SELF TUNING TECHNIQUES FOR LOAD FREQUENCY CONTROL

by

H.K.D.A.D.U. ANNAKKAGE

A thesis submitted to

THE UNIVERSITY OF MANCHESTER

for the degree of

DOCTOR OF PHILOSOPHY

in the faculty of technology

December 1986

Power Systems Laboratory
Department of Electrical Engineering and Electronics
The University of Manchester Institute of Science and Technology

To my brother Nihal Kumara

ABSTRACT

The load frequency control of inter-connected power systems using the self tuning control techniques is presented in this thesis. Different self tuning techniques are analysed and it is shown that with some controllers the integral action, which is essential to provide the zero steady state condition, is achieved as a result of the chosen predictive model. Some schemes where the integral action is achieved through the choice of the cost function and the predictive model as well as schemes with the integral action built into the control algorithm are presented. It is shown that the requirement of the integral action can be avoided by using a predicted load level variations as a feed back signal.

It is also shown that for slow sampling rates the basic minimum variance controller can function but as the sampling rate is increased to cover the required band width, the controller fails. The application of pole assignment techniques and generalised minimum variance control techniques are considered and it is shown that a stable control situation can be achieved with sampling rates at which the minimum variance controller is unstable.

DECLARATION

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institution of learning.

ACKNOWLEDGEMENTS

I am indebted to my supervisor, Dr. F.M. Hughes, for his constant guidance, advice and encouragement during the preparation of this thesis.

I would like to express my gratitude to:

the Association of Commonwealth Universities for their sponsorship,

the University of Moratuwa, Sri Lanka for granting me study leave,

Peter Ashmole and Roger Bowdler in Technology planning and research division for useful discussions and information about the CEGB system.

David Lee for his valuable help, and Diana Cullen for typing this thesis with careful attention.

I would also like to express my gratitude to my friends and colleagues who helped in the completion of this work.

Finally, I am greatly indebted to my parents, brothers and sister for their support and encouragement.

LIST OF SYMBOLS AND ABBREVIATIONS

(a) Self-tuning Control and Identification

$d(t)$	Disturbance variable
$r(t)$	Reference signal
$u(t)$	Input variable
$y(t)$	Output variable
T_s	Sampling interval
β	Damping factor
ω_n	Natural frequency of oscillations
ϕ	Cost function
$\xi(t)$	Noise disturbance
$\hat{\xi}(t)$	Estimated value of $\xi(t)$
$\underline{\theta}$	Unknown parameter vector
$\hat{\underline{\theta}}$	Estimated $\underline{\theta}$
ρ	Forgetting factor

(b) Power System Models and Load Frequency Control

a_{12}	Ratio between the rated capacities of areas 1 and 2
B_s	Frequency bias setting
D	Frequency dependancy of the load (pu MW/Hz)
f	Frequency (Hz)
f_0	Nominal frequency (Hz)
k_I	Integral gain setting
k_p	Load frequency sensitivity (Hz/puMW)
k_{Pr}	Proportional gain setting
H	Machine inertia constant (s)
P_c	Generation change control command (pu)

P_d	Load demand (pu)
P_r	Rated power (MW)
P_T	Turbine output power (pu)
P_t	Tie line power transfer (pu)
P_{t12}	Tie line power transfer from area 1 to area 2 (pu)
P_v	Turbine valve opening (pu)
R	Load frequency droop characteristics (Hz/puMW)
T_{12}	Tie line synchronising coefficient (pu)
T_G	Governor actuator time constant of steam turbine units (s)
T_1, T_2, T_R	Time constants associated with speed governing systems of hydro turbine units (s)
T_p	Power system time constant associated with the machine inertia (s)
T_T	Time constant of a steam turbine (s)
T_w	Penstock time constant (s)
T_{RS}	Time constant associated with mechanical speed governors (s)
$V_{\Delta f}$	Variance of frequency error
$V_{\Delta P_t}$	Variance of tie line power deviation
W	Weighting factor used in calculating a single output variable y; $y = w\Delta P_t + (1 - w)\Delta f$
W_{kin}	Kinetic energy of the rotating machines
W_{kin}^0	Nominal value of W_{kin}
Δf	Change in frequency from nominal valve (Hz)
ΔP_c	Change in command signal (pu)
ΔP_d	Change in load demand (pu)
ΔP_T	Change in turbine output power (pu)

ΔP_t	Tie line power deviation (pu)
ΔP_v	Change in turbine valve opening (pu)
δ_1	Power angle at the area 1 end of the tie line (rad)
δ_2	Power angle at the area 2 end of the tie line (rad)
λ	Weighting factor that determine the relative penalty attach to $V_{\Delta P_t}$ in calculating w

(c) Mathematical Operations

Δ	Incremental operator
$E\{\ \}$	Statistical expectation
q^{-1}	Backward shift operator defined by: $q^{-1}x(k+1) = x(k)$

(d) Abbreviations

ACE	Area Control Error
LFC	Load Frequency Control
LQP	Linear dynamics and Quadratic Performance index
LQG	Linear dynamics, Quadratic performance index and Gaussian distributed uncertainties
PI	Proportional plus Integral
PID	Proportional, Integral plus Derivative
ss ; as a suffix	Steady state value

CONTENTS