Control Algorithms and Approaches

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Background:

Use of control techniques for generating and maintaining plasmas in experimental fusion devices has grown tremendously since the advent of fusion in the fifties. A large number of plasma characteristics are routinely feedback-controlled in modern devices. However, most routine plasma control still uses rather rudimentary techniques, e.g. PID controllers tuned empirically. Consideration of model-based control as an alternative has grown since around the time of the initial ITER engineering design activity (EDA), in large part driven by the anticipated needs of ITER for higher performance control.

A number of model-based control schemes have been successfully tested experimentally, but only a very few form the basis for routine operation. The main issues that seem to prevent more widespread adoption is the initial cost in implementing and testing such controllers, their complexity relative to PID controllers, and the lack of confidence that the increased investment in cost and complexity will pay dividends in improved performance. Often, existing empirically tuned systems offer performance that is "good enough" for most experiments, although demands for improved performance are increasing as more precise control is seen to be necessary for some high performance physics experiments. A significant portion of the investment required to implement model-based controllers lies in the development and validation of predictive control-level models, which are often substantially different in form from existing models developed for physics studies. In addition, model-based controllers often require more effort to implement and test in real-time control software. Although plans for ITER and DEMO both envision substantial heavily integrated model-based control as a critical portion of their infrastructure, the reality on present-day devices is far from that goal.

Control engineering is a mature discipline - the result of over 60 years of development and application in thousands of products and systems worldwide. As a result, there is a huge literature on control technologies and and equally large community of experts in control that can be tapped to provide support in the development of modern controllers for fusion plasmas. There is presently some participation by control experts in developing solutions for fusion control problems, but there are also some significant impediments to this participation. A global issue is the dearth of control level predictive models that can be used for model-based controller design. A problem local to certain countries, including the U.S., is the lack of a funding mechanism to support control experts' participation in fusion programs. On the fusion side, plasma control has come to be viewed as a useful support technology for advancing a plasma physics research agenda, but rarely as a high-priority research topic in itself.

The Needs of ITER and DEMO:

Requirements for control in ITER and DEMO are fundamentally different from existing devices. Even the best understood and controlled plasma characteristics in existing tokamaks are made more challenging on ITER and DEMO by control actuation margins that are reduced due to cost considerations, by potentially severe consequences of control failure, and by limitations on the ability to sense the state of the plasma due to the harsh environment. In ITER, separate safety and interlock systems are assumed to backstop any control failures to guarantee personnel safety and to provide a certain amount of device protection. A third level of off-normal event detection and response algorithms is expected to operate in parallel with the plasma control to provide further protection for the device. However, both the interlock system and the off-normal event system in ITER can respond to control problems with methods to shut down the plasma that have consequences in terms of lost machine time and therefore increased operational costs.

DEMO will require control that is much more fool-proof as a consequence of a much greater emphasis on demonstrating true steady state operation and economic viability. As a result, there will be a much greater emphasis on provability of control performance, since far less control failure followed by recovery or shutdown is allowed and, similarly, far less variability from nominal operation is acceptable. On the other hand, commercialization is as much about cost minimization as it is about fusion performance. If the true objective for DEMO is to be a demonstration of commercial reactor technology, then the cost issue must be addressed. This implies minimizing control margins subject to maintaining the required performance, since actuators (coils, heating systems, etc) are a substantial cost item. Cost minimization and the demand for provable performance lead to a strong demand for model-based control

What needs to be done:

To prepare for ITER and DEMO, a program of research in plasma control must be established and supported with a priority that is competitive with plasma physics research. Major components of this program include:

- development and validation of predictive models for all characteristics of the plasma that need to be actively controlled or that influence any active control loop,
- use of experimental time on major devices and a commitment to incorporate ITER/DEMO-relevant control into routine plasma operation on those devices,
- incorporation of ITER/DEMO-relevant diagnostics and actuators into devices where controls are to be developed,
- development and experimental test of ITER/DEMO-relevant model-based control solutions using ITER/DEMO-relevant diagnostics and actuators by cross-disciplinary teams of fusion scientists and control experts.

For this program to be successful, a mechanism must be provided to encourage and support collaboration by outside control experts on plasma control problems.