Three-phase UPS transformer using stand-by inverter of a single cores

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THREE-PHASE UPS TRANSFORMAER USING STAND-BY INVERTER OF A SINGLE PHASE

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Abstract - A new three-phase UPS transformer for an uninterruptible power supply (UPS) is described. Its configuration is a magnetic integration of a three-phase ferroresonant transformer and a single- to three-phase converter. The three-phase commercial source takes over a load on normal condition. The three-phase output is supplied from the single-phase input port with a stand-by inverter in a failure of a commercial source. The structure and the control means become considerably simple in the new method.

INTRODUCTION

The ferroresonant voltage regulator has been widely used because of many advantages such as simple construction, high reliability, low-cost, transient suppression, etc.. A new constant voltage transformer based upon the ferroresonant circuit has been developed for the no-break UPS (uninterruptible power supply).[1-3] As the transformer of this UPS has three ports, i.e. the main input, the stand-by input and the output, it is called as a "Triport". The Triport has been reported as a parallel processing system of high efficiency and high reliability.

In order to treat comparatively small capacity of power, the Triport is used as a single-phase unit. However, when its power capacity is increased, the Triport is used under the three-phase supply. When the three-phase Triport is considered, it should be composed of three single-phase units as the basic component. In the case, the three-phase inverter is necessary as a stand-by unit. The circuit construction and control methods of the three-phase inverter are not always simple in comparison with the single-phase one.

The integrated transformer in the UPS system reported here has two functions : a constant voltage transformer (CVT) of a three phase and a single- to three-phase converter. When a commercial source is available, a three-phase CVT operates producing regulated output voltages. When the commercial source fails, the UPS acts as a single- to three-phase converter and a three-phase output power is delivered from the single-phase inverter through the single-phase port. As use is made of a simple single-phase inverter in this three-phase UPS, the construction and the control method become simple as in the single-phase Triport in comparison with the conventional three-phase Triport.

CONFIGURATION OF THE NEW UPS TRANSFORMER

The schematic structure of the new UPS system with the integrated transformer is shown in Fig.1(a). Figure 1(b) shows the photograph of the tested device.

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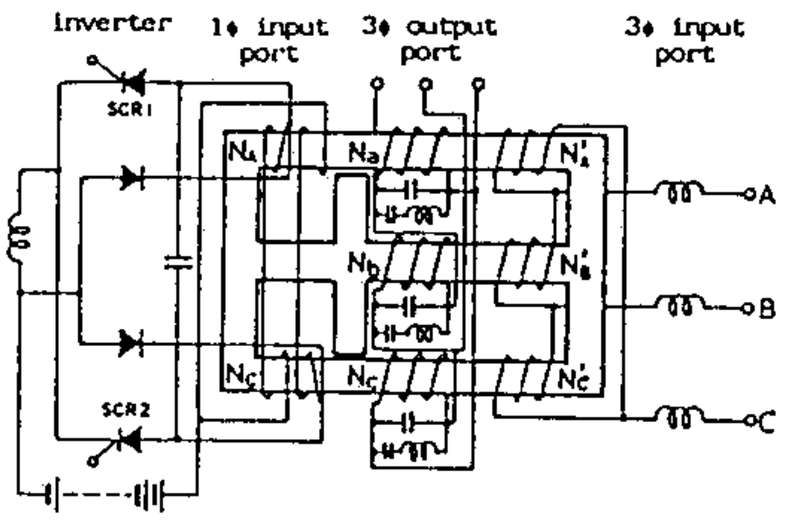
The three input windings N'_A, N'_B and N'_C encircling at each limb form the three-phase input port connected to a three-phase commercial source. The winding N_A and N_C are for the stand-by port of the single-phase input connected to a square-wave inverter. The cross sections of three limbs for output windings N_a, N_b and N_c are made smaller than those of the other flux pathes and operate as saturable reactors. Each reactor and capacitor in parallel becomes a ferroresonant circuit. The L-C series circuit connected to each resonant circuit is a kind of filter, which reduces harmonic components.

