TE-SAT: Transactive Energy Simulation and Analysis Toolsuite

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***Abstract*—*Transactive Energy* (TE) is an emerging discipline that utilizes economic and control techniques for operating and managing the power grid effectively. Distributed Energy Resources (DERs) represent a fundamental shift away from traditionally centrally managed energy generation and storage to one that is rather distributed. However, integrating and managing DERs into the power grid is highly challenging owing to the TE implementation issues such as privacy, equity, efficiency, reliability, and security. The TE market structures allow utilities to transact (i.e., buy and sell) power services (production, distribution, and storage) from/to DER providers integrated as part of the grid. Flexible power pricing in TE enables power services transactions to dynamically adjust power generation and storage in a way that continuously balances power supply and demand as well as minimize cost of grid operations. Therefore, it has become important to analyze various market models utilized in different TE applications for their impact on above implementation issues.**

In this demo, we show-case the *Transactive Energy Simulation and Analysis Toolsuite* (TE-SAT) with its three publicly available design studios for experimenting with TE markets. All three design studios are built using metamodeling tool called the Web-based Graphical Modeling Environment (WebGME). Using a Git-like storage and tracking backend server, WebGME enables multi-user editing on models and experiments using simply a web-browser. This directly facilitates collaboration among different TE stakeholders for developing and analyzing grid operations and market models. Additionally, these design studios provide an integrated and scalable cloud backend for running corresponding simulation experiments.

***Index Terms*—Transactive Energy, Solar Energy, Modeling and Simulation, Cyber-Physical Systems, Global Grid, Co-Simulation, Societal Implications, GridLAB-D, Collaboration Platform, Grid Security, Design Studio**

I. Introduction

The presented work considers the various challenges [1] that arise in managing transactive energy enabled power grids and presents TE-SAT toolsuite, developed at Vanderbilt University, which aims to support analyzing various aspects of TE implementation. In the following, we highlight some of the core concerns in TE implementation and the associated analysis requirements, describe the tools and platforms leveraged in developing TE-STAT, and present the three publicly available design studios in TE-STAT.

Implementing TE requires analyzing for various orthogonal concerns (shown in Fig. 1) individually as well as in an integrated manner for evaluating grid operations holistically.

- ***Market and pricing models***: TE market structures for transacting power services are formed by utilities, surrounding policies and regulations, consumers, and other market participants. Consumers with local generation and storage and larger DER providers can directly participate in these markets. The consumers and local DER providers (e.g., ISOs and DSOs) can also form microgrids that exchange power services bypassing the utilities. Business models and market structures aim to not only incentivize green energy production and DER integration, but also to balance demand and supply and reduce costs. Distribution locational marginal pricing (D-LMP) is a common model used for pricing power where a market operator collects price bids from suppliers and consumers periodically and enables transactions at the market clearing price. The time interval for market clearing directly affects grid stability as well as efficiency.
- ***Policy and regulatory considerations***: Policies and regulations must be carefully considered to ensure proper implementation and evolution of TE and protection of consumers and utilities. Tax rebates and subsidies can incentivize greater TE participation. Regulations also aim to manage conflicting interests of utilities, market operators, and consumers. Utilities may focus on profits, while consumers may want fair and equitable markets. With access to a large amount of consumer data, privacy is a huge regulatory concern.
- ***Operational Concerns***: As new DER technologies emerge, their integration into the grid has become an ongoing challenge. The increase in intermittency (e.g., cloud cover on solar panels) requires grid operations to utilize accurate long- and short-term demand forecasting models with detailed planning for increased number and scale of power failures and outages. The increase in digital connectivity and control has also made grid more vulnerable to cyber-attacks – attackers can both make profit and disrupt grid operations.
- ***Needed analysis tools***: Every concern described in Fig. 1 merits an analysis tool. The unique characteristics of TE such as DER integration and maintenance of power supply and demand balance also require additional analysis tools. Cybersecurity evaluation is another dimension that may need a number of analysis tools. Furthermore, the holistic evaluation of TE, and all of its associated concerns, requires large-scale simulation integration frameworks.

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MODELING CONCERNS	ANALYSIS CONCERNS
Power grid component & dynamics: • Generation, transmission, & distribution • Distributed Energy Resources (DERs) • Distributed sensors & controllers • Multi-physical domain & multi-rate dynamics	**Power flow analysis:** • Matching power generator with consumers • Grid stability
Environment & disaster recovery: • Seasons & weather • Recovery & management for natural disasters • Environment hazards & safety • Special events creating power demand surges	**Integration of automated control & market factors:** • Optimization of utility services • Reliable & secure operations
Communication network & cyber-attacks: • Sensors & controllers comm. & Cybersecurity • Large-scale data flows • Distributed data processing & real-time delivery	**Dynamic effects:** • Demand-response concerns
Operations & planning: • Power markets & Pricing models • Regional and federal regulations & policies • Consumer & Business models • Short-term to long-term planning	**System-level impact analysis:** • Cyber-attacks modeling & simulation • Analyzing resilient cyber-defenses • Analyzing market approaches for handling renewables

Figure 1: TE modeling and analysis concerns

II. Building Blocks for Design Studios

TE-SAT leverages a number of existing technologies for developing design studios. A design studio is a web-based platform that enables system modeling and analysis with its integrated tools and computational infrastructure. The CPS-VO [2] provides a range of modeling, experimentation, user management, and cloud computing services that enable creating rich design studios. We also leverage WebGME [3] metamodeling tool that enables creation of online domain-specific graphical modeling and analysis platforms.

III. TE-SAT Toolsuite

A. GDSim

Our design studio for distribution grid simulation and analysis, called *GDSim* [4], allows modeling and simulation of power distribution grids along with different market models as well as cyber-attacks. These features allow analysis of TE implementation issues (e.g., how a grid will behave when an attacker intercepts market bids and modifies them [4]).

B. CPSWTTE

The smart grid with TE involve several multi-domain subsystems such as the grid's electrical network, DERs, cyber-communications and cybersecurity, and control systems. The grid operations are also directly affected by surrounding market structures, policies, and regulations. Our *CPSWTTE* design studio [5] enables collaborative modeling and analysis of TE systems by supporting co-simulation of open-source tools, such as GridLAB-D, and provides Java and C++ APIs for integration of other simulators in the co-simulation (e.g., integrated power and communication network simulations [5]).

C. TeSER

The design studio for secure load predictions [6] enables analyzing the security and resilience of learning-based prediction models in power distribution networks by utilizing a domain-specific deep-learning and testing framework. This design studio is developed using DeepForge [7] and enables rapid design and analysis of attack scenarios against distributed smart meters in a power distribution network (e.g, adversarial attacks on smart meter readings can go undetected and yet significantly degrade load predictions [6]).

IV. Conclusions & Future Work

The design studios described above enables analysis of a large number of TE implementation concerns. In addition, we have also developed a modeling, simulation, and optimization tool [8] to evaluate the feasibility of operating a longitudinally-distributed global solar grid. We plan to release it in the future as a new design studio. We plan to extend TE-SAT further with tools that address many other markets, policies, regulations, privacy, and security issues. All of the design studios described in the paper are available online with request. In addition, we intend to release the codebase as open-source. Furthermore, the design studios are extensible for easier updates for incorporating additional functionality and tools.

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