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# 교류 전압원의 극성에 따라 구동하는 양방향 반도체 변압기의 설계

# Design of Semiconductor-Operated Bidirectional Transformers Driven by Polarities of Alternating Voltage Sources

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**요 약** 우리는 이 논문에서 교류전압원의 극성에 따라서 쌍방향으로 동작하는 반도체 변압기설계를 제시한다. 변압기는 회로 사이의  유도성 결합에 의하여 에너지를 전달하는 장치이다. 대부분의 변압기는 교류 전압에 의하여 1차 및 2차 코일로 구성된 장치이다. 우리가 제시하는 시스템은 전압신호 레벨을 두 방향으로 즉, 전원에서 부하까지 전압신호가 전달되기도 하고, 부하에서 전압원까지 전달되기도 한다. 전환하는 하나의 회로로 설계되어있다. 구성한 반도체 스위치는 NPN 트랜지스터가 교류 전압원 단자에 연결되어 있고, 에너지 저장 요소로서는 이미터 단자에 연결되어 있는 인덕터를 채택하였다. 제어 신호는 반도체의 베이스 단자에 인가된다.  제시하는 시스템은 전압신호의 진폭을 가역 방향으로 변화시킬 수 있다.

**Abstract** In this paper, we propose a transformer of alternating voltage source utilizing a semiconductor, operating in bidirectional fashion. Transformer is a device transferring energy by inductive coupling between its winding circuits. Conventional transformer is a device, composed of a primary coil and a secondary coil, transforming an alternating voltage. The system we propose is designed with a single circuit transforming the level of voltage signal in two ways; from the source to the load, and vice versa. For semiconductor switches, the NPN transistor is connected to the alternating voltage source terminal, and emitter terminal is connected to the inductor in the system as an energy storage element. The control signal is applied to the base terminal of the semiconductors. We have shown that the system we propose, by adopting only one circuit, drives an alternating voltage transformer that changes the amplitudes of voltage signal in reciprocal way.

**Key Words :** Transformer, Electromotive force (EMF), Semiconductor switches, Gradient of current flow, Time ratio

## Ⅰ. Introduction

A transformer is a static electrical device that transfers energy by inductive coupling between its winding circuits. A varying current in the primary winding creates a varying magnetic flux in the transformer's core and thus a varying magnetic flux through the secondary winding. A transformer is designed by making use of Faraday's law and the

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ferromagnetic properties of an iron core to efficiently raise or lower AC voltages to another value[1]. It of course cannot increase power so that if the voltage is raised, the current is proportionally lowered and vice versa. This varying magnetic flux induces a varying electromotive force (EMF) or voltage in the secondary winding. Transformers can be used to vary the relative voltage of circuits and/or isolate theme[2]. Since the transformer is composed of iron cores and copper wire wounded the cores, it is too big and too heavy to conveniently deal with. Furthermore, in case when the power in the load is zero, the power is dissipated due to the remnant magnetic flux of the iron cores due to the intrinsic physical properties of magnetic materials. These conventional techniques are used in order to transform the alternating voltage to the direct voltage, stores in the capacitor, and then transform into the alternating voltage using transistor operating the short circuit and open circuit with high speed. In this case there is an advantage that the frequency of 60 Hz voltage source can be easily transformed into 50 Hz. However, if the load of reactive powers, such as an electric motors with reactive components or any device with capacitive components, the operating properties of transformers can be deteriorated or cannot be put into operatione[3]. But the application of the semiconductor transformer is limited to a system with an excessive amount of reactive power due to the inductive or capacitive loads. Reactive power flow is needed in an alternating-current transmission system to support the transfer of real power over the network. In alternating current circuits, energy is stored temporarily in inductive and capacitive elements, which can result in the periodic reversal of the direction of energy flow. The ratio between real power and apparent power in a circuit is called the power factor. It's a practical measure of the efficiency of a power distribution system. The power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load, to the apparent power in the circuit systeme[4]. In our work, the proposed system is operating in reciprocal manner so that it is not affected by reactive component of electric power. With a reactive load connected, during the first half of operation, the electric power is delivered from the source to the load, and during the next half of operation, the electric power is delivered from the load to the source. The system we propose can be put into motion with stability. In the paper we presented at the International Symposium on Advanced and Applied Convergence held on November 14-16, 2013 at Seoul, Korea, we showed some basic ideas for the bidirectional transformer. In this paper, we show a more detailed explanation by introducing operating principles of each subsystem.

