Hybrid Model Predictive Control of Chiller Plant with Thermal Energy Storage Evaluated with Modelica-Python Co-Simulation

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As the heating, ventilation and air conditioning (HVAC) systems dominate the energy consumption of building operation, energy efficiency and power demand management have become important for HVAC system controls to achieve cost reduction and grid support. The system of interest is a chiller plant coupled with chilled-water based thermal energy storage (TES) for air conditioning of commercial buildings (Figure 1).

With day-ahead electricity price profile, a hybrid model predictive control strategy is proposed to optimize the chiller-TES operation based on the weather and load forecast by minimizing the overall energy cost that combines the time-of-use (TOU) and demand charges, with the cooling load satisfied in real time. Such strategy is implemented with a two-level hierarchical structure. At the lower level, two PID control loops are implemented, which regulate the compressor suction refrigerant superheat with EEV opening and the supplied chilled water temperature with compressor speed. At the higher level, the hybrid MPC is designed with mixed-integer nonlinear programming (MINLP) such that the charging and discharging of TES can be optimally scheduled in parallel to the manipulation chiller operation.

As for control-oriented modeling, both first-principle and data-driven modeling approaches are used. A two-layer water temperature dynamic model is built for the TES, where the states include the top- and bottom-layer water temperatures (T_a and T_b). In light of the nonlinearities of the chiller plant characteristics, a data-driven Koopman-operator model is developed, where the states include the cooling-tower return water temperature (T_{cw}), compressor discharge temperature (T_{cd}) and compressor suction pressure (P_{cs}), and the manipulated inputs include the tower fan speed, the condenser water mass flow rate, the evaporator leaving water setpoint, the evaporator water mass flow rate, and a binary control command for TES charging or discharging. The building dynamic is approximated as a first-order model with the building return-water temperature (T_r) as its state. The predictable disturbances include ambient temperature, ambient relative humidity (RH) and building cooling rates.

The proposed control strategy is evaluated with Modelica based simulation study. Based on the development a Modelica based dynamic simulation model for a chiller plant with TES, as shown in Figure 2, a Functional Mockup Interface (FMI) based Python-Modelica co-simulation framework is developed, where the hybrid MPC is implemented in Python with the IPOPT solver. While the quality of the co-simulation mechanism has been validated, simulation study for validating the proposed control strategy is being conducted.

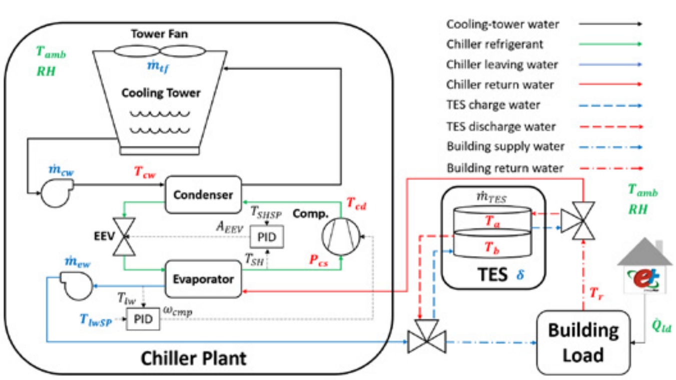

Figure 1. Schematic for Chiller Plan coupled with Thermal Energy Storage (TES)

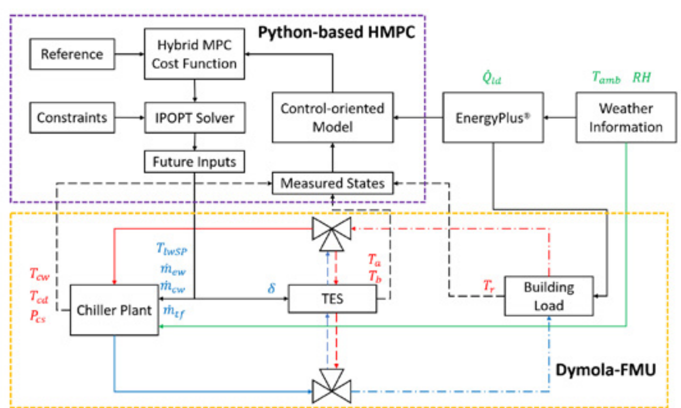

Figure 2. FMI based co-simulation platform for hybrid MPC Energy management of Chiller Plant with TES