C2WT-TE: Command & Control Wind Tunnel for Transactive Energy

A Model-Based Co-Simulation Platform for Rapid Synthesis of Distributed Heterogeneous TE Simulations

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Modeling and Simulation Challenges

• Transactive Energy presents a highly complex “Cyber-Physical-Human-Economical Problem”:
  – multi-users,
  – multi-domain (e.g. analog transmissions & control, digital control, transients, thermal,...),
  – multi-time-resolution,
  – multi-time-scales of generators & consumers,
  – multi-tier grid control & synchronization,
  – multi-pricing-methods,...

• Huge challenges for correct modeling and simulation:
  – It is a multi-provider system with highly dynamic capacity – even consumers can be producers
  – Demand is highly dynamic, providers have diff. views – can lead to “instability or chaotic behavior”
  – Highly complex interdependent network – driven by highly unpredictable elements – weather, humans (users, policies, security, trust, irrationality, politics,..), malicious agents & cyber attacks, ..
Open Questions

• How do we address the heterogeneity of TE issues and participating players (generators, distributors, power markets, controls, consumers,..)?
• How we address different operational policies and requirements?
• How do we ensure reliability and security of the grid?
• How do we generate insights into the behavior of TE approaches and gain confidence in control mechanisms for Smart-Grids?
• How to design policies, standards, & controls for max. resource utilization?
• How to provide resilience against cyber vulnerabilities?

• As of this writing, there is no single tool
  – that can model power, communication, and control systems in a combined manner, or
  – that can model systems at transmission and distribution levels with fine-grained attention to details
What is needed?

• An “Open Co-Simulation Platform” for:
  • Integrating and coordinating across a diverse suite of modeling and simulation tools, and conduct integrated experiments
  • Allowing multiple players to provide their solutions to parts of above problem relevant to them and use solutions provided by others to solve part of the problem someone else has already contributed
  • Supporting multi-rate execution, time synchronization, and communication among tools
  • Providing a publish/subscribe architecture that allows for fine-grained modeling of only relevant updates (e.g. within a given geographical area, around a certain location, between given time-period, etc.)
• The platform provides modeling, experimentation, and analysis facilities that will enable “weaving” of a customized TE simulation by selecting from the tools are already supported or were custom added by users.
• The platform also supports Model libraries, Simulation tool integrator libraries, Library of TE approaches, Library of cyber attack and defense models.
C2WT-TE: System-of-Systems (*notional*) Architecture

Data Distribution Network

Model-Based Multi-Model Integration & Analysis Environment: C2 Wind Tunnel for Transactive Energy (C2WT-TE)

**Transactive Energy issues to be studied experimentally:**

- **Understand & Track Consumer behavior**
  - Individual Home Level
  - Aggregate substation Level
  - Incentives, Off-peak use, Real-time pricing

- **System Level Impact Analysis**
  - Cyber attacks & resilient solutions
  - TE approaches

- **Seamless Integration of Automated controllers & Market factors**
  - Optimize utility services
  - Reliable and secure operations

- **Dynamic Utility Functions**
  - Demand-Response
  - Power network effects
Model-Based Integration Approach in C2WT

Simulation models
- Domain-specific models (abstract simulation models)
  - Data models (interaction & data models)
  - Integration models (data-flow, timing, parameters)
  - Compute Infrastructure models
  - Deployment models
  - Experiment models

Domain-specific federates

CPN federate
Simulink federate
FMUs Modelica federate
Gridlab-D OpenDSS federate
OMNeT++ NS 3 federate
Custom fed.: - Direct - FMI - Web service

High-Level Architecture (HLA) Run-Time Infrastructure (RTI): Portico (open source)
Current Team and Project

- Vanderbilt Univ. (led by Dr. Janos Sztipanovits) has formed a team with Univ. of Michigan (led by Dr. Ian Hiskens) and MIT (led by Dr. Saurabh Amin)
- C2 Wind Tunnel (C2WT\(^1\)) is an existing generic co-simulation platform based on High-Level Architecture\(^2\) standard. We are working on extending it to support tools for power flow dynamics, transmission & distribution, and market dynamics for evaluation of TE approaches.
- We plan to demonstrate modeling and analysis of grid stability in the presence of unpredictable network behavior (potentially cyber exploits) and market-based demand-response variations.
- We will welcome interested Transactive Energy tool vendors/users if they want to bring their tool/experience for improving the capability of the Open C2WT-TE Co-Simulation Platform.

Backup slides
Basic Example\textsuperscript{3} of Integrated Smart-Grid Simulation of Power, Communication, and Control Systems

Integrated control, comm., and power system

Power-Grid model (Simulink, SimPower)

Communication model (NS-2)

Control Center model

Integration model (simplified)

- Small 5-bus model including two generators, three transmission lines, two transformers and three loads
- Loads are modeled to be switched ON at given time during the runtime simulation as a step change


C2 Wind Tunnel\textsuperscript{4} Capabilities Summary

- **Simulation Tools**
  - Simulink
  - Omnet++/Ns-2
  - DEVSJAVA
  - Ogre3D/Delta3D
  - Google Earth
  - CPN Tools
  - Java/C/C++
  - FMU-CS, etc.

- **Passive Federates**
  - Data loggers
  - Monitors
  - Analysis
  - Prognostics
  - Projections

- **Live components**
  - UAVs
  - Command & Control
  - Live deployment feedback
  - Live traffic conditions
  - Emergency Response
  - Human-in-the-loop

- **Advanced support**
  - Compute infrastructure models
  - Deployment config
  - Remote execution Expt. config
  - Legacy sys. & FOMs (FOM-mapping)
  - Course-Of-Action (COA) Simulation
  - Blue Vs Adversary game generations
  - Cyber attack lib

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**C2 Wind Tunnel Component Integration Framework**

**Run-Time Infrastructure (RTI)**