Case Study 10: LQG Control of WECS with Rigid Drive Train Using the 2LFSP Structure

This case study contains an application for implementing the optimal control structure designed according to the frequency separation principle on a rigid-drive-train-based WECS. This control structure contains two loops, one dealing with the low-frequency (LF) evolutions of system variables (LFL), and the other one processing the high-frequency (HF) components of the system variables (HFL). The optimization target requires restraining the operating point position around a certain domain including ORC, but the minimization of the control input (electromagnetic torque) variation is also envisaged. This trade-off is expressed by a linear quadratic performance index, where the two contradictory requirements are weighted using the coefficient α. The application uses the mdl-file named `rigid_2LPSF_ctrl.mdl`, implementing the control, and two m-files `lin_param_comp.m` and `LQR_comp.m` for determining the linearized system parameters and the LQG controller components, respectively. All these are briefly described bellow.

Scope: Generation of the LQG control parameters and assessment by numerical simulation of the two-loop optimal loop structure applied on the rigid-drive-train-based WECS.

Application analysis: The file `data_rigid_2LFSP.m` contains the system data. The mdl-file is organized as follows. The plant is placed at the right, the controller blocks are below the plant. One of them contains the control structure and the other one performs the splitting of the frequency ranges. The wind generator, placed upper-central, synthesizes a non-stationary wind velocity sequence. In the upper-left corner one can see some blocks (from up to down): the system data loading button, the linearized system parameters computation, the LQG control components computation, the scopes and some computation/display blocks. The electromagnetic system within the plant is simplified, being approximated with a first-order element having t_g as time constant. The block named `LF-HF splitter / adder` implements the identification of low- and high- frequency components of the wind speed, rotational speed and electromagnetic torque. To this end, a low-pass Butterworth type filter of order 4 has been used. The block named `2LFSP control` contains the LFL (based on a PI controller) and the HFL (based on a LQ controller) control structures.

Running the application:

A: **Computation** of the linearized model parameters and LQ controller

Step 1: Load system parameters (WECS data).

Step 2: Compute the linearized (HF) system parameters around a certain steady-state wind velocity (double-click on the appropriate block runs the script-file `lin_param_comp.m`). The system parameters (`gamma`, `JT` and `Tw`) can be viewed in the command window and will be automatically employed in the HFL.

Step 3: Compute the LQ controller parameters for a certain weighting parameter (double-click on the appropriate block runs the script-file `LQR_comp.m`). The controller parameters, `K1` and `K2`, can be viewed in the command window and will be automatically employed in the HFL.

B: **Assessment** of the 2LFSP

Step 1: Run part **A** of the application. Consider a value of the average wind velocity, `wind_st` (say 7 m/s), and a value of the weighting coefficient, α (`weight` – say 10), and ensure that *Step* 3 has been completed.

Step 2: Select from the menu "Simulation → Parameters" a convenient time horizon and proceed with the simulation (say 300 s).

Step 3: Dynamical system behaviour can be overviewed by opening the scopes (upper-left corner of the application file). Operating point position or its deviation around the ORC can be seen directly on the XY scope or can be plotted by using the LSS mechanical power and rotational speed data (vectors `pwrl` and `omgl`) saved in the workspace from the corresponding scopes. Check the control performance by opening the tip speed (`lam`) (or else the power coefficient – `cp`) scopes and the scope visualizing the control input (the electromagnetic torque, `emT`). These are the two terms of the quadratic performance criterion and should be antagonistic. This means that if the tip speed variance is small, the control input variations around its average value is large (this happens for large values of α). The HF variations of the control input, `HF_emT`, and of the tip speed ratio, `HF_lam`, can be visualized and assessed separately (*e.g.*, by computing their histograms or their FFTs).

Step 4: Restart from *Step* 1. Run only *Step* 2 and *Step* 3 of part **A** using a new value of the weighting coefficient, α.

Step 5: Compare the standard deviation of the HF-component of the tip speed ratio and of HF-component of the control effort and the operating point standard deviations around ORC for different values of α.

Step 6: Change the value of the steady-state wind speed, `wind_st` (restart from *Step* 1), and compare the control law efficiency for the same wind velocity sequence and for the same weighting coefficient, `weight`.

Remarks: During its start-up the system works at zero electromagnetic torque; after few moments, the reference automatically switches to the one issued from the 2LFSP control algorithm. The start-up strategy can be changed by the user, if needed.