## II. System Configuration

In Fig.1, our device for transformer of alternating voltage source is shown. Each subsystem is connected by power lines with zero resistances[5].

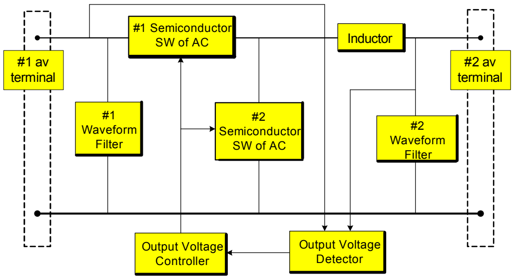



그림 1. 교류 전압원의 극성에 따라 동작하는 변압기의 구성
Fig. 1. Configuration of transformer for alternating voltage source

As shown in the Fig. 1, #1-terminal of alternating voltage source receives the #1-alternating voltage signal, changes voltage level to obtain #2-alternating voltage signal, and transmit to the load. The #2-Terminal of alternating voltage source: receives the #2-alternating voltage signal, changes voltage level to obtain #1-alternating voltage signal, and transmit to the load. The two AC semiconductor switches #1- and 2-

operate mutually exclusively at the time rate corresponding to the control signal. The switch is ON in response to the signal of controller[6]. Depending on the control signal, the #1-alternating voltage source signal provides a path to the corresponding load, through the #2-alternating voltage source terminal. The #1-alternating voltage source semiconductor switches. Depending on the control signal, the #2-alternating voltage source signal, through the #1-alternating voltage source terminal, generates a path to the corresponding source. Output voltage controller produces signals in order to control the time ratio of the #1-and #2-semiconductor switches for alternating currents[7]. Due to the operation, the output voltage controller can manipulate the change of rate of voltage level of #1-AC source signal and #2-AC source signal. Output voltage detector is to determine the level of output voltages of #1-and #2-AC source signal and the output voltage controllers are used in order to control the time ratio of #1- and #2-semiconductor switches of AC.

## III. TRANSFORMER OF ALTERNATING VOLTAGE SOURCE

In Fig. 2, the system we propose for the voltage source is shown. The transformer is driven by #1 alternating voltage source.

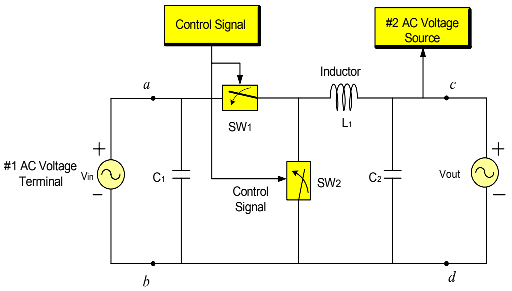
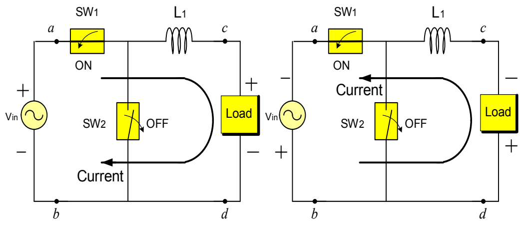



그림 2. #1 교류 전압원의 동작 따라 동작하는 변압기
Fig. 2. Transformer driven by #1 alternating voltage source

The #1-AV (alternating voltage) signal is applied to the terminal of #1-alternating voltage source connected at *a*-*b*. Then the applied voltage level is transformed to the #1-alternating voltage signal transported to output terminal through the #2-alternating voltage signal terminal. Suppose that the #1-alternating voltage signal is flowing into the right direction.

