

Preface

The circuit regime analysis is one of the main problems for electric circuit theory. The finding of the actual (absolute) value of regime parameters (voltage, current, power, and transformation ratio for different parts of a circuit) is the simplest analysis task. If a circuit has variable elements (loads and voltage regulators), additional analysis tasks appear.

The interest in such circuits is defined, in particular, by the state and tendencies of development of power electronics, modular power supply, or distributed power supply systems with renewable power sources. Similar devices, in general, represent the complex multiple inputs and multiple outputs systems and their loads can change from the short circuit to open circuit and further give energy. In turn, the loads can be subdivided into high priority and additional (ballast) loads. For definiteness, it is possible to accept that such systems, for circuit theory, present linear mesh circuits of a direct current or multi-port networks.

We will consider some of the arising additional tasks of analysis. For example, it is important to confront operating regime parameters with characteristic values; that is, to represent these parameters in the normalized or relative form. In this case, the informational content of these parameters is increasing; it is possible to appreciate qualitative characteristics of an operating regime or its effectiveness, to compare regimes of different circuits, and to set a necessary regime.

The other task of analysis is the determination of the dependence of the regime parameter changes on the respective change of element's parameters (for example, the problem of the recalculation of load currents). Thus, it is necessary to set the form of these changes reasonably; that is, to determine whether these changes are increments or any other expressions.

Another task of analysis is the definition of the view or character of such an active circuit with a changeable element (as a power source concerning load); that is, this circuit shows more property of a voltage source or current source.

In the electric circuit theory, a range of circuit's properties, theorems, and methods is well known, and their use simplifies the decision of these problems.

However, the known approaches do not completely disclose the properties of such circuits, which reduces the effectiveness of analysis.

The method of analysis for a circuit with variable element parameters is developed by the author. For interpretation of changes or “kinematics” of circuit regimes, projective geometry is used. For example, the known expression has the typical fractionally linear view for functional dependence of current (or voltage) via resistance. It gives the grounds for considering this expression as a projective transformation. The projective transformations preserve an invariant; there is a cross ratio of four points (a ratio of two proportions) or four values of current and resistance. The value of this invariant is preserved for all the variables (as a current, voltage, and resistance) and for parts or sections of a circuit. Thus, this invariant is accepted as the determination of the regime in the relative form. Therefore, obvious changes in regime parameters in the form of increments are formal and do not reflect the substantial aspect of the mutual influences: resistance \rightarrow current.

In general, this geometrical approach grounds the introduction and determination of required concepts.

The book has an introduction (Chap. 1) and four parts. The disadvantages of known methods are considered in Chap. 1.

Part I (Chaps. 2–5) considers electrical circuits with one load. The application of projective geometry to analysis of an active two-pole is shown in Chap. 2. The concept of generalized equivalent circuits is introduced in Chap. 3. The invariant relationships of cascaded two-ports are considered in Chap. 4. In Chap. 5, the paralleling voltage sources are presented.

Part II (Chaps. 6–9) considers multi-port circuits. The application of projective geometry to analysis of an active two-port and three-port is shown in Chap. 6. The concept of generalized equivalent circuits of multi-port is introduced in Chap. 7. The recalculation formulas of load currents are obtained in Chap. 8. The invariant relationships of cascaded four-ports are considered in Chap. 9.

Part III (Chaps. 10–12) considers circuits with nonlinear regulation curves. The voltage regulator regimes are studied in Chap. 10. The load voltage stabilization is shown in Chap. 11. The pulse-width modulation converters are considered in Chap. 12.

Part IV (Chaps. 13 and 14) discusses circuits with nonlinear load characteristics. The concepts of power-source and power-load elements with two-valued characteristics are shown in Chap. 13. Quasi-resonant voltage converters with self-limitation of current are considered in Chap. 14. The attention to similarity of characteristics of this converter and some electronic devices is paid.

The book may be useful to those who are interested in the foundations of the electric circuit theory and also for a professional circle of experts in various areas of electrical engineering and radio electronics.

The author thanks Prof. A. Scherba (Ukraine) for the attention shown and recommendations to the publication of the first results. He also thanks Prof. P. Butyrin (Russia) for long-term constructive criticism and recommendations to the publication of series of papers. He also thanks Prof. V. Mazin (Russia), who shares his

area of researches, and appreciates scientific editor B. Makarshin (Russia) for a 20-year hard effort on the preparation of paper manuscripts for publication.

The author is grateful to academician D. Ghitu, the founder of Institute of Electronic Engineering and Nanotechnologies (Moldova), for the given opportunity to work according to the individual plan of researches. He appreciates Prof. A. Sidorenko, the director of “D. Ghitu” Institute of Electronic Engineering and Nanotechnologies, for permanent interest to the direction of research, support for this direction and the book publication.

