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AI-driven tokamak control in HL-2A/2M

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Machine learning and artificial intelligence (ML/AI) methods have been applied to fusion energy research for over 2 decades, including the areas of disruption prediction, particle distribution and loss prediction, plasma equilibrium reconstruction and so on. The success in achieving magnetic control of the TCV tokamak with deep learning methods has demonstrated great opportunities for intelligent control of fusion power plants by ML/AI. There are currently huge needs of AI/ML for accelerated progress toward realization of the fusion energy. This work reports progresses on AI-driven tokamak control in HL-2A/2M based on both the experimental and simulation data, covering the areas of disruption prediction, the magneto-hydrodynamic (MHD) modes recognition, and predicting the operation beta limit.

The electromagnetic and thermal energy loads on the first wall and other plasma facing components during tokamak disruptions are often sufficiently high to cause huge damages to the device. Disruptions are hardly avoidable in tokamaks, and are often difficult to predict. AI/ML provides a potential way to address this issue. A machine learning model has been trained to predict disruptions in HL-2A. Further efforts have been made to improve accuracy and interpretability of the model. Both the off-line and real-time tests achieved good performance.

The tokamak plasma disruption can be due to many factors, with the macroscopic MHD instability being one of them. It is known that the pressure-driven external kink (XK) mode sets a 'hard'limit to the tokamak operation. As the plasma pressure exceeds the so-called Troyon β_N limit, major disruptions can occur. The operational β_N limit can be calculated with first-principle MHD codes but is always time-consuming. To meet the requirements of the XK mode control in real time in experiments, artificial neural networks (NNs) have been trained to predict the no-wall and ideal-wall β_N limits based on the numerical database generated for HL-2M. The NN-prediction is found to reach 95% accuracy compared to the numerical results directly computed by the MARS-F MHD stability code.

The edge localized mode (ELM) is another type of instability, that may not cause plasma disruption but can produce a large amount of heat and particle fluxes to the divertor target, which in turn potentially cause material erosion in future reactor-scale devices such as ITER. Therefore, large ELMs need to be identified and controlled, with the latter achieved by 3D magnetic coils, impurity injection or other means. We report an example of ELM recognition and mitigation experiment by the AI control system. An advanced AI model for the ELM identification via L-H transition will also be reported. Similar methods have been employed to identify the long-live mode, the tearing mode, the fish bone mode and the sawtooth in HL-2A.

As the last part of the report, we show some of the AI modeling effort which is still in progress, i.e., the device-independent disruption prediction for HL-2M with the data support from HL-2A and J-TEXT experiments, and the intelligent strategy during operations.

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