Modeling of the Process Control of a High Performance Molten Salt Tower Receiver System Via State Machines

Introduction

In order to increase the economic efficiency of solar thermal power plants using molten salt as the heat transfer medium, they are constantly being optimized. With growing understanding of this technology, the process parameters such as the molten salt temperature are pushed further and further to the applicable limits. This also increases demands for comprehensive process and operational control. By simulating process models, the dynamic states can be analyzed to identify critical operating conditions and optimized accordingly. In addition to the system models, which represent its physical components, the process and operational control system developed for the system, including controllers, should also be integrated into the simulation model. Depending on the modeling approach, mapping a complex process control into a simulation model can result in an unstable system model that is difficult to manage and debug. Therefore, when modeling dynamic processes, in addition to the physical behavior of the system components, attention should also be paid to a clear and structured implementation of process control.

System model of the HPMS-II test receiver system

In the HPMS-II (High Performance Molten Salt Tower Receiver System) project, a molten salt test receiver system is being developed, manufactured and will be operated at the Multi Focus Tower Jülich (Germany) [1]. The receiver is designed to operate at an outlet temperature of up to 600 °C. Due to the high receiver output temperatures and the underlying properties of the solar salt, special focus is set on maintaining the process parameters. Especially in the transitions between the operating states, temporary temperature changes can occur in the system. If the temperature range of the salt mixture is undershot, the salt may freeze. If the temperature exceeds the temperature range of the salt, increased thermal degradation of the salt, metallic corrosion and the destruction of the receiver may occur. In order to investigate the transient behavior of the system, a dynamic simulation model based on previous developments is modeled using the Dymola modeling environment (Fig. 1). With this model, critical process sequences can be identified and investigated in advance to the real experiments. The dynamic simulation model represents both the physical components such as the test receiver, including the salt circuit and peripherals, and the process control system, including closed-loop control. The flux densities occurring at the receiver are simulated in advance using a ray tracing program developed by DLR and embedded in the simulation model. A dynamic two-phase fluid model, representing both solar salt and air, allows a detailed simulation of the transitions the HPMS-II system must go through during test operation. Especially in the transitions between the operating states, these simulations can be used both to identify locally occurring temperature gradients and to analyze the control behavior.

