# A DC-AC Converter Using a Voltage Equational Type Switched-Capacitor Transformer

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***Abstract*** **- A new type DC-AC converter using a voltage equational type SC transformer is presented. A test circuit which converts DC voltage (160 V) to an AC voltage (100 V / 60 Hz) was built. The experimental results of the prototype DC-AC converter show that the efficiency is very high (98 %) and its output power is large (300 W).**

## I. INTRODUCTION

A switched-capacitor (SC) transformer consists of only capacitors and switches. It converts a voltage to other by means of changing the connection of capacitors using switches. Recently, power supplies using SC transformers are applicable to DC-DC [1]~[2], AC-DC [3]~[4], DC-AC [5]~[6], and AC-AC converters [7] . These converters are small size and light weight, since they don't have magnetic parts such as coils and transformers. However, the conventional converters could not realize high power and high efficiency, since the input current flows non-continuously. The maximum power of the conventional converters was less than 100 W and the highest efficiency of these was less than 95 %.

In this paper, a new DC-AC converter using a voltage equational type SC transformer is presented. The features of this circuit are as follows. (1) The output power is large and its efficiency is high, since the input current is continuous. (2) Applied voltage of each charge-transfer capacitor is low. A prototype DC-AC converter is built and tested to confirm the characteristics. The test circuit converts a DC voltage (160 V) to an AC voltage (100 V / 60 Hz) .

## II. CIRCUIT CONFIGURATION AND PRINCIPLE OF OPERATION

### A. Conventional DC-AC Converter

Fig.1 shows the circuit configuration of a conventional converter [6] using an SC transformer (the transformer ratio is 4) and its clock waveforms. In Fig.1, the symbols $\phi_{ik}$, $\phi_{ok}$, $\phi_P$, and $\phi_N$ are ideal switches. The charge-transfer capacitors $C_k$ (k=1~4) are always connected in series. The input-side switches $\phi_{ik}$ (k=1~4) are closed when the 4 phase non-overlapping clocks $\phi_{ik}$ are in a high level, respectively. Each capacitor $C_k$ is charged up to the DC input voltage $V_1$

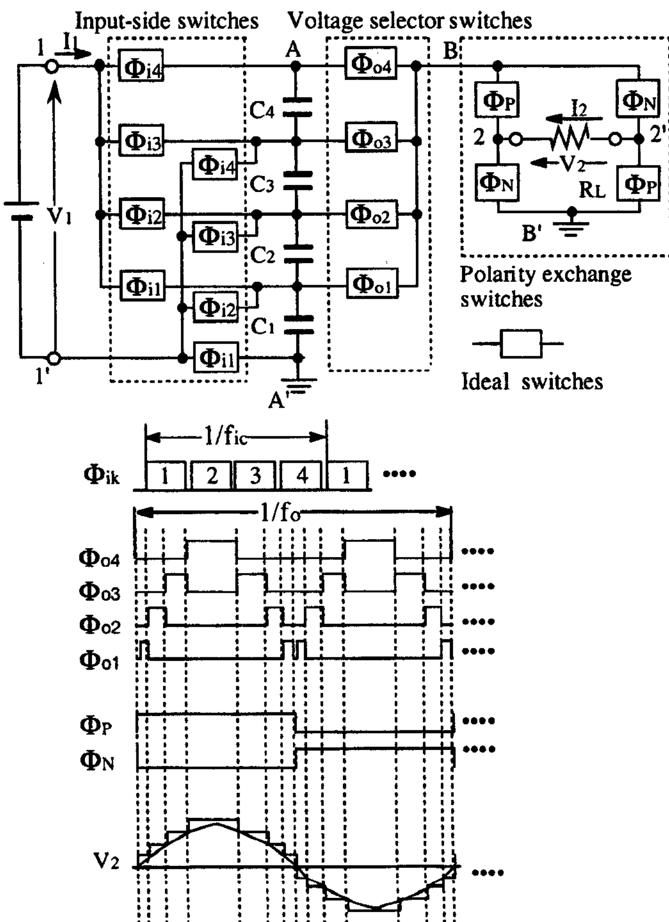


Fig.1 Conventional converter and clock waveforms.

by the input-side switches. The both ends voltage of the capacitors string $C_k$ (k=1~4) is equal to 4 times $V_1$ at no-load.

The voltage selector switches $\phi_{ok}$ (k=1~4), and the polarity exchange switches $\phi_P$, $\phi_N$ are closed when the clocks $\phi_{ok}$, $\phi_P$, and $\phi_N$ are in a high level, respectively. The voltage selector switches $\phi_{ok}$ select the voltages of $C_k$ according to a sinusoidal wave, and the polarity exchange switches $\phi_P$ and $\phi_N$ are toggled every half period of the output voltage $V_2$. Therefore, the output voltage waveform becomes a quasi sinusoidal wave.

