ATLANTIS PRESS

Advances in Intelligent Systems Research, volume 164

International Conference on Mathematics, Modeling, Simulation and Statistics Application (MMSSA 2018)

Design and Operation of Distribution Automation Test Simulation Platform Based on RTDS

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***Abstract*—Distribution automation is the most effective means to improve the quality and reliability of power supply.In view of the complexity of distribution automation test, this paper presents a design and operation scheme of distribution automation test platform based on RTDS.Based on the common distribution network connection mode, using the powerful component library system of RTDS system and its good expansibility and compatibility, the simulation examples and the specific configuration of distribution terminals are designed, and the scale and requirements of each network structure simulation example are analyzed.Finally, the validity of the proposed scheme is verified by a test case.**

Keywords—distribution automation; testing technique; RTDS; simulation platform

I. INTRODUCTION

As the requirements for power supply reliability and grid operation efficiency continue to increase, Distribution Automation (Distribution Automation, DA) has been attached high attention. DA is an important means to improve power supply reliability and power supply quality, and to achieve efficient and economical operation of distribution network. It is also an important basis for realizing smart grid [1].

The distribution automation system needs to be coordinated and tested in all parts of the system before it is put into operation. Distribution network has distinctive features such as wide geographical distribution, large grid scale, multiple types of equipment, diverse network connections, and varied operating modes. At present, testing the distribution automation system on site requires a variety of instruments such as the relay protection testers and the multimeters, and the testers need to repeatedly test and record the test items one by one, not only the process is complicated, it takes a long time, and it is difficult to achieve complete and complete testing, there will be large errors, which is not conducive to the safe operation of the power system [2].

Many scholars at home and abroad have studied the testing of DA. In [3], authors systematically expounds the test methods, test environment, test content and specific technical indicators of distribution automation products; In [4], the testing contents, method and its environment of FA in FAT and SAT stages are discussed. Furthermore, a FA testing case of Shanghai distribution networks including function test, performance test, reliability test and availability test are discussed in details. In references [5-6], conducted data mining on the operational test data of the mass distribution automation system in Korea and the United States and analyzed the function and performance of the distribution automation system. Due to the difficulty in real-time operation data collection of the distribution network, some functional tests cannot be completely performed, and establishing a DA simulation test environment can accelerate the development and implementation of the system and reduce the risk of on-site debugging. At present, power system simulation has become an important method for power system research and design. In [7], the structure, function, characteristics and applications of some kinds of mainly power system simulation software are discussed, such as BPA, EMTP, PSCAD/EMTDC, NETOMAC and PSASP. In [8], a feeder automation simulation test environment based on parallel calculation environment is studied and created. The short-circuit calculation, power flow calculation and MPI parallel calculation are used to simulate the operation of different types of feeder automation under different fault conditions, but this method focuses on proving the operation logic in this environment and needs to establish the simulation environment of distribution system separately. In [9], authors put forward a host injection testing platform to simulate various faults occurring in the distribution network and test the fault handling performance of the distribution automation master station, but the main station test procedure of the method is more complicated, and the influence of equipment parameters such as communication systems on the results is ignored. In summary, although domestic and foreign experts have carried out a lot of research on DA testing, the simulation platform testing steps are complicated, and real-time simulation is difficult, which is not conducive to operation.

RTDS (Real Time Digital Simulator) software platform integrates data acquisition, communication and fault detection. It has strong practicability and can accurately simulate the distribution network automation dynamic system. It can accurately simulate the dynamic system of distribution network automation, and can be changed according to the operation mode of external distribution network. Real-time change distribution network equipment comprehensive modeling, accurate simulation of the distribution network.In this paper, a design and running scheme of DA test platform based on RTDS is put forward. Using the powerful real-time simulation function of RTDS to test DA system and equipment, it has the advantages of flexible networking, good compatibility and good expansibility. Able to adapt to various different manufacturers and different types of distribution

network terminals so as to reduce the test workload and improve the maintenance efficiency.

II. THE OVERALL FUNCTION AND ARCHITECTURE OF THE TEST PLATFORM

This DA test platform is based on RTDS real-time simulation and combines with the main station, communication and terminal of actual distribution automation to build a set of DA test simulation platform with flexible mode and advanced technology. The platform can carry out network access tests for different manufacturers and different types of distribution network terminals, can simulate distribution network architectures of any scale and any complexity, and can carry out the development of advanced functions in a real master station system, thus ensuring that the platform has a high level of research.

