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

K. Ishimatsu
Kumamoto Industrial Research Institute
3-11-38 Higashi-machi Kumamoto-shi, 862 Japan

I. Oota , F. Ueno
Kumamoto National College of Technology
Kumamoto-ken, 861-11 Japan

***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 ϕ_{ik}, ϕ_{ok} , ϕ_P , and ϕ_N are ideal switches. The charge-transfer capacitors C_k (k=1~4) are always connected in series. The input-side switches ϕ_{ik} (k=1~4) are closed when the 4 phase non-overlapping clocks ϕ_{ik} are in a high level, respectively. Each capacitor C_k is charged up to the DC input voltage V_1

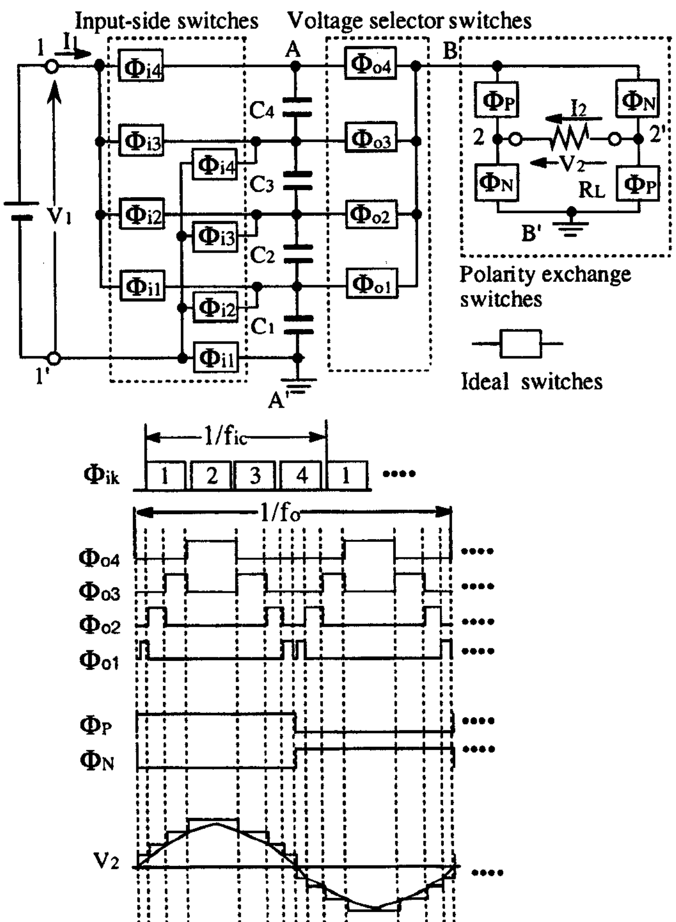

Fig.1 Conventional converter and clock waveforms.

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 ϕ_{ok} (k=1~4), and the polarity exchange switches ϕ_P , ϕ_N are closed when the clocks ϕ_{ok} , ϕ_P, and ϕ_N are in a high level, respectively. The voltage selector switches ϕ_{ok} select the voltages of C_k according to a sinusoidal wave, and the polarity exchange switches ϕ_P and ϕ_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 ϕ_{ek} (k=1~4) are closed when the 4 phase non-overlapping clocks ϕ_{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 ϕ_{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 ϕ_{ok} (k=1~4), and the polarity exchange switches ϕ_P , ϕ_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 ϕ_{ok} need not synchronize with the voltage equational switches ϕ_{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-

