Review on simulation methods of Cyber-physical Complicated Distribution System

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Abstract. Cyber-physical complicated distribution system is heterogeneous and has special space-time characteristics. Communication system is event-driven discrete and distribution network is time continuous, which brings difficulties to the hybrid system simulation. Based on characteristics of complicated distribution network and electric power communication system, the concept of cyber-physical complicated distribution system is proposed. Distribution network, distributed generators, storage systems and load power demand constitute physical system. Analyze its construction features, operating features and the effects of communication system to distribution networks. Review simulation methods of cyber physical systems and complicated distribution networks, including modeling methods and time synchronization methods mainly.

Introduction

With the development of computation technology, communication technology, auto-control technology, and so on, Cyber-Physical System (CPS) appears and develops very fast in recent years. CPS is a complicated system which integrates computation system, communication system, sensitive system and control system together in order to merge cyber and physical closely to perceive the safety, reliability, efficiency of the physical system. Characteristics of CPS include: deep merged, complicated network, event driven, isomerism and heterogenic, difficult cognition, space-time constraint, safe and reliable, etc. These characteristics lead a lot of challenges for design and accomplish CPS. For example: how to observe and cognize the physical world correctly and comprehensively; how to control the physical world real-timely, accurately and correctly.

CPS has been used in electric power system at present. There have been many researches on simulation of cyber-physical electric power system. Ref.[1] proposes EPOCHS method to simulate cyber-physical electric power system: PSCAD/EMTDC is used to electric transit simulation, PSLF is used to build the model of electric power system and NS2 is used to build communication system model; Ref.[2] proposes a method that using discrete event system and NS2 to build electric power system model; Ref.[3] researches the dependency between electric power system and communication system with MATLAB/Simulink and OPNET; Ref.[4] uses Virtual Test Bed (VTB) and OPNET to simulate remote controllable electronic devices; Ref. [5] uses OPNET to simulate the wide-area communication system in electric power system.

These researches have contributed a lot in cyber-physical electric power system, but there are still some problems need to be paid more attention:

a) The model should reflect the discrete communication system and the continuous electric power system;

b) Distributed calculation algorithms should be adopted in cyber-physical electric power system;

c) Standardize cyber-physical electric power system to make it convenient to cooperate with CPS in other field.

This paper proposes the concept and framework of cyber-physical complicated distribution

system firstly, and then summarizes modeling methods and time synchronization methods of cyber-physical complicated distribution system.

Cyber-Physical Complicated Distribution System Overview

The concept and characteristics of cyber-physical complicated distribution system are discussed in this paper.

A. The concept of cyber-physical complicated distribution system

Cyber-physical complicated distribution system can be defined as a complicated system which merges distribution system, sensor system, complicated system, control system and communication system deeply to perceive and optimal control the distribution system, share information and cooperation with CPS in other areas under uniform communication and interface standards. The essential of cyber-physical complicated distribution system is merge distribution system, electric information, and control information deeply based on fully perceiving the operation environment of electric power system. The final objective of cyber-physical complicated distribution system is to accomplish informational control in distribution system.

In cyber-physical complicated distribution system, electric primary system is the physical system; cyber system includes complicated system, sensor system and communication system. The communication system consists of Internet, wireless communication network and electric private communication network.

B. Characteristics of cyber-physical complicated distribution system

Compared with traditional electric power system, the characteristics of cyber-physical complicated distribution system are:

a) Monitoring electric primary system and electric information in real time;
b) Merging electric primary system and cyber system deeply;
c) Transforming, integrating, storing, sharing and cooperating mass information;
d) Kinds of loads and distributed generators can be controlled by the control center directly;
e) Abundant distributed communication and global optimal control;
f) Debugging faults in electric system and cyber system automatically.

Framework of Cyber-Physical Complicated Distribution System

In cyber-physical complicated distribution system, the physical system is composed of primary electric equipment, such as distributed generators, energy storage systems, electric vehicles, smart buildings, and so on. They are connected to each other through distribution networks; the cyber system is composed of computation system, control system and communication system. Computation devices are servers, computers, embedded computers, etc.; data acquisition equipment includes sensor, PMU, embedded data acquisition equipment, and so on. These devices are connected to each other by communication networks. The frame structure of cyber-physical complicated distribution system is shown as Figure1.