A. Function of the DA Test Platform

Comprehensive testing of the application functions and communication reliability of the DA master system equipment and terminal equipment before entering the network can provide guarantee for the safe and stable operation of the distribution network automation system. The main test functions of the platform are as follows:

(1)Digital simulation can be used to research and test distribution automation from equipment and system, simulate typical distribution network structure, and simulate distribution network operation environment, including: equipment access network test (FAT test), equipment failure analysis, distribution network Fault analysis, system fault handling algorithms, system function detection, etc.

(2)The test functions of the main station system and the communication system mainly include: operation and maintenance of the main system of the analog distribution automation system, functional test of the main station, analog communication failure, and communication detection of the terminal equipment.

B. Construction Content and System Structure of the DA Test Platform

The DA test platform is mainly composed of two major systems. The main station system is the control center and monitoring center of the DA system. The digital simulation system mainly performs simulation modeling and simulation test. The two systems pass signals such as voltage and current, input and output. The quantity interacts with each other, thus achieving the seamless connection between the two systems, realizing multiple functions, multiple uses, and various forms of distribution automation experiment tasks. The structure diagram is shown in Figure 1.

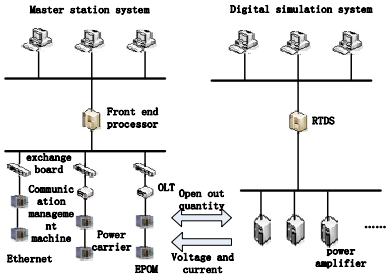

FIGURE I. STRUCTURE DIAGRAM OF DISTRIBUTION AUTOMATION LABORATORY

(1)Master station system and communication system

The DA test platform plans to use NARI's Open-3200 master station system, and its overall structure is shown in Figure 2(a). The distribution automation management system is divided into SCADA system, DPAS system, DA system and DWM system. The DWM system is divided into GIS and OMS (power outage management system). These functions can be realized on the computer platform of the laboratory. Historical data is used as a reference to build a distribution network model using a simulation system to form real-time operational data to build a master station system.

The communication system is based on the ZTE or Huawei EPON equipment, and forms an EPON communication platform structure composed of an optical line terminal (OLT), an optical distribution network (ODN), and an optical network unit (ONU), which is connected by an optical fiber, to implement the terminal equipment (FTU, DTU, FA system, etc.) communication test lays the foundation, as shown in Figure 2(b). According to the actual needs, improve the distribution automation communication method, and establish a communication system such as carrier wave and wireless.

The simulation model of the DA test platform is based on the actual circuit structure of the power distribution automation pilot area of a power company, and the main station system is built based on its actual operational history data.

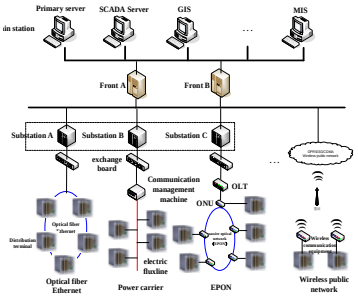

FIGURE II. (a)

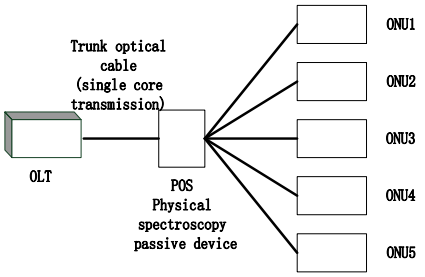

FIGURE II. (b)

FIGURE II. MASTER STATION SYSTEM (A)AND COMMUNICATION SYSTEM(B)

(2)Digital Simulation System

The DA test platform is based on the RTDS system, and is equipped with equipment such as GPC board, GTAO board and power amplifier. At the same time, the control system is separately purchased to build an experimental operation platform. Use computer RSCAD software to build a distribution network system architecture, simulate various complex operating conditions, and reflect the state of the system in real time through secondary voltage and current, simulate various fault conditions of the distribution network, help plan the distribution network structure, and understand the distribution network trend and so on; The system can output the secondary voltage and current in real time through the power amplifier, and can dynamically detect the FTU, DTU and other distribution network automation equipment terminals to verify the performance and quality during the on-site operation; At the same time, the system can simulate the configuration protection system, truly reflect the action of the protection device under the fault condition of the distribution network, and study the connection and cooperation between the distribution automation and protection.