According to the rate of time operation of control signal, the # 1-and # 2-alternating semiconductor switches toggle in mutually exclusive time duration[8]. During the #1-alternating semiconductor switch is ON, the #2-alternating semiconductor switch is OFF. Conversely, during the #1-alternating semiconductor switch is OFF, the #2-alternating semiconductor switch is ON. The #1-alternating semiconductor switch is ON according to the control signal. It provides a signal flow path for the #1-alternating voltage signal to pass on to the load through the #2-alternating voltage terminal. In Fig. 2, #1 alternating voltage signal is applied to the input terminal *a*-*b*. The level of the voltage signal is transformed before the output terminal. The transformer is shown where each of the two switches SW1 and SW2 is ON or OFF in the mutually exclusive way according to the duty ratio determined by the control signal. When SW1 is closed, the SW2 is opened. When SW2 is closed, the SW1 is opened. Depending on the switching operations of the switch SW1, the inductor stores part of input alternating voltage signal. When SW1 is off, the SW2 is on. When SW2 is closed, the SW1 is opened. According to the control signal, SW1 (alternating voltage semiconductor switch) is on, so that the #1-AC voltage signal is transferred to the output terminal through the terminal *c*-*d*, as shown in Fig. 2. Depending on the toggling operations of the switch SW1, the inductor stores part of input alternating voltage signal in order to transfer #1-alternating voltage signal through the terminal *c*-*d* to the load side as shown in Fig.3 [9]. Shown in Fig. 3 (a) the voltage source sends the current in clockwise direction, when the SW1 is closed and the SW2 is opened. Shown in

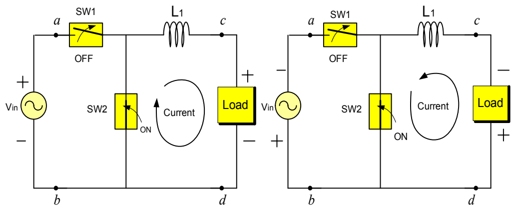
Fig. 3 (b) current flows in counterclockwise direction, when the SW1 is closed and the SW2 is opened, due to the polarity of the voltage source reversed. The current from the voltage generator flows according to the control signal. The switch provides a flow path for the #1-alternating voltage signal stored in the inductor to pass on to the load through the #2-alternating voltage terminal. In Fig. 4, the SW1 is opened, while the SW2 is closed. The current from the stored magnetic energy in the inductor $L_1$ flows clockwise in the right-hand loop according to the control signal .The two switches provides a flow path for the #1-alternating voltage signal stored in the inductor to pass on to the load through the #2-alternating voltage terminal. According to the control signal, SW2 is on, so that the #1-AC voltage signal (stored in the inductor $L_1$) is transferred to the output terminal through the terminal $c$-$d$ , as shown in Fig. 4(a) and (b).




(a) (b)

그림 3. 단락 SW1 ,개방 SW2 의 경우; (a) 시계방향으로 흐르는 전류, (b) 반시계방향으로 흐르는 전류

Fig. 3. Transformer of alternating voltage source, with SW1 is closed and the SW2 is opened; (a) Clockwise current flow, (b) Counterclockwise current flow




(a) (b)

그림 4. 개방 SW1 ,단락 SW2 의 경우; (a) 시계방향으로 흐르는 전류, (b) 반시계방향으로 흐르는 전류

Fig. 4. Systems with SW1 OFF and SW2 ON; (a) Clockwise current flow, (b) Counterclockwise current flow

In Fig. 5, the #2-AC voltage signal is applied to the terminal $c$-$d$. The voltage level is transformed before being applied to the terminal $a$-$b$. The applied signal is produces as the output signal of the $V_{out}$.

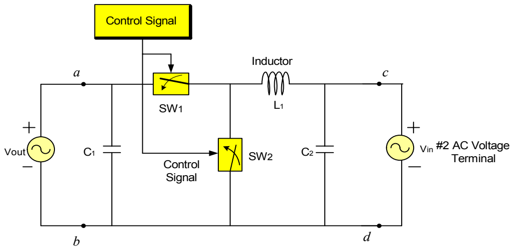



그림 5. #2-AC 전압신호가 인가된 시스템

Fig. 5. System with #2-AC voltage signal applied

In Fig. 6, the two switches are operating in a mutually exclusive fashion in a time ratio, depending on the control signal. When SW1 is ON, the voltage level #2-ac voltage signal produces as the output signal of the as shown in the figure. Fig. 6. Systems with SW1 is ON and SW2 is OFF;