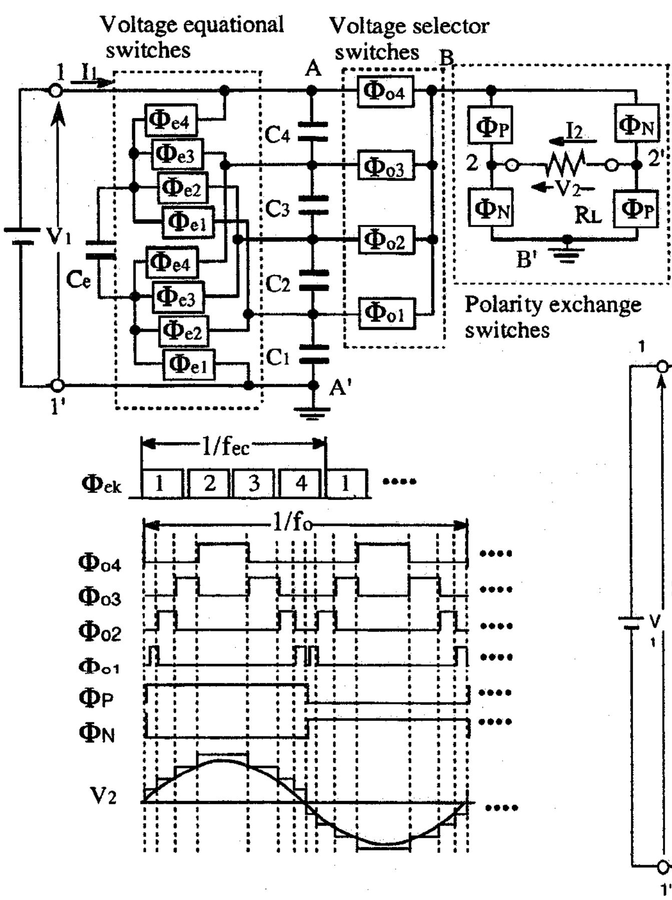

Fig.2 Proposed converter.

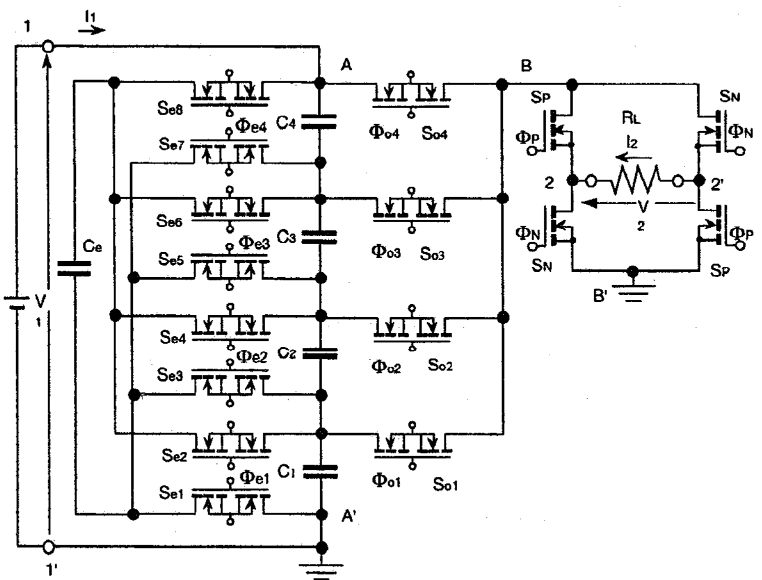

Fig.3 Actual circuit configuration of the proposed converter.

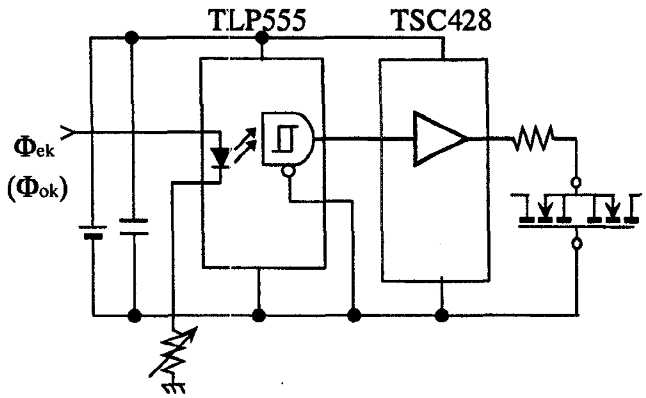

Fig.4 Configuration of a switch and a clock driver.

