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An all-in-one, harmonized planning-to-Digital Twin tool for renewable energy systems

Summary

The decarbonization of large-scale energy systems and industrial applications requires the integration of various renewable energy sources complicating the system design. As a result, there is an increasing demand for sophisticated design and planning tools to accurately manage and optimize such complex systems. To address these challenges, a harmonized, all-in-one tool built on a single, robust engine that ensures reliability and accuracy throughout every project phase — from early feasibility studies to the detailed engineering — is being developed. This tool introduces dynamic simulation capabilities right from the early stages of the project, leveraging TRNSYS as the computational backbone. This unified framework enables the rapid assessment of large-scale hybrid renewable energy systems through a consistent, traceable methodology that spans all phases.

Keywords: district heating, seasonal thermal energy storage, peak shaving, solar heat for industrial processes, digital twin, system integration, TRNSYS, pytrnsys, energy system modelling, renewable energy sources

1. Introduction

The decarbonization of large-scale energy systems and industrial applications requires the integration of various renewable energy sources, such as solar thermal energy, photovoltaics, heat pumps, biomass, and energy efficiency measures like waste heat recovery. Despite significant technological advancements, one of the main barriers to widespread adoption remains the high upfront investment required. This is further complicated by the growing complexity of system design, particularly as higher solar fractions and hybrid configurations become necessary to meet decarbonization targets. As a result, there is an increasing demand for sophisticated design and planning tools that can accurately manage and optimize such complex systems. Dynamic simulation tools are key to addressing this challenge, as they can account for the time-dependent interactions between renewable energy sources, energy demand, and storage. Unlike conventional static models, dynamic simulations provide a more realistic representation of system behavior, enabling better decision-making and system optimization. However, most state-of-the-art tools used today still rely on static calculations, especially during the early stages of project development when the greatest potential for impact exists. Without accurate dynamic modelling in the initial phases, system designs can be inefficient, costlier in the long run, and may ultimately underperform — reducing the confidence of investors and slowing the transition to renewable energy in industry.

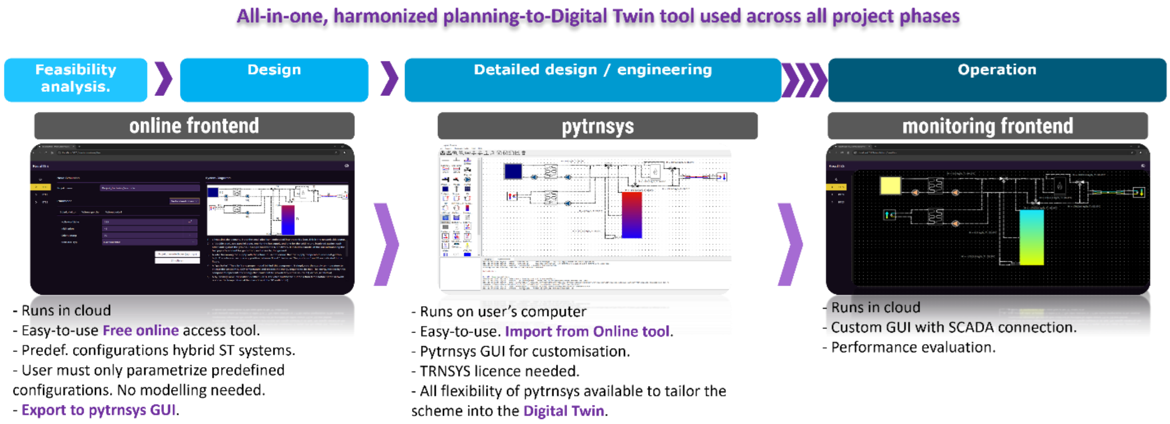
2. All-in-one planning-to-Digital-Twin harmonized tool

To overcome these limitations, a harmonized, all-in-one tool built on a single, robust engine that ensures reliability and accuracy throughout every project phase — from early feasibility studies to the detailed engineering — is being developed. This tool introduces dynamic simulation capabilities from early stages of the project, leveraging TRNSYS as the computational backbone. This unified framework enables the rapid assessment of large-scale hybrid renewable energy systems through a consistent, traceable methodology that spans all phases. It also addresses the common misconception that dynamic simulation tools are too complex, time-consuming and computationally expensive for early-stage planning, which often lead to the adoption of oversimplified static tools that compromise the credibility and bankability of projects. To counter this, the tool simplifies the two main activities necessary for energy system modelling: the system model development and the dynamic simulation.

The tool features dedicated graphical user interfaces (GUIs) tailored to the specific data availability, complexity, and resource allocation typical of each phase (cf. Fig. 1). The online frontend supports early-stage planning through dynamic simulations of predefined technologies and configurations, expediting feasibility assessments. In later project stages, where more advanced and customized controls and hydraulic configurations are necessary, the pytrnsys interface (which see below) provides full design flexibility. Finally, during the operational phase, the monitoring frontend employs the customized digital twin—developed during the detailed design stage—for each SCADA-monitored plant.

The development of part of this tool is currently being carried out within the ResulTES ("RESULTES - Reliable pre-feasibility and design tool for quick assessment of large TES integrated with renewable energy sources and DHN - Basic data," n.d.) project. In parallel, other project proposals are being developed to complete the tool's overall development.

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.



