

References

* An item marked with an asterisk is one of several papers on the same subject by the same author. Other references can be found in the bibliography of the paper.

Ref. No.

- [1] Doherty, R. E. (1923). 'A Simplified method of Analysing Short-circuit Problems', *Trans. A.I.E.E.*, 42, p. 841.
- [2] West, H. R. (1926), 'Cross-field Theory of Alternating Current Machines', *Trans. A.I.E.E.*, 45, p. 466.
- [3] Park, R. H. (1928), 'Definition of an Ideal Synchronous Machine', *G.E. Review*, 31, p. 332.
- [4] Park, R. H. (1929), 'Two-reaction Theory of Synchronous Machines', *Trans. A.I.E.E.*, 48, p. 716.
- [5] *Doherty, R. E. and Nickle, C. A. (1930), 'Synchronous Machines I to V', *Trans. A.I.E.E.*, 49, p. 700.
- [6] Park, R. H. (1933), 'Two-reaction Theory of Synchronous Machines. II', *Trans. A.I.E.E.*, 52, p. 352.
- [7] Kingsley, C., (1935), 'Saturated Synchronous Reactance', *Trans. A.I.E.E.*, 54, p. 300.
- [8] *Kron, G. (1942) 'Application of Tensors to the Analysis of Rotating Electrical Machinery', *G.E. Review*.
- [9] Szwander, W. (1944), 'Fundamental Characteristics of Synchronous Turbo-generators', *Jour. I.E.E.*, 91, Part II, p. 185.
- [10] Rankin, A. W. (1945), 'The Direct and Quadrature-Axis Equivalent Circuits of the Synchronous Machine', *Trans. A.I.E.E.*, 64, p. 861.
- [11] Crary, S. B. (1947) *Vol. 2. 'Power System Stability Transient Stability'*, John Wiley, London.
- [12] *Gibbs, W. J. (1948), 'Induction and Synchronous Motors with Unlaminated Rotors', *J.I.E.E.*, 95, Part II, p. 411.
- [13] Linville, T. M. and Ward, H. C. (1949), 'Solid Short Circuit of d.c. Motors and Generators', *Trans. A.I.E.E.*, 68, p. 119.
- [14] Deusterhofft, W. C. (1949), 'The Negative Sequence Reactances of an Ideal Synchronous Machine', *Trans. A.I.E.E.*, 68, p. 510.
- [15] Adkins, B. (1951) 'Transient Theory of Synchronous Generators Connected to Power Systems', *J.I.E.E.*, 98, p. 510.

274 The General Theory of Alternating Current Machines

- [16] **Concordia, C.** (1951), *Synchronous Machines*, John Wiley, London.
- [17] **Laible, Th.** (1952), *Die Theorie der Synchronmaschine in Nichtstationarem Betrieb*. Springer.
- [18] **Walker, J. H.** (1953), 'Operating Characteristics of Salient-pole Machines', *Proc. I.E.E.* Part II, **100**, p. 13.
- [19] **Ching, Y. K. and Adkins, B.** (1954), 'Transient Theory of Synchronous Generators under Unbalanced Conditions', *Jour. I.E.E.*, **101**, Part IV, p. 106.
- [20] **Adkins, B.** (1957), *The General Theory of Electrical Machines*, Chapman and Hall.
- [21] **Dalal, M. K.** (1957), *The two Reactions of a Synchronous Machine*. M.Sc. Thesis, London University.
- [22] **Say, M. G.** (1958), *The Performance and Design of Alternating Current Machines*, Pitman.
- [23] **White, D. C. and Woodson, H. H.** (1959), *Electromechanical Energy Conversion* John Wiley.
- [24] **Mehta, D. B. and Adkins, B.** (1960), 'Transient Torque and Load Angle of a Synchronous Generator following several Types of System Disturbance', *Proc. I.E.E.*, **107**, Part A, p. 61.
- [25] **Concordia, C.** (1960), 'Synchronous Machine with Solid Cylindrical Rotor - Part II, *Trans. A.I.E.E.*, **78**, Part III.
- [26] **Carter, G. W. et al.** (1961), 'The Inductance Coefficients of a Salient-pole Alternator in Relation to the Two-axis Theory', *Proc. I.E.E.*, **108**, Part A, p. 263.
- [27] **Ralston, A. and Wilf, H. S.** (1962), *Mathematical Methods for Digital Computers*, John Wiley.
- [28] **Bharali, P. and Adkins, B.** (1963), 'Operational Impedances of Turbo-generators with Solid Rotors', *Proc. I.E.E.*, **110**, p. 2185.
- [29] **Shackshaft, G.** (1963), 'A General Purpose Turbo-alternator Model', *Proc. I.E.E.*, **110**, p. 703.
- [30] **Alger, P. L.** (1965), *The Nature of Polyphase Induction Machines*, Gordon and Breach, New York.
- [31] **Humpage, W. D. and Stott, B.** (1965), 'Predictor-corrector Methods of Numerical Integration in Digital-computer Analyses of Power-system Transient Stability', *Proc. I.E.E.*, **112**, p. 1557.
- [32] ***Rawcliffe, G. H. and Fong, W.** (1965), 'Two-speed Induction Motors with Fractional-slot Windings' *Proc. I.E.E.*, **112**, p. 1899.
- [33] **Jacovides, L. J. and Adkins, B.** (1966), 'Effect of Excitation Regulation on Synchronous Machine Stability', *Proc. I.E.E.*, **113**, p. 1021.
- [34] **Jones, C. V.** (1967), *The Unified Theory of Electrical Machines*, Butterworths.
- [35] **Elgerd, O. I.** (1967), *Control System Theory*, McGraw-Hill.
- [36] **Humpage, W. D. and Saha, T. N.** (1967), 'Digital Computer Methods in Dynamic Response Analysis of Turbo-generator units', *Proc. I.E.E.*, **114**, p. 1115.
- [37] **Smith, I. R. and Sriharan, S.** (1967), 'Induction Motor Reswitching Transients', *Proc. I.E.E.*, **114**, p. 503.
- [38] **Dunfield, J. C. and Barton, T. H.** (1967), 'Effect of m.m.f. and Permeance Harmonics in Electrical Machines, with Special Reference to a Synchronous Machine', *Proc. I.E.E.*, **114**, p. 1443.