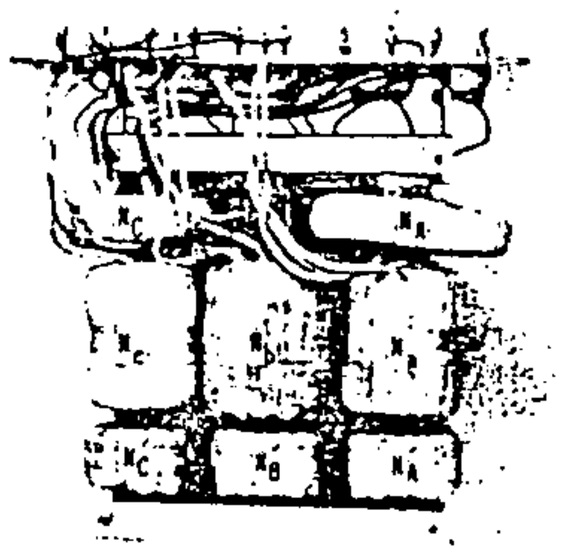
The simplified equivalent circuit of the integrated transformer is shown in Fig.2 for discussing operations. The inverter at the single-phase port is eliminated for simplicity. The symbols X_{LA} and X_{LC} represent inductances of two leakage pathes on the transformer. The parallel ferroresonant circuits at three limbs are indicated by symbols Y_a, Y_b and Y_c. A three-phase CVT and a single- to three-phase converter have common ferroresonant circuits. The three-phase output power can be delivered from either of the two input ports.

STATIC PERFORMANCES

Figure 3 shows the phasor diagram of the equivalent circuit shown in Fig.2. Here we assume that the



(a) Structure



(b) Photograph of the major component. It is 28cm wide, 26cm high, 16cm deep and 32kg in weight.

Fig.1 New UPS transformer

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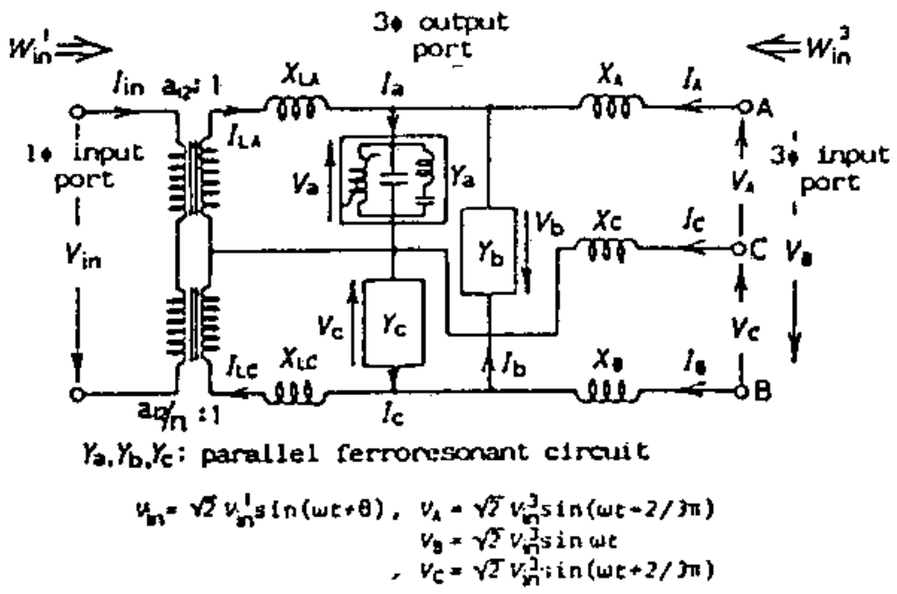

Fig.2 Simplified equivalent circuit

sinusoidal voltage or current is of the same rms value as that of the distorted one and of the same phase angle as that of the fundamental frequency component.

If $I_{in}=0$ in Fig.2, the operation is equivalent to that of a three-phase CVT, which is of the basically same operation as that of the well-known ferroresonant circuit of a single phase. When $I_A=I_B=I_C=0$, the phase converter is the same circuit as that mentioned in ref.[4]. The phase rotation of three-phase output can be fixed independent of variations of the input voltage and loads. It will be an important feature especially when the ac motor is to be driven by this system.