### *B. Proposed DC-AC Converter*

Fig.2 shows the circuit configuration of the proposed converter using a voltage equational type SC transformer (the transformer ratio is 1/4 ) and its clock waveforms. The voltage equational switches $\phi_{ek}$ (k=1~4) are closed when the 4 phase non-overlapping clocks $\phi_{ek}$ are in a high level, respectively. Each capacitor $C_k$ is connected to the voltage equational capacitor $C_e$ in parallel by the switches $\phi_{ek}$. Therefore, the voltages of $C_k$ and $C_e$ are equal to 1/4 times $V_1$ at no-load. The clock sequence of the voltage selector switches $\phi_{ok}$ (k=1~4), and the polarity exchange switches $\phi_P$, $\phi_N$ is the same as that of the conventional converter (Fig.1). Therefore, the output voltage waveform becomes a quasi sinusoidal wave.

In Fig.2, the input terminals 1-1' are always connected to the both ends of the capacitors string. Therefore, the instantaneous input current $i_1$ never falls to zero. On the other hand, in the conventional converter (Fig.1), the input current falls to zero during a dead time duration of the input side switches. Since the input current is continuous in the proposed converter, the large output power and high efficiency can be obtained. In addition, the output frequency $f_o$ can be changed arbitrarily, since the voltage selector switches $\phi_{ok}$ need not synchronize with the voltage equational switches $\phi_{ek}$.

### *C. Actual Circuit Configuration*

Fig.3 shows the actual circuit configuration of the proposed converter. The capacitors $C_1$ ~ $C_4$ and $C_e$ are multi-

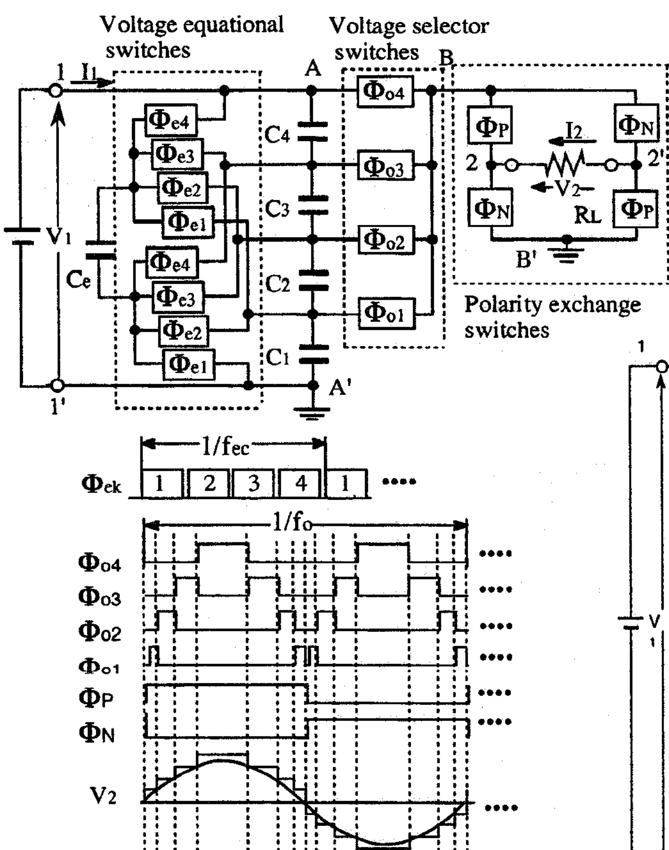


Fig.2 Proposed converter.

