Analysis of Rectifier Operation*

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***Summary*—An analysis of rectifier operation in principal circuits is made. The introduction of linear equivalent diode resistance values permits a simplified and accurate treatment of circuits containing high-vacuum diodes and series resistance. The evaluation of these equivalent resistance values and a discussion of emission characteristics of oxide-coated cathodes precede the circuit analysis.**

Generalized curve families for three principal condenser-input circuits are given to permit the rapid solution of rectifier problems in practical circuits without inaccuracies due to idealizing assumptions.

The data presented in this paper have been derived on the basis of a sinusoidal voltage source. It is apparent that the graphic analysis may be applied to circuits with nonsinusoidal voltage sources or intermittent pulse waves.

It is also permissible to consider only the wave section during conduction time and alter the remaining wave form at will. Complicated wave shapes may thus be replaced in many cases by a substantially sinusoidal voltage of higher frequency and intermittent occurrence as indicated by shape and duration of the highest voltage peak.

The applications of these principles have often explained large discrepancies from expected results as being caused by series or diode resistance and excessive peak-current demands.

Practical experience over many years has proved the correctness and accuracy of the generalized characteristics of condenser-input circuits.

Introduction

RECTIFIER circuits, especially of the condenser-input type, are extensively used in radio and television circuits to produce unidirectional currents and voltages. The design of power supplies, grid-current bias circuits, peak voltmeters, detectors and many other circuits in practical equipment is often based on the assumption that rectifier- and power-source resistance are zero, this assumption resulting in serious errors. The rectifier element or diode, furthermore has certain peak-current and power ratings which should not be exceeded. These values vary considerably with the series resistance of the circuit.

General operating characteristics of practical rectifier circuits have been evaluated and used by the writer for design purposes and information since early 1934, but circumstances have delayed publication. Several papers[1–4] have appeared in the meantime treating one or another part of the subject on the assumption of zero series resistance. Practical circuits have resistance and may even require insertion of additional resistance to protect the diode and input condenser against destructive currents. The equivalent diode resistance and the emission from oxide-coated cathodes are, therefore, discussed preceding the general circuit analysis. This analysis is illustrated on graphic constructions establishing a direct link with oscillograph observations on practical circuits. A detailed mathematical discussion requires much space and is dispensed with in favor of graphic solutions, supplemented by generalized operating characteristics.

I. Principles of Rectification

General

Rectification is a process of synchronized switching. The basic rectifier circuit consists of one synchronized switch in series with a single-phase source of single frequency and a resistance load. The switch connection between load terminals and source is closed when source and load terminals have the same polarity, and is open during the time of opposite polarity. The load current consists of half-wave pulses. This simple circuit is unsuitable for most practical purposes, because it does not furnish a smooth load current.

The current may be smoothed by two methods: (a) by increasing the number of phases, and (b) by inserting reactive elements into the circuit. The phase number is limited to two for radio receivers. The circuit analysis which follows later on will treat single- and double-phase rectifier circuits with reactive circuit elements.

Switching in reactive circuits gives rise to "transients." Current and voltage cannot, therefore, be computed according to steady-state methods.

The diode functions as a self-timing electronic switch. It closes the circuit when the plate becomes positive with respect to the cathode and opens the circuit at the instant when the plate current becomes zero.

The diode has an internal resistance which is a function of current. When analyzing rectifier circuits, it is convenient to treat the internal resistance of the diode rectifier as an element, separated from the "switch action" of the diode. Fig. 1 illustrates the three circuit elements so obtained and their respective voltage-current characteristics (see Section II). The diode characteristic is the sum of these characteristics. The resistance r_d is effective only when the switch is closed, i.e., during the conduction period of the diode. The effective diode resistance must, therefore, be measured or evaluated within conduction-time limits. Consider a

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