Tensorize the Grid

From Dynamic Models to Stability Analysis

HackUPC 2026 Challenge Proposal

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Proposed by the TenSyGrid Consortium

1 Background

Power grids are undergoing a fundamental transformation. Traditional synchronous generators, large rotating machines that have provided stability for over a century, are being replaced by power electronic converters: wind turbines, solar inverters, battery systems, and HVDC links.

These converters respond in milliseconds rather than seconds, creating complex dynamic interactions that are difficult to analyze with classical tools. Grid operators face a critical challenge: **how do we ensure stability in a grid dominated by fast acting power electronics?**

TenSyGrid (*Tensors for System Analysis of Converter Dominated Power Grids*) is a European research project developing new mathematical methods to address this challenge. Our key insight: by representing dynamic models as **tensors**, we unlock powerful techniques for linearization, eigenvalue analysis, and stability assessment that scale to large systems.

2 The Challenge

Your mission: Build a tool that converts dynamic power system models into tensor representations, enabling automated stability analysis.

2.1 Mathematical Formulation

Power system components are described by nonlinear differential algebraic equations (DAEs):

$$\dot{x} = f(x, u, p) \tag{1}$$

$$y = g(x, u, p) \tag{2}$$

where $x \in \mathbb{R}^n$ represents the state vector, $u \in \mathbb{R}^m$ the inputs, $y \in \mathbb{R}^p$ the outputs, and p the system parameters.

Example: Synchronous Machine

The synchronous machine dynamics follow the classical swing equation:

$$\frac{d\delta}{dt} = \omega - \omega_0 \tag{3}$$

$$M\frac{d\omega}{dt} = P_m - P_e - D(\omega - \omega_0) \tag{4}$$

$$P_e = \frac{E'V}{X'_d}\sin(\delta) \tag{5}$$

where M is the inertia constant, D the damping coefficient, δ the rotor angle, and E' the transient EMF.

2.2 Technical Objective

Given a dynamic model, create a software pipeline that:

1. **Parses** the model equations from a symbolic or structured input format
2. **Extracts** state variables, inputs, outputs, and parameters
3. **Constructs** the tensor representation of the nonlinear dynamics
4. **Linearizes** the model around a specified operating point
5. **Outputs** state space matrices (A, B, C, D) or transfer functions

2.3 Linearization and State Space Form

The tool should produce a linearized state space representation:

$$\Delta\dot{x} = A\,\Delta x + B\,\Delta u \tag{6}$$

$$\Delta y = C\,\Delta x + D\,\Delta u \tag{7}$$

where the Jacobian matrices are computed as:

$$A = \left.\frac{\partial f}{\partial x}\right|_0, \quad B = \left.\frac{\partial f}{\partial u}\right|_0, \quad C = \left.\frac{\partial g}{\partial x}\right|_0, \quad D = \left.\frac{\partial g}{\partial u}\right|_0 \tag{8}$$

This representation enables:

- **Eigenvalue analysis:** identifying oscillation modes via $\det(A - \lambda I) = 0$
- **Participation factors:** $p_{ki} = \phi_{ki}\psi_{ik}$ relating states to modes

3 Evaluation Criteria

Criterion	Weight	Description
Correctness	30%	Mathematical accuracy of the linearization, validated against reference results
Generality	25%	Ability to handle different model structures beyond the provided examples
Usability	20%	Clear interface, documentation, and ease of use
Performance	15%	Efficiency with larger models (50+ state variables)
Creativity	10%	Bonus for visualization, additional analysis features, or novel approaches

4 Resources Provided

Participants will receive:

- 3 to 5 sample dynamic models of increasing complexity
- Reference linearization results for validation
- Tutorial materials on power system dynamics and tensor methods
- Mentorship from TenSyGrid researchers throughout the hackathon

5 Why This Matters

This is not a toy problem; it is **real research**. The European grid must integrate hundreds of gigawatts of renewable generation while maintaining stability. Current tools struggle with the complexity of converter dominated systems.

The tool you build could become part of an **open source stability analysis framework** used by grid operators, researchers, and engineers worldwide. Your work this weekend could help keep the lights on in a 100% renewable future.

6 Prizes

- **First Place:** eRoots merchandise pack + invitation to present at TenSyGrid consortium meeting

All participants will receive certificates of participation.

7 About TenSyGrid

TenSyGrid is a European research consortium developing innovative stability analysis methods for converter dominated power grids. The project brings together:

- **Fraunhofer IWES** (Germany): Energy systems research
- **HAW Hamburg** (Germany): Applied sciences and control systems
- **University of Malta**: Power systems and renewable integration
- **Universitat Politècnica de Catalunya** (Spain): Electrical engineering research
- **eRoots Analytics** (Spain): Power systems software development

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https://tensygrid.eu