

A Collaborative Simulation Architecture for Influence Evaluation of Communication Network Faults on Power Grid System

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Abstract— With the rapid development of the smart grid, the power grid simulation integrated with its communication system becomes very important for power grid evaluation and deployment. In this paper, a collaborative simulation architecture for power grid system with the consideration of its communication system, in which the DIGSILENT, the QualNet, and an association controller are connected by two investigated interfaces, i.e., a data interaction interface (DII) and a dynamic control interface (DCI), is proposed for the influence evaluation of communication network faults on the power grid system. DII supports the information exchanging between the DIGSILENT and the QualNet, and the DCI is in charge of dynamical fault configuration of communication network, control message transmission from association controller to both DIGSILENT and QualNet, and state information feedback from DIGSILENT and QualNet to association controller. Experimental results show that the proposed interfaces can effectively implement data exchange between DIGSILENT, QualNet and association controller with an acceptable interface delay. And the influence of communication network faults on power grid system can be obtained obviously.

Keywords— Dynamic control interface; Power grid system; Data interaction interface; QualNet; DIGSILENT; Association controller

I. INTRODUCTION

Power grid system has been regarded as the most essential infrastructure for the modern society and the influence of communication network faults has become more and more critical for the stable operation of power grid system, e.g., U.S-Canada power system outage, which was caused by the failure of its information system, made a \$20 billion economic loss in 2003[1]. Thus, simulation systems by considering the power grid system together with its communication network have been widely considered as a hot issue for improving the reliability of power grid systems [2-4].

Based on Real-time digital simulator, synchrophasor devices, DeterLab, and NS-3, the author in [5] proposed a co-simulation experimental platform of power system and communication network to analyse the impact of three different possible cyber events on physical power grid. In [6]

a testing platform named wide area monitoring and control (WAMC) was investigated by allowing the OPNET to connect a real-time power system simulator through a virtualized phasor measurement unit (PMU) device to facilitate the real-time simulation of dynamic power grid. In addition, [7] presented a novel code transformer DecompositionJ to convert multi-agent platform java agent development framework (JADE) into direct-execution simulators and integrates with electromagnetic transient simulator (PSCAD) and packet-level network simulator (OPNET) by using standardized co-simulation runtime infrastructure in order to realize the co-simulation. However, the dynamic fault configuration of communication network for power grid system, which is essential for the transient influence analysis for power grid system, was not further considered. In [8], an efficient interactive approach together with a real-time user interface for QualNet based dynamical network simulation was proposed for the network model evaluation as well as protocol test. Furthermore, in order to shorten the delay overhead of parameter re-configuration commands transmission for a great amount of parameters in a large scale network model, a programmable dynamic simulation interface (PDSI), in which depending on the time label, the reconfiguration command is pre-cached in the event queue and precisely implemented according to the pre-programmed order, is further proposed [9]. However, the collaborative simulation architecture for influence evaluation of communication network faults on power grid system is not considered.

In this paper, a collaborative simulation architecture with two interfaces, i.e., DII and DCI, is proposed and designed to evaluate the impact of communications network faults on power grid system. DII is designed for the data information exchanging between DIGSILENT and QualNet, and the DCI is investigated for dynamical fault configuration of communication network, control message transmission from association controller to both DIGSILENT and QualNet, and state information feedback from DIGSILENT and QualNet to association controller. Together with the graphical user interface (GUI) of association controller as well as both of DII

and DCI, the fault of communication network can be dynamically configured during the simulation process and its influence on power grid system can be obviously observed on the DIgSILENT.

The remainder of the paper is organized as follows. In Section II, the collaborative simulation architecture as well as its working process is described in detail. Section III verifies the feasibility of the proposed collaborative system by intensive simulation experiments. Finally, conclusions are drawn in Section IV.