- [39] BS 4296/1928. *Methods of Test for Determining Synchronous Machine Quantities*.
- [40] Prabhashankar, K. and Janischewsyj, W. (1968), 'Digital Simulation of Multi-machine Power and Systems for Stability Studies', *Trans. I.E.E.E.*, PAS-87, p. 73.
- [41] Widger, G. F. T. and Adkins, B. (1968), 'Starting Performance of Synchronous Motors with Solid Salient Poles', *Proc. I.E.E.*, 115, p. 1471.
- [42] Canay, I. M. (1969), 'Causes of Discrepancies on Calculation of Rotor Quantities and Exact Equivalent Diagrams of the Synchronous Machine', *Trans. I.E.E.E.*, PAS-88, p. 1114.
- [43] Soper, J. A. and Fagg, A. R. (1969), 'Divided-winding-rotor Synchronous Generator', *Proc. I.E.E.*, 116, p. 113.
- [44] Kapoor, S. C. *et al.* (1969) 'Improvement of Alternator Stability by Controlled Quadrature Excitation', *Proc. I.E.E.*, 116, p. 771.
- [45] Gupta, S. C. and Hasdorf, L. (1970), *Fundamentals of Automatic Control*. John Wiley.
- [46] Speedy, C. B., *et al.* (1970), *Control Theory: Identification and Optimal Control*. Oliver and Boyd, Edinburgh.
- [47] Harley, R. G. and Adkins, B. (1970), 'Stability of Synchronous Machine with Divided Winding Rotor', *Proc. I.E.E.*, 117, p. 933.
- [48] Willems, J. L. and Willems, J. C. (1970), 'The Application of Liapunov Methods to the Computation of Transient Stability Regions for Multi-machine Power Systems', *Trans. I.E.E.E.*, PAS-89, p. 795.
- [49] Harley, R. G. and Adkins, B. (1970), 'Calculation of the Angular Back Swing following a Short Circuit of a Loaded Alternator', *Proc. I.E.E.*, 117, p. 377.
- [50] Shackshaft, G. (1970), 'Effect of Oscillatory Torques on the Movement of Generator Rotors', *Proc. I.E.E.*, 117, p. 1969.
- [51] Rajamaran, K. C. and Carter, G. W. (1970), 'Effect of Harmonics on Hunting of Synchronous Machines', *Proc. I.E.E.*, 117, p. 1143.
- [52] Harris, M. R., Lawrenson, P. J. and Stephenson, J. M. (1970), *Per-unit Systems*, C.U.P.
- [53] *Chari, M. V. and Silvester, P. (1971), 'Analysis of Turbo-generator Magnetic Fields by Finite Elements', *Trans. I.E.E.E.*, PAS-90, p. 454.
- [54] *Laithwaite, E. R. *et al.* (1971), 'Linear Motors with Transverse Flux', *Proc. I.E.E.*, 118, p. 1761.
- [55] Iyer, S. N. and Cory, B. J. (1971), 'Optimization of Turbo-generator Transient Performance by Differential Dynamic Programming', *Trans. I.E.E.E.*, PAS-90, p. 2149.
- [56] Kalsi, S. S. and Adkins, B. (1971), 'Transient Stability of Power Systems Containing both Synchronous and Induction Machines', *Proc. I.E.E.*, 118, p. 1467.
- [57] Kalsi, S. S. *et al.* (1971), 'Calculation of System Fault Currents due to Induction Motors', *Proc. I.E.E.*, 118, p. 201.
- [58] Hammond, P. (1971), *Applied Electromagnetism*, Pergamon Press, London.
- [59] Outhred, H. R. and Evans, F. J. (1972), 'A Model Reference Adaptive Controller for Turbo-alternators in Large Systems', *Fourth Power Systems Computation Conference*, Grenoble.

