On carrier-frequency gating systems for static switching circuits

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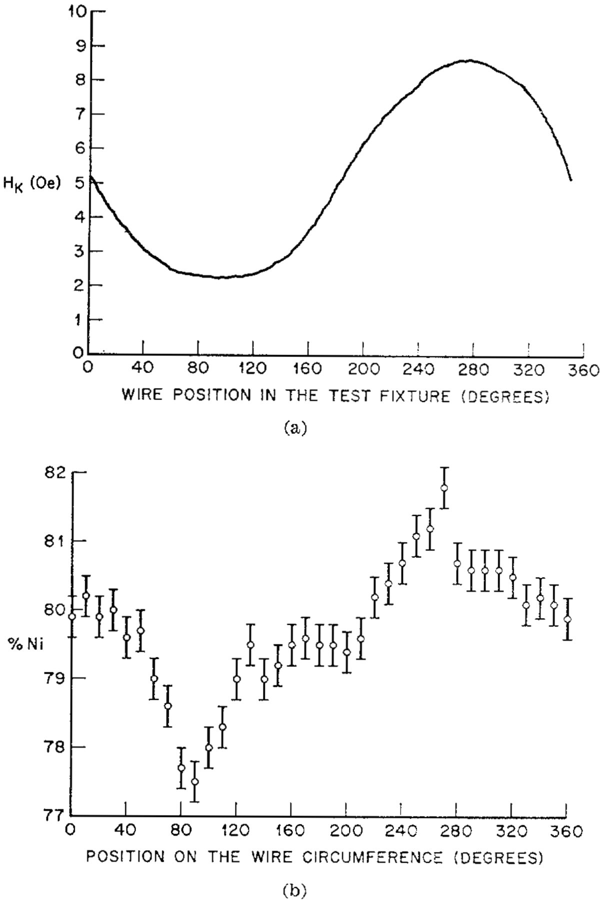

Fig. 3. (a) Anisotropy field as a function of circumferential position in the test fixture. (b) Percentage of Ni as a function of position on the circumference.

The assumed nonuniform composition was vérified by A. E. Baltz, using X-ray fluorescence techniques with an electron beam microprobe. This microprobe analyzes the Ni–Fe composition for a 0.1-by-0.1-mil (2.5 × 2.5 μm) area of the wire surface. Although the average composition around the circumference of the test sample exhibited a low magnetostrictive 80–20 Ni–Fe ratio, deviations of composition of ±2 percent were measured as shown in Fig. 3(b). Circumferential position reference was kept between both experiments which is apparent from Fig. 3(a) and (b). Calculations of the strain in the wire and the resulting change in H_k were made with the assumption of a sinusoidal variation of composition around the wire circumference [3]. Good agreement with the experimental results was obtained.

The plated wire used in these tests was manufactured using a plating process as described in [4]. The conclusion is reached that the total system involved in preparing the substrate and producing the plating must be monitored to provide adequate plating uniformity in the circumferential direction.

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On Carrier-Frequency Gating Systems for Static Switching Circuits

***Abstract*—Carrier-frequency gating systems for exciting static electronic switches such as thyristors are examined. The effect of the commutation in the output rectifiers during transmission of the carrier wave is to cause an instantaneous drop in the output voltage during commutation. A compensation for the commutation drop by an overlap technique is proposed, and comparative experimental observations presented on two types of systems.**

I. INTRODUCTION

One of the most important parts of a power-electronic system operating at a high power and voltage level is the gating circuit of the static switches. This usually employs a high-frequency transformer with magnetic core to obtain the necessary isolation between information electronics and power electronics. Various forms have been described, and are used in practice [1], and in some applications the circuit configuration employed is not critical. The explanation of why a carrier-frequency gating system represents an optimum choice for static converters has previously been treated extensively in this journal [2]. The present contribution is intended to extend the carrier-frequency triggering technique by proposing a system delivering a constant output signal during transmission, without using filters in the output circuit. The most important aspect turns out to be the arrangement of the magnetically cored transformer and output rectifier circuit.

II. SOME PROBLEMS CONCERNING GATING OF STATIC SWITCHES

During gating of these switches careful consideration must be given to the rise time, the duration, and the fall time of the output signal.

1) In high-performance power-electronic circuits triggering pulses with a short rise time are desirable. Neglecting the effect of an output filter, the rise time is limited by the leakage inductance of the isolation transformer. To reduce this effect the transformers may be kept small, which dictates shorter pulse duration, a given order of magnitude for the saturation flux of the possible core materials being assumed.

