CPS: Medium: Data-driven Causality Mapping, System Identification and Dynamics Characterization for Future Power Grid

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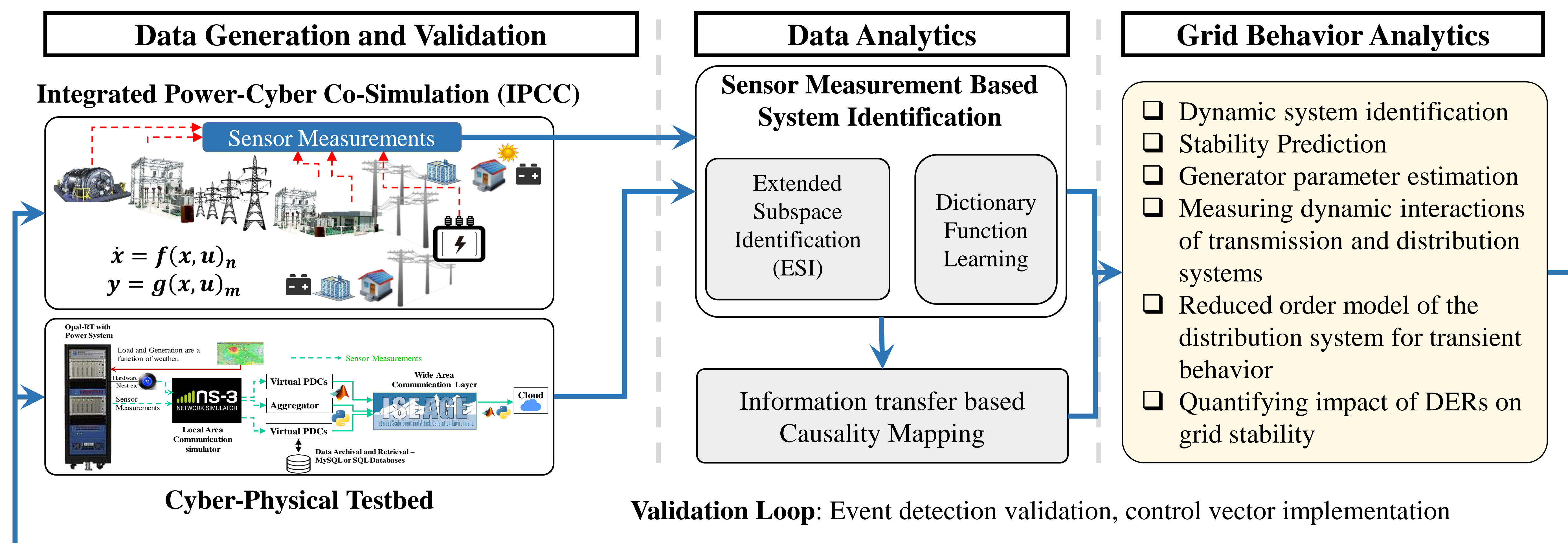
Challenge:

Utilize high proliferation of sensor measurements in the modern electric grid for dynamic behavior characterization and root cause analysis of dynamic events.

➢ Use of output measurements to overcome the challenge of non-measurable system states

➢ Characterize highly nonlinear dynamic behavior of the underlying power system.

➢ Replicate interactions of transmission-distribution and communication components of an electric grid.

Data Generation and Validation

Integrated Power-Cyber Co-Simulation (IPCC)

Sensor Measurements

$$\dot{x} = f(x,u)_n$$
$$y = g(x,u)_m$$

Cyber-Physical Testbed

Data Analytics

Sensor Measurement Based System Identification

Extended Subspace Identification (ESI)

Dictionary Function Learning

Information transfer based Causality Mapping

Grid Behavior Analytics

❑ Dynamic system identification
❑ Stability Prediction
❑ Generator parameter estimation
❑ Measuring dynamic interactions of transmission and distribution systems
❑ Reduced order model of the distribution system for transient behavior
❑ Quantifying impact of DERs on grid stability

Validation Loop: Event detection validation, control vector implementation

Solution (Key outcomes):

➢ Developed a linear operator based novel robust Extended subspace identification (ESI) approach for identification of nonlinear dynamics for power systems using sensor measurements (outputs of the system).

➢ Developed data-driven ESI algorithm for power system eigenvalue estimation, participation factor computation and dynamic parameter estimation.

➢ Developed an open source multi-timescale transmission and distribution co-simulation framework that is tested for large T-system & multiple D-system.

➢ Derived kernel based physics inspired structured reduced order model of the distribution system dynamics for large signal disturbances. The derived model reduced the simulation time by up to 10x for large power systems.

Scientific Impact:

➢Address the emerging challenges of 'highly dynamical systems' and 'data revolution' in CPS framework.

➢Developed data-driven nonlinear system characterization for a general CPS system with output measurements.

Broader Impact:

➢Incorporated the research findings and developments on IPCC in a course for graduate students in electrical engineering at Iowa State University.

➢ Developed a data-analytical and co-simulation framework that can analyze the impact of distributed energy resources (DERs) on the bulk electric grid.