3. ResulTES

ResulTES is a digital tool to study the integration of large-scale/seasonal (or smaller) thermal energy storages into district heating networks (DHNs). It is aimed at planners and shall be easy to use. It shall allow to simulate the system of interest and obtain first results in the order of minutes. The tool can be used throughout the different project design phases. The same backend model that is used in the pre-design phase can be re-used in the design phase and finally in the detailed design phase by extending and refining it. Therefore, the time-consuming and error prone process of transferring models from one design phase's preferred tool to the next is eliminated.

We identified three DHN system types that cover the majority of systems in operation today or in the near future: a system with a steel tank TES (TTES), one with a pit storage TES (PTES) and one with a borehole TES (BTES). A solar thermal field source is included in all three systems, and they can all be extended with additional generic sources defined by a supply profile. These generic sources can represent waste heat, heat pumps, heating rods, etc. Figures 2 and 3 show two different modes of operations of ResulTES' PTES system as represented in the pytrnsys software. Figure 4 shows a mode of ResulTES' BTES system.

Fig. 2: One mode of operation of the ResulTES' PTES system shown in the pytrnsys software. The sources are charging the pit storage at medium temperature. The storage is discharged at the same time through its top port and the heat pump is active to lift the temperature to the set point temperature.

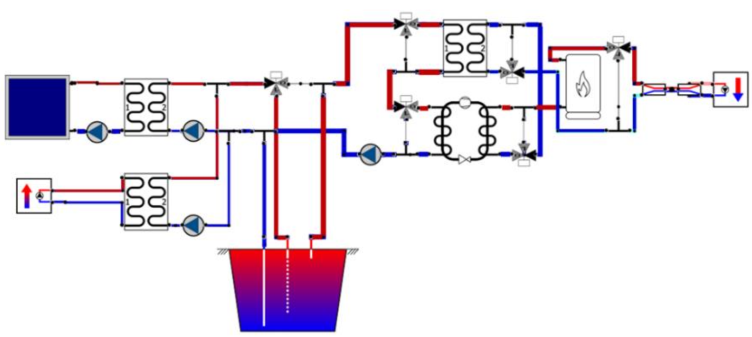


Fig. 3: The sources are charging the storage and providing heat to the network (cf. Fig. 2 for more details)

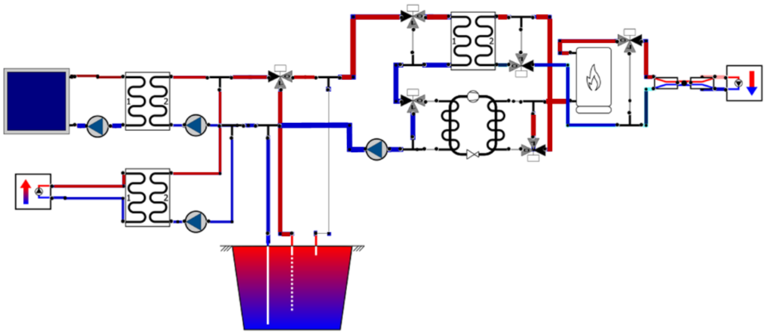
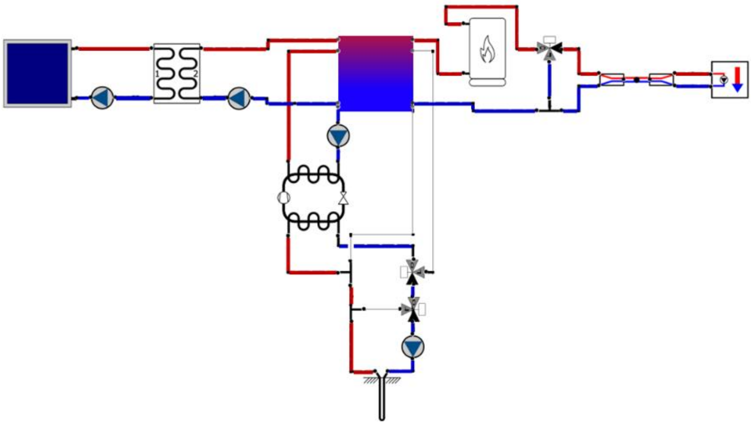


Fig. 4: One mode of operation of the ResulTES' BTES system shown in the pytrnsys software. The buffer tank is charged by the solar collector field and from the borehole storage via the heat pump. At the same time the buffer tank is discharged to satisfy the demand.



ResulTES is a web-based tool that runs, post-processes and manages simulations in the cloud. Only a web browser is needed to run simulations. No software licenses need to be purchased. The computational resources required can be scaled up and down automatically according to the demand. This lowers the cost of the computing infrastructure for the users and allows connecting the simulations to the internet, e.g. for digital twins. The simulation core running in the cloud is based on the open source pytrnsys software ("pytrnsys — pytrnsys documentation," n.d.) which is a Python wrapper of the industry-standard TRNSYS software. In the most detailed design phase, the user can download the underlying pytrnsys project of the earlier design phases and the pytrnsys software to customize and run simulations on their own computer. Then they have the full power and flexibility of (py)TRNSYS at their disposal (at this stage a TRNSYS license is needed). ResulTES is funded by the Swiss Federal Office of Energy (SFOE).

4. References

pytrnsys — pytrnsys documentation [WWW Document], n.d. URL https://pytrnsys.readthedocs.io/en/latest/ (accessed 9.18.22).

RESULTES - Reliable pre-feasibility and design tool for quick assessment of large TES integrated with renewable energy sources and DHN - Basic data [WWW Document], n.d. URL https://www.aramis.admin.ch/Grunddaten/?ProjectID=55434 (accessed 4.4.25).