2) The duration of the triggering signal cannot be chosen at will. Several factors dictate that the triggering signal on the control electrode of the power switch be sustained for an appreciable part of the operation cycle. This may be due to the fact that the power switch is a transistor, to large inductances in thyristor-controlled circuits [1], or to variable power factor operation of thyristor-inverters [3].

3) In some applications the fall time of the output signal after switch-off of transmission of the triggering signal is critical. Again neglecting the effect of a filter in the output, this fall time is determined by the arrangement of windings on the core and the magnetic energy contained in the transformer as a whole. A filter circuit included in the output increases the fall time.

When it is desired to have a triggering signal of extended duration a carrier-frequency solution is optimal [2]. Unfortunately the output signal, after rectification, will not be absolutely constant. This is due to the departure of the input waveform to the transformer from an ideal square wave and the leakage inductance of the transformer.

This drawback is mostly alleviated by adding a small capacitive filter circuit in the output. In some applications this is allowable, although rise and fall time deteriorate (Section II:1 and 2). Nevertheless, this may not be desirable in some circuits employing forced commutation, as the energy stored in this filter tends to apply positive gate drive to the thyristor during part of the period of negative anode to cathode voltage applied by the forced commutation

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circuit to the thyristor. This increases the requirements for the commutation circuit and the dissipation in the thyristor [1].

The voltage drop caused in the output during commutation by leakage inductance is fundamental. Improvement of the input waveform to the transformer, by cascaded stages of amplification and reduction of the leakage reactance, both have a definite limit. In addition this approach requires small tolerances in components and manufacture. It is now proposed to investigate whether elimination of the voltage drop cannot be achieved by an overlap technique. This will eliminate all the above drawbacks, and add but little to the system complexity.

III. THE PROPOSED TRIGGERING SYSTEM

In Fig. 1(a) a schematic representation is given of the output circuit of a conventional carrier-frequency triggering system (system I) without an output filter. Schematic representation of the output circuit of the proposed overlap-unit is given in Fig. 1(b) (system II). The difference in the input voltages, as indicated in the diagram, will be that for system I they are symmetrical, whereas for system II the two input voltages are asymmetrical and overlap by a time Δt. Therefore, in the idealized case

$$v_1 \begin{cases} 0, & 0 < t < T/2 \\ -E_b, & T/2 < t < T \end{cases} \tag{1}$$

$$v_{10} \begin{cases} 0, & 0 < t < T/2 - \Delta t \\ -E_b, & T/2 - \Delta t < t < T \end{cases}$$

$$v_{20} \begin{cases} -E_b, & -\Delta t < t < T/2 \\ 0, & T/2 < t < T - \Delta t. \end{cases} \tag{2}$$

It is to be noted that for system I a single output transformer is needed, and in the proposed system II two are needed. Assume now that transmission of a triggering signal is taking place. The commutation transient is of duration t_1, and it is stated that

$$t_1 \ll T. \tag{3}$$

Assume the rectifiers and switching transistors to be ideal, and the transformers to operate in a nonsaturated region.

System I

Let D_1 and D_4 conduct. At $t = 0$, when the input voltage changes sign, a transient in the output is initiated. Reverse-bias on D_2 and D_3 is exerted by i_R, and they only come into conduction at

$$i_1 = i_R = 0.$$

This then predicts that the output voltage will reduce to zero during the commutation transient.

It is not expected that this simplified view will take into account all stray winding capacitance effects, leakage inductance effects, dynamic semiconductor effects, or input waveform effects. However, practical experience indicates that in these types of systems the output voltage during commutation indeed becomes zero or even negative (see Section IV).

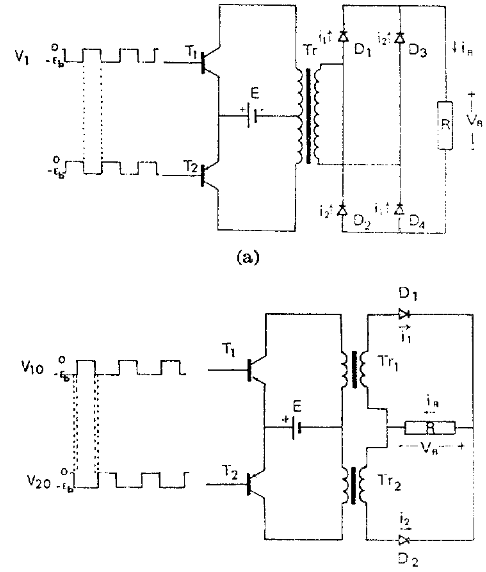
System II

At $t < -\Delta t$, let D_1 conduct, and when E_s is the steady-state secondary open circuit voltage of Tr_1 and Tr_2

$$i_1 = i_R \simeq E_s/R_\Sigma \tag{4}$$

when taking (3) into account, with $R_\Sigma = R + R_t$, and R_t representing the equivalent secondary winding resistance of Tr_1 or Tr_2. At $t = -\Delta t$, the voltage on Tr_2 is switched on, and D_2 will tend to conduct. Current i_1 commutates from an initial value given by (4) to

$$i_1 \simeq E_s/R_\Sigma' \tag{5}$$



(a)

