional solid state switches which are connected back to back and can be used for the switches S_1 and S_2 in <Fig. 1>, where two of symmetric semiconductors operating in complementary functions are used. Since the reverse diodes are not included in the MOSFET, we introduced the series diodes in the experiments. Two main transistors are connected to each other with input to input and input referenced output to input referenced output. Those bi-directional switches can control terminal voltage and current by adjusting on-off control signals applied at port C.

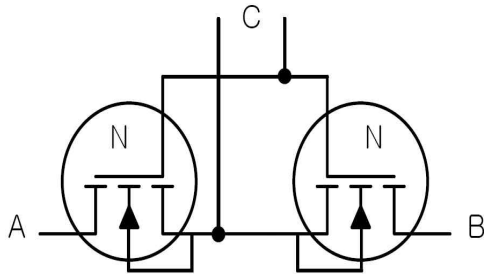


그림 4. 양방향 솔리드스테이트 스위치
Fig. 4. The Bi-directional Solid State Switch

Since the MOSFET in the circuit can operate with a relatively low voltage, it can be used as ideal bi-directional switching device. But most of the individual MOSFET commercially available includes the reverse diode and the P-type MOSFET is not easily available for operating in complementary pattern. We can design various kinds of bi-directional solid switches using metal-oxide semiconductor field-effect transistor(MOSFET), bipolar junction transistor(BJT), diode, or insulated gate bipolar transistor(IGBT) [13].

Each of the unreferenced transistor output is separately connected to an output terminal. A driver signal is

connected across the input connection and one output terminal. This circuit topology is counter-intuitive, but provides advantages which can include eliminating the need for electrical isolation, being capable of turning on or off at any time, at or between zero crossings, having a high speed of response, simplicity, reliability, cost-effectiveness, and energy-efficiency [14]. In <Fig. 4>, two transistors connected in series operate as a bipolar voltage and bi-directional current switch. When the gate voltage is sufficiently higher than the source voltage, the two transistors flow the current in the direction of the drain to the source or vice versa [15, 16].

III. Simulated Results

The proposed converter needs an intelligent digital controller circuit, and can be applied to operate an automatic voltage regulation function, which is better than an ordinary magnetic coupled autotransformer.

In this configuration, the perturbed input voltage is regulated for stable low side output voltage by changing the duty cycle of the circuit.

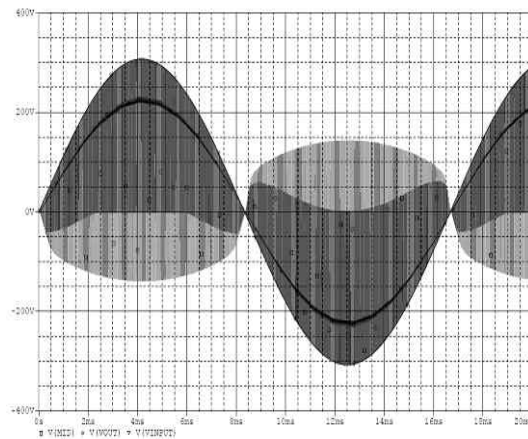


그림 5. 필터 통과 암호화 과정하기전의 V2의 전압 파형

Fig. 5. Voltage Pattern of V2 Before Filtering

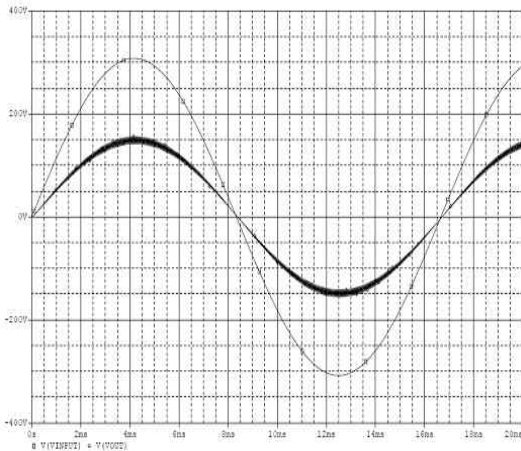


그림 6. P-spice 결과: 필터 통과 한 후의 V2의 전압 파형

Fig. 6. P-spice Simulation Result of V2, After Filtering

Our proposed solid state switches with simulated results illustrated in <Fig. 5> and <Fig. 6> show that it converts the $220 V_{rms}$ input AC voltage to $110 V_{rms}$ output ac voltage as shown. [15, 17].

IV. Conclusion

Up to now, SMPS (switched-mode power supply) has been used only to generate dc power. Switching regulators are used as replacements for the linear regulators when higher efficiency, smaller size or lighter weight are required. We applied various kinds of bi-directional solid switches using MOSFET, BJT, diode, or IGBT in order to transform ac voltage to ac voltage directly. Since the voltage is transformed without using the dc-link, the properties are the same as those of an autotransformer.

Compared to a conventional grid frequency passive transformer, an SST has the following advantages: being compact high frequency transformer, can control active/reactive power flow, and can protect the power system against short-term voltage sag and over-current.

Remarks

This work is the extended and modified version of presentations(including PPT slides) in the previous conferences; the institute of Webcasting, Internet and Telecommunication (IWIT) 2011 and the Korean Institute of Electrical Engineers(KIEE) 2005.

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