System-level simulation of a wind turbine cooling system

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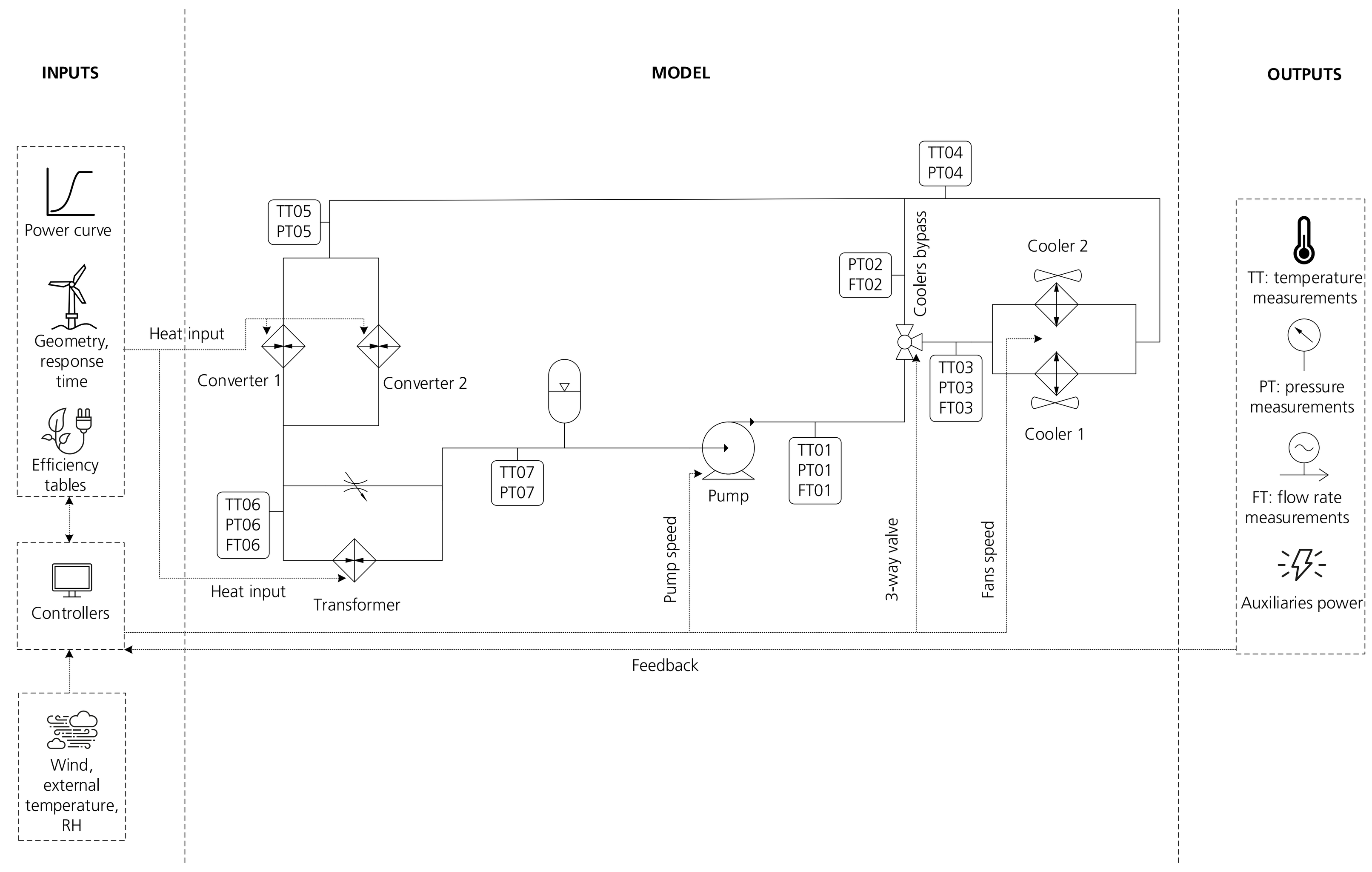
ReaLCoE

Introduction

The baseline model is implemented in MATLAB/Simulink and is structured around a set of interacting modules. For the turbine used in the ReaLCoE project[1], an offshore prototype, heat transfer is represented using thermal masses and energy balance equations, enabling representative dynamic simulations. Pumps and fans are parameterized using similarity rules, while the air–liquid heat exchangers are modeled with the ε-NTU method. The turbine model links wind speed to heat dissipation, establishing the thermal load input to the cooling system. Controllers coordinate the response of pumps, fans, valves, and derating strategies to both operational and environmental conditions. The modular design allows flexible modification of components, control strategies, turbine models, cooling media, and operating conditions.

How the model works

1. We receive information about power curve, response times, efficiency tables and geometry as well as from the controllers: logics, pump and fans PI, operating regime and derating strategies[2].
2. Environment: external temperature, relative humidity (RH) and wind profile are fully customizable according to desired test cases.
3. Test cases are defined as a combination of operational and environmental conditions.
4. Overall energy production and auxiliary power consumption are calculated, and pressure, temperature and flow rate are measured on selected points of the circuit.
5. Interaction between external conditions, control strategies and turbine design and operation can be evaluated in a wide range of settings.



Model simplified diagram.