Moldova Republic
October 2015

A. Penin

Contents

1	Introduction	1
1.1	Typical Structure and Equivalent Circuits of Power Supply Systems. Features of Circuits with Variable Operating Regime Parameters	1
1.2	Disadvantages of the Well-Known Calculation Methods of Regime Parameters in the Relative Form for Active Two-Poles.	3
1.2.1	Volt–Ampere Characteristics of an Active Two-Pole	3
1.2.2	Regime Parameters in the Relative Form.	4
1.2.3	Regime Change in the Relative Form	7
1.2.4	Active Two-Port with Changeable Resistance	9
1.2.5	Scales of Regime Parameters for Cascaded Two-Ports	9
1.3	Analysis of the Traditional Approach to Normalizing of Regime Parameters for the Voltage Linear Stabilization	11
1.4	Active Two-Port	14
1.4.1	Volt Characteristics of an Active Two-Port	14
1.4.2	Traditional Recalculation of the Load Currents.	14
1.5	Nonlinear Characteristics.	17
1.5.1	Efficiency of Two-Ports with Different Losses	17
1.5.2	Characteristic Regimes of Solar Cells	20
1.5.3	Quasi-resonant Voltage Converter.	20
1.5.4	Power-Source and Power-Load Elements.	21
1.6	Regulated Voltage Converters	21
1.6.1	Voltage Regulator with a Limited Capacity Voltage Source	21
1.6.2	Buck Converter	23
1.6.3	Boost Converter.	24
	References	25

Part I Electrical Circuits with one Load. Projective Coordinates of a Straight Line Point

2	Operating Regimes of an Active Two-Pole. Display of Projective Geometry.	29
2.1	Volt–Ampere Characteristics of an Active Two-Pole. Affine and Projective Transformations of Regime Parameters	29
2.1.1	Affine Transformations	29
2.1.2	Projective Transformations	37
2.2	Volt–Ampere Characteristics of an Active Two-Pole with a Variable Element	42
2.2.1	Thévenin Equivalent Circuit with the Variable Internal Resistance	42
2.2.2	Norton Equivalent Circuit with the Variable Internal Conductivity	44
2.3	Regime Symmetry for a Load-Power	47
2.3.1	Symmetry of Consumption and Return of Power	48
2.3.2	Symmetry Relatively to the Maximum Power Point	50
2.3.3	Two Systems of Characteristic Points	52
	References	54
3	Generalized Equivalent Circuit of an Active Two-Pole with a Variable Element.	55
3.1	Introduction	55
3.2	Circuit with a Series Variable Resistance	56
3.2.1	Disadvantage of the Known Equivalent Circuit	56
3.2.2	Generalized Equivalent Circuit	57
3.2.3	Relative Operative Regimes. Recalculation of the Load Current	60
3.2.4	Example	65
3.3	Circuit with a Shunt Variable Conductivity	70
3.3.1	Disadvantage of the Known Equivalent Circuit	70
3.3.2	Generalized Equivalent Circuit	71
3.3.3	Relative Operative Regimes. Recalculation of the Load Current	74
3.3.4	Example	78
3.4	General Case of an Active Two-Pole with a Variable Conductivity	82
3.4.1	Known Equivalent Generator	83
3.4.2	Generalized Equivalent Circuit	84
3.4.3	Example of a Circuit. Recalculation of the Load Current	87
3.5	Stabilization of the Load Current	91
	References	94