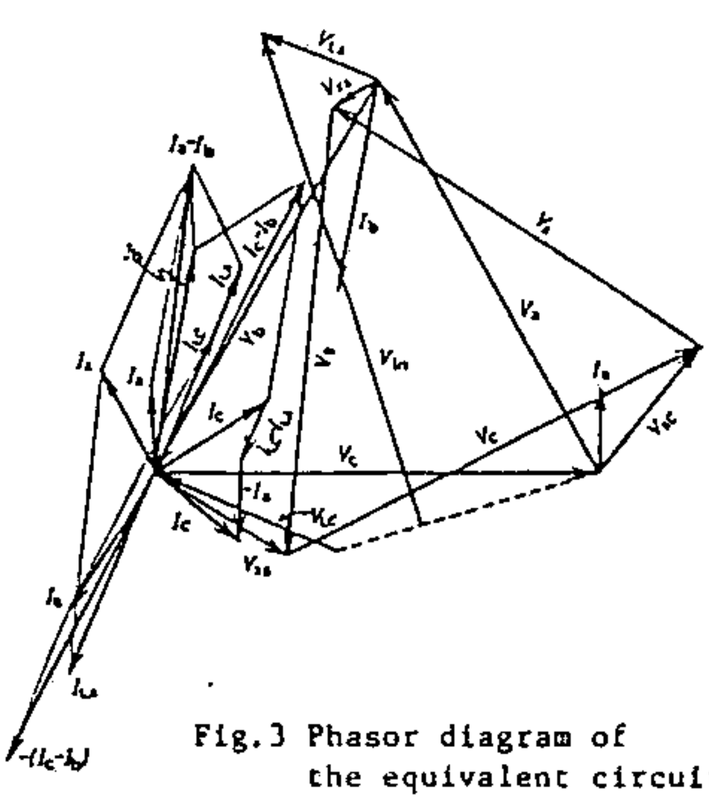

Fig.3 Phasor diagram of the equivalent circuit

For examining the basic operations of the new UPS proposed here, we consider the case that the single-phase voltage $V_{in}=\sqrt{2}\, V_{in}^1 \sin(\omega t+\theta)$ is connected to the single-phase port, instead of the thyristor inverter. This single-phase supply is of the same frequency as that of the voltage connected to the main port of the three-phase input. Although flows of power among two inputs and one output are the function of the magnitude V_{in}^1 and phase angle θ and also of the load condition, θ is the most important parameter, because it can be easily controlled by a simple electronic circuit. And so we select θ as a key parameter.

Figure 4 shows output voltages and power flow under no-load condition taking θ as an independent variable. An input port with a leading phase delivers power to the other. The sum of powers from two input ports in Fig.4 represents the loss in the device. The condition $W_{in}^1=0$ is called "NORMAL" as mentioned in ref.[2].

The normal mode is always realized by adjusting the phase angle θ under various load conditions. Figure 5 shows the load characteristics of normal mode. The phase angle θ should be controlled along the curve shown in Fig.5 for various load conditions so that the single-phase port does not deliver power to the load. If the square-wave inverter is connected to a single-phase input port, the gate signal should be synchronized with the three-phase commercial source and the phase angle of the gate signal can be adjusted by monitoring the power flow.

TRANSIENT PERFORMANCES

Figure 6 shows full blocks of the new UPS system. During normal operation, a three-phase commercial

