A Phase Converter Using Shading Coil Effect

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Abstract — **In this paper, we propose a new type of phase converter that has a new configuration with a core, shading ring, a single-phase ac winding and two output windings. The induced voltages in the output windings are proportional to the fluxes that link the windings and are similar in principle to those of in a transformer. But the phase angle between the induced voltages is not equal as the flux that links each output winding is not equal due to a shading effect which makes the lag. By setting the proper shading ring, 2-phase and 3-phase output voltages are obtained from the single-phase source. This new type of converter makes the induced voltages with good sine waveform because it does not contain switching elements and is not based on ferro-resonance. Experimental results show the effectiveness of the proposed structure.**

Index Terms — **Phase converter, shading coil effect, single-phase to 2-phase, single-phase to 3-phase.**

I. INTRODUCTION

Conventional phase converters use either magnetic cores and are based on ferro-resonance [1], [2] or use semiconductor devices [3]. In this paper, we propose a new type of phase converter using the core. The conversion mechanism is based on the shading coil effect of a conductive ring. By properly altering the length of the ring, 2-phase and 3-phase output voltages are obtained from the single-phase source. This converter also makes the induced voltages with good sine waveform, because it does not contain the switching elements and does not base on the ferro-resonance.

II. QUALITATIVE EXPLANATION

The construction of the phase converter in this paper is shown in Fig. 1. The exciting winding is excited by a single-phase ac source. The two output windings and the conductive ring are inserted into the air gap, as shown in Fig. 1. To consider the multi-shading coil eff ect, we divide the ring into many small parts such as parts 1 and 2 shown in Fig. 2. We call these parts 1 and 2, rings 1 and 2, respectively. The winding excited by the ac source produces flux $\dot{\Phi}_M$ as shown in Fig. 2. Let $\dot{\Phi}_0$ denote the flux that interlinks with neither ring 1 nor ring 2. If ring 1 does not exist, the flux passing through the point of ring 1 is of the same phase as $\dot{\Phi}_0$. However, if ring 1 exists, then ring 1 interlinks with flux $(\dot{\Phi}_M - \dot{\Phi}_0)$ inducing an ac current. This current produces a flux $\dot{\Phi}_{r1}$ that lags behind flux $\dot{\Phi}_1$ as shown in Fig. 2. In the presence of ring 2, however, it interlinks with flux $\dot{\Phi}_M - (\dot{\Phi}_0 + \dot{\Phi}_1)$ producing flux $\dot{\Phi}_{r2}$. Again, the phase of flux $\dot{\Phi}_2$ as shown in Fig. 2 lags behind that of flux $\dot{\Phi}_1$. This phenomenon is called the shading coil effect. The vector diagram of related quantities is given in Fig. 3.

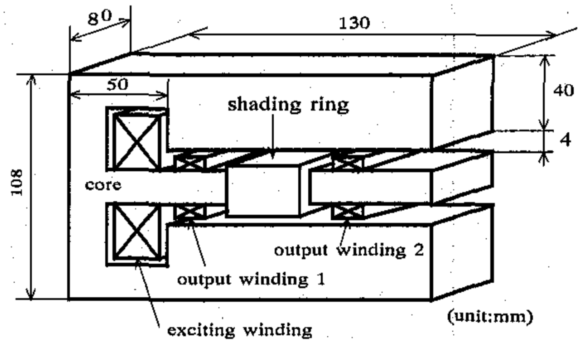

Fig. 1 The proposed phase converter.

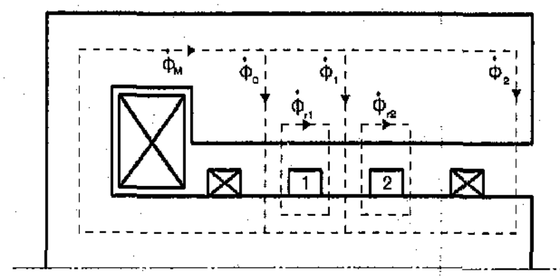

Fig. 2. Magnetic paths equivalent to the converter of Fig. 1.

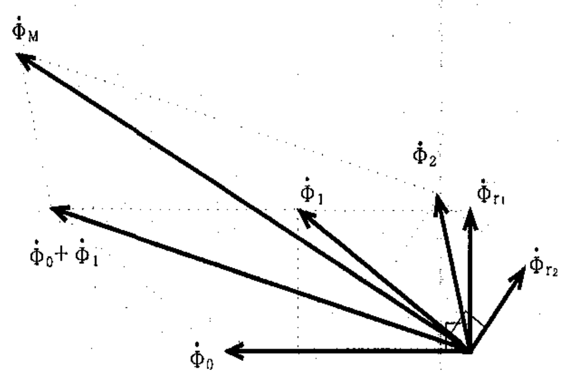

Fig. 3 Vector diagram.

