

IEEE Standard for Ferroresonant Voltage Regulators

Sponsor

**Electronics Transformer Technical Committee
of the
IEEE Power Electronics Society**

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Abstract: Ferroresonant transformers used as regulators in electronic power supplies and in other equipment are covered. Guides to application and test procedures are included.

Keywords: controlled ferroresonant regulators, ferroresonant transformer regulators, series ferroresonant regulators, series-parallel ferroresonant regulators

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Introduction

(This introduction is not part of IEEE Std 449-1998, IEEE Standard for Ferroresonant Voltage Regulators.)

The purpose of this standard is to provide a common ground of understanding between engineers involved in the design, manufacture, sale, and use of ferroresonant transformers. It pertains to ferroresonant transformers used as regulators in electronic power supplies and in other equipment where the inherent properties of voltage regulation and current limiting are useful.

This publication was prepared by the Ferroresonant Transformer Subcommittee of the Electronics Transformer Technical Committee of the IEEE Power Electronics Society. The subcommittee had the following membership:

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The Institute wishes to acknowledge its indebtedness to those who have given so freely of their time and knowledge in the development of the original version of this standard. The followship of authors of the inaugural publication, IEEE Std 449-1984, include the following distinguished members:

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IEEE Standard for Ferroresonant Voltage Regulators

1. Scope

This standard pertains to ferroresonant voltage regulators that operate at relatively constant frequencies and provide substantially constant output voltages in spite of relatively large changes of input voltage. It also covers controlled ferroresonant regulators that maintain substantially constant output voltages regardless of variations, within limits, of input voltage, temperature, frequency, and output load. Guides to application and test procedures are included. Provisions are made for relating the characteristics of ferroresonant regulators to associated rectifiers and circuits. Definitions pertaining to ferroresonance and ferroresonant regulators that have not been found elsewhere are included with an appropriate discussion.

This standard includes, but is not limited to, the following types of ferroresonant regulators:

- a) Series ferroresonant regulators
- b) Series-parallel ferroresonant regulators (electrically connected)
- c) Ferroresonant transformer regulators (magnetically coupled)
- d) Controlled ferroresonant regulators

2. References

This standard shall be used in conjunction with the following publications. When the following publications are superseded by an approved revision, the revision shall apply.

ANSI S1.2-1962 (Reaff 1976), American National Standard Method for the Physical Measurement of Sound.¹

ANSI S1.4-1983, American National Standard Specification for Sound Level Meters.²

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms, Sixth Edition.³

¹ANSI S1.2-1962 has been withdrawn; however, copies can be obtained from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

²ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

IEEE Std 260.1-1993, American National Standard Letter Symbols for Units of Measurement (SI Units, Customary Inch-Pound Units, and Certain Other Units).

IEEE Std 280-1985 (Reaff 1997), IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering.

IEEE Std 389-1996, IEEE Recommended Practice for Testing Electronics Transformers and Inductors.

IEEE Std 436-1977, IEEE Guide for Making Corona (Partial Discharge) Measurements on Electronics Transformers.⁴

3. Definitions

For purposes of this standard, the following terms and definitions apply. IEEE Std 100-1996⁵, The IEEE Standard Dictionary of Electronics and Electrical Terms, should be referenced for terms not defined in this clause.

The letters and graphic symbols used in this standard shall be in accordance with IEEE Std 260-1978 and IEEE Std 280-1985 insofar as they apply, except as herein stated.

3.1 air gap: The space between the magnetic shunt and the core, used to establish the required reluctance of the shunt flux path.

3.2 basic series ferroresonant voltage regulator: This regulator consists of a series connection of a saturating inductor and a capacitor connected across the source. The load is inductively or conductively coupled to the saturating inductor. See Figure 1.

NOTE—Applications of this circuit are limited by the requisite large ratio of reactive to real powers.