C. Overall Wiring Scheme of the DA Test Platform

The wiring of the DA test platform is shown in Figure 3. The Rack is connected to each input and output board through the optical fiber. The cable between the screen cabinets is mainly connected, and the host and each terminal are connected by a network cable.

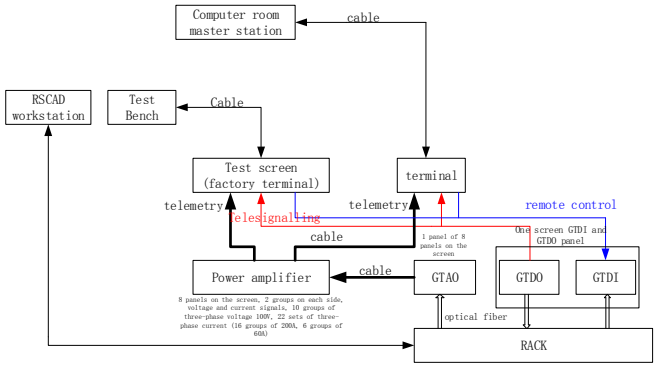

FIGURE III. OVERALL WIRING SCHEME OF THE DA TEST PLATFORM

III. RTDS CONFIGURATION DESIGN OF THE DA TEST PLATFORM

Based on the connection mode of distribution network commonly used in China, this paper designed the simulation example and the specific configuration of the distribution terminal, and analyzed the scale and demand of each network structure simulation example, such as the number of nodes, the number of switches, the number of FTU or DTU, and the number of sets of electric voltage and current transformer required by the power amplifier.

A. Design of wiring and terminal configuration

(1) Overhead network

The commonly used overhead line wiring methods in China mainly include single radiating network, hand-in-hand network, multi-sectioned and multi-linked network . The line simulation and its terminal configuration are shown in Figure 4-6.

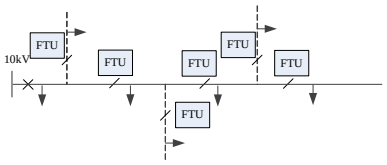

FIGURE IV. RADIANT OVERHEAD NETWORK AND ITS TERMINAL CONFIGURATION

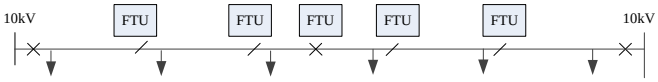

FIGURE V. HAND-IN-HAND OVERHEAD NETWORK AND ITS TERMINAL CONFIGURATION

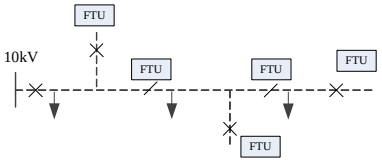

FIGURE VI. THREE-SECTIONED AND THREE-LINKED NETWORK AND ITS TERMINAL CONFIGURATION

The single radiation overhead network divides the main line into 4 sections, and has 3 branch lines, and the branch lines are not segmented. The distribution automation simulation of the wiring mode requires 6 FTUs (segment switch requires 3 FTUs, branch line switch requires 3 FTUs), and measure 6 sets of voltage and current . Each line of the hand-in-hand overhead network is divided into 3 sections, and there is a normally open contact switch in the middle. The distribution automation simulation of the wiring mode requires 5 FTUs (segment switch requires 4 FTUs, contact switch requires 1 FTUs), and measure 5 sets of voltage and current. The main line of multi-sectioned and multi-linked network is divided into 3 sections, and each section has 1 standby contact switches, The distribution automation simulation of its connection mode requires 5 FTUs (segment switch requires 2 FTUs and contact switch requires 2 FTUs), and measures 5 sets of voltage and current.

(2) Cable network

The cable wiring methods commonly used in China mainly include radiant cable network, cable single loop network, cable double loop network. The line simulation and terminal configuration as shown in Figure 7-9.