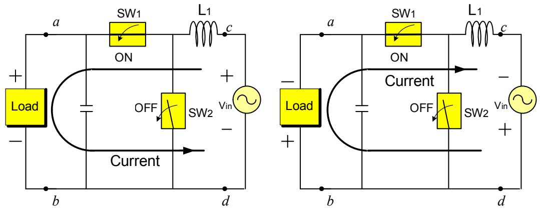



그림 6. 단락 SW1 ,단락 SW2 의 경우; (a) 반시계방향으로 흐르는 전류, (b) 시계방향으로 흐르는 전류

Fig. 6. Systems with SW1 ON and SW2 ON; (a) Counterclockwise current flow, (b) Clockwise current flow

In Fig. 7, when SW2 is ON depending on the control signal, the voltage level #2-ac voltage signal produces as the output signal of the $V_{out}$ as shown.

In Fig.7 (a), both currents flow in counterclockwise direction.

In Fig.7 (b), one current flows in clockwise direction the other flows in counter clockwise direction. The #1-wave form filter smoothes #2-AC source voltage (with a level representing the stored energy), when the

#1-AC semiconductor is OFF as shown. The #1-wave form filter is implemented with a capacitor as shown. It is used to smooth the discrete-time waveform to the continuous wave forms. The #2-wave form filter is also implemented with a capacitor. It is used to smooth the discrete-time waveform to the continuous wave forms. When the capacitor is connected to the inductor, the wave form of output signal is stabilized. In order to realize the semiconductor switches operating with high speed, semiconductor should be implemented so that it can operate to the bidirectional flows of currents.

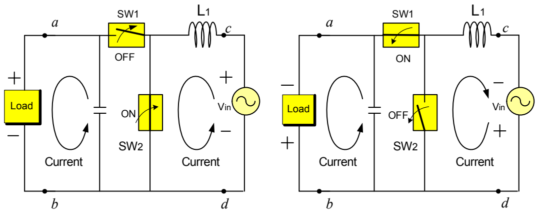



그림 7. SW1 and SW2 가 반대로 동작하는 경우; (a) 개방 SW1 단락 SW2. (b) 단락 SW1 ON 개방 SW2.
Fig. 7. Toggling Operations of SW1 and SW2; (a) SW1 OFF and SW2 ON, (b) SW1 ON and SW2 OFF

Fig. 8 shows that the gradient of current flow is proportional to the voltage across the inductor. As shown in Fig 7, when the SW2 is on, energy is stored in the inductor so that the gradient of the current is increasing. When the #1-AC semiconductor switch is ON, the energy from the inductor is discharging and the current from the inductor is decreasing. When the voltage level of #2-AC voltage source is 110volts, the voltage is stored in the inductor.

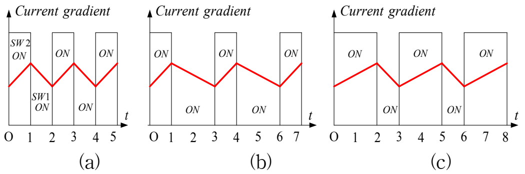



그림 8. 전압 레벨의 경사도 변환; (a) 비율 1:1, (b)비율 2:1,(c) 비율 1:2
Fig. 8. Gradient of voltage level transforming ; (a) Ratio of 1:1, (b) Ratio of 2:1,(c) Ratio of 1:2

As shown in Fig. 8(a), the time ratio of ON by the #2-AC semiconductor switch during a period is a half. Therefore, the gradient of energy dissipation is equal to the gradient of energy storage; the voltage of dissipating energy is also 110 volts. The total voltage from the inductor is 220 volts, which is the sum of 110 volts from the input of #2-AC voltage source and the 110 volts from the stored energy.

Fig. 8(b), the time ratio of ON by the #2-AC semiconductor switch during a period is a third. When the gradient is 2 during the time of energy storage, the gradient of energy dissipation is 1, so that the output voltage is 55volts. Therefore, the total voltage for the inductor is 165volts, because 110 volts due to the #2-AC voltage source and 55 volts due to the stored energy in the inductor.

