Model and Application of Cyber-Physical System in Distribution Network

Liu Dong
Shanghai Jiao Tong University

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1. CPS for Distribution Network
2. CPS Modeling of Distribution Network
3. H-S Model in Distribution Network
4. Implementation Frame of DCPS
Cyber-Physical System, CPS

*Orchestrating networked computational resources with physical systems*

The traditional embedded systems problem:
Embedded software is software on small computers. The technical problem is one of optimization (coping with limited resources and extracting performance).

The CPS problem:
Computation and networking integrated with physical processes. The technical problem is managing dynamics, time, and concurrency in networked computational + physical systems.
1. CPS for Distribution Network

Integration of Cyber and Physical

Control
Communication Network
1. CPS for Distribution Network

The development process of modern industry

- Single Device
- Unit Integration
- Systematic Solution
- Synthetic System consisted of information and physical process
- Spontaneous CPS

Two Problems

- Insufficient Information Utilization
- Insufficient Information Utilization
- The gap between C and P
- Lack of mathematic tools

Lack of research for interconnection
Distribution network gradually converts to high-order form which information and energy flow co-exist.

**Active Distribution Network** consuming high-capacity distributed resources:
- Contains distributed resources
- Consumes clean energy, reduces feed-in energy
- Hierarchical distribution system of information collection and control
- Cyber-Physical System
Challenges faced by construction of Cyber-Physical System

1. Construct a unified information exchange system
   - form an information exchange system to meet the requirements of system control
   - form an unified information exchange model of secondary system

2. Construct Cyber-Physical System model
   - meet the requests of component and function description in distribution system
   - meet the requests of controlling the operation of distribution system

3. Improve capabilities of obtainment and application of information
   - expand and optimize information collection system in distribution network
   - fully apply bulk data techniques in distribution network
1. CPS for Distribution Network

Shanghai Jiao Tong University – Smart Grid Laboratory

Research Fields

- Active Distribution Network
- Distribution Network Automation
- Cyber-Physical System
- Information Model

The research fields above may all contribute to CPS

Major Projects

- National High Technology Research and Development of China 863 Program (2014AA051902): Active Distribution Network in Guizhou
- National High Technology Research and Development of China 863 Program (2012AA050212): Active Distribution Network in Guangdong
- National High Technology Research and Development of China 863 Program (2012AA050803): Cyber-Physical System
1. CPS for Distribution Network

2. CPS Modeling of Distribution Network

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4. Implementation Frame of DCPS
There are three types of modeling approaches of Cyber-Physical System at home and abroad:

**CP model based on control theory**
- The main objective is to introduce the monitor, collection, communication and control sectors of physical process into dynamic modeling system, so that the process can be better expressed as differential algebraic equation form, then form the state equations.

**Hybrid–System model**
- Hybrid system model is a combination of continuous equations describing physical processes and finite state machine model, it has a discrete dynamic nature, the essence can be used to model cyber-physical power system.

**CP computational model**
- At the time of the CPS system control, connection relationships and interaction among controlled models. The computational model also includes the operation mode, control strategies and coordinated control mode of each physical device.
2、CPS Modeling of Distribution Network

SJTU Smart Grid Laboratory: Two layers framework of DCPS

Fusion Model of Physical & Cyber

Diagram:

- Two layers framework of DCPS
- Fusion Model of Physical & Cyber
1. CPS of Distribution Network
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The Hybrid-System method is suitable for modeling of DCPS.

Hybrid-System: Discrete State Model + Continuous Dynamic Model

Distribution System: Secondary System + Primary System
3、H-S Model in Distribution Network

Unit model and coordinated combination of models

Connection of dynamic characteristics for single CP module

Split dynamic characteristics of components to obtain permission of required variables

Multiple methods of CP module integration
3、H-S Model in Distribution Network

PV Cyber-Physical model based on Hybrid-System: Continuous Model

- Continuous model describes the behavior of sequential actions of coordination control under various control modes.
- State model describes the logic of control mode transition.

Block diagram of simulation for energy storage battery module

PV array simulation model based on M-function
3. H-S Model in Distribution Network

The CP model for Photovoltaic-Storage based on Hybrid-System: State Model

PTOLEMY: Outer Structure of Control Model

State Model of Control Module

Refined Model for State full/empty
Photovoltaic-Storage Cyber-Physical unit model and coordinated combination

CP model of PV cell module, the solid line is physical quantity, the dotted line is internal and external information

Flowchart of integration of physical and informational model

Start

Physica Modeling

GET

Inner Variable & Interaction

NO

Class & Application

NO

Light Temperature
3. H-S Model in Distribution Network

CP control module for Photovoltaic Energy Storage

MPPT

\[ P_m(U_m) \]

\[ U \]

\[ U_{ref} \]

Dynamic Storage

Dynamic

Temperature

Light

module
3、H-S Model in Distribution Network

Active power control of the DGs integration distribution network

Control Target:
- Normal---DGs output as planned
- Disturbance---keep power balance with less external power

<table>
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<tr>
<th>STATE</th>
<th>P_E</th>
<th>P_DG1</th>
<th>P_DG2</th>
<th>ΔP_Load1</th>
<th>ΔP_Load2</th>
<th>ΔP_Load3</th>
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<tr>
<td>State1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>+50</td>
<td>-30</td>
<td>+60</td>
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<td>100</td>
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<td>0.6</td>
<td>0.4</td>
<td>300</td>
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<tr>
<td>State3</td>
<td>200</td>
<td>135</td>
<td>320</td>
<td>0.6</td>
<td>0.4</td>
<td>300</td>
</tr>
</tbody>
</table>

Plan output Disturbance event
3. H-S Model in Distribution Network

Active power control of the DGs integration distribution network

$$\Delta P_{\text{Load}}$$

State Transition

Disturbance 1

Disturbance 2

State Transition 1

State Transition 2

External Power Curve

DG1 Output Curve

DG2 Output Curve
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4. Implementation Frame of DCPS

Framework of Cyber-Physical collection and control system

- Distribution system with different primary equipment and region, controlled by distributed controller;
- Multi-level control hierarchy unifies functions of distributed controllers;
- Mass distributed monitoring points form the integration of physics and information;
- Meet the need of system expansion, can be used to monitor distributed Social SCADA;
- Decentralized monitoring functions reduce the burden of main station and communication networks;
4. Implementation Frame of DCPS

Information exchange framework of CPS distribution network

- Unified information model standards;
- Different information flows map to different transport protocols;
- Different information streams transmitted through different channels;
- Consider the condition that user side access active load and distributed generation with small capacity;
- Transport layer protocol takes the possibility of data transition with model.
4. Implementation Frame of DCPS

DCPS Simulation Control Station-Terminal System

Function

- Plug and Play;
- Based on Hybrid-System unit model;
- Terminal self-recognition;
- Terminal safety certification;
- Simulation Control;

Cyber-Physical Platform

Physical Simulation

Information model

Hybrid model
4. Implementation Frame of DCPS

DCPS Simulation Control Station: CPS Platform

- Information model formal verification;
- Interaction between information model and physical model;
- Interaction between control model and physical model;
Thank You!