User guide: General information

Scope of the guide: This file is intended to serve as user guide for the software package related to the textbook entitled *Optimal control of wind energy systems – Towards a global approach*. The software package is organized in 11 folders, each containing an application referred to as case study in the book. Each application is designed to work independently and consists in a set of MATLAB® 6.5.0 / Simulink® 5.0 (R13) application files and an explanatory note for guiding users in running the application files. Explanatory notes are generally named `readmeX.pdf` for case study X.

These guidance files have been written for users that have already read the book. In order to properly use these files when running the applications, basic skills of MATLAB® and Simulink® are required. However, some advanced knowledge of control systems and signal processing may be necessary to fully understand the results.

Brief analysis of the back-of-book software material: Most of the case studies report preliminary checking by simulation of control laws dedicated to various configurations of variable-speed WECS operating in partial-load regime.

Case study 1 deals with obtaining a reduced-order linear model for a high-power induction-generator-based WECS by using the MATLAB® function `linmod`.

Case studies from 2 to 8 concern different control approaches aiming exclusively at WECS energy conversion optimization in the partial-load regime, *i.e.*, under the rated wind speed. From these seven case studies, those from 2 to 6 are built around squirrel-cage-induction-generator (SCIG)-based WECS, whereas the others concern permanent-magnet-synchronous-generator (PMSG)-equipped WECS. The considered systems have all rigid drive train.

Case study 2 illustrates comparatively the simulation results for two versions of Maximum Power Point Tracking (MPPT) applied to a low-power WECS: a classical one, which requires computation of time derivatives, and another one based upon an extremum seeking control algorithm that uses the wind turbulence as searching signal.

The PI-based control is employed in case studies 3 and 4, for building a speed and a power control loop, respectively.

Case studies 5 and 6 envisage the use of on-off nonlinear control aiming at maximizing the energy captured from the wind. An on-off control law has been tested in case study 5 for steady-state wind turbine optimal operation. Case study 6 is used for the assessment of a torque sliding-mode control law aiming at dynamic optimization of the captured energy, meanwhile allowing the alleviation of loads induced by the control input effort.

Case studies 7 and 8 are applied on the PMSG-based WECS and focus on the assessment of two kinds of control loops used for energy efficiency maximization. The first control loop implements a feedback linearization control and the second one uses a QFT-based robust controller.

Case studies from 9 to 11 deal with WECS optimal control problems defined by mixed criteria. The criterion considered here expresses a trade-off between energy optimization and mechanical loads alleviation.

Case study 9 illustrates an R-S-T-controller-based solution for a low-power flexible-drive-train SCIG-based WECS.

Case studies 10 and 11 deal with the assessment of a two-loop control configuration based on the frequency separation principle. The low-frequency loop achieves a steady-state optimal operation (using PI speed control), and the high-frequency loop employs LQG controllers for dynamic optimization. Case study 10 refers to a rigid-drive-train-based WECS and case study 11 to a system having flexible drive train. In both cases, the LQG problem is formulated using a previously stated mixed criterion and high-frequency models of wind turbine generators.

	Name:	MAIN FILE(S) .mdl	INITIALIZATION FILE(S)	OTHER FILES			APPENDIX
				.mdl	.m	.mat	
CS1	**Reduced-order Linear Modelling of a SCIG-based WECS**	ord3mw2lin.mdl ord5mw2lin.mdl	datawecs2Mw_3ord.m datawecs2Mw_5ord.m		matrixlin5ord.m		A.6
CS2	**Classical MPPT *vs.* MPPT with Wind Turbulence as Searching Signal**	mppt1.mdl mppt2.mdl	data_mppt1.m data_mppt2.m		asmcn.m test_def_clk.m	vntu.mat	A.2
CS3	**2 MW WECS Optimal Control by PI Speed Control**	PI_speed_ctrl.mdl	data_PIspeed.m		asmcn.m	vntu.mat	A.7
CS4	**6 kW WECS Optimal Control by PI Power Control**	PI_power_ctrl.mdl	data_PIpower.m		asmcn.m	vntu.mat	A.2
CS5	**On–Off Control**	onoff_ctrl_cplx.mdl onoff_ctrl_simp.mdl	data_onoff.m		asmcn.m		A.2
CS6	**Sliding-mode Control**	sliding_mode_ctrl.mdl	data_sliding_mode.m			w_velocity.mat	A.2
CS7	**Feedback Linearization Control**	feedback_lin_ctrl.mdl	data_feedback_lin.m			vntu.mat	A.3
CS8	**QFT Robust Control**	robust_QFT_ctrl.mdl	data_robust_QFT.m			vntu.mat	A.3
CS9	**LQ Control of WECS with Flexibly-coupled Generator Using R-S-T Controller**	LQ_RST_ctrl.mdl	data_LQ_RST.m	controllers.mdl	asmcn.m discrete_model_gen.m RST_gen.m	iden.mat iden_witness.mat vntu.mat	A.4
CS10	**LQG Control of WECS with Rigid Drive Train Using the 2LFSP structure**	rigid_2LPSF_ctrl.mdl	data_rigid_2LFSP.m		lin_param_comp.m LQR_comp.m		A.2
CS11	**LQG Control of WECS with Flexible Drive Train Using the 2LFSP structure**	flexible_2LPSF_ctrl.mdl	data_flexible_2LFSP.m		estimator_comp.m LFwind_prediction.m lin_param_comp.m LQR_comp.m	vinti.mat vwind.mat	A.4
CS12	**Building of a HIL Simulator for a DFIG-based WECS**	No software					A.5

The previous table contains a guidance map identifying each case study and application files.