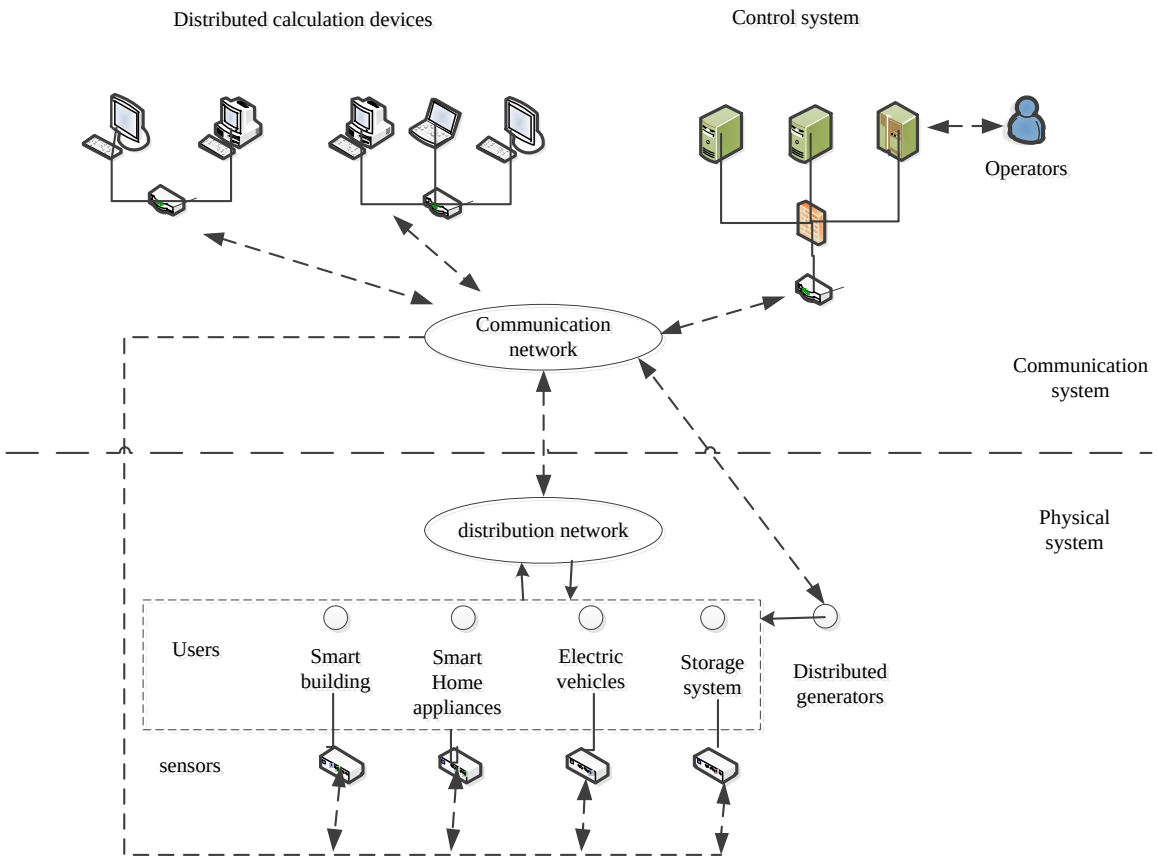

Fig. 1 Framework of cyber-physical complicated distribution system

a) Control system

Control system is the core of cyber-physical complicated distribution system, which is similar to the dispatch center of electric power system. Its responsibilities include: Synthesize all information got from data acquisition equipment; Revise, simulate and analyze the system model; Control physical devices based on the simulating and analyzing results, and revise parameters of controllers in necessary; Cooperate with other cyber-physical systems, such as traffic cyber-physical systems, and so on. Furthermore, the control system can get operating information including temperature, humidity, wind speed, battery state of electric vehicles, etc.

b) Distributed calculation devices

Strong capability of calculation and information processing is important esurience for cyber-physical complicated distribution system to control lots of physical devices optimally. Instead of traditional integrated calculation platform, distributed calculation platform based on grid computing or cloud computing technologies is necessary in cyber-physical complicated distribution system to integrate kinds of heterogeneous calculation devices.

c) Communication system

Besides LAN and wireless network in common, there is appropriative wired network in electric power system. Appropriative wired network is used to connect the control system and sensitive devices or controllers, which helps to avoid communication delay and improve the reliability of signal transformation. In cyber-physical complicated distribution system, normal LAN can connect non-critical devices and wired network connect non-settled devices and wireless sensitive devices.

d) Distribution network

In cyber-physical complicated distribution system, distribution network is in charge of connect all kinds of electric devices together, it is accurate control, remote cooperation and self-governing, which is in accordance with the characteristics of smart distribution network.

e) Electric power source and load power demand

Distributed generators and load power demand devices will be installed embedded PMU and controllers to connect with the control system by communication system. Each of them can be

assigned one and only internet address to be identified and searched. The control system can control distributed generators and load power demand directly in necessary. Then, when it is needed to shed load, the control system can choose to shed not important load power demand, such as intelligent home appliances, instead of shedding power supply of one area. Therefore, the range of power outage is decreased and reliability of power supply is improved.