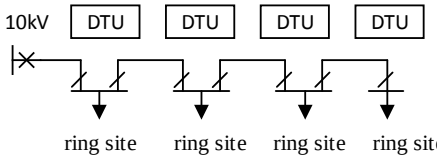

FIGURE VII. RADIANT CABLE NETWORK AND ITS TERMINAL CONFIGURATION

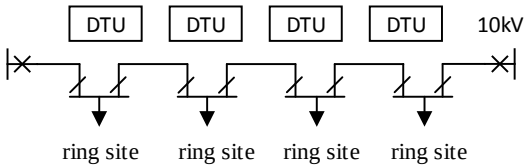

FIGURE VIII. CABLE SINGLE RING NETWORK AND ITS TERMINAL CONFIGURATION

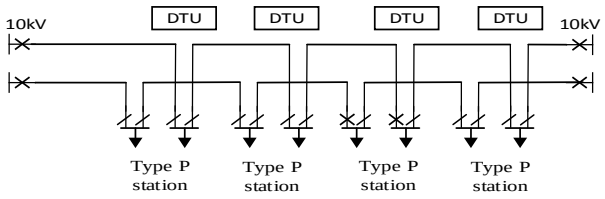

FIGURE IX. CABLE DOUBLE LOOP NETWORK AND ITS TERMINAL CONFIGURATION

There are 4 ring sites in the radiant cable network, which are powered by the single radiation of the 10kV bus. The power distribution automation simulation requires 4 DTUs and measures 4 sets of voltage and 7 sets of current. The cable single loop network has 4 ring stations, which are powered by double-end power supply. The distribution automation simulation requires 4 DTUs and measures 4 sets of voltage and 8 sets of current. The cable double loop network has 4 ring stations, powered by double-end power supply. The distribution automation simulation requires 4 DTUs, and 8 sets of voltage and 16 sets of current are measured.

B. Comparison and Summary of Simulation Examples of Distribution Network

This paper designed 6 typical wiring modes and configured distribution terminals, which basically covers the wiring modes of overhead lines and cables commonly used in China. The smallest scale example is radiant cable network with 5 nodes. The largest scale example is a cable double loop network with 12 nodes. The cable double loop network requires the most electrical analog signals, requiring 8 sets of voltage and 12 sets of current. See Table 1 for details.

TABLE I. SIMULATION SCALE AND REQUIRED CONFIGURATION OF VARIOUS WIRING MODES

network	Wiring modes	Node size	Number of switches	Configuration		
				The number of FTU or DTU	Sets of voltage	Sets of current
Overhead network	Radiant overhead line	8	6	6	6	6
	Hand-in-hand overhead line (Three segments)	8	5	5	5	5
	Three-sectioned and three-linked overhead line	7	5	5	5	5
Cable network	Radiant cable network (4 ring stations)	5	7	4	4	7
	Cable single ring network (4 ring stations)	6	8	4	4	8
	Cable double loop network (4 ring stations)	12	16	4	8	16

It can be known that at least six terminals need to be configured, the voltage analog signals is 8 sets, and the current analog signals is 16 sets.

C. DA Test Platform Specific Configuration

The specific configuration number of the platform determines the size of the simulation example. in order to meet the simulation requirements for the typical example mentioned above, the following configuration scheme is proposed.

(1)terminal configuration

In view of the relatively powerful DTU function, only DTU with three-remote functions can be configured, while FTU and one-remote terminal and two-remote terminals can use three-remote DTU to simulate. Each DTU needs to be able to measure 2 groups of voltages, 4 groups of currents, 4 switches remotely controlled, and 4 remote signals. This type of DTU is configured with at least 6.

(2) RACK

There are 10 RACKs in total, each RACK can simulate the system scale of 72 three-phase nodes, which can fully meet the simulation requirements of the above design example. In order

to satisfy the simulation analysis and research of large-scale distribution network in the future, a certain amount of RACK resources, such as 1 ~ 3 RACKs, can be introduced as appropriate according to the actual situation.

(3)GTAO board and panel cabinet

Each GTAO board has 12 channels and can output 4 groups of 3-phase voltage or 3-phase current signals. each cabinet can be equipped with 8 boards and can output 32 groups of signals.It is suggested that two GTAO cabinets have 10 GTAO boards built in them, which can output 40 groups of three-phase voltages or currents to satisfy the simulation analysis and research of large-scale distribution network in the future.