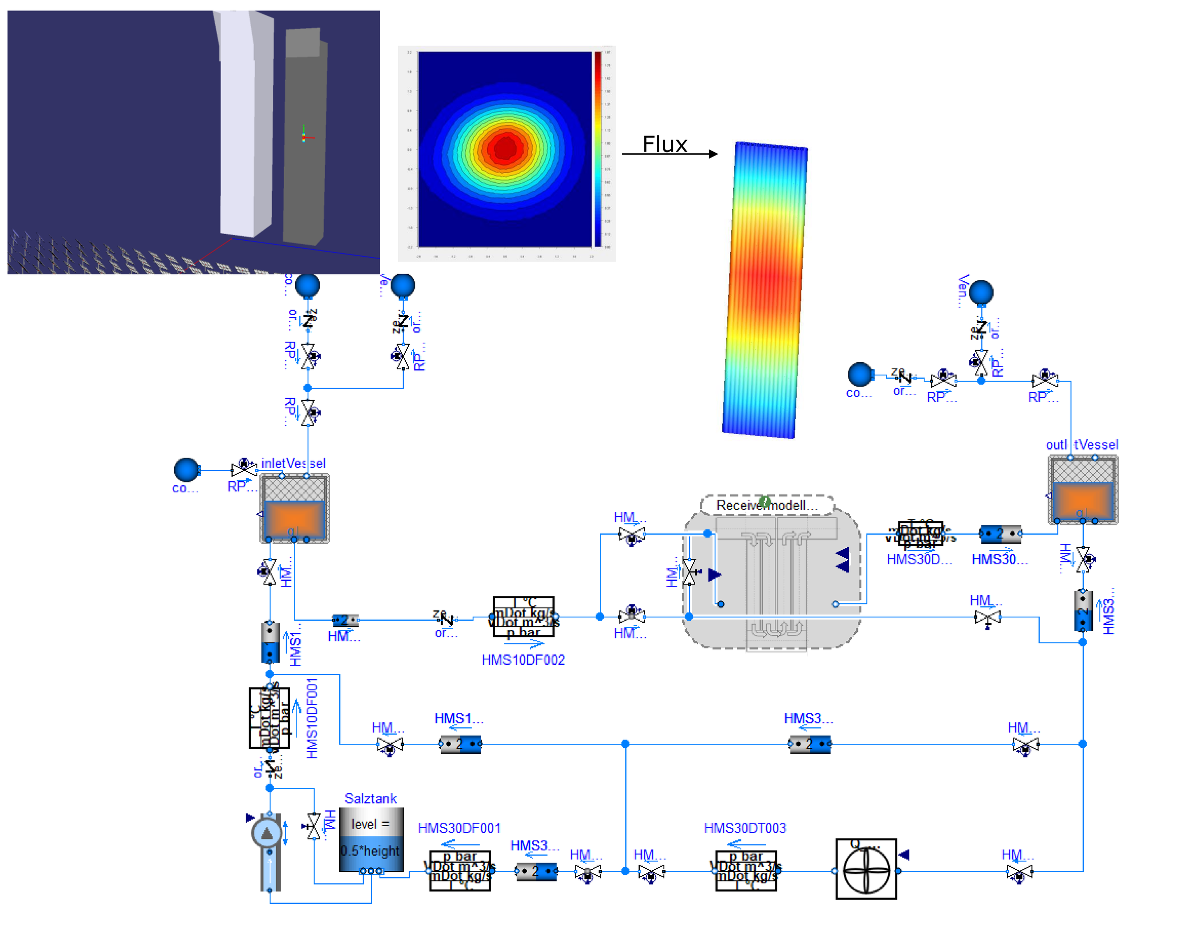

Figure 1: System model of the HPMS-II test receiver system including all physical components, flux density simulation and visualization

Process control model of the HPMS-II test receiver system

For the implementation of the process control, different approaches with specific advantages and disadvantages are feasible. One approach includes the implementation of the system control by conditional instructions in the text layer at top level of the simulation model. Here the individual states are defined by sequential instructions with If or When conditions in the algorithm domain. However, no graphical feedback is provided when following this approach, which reduces the clarity of the process flow and thus complicates traceability as well as debugging. In a further approach system control is implemented with the help of state machines, which are particularly suitable for the description of event-discrete systems. The control system is thereby always exactly in a discrete state and can be transferred into another state under certain conditions. These are usually visualized using so-called statecharts (state diagrams), in which the states and their transitions are clearly and explicitly sketched. The basic components, as available in the Stategraph2 library, are Steps and Transitions (T). The steps represent the possible states of the system, the transitions switch the process from one state to the other. Conditions can be defined for switching a transition.

In the HPMS-II project, the modeling approach of implementing process control into the dynamic simulation model via state machines is pursued. The system control was initially implemented for the operating states and step chains during solar operation of the HPMS-II system (Fig. 2). This includes the operating states Standby Overall System (GA), operation Flow Control (FC), operation Temperature Control (TC) as well as operation Robust Cloud Control (RWR). The operating states are represented in the "StateGraph2" model by "Steps". The step chains are modeled in "Subgraph" classes which can contain "Steps" and "Transitons" as required.

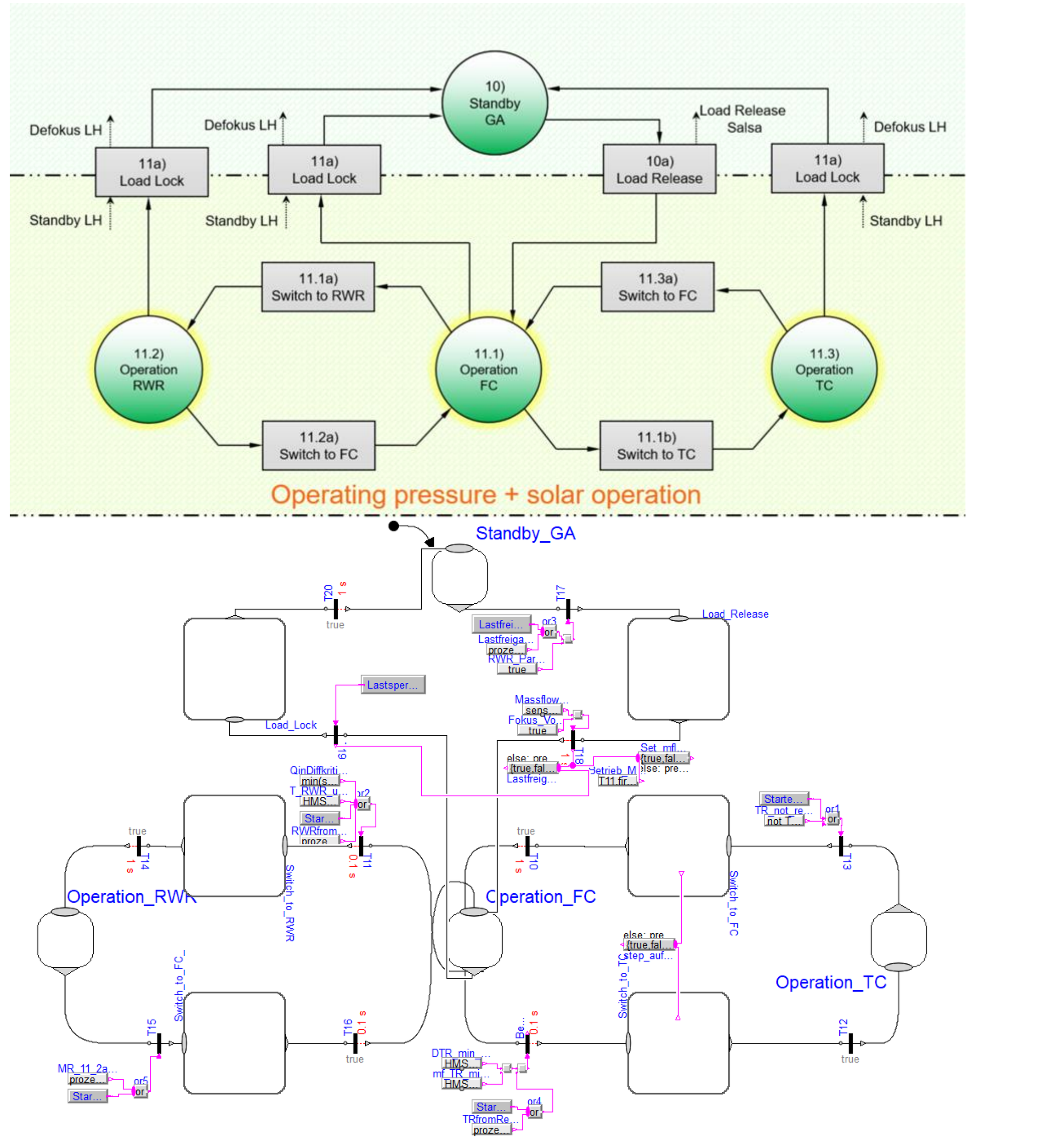

Figure 2: Part of the statechart of the HPMS-II system (top), and its implementation in the dynamic simulation model with StateGraph2 objects (bottom)

If a step chain or state object is active, a designated boolean variable is set to true. These "active" variables have been declared as "inner" variables in the simulation model. This allows the variables to be accessed at all levels of the simulation model. Thus, when the corresponding conditions are set, the possible actions during the simulation and the execution of a step chain are only enabled if the "StateGraph" object is active. For example, the mass flow setpoint is set to the maximum value (1 in Fig. 3) via the Load Release step chain (10a in Fig. 2) when changing from the Standby Overall System operating state to the Flow Control operating state and is transferred to the Mass Flow Controller (MFC) via the controller bus. The MFC sets the control valve accordingly. When the maximum mass flow is reached, the system switches (T18 in Fig. 2) to the operating state Flow Control. A new mass flow setpoint can only be set again when the step chain has ended and the Flow Control operating state is active (2 in Fig. 3). From this state, if the respective conditions are fulfilled, it is possible to change to the state Operation Temperature Control, Operation Robust Cloud Control or back to the operating state Standby Overall System.

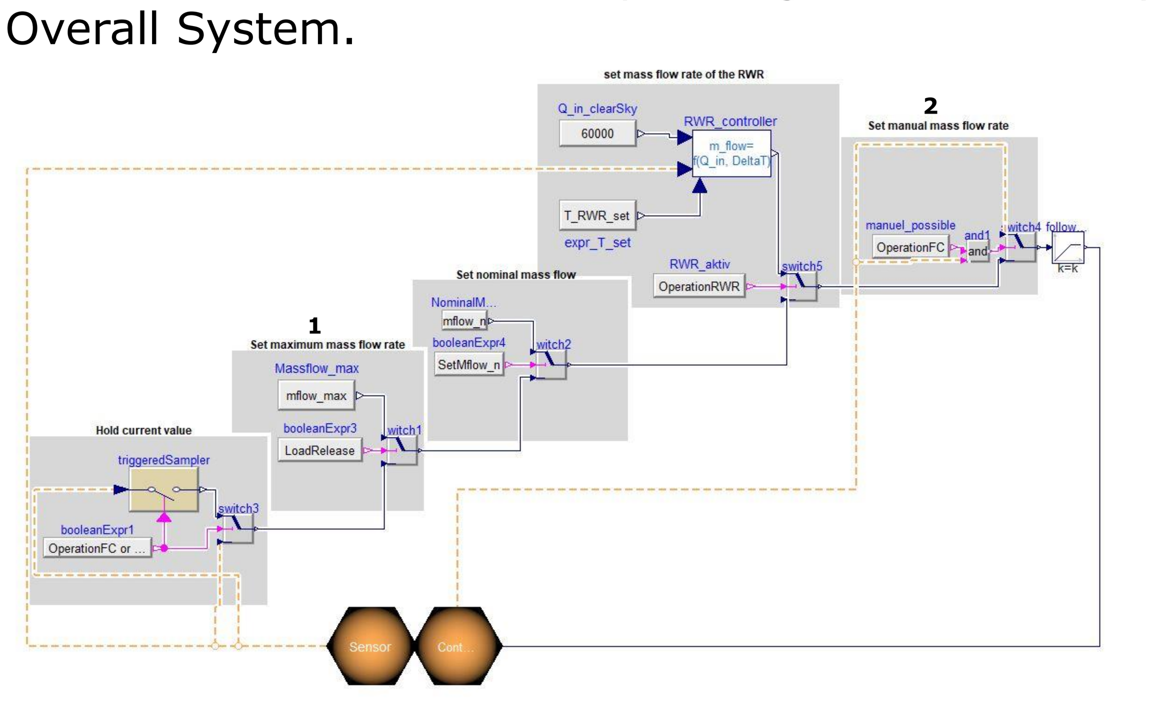

Figure 3: Class to set Massflow depending on State

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