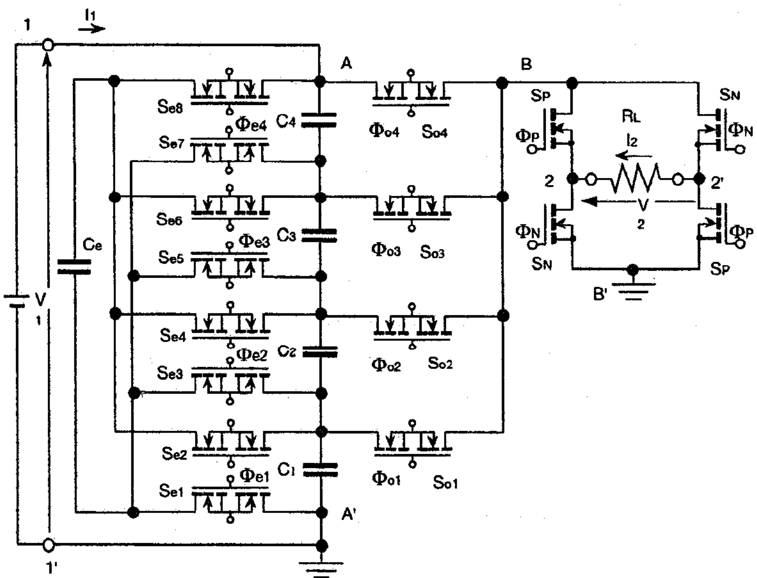

Fig.3 Actual circuit configuration of the proposed converter.

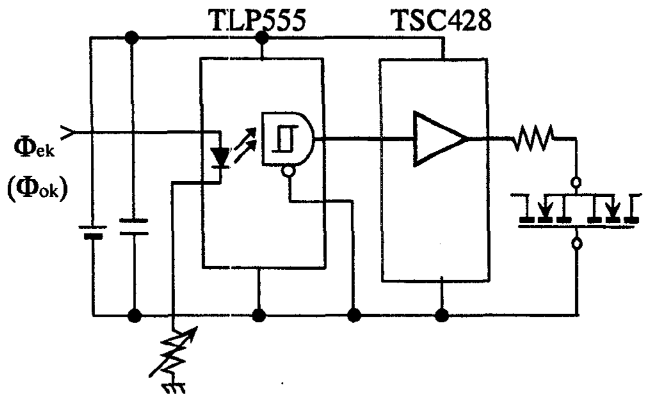


Fig.4 Configuration of a switch and a clock driver.

layer ceramic capacitors whose equivalent series resistance is low. Each switch consists of two n-channel power MOSFET's connected in series so that the MOSFET's cannot conduct by its body diode. The source pin of each switch is not grounded. Therefore, each switch is driven by means of a photo-coupler (TLP555) and a FET driver (TSC428), as shown in Fig.4. All switches used are n-channel power MOSFET's (IRF940) because of their low on-resistance. The value of each capacitor is 60 μF. Then, the total capacitance is small (300 μF). The frequency $f_{ek}$ of the voltage equational clock $\phi_{ek}$ is fixed to 25 kHz and the dead time duration of the voltage equational switches ($S_{e1}$ ~ $S_{e8}$) is set to 2 μs. The frequency of the output voltage $V_2$ is fixed to 60 Hz and the dead time duration of the voltage selector switches ($S_{o1}$ ~ $S_{o4}$) is set to 20 μs.

## III. EXPERIMENTAL RESULTS

Fig.5 shows the measured characteristics: the output voltage $V_2$ (root-mean-square value) and the efficiency η versus the input voltage $V_1$, under the condition that the value of the load resistor $R_L$ is fixed to 100 Ω. The output voltage $V_2$ is proportional to the input voltage $V_1$. The measured efficiency η is decreased slightly in the low input voltage region due to the power loss at no-load.

Fig.6 shows the measured characteristics: the output voltage $V_2$ and the efficiency η versus the output current $I_2$ (root-mean-aquare value), under the condition that the input voltage $V_1$ is fixed to 160 V. When the output current $I_2$ is increased, the voltage ripple of each capacitor $C_k$ increases and the measured efficiency η decreases. When the output current $I_2$ is 2.6 A, the measured maximum output power is 300 W and the maximum efficiencies η is over 96.3 %. As the output current $I_2$ is increased, the output voltage $V_2$ decreases due to the voltage drop of the on-resistances of the switches and the SC resistance [1] of the test circuit. From Fig.6, the value of the output resistance $|\Delta V_2 / \Delta I_2|$ of the test circuit is about 1.2 Ω, which is very small as compare with the conventional one (13 Ω).