(4) power amplifier and panel cabinet

During distribution network simulation, the voltage measurement points are generally less than the current measurement points, and the current needs to consider 5A and 1A types of CT. therefore, more current output terminals can be configured. it is suggested that 8 groups of three-phase voltage amplifiers (100V), 24 groups of 60A three-phase current amplifiers, and 9 channels of 200A current amplifiers. the specific number of power amplifier cabinets depends on the type of equipment purchased and the manufacturer.

(5) GTDO and GTDI boards and cabinets

The acquisition of switch status in the simulation grid needs to be based on GTDO board, which outputs real-time switch status. GTDO board has 64 channels, which meets the basic requirements of simulation examples. In order to control switches and other equipment in the distribution network, GTDI boards are required. It is recommended that GTDI and GTDO boards be placed together in one panel cabinet.

(6) server and workstation

1 set of distribution automation master station system software;2 data servers placed in the computer room;2 maintenance workstations and 2 monitors placed on the test bench;2 switches in backbone network.

IV. TEST CASE ANALYSIS

A. *Basic Fault Settings*

The simulated test environment consists of two power supply points, four distribution substations, and one tie switch. The communication mode should be consistent with the actual situation, and the communication medium can be replaced by the network cable; It can intuitively reflect the operation status of each switch in the loop. Substation A and B circuit breakers are equipped with conventional protection, and the protection function can be selected. The test platform can simulate various fault conditions as required; The analog master station can view the received information Intuitively. The fault setting is shown in Figure. 10 and Table. 2

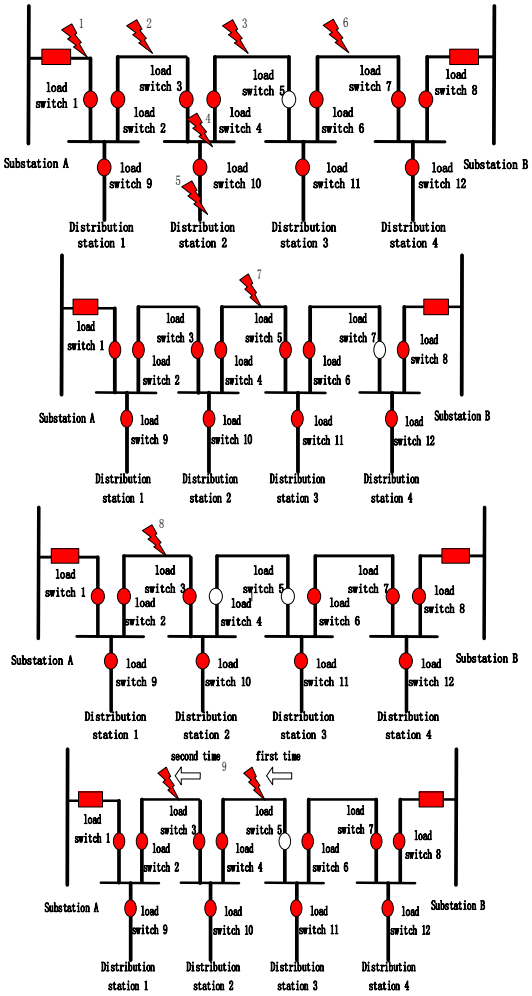

FIGURE X. BASIC FAULT SETTINGS

TABLE II. BASIC FAULT SETTINGS

Fault point 1	Overcurrent fault occurred at the analog loop power line exit
Fault point 2	Overcurrent fault between analog switches
Fault point 3	Overcurrent fault at the end of the analog line
Fault point 4	Overcurrent fault occurred in the internal bus of the analog substation
Fault point 5	Analog branch line fault
Fault point 6	Peer power failure
Fault point 7	Overcurrent fault occurs when the simulation operation modes changes
Fault point 8	Overcurrent fault occurred during analog maintenance
Fault point 9	Overcurrent fault at two different locations in succession.

B. Analysis of Experimental Results

The purpose of the DA test simulation is to verify the processing capability of the distribution terminal to each segment fault on the feeder. By simulating the faults, observe the action of the corresponding switch. In the above simulated experimental environment, nine kinds of faults under normal condition and abnormal conditions were respectively simulated. The action logic in the normal condition is shown in Table. 3. The recovery of the FA function requires a 25s signal reset, and the overcurrent setting is 2.0A.