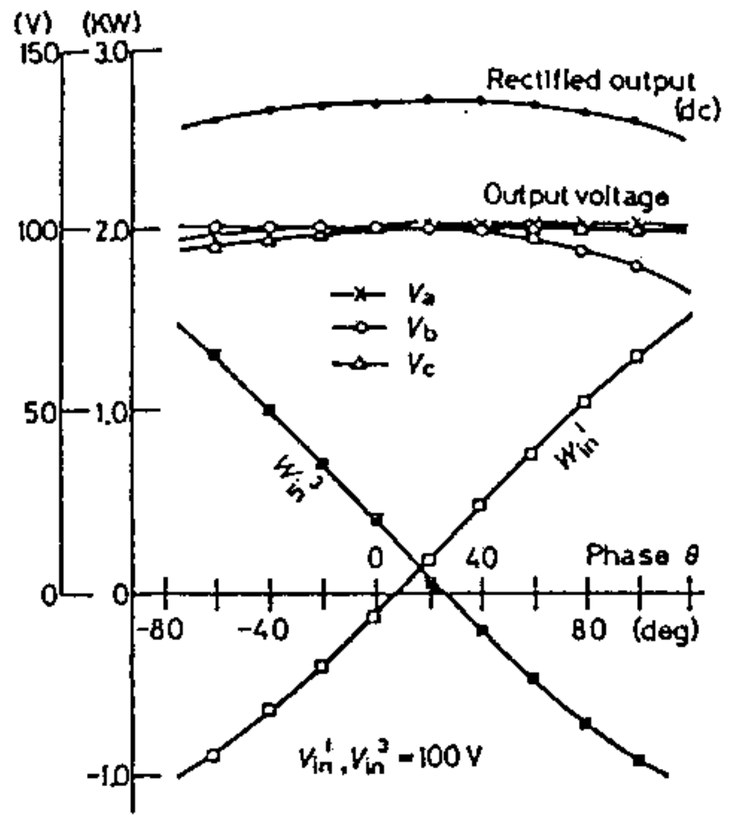

Fig.4 Characteristics of the power flow between two input ports for various values of the phase difference θ. A dc output is that for the three-phase rectifier.

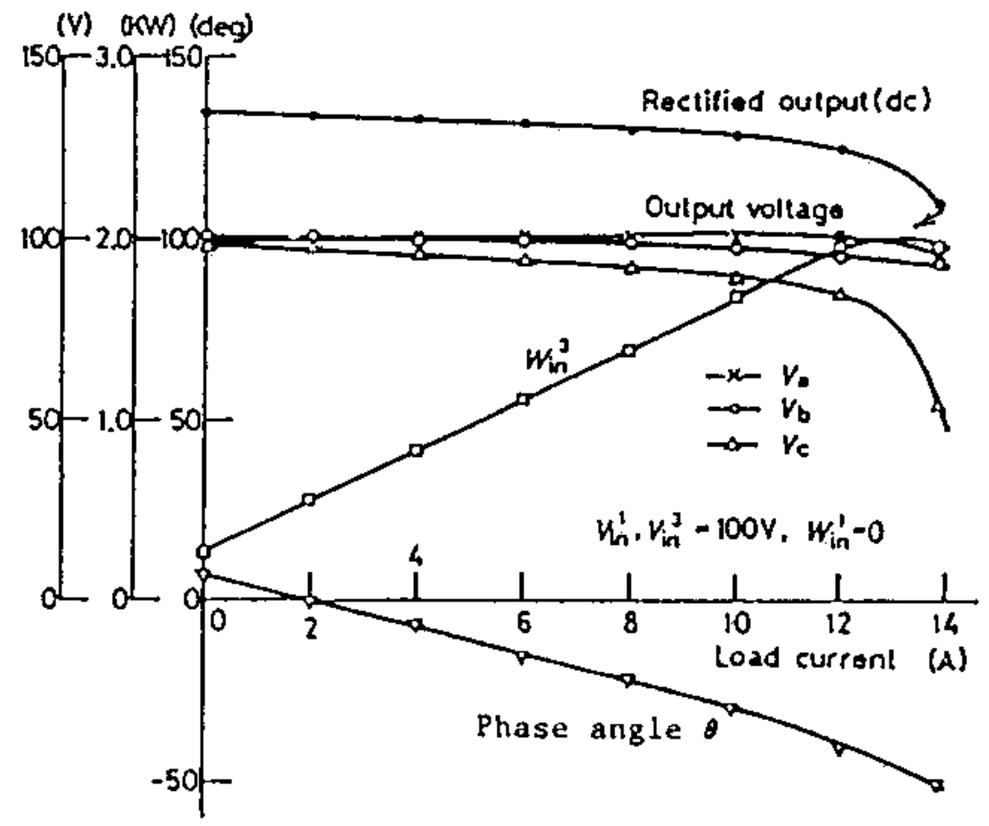

Fig.5 Load characteristics on the condition $W_{in}^1 = 0$. A resistive load is connected to the full-wave rectified output.