276 The General Theory of Alternating Current Machines

- [60] Mason, T. H. *et al.* (1972), 'Asynchronous Operation of Turbo-generators', *C.I.G.R.E.*, Paper 11-02.
- [61] Shackshaft, G. and Neilson, R. (1972), 'Results of Stability Tests on an Under-excited 120 MW Generator', *Proc. I.E.E.*, **119**, p. 175.
- [62] *Fuchs, E. F. and Erdelyi, E. A. (1972), 'Determination of Water-wheel Alternator Steady-state Reactances from Flux Plots', *Trans. I.E.E.E.*, PAS-91, p. 1795.
- [63] *Lawrenson, P. J. and Mathur, R. M. (1972), 'Asynchronous Performance of Reluctance Machines allowing for Irregular Distribution of Rotor Conductors', *Proc. I.E.E.* **119**, p. 318.
- [64] Raman, S. and Kapoor, S. C. (1972), 'Synthesis of Optimal Regulators for a Synchronous Machine', *Proc. I.E.E.*, **119**, pp. 1383, 1391.
- [65] Humpage, W. D. (Sept., 1973), 'Numerical Integration', *U.M.I.S.T. Symposium on Power System Dynamics*.
- [66] Canay, M. (1972), 'Experimentelle Ermittlung der Ersatzschemata und der Parameter einer Idealiserten Synchronmaschine', *Bulletin des Schweizerischen Elektrotechnischen Vereins*, **63**, p. 1137.
- [67] Takeda, Y. and Adkins, B. (1974), 'Determination of Synchronous Machine Parameters Allowing for Unequal Mutual Inductances', *Proc. I.E.E.*, **121**, p. 1501.
- [68] Dineley, J. L. and Fenwick, P. J. (1974), 'The Effect of Prime-mover and Excitation Control on The Stability of Large Steam Turbine Generators', *Trans. I.E.E.E.*, PAS-93, p. 1613.
- [69] Rao, K. V. N. *et al.* (1974), 'Peak Inverse Voltages in the Rectifier Excitation Systems of Synchronous Machines', *Trans. I.E.E.E.*, PAS-93, p. 1685.
- [70] Faruqi, F. A. (1973), *Optimal Feed-back Design for Transient Stability of Multi-machine Power Systems*, Ph.D. Thesis, London University.
- [71] Hannalla, A. Y. and Macdonald, D. C. (1974), *Numerical Analysis of the Transient Field Problems in Electrical Machines*, Internal Report, Imperial College.

Index

- Adaptive control, 119, 207.
- Air-gap flux density, 2, 43.
 - m.m.f., 15, 43.
- Ampere's law, 223, 236.
- Analyser, network, 193.
- Approximations, 7, 15, 23, 38, 45, 67, 136, 191, 220, 253.
- Autonomous system, 111, 113.
- Axis coil, 33, 63, 72.
 - components of current, 52, 134, 264.
 - flux linkage, 70.

- Bellman's equation, 117, 207.
- Brushes, 4, 7, 34, 256.

- Characteristic equation, 110, 159.
- Coil axis, 5, 15.
- Commutator machine, 9, 255.
 - winding and brushes, 4, 5, 8.
- Complex numbers, xiv, 37, 45, 263.
- Complex variables and equations, 99, 242.
- Concentrated coils, 10, 25.
- Connection matrix, 259.
- Constants of the machine, xiii, 17, 27, 88.
- Controlability, 104.
- Control system theory, vi, 104.
- Control variables, 102, 110, 153.
- Conventions, 5–11, 18, 20, 48, 57, 135, 264.
- Core loss, 214.
- Cost function, 115.
- Current distribution, 14.

