Case Study 5: On–Off Control

This case study contains two applications implementing the on-off control in order to maximize the power captured by a rigid-drive-train WECS. These applications, using the mdl-files named `onoff_ctrl_simp.mdl` and `onoff_ctrl_cplx.mdl`, are described below. The main difference between them is that in the first case, the electromagnetic subsystem (composed by generator, inverter, inner torque control) is modelled as a first-order system with fast dynamic response. The two applications are using the same aerodynamic parameters and the same on-off controller.

Scope: Evaluation by numerical simulation of the control method aiming at captured power maximization for a low-power fixed-pitch SCIG-based wind turbine by using an on-off control. This method superposes the tracking of the optimal torque value issued from the $K \cdot \Omega^2$ relation (Relation 4.9 in the book) and the tracking of the optimal tip speed ratio. Therefore, the control input – which is the generator torque – has two main components: a low-frequency (equivalent) component and a switched component (following the sign of the tip speed ratio error). The system operates at self-oscillations.

1. Uses the mdl-file named `onoff_ctrl_simp.mdl`.

Application analysis: The file `data_onoff.m` contains the system data. The mdl-file is organized as follows. At the right side is placed the plant at the top and the on-off control block at the bottom. The electromagnetic system is simplified, its dynamic behaviour being approximated with that of a first-order element; a non-stationary wind speed sequence is synthesized using the wind generation block (central-upper part of the application file). At the left one can see some blocks (from up to down): the system data loading button, the scopes and some computation/display blocks. The parameter β (denoted as `BETA` and which can be found in the block labeled `On-Off Control`), is the primary adjusting element of the control law. The diagram presents an additional low-frequency component, u_{N_f}, obtained by filtering the alternate component, u_N, in order to ensure robustness to parametric uncertainties. The wind speed used for the equivalent control component computation is filtered by means of a low-pass Butterworth-type filter.

Running the application:
Step 1: Load system parameters.
Step 2: Select the wind velocity sequence according to your test needs.
Step 3: Select from the menu “Simulation $\rightarrow$ Parameters” a convenient time horizon and proceed with the simulation.
Step 4: Dynamical system behaviour can be overviewed by opening the scopes (left-upper part of the application file). Operating point position and/or its dispersion around the ORC can be plotted using the LSS mechanical power and rotational speed data (vectors `pwrl` and `omgl`) saved in the workspace from the corresponding scopes. The limit cycle can be visualized by plotting the (Ω_h, Γ_G) trajectory using data stored by the appropriate scopes (`emT`).
Step 5: Change the `BETA` control parameter (in the outer control block) and restart the simulation.

2. Uses the mdl-file named `onoff_ctrl_cplx.mdl`.

Application analysis: The file `data_onoff.m` contains the system data. The mdl-file is organized as follows. At the right side is placed the plant (containing also the inner torque control loop), whereas at the left one can see, from up to down: the system data loading button, the scopes and some computation/display blocks (containing, for example, the active power calculation), some conditioning operations and the outer control loop implementing the on-off control algorithm (bottom-left). The SCIG model is coded in the `asmcn.m` s-function; a non-stationary wind speed sequence is synthesized using the wind generation block (central-upper part of the application file).

The interaction regime between the WECS and the electrical grid cannot be changed. The WECS implementation comprises the turbine, the rigid drive train, the induction machine and the generator-side inverter. The electrical grid has been taken as ideal, because the grid interface is not of interest in this application. The parameter β (denoted as `BETA` and which can be found in the block labeled `On-Off Control`), is the primary adjusting element of the control law. The diagram introduces an additional low-frequency component, u_{N_f}, obtained by filtering the alternate component, u_N, in order to ensure robustness to parametric uncertainties. The wind speed used for the equivalent control component computation is filtered using a low-pass Butterworth-type filter.

Running the application:

Step 1: Load system parameters.

Step 2: Select the wind velocity sequence according to your test needs.

Step 3: Select from the menu “Simulation → Parameters” a convenient time horizon and proceed with the simulation.

Step 4: Dynamical system behaviour can be overviewed by opening the scopes (left-upper part of the application file). Operating point position and its dispersion around the ORC can be plotted using the LSS mechanical power and rotational speed data (vectors `pwrl` and `omgl`) saved in the workspace from the associated scopes. The limit cycle can be visualized by plotting the (Ω_h, Γ_G) trajectory using data stored by the appropriate scopes (`emT`).

Step 5: Change the `BETA` control parameter (in the outer control block) and restart the simulation.

General remarks: During its start-up the system works at zero electromagnetic torque; after few moments, when the rotational speed reaches a normal operating regime, the reference automatically switches to the on-off control. The start-up strategy can be changed by the user, if needed.

The oscillation analysis can be done at a normal operating point, for constant wind speed; the auto-oscillations amplitude and frequency depends on the chosen operating point (and therefore on the wind velocity).

Using the tip speed ratio error information using the first-order holder or its equivalent should not significantly change the controlled system behaviour. The electromagnetic subsystem dynamic behaviour is that of a fast second-order system in the second application, but the closed-loop system behaviour is essentially the same for both applications. However, the user can change the controller parameters of the inner torque control loop to obtain the desired behaviour.