On the other hand, electric vehicles, the important part of distribution network in the future, can be controlled by cooperation of cyber-physical complicated distribution system and cyber-physical traffic system.

Simulation Methods of Cyber-Physical Complicated Distribution System

A. Modeling methods of cyber-physical complicated distribution system

Communication system is normally derived by disperse information or incidents, its basic theory is disperse mathematics. However, the theory of electric power system is based on continuous mathematics which requires more real-time and in its model the variable of time is used to shown the sequence of physical process; on the contrary, communication system is not strict on the real-time, then the variable of incidents or calculation orders are shown instead of the time.

At present, modeling methods of cyber-physical complicated electric power system can be classified as follows by different research objectives:

a) Modeling methods to research the reliability of electric communication system

In this kind of modeling methods, electric communication system is researched in detail and electric power system is simplified or ignored. For example, in research on reliability evaluation method for the communication systems in wide-area protection (CSWAP), system structure and characteristics of the CSWAP are hierarchically analyzed from layers of substation communication [6].

b) Modeling methods to research the effects of failures in communication system on electric power system

There are failures such as delay, error codes, and interrupts always happening in communication system, their effects on electric power system research can't be ignored, in which the communication system is simplified to a fixed delay or interrupt. For example, in the research on assessing the effect of failures in the information and communication infrastructure on power system reliability, the failure in the information infrastructure is assumed to occur before or after the system enters the electrically abnormal state [7]; in the research on impacts of information and communication failures on optimal power system operation, optimal power flow model is built in detail but only three types of failure are studied respectively [8].

c) Modeling methods to research the coupling relationship between communication system and electric power system

In this kind of modeling methods, the interaction of communication system and electric power system are both considered. Information flow and electric power flow are different in essence. The former is discrete and the latter is continuous. Then, time synchronization, isomerism and construction differences are needed to be resolved in the model. Many technologies have been used in the research of cyber-physical electric power system, such as multi-agent technology, high level architecture (HLA), hybrid control technology, and so on.

In the future, developing simulation platform of cyber-physical complicated distribution system to accomplish multi-state, multi-grade simulation is very important.

B. Time synchronization methods of cyber-physical complicated distribution system

Cyber-physical complicated distribution system is multi-time sequence [9], how to coordinate the continuous character of electric power system and the discreteness of communication system is a key problem for non-real time simulation of cyber-physical complicated distribution system to accomplish time synchronization.

Time synchronization methods can be mainly classified in two:

a) Alternate operation time synchronization method

The basic theory of alternate operation time synchronization method is: Firstly, the last step

simulation results of electric power system simulation platform is passed to communication system simulation platform; then the communication system begins to simulate and passes the results to the electric power system platform; it is turn to the electric power system corrects the initial values and simulates. The total simulation time of this method equals to the sum of time periods of electric power system simulation time step, communication system simulation time step and two times of data exchange. This method has been used on PSCAD/EMTDC and independent communication system simulation modules.

b) Independent operation time synchronization method

In this method, electric power system simulation and communication system simulation operate by themselves at each simulation step and their results are stored in cache temperately. When it is needed to exchange data, all simulation is suspended. Then, the exchange data are initial data of next step simulation. The total simulation time of this method equals to the simulation time step of the slower simulation platform between electric power system and communication system, it is electric power system in normal. This method has been used between PSCAD/EMTDC and NS3, MATLAB/Simulink and OPNET, and so on.

Corresponding to alternate operation time synchronization method, the efficiency of independent operation time synchronization method is higher, but its accuracy may be lower considering the difficulty to make sure the data synchronization time.

Conclusion

Cyber-physical complicated distribution system is heterogeneous and has special space-time characteristics. Communication system is event-driven discrete and distribution network is time continuous, which bring difficulties to the hybrid system simulation. To this end, this paper proposes the concept and framework of cyber-physical complicated distribution system and summarizes modeling methods and time synchronization methods of cyber-physical complicated distribution system. Comparing alternate operation time synchronization method and independent operation time synchronization method, the former is more accurate than the latter, but its efficiency is lower.

Developing simulation platform more suitable for complicated distribution network, researching accurate and efficient simulation methods for cyber-physical complicated distribution network are necessary in the future.

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