PYTRNSYS SUITE: AN ALL-IN-ONE, HARMONIZED PLANNING-TO-DIGITAL-TWIN TOOL FOR RENEWABLE ENERGY SYSTEMS

Summary

The deep decarbonization of large-scale energy systems and industrial applications requires the integration of multiple renewable energy technologies. This increasing technological hybridization significantly complicates system design and planning processes. As a result, there is a growing demand for advanced tools capable of consistently integrating, harmonizing, and optimizing complex multi-technology energy systems. To address these challenges, a harmonized, all-in-one tool based on a single, robust simulation engine is being developed to ensure reliability and methodological consistency throughout all project phases — from early feasibility studies to detailed engineering and operational monitoring. The proposed framework introduces dynamic simulation capabilities from the earliest stages of project development, leveraging pytrnsys / TRNSYS as the computational backbone. This unified environment enables rapid and consistent assessment of large-scale hybrid renewable energy systems through a traceable methodology that spans all phases.

Keywords: TRNSYS, pytrnsys, renewable energy system modelling, digital twin, system integration

Field of application for the findings: industry, district heating networks

Addressed audience: solar field planners, energy system designers, system operators, solar energy researchers

1. Introduction

The deep decarbonization of large-scale energy systems and industrial applications requires the integration of multiple renewable energy technologies, including solar thermal energy, photovoltaics, heat pumps, biomass systems, and energy efficiency measures such as waste heat recovery. Although substantial technological progress has been achieved, one of the main barriers to widespread implementation remains the high upfront investment associated with such systems.

These investment challenges are closely related to the increasing complexity of combining diverse technologies into cohesive and efficiently operating energy solutions. Inadequate integration may lead to performance mismatches and higher operational costs, ultimately reducing project profitability and delaying the recovery of initial investments. Consequently, achieving cost-effective decarbonization relies on advanced planning and design tools capable of accurately modelling, simulating, and optimizing hybrid energy systems, thereby supporting informed decision-making during early project stages and ensuring technically reliable and economically viable outcomes.

Dynamic simulation tools play a crucial role in addressing this challenge, as they capture time-dependent interactions among renewable energy sources, energy demand, storage systems, and control strategies. Unlike conventional static calculation approaches, dynamic simulations provide a more realistic representation of system behavior, enabling better decision-making and system optimization.

However, many state-of-the-art planning tools still rely on simplified static calculations, particularly during early project stages — despite these phases offering the greatest potential for influencing system performance and economic viability. The absence of accurate dynamic modelling during initial design stages can lead to inefficient system configurations, higher lifecycle costs, and underperforming installations, ultimately reducing investor confidence and slowing industrial energy transition efforts.

2. Pytrnsys suite

To overcome these limitations, a harmonized all-in-one software, the *pytrnsys* suite (1) is being developed based on a single, robust simulation engine that ensures consistency and accuracy across all project phases —

from feasibility assessment and system design to operational monitoring.

The suite introduces dynamic simulation capabilities from the earliest planning stages by leveraging TRNSYS as its computational backbone and exploiting its extensive validated model library. The unified framework enables rapid evaluation of large-scale hybrid renewable energy systems through a consistent and traceable modelling methodology.

A key objective of the suite is to challenge the widespread perception that dynamic simulations are too complex, time-consuming, or computationally expensive for early-stage planning. This misconception often leads planners to rely on oversimplified static tools, which can compromise project credibility, bankability, and long-term economic viability.

The *pytrnsys* suite divides and simplifies the two main tasks required for energy system simulation: system model development and dynamic simulation execution.

Within the suite, system models are pre-developed: hydraulic configurations are predefined, equipment components are represented by validated mathematical models, and standard control strategies are already implemented. Users therefore do not build models from scratch; instead, they parameterize existing system configurations and define operational setpoints. This approach allows users to focus on simulation and analysis rather than model construction, significantly reducing modelling time and required expertise.

The tool includes dedicated graphical user interfaces (GUIs) tailored to the data availability, complexity level, and resource allocation typical of each project phase (cf. Fig. 1):

- Early planning phase: an *online frontend* enables rapid feasibility studies through dynamic simulations of predefined technologies and configurations.
- Design and detailed engineering phase: the *pytrnsys* interface provides advanced flexibility for customized hydraulic layouts and control strategies, while starting from a fully functional baseline model rather than a blank configuration. This substantially reduces modelling effort and development time for advanced users.
- Operational phase: a *monitoring frontend* employs a customized digital twin — developed during the design phase — for SCADA-connected plants, enabling performance analysis and operational optimization.

The development of part of this tool is currently being carried out within ResulTES (2) and DigiSolar (3).

