Fuzzy Logic Control (FLC) is an important alternative method to the conventional Proportional, Integral, and Derivative (PID) control method for use in nonlinear systems. This book, therefore, highlight the feasibility and effectiveness of fuzzy logic control in application to mathematical models of two basic types of steam turbines; straight expansion and single-automatic extraction turbines. The derived performance of the developed mathematical models, in terms of input/output duty variables without mean of control, is found to be in a good agreement with the actual performance of typical steam turbines with practical technical data and operating conditions. Model components exhibit nonlinear behavior. A comparison is made between the efficiency of Fuzzy Logic Control and the conventional PID control for the dynamic responses of the closed loop drive system. In case of straight expansion steam turbines, the control task is either speed or backpressure control. In case of single extraction steam turbines, the control task is to maintain both speed and extraction pressure of the turbine constants. This is done in presence of severe changes in load and/or steam demand conditions.

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Preface

Steam turbines are used in industry to drive electrical/mechanical loads and/or to produce steam for heating processes. For improved dynamic behavior of steam turbine control systems, a good simulation of the system mathematical model should be implemented. The transient behavior of the system should be well-known for the safe operation and reliable control in presence of various types of disturbances.

About this Book:

This book deals with dynamic simulation and analysis of the transient behavior of the steam turbine control systems. It also presents an implementation of the fuzzy logic control to steam turbines during cyclic operation. The book consists of six chapters, organized as follows:

Chapter 1 provides a general introduction to the current techniques of steam turbine control, speed and pressure control of the turbine in specific. Basic steam turbine types, control system configurations as well as recommend functional and performance characteristics related to steam turbine control systems are presented.

Chapter 2 reviews the basics of classical PID implementation and design algorithms. Practical implementation issues such as anti-windup and disturbances are discussed, including a brief background on the limitations of this most popular technique of control. In addition, the concepts of fuzzy set and the constituent components of a fuzzy controller are described.

In **chapter 3**, a nonlinear detailed mathematical model for the straight expansion steam turbine (no extraction or bleed points are available along the expansion process) control system will be developed and simulated. Steam turbine performance analysis (model parameters are compared to those of actual turbine data) and control system components model are included.

In **chapter 4**, the model of the straight expansion steam turbine, developed in chapter 3, is made to function inside a generalized control system. Only one of the two control objectives (turbine speed or backpressure) can be controlled at a time. Control signals in the governing valves-set are generated by means of PID controller or a fuzzy inference calculation to correspond to the anticipated load and/or process demand profiles. Control signals are applied to respective regulatory function actuators in the steam turbine to implement the desired trajectory of steam plant operation. The results that will be obtained by the Fuzzy controlled turbine are to be compared to those obtained from the PID controlled turbine.

Single extraction steam turbines have two sections, high-pressure (HP) and low-pressure (LP), separated by one controlled extraction point available along the expansion process. In **chapter 5**, a nonlinear detailed mathematical model for the single extraction steam turbine control system will be developed and simulated. Steam turbine performance analysis (model parameters are compared to those of actual turbine data) and control system components model are included.

In **chapter 6**, the model of the single extraction steam turbine, developed in chapter 5, is made to function inside a generalized control system. The two control objectives (turbine speed and extraction pressure) are controlled at a time. Control signals in the governing valves-set are generated by means of PID controller or a fuzzy inference calculation to correspond to the anticipated load and/or process demand profiles. Control signals are applied to respective regulatory function actuators in the steam turbine to implement the desired trajectory of steam plant operation. The results that will be obtained by the Fuzzy controlled turbine are to be compared to those obtained from the PID controlled turbine.

The book concludes with a brief description of the advantages of using fuzzy logic controllers over the conventional PID controllers through the implementation of each type of controller on steam turbine models. Also, in the ”***Conclusions***” section, an emphases is assigned to the detailed mathematical modeling of the steam turbine control systems, based on the steam thermodynamic property diagram (the enthalpy-entropy diagram).

There are many software functions and modules, developed with MATLAB-Simulink software, contributed in developing the results of the present study on steam turbine control systems. Selected models are included in the ”***Appendices***” section, which represent the two types of steam turbines under investigation, the straight expansion and the single extraction steam turbines.

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And finally never enough thanks to my wife, for her great support and encouragement for this work to see the light.