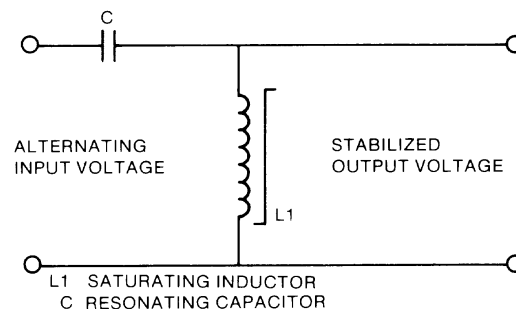


Figure 1—Basic series ferroresonant voltage regulator

3.3 basic series parallel ferroresonant voltage regulator: This regulator consists of an essentially linear inductor connected in series with a parallel combination of a nonlinear inductor and a capacitor. This

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://www.standards.ieee.org/>).

⁴IEEE Std 436-1977 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://www.global.ihs.com/>).

⁵Information on references can be found in Clause 2.

combination is connected across the source as shown in Figure 2. Load voltage is derived by inductive or conductive coupling to the nonlinear inductor.

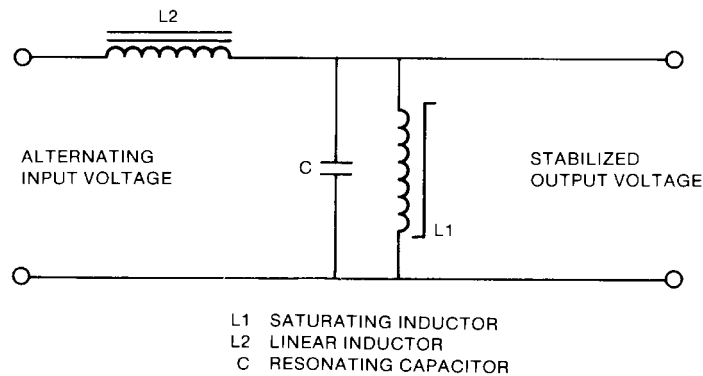


Figure 2—Basic series parallel ferroresonant voltage regulator

3.4 controlled ferroresonant regulators: A regulator consisting basically of an inductor connected in series with a parallel combination of a capacitor and controllable simulated inductor. This combination is connected across the source as shown in Figure 3. Stabilized output voltage is derived by inductive or conductive coupling to the parallel combination of C and the controllable simulated inductor. In a controlled ferroresonant regulator the controllable simulated inductor can be a combination of switching devices (such as thyristors or transistors) and linear or saturating inductors. This circuit, in combination with a control input to the simulated inductor, controls the flux swing (or simulated flux swing) in the saturated (or simulated saturating) inductor, thereby controlling the stabilized output voltage.

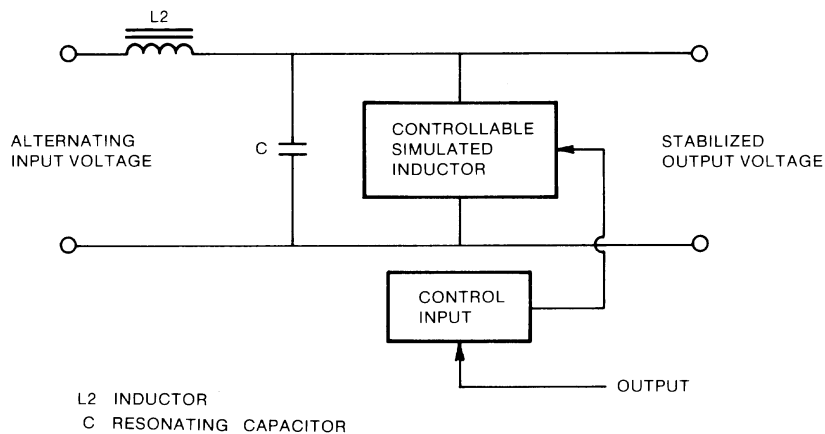


Figure 3—Controlled ferroresonant regulator schematic

3.5 ferroresonance: The steady-state mode of operation that exists when an alternating voltage of sufficient magnitude is applied to a circuit consisting of capacitance and ferromagnetic inductance causing changes in the ferromagnetic inductance that are repeated each half cycle.

NOTE—When certain critical relations exist among circuit parameters, self-sustaining subharmonic or harmonic oscillations may also be excited in the circuit.

3.6 ferroresonant voltage regulation: The effect obtained by the limiting action of the saturation characteristic of the magnetic material in a ferroresonant circuit, which regulates the output voltage over a specified range of input voltages and a specified frequency of excitation.

