

Project Title: Reinforcement Learning and Symbolic Transformer for Stability Certificates of Nonlinear Power Systems

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Traditional power systems, once dominated by synchronous generators, are increasingly being replaced by converter-interfaced renewable generators, which are highly nonlinear, high-dimensional, and complex systems. Conventional stability assessment methods primarily rely on extensive time-domain simulations or linearised small-signal analysis, both of which become inadequate for analysing nonlinear responses under large disturbances or across broad operating conditions. Lyapunov stability theory provides a rigorous mathematical framework for certifying the stability of nonlinear dynamical systems without the need for exhaustive simulations. However, constructing suitable Lyapunov functions for complex systems remains extremely challenging and generally requires significant analytical insight. Recent advances in AI suggest that symbolic transformer models can assist this process by analysing mathematical equations and proposing candidate Lyapunov functions, offering structured hypotheses for stability certificates where explicit analytical construction is difficult.

This project introduces a new AI-powered computational framework that combines reinforcement learning (RL) and symbolic transformers to automatically identify Lyapunov functions for nonlinear dynamical systems. The work builds on a current N8 CIR winter internship exploring symbolic transformer methods for stability analysis of general nonlinear systems. Although symbolic approaches demonstrate strong reasoning capabilities, they often rely on large, carefully curated training datasets. The proposed project enhances this work by using a direct search for symbolic expressions and rewarding candidates that meet Lyapunov stability conditions, while the symbolic transformer refines promising candidates into concise, understandable analytical forms. The framework will then be tested on representative power system models.

Project schedule (8 weeks)

Week 1: Literature review and reproduce baseline experiments from the ongoing winter internship.;

Week 2-4: Implement a RL framework and symbolic transformer models to analyse candidate expressions and identify compact analytical structures for Lyapunov functions.

Week 5-6: Apply the framework to classical nonlinear swing-equation models of power systems to validate the methodology. Perform large-scale experiments using HPC resources to explore candidate functions and evaluate stability regions under different scenarios.

Week 7-8: Analyse results, refine the framework, and prepare a short technical report and reproducible research code documenting the computational workflow and findings.

The research involves large-scale exploration of candidate symbolic expressions and repeated verification of stability conditions across multiple operating scenarios, making it well-suited for computational research environments. High-performance computing resources such as the University of Liverpool's Barkla HPC cluster will be utilised to accelerate RL training and symbolic discovery through GPU-based parallel computation. Working with the dRTP mentor, the intern will develop reproducible research workflows and gain practical experience in research software development, HPC job management, and data-driven modelling. The project thus provides hands-on training in computational science while contributing to an emerging research area at the intersection of machine learning, symbolic reasoning, and nonlinear power system dynamics.