Kiel University
Christian-Albrechts-Universität zu Kiel

IEEE PES Power & Energy Society

IEEE Advancing Technology for Humanity

PowerTech Kiel 2025

June 29th - July 3rd, 2025

Simple and Flexible Power System Simulation Coupling Using Remote Object Communication

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Highlights:

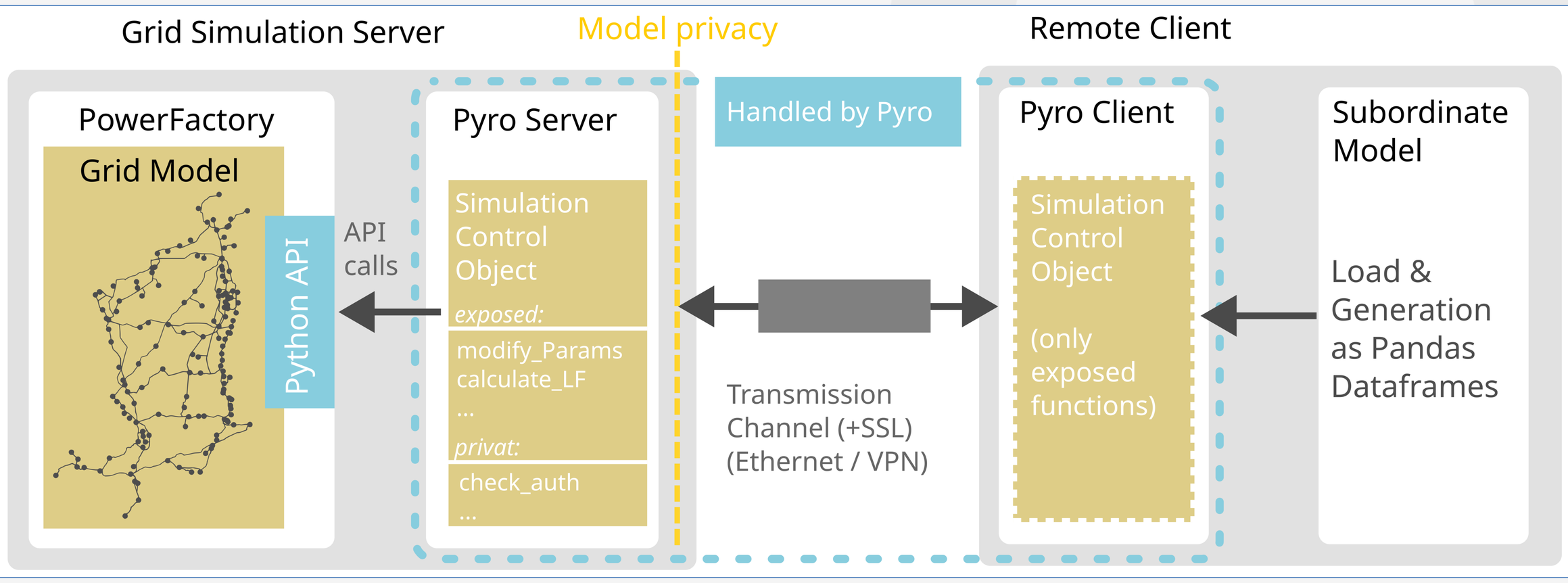
- A simple, flexible, and secure distributed power system simulation coupling using **Python Remote Objects (Pyro)**.
- Tackles challenges of data privacy, hardware and licensing constraints, and the lack of standardized exchange formats for simulation coupling.
- Tool-agnostic simulation coupling compatible with any API-enabled simulator.

Introduction & Motivation

- **Power systems**: Renewables, storage, and markets are increasing system complexity.
- **Simulation coupling**: Couple specialized tools for collaboration, and reduces costs.
- **Challenges**: Data privacy, security, and lack of standard interfaces.
- **Problem**: Existing frameworks are too complex for simple use cases.
- **Solution:** A simple, secure, and flexible simulation coupling using Pyro.

Results & Insights

- **Fast setup:** Quick connection, SSL encryption, and model initialization.
- **Runtime**: Driven by data size & network.
- **Server execution**: Simulations run fully on the server.
- **Minimal overhead:** <2% total time increase for secure data transfer.
- **Privacy**: Only selected parameters are shared, model remain private.
- **Access control**: Secured via VPN & SSL, access is revocable.
- **Extension**: Flexible extension of functions.



Workflow

Step 1 *Model Preparation and Parameter Definition*

- Development of grid models in PowerFactory.
- Definition and exchange of parameters with the client.

Step 2 *Remote Simulation Hosting using Pyro*

- Wrapping of PowerFactory API in Python (@expose decorator).
- Selective parameter exposure for ensuring privacy.
- Secure connection using VPN + 2-way SSL.

Step 3 *Remote Execution and Result Exchange*

- Client connects and accesses exposed functions (using URI).
- Modification of parameters, executing simulations, and retrieving results.
- Data transfer handled by Pyro.
- Custom serializers used for custom data structures.

Test Setup & Model Structure

Test Setup: PowerFactory 2023 | Python 3.11 | Pyro 5 | Windows 11 PCs
Connections: Local:1 Gbps Ethernet | Remote:100 Mbps via VPN

Grid	Voltage(kV)	Substations	Transformers	Generators	Loads modified	Generators queried
DSO	110	140	300	140	233	20
TSO	380/220	745	945	489	10	20

Table 1: Key components of the PowerFactory grid models used for Powerflow simulation.

Performance of Pyro with PowerFactory

Grid	SSL	Server/Client	Activation (s)	Param Def. (s)	Sim Exec. (s)	Total (s)
DSO	✗	Ethernet	0.01	3.51	0.08	3.61
DSO	✓	Ethernet	0.07	3.50	0.08	3.65
DSO	✗	Ethernet/VPN	0.09	3.91	0.12	4.12
DSO	✓	Ethernet/VPN	0.20	3.93	0.12	4.25
TSO	✗	Ethernet	0.01	1.73	0.89	2.63
TSO	✓	Ethernet	0.07	1.74	0.90	2.71
TSO	✗	Ethernet/VPN	0.09	1.84	0.96	2.89
TSO	✓	Ethernet/VPN	0.21	1.87	0.97	3.05

Table 2: Summarizes the PowerFactory-Pyro performance with and without SSL over local and VPN setup.

- Activation time (connection, authentication, and initialization) is low even with encryption, due to Pyro's low overhead.
- Parameter definition time (serializing, transmitting and modification) is highest and scales with the number of exchanged model parameters.
- Simulation time is consistent, as execution runs fully on the server side.

Conclusion & Future Work

- Simple, flexible, and secure power grid simulation coupling.
- Model privacy via selective exposure, access control, VPN , and SSL.
- Negligible overhead for loosely coupled simulations.
- Less optimized for tightly coupled, high-performance simulations.
- Compatible with Pyrolite (Java/.NET) & any API-enabled simulator.
- Extensible for advanced, secure collaborative research.
- Future work: integration with Pandapower, PyPSA, multi-energy systems, energy markets, weather and cyber-physical systems.

Acknowledgements

This work is funded by the Helmholtz Platform for the Design of Robust Energy Systems and their Supply Chains (RESUR).

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