Test cases

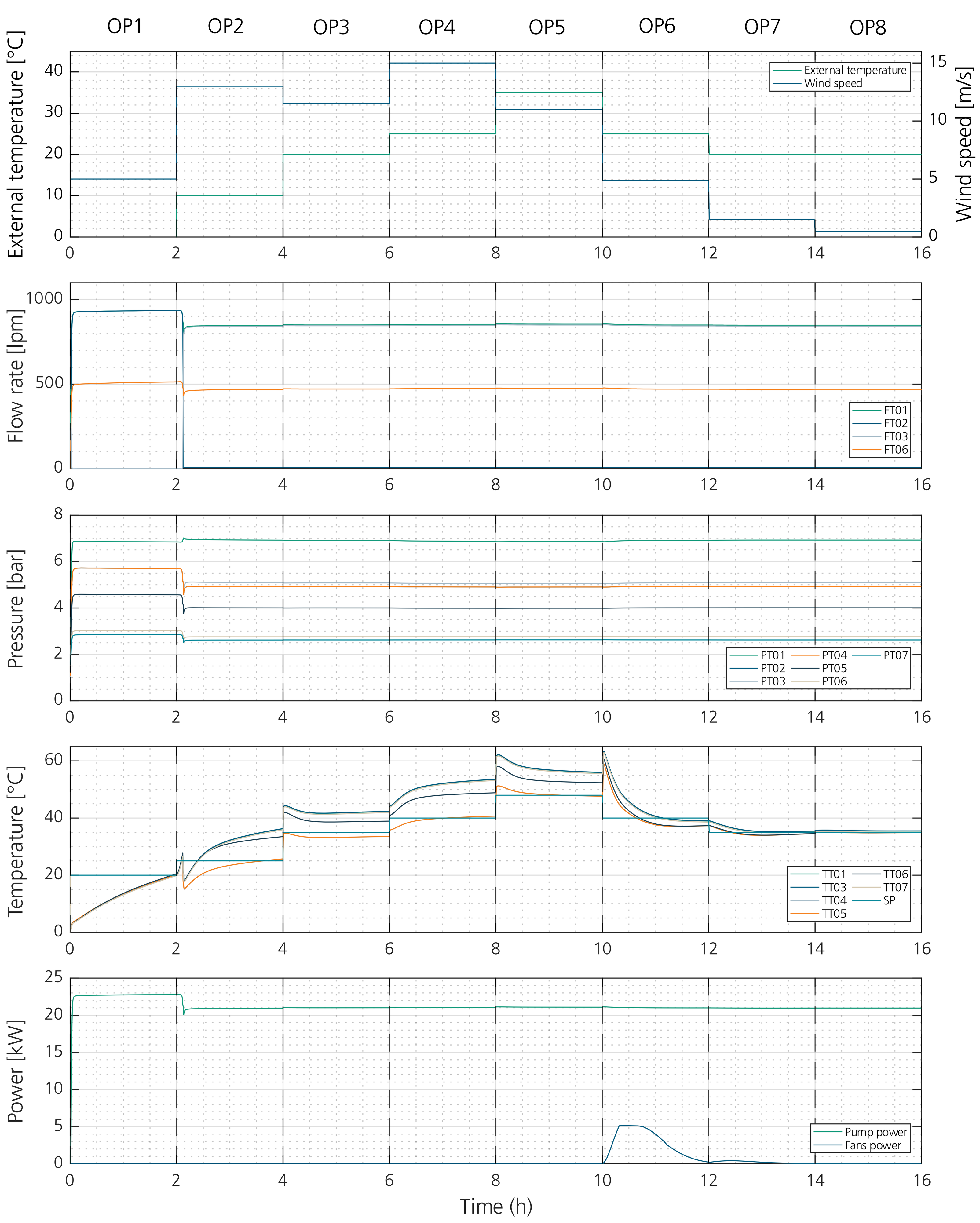
The model is simulated over 16 h using consecutive test cases of equal duration, as described in Table 1. The temperature setpoint (SP) is controlled at the converters' inlet (TT05).

Table 1: test cases.

Test case	OP1	OP2	OP3	OP4	OP5	OP6	OP7	OP8
Ambient temperature [°C]	-5	10	20	25	35	40	20	-10
Wind speed [m/s]	5	13	11.5	10	15	0	1.5	0.5

Test cases

The plots below show the measurements at each point of the simplified diagram and, additionally, the power consumed by pump and fans.



Simulation results.

Conclusion and outlook

The baseline model enables flexible simulation of a wide range of scenarios, fulfilling the requirements of Task 3.3 of the ReaLCoE project. The modular design leaves plenty of room for testing other turbines in different environments and with several combinations of parameters and subsystems.

The model is continuously being improved and will, in future work, be validated against experimental data from Fraunhofer IWES test benches. Upcoming research plans also include investigating alternative, environmentally friendly cooling media beyond conventional glycol-based solutions and incorporating AI-based control strategies to reduce auxiliary power consumption and thermal stress on components within a predictive cooling framework.

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1. Task 3.3 – Virtual Testing of Cooling System for Converter and Transformer (n.d.) Task 3.3 – Virtual Testing of Cooling System for Converter and Transformer. [Confidential internal document]. Unpublished.
2. Perez, L. (2023) Load Profile and WEC Data Available. Deliverable D1.2, ReaLCoE – Next Generation 14+MW Rated, Robust, Reliable and Large Offshore Wind Energy Converters for Clean, Low Cost and Competitive Electricity (Project No. 791875) [Confidential internal document]. Unpublished.