Fig.7 shows the measured waveforms in a steady state

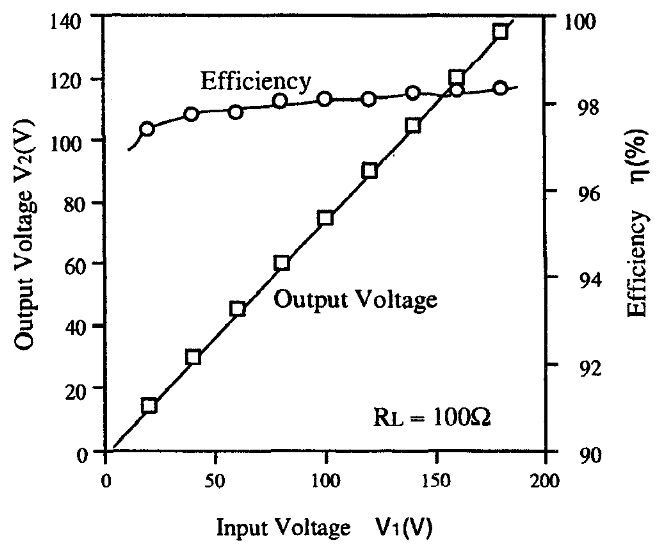


Fig.5 $V_2$ and η vs. $V_1$

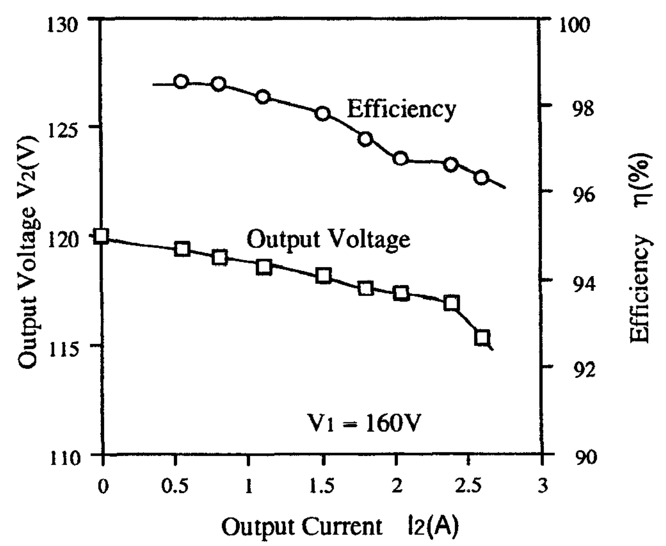


Fig.6 $V_2$ and η vs. $I_2$

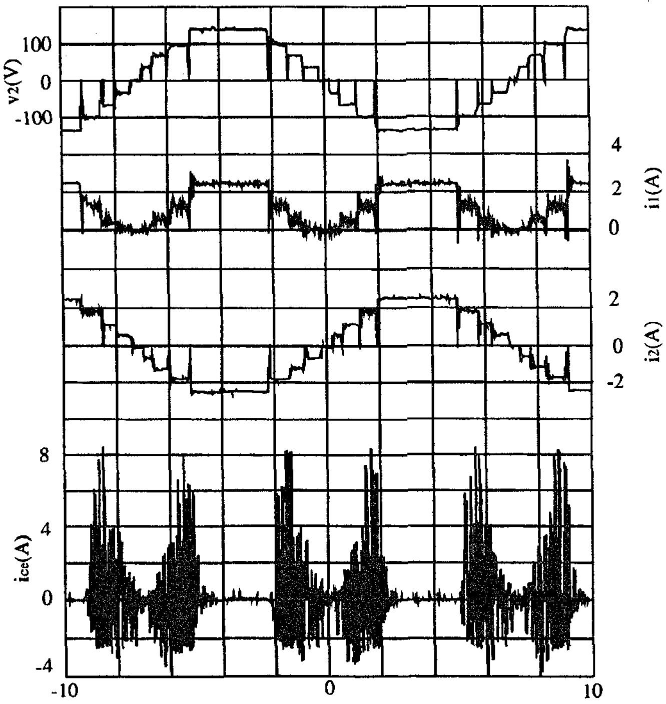

Fig.7 Mesured waveforms.

under the condition that the value of the load resistor $R_L$ and the input voltage $V_I$ are fixed to 50 Ω and 140 V, respectively. The waveform of the output voltage $v_2$ looks like sinusoidal, but the instantaneous output voltage $v_2$ falls to zero when all of the voltage selector switches are off. The peak current of $i_{ce}$ flowed into the voltage equational capacitor $C_e$ is about 8.2 A when the switch $\phi_{o3}$ is on.

## IV. CONCLUSIONS

A new DC-AC converter using a voltage equational type SC transformer is presented. The prototype DC-AC converter is built to confirm the characteristics. The converter provides an AC voltage (100 V / 60Hz) in the condition of a 160 $V_{DC}$ input. The experimental results of the test circuit show that the efficiency of the SC transformer is very high (98 %) and the output power is very large (300W). The features of this circuit are as follows.

(1) The conversion efficiency is high, since the input current is continuous and the power loss by the on-resistances of the switches is small.

(2) Applied voltage of each charge-transfer capacitor is low.

(3) It can be made in small size (thin shape ) and light weight, since magnetic parts such as coils and transformers are not used.

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