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Parameter Estimation and Identifiability Study of Wind Turbine Generator Models

by

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Abstract

The power system analysis of wind turbine generators requires accurate modelling and robust estimation of parameters. However, the parameters are influenced by electrical factors, such as load level, and environmental factors, such as temperature. To avoid parameter variations with these factors, parameter estimation should be applied under various operating conditions. Nowadays, various estimation methods are available. The commonly used estimation methods based on local iterative optimisation lack accuracy because they depend on initial values. In addition, such methods do not apply sensitivity analysis, to test the significance of the parameters, which is defined as 'identifiability'. Previous methods have not proposed mathematical ways to select the signal which has the richest information on estimating the parameters.

The aim of this thesis is to develop a complete solution to estimate the parameters in wind generation unit models with high accuracy under normal condition. Initially, sensitivity analysis methods are used to select the identifiable parameters and the set of signals with the richest information. This sensitivity analysis makes the estimation problem well-conditioned and more efficient. After the sensitivity analysis, the global optimisation method is applied to find the numerical values efficiently and accurately under normal operation condition.

The principle contribution of this thesis is to propose a new method for parameter estimation of wind turbine generators with the advantage that no special excitation is required.

Declaration of Authorship

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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List of Publications

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[1] Q. Fang and R. Zivanovic, “Identifiability analysis of a wind generation unit model using global sensitivity analysis,” 2016 IEEE International Conference on Industrial Technology (ICIT), Taipei, 2016, pp. 993-998.

[2] N. Ertugrul, G. Bell, G. G. Haines and Q. Fang, “Opportunities for battery storage and Australian energy storage knowledge bank test system for Microgrid Applications,” 2016 Australasian Universities Power Engineering Conference (AUPEC), Brisbane, Australia, 2016, pp. 1-6.

[3] Q. Fang, “A global optimization framework for parameter estimation of a wind generation unit model,” IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society, Yokohama, 2015, pp. 000048-000052.

[4] Q. Fang and R. Zivanovic, “Parameter identification of a wind generator unit RMS model using sparse grid optimization algorithm,” Proceedings of 2014 International Conference on Modelling, Identification & Control, Melbourne, VIC, 2014, pp. 283-288.

Submitted:

[1] Qing FANG and Rastko ZIVANOVIC, “Identification of a Wind Turbine Generator Model Using Sparse Grid Optimisation Algorithm”, International Journal of Electrical Power & Energy Systems.

[2] Qing FANG and Rastko ZIVANOVIC, “Application of Global Methods in DFIG based Wind Turbine Generator Model Identification and Identifiability Analysis”, International Transactions on Electrical Energy Systems.

Abbreviations

Acronym	**What it Stands For**
ANOVA	Analysis of Variance
DFIG	Doubly Fed Induction Generator
DFR	Digital Fault Recorder
EFAST	Extended Fourier Analysis Sensitivity Test
EKF	Extended Kalman Filter
EMT	Electromagnetic Transient
FIR	Finite Impulse Response
GMS	Global Mean Sensitivity
GSA	Global Sensitivity Analysis
HCP	Hyperbolic Cross Points
IEC	International Electrotechnical Commission
IGBT	Insulated Gate Bipolar Transistor
LM	Levenberg–Marquardt algorithm
MAE	Maximum Absolute Error
MATLAB	The Language of Technical Computing
PMSG	Permanent Magnet Synchronous Generator
PMW	Pulse-width Modulation
PSS/E	Power System Simulator for Engineering, a software tool used for
electrical	transmission networks
RMS	Root Mean Square
SCIG	Squirrel-Cage Induction Generator
SIMLAB	Simulation environment for uncertainty and sensitivity analysis
TGMS	Total Global Mean Sensitivity

UKF	Unscented Kalman Filter
WRIG	Wound Rotor Induction Generator
WTG	Wind Turbine Generator

Physical Constants

Constant Name	Symbol	Constant Value
Air density	ρ_A	expressed as a function of temperature and pressure (kg/m^3)
Circular constant	π	= 3.14159265359
Natural logarithm constant	e	= 2.718281828459