(b)

Fig. 1. Schematic representation of the different output circuits of the carrier-frequency systems.

and i_2 will commutate from an initial value of zero to

$$i_2 \simeq E_s/R_\Sigma' \tag{6}$$

with $R_\Sigma' = (2R + R_t)$. Equations (4), (5), and (6) indicate that the output current commutates to

$$i_R \simeq E/0.5R_\Sigma'. \tag{7}$$

As $0.5R_\Sigma' < R_\Sigma$, the output current actually rises in the period $-\Delta t < t < 0$. At the end of the overlapping time, i.e., at $t = 0$, a new transient is initiated, i_1 commutates to zero, and i_2 to

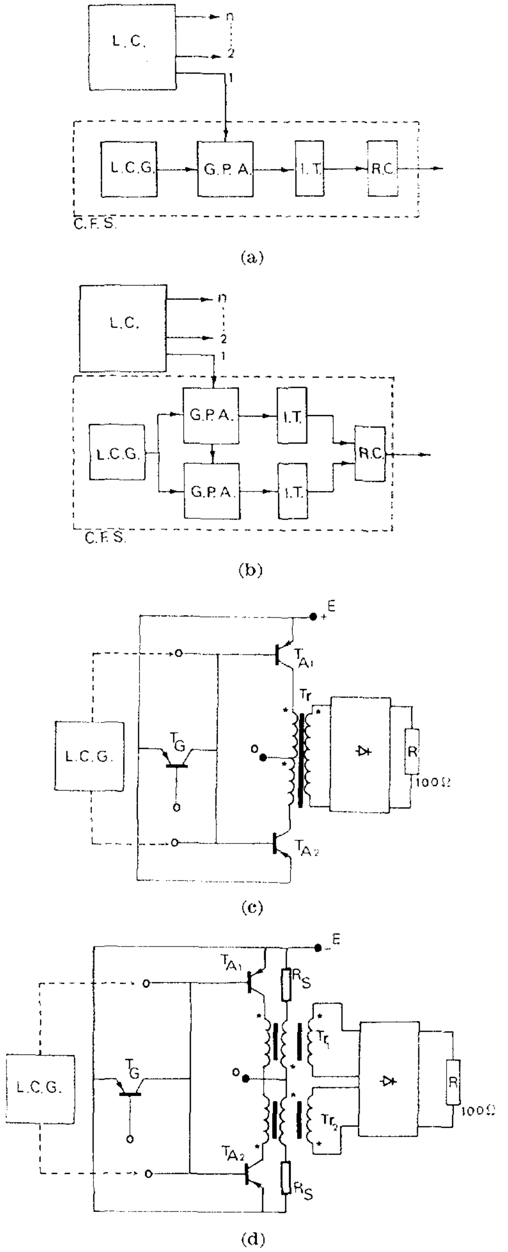
$$i_2 = i_R \simeq E/R_\Sigma$$

so that the output current tends to a somewhat lower value again. Practical observations also indicate this effect (see Section IV).

IV. EXPERIMENTAL VERIFICATION

Experimental verification of these characteristics was found in the practical gating systems employed in our laboratory. In contrast to previous solutions described in the literature [2], these systems have local carrier wave generation. Adaptability is higher with each unit having its own carrier supply, since units may be removed or added to a system at will, without the possibility of affecting each other through loading of a central carrier-frequency supply. Extensive circuit detail of the electronic system will not be presented.