4 Two-Port Circuits 97

4.1 Input-Output Conformity of Two-Ports as Affine Transformations 97

4.1.1 Conformity of a Two-Port 97

4.1.2 Conformity of Cascaded Two-Ports 99

4.2 Input-Output Conformity of Two-Ports as Projective Transformations 102

4.2.1 Conformity of a Two-Port 102

4.2.2 Versions of Conformities, Invariants, and Cross Ratios 106

4.2.3 Conformity of Cascaded Two-Ports 109

4.3 Use of Invariant Properties for the Transfer of Measuring Signals 116

4.3.1 Transfer of Signals over an Unstable Two-Port 116

4.3.2 Conductivity Measurement by an Unstable Two-Port 119

4.4 Deviation from the Maximum Efficiency of a Two-Port 120

4.4.1 Regime Symmetry for the Input Terminals 121

4.4.2 Regime Symmetry for the Output or Load 123

4.5 Effectiveness of Modular Connections 126

4.5.1 Complementary Knowledge About a Two-Port 126

4.5.2 Parallel Connection of Two Converters 127

4.5.3 Connection of Two-Ports with the Interaction 130

4.6 Effectiveness Indices of a Two-Port with Variable Losses 131

4.6.1 Problems of Energy Indices 131

4.6.2 Influence of Losses on the Load Power 131

4.6.3 Influence of Losses on the Efficiency 135

References 138

5 Paralleling of Limited Capacity Voltage Sources 141

5.1 Introduction 141

5.2 Initial Relationships 141

5.3 Influence of the Load Value on the Current Distribution 143

5.3.1 Analysis of Paralleling Voltage Sources 143

5.3.2 Introduction of Two Concepts 145

5.3.3 Comparison of a Loading Regime of Different Circuits 148

5.4 Influence of the Equalizing Resistance on the Current Distribution 153

5.4.1 Analysis of Paralleling Voltage Sources 153

5.4.2 Introduction of Two Concepts 154

5.4.3 Comparison of a Loading Regime of Different Circuits 157

References 162

Part II Multi-port Circuits. Projective Coordinates of a Point on the Plane and Space

- 6 Operating Regimes of an Active Multi-port 167**
 - 6.1 Active Two-Port. Affine and Projective Coordinates on the Plane 167
 - 6.1.1 Affine Coordinates 167
 - 6.1.2 Particular Case of a Two-Port. Introduction of the Projective Plane 173
 - 6.1.3 General Case of a Two-Port. Projective Coordinates 175
 - 6.2 Projective Coordinates in Space 183
 - 6.2.1 Particular Case of a Multi-port. 183
 - 6.2.2 General Case of a Multi-port. The Balanced Networks 190
 - 6.3 Projective Coordinates of an Active Two-Port with Stabilization of Load Voltages 198
 - References 205
- 7 Recalculation of Load Currents of Active Multi-ports 207**
 - 7.1 Recalculation of Currents for the Case of Load Changes 207
 - 7.1.1 Active Two-Port. 207
 - 7.1.2 Active Three-Port. 210
 - 7.2 Recalculation of Currents for the Case of Changes of Circuit Parameters 213
 - 7.2.1 Change of Lateral Conductivity 213
 - 7.2.2 Change of Longitudinal Conductivity 219
 - 7.3 Comparison of Regimes and Parameters of Active Two-Ports 224
 - 7.4 Comparison of Regime of Active Two-Ports with Linear Stabilizations of Load Voltages 228
 - References 235
- 8 Passive Multi-port Circuits 237**
 - 8.1 Input-Output Conformity of Four-Ports as an Affine Transformation. 237
 - 8.2 Input-Output Conformity of Four-Ports as a Projective Transformation. 244
 - 8.2.1 Output of a Four-Port 244
 - 8.2.2 Input of a Four-Port 246
 - 8.2.3 Recalculation of Currents at Load Changes 251
 - 8.2.4 Two Cascaded Four-Port Networks. 252
 - 8.2.5 Examples of Calculation 254
 - 8.3 Transmission of Two Signals Over Three-Wire Line. 260
 - 8.3.1 Transmission by Using of Cross-Ratio 260
 - 8.3.2 Transmission by Using of Affine Ratio 262

8.4	Input-Output Conformity of a Balanced Six-Port	263
	References	273
9	Generalized Equivalent Circuit of a Multi-port	275
9.1	Generalized Equivalent of an Active Two-Port.	275
9.1.1	Disadvantages of Known Equivalent.	275
9.1.2	Introduction of the Formal Variant of a Generalized Equivalent.	276
9.1.3	Introduction of the Principal Variant of a Generalized Equivalent Circuit	279
9.2	Generalized Equivalent of an Active Three-Port	282
	References	286
 Part III Circuits with Non-Linear Regulation Curves		
10	Regulation of Load Voltages.	289
10.1	Base Model. Display of Conformal Geometry	289
10.2	Using of Hyperbolic Geometry Model	295
10.2.1	Case of One Load	296
10.2.2	Case of Two Loads	299
10.3	Example	305
10.3.1	Case of One Load	306
10.3.2	Case of Two Loads	308
	References	312
11	Stabilization of Load Voltages	313
11.1	Analysis of Load Voltage Stabilization Regimes	313
11.1.1	Case of One Load	313
11.1.2	Use of Hyperbolic Geometry	315
11.1.3	Case of Two Loads	322
11.2	Given Voltage for the First Variable Load and Voltage Regulation of the Second Given Load.	324
11.2.1	Use of Hyperbolic Geometry	328
11.2.2	Regime Change for the First Given Load Resistance.	330
11.2.3	Example	333
	References	334
12	Pulse-Width Modulation Regulators	337
12.1	Introduction.	337
12.2	Regulation Characteristic of Boost Converter.	337
12.3	Regulation Characteristic of Buck–Boost Converter	348
12.3.1	Buck–Boost Converter with an Idealized Choke.	348
12.3.2	Buck–Boost Converter with Losses of Choke	354
	References	357