Case Study 9: LQ Control of WECS with Flexibly-coupled Generator Using R-S-T Controller

This case study contains an application implementing the LQ optimal control structure in a form of an R-S-T controller. An input-output discrete model of the WECS has been used for implementing an input-output approach of the optimal control problem. The performance criterion has two terms, one involving the maximum power capture and the other one corresponding to mechanical fatigue loading (control input) minimization. This application uses the mdl-file named `LQ_RST_ctrl.mdl` and two m-files, `discrete_model_gen.m` and `RST_gen.m`; all these are described bellow.

Scope: Assessment by numerical simulation of an I/O control approach aiming at minimizing a performance criterion having two contradictory elements: minimization of the distance from the optimal rotational speed (corresponding to the ORC) and minimization of the control input (electromagnetic torque) variations. The balance between these parameters can be adjusted by means of a weighting parameter, α. The R-S-T controller is built over an I/O discrete model of the WECS resulting from a statistic identification procedure (*instrumental variables algorithm* – `iv4` function from MATLAB®).

Application analysis: The file `data_LQ_RST.m` contains the system data. The mdl-file is organized as follows. The plant is placed at the right, the controller blocks are at left and bottom of the diagram. The wind velocity synthesizer, paced upper-central, allows using multiple types of wind velocity sequence (section 3 with an average of 8 m/s has been used here for system behaviour evaluation). In the upper-left corner one can see, from up to down: the system data loading button, the scopes and some computation/display blocks.
The interaction 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 SCIG model is coded in the `asmcn.m` s-function; a flexible model of the drive train (two-mass model) has been used.
The controller block, labelled `Identification / RST control`, allows recording data for the discrete-time model identification and is structured as follows. Centrally, one can find the structure used for identification; extreme-up and -down parts of the controlling structure (rotational speed reference and the R-S-T structure, respectively) are visible. The switch feeding the control input is used for selecting one of the above-listed two operations: position 1 – **identification** and position 2 – **control**.

Running the application:
A: **Identification** of the discrete-time model parameters
Step 1: Load system parameters (WECS data).
Step 2: In the block labelled `Identification / RST control`, set the switch feeding the control input to position 1 – **identification**.
Step 3: Use the wind velocity sequence corresponding to selection 3 with an average value of 8 m/s. Select from the menu “Simulation → Parameters” a convenient time horizon and proceed with the simulation (say 180 s).

Step 4: At the end of the simulation the mat-file `iden.mat` should contain records of some important variable evolutions (including the probing signal and rotational speed).

Step 5: Use the m-file `discrete_model_gen.m` to obtain the stochastic discrete-time model of the plant, based on the instrumental variable method.

Step 6: Based on a given weighting coefficient $\alpha \in [2, 50]$ and on the previously obtained plant model, employ the m-file `RST_gen.m` to generate the R, S and T parameters of the controller. α (`weight`) must be given directly in the m-file.

Step 7: Introduce these coefficients into the corresponding transfer functions of the controller block, labelled `Identification / RST control`.

B: **Evaluation of the dynamic behaviour** of the closed-loop system when using various weighting parameters

Step 1: Run part **A** of this application. Consider a value of the weighting coefficient α (say 2) and ensure that *Step* 7 has been completed.

Step 2: Reload system parameters (WECS data). In the block labelled `Identification / RST control`, set the switch feeding the control input to position 2 – **control**.

Step 3: Use the wind velocity sequence according to your needs (*e.g.*, selection 3 with an average value of 8 m/s). Select from the menu "Simulation → Parameters" a convenient time horizon and start the simulation.

Step 4: Dynamical system behaviour can be viewed by opening the scopes (upper-left corner of the application file). Operating point position or its standard deviation 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. Check the control performance by opening the tip speed (`lam`) (or else the power coefficient – `cp`) scopes and also the one visualizing the control input (the electromagnetic torque, `emT`). These are the two parts 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 small α).

Step 5: Restart from *Step* 1. Run only *Step* 6 and *Step* 7 of part **A** by using a new value of the weighting coefficient, α.

Step 6: Compare the standard deviation of the tip speed ratio and of the control effort (by extracting its average value or possibly by computing the FFT) for different values of α.

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 one provided by the R-S-T speed control algorithm. Also, the R-S-T controller is activated after a few moments. The start-up strategy can be changed by the user, if needed. Running the application may damage the content of the file `ident.mat`. If this happens load the file `iden_witness.mat` instead.

File `controllers.mdl` contains some R-S-T controllers obtained using the file `RST_gen.m`, for various values of the weighting coefficient, α. For a given value of α, take the corresponding controller and replace it into the control block in the file `LQ_RST_ctrl.mdl`.