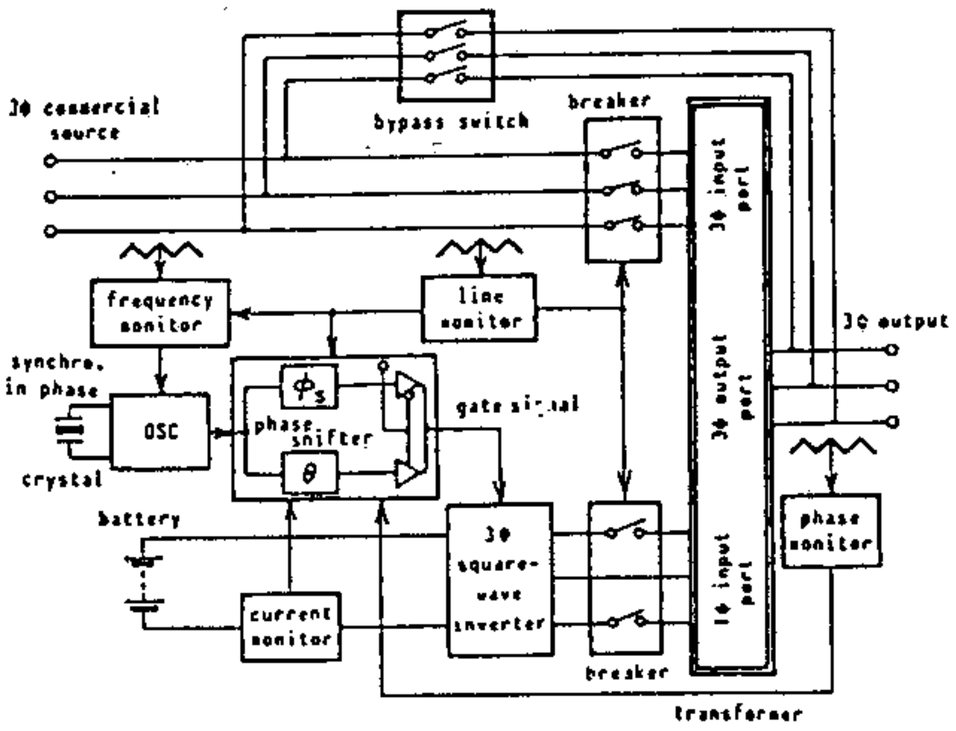

Fig.6 Block diagram of the new UPS system

source delivers power to the load. The inverter is on the stand-by condition $W_{in}^{1}=0$, by adjusting the phase angle of thyristor gate signal. As soon as a commercial source is interrupted, the single-phase inverter takes over the load of a three phase through the phase converter.

The oscillator OSC produces the signal of the frequency near to that of the three-phase line in the case of free running operation. The signal is synchronized with a commercial source on normal mode condition. The phase of the gate signal is adjusted by the phase shifter to prevent the power flow from an inverter.

The gate signal normally lags a commercial source. When the power is to be drawn from the inverter in a failure of the three-phase source, a transient disturbance occurs in the output voltages due to a phase difference between V_{in} and V_B. Figure 7 shows the phase difference of the output to the input voltage when each input port operates independently with the same frequency. As soon as the commercial source fails, the phase angle of the gate signal should be changed from θ to ϕ_s so that the transient disturbance may be removed. The experimental results of transient phenomena are shown in Fig.8. The transient disturbances are hardly observed in these waveforms.

When the failure of the three-phase supply is repaired, the re-synchronization process of the three-phase supply is as follows. At first, the gate signal is synchronized with the three-phase supply. Next the phase of gate signal is in phase with an output. Then the line breaker is closed. At this instant, the energy flow from a three-phase port is essentially zero and the transient disturbance of output voltages hardly occurs. Figure 9 shows waveforms when the breaker is closed again. After this transition is completed, the transfer without disturbance to normal mode condition can be achieved by controlling the phase of an inverter gate signal slowly.

