Case Study 6: Sliding-mode Control

This case study contains an application implementing the sliding-mode control in order to maximize the power captured by WECS; meanwhile, the mechanical loads are alleviated by choosing a certain sliding surface. This application uses the mdl-file named `sliding_mode_ctrl.mdl`; it is described below.

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 means of a sliding-mode controller. The key feature of this method is a wisely chosen sliding surface which allows the turbine to operate more or less close to the ORC. This surface depends on the wind speed; its image in the (Ω_l, P_{wt}) plane must have a nonempty intersection with the ORC for each value of the wind speed and also an adjustable slope for tuning the sliding-mode dynamics. Three control parameters are employed: a_1 – results from imposing the convergence speed to the sliding-mode, k – the slope of the surface (quality of ORC tracking) and α – the switching (on-off) component amplitude.

Application analysis: The file `data_sliding_mode.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, being approximated with a first-order element having t_g as time constant; a pre-computed non-stationary wind speed sequence can be used for feeding the WECS (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 control parameters, a_1, k and α (`alpha`) can be found in the block named `sliding-mode controller`.

The controller structure is as follows. The rotational speed derivative is estimated by a lead-lag element having the time constant T_f =0.1 s (upper part of the diagram). The parameter a_2 of the sliding surface expression is computed in the upper-left part of the scheme. The upper-right part is occupied by the sliding surface, σ (`sigma`), equivalent and switching components of the control law (u_N and u_{eq}). The intermediary parameter, $A(\lambda, v)$, is computed at the bottom part of the control structure. It involves the computation of an important variable, $\delta(\lambda) = \left(C_p^{'}(\lambda)\cdot\lambda - C_p(\lambda)\right)/\lambda^2$, which equals almost $\delta(\lambda_{opt})$ = –0.01 for the optimal tip speed ratio ($\lambda_{opt} = 7$ in this case). The switching surface can be obtained by using a sign function (involving quite larg high-frequency torque variations) or a hysteretic sign function (yielding lower variations of high-frequency torque components).

Running the application:

A. Exploring the system behaviour at step changes of wind velocity

Step 1: Load system parameters.

Step 2: Select from the menu “Simulation → Parameters” a convenient time horizon and proceed with the simulation.

Step 3: Select the wind velocity on a suitable constant value (between 5 and 10 m/s).

Step 4: The control parameters must be set at $a_1 \in (-1;-10)$, $k = 0$ and $\alpha \in (0.1;5)$. Start the simulation and wait for the controller activation (after 5 seconds). At the desired moment (after the system has reached steady-state) change the wind velocity to another value and wait for the new steady-state to stabilize. Next, change the wind to the first value and wait for the steady-state. These manoeuvres allows to plot the operating point trajectories in the planes (Ω_h, Γ_G), (Ω_l, P_{wt}) or (λ, Γ_G), using the data stored on the appropriate scopes (vectors `pwrl`, `omgl`, `omgh`, `lam`, `emTrq`). For example, after stopping the simulation, the script sequence for plotting the $\lambda - \Gamma_G$ trajectory is:

```
lm=lam(:,2);          % uses the tip speed ratio sequence data
                      % stored on the associated scope
emT=emTrq(:,2);       % uses the electromagnetic torque sequence data
                      % stored on the associated scope
plot(lm,emT,'k');     % plot (x-y scope)
```

The temporal evolutions of various variables can be seen on the corresponding scopes.

B. Exploring the system behaviour at pseudorandom wind velocity

Step 1: Load system parameters.

Step 2: Select the pre-computed sequence of wind velocity.

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 part of the application file –for example the C_p and tip speed evolutions). Operating point position or its variation around the ORC can be plotted – after stopping the simulation – using the LSS mechanical power and rotational speed data (vectors `pwrl` and `omgl`) or electromagnetic torque and tip speed ratio (vectors `emTrq` and `lam`) saved in the workspace by the associated scopes.

Step 5: Change one of the control parameters, a_1, k or α, and restart the simulation.

Step 6: Change the switch `Man1` such that the parameter **`delta`** be constant, corresponding to the maximum energy efficiency and evaluate the behaviour of the system.

Step 7: Change the switch `Man2` such that the switching component of the control law be computed using a hysteretic sign function and re-evaluate the behaviour of the system.

Remarks: During its start-up the system works at zero electromagnetic torque; after few moments, when the rotational speed reaches a normal operation value, the reference automatically switches to the sliding-mode control. The start-up strategy can be changed by the user, if needed.

Other parameters can also be changed (for example, the hysteresis width).

In this application, the J_t parameter is in fact the high-speed shaft inertia, `JHSS`.