TABLE III. ACTION LOGIC UNDER NORMAL CONDITIONS

Test items	Test results	Description	analysis
Fault point 1	A open, 1 open, 5 close	Basic conditions for starting FA: protection action signal, overcurrent setting value	FA action logic correct
Fault point 2	A open, 2 open, 3 open, 5 close, A close	Basic conditions for starting FA: protection action signal, overcurrent setting value	FA action logic correct
Fault point 3	A open, 4 open, A close	Basic conditions for starting FA: protection action signal, overcurrent setting value	FA action logic correct
Fault point 4	A open, 4 open, 3 open, A close, 5 close	Basic conditions for starting FA: protection action signal, overcurrent setting value	FA action logic correct
Fault point 5	A open, 10 open, A close	Basic conditions for starting FA: protection action signal, overcurrent setting value	FA action logic correct
Fault point 6	B disconnect, 6 disconnect, 7 disconnect, b closure, 5 closure	Basic conditions for starting FA: protection action signal, overcurrent setting value	FA action logic correct
Fault point 7	A open, 4 open, 5 opent, A close, 7 close	Basic conditions for starting FA: protection action signal, overcurrent setting value	FA action logic correct
Fault point 8	A open, 2 open, 3 open, A close	Basic conditions for starting FA: protection action signal, overcurrent setting value	FA action logic correct
Fault point 9	First time: A open, 4 opent, A close. Second time: A open, 2 open, 3 open, A close	Start the second fault after 30 seconds Basic conditions for starting fa: protection action signal, overcurrent setting value	FA action logic correct

The abnormal situation includes 11 kinds of abnormal situations such as switch rejecting act (remote control failure), switch misoperation, communication interruption with the control unit in the substation station, communication interruption between the distribution station, communication interruption between the control unit in the distribution station and the conventional FTU, communication interruption in the processing process, receiving the " general fault signal" in the distribution station during the processing process, receiving the " general fault signal" in the power station during the processing process, prejudging the line overload, primary reclosing protection of the power point switch in operation, and the distribution station switch being configured as a circuit breaker. the abnormal situation of the switch rejecting act is shown in table. 4.

TABLE IV. ACTION LOGIC UNDER SWITCH FAILURE

Test items	Test results	Description	analysis
Fault point 1	A open	1 rejecting act	1 rejecting act, FA function atresia, correct
Fault point 2	A open 3 open	2 rejecting act	2 rejecting act,, fa function atresia, correct
Fault point 3	A open	4 rejecting act	4 rejecting act,,FA function atresia, correct
Fault point 4	A open 3 open	4 rejecting act	4 rejecting act, FA function atresia, correct
Fault point 5	A open	10 rejecting act	10 rejecting act,, FA function atresia, correct
Fault point 6	B open	7 rejecting act	7 rejecting act, FA function atresia, correct
Fault point 7	A open	4 rejecting act	4 rejecting act,, FA function atresia, correct
Fault point 8	A open	2, 3 rejecting act	2, 3 rejecting act,, FA function atresia, correct
Fault point 9	First time: A open	4 rejecting act	First time , 4 rejecting act,, FA function blocking, Second time, no fault current, correct

During the simulation process, each fault point was tested in one normal state and 11 abnormal states. A total of 108 tests were performed, which basically realized the complete detection of the DA processing fault logic. It is known that the simulation of the fault location and isolation of the power distribution terminal equipment is realized by simulating the topology of the power supply ring network on the RTDS simulation platform. The performance of the action is consistent with the theoretical behavior, so the DA simulation based on RTDS can be equivalent to the actual operation of the distribution system.

V. CONCLUSION

In order to ensure the power supply reliability of the distribution network, DA system needs to be tested, and simulation experiments can simulate the operation conditions close to the real distribution network, eliminating the potential safety hazard of directly connecting distribution equipment to the power grid. In this paper, the DA test simulation method based on RTDS, which makes full use of the powerful real-time simulation function of RTDS, accurately simulates the DA dynamic system, and can detect whether the response of various distribution terminals to different types of faults meets the requirements. It provides a great reference value for the operation of the tested equipment on the real distribution network, and has the advantages of flexible networking, good compatibility and good expansibility. Therefore, RTDS simulation platform is of great significance to improve the reliability of distribution network power supply.

ACKNOWLEDGEMENT

This research was financially supported by State Grid Corporation.(Grant NO.52094017001N).

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