Symbols

In electromagnetic model

Symbol	**Name (Unit)**
$*^{base}$	Signal with base parameters
$*_{em}$	Electromagnetic
$*_{meas}, *^{meas}$	Measured signal
$*_a, *_b, *_c$	Components in three phases
$*_c$	Grid side coupling inductor
$*_l$	Leakage
$*_q, *_d$	Quadrature and direct axes components
$*_{ref}$	Reference value
$*_s, *_r$	Stator and rotor quantities
$*_t, *_g$	Turbine and generator quantities
β	Blade pitch angle (rad)
λ	Tip speed ratio (unitless)
ω	Rotational speed (pu of rad/s)
ω_b	Base rotational speed (rad/s)
ϕ	Magnetic flux (pu in $Weber$)
θ	Difference between turbine and generator rotor angles (rad)
θ_r	Generator rotor angle (rad)
B_d	Drive train damping constant (pu of $nominal\ mechanical\ torque/pudw$)
c_{dclink}	DC bus capacitor (pu of $Farad$)

c_p	Turbine performance coefficient (%)
F	the generator friction factor (unitless)
H	Machine inertia constant (s)
i	Current (pu in $Ampere$)
J	Inertia (pu of $kg \cdot m2$)
k_{pitch}	Pitch controller gain (unitless)
k_{pp}, k_{ip}	Pitch compensation proportional and integral gains (unitless)
k_{ps}, k_{is}	Speed regulator proportional and integral gains (unitless)
k_{qi}, k_{vi}	Reactive power and voltage regulator proportional and integral gains (unitless)
K_d	Drive train stiffness constant (pu of Nm/rad)
l	Inductance (pu in $Henry$)
l_g	grid-side coupling inductor inductance (pu in $Henry$)
l_m	Magnetising inductance (pu in $Henry$)
P	Active power
q_{line}	Line filter capacity (var)
R	Blade radius (m)
r	Resistance (pu in Ω)
r_g	grid-side coupling inductor resistance (pu in Ω)
S_b	Base (rated) power (W)
t	Time (s)
T	Torque (pu of Nm)
v	Voltage (pu in $Volt$)
v_w	Wind speed (m/s)

In generic phasor model

Symbol	Name (Unit)
$*_{cmd}$	Controlled component
$*_{cps}$	Compensation component
$*_{ord}$	Orderd component
$*_{ref}$	Reference component
$*_{reg}$	Regulated component
$*_0$	Initial value
$*_e$	Electrical component
$*_g$	Signal from generic model
$*_m$	Mechanical component
$*_p$	Active component
$*_q$	Reactive component
$*_t$	Signal on generator terminal
$*_vs$	Signal from vendor specific model
ω	Rotational speed (pu of rad/s)
θ	angle (rad)
E	Electromotive force (pu in $Volt$)
H	Machine inertia constant (s)
i	Current (pu in $Ampere$)
k_{ic}	Pitch compensator integrator gain (unitless)
k_{ip}	Pitch regulator integrator gain (unitless)
k_{it}	Torque regulator integrator gain (unitless)
k_{pc}	Pitch compensator proportional gain (unitless)
k_{pp}	Pitch regulator proportional gain (unitless)
k_{pt}	Torque regulator proportional gain (unitless)
k_{qi}	Reactive power to voltage gain (unitless)
k_{qv}	Voltage to reactive power gain (unitless)
k_a	Aerodynamic gain factor (rad^{-1})
P	Active power (pu in $Watt$)
pf_{ref}	Power factor angle reference (rad)

Q	Reactive power (pu in var)
S	Apparent power (pu in $Volt - Amps$)
t	Time (s)
T	Torque (pu of $N\dot{m}$)
t_{ap}	Transformer turns ratio (unitless)
T_{FP}	Time constant of the torque regulator (s)
T_p	Lag time constant in wind reactive power controller (s)
V	Voltage (pu in $Volt$)
x_{eq}	Generator equivalent reactance (pu in Ω)
x_t	Transformer equivalent reactance (pu in Ω)