Abbreviations and Symbols

ABBREVIATIONS

FLC	Fuzzy Logic Controller
FOL	First order lag transfer function
FPID	Fuzzy-PID Controller
HP	High Pressure
IAE	Integral of the Absolute Error
ISE	Integral of the square Error
ITAE	Integral Time multiply the Absolute Error
LP	Low Pressure
PID	Proportional, Integral and Derivative

GREEK LETTERS

$\boldsymbol{\alpha}$	Part load factor
$\boldsymbol{\beta}$	Fraction of turbine power
$\boldsymbol{\eta}$	Turbine efficiency
$\boldsymbol{\delta}$, $\boldsymbol{\Delta}$	Difference
$\boldsymbol{\theta}$	Constant that depend on turbine performance
$\boldsymbol{\omega}$	Turbine speed, rad/s
$\boldsymbol{\mu}$	Membership function for fuzzy inference system
$\boldsymbol{\tau}$	Time constant, sec

NOMENECLATURE

C_{eq}	equivalent viscous friction coefficient of the turbine and load (turbine shaft), N.m.s
ce_s	Change in the speed error signal
ce_p	Change in the pressure error signal
cu_s	Change in the speed control signal
cu_p	Change in the pressure control signal
D	Delay time, s
e_s	Error in the speed signal

e_p	Error in the pressure signal
f	Correction factor for part load efficiency
G	Transfer function
H	Hysteresis, %
h_1	Steam specific enthalpy at turbine inlet (steam chest), kJ/kg
h_2	Steam specific enthalpy at turbine exit (straight expansion turbines), kJ/kg
h_2	Steam specific enthalpy at HP-section exit (single extraction turbines), kJ/kg
h_3	Steam specific enthalpy at turbine LP-section inlet, kJ/kg
h_4	Steam specific enthalpy at turbine LP-section exit, kJ/kg
I	Shaft inertia, kg.m^2
J	Performance index
K_t	Constant for Stodula's relation (straight expansion turbines), m^2
K_{t1}	Constant for Stodula's relation (single extraction turbines, HP-section), m^2
K_{t2}	Constant for Stodula's relation (single extraction turbines, LP-section), m^2
$K_{v,x}$	Valve coefficient (function of valve position), m^2
$K_{v,s}$	Maximum valve coefficient, m^2
K_p	Proportional part of the PID-controller
K_i	Integral part of the PID-controller
K_d	Derevative part of the PID-controller
K_e	Constant for the error signal input to the Fuzzy-PID controller
K_{ce}	Constant for the change of error signal input to the Fuzzy-PID controller
K_{iu}	Constant for the integration of the control signal output from the Fuzzy-PID controller
K_{cu}	Constant for the differentiation of the control signal output from the Fuzzy-PID controller
K_{pv}	Pilot valve gain
K_1	Actuator gain for the first part of the transfer function
K_2	Actuator gain for the second part of the transfer function
$\dot{m}_s$	Steam quantity (straight expansion turbines), ton/h
$\dot{m}_1$	Steam quantity at turbine inlet (single extraction turbines), ton/h
$\dot{m}_2$	Steam extraction flow (single extraction turbines), ton/h
$\dot{m}_3$	Steam exhaust flow (single extraction turbines), ton/h

$\dot{m}_{exh}$	Exhaust demand flow, ton/h
$\dot{m}_{ext}$	Extraction demand flow, ton/h
N	Turbine speed, rpm
n	Number of steam throttle valves
P_o	Steam inlet pressure, bar
P_{1v}	Pressure at inlet valve opening, bar
P_1	Chest steam pressure, bar
P_2	Backpressure (straight expansion turbines), bar
P_2	Extraction pressure (single extraction turbines), bar
P_{3v}	Pressure at LP-valve opening(single extraction turbines), bar
P_3	Pressure at LP-section inlet (single extraction turbines), bar
P_4	Backpressure (single extraction turbines), bar
P_c	Control pressure, bar
R	Degree of reaction
S_v	Valve stroke, mm
S_1	Steam entropy at steam chest, kJ/kg.K
S_3	Steam entropy at LP-section inlet (single extraction turbines), kJ/kg.K
t	time, s
T_o	Steam inlet temperature, ^oC
T_1	Chest steam temperature, ^oC
T_3	Steam temperature at LP-section inlet (single extraction turbines), ^oC
u	Control signal
V_c	Voltage output from controller, volt
V_{th}	Threshold voltage for the pilot valve, volt
V_s	Voltage output from speed sensor, volt
V_p	Voltage output from pressure sensor, volt
V_1	HP-valve racks of an extraction turbine
V_2	LP-valve racks of an extraction turbine
$\forall_{exh}$	Exhaust header volume, m^3
$\forall_{ext}$	Extraction header volume, m^3
v	Steam specific volume, m^3/kg
$\dot{W}_t$	Turbine power output, MW
$\dot{W}_L$	Driven load, MW
X	Valve position, %
X_H	Valve position including hysteresis, %

X_d	Valve position including time delay, %

SUBSCRIPTS AND SUPERSCRIPTS

c	control
exh	exhaust
ext	extraction
is	isentropic
p	pressure
pv	pilot valve
s	speed
sm	servomotor
t	turbine
v	valve