II. PROPOSED COLLABORATIVE SIMULATION SYSTEM

A. Proposed Collaborative Simulation Architecture for Power Grid System

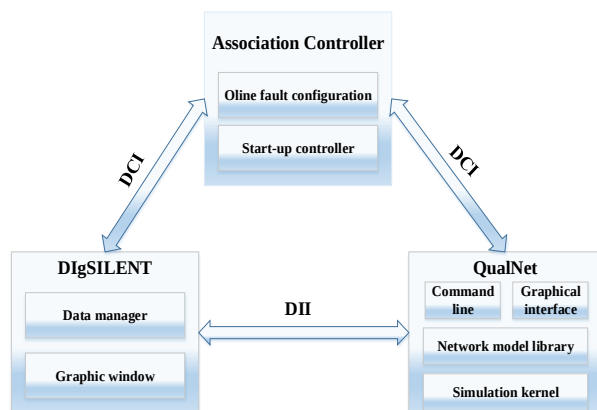


Figure 1. Collaborative simulation architecture for the influence evaluation of communication network faults on the power grid system

The proposed collaborative simulation architecture for the influence evaluation of communication network faults on the power grid system is shown in Fig. 1. The collaborative architecture is composed of DIgSILENT, QualNet, association controller, DCI and DII.

DIgSILENT: is widely considered for the power grid system simulation and its power factory covers the full range of functionality from standard features to highly sophisticated and advanced applications. As the simulator of power grid system, it simulates the power stations and dispatch center of the power grid. The power stations send their information, e.g., bus number, voltage amplitude and voltage phase angle, to the dispatch center. Then, the dispatch center calculates the information and returns the control command, e.g., the voltage correction parameter to each power station.

QualNet: is regarded as the corresponding network simulator for power grid topology in DIgSILENT. As the simulator of communication network for power grid system, the communication nodes in QualNet correspond to those in DIgSILENT to model the data transmission among dispatch center and power stations. The packets produced by the power stations and the dispatch center in DIgSILENT will be sent to the corresponding communication nodes simulated by QualNet for transmission. After the packets for power system

are routed and received at the destination nodes in QualNet, they will be sent back to the DIgSILENT via the DII.

Association controller: is considered as the centralized controller for the collaborative simulation, by which the user is able to dynamically configure the communication network faults via a graphical user interface (GUI) during the simulation process and the start-up of the QualNet and the DIgSILENT can be achieved simultaneously.

DCI: is investigated for dynamical fault configuration of communication network, start-up control message transmission from association controller to both DIgSILENT and QualNet, and state information feedback from DIgSILENT and QualNet to association controller.

DII: realizes the data interaction between the power nodes in DIgSILENT and the corresponding communication nodes in QualNet. The packets generated from the simulated dispatch center as well as power stations in DIgSILENT, which contain the power grid information or the control command, will be changed into corresponding message types for the QualNet. After the message from corresponding communication node in QualNet of dispatch center or power station arrives at the desired node, the feedback message will be transformed back to the formats of DIgSILENT and sent back to corresponding dispatch center or power stations via the DII.

B. Working flow chat of proposed DCI and DII

Before starting the co-simulation, the DIgSILENT, the QualNet, and the association controller should be started in sequence. Association controller should be started at first. Then, the packets which contain start-up information packets will be generated and sent to the DIgSILENT and the QualNet via DCI, simultaneously.

The working procedure of DCI is shown in Fig. 2. After the external interface of the DIgSILENT or QualNet receives comment packets through the UDP socket, the packet will be parsed and the corresponding script file is called to start the QualNet or the DIgSILENT. Then, the association controller can set dynamic control on the communication network simulated by QualNet, e.g., network fault configuration and parameters configuration of the network model. When command packets with a time label for execution arrive at the receive buffer of the external interface of QualNet, they are realized and sent to the packet parser to be rebuilt into the corresponding formats. If the packets are parsed unsuccessfully, the corresponding error packets used for reporting error information will be generated and sent to the send buffer. With a successfully parsing, the packets are packed into messages that can be realized by QualNet. According to the time label included in the event, messages will be pushed into the event queue of the QualNet. Then the event dispatcher retrieves the message from the event queue and send it to the event processor, which results into the fault configuration as well as parameter resetting at the corresponding network nodes in QualNet. The feedback information is encapsulated as packets to be put into the send buffer. Finally, the feedback packets are fed back to the GUI

via the UDP socket.