In the above discussion, we have considered only two rings, namely, rings 1 and 2. A similar statement holds even if there exist more rings. In fact, the long ring can be regarded as consisting of multiple short rings. We call the shading coil effect of the long ring the multiple shading coil effect. Due to the multiple shading coil effect, the phase of the flux passing through the winding 2 lags more and more as we make the ring longer.

III. Equivalent Circuits

To simplify analysis, we assume that the air permeability is $\mu_0 = 4\pi \times 10^{-7}$ H/m and the iron core permeability is infinity large.

In practice, the ring consists of a one-turn coil, but we represent it by an equivalent winding consisting of N-turn coil, where N is the number of turns of exciting winding. We also denote the ring coil resistance by R_s.

The equivalent magnetic circuit using this equivalent ring is shown in Fig. 3, where

l_g : air gap length

$\Re_0, \Re_2$: air gap reluctance

r_s : resistance of ring

R_s : resistance of equivalent N-turn ring.

The equivalent magnetic circuit in Fig. 4 can be transformed to the equivalent circuit as shown in Fig. 5, where L_0 and L_2 are inductances and are given by

$$L_0 = \frac{N^2}{\Re_0} \tag{1}$$

$$L_2 = \frac{N^2}{\Re_2}. \tag{2}$$

Referring the equivalent circuit in Fig. 4, we obtain

$$\dot{E}_0 = j\omega L_0 \dot{I}_0 \tag{3}$$

$$\dot{E}_2 = j\omega L_2 \dot{I}_2 = j\omega L_2 \dot{I}_0 \frac{R_s}{R_s + j\omega L_2}. \tag{4}$$

Fluxes $\dot{\Phi}_0$ and $\dot{\Phi}_2$ are given by

$$\dot{\Phi}_0 = \frac{\dot{E}_0}{j\omega N} \tag{5}$$

$$\dot{\Phi}_2 = \frac{\dot{E}_2}{j\omega N}. \tag{6}$$

Equations (3) to (6) give

$$\frac{\dot{\Phi}_2}{\dot{\Phi}_0 + \dot{\Phi}_2} = \frac{\dot{E}_2}{\dot{E}_0 + \dot{E}_2}$$

$$= \frac{L_2 R_s}{\sqrt{R_s^2 (L_0 + L_2)^2 + (\omega L_0 L_2)^2}} \varepsilon^{-j\alpha}. \tag{7}$$

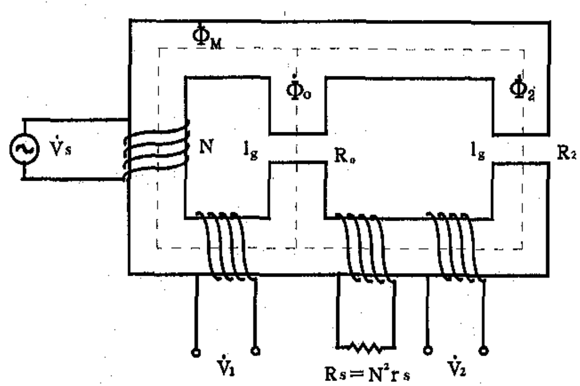

Fig. 4. Equivalent magnetic circuit.

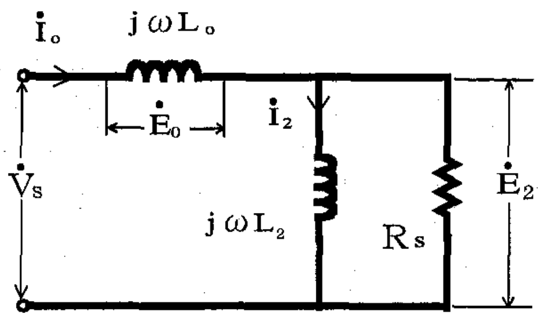

Fig. 5. Equivalent electric circuit.

where

$$\alpha = \tan^{-1} \frac{\omega L_0 L_2}{R_s (L_0 + L_2)} = \tan^{-1} \frac{\omega}{r_s (\Re_0 + \Re_2)}. \tag{8}$$

As shown in Fig. 4, the output voltages $\dot{V}_1$ and $\dot{V}_2$ of the winding 1 and 2 are induced by fluxes $\dot{\Phi}_M (= \dot{\Phi}_0 + \dot{\Phi}_2)$ and $\dot{\Phi}_2$, respectively. Therefore, phase difference β between $\dot{V}_1$ and $\dot{V}_2$ is given by

$$\beta = \alpha = \tan^{-1} \frac{\omega}{r_s (\Re_0 + \Re_2)}. \tag{9}$$

According to (9), the phase difference β is governed by the ring resistance and magnetic reluctance. The reluctances can be assumed to be constant if the position of the ring is fixed and its length is very short in comparison with the air gap depth. In addition, it is independent of the ac exciting winding if the supply voltage and its frequency are fixed. Therefore, increasing the length of the ring results in a smaller r_s and hence a larger β. Needless to say, β is produced by the shading coil effect and the phase $\dot{V}_2$ lags behind that of $\dot{V}_1$.