- Derivative operator, vi, 13, 267, 671.
- Developed diagram, 3, 14, 43.
- Diesel-driven generator, 37, 149.
- Digital computer, v, 118, 254.
- Direct axis, 5, 33, 44.

- Direct current machine, 4, 33, 41.
 - armature reaction, 22, 37.
 - cross-field, v, 7, 28.
 - short circuit, 37.
 - time constants, 39–41.
 - transient resistance, 40.
- Divided-winding rotor, 130, 157.
- Doherty, xv, 108, 185.
- Dynamic programming, 117, 207.

- Eddy currents, vi, 75, 213–216, 221–229, 255.
- Effective number of turns, 26.
- Eigenvalue and eigenvector, 110, 159.
- Electrical torque, 19–23.
- Equal-area criterion, 109, 192.
- Equivalent axis coils, 9.
- External impedance, 90, 106.

- Faraday's law, 223, 236.
- Fault conditions, 37, 160, 179, 191, 198, 243–251.
- Fictitious currents and voltages, xv, 18, 72.
- Flux, axis of, 14.
 - leakage, 10, 25, 27, 32.
 - linkage, 29.
 - main, 10, 14, 25.
 - mapping, 14, 27, 216–218.
- Forced oscillations, 147–150.
- Fourier series, 59, 67, 176, 261.
- Free oscillations, 151.

- General equations, 16–22, 58, 70, 94.
 - theory, v, xiii, 8, 16, 28, 263.
- Generalized machine, vi, 8.
- Generalized phasor, 265.

- Harmonics, vi, 23, 67, 174, 177, 255, 261.
- Heaviside, vi, 267.

278 The General Theory of Alternating Current Machines

- Historical development, xiv.
Homogeneous equations, 112.
Hunting, 150, 262.
- Idealized machine, v, xiii, 5, 8, 22, 44.
Impedance matrix, 18, 34, 60, 62, 95, 96, 260.
Impressed voltage, 11, 71.
Induced and internal voltages, 12, 30, 45, 50, 70.
Inductance, 11–13, 17, 26, 27.
 complete, 13, 76.
 leakage, 12, 80.
 magnetizing, 80.
 self and mutual, 32, 77, 91.
 zero sequence, 71.
Induction motor, 4, 44, 94, 235, 240–253.
 capacitor, 240.
 change-pole, 69, 255.
 comparison with synchronous machine, 244.
 complex form of equations, 242.
 deep bar, 236.
 double-cage, 235, 241.
 equivalent, circuit, 47, 245.
 magnetizing current and reactance, 46–47.
 operational impedance, 243, 251.
 phasor diagrams, 45.
 short circuit, 243–249.
 single-phase, 4, 240.
 slip, 45, 101, 267.
 synchronous reactance, 243.
Inertia, moment of, 19.
Infinite bus, 53, 101, 262.
Initial value, 39.
Input variable, 102.
Interconnected systems, 257.
Invariance of power, 66, 257, 265–267.
- Kron, xv, 8, 11, 19, 95.
- Laplace transforms, vi, 39, 110, 163–166, 175, 243, 246, 249, 267–269.
Liapunov, 113, 208.
Linear motor, 3, 262.
Load flow study, 51, 210.
 loss, 214.
- Magneto-motive force (m.m.f.), 14–15, 42, 48.
Measurement techniques, 27.
Micro-machine, vii, 23, 130, 154, 157, 253.
Multi-machine system, 102, 106, 119, 208, 253.
Mutually coupled coils, 10, 91.
- Non-linear equations, 35, 99.
 system, 103, 112, 114.
Notation, vii, xvi, 43, 160.
Numerical integration, 98, 118.
- Observability, 104.
Off-line and on-line control, 119, 207.
Operational impedance, 77, 83, 243.
 reactance, 267.
Optimal control, 115, 206.
Optimality, principle of, 116.
Original value, 39.
Oscillogram, analysis of, 93, 167.
Output variables, 102.
- Parameters, xiii, xvi, 26.
Park, xv, 11, 18, 22, 61, 67, 70, 94, 136, 241, 253, 261.
Partial fractions, 85.
Performance index, 115, 207.
Permeance, air-gap, 68, 261.
Per-unit system, xvi, 12, 19, 46, 269–272.
 advantages, 13, 21.
 axis currents, 63.
 transformer, 12, 269.
Phase equations, 60, 62, 254–255, 261.
Phase-plane diagram, 103, 113.
Phasor, vii, 263.
 generalized, 264.
 space and time, 42.
 equations, 36, 135.
Primitive machine, v, xv, 8, 10, 18, 28, 33, 72, 258, 265.
Problems, types and methods of solution, 98–100.
Pseudo-stationary coil, 9, 17, 33, 72.
- Quadrature axis, 5, 30, 44.
 field winding, 128.
- Reactance, leakage, 24, 49.
 magnetizing, 49, 52.
 negative sequence, 143–145, 177.
 positive sequence, 178.
 transient and subtransient, 84, 89, 170, 184, 243, 247, 250–251.
 zero-sequence, 178.
Reference frame, xv, 9, 53, 63, 66, 94, 100, 109, 156, 208, 240, 256, 265.
Regulator, 102, 119, 124–129, 153–158, 196, 200.
Reluctance motor, 69, 256, 260.
 torque, 136.
Reluctivity, 219.
Repulsion motor, 256.
Riccati equation, 118, 207.
Rotating field theory, 44.