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 ϕ_{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

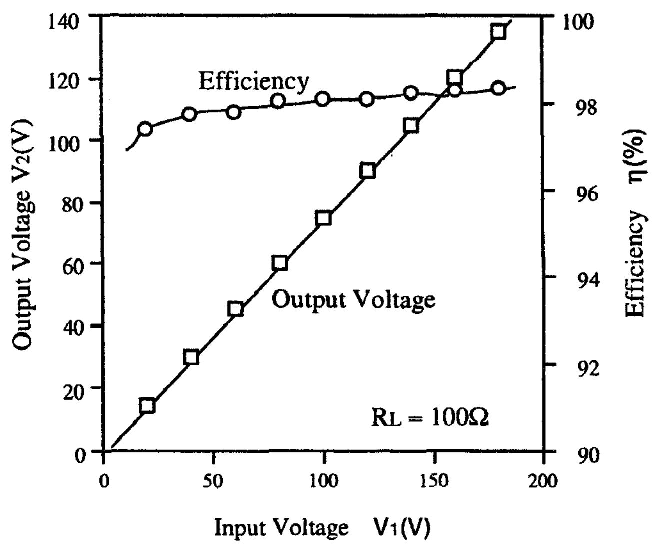

Fig.5 V_2 and η vs. V_1

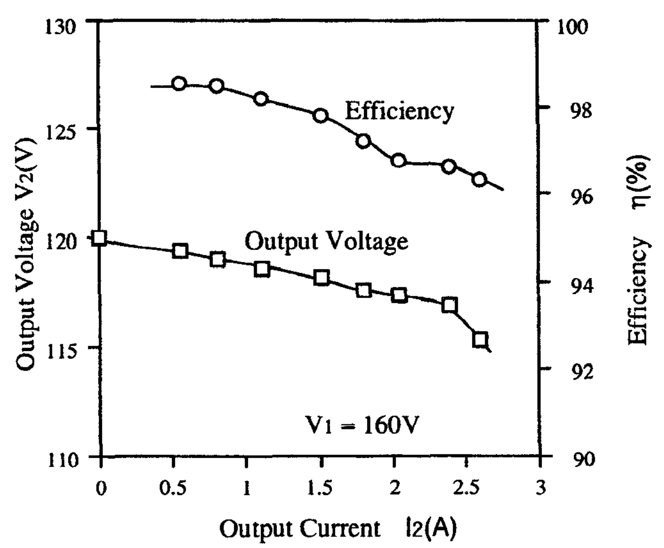

Fig.6 V_2 and η vs. I_2

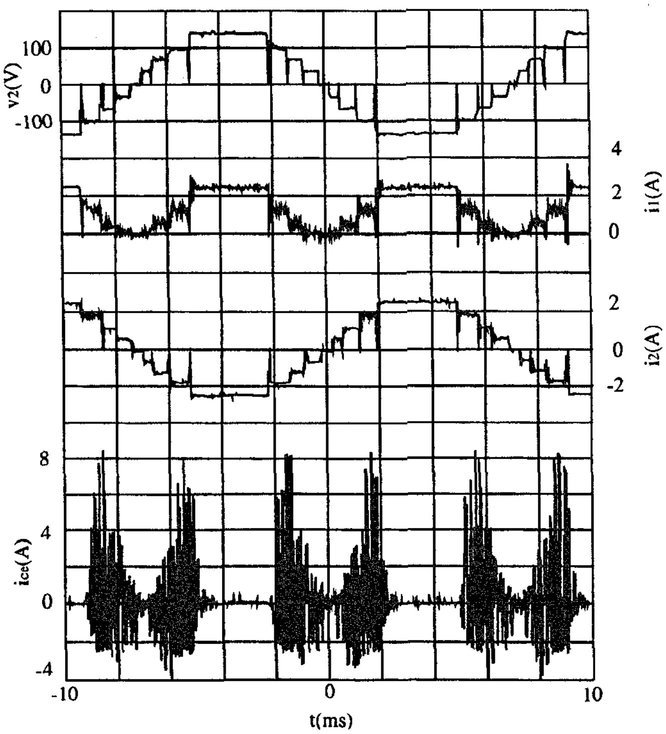

Fig.7 Mesured waveforms.

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 ϕ_{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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