IV. Experimental Results

Fig. 6 shows the phase difference β between the windings output voltages $\dot{V}_1$ and $\dot{V}_2$ for the ring length l. From this figure, we learn that the phase difference β changes by up to 110°. Due to the multiple shading coil effect as described in section II, the phase gets bigger than 90°. Therefore, it is clear that a 2-phase system is obtained. In addition, a 3-phase system using only 2 windings connected in open-delta can be obtained by using a phase shift of 60°. In this case, the amplitude of $\dot{V}_2$ has to be equal to that of $\dot{V}_1$. Fig. 7 and 8 show the waveforms of the output voltages for the two cases.

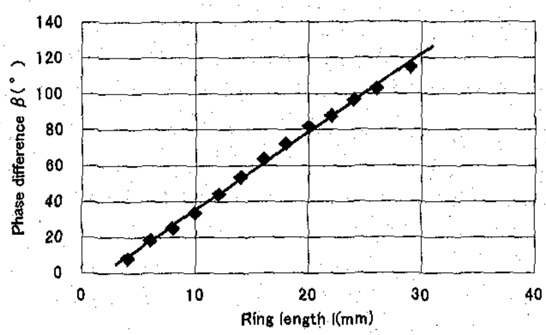

Fig. 6. Ring length versus phase difference.

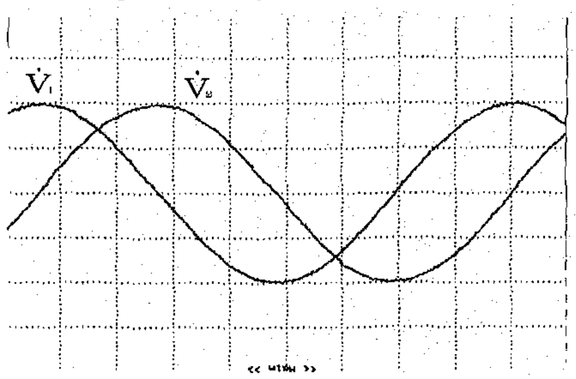

Fig. 7. The waveforms of the experimental output voltages for 2-phase system.

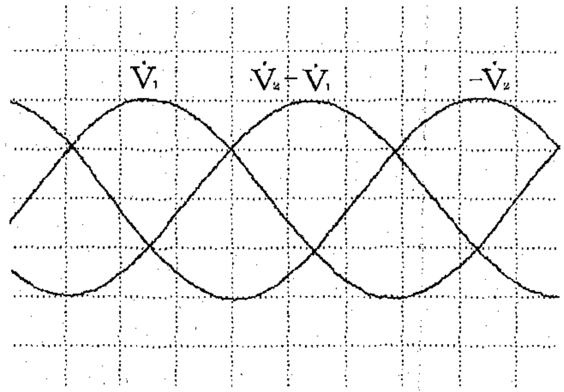

Fig. 8. The waveforms of the experimental output voltages for 3-phase system.

V. Conclusion

In this paper, a new phase converter based on the shading coil effect has been proposed. It was confirmed experimentally that 2-phase and 3-phase sinusoidal voltages were obtained from single-phase source without using filters. A disadvantage of the proposed converter is the low efficiency. Therefore, it is advisable to use this converter as signal generator.

References

[1] M. Tadokoro, "A Mechanism of Single-Phase to Three-Phase Conversion of Three-Phase Ferro-Resonance," *Jour. IEE Japan*, vol.86, pp1305-1314, Aug. 1966

[2] T. Haneyoshi, T. Hirokawa and M. Tadokoro, "Mechanism of Stabilizing Output Voltage of Ferro-resonance Type Phase Converter," *Trans. IEE Japan*, vol.96-B, pp.473-480, Oct. 1976

[3] S. B. Dewan and M. Showleh, "A Novel Static Single-to Three-Phase Converter," *IEEE Trans. on Magnetics*, vol.17, pp3287-3289, Nov. 1981