- Rotating flux wave, 42, 164.
 Rotational voltage, 18, 30, 73.
 Rupturing capacity, 191.
- Salient poles, 2, 5, 15, 44, 51, 260–261.
 Saturation, vi, 22, 38, 197, 213, 216–221, 254–265, 262, 264.
 Selsyns, 257–260.
 Separatrix, 113.
 Skin effect, 221, 225, 231.
 Small changes and oscillations, 35, 53, 100, 148.
 Special machines, vi, 255.
 Speed governor, 102, 119, 124, 132, 153.
 Stability, 110, 113.
 asymptotic, 113.
 steady-state, 100, 151–159.
 transient, 100, 191, 251.
 Starting of motor, 135, 233.
 State space and state variable, vii, 103, 261.
 Steady operation, 16, 42, 133.
 Step-by-step calculation, vii, 99, 110, 118, 198, 210, 219, 251.
 Adams-Bashforth, 122.
 Newton-Raphson, 261.
 Predictor-corrector, 121.
 Runge-Kutta and Kutta-Merson, 121, 261.
 Superposition, 23, 39, 51, 138, 160, 172, 196, 213, 267–268.
 Swing curve, 109, 112, 118, 198–201.
 Switching time, 112.
 Synchronous machine, 4, 48, 51, 72, 78, 87, 91, 104, 115, 124–212, 271.
 automatic control, 124, 152–159.
 assumptions, 67, 136, 190, 220.
 asynchronous operation, 136, 204.
 back swing, 201.
 constant flux linkage theorem, 108, 185, 192.
 damper winding, 5–7, 74, 78, 87, 90, 261.
 damping factor, 106, 108.
 equivalent circuit, 51, 82, 141, 180–185, 233, 234.
 inertia constant, 20.
 modified machine, 90, 106.
 natural frequency, 149.
 operating chart, 56, 152, 154.
 operational admittance, 85, 231.
 per-unit system, 271.
 phasor diagram, 49, 50, 52, 54, 188, 190.
 Potier reactance, 22, 26.
 power-angle curve, 54, 109, 149, 152.
 pulsating torque, 137.
 rectifier excitation, 205.
 root loci, 155, 158.
 rotor angle, 53, 101, 105, 157, 203.
 saturated reactance method, 217.
 short circuit, 160–179, 200.
 simplifications, 108, 200, 209.
 slip, 138.
 state-space model, 104, 205.
 stability limit curve, 57, 154–159.
 sudden load change, 193–197, 201.
 summary of equations, 87.
 synchronizing, 137.
 torque coefficient, 56.
 synchronous reactance, 50, 52, 84.
 torque-speed curve, 136–140.
 voltage behind synchronous, transient and subtransient reactance, 51, 187–189.
- Terminology, xvi, 70, 88.
 Time constants, 83, 89, 170, 243.
 Torque, 19, 21, 34.
 equation, 22, 74, 95, 96, 140.
 Trajectory, 103, 115.
 Transition matrix, 112.
 Transformer, 10, 269.
 voltage, 18, 28.
 Transformation, 9, 53, 61, 64, 94, 130, 208, 256, 259, 264–266.
 Two-axis theory, vi, xv, 8, 44, 51, 67, 70, 255–259.
- Unbalanced operation, 178, 255.
- Vector, vii, 103.
- Winding, cage, 5, 75, 97.
 classification, 4, 7.
 distribution, 25, 69.
 factor, 26.
 fractional slot, 3.
- Zero-sequence current and voltage, 64, 220.