
Contents

List of figures	ix
List of tables	xvii
Preface	xix
Acknowledgments	xxiii
Authors	xxv
Nomenclature	xxvii
 Chapter 1 Introduction to modeling of gas turbines	 1
1.1 GT performance	2
1.2 GT classification	3
1.3 Considerations in GT modeling	4
1.3.1 GT type	4
1.3.2 GT configuration	4
1.3.3 GT modeling methods	5
1.3.3.1 Linear and nonlinear models	6
1.3.3.2 Deterministic and stochastic (probabilistic) models	6
1.3.3.3 Static and dynamic models	7
1.3.3.4 Discrete and continuous models	7
1.3.4 GT control system type and configuration	7
1.3.5 GT modeling objectives	8
1.3.5.1 Condition monitoring	8
1.3.5.2 Fault detection and diagnosis	9
1.3.5.3 Sensor validation	9
1.3.5.4 System identification	9
1.3.5.5 Design and optimization of control system	9
1.3.6 GT model construction approaches	10
1.3.6.1 White-box models	10
1.3.6.2 Black-box models	10
1.3.6.3 Gray-box models	10
1.4 Problems and limitations	11
1.5 Objectives and scope	12
1.6 Summary	13

Chapter 2	White-box modeling, simulation, and control of GTs.....	15
2.1	White-box modeling and simulation of GTs	15
2.1.1	White-box models of low-power GTs	15
2.1.2	White-box models of IPGTs.....	17
2.1.3	White-box models of aero GTs.....	25
2.2	White-box approach in control system design.....	28
2.3	Final statement.....	31
2.4	Summary	32
Chapter 3	Black-box modeling, simulation, and control of GTs.....	33
3.1	Black-box modeling and simulation of GTs.....	33
3.1.1	Black-box models of low-power GTs.....	33
3.1.2	Black-box models of IPGTs.....	34
3.1.3	Black-box models of aero GTs	37
3.2	Black-box approach in control system design	39
3.3	Final statement.....	43
3.4	Summary	45
Chapter 4	ANN-based system identification for industrial systems	47
4.1	Artificial neural network (ANN).....	47
4.2	The model of an artificial neuron.....	48
4.3	ANN-based model building procedure	49
4.3.1	System analysis	50
4.3.2	Data acquisition and preparation.....	50
4.3.3	Network architecture	51
4.3.3.1	Feedforward neural network	51
4.3.3.2	Feedback neural network	51
4.3.4	Network training and validation	53
4.3.4.1	Number of hidden layers and neurons.....	55
4.3.4.2	Training algorithms.....	55
4.3.4.3	Transfer functions.....	55
4.3.4.4	Weight values	55
4.3.4.5	Error criteria	57
4.3.4.6	Training stop criteria and overfitting	57
4.4	ANN applications to industrial systems.....	58
4.5	ANN limitations	59
4.6	Summary	60
Chapter 5	Modeling and simulation of a single-shaft GT	61
5.1	GT Simulink® model	62
5.2	ANN-based system identification.....	62
5.2.1	Data generation.....	68
5.2.2	Training process.....	69

5.2.3	Code generation	69
5.3	Model selection process	72
5.4	Summary	83

Chapter 6 Modeling and simulation of dynamic behavior of an IPGT

85

6.1	GT specifications	86
6.2	Data acquisition and preparation	86
6.3	Physics-based model of IPGT by using Simulink [®] : MATLAB [®]	88
6.3.1	Measured parameters	89
6.3.2	Calculated or estimated parameters	89
6.3.2.1	Turbine inlet stagnation pressure	90
6.3.2.2	Turbine outlet stagnation pressure	90
6.3.2.3	Specific heat of air and gas at constant pressure	90
6.3.2.4	Turbine inlet temperature and mass flow rate of air	91
6.3.2.5	Efficiency and corrected parameters of the compressor and turbine	91
6.3.3	Model architecture	92
6.3.4	Discussion on physics-based modeling approach	93
6.4	NARX model of IPGT	98
6.5	Comparison of physics-based and NARX models	99
6.6	Summary	109

Chapter 7 Modeling and simulation of the start-up operation of an IPGT by using NARX models

111

7.1	GT start-up	112
7.2	Data acquisition and preparation	112
7.3	GT start-up modeling by using NARX models	113
7.3.1	NARX model training	116
7.3.2	NARX model validation	116
7.4	Summary	127

Chapter 8 Design of neural network-based controllers for GTs

129

8.1	GT control system	129
8.2	Model predictive controller	132
8.2.1	Design of ANN-based MPC	133
8.2.1.1	System identification of ANN-based MPC	135
8.2.1.2	Adjustment of controller parameters for ANN-based MPC	136
8.2.2	Simulation of ANN-based MPC	138
8.3	Feedback linearization controller (NARMA-L2)	138
8.3.1	Design of NARMA-L2	140

8.3.2	Simulation of NARMA-L2.....	141
8.4	PID controller	142
8.4.1	Design of PID controller	144
8.4.2	Simulation of PID controller	145
8.5	Comparison of controllers performance	147
8.6	NMP systems	147
8.7	Summary	152
	References	153
	Index	169