Power System Simulation

J.-P. Barret

Formerly Scientific Advisor Power Systems Department Research and Development Division Electricité de France

P. Bornard

Manager Power Systems Department Research and Development Division Electricité de France

B. Meyer

Deputy Branch Manager Power System Economics and Design Power Systems Department Research and Development Division Electricité de France



London · Weinheim · New York · Tokyo · Melbourne · Madras

Contents

Ack	Acknowledgements		
1	Introduction	1	
1.1	The study of electrical power systems	1	
1.2	Simulation tools	2	
	Further reading	5	
2	Modelling	6	
2.1	The role, importance and constraints of modelling	6	
2.2	Models of knowledge and of behaviour	7	
2.3	Data	11	
	Further reading	11	
3	Steady state operation	12	
3.1	Introduction	12	
3.2	System modelling	13	
3.3	Power system equations	17	
3.4	Load flow calculations	20	
3.5	Direct current approximation	30	
3.6	From load flow calculations to constrained		
	optimization	- 33	
	Appendix 3.A Recursive quadratic programming algorithms	46	
	References	52	
4	Short-circuit currents	57	
4.1	Introduction	57	
4.2	Definition of the short-circuit current	58	
4.3	Method of calculating short-circuit currents	60	
4.4	Modelling network elements for short-circuit		
	calculations	66	
	Further reading	78	

vi CONTENTS

5	Long-term dyna	amics	79
5.1	Introduction		79
5.2	Long-term dyna	amics model	80
	Appendix 5.A	Representation of a classic thermal unit with a drum boiler	88
	Appendix 5.B	Representation of a pressurized water reactor	
		(PWR) nuclear unit	91
	Appendix 5.C	Modelling a hydroelectric power unit	94
	Further reading	2	97
6	Stability and el	ectromechanical oscillations	98
6.1	Introduction		98
6.2	Transient stabil	lity	99
6.3	Small signal sta	bility	119
	Appendix 6.A	Representation of the saturation	125
	Appendix 6.B	Representation of faults	126
	Appendix 6.C	The representation of rotating machines taking	;
		the dampers into account	129
	References		133
	Further reading		134
7	Electromagneti	c transients	137
7.1	Introduction		137
7.2	Physical pheno	mena calling for modelling of	
	electromagneti	c transients	138
7.3	Types of mode	lling used	140
7.4	Method of solu	ition	174
	Further reading		176
8	Harmonics		177
8.1	Introduction		177
8.2	Modelling of sy	stems in harmonic conditions	178
8.3	Method of calc	ulation	187
8.4	Propagation of	harmonics in systems	188
8.5	Conclusion		202
	Appendix 8.A	Representation of system components	202
	Appendix 8.B	Distribution system	205
	References		206
	Further reading	g	207
9	Digital real-tim	e simulation	208
9.1	Introduction		208
9.2	Real-time simu	lation for training dispatchers	209

•

9.3	Real-time simulation for tests on equipment Further reading	224 230		
10	10 Computing facilities			
10.1	Introduction	231		
10.2	Information technology architecture	232		
10.3	The graphical user interface	239		
	Further reading	242		
11	New developments	243		
11.1	The coupling of different time-scales	243		
11.2	Bringing together stability and long-term dynamics	247		
11.3	New needs, new responses	248		
	Appendix 11.A EUROSTAG integration methods	255		
	Appendix 11.B Automatic differentiation method	257		
	Appendix 11.C Application of a unique model of long-term dynamics and transient stability			
	(EUROSTAG)	261		
	Appendix 11.D A modelmaker-solver modelling application	263		
	References	267		
	Further reading	267		
Appe	endix A: The modelling of direct current links	270		
A.1	The composition of direct current links	270		
A.2	Mode of operation and control of a station	270		
A.3	Characteristics of a direct current station with			
	$U_{\rm d} = f(I_{\rm d})$	273		
A.4	Mode of operation of two stations connected by			
	a single direct current link	274		
A.5	The modelling of direct current links	275		
	Further reading	277		

Index

278