System modelling and operation aspects: Models as well as assumptions for each particular case study can be found in the textbook. Some of the WECS modelling elements have not been introduced as they were considered not of interest for the particular control application. Please find here some general modelling / implementation aspects:

1. WECS always operate in partial load – as the full-load regime is not of primary interest here, aerodynamic power limitation has not been employed. Therefore, almost all the wind sequences used in applications have values below 10-11 m/s, considered as rated wind velocity.
2. The interaction regime between the WECS and the electrical grid has not been implemented in any application. The WECS implementation comprises the turbine, the drive train, the induction machine and the generator-side control. The electrical grid has been taken as ideal, the grid-side inverter and the DC-circuit have never been implemented because the grid interface is not of interest for all the case studies.
3. The generator-side inverter is considered ideal (no losses, no dynamics, *etc.*); in some applications, the generator torque control has been approximated with a first-order dynamic, with very fast time response.
4. Only the average aerodynamic behaviour has been implemented; wind-shear-, variable-pitch-, rotational-sampling- or tower-shadow-related behaviours have not been introduced in the application files.
6. The wind velocity models (stationary or not) does not involve wind gusts; 1-D wind velocity sequences are used, as the wind turbine rotor is normal to the wind flow direction.
7. The WECS start-up procedure is simplified and the shut-down sequence has not been implemented.

All the elements that have not been considered for implementation can be added later for more detailed assessment of the closed-loop system behaviour.

Implementation aspects: All the primary applications are encoded in mdl-files. The plant and the control blocks are separately encoded. The variables' evolution can be viewed by checking the scopes in blocks labelled `Scopes` or `Supplementary Computations & Displays`. All the applications have an initialization m-file used for loading WECS and wind data; this is done by double-click on the associated block. The wind synthesizers can output various wind velocity stochastic sequences. Some of the control structures can be changed – by using manual switches – according to each application's running necessities. In most of cases the controller parameters can be changed on-line, but some applications may require off-line computation of the control parameters and restart of the simulation.

General remarks: The control law must be applied when the WECS has reached a "normal" operating point (*i.e.*, its rotational speed is sufficiently large, the tip speed ratio is larger than its optimal value, the rotor is approaching the blade-feathering regime); therefore almost all control applications are employing a start-up sequence to avoid erratic behaviour of the system.

Variable limitations (*e.g.*, of the electromagnetic torque) have been taken into account; the extreme operating regimes and malfunctions have not been considered in the applications.

Most of applications allow the possibility of selecting the desired wind sequence from a set of signals with various spectral properties.

The list below contains the meaning of variables used in mdl-, m- and mat-files throughout applications.

Aerodynamics and drive train

`omg`	– rotational speed (generic)
`Trq`	– mechanical torque (generic)
`ro`	– air density
`eta`	– mechanical transmission efficiency
`omgh`	– high-speed shaft rotational speed
`omgl`	– low-speed shaft rotational speed
`pwrh`	– high-speed shaft mechanical power
`pwrl`	– low-speed shaft mechanical power
`wTrq`	– wind (aerodynamic) torque
`inT`	– drive train internal torque (flexible drive train)
`tC`	– torque coefficient
`cp`	– power coefficient
`lam`	– tip speed ratio
`wind, v`	– wind velocity

Generator

`emT`	– electromagnetic torque
`isd, isq`	– (*d*,*q*) stator currents
`ird, irq`	– (*d*,*q*) rotor currents
`vsd, vsq`	– (*d*,*q*) stator voltages (SCIG)
`ws`	– electrical variables frequency
`theta`	– electric angle
`P,Q`	– active and reactive power
`psi_sd, psi_sq`	– (*d*,*q*) stator flux
`psi_rd, psi_rq`	– (*d*,*q*) rotor flux
`ud, uq`	– (*d*,*q*) stator voltages (PMSG)
`Fie`	– machine flux (PMSG)
`Rch, Lch`	– chopper equivalent resistance and inductance (PMSG control)

Control

`set_spd, spd_ref`	– speed reference (set value)
`set_emT, Trq_ref, emT_ref`	– electromagnetic torque reference
`enb`	– control enable
`gamma`	– torque coefficient
`theta`	– MPPT2 control parameter
`weight`	– weighting coefficient (called α in the text of book)
`beta, C`	– on-off control parameters
`alpha, delta`	– sliding mode control parameters
`d_`*variable*	– variations of the concerned variable
`ctrl`	– generic control input
`HF_`*variable*	– variable belonging to the WECS high-frequency model
`LF_`*variable*	– variable belonging to the WECS low-frequency model