NOTE—This effect regulates the half-cycle average value of the output voltage.

3.7 ferroresonant voltage regulator transformer: A high-reactance transformer employing magnetic shunts that allow the magnetic functions of the basic series parallel ferroresonant regulator circuits to be combined into a single magnetic component. See Figure 4 and Figure 5.

NOTE—Hereafter this will be referred to as a ferroresonant transformer.

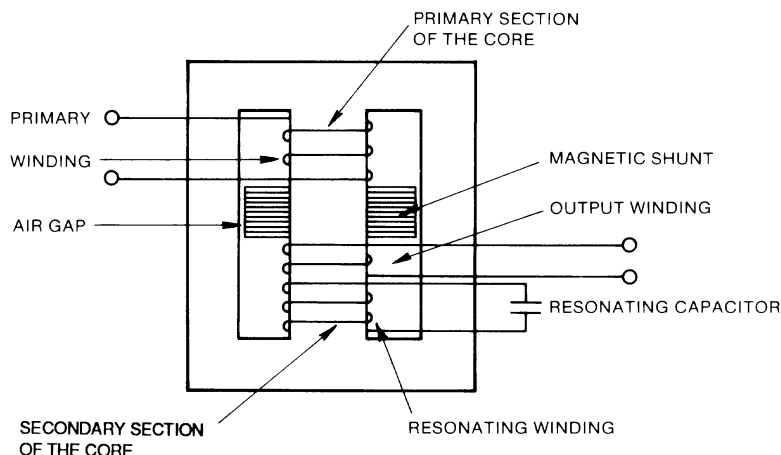


Figure 4—Common form of the ferroresonant transformer voltage regulator

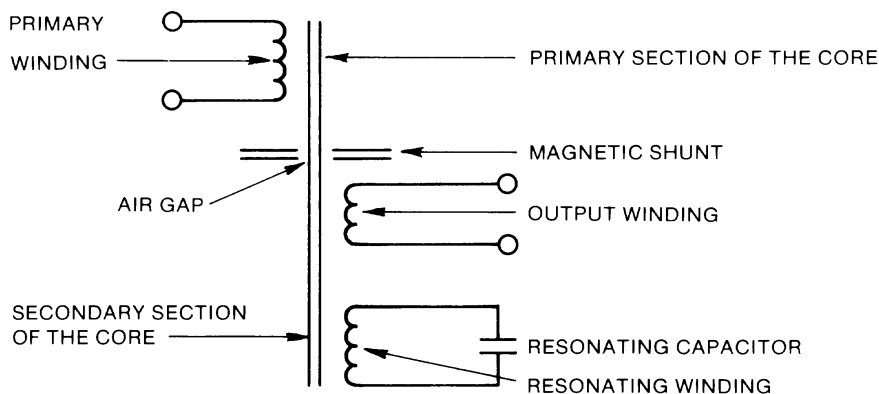


Figure 5—Schematic of a common form of the ferroresonant transformer voltage regulator

3.8 jump resonance: A phenomenon associated with ferroresonant regulators where the output voltage suddenly changes to the regulating mode of operation at some value of the ascending input voltage (see Figure 6 and Figure 7), or suddenly drops out of the regulating mode of operation with descending input voltage.