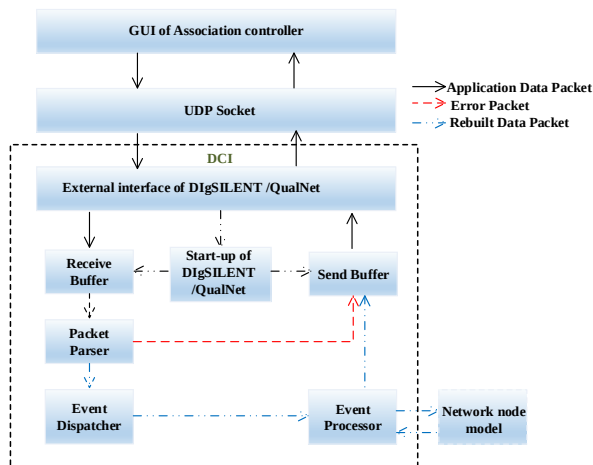


Figure 2. The working procedure for DCI

For data exchanging between QualNet and DigSILENT, the data packets transmission is accomplished by the DDS middleware based DII. The working procedure of DII is shown in Fig. 3. The virtual communication node simulated in QualNet and power stations as well as the dispatch center simulated in DigSILENT are considered as a pair of independent domain participants. To complete the information interaction, four different topics are needed at least. And those are power grid information topic (PGI Topic) for DigSILENT, power grid control command topic (PGCC Topic) for DigSILENT, corresponding feedback information topic (CFI Topic) for QualNet, and the corresponding feedback control command topic (CFCC Topic) for QualNet. All topic structures are known to both QualNet and DigSILENT. Once a message that contains the information of the power grid is sent from the DigSILENT to the QualNet, an instance of PGI Topic will be immediately created, and will be published to the corresponding domain through information writer. As long as an instance of PGI Topic is published to the domain, the QualNet will get the instance through the information reader. In addition, when the DigSILENT has a message that contains control command to send to the QualNet, all the procedure are similar to that, except another topic (PGCC Topic) is utilized. Once the DigSILENT sends the packets to the QualNet, the QualNet will packetize the corresponding parameters and the statistical data back to the DigSILENT via CFI Topic and CFCC Topic by using the different reader and writer.

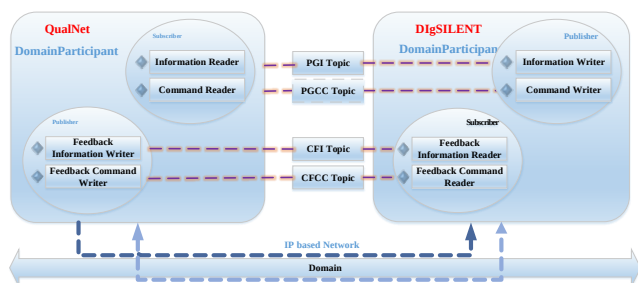


Figure 3. The working procedure for DII

III. EXPERIMENTS AND RESULTS

The experiments are set to evaluate the performance of the proposed collaborative simulation system for the power grid as well as the access delay of the proposed interfaces. In the experiment, the power data is produced by the DigSILENT and a corresponding communication network model is simulated by the QualNet, in which the faults of communication network is configured by the association controller dynamically.

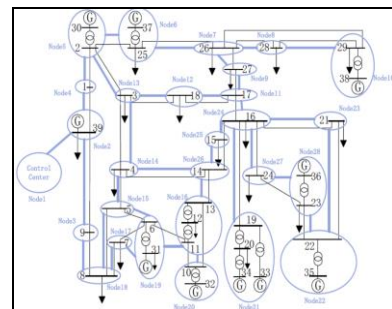
A. Experiment Scenario

In the experiment, three simulation servers work for the simulation. QualNet version 5.1 is running on a simulation server to model the corresponding virtual communication network for the power grid system, which is simulated by another server with version of DigSILENT 15.1.6. Meanwhile, one more server works as the association controller. The detailed parameters of the simulation servers for QualNet, DigSILENT, and association controller are listed in