Automation of Energy Systems

Proposed projects

Foreword and general rules

- Projects can be carried out either individually or in groups of *maximum* two components.
- The project is evaluated based on correctness, organisation, and clarity.
- Since to carry out the project you can take all the time you wish, it is assumed that you have checked all the material before handing it in. As such, no excuse for possible mistakes will be accepted based on "hurry".
- The indicated response lengths (figures included, incidentally) are intended to provide an idea of the expected detail, not to be strict limits.
- Both completeness and conciseness are merits–joined, even more.
- Normally the evaluation of a project does not imply a colloquium. Nonetheless the teacher may ask for one if this is deemed necessary for a precise judgement.
- Please adhere to the provided instructions concerning the material to hand in and the way to do so. Failure to respect a standard is detrimental for an engineer, thus will adversely affect the project score.
- When in doubt, first try to sort things out on your own, but if stuck ask for advice. The worst result of such a request is getting an answer like "sorry, I can give explanations and/or directions but not solve this part of the problem for you". Asking for advice will not affect your score, but please – and basically for your professional growth – use this possibility with moderation.

Project 1

Assignment

Consider a synchronous rigid electric network with three generators $G_{1,2,3}$, primary and secondary power and frequency control, and input lines for tertiary control. Assume that G_3 does not participate to secondary control.

1. [2 pages] Draw and comment the block diagram representing the controlled network, evidencing the role of each block and the meaning of each parameter, employing the standard notation used in the course.

2. [1 page] Express the steady-state variations of each generator's power caused by a network power demand step of amplitude ΔP_e as a function of the involved parameters.

3. [2 pages] Assuming that the maximum powers of $G_{1,2,3}$ are respectively $80\,MW$, $120\,MW$ and $100\,MW$, and that the secondary control gain is unitary, determine the secondary control distribution coefficients so that the steady-state power variations of the involved generators for the same ΔP_e above be in the same ratio as their maximum powers.

4. [5 pages] Write a Modelica model representing the controlled system, based on the material provided in the course (typically, the `AES_PFcontrol.mo` library available on the course page). Test its behaviour in the face of a $+15\,MW$ step variation of the electric power demand from a base value of $200\,MW$, assuming all the three generators active. Discuss, by showing a few simulations, the effects of the (still) free control parameters with respect to the obtained transients, specifically as for the peak frequency deviation and the time required to recover from the power event.

Deliverable

A single compressed file (.tar.gz, .zip,...) named `AES-year-AuthorSurname(s).ext` (e.g., `AES-2013-Smith.tar.gz`, `AES-2013-LaurelHardy.zip`,...) containing

- a report organised as per the assignment points above, in pdf format,
- and an OMNotebook/OMEdit file containing all the created Modelica models.

Project 2

Assignment

Consider an islanded thermoelectric generator that can be managed with a boiler-follows, a turbine-follows, or a sliding pressure policy.

1. [2 pages] Draw and comment the block diagrams representing its operation in the three mentioned modes, based on the equation-based descriptions given in the course.
2. [4 pages] Assuming a lossless generator with a nominal power of $100\,MW$ and both a draw and a restore time constant of $50\,s$, set up convenient control schemes for power and frequency control, and energy level control where applicable, using proportional or PI-type controllers.
3. [4 pages] Write a Modelica model representing the devised controlled systems, and discuss – based on some simulation studies – the effect of the involved parameters on the typical power and frequency transients caused by a power demand step. If necessary/convenient, you can use elements from the Modelica library `AES_PFcontrol.mo`, available on the course page.

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Project 3

Assignment

Consider a heat network composed of a single loop with a main heater, four heat exchangers (primary side) and five underground piping sections. Denote by γ_{ft} the fluid-to-terrain heat exchange coefficient (lumping all insulation together and neglecting energy storages in the pipe walls), and assume the vector fluid to be subcooled water. Also, denote by T_t the terrain temperature, assumed uniform, by P_h the power released to the heater (control variable), and by Q_i, $i = 1 \cdots 4$, the thermal loads required by each exchanger on the secondary side (assumed as exogenous disturbances). Finally, denote by w the mass flowrate in the loop.

1. [3 pages] Write a Modelica model of the system, using a single volume for the heater and finite-volume descriptions for the other components (indicatively, take two volumes for the heat exchangers and three for the piping sections). Denote by V_h, V_e and V_p the total volume of the heater (assumed lossless), one heat exchanger, and one piping section, the exchanging surface of which shall be indicated by S_p. If necessary/convenient, you can use elements from the Modelica library `AES_Thermo.mo`, available on the course page. As for numeric values, assume $\gamma_{ft} = 1.2\,W/m^{2\circ}C$, $T_t = 5\,^{\circ}C$, $V_h = 2\,m^3$, $V_e = 1\,m^3$, and that each piping section is $50\,m$ long and $5\,cm$ in diameter. Determine the maximum value for P_h so as to fulfill thermal loads Q_i all equal to $50\,kW$ with a 20% surplus.

2. [4 pages] Set up and tune the heater outlet temperature controller, assuming the flowrate one as idealised and characterised by a closed-loop time constant of $5\,s$. Consider P_h as the control variable, and stipulate reasonable specifications as for the required response speed, assuming that the thermal loads undergo step-like variations, spaced with a minimum time distance of $1\,h$.

3. [4 pages] Discuss the relationships between the set points for the loop flowrate and the heater outlet temperature, and the overall energy consumption. Assume that the fuel calorific HH power is constant, while the power consumption of the impelling pump be a cubic function of the water flowrate. Note that a qualitative discussion is required, thus it is not necessary to report figures provided that the presented conclusions are suitably grounded on the model.

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Project 4

Assignment

Consider the heating system of a house with two rooms, each endowed with a heating element using hot water, and possibly a heat pump.

1. [3 pages] Write a Modelica model of the system in open loop, having as control inputs the valves' and heat pumps' commands. For sizing boiler, pump, pipes, valves, heating elements, room air capacities and walls, refer to the `Base` model in the package named `CaseStudies.TwoRooms_WaterHeating` of the `AES_Thermo` library, available on the course site. It is not required to model window openings nor solar radiation, just the wall thermal loss toward a varying external temperature. Test the model in the presence of *constant* inputs, and check the balances.

2. [2 pages] Complete the model with two heat pumps, one per room, with the cold side connected to the external temperature. Set both the hot and cold capacities to 500 J/K, assume a constant heating COP of 1.8, and suppose that the thermal exchange between the pump sides and the corresponding environments is equally efficient as that of the water heaters.

3. [2 pages] Set up a PI-based (decentralised) temperature control scheme for the two rooms, using the heat pump and the water heater in a daisy-chain configuration. Tune the PI controllers so that a step variation of $-2\,K$ of the external temperature be recovered in a "reasonable" time without excessively stressing the actuators. The specifications here are deliberately vague, and correspondingly there is no "right" solution to match: what is important is how you state and motivate your control requirements. Assume the boiler always on, for simplicity.

4. [1 page] Create a second scheme, again with decentralised PI-based temperature control, but without heat pumps.

5. [2 pages] Conduct a simulation campaign (not too extensive, four–five conditions are enough) and use your results to quantify the energy saving achieved with the heat pumps in place.

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