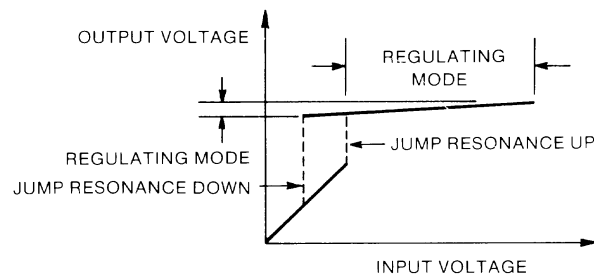


Figure 6—Output versus input voltage with jump resonance

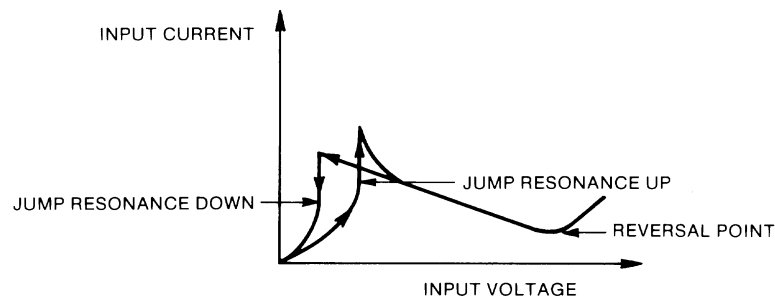


Figure 7—Reversal point with jump resonance

3.9 magnetic shunt: The section of the core of the ferroresonant transformer that provides the major path for flux generated by the primary winding current that does not link the secondary winding. In addition, the shunts provide a major path for the flux resulting from the output and resonating winding currents that do not link the primary winding.

3.10 output voltage versus input voltage characteristics: Ferroresonant regulators may have output versus input characteristics as shown in Figure 6 and Figure 8.

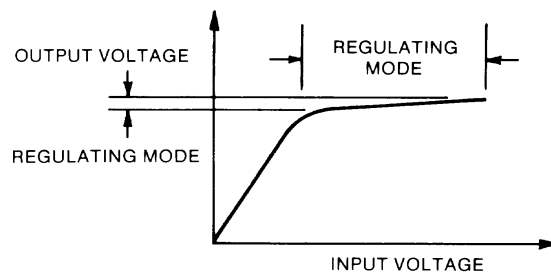


Figure 8—Output versus input voltage without jump resonance

3.11 output winding: The winding of the ferroresonant transformer used to provide the regulated output voltage.

NOTE—The output winding is wound on the secondary section of the core and separated from the primary by a magnetic shunt.

3.12 overall regulation (power supplies): The maximum amount that the output will change as a result of the specified change in line voltage, output load, input frequency, temperature, or time.

NOTE—Line regulation, load regulation, effect of frequency variation, stability, and temperature coefficient are defined and usually specified separately as follows:

- *Line regulation.* The maximum amount that the output voltage or current will change as the result of a specified change in line voltage. (Regulation is given either as a percentage of the rated output voltage or current, or as an absolute change, ΔE or ΔI .)
- *Load regulation.* The maximum amount that the output voltage will change as the result of a specified change in load current. (Regulation is given either as a percentage of the rated output voltage or as an absolute change, ΔE .)
- *Frequency regulation.* The maximum amount that the output voltage or current will change as the result of a specified change in line frequency. (Regulation is given either as a percentage of the rated output voltage or current, or as an absolute change, ΔE or ΔI .)
- *Temperature coefficient (power supplies).* The percent change in the output voltage or current as a result of a 1°C change in the ambient operating temperature (percent per degree Celsius).
- *Long-term stability (LTS) (power supplies).* The change in output voltage or current as a function of time, at constant line voltage, load, and ambient temperature (sometimes referred to as *drift*).

3.13 overload characteristic: That portion of the output voltage versus output current characteristic of ferroresonant regulators from rated current to short-circuit current. Figure 9 shows the typical overload characteristic when inductor L2 (see Figure 2) does not saturate. Figure 10 shows the effect of L2 saturation in the overload condition where the short-circuit current is less than maximum overload current.