Arrangement of a system to Fig. 1(a) is shown in Fig. 2(a), the power amplifier being gated at its input by the logic circuitry. In the schematic layout of the gated power amplifier in Fig. 2(c), T_G represents the gating circuit. The waveform of the local carrier-frequency generator is symmetrical as already specified in (1), having a rise time of the order of a microsecond. The composition of an overlap-system is given in Fig. 2(b), while the schematic arrangement of the output is given in Fig. 2(d), the carrier wave being asymmetric. As the output transistors in Fig. 2(c) are in a balanced arrangement, conditions for resetting the core of Tr are fulfilled. To obtain the same utilization of the material in Tr_1 and Tr_2, it is advisable to add the resetting winding shown in Fig. 2(d). In the balanced arrangement, all other parameters being equal, the switch-off time at the end of a transmission period will be longer, since with T_{A1} and T_{A2} nonconducting due to gating, the magnetic energy will decay through the load. In the overlap system the third winding enables the magnetic energy to be fed back against the constant supply voltage via R_s. This results in fast switch-off, an important added advantage of this system, and not possible when using only one transformer core as in conventional carrier-frequency systems.



(a)

(b)

(c)

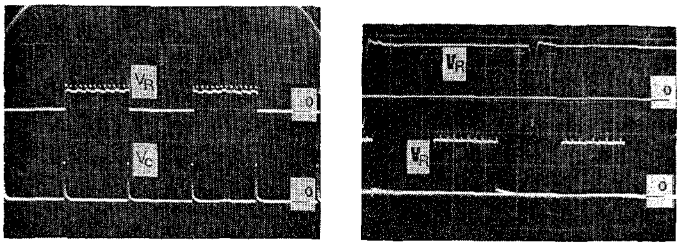
(d)

L.C.	logic circuitry
L.C.G.	local carrier-frequency generator
G.P.A.	gated power amplifier
I.T.	isolation transformer
R.C.	rectifier circuit
C.F.S.	carrier-frequency triggering system.

Fig. 2. (a) and (b) Block diagram of built-up systems. (c) and (d) Schematic layout of output circuits.

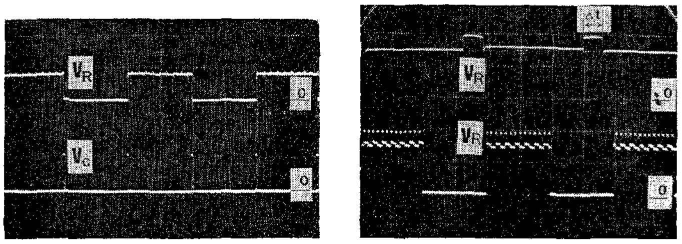
In Figs. 3 and 4 the output voltage V_R across a 100-ohm carbon-film resistor is displayed for both systems. The command pulses V_c indicate the start and termination of a transmission period (approximately 500 Hz) as prescribed by the logic circuitry. Fig. 3(a) and (b) indicates clearly that the rectifier output becomes zero and even negative during the commutation in the conventional system.

Fig. 4(a) and (b) indicates clearly that the output voltage of the overlap-unit never becomes negative or zero during a transmission period. Due to the resistance of the transformer as described, one may even mention an overcompensation during commutation. It may also be observed that the two output transformers Tr_1 and Tr_2 are not precisely identical. The approximate time of overlap Δt may be observed. Figs. 3(b) and 4(b) demonstrate the difference in switch-off times for the two systems clearly.



(a) (b)

Fig. 3. Observed output waveforms, conventional carrier-frequency gating system without output filter. (a) Upper trace: output 10 V/div, 500 μs/div; lower trace: commands 10 V/div, 500 μs/div. (b) Upper trace: output 5 V/div, 20 μs/div; lower trace: output 5 V/div, 500 μs/div.



(a) (b)

Fig. 4. Observed output waveforms, overlapping carrier-frequency gating system without output filter. (a) Upper trace: output 5 V/div, 500 μs/div; lower trace: commands 10 V/div, 500 μs/div. (b) Upper trace: output 2 V/div, 20 μs/div; lower trace: output 2 V/div, 500 μs/div.

V. Conclusion

It has been demonstrated that during carrier wave transmission of gating signals for static switches it is impossible to deliver a constant output voltage during transmission due to commutation effects in the indispensible rectifiers. The situation may be improved by constructing transformers with very low leakage to precise tolerances, and by cascaded stages of amplification in an attempt to reduce the carrier-wave rise time. These solutions are only partly effective without an output filter, and the feasibility disputable. In specialized applications necessitating such an output with fast switch-off times (no filter), it has been demonstrated effective to employ an overlapping technique with an asymmetric waveform. In this system neither the rise and fall time of the input waveform nor the leakage inductance of the transformers is critical. Their effect on the output may be compensated by a simple adjustment of the asymmetry of the carrier wave. The system retains all the inherent advantages of a carrier-frequency gating system as previously exposed in the literature [2].

VI. Acknowledgment

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