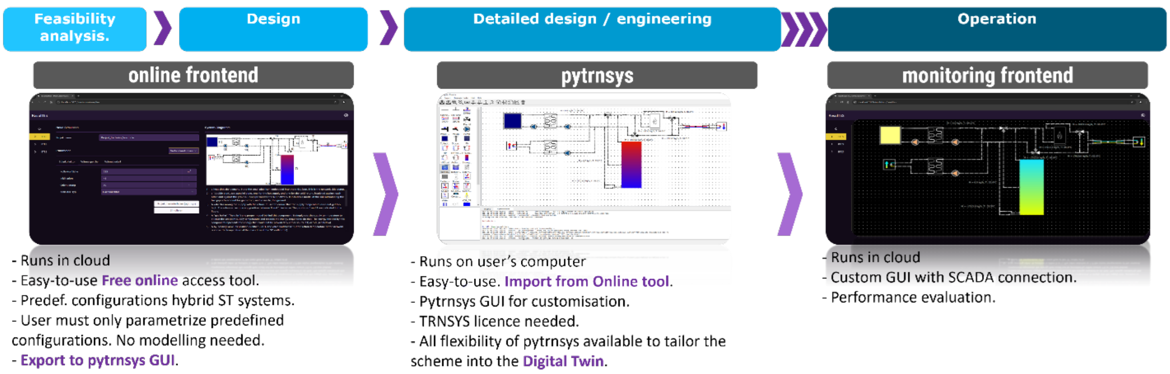

Fig. 1: Tool used throughout the different project phases. The two left-most screen shots show the respective user interfaces of the current state of the ResulTES project, while the monitoring frontend is being developed under DigiSolar.

3. Current development

ResulTES is a digital tool designed to analyze the integration of large-scale or seasonal thermal energy storage (TES) systems into district heating networks (DHNs). The tool targets planners and emphasizes ease of use, allowing system simulations and preliminary performance results to be obtained within minutes.

The same backend model can be reused throughout successive project phases. A model created during the pre-design phase can be progressively refined and extended during the design and detailed engineering phases. To support this workflow, the tool allows different modelling resolutions for the same system: an initial simplified representation using larger simulation time steps and lower spatial discretization, and a refined model with adjusted time steps and higher discretization suitable for detailed analysis. The detailed model can subsequently be further customized by advanced users.

Three representative DHN system configurations — covering most current and near-future applications — have been defined: systems with tank thermal energy storage (TTES), systems with pit thermal energy storage (PTES), and systems with borehole thermal energy storage (BTES).

All configurations include a solar thermal field as a primary heat source and can be extended with additional generic heat sources defined via supply profiles, such as waste heat recovery, heat pumps, or electric heating elements. Fig. 2 illustrates one operating mode of the PTES configuration as implemented in the *pytrnsys* graphical interface.

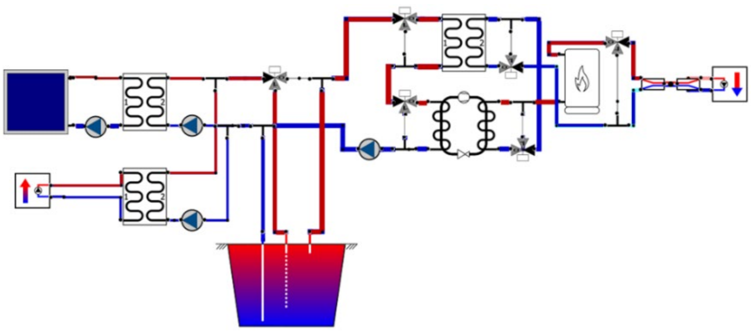

Fig. 2: Operating mode of the ResulTES PTES system implemented in pytrnsys. Energy sources charge the pit storage through an intermediate port while simultaneous discharge occurs at the top port, with a heat pump raising the supply temperature to the demand setpoint.

The *pytrnsys* suite is also being developed under DigiSolar, which aims to create and integrate digital tools to enable hybrid solar thermal solutions that drive decarbonization, electrification, and energy flexibility. At its core, DigiSolar will deliver its own suite, a unified digital platform designed to optimize every stage of hybrid solar thermal system's lifetime. This suite leverages the capabilities of the *pytrnsys* suite with AI-driven fault detection, supply and demand forecasting and model predictive control, and life cycle assessment.

Within the scope of the project, more hybrid solar thermal models will be implemented reflecting real-world solutions (including district heating networks and industries) or archetypes that are thought to be representative systems. Furthermore, the interconnection of the *pytrnsys* suite with other state-of-the-art software solutions (such as, model predictive control or fault detection) will prove its potential not only in the design phase, but also in the operation and monitoring phase.

4. Acknowledgements

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