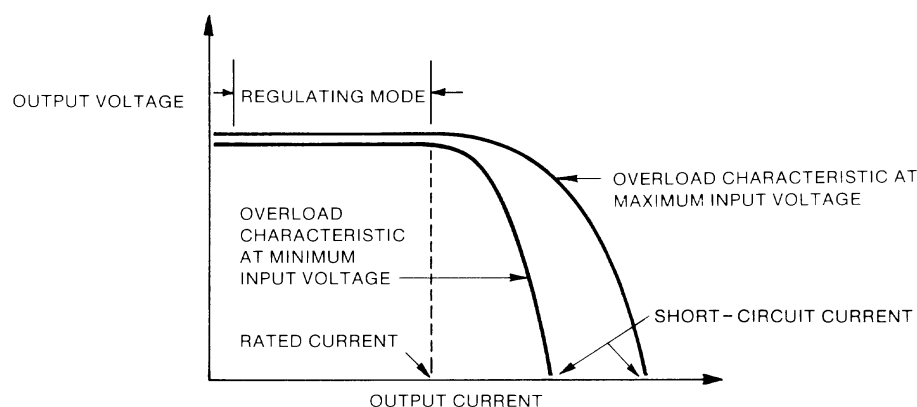


Figure 9—Overload characteristic with unsaturated series inductance

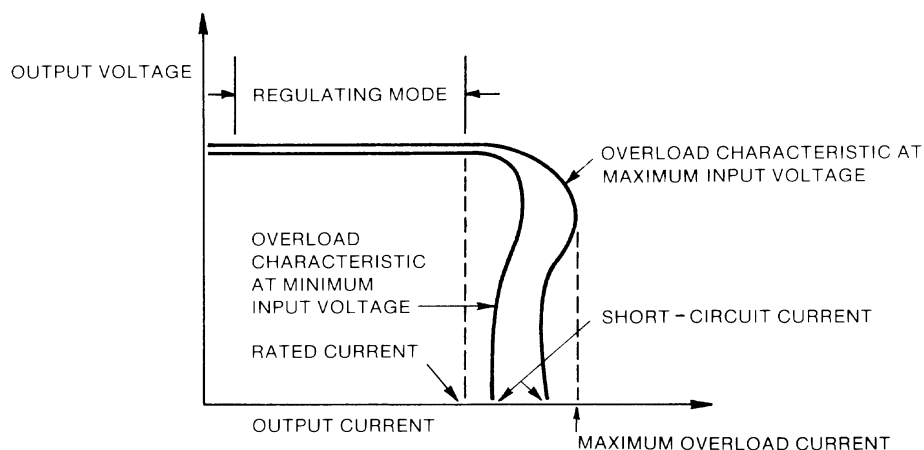


Figure 10—Overload characteristic with saturated series inductance

3.14 primary section of the core: The section of the core of a ferroresonant transformer on which the primary winding is wound.

3.15 primary winding: The winding of the ferroresonant transformer to which the input voltage is applied.

3.16 rated input power: The input power to the ferroresonant regulator with the rated load and under stated operating conditions.

3.17 rated input voltamperes: The input voltamperes to the ferroresonant regulator with the rated load and under stated operating conditions.

3.18 rated output voltamperes of the ferroresonant regulator: The sum of the rated output winding voltamperes under stated operating conditions.

3.19 rated output winding voltamperes: The product of the output voltage and output current (root-mean-square values) at the rated load and under stated operating conditions.

3.20 resonating capacitor: Provides the capacitance associated with ferroresonant regulating circuits for the purpose of producing ferroresonance.

3.21 resonating capacitor voltamperes: The product of the voltage across the resonating capacitor and the current through the resonating capacitor (root-mean-square values) under stated operating conditions.

3.22 resonating winding: The winding of the ferroresonant transformer used to connect the resonating capacitance to the circuit.

NOTE—It is wound on the secondary section of the core and is separated from the primary winding by a magnetic shunt. It may itself be the output winding or a portion of the output winding.

3.23 reversal point: That point on the input current versus input voltage characteristics where the input current reaches a minimum value and begins to increase. See Figure 7 and Figure 11.

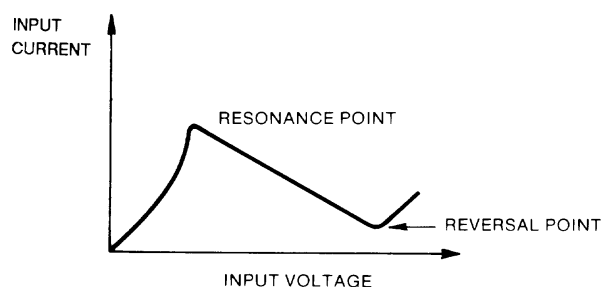


Figure 11—Reversal point without jump resonance

3.24 secondary section of the core: The section of the ferroresonant transformer on which the output and resonating windings are wound. In steady-state operation, this section of the core is normally driven into magnetic saturation.

3.25 short-circuit input voltamperes: The product of the input voltage and input current (rms values) with the resonating winding short circuited.