SmartGridLab+: A Software-Hardware Hybrid Smart Grid Testbed

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Smart Grid: power grid + information network

**SMART GRID**
A vision for the future — a network of integrated microgrids that can monitor and heal itself.

- **Smart appliances**
  Can shut off in response to frequency fluctuations.

- **Solar panels**

- **Processors**
  Execute special protection schemes in microseconds.

- **Storage**
  Energy generated at off-peak times could be stored in batteries for later use.

- **Generators**
  Energy from small generators and solar panels can reduce overall demand on the grid.

- **Demand management**
  Use can be shifted to off-peak times to save money.

- **Sensors**
  Detect fluctuations and disturbances, and can signal for areas to be isolated.

- **Disturbance in the grid**

- **Isolated microgrid**

- **Central power plant**

- **Houses**

- **Offices**

- **Wind farm**

- **Industrial plant**
2011 NSF CPS Project ($1.87M 2011-2015): Information and Computation Hierarchy for Smart Grids (PI: Tong (Cornell), Co-PI: Birman, Mount, Thomas (Cornell), Varaiya (UC Berkeley), Song (GSU)

The goal is to gain a foundational understanding of how information should be partitioned in time and space; how it should be collected, distributed, compressed, and aggregated.
Related works

- Hardware Testbed:
  Advantages: 1) High fidelity: transient analysis, renewable integration, etc 2) Code can be directly migrated.
  Disadvantages: 1) No open or remote access 2) Low scalability

- Software Simulator:
  Advantages: 1) High scalability and accessibility. 2) Both real-time and virtual-time.
  Disadvantages: 1) Low fidelity. 2) Code cannot be directly migrated (only duplicate the behavior but not the execution environment).
Features: (combine the merits from both hardware and software platforms).
- Exact same code can run on both testbed and emulator.
- Remote access and configuration of hardware testbed.
- Scalable distributed experiment platform, plug-and-play through Internet.
- A virtual node can exchange energy and communicate with a real node.
Part I: Software Emulator
Software Emulator Design

Song Tan, et al., SCORE: Smart-grid Common Research Emulator, IEEE SmartGridComm, 2012
SCORE: Smart-grid Common Open Research Emulator

Open source release at http://sourceforge.net/projects/score-sensorweb/ > 200 downloads

double-click a node will pop out a linux terminal window, just like access a real linux device
Fig. 11. Dynamic connections of two Smart Grid emulation instances in SCORE

Integrating GridLAB-D with CORE: real/virtual time

Song Tan, et al., Integrated Software Testbed for Cyber-Physical Analysis in Smart Grid, ISGT 2014.
Open source release at: http://sourceforge.net/projects/scoreplus/ > 60 downloads
Part II:
Hardware Testbed
Hardware Testbed Design

Song Tan, et al., ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid, IEEE SECON, 2015
Hardware Testbed modules

(a) Solar Panel Controller
(b) Demander
(c) Storage

(d) Topology Switch
(e) Solar Panel
(f) Wind Turbine

Song Tan, et al, ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid, IEEE SECON, 2015
Hardware Testbed Module in Detail

Song Tan, et al, ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid, IEEE SECON, 2015
Dynamic Topology configuration

Fig. 11. Design of Energy board for Topology Switch

Song Tan, et al., ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid, IEEE SECON, 2015
Testbed setup
Part III: Integrate Software Emulator with Hardware Testbed
Fig. 12. Communication between virtual node and real node through GRE tunneling

Song Tan, et al., *ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid*, IEEE SECON, 2015
Domain Decomposition:
Calculate the boundary node voltages and then set the interface module in hardware testbed, which is essentially a supplier and demander with large capacity!!

Song Tan, et al., *ScorePlus: An Integrated Scalable Cyber-Physical Experiment Environment for Smart Grid*, IEEE SECON, 2015
Conclusion

In Summary:
- Exact same code can run on both testbed and emulator.
- Remote access and configuration of hardware testbed.
- Scalable distributed experiment platform, plug-and-play through Internet.
- A virtual node can exchange energy and communicate with a real node.
Future Works

- Employ cloud computing with web portal.
- Current model still DC circuit model, upgrade to AC model.
- Allow seamless integration with real power grid;
  - Include yet beyond injecting data from real power grid to emulate
Questions?