Fig. 8(c), the time ratio of ON by the #2-AC semiconductor switch during a period is two thirds. When the gradient is 1 during the time of energy storage, the gradient of energy dissipation is 2, so that the output voltage is 220volts. Therefore, the total voltage for the inductor is 330volts, because 110volts due to the #2-AC voltage source and 220volts due to the stored energy in the inductor.

It is possible to transform a lower voltage to a higher voltage by adopting the system we propose. Accordingly, even when the level of output voltage is abruptly changed, the predetermined value of voltage is recovered right after. Suppose two electrical devices (such as an electric light bulb and a cooker) are to be connected to the same system we proposed. When the cooker is operating, the illumination of electric light bulb becomes dimmer, from 110volts to 105volts. By adopting the system we propose, this uneven brightness of light can be protected.

## Ⅳ. Configuration and Simulation results

Fig. 9 shows the configuration and simulation of semiconductor switches of AC [2, 10]. In Fig. 9(a), the collector terminal of NPN transistor is connected to the #1-AV terminal, and emitter terminal is connected to the inductor[11].

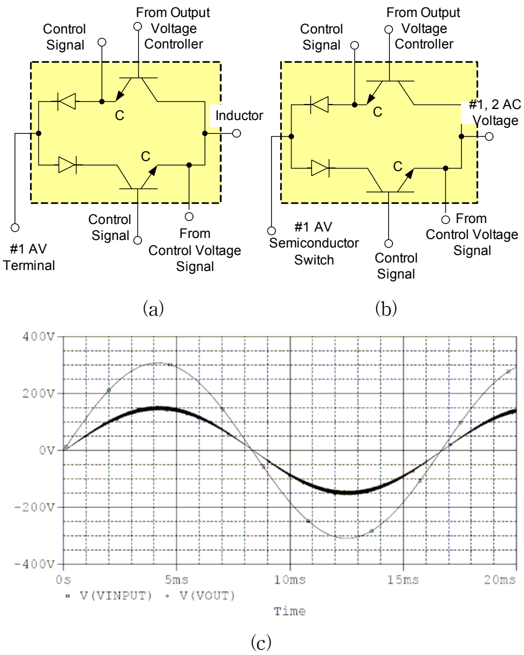



**그림 9. 시스템 구성 및 시뮬레이션;(a) #1-AC 반도체 스위치, (b)#2-AC 반도체 스위치, (c) PSICE 시뮬레이션**
**Fig. 9. Configuration of semiconductor switches; (a) #1-AC semiconductor switch, (b) #2-AC semiconductor switch. (c)PSICE Simulation**

In Fig. 9(b), the collector terminal of NPN transistor is connected to the #1-AV semiconductor switch, and emitter terminal is connected to the #1 and #2-AC voltage terminal. When the control signal is applied to the base terminal, the #1- and #2-AC voltage signals from the inductor are transmitted to the #2-AC voltage terminal. The emitter terminal is connected to the #1-AV semiconductor switch, the collector terminal is connected to the #1-and #2-AC voltage terminal .The control signal is applied to the base terminal. The #1-AC voltage signal (from the #2-AC voltage terminal) and the #2-AC voltage signal (from the #1-AC voltage terminal) is transmitted to the inductor. The diodes are adopted in order to protect two NPN transistors from reverse voltages. The upper diode is connected to the collector terminal of the upper NPN transistor. The lower diode is connected to the emitter terminal of the lower NPN transistor. Fig. 9(c) shows the simulation result from PSPICE.

## Ⅴ. Conclusions

In this paper, by adopting only one circuit, we designed a system of alternating voltage transformer that changes the amplitudes of voltage signal in reciprocal way. Since the reactive power does not exist in the system, it can be adopted and operated in a simple fashion in many electrical products. Furthermore, by integration in a plug socket with a smaller volume, it can be easily implemented. Since a pair of terminals as input and/or output port is used as output and/or input terminals, the whole volume of the system can be remarkably reduced. The proposed system is operating in reciprocal manner so that it is not affected by reactive component of electric power. It was shown that the operation of the system is not affected even when the device with a low power factor is connected externally, because the terminals of input and output are used reciprocally.

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