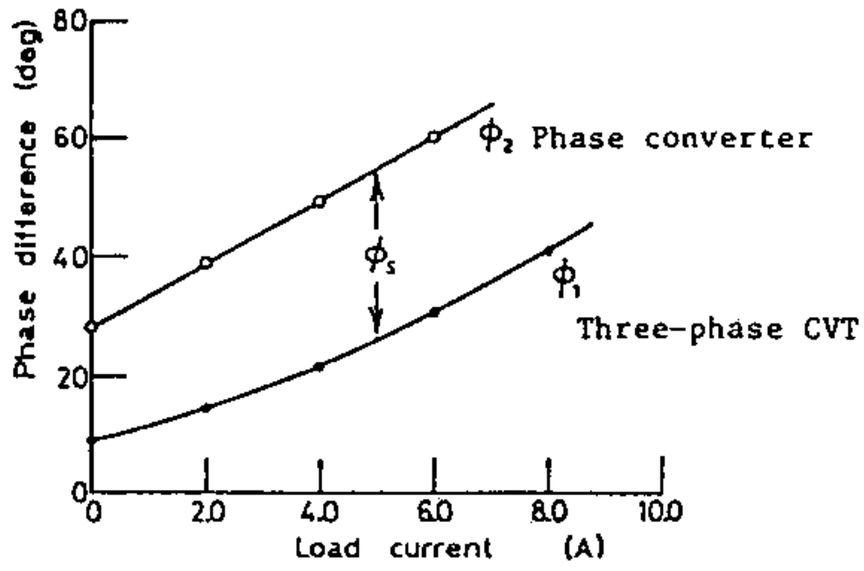

Fig.7 Phase differences between an output and an input voltage on a three-phase CVT and a phase converter. As soon as a ac line fails on UPS, the thyristor gate signal is shifted by the phase ϕ_s.

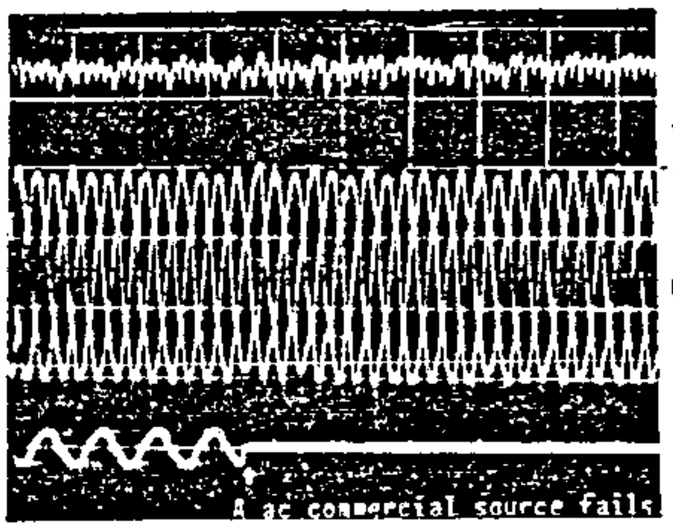

Fig.8 Waveforms as a ac commercial source fails

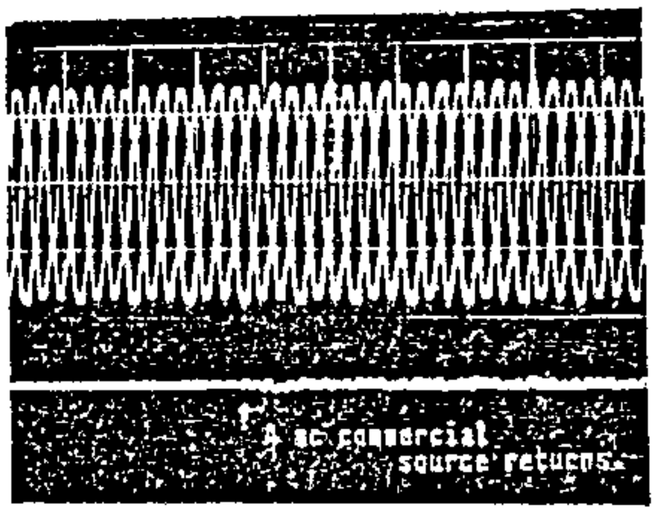

Fig.9 Waveforms as a ac commercial source returns

CONCLUSION

The new three-phase UPS transformer proposed has a simple structure because a single-phase inverter is used as a stand-by unit instead of the three-phase one. The integration of a three-phase CVT and a single- to three-phase converter contributes to the simplification of UPS system.

The transient performances of UPS are discussed experimentally on both cases that the commercial source fails and returns. As a result, transient disturbances of waveforms are hardly observed by controlling properly the phase angle of the inverter.

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