Approaches to Tokamak Off-Normal Event Detection and Response at DIII-D, KSTAR, and EAST*

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The DIII-D digital plasma control system (PCS) has been adapted and used at a number of tokamaks around the world over the past several years. Implementations of the DIII-D PCS at KSTAR and EAST in particular have made use of, and improved upon, the methodology for off-normal event detection (ONED) and off-normal event response (ONER) that was originally incorporated into the DIII-D PCS.

ONED/R runs in parallel with the time-dependent PCS control algorithms. At DIII-D, the PCS uses a limited number of responses to deal with a large number of possible events, in large part because DIII-D takes advantage of a significant hardware interlock infrastructure to address safety concerns. Both EAST and KSTAR requested inclusion of additional methods for assisting in device protection, especially with regard to protections for superconducting coils.

While installations of ONED/R have been successful in meeting the needs of present day devices, future devices such as ITER will demand a significantly more sophisticated collection of actions to be taken in response to a much larger number of off-normal events. Currently, there exist a number of proposed response actions for only a small subset of off-normal events, the most notable being plasma disruptions. For example, physics research underway at DIII-D is focused on characterizing plasma disruption events and their causes, as well as designing possible mitigation and recovery schemes. There are also similar efforts underway by the DIII-D operations group to dynamically select the best possible response to faults in the device itself. However, the set of defined responses in either case is far from comprehensive. In addition, many types of off-normal events can have any number of causes and the possible responses are dependent on device and plasma state.

The large numbers of anticipated sequences of complex state-dependent responses highlight the need for a more flexible and robust software approach to support of ONED/R research. This need motivated a proposal for a finite state machine (FSM) architecture to control asynchronous switching of control algorithms in the DIII-D PCS. The proposed framework incorporates elements similar to the ITER CODAC design, including the use of State Chart XML (SCXML) as a means of defining an FSM, but differs slightly in that its purpose is primarily as a support tool for development of ONER scenarios.

This work discusses the lessons learned implementing and installing codes for detecting and responding to off-normal events in both plasma discharges and tokamak systems. In particular, we will present the implementation details for codes at DIII-D, EAST, and KSTAR, and discuss how those experiences are being incorporated into the proposed FSM architecture in support of ITER research at DIII-D

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