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Dynamic simulations of hydro turbine and its state estimation based LQ control

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Abstract

The effect of the elasticity of the water column in the penstock of a hydro power plant represents an irrational mathematical function. In this paper, this function is reduced to a lower order using the *H*-infinity approximant method. The gate position-turbine power nonlinear steady state characteristic is modeled by this reduced order function, and then, the time domain and frequency domain simulations of turbine power are presented and compared with the widely known Padé approximant method for order reduction of irrational functions.

State estimation of the inelastic and elastic fifth order state space model of the hydro plant is also performed. The method adopted for state estimation is based on second order polynomial approximations of a multi-dimensional interpolation formula. It is found that the state estimation of the plant by this method outperforms the linear Kalman filter in terms of estimation. Then, a state estimation based linear quadratic (LQ) control approach for the hydro turbine speed control is also presented. The simulated results are compared to the linear quadratic regulator that assumes all the states are measurable.

Keywords: Estimation; Hydro turbine; Linear quadratic; Water column; Control

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1. Introduction

A power system study largely depends on the type of models used, which, in turn, are required for the study of low frequency oscillations, islanding and isolated operation, system restoration following a break up, load acceptance and water hammer dynamics in the penstock etc. [1], and the approximation of high order models by low order models seeks importance, particularly in the controller design. The cost of the controller increases with the model order. For designing an efficient hydro turbine control system, it becomes necessary to use a reduced order model with the elastic water column effect in the penstock. The numerous literatures [2–4] on governor design or stability studies of the hydro plant have considered a simple linear model neglecting

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Nomenclature

CARE	continuous algebraic Riccati equation
EV	eigenvalue
EEV	estimator eigenvalue
EKF	extended Kalman filter
LQ	linear quadratic
LQG	linear quadratic Gaussian
LQR	linear quadratic regulator
LTR	loop transfer recovery
REV	regulator eigenvalue
SDDF	second order divided difference filter
SISO	single input single output
TF	transfer function
Δq	incremental flow deviation, p.u.
Δz	incremental guide vane/wicket gate position deviation, p.u.
Δh	incremental head deviation, p.u.
Δw	incremental speed deviation, p.u.
Δp_{m}	incremental torque deviation, p.u.
d	constant, $=2T_{\mathrm{e}}$, s
z	guide vane/wicket gate position, p.u.
q	turbine flow, p.u.
h	turbine head, p.u.
w	turbine speed, p.u.
$\Delta Q(s)$	Laplace transform of Δq, p.u.
$\Delta G(s)$	Laplace transform of Δz, p.u.
$\Delta H(s)$	Laplace transform of Δh, p.u.
$\Delta P_{\mathrm{m}}(s)$	Laplace transform of Δp_{m}, p.u.
T_{a}	accelerating torque, p.u.
w_0	base angular speed (377 rad/s)
D	damping factor
T_{e}	elastic time, s
F	friction loss in hydraulic structure, p.u.
Z_{p}	hydraulic surge impedance, $=T_{\mathrm{w}}/T_{\mathrm{e}}$
p_{l}	load torque, p.u.
T_{rb}	runner blade servomotor constant, p.u.
p_{m}	turbine torque developed, p.u.
T_{w}	water starting time, s
T_{gv}	wicket gate servomotor constant

Greek symbols

$\Delta\theta$	incremental runner blade position deviation, rad
δ	rotor angle, rad
θ	runner blade position, rad

Subscripts

a	accelerating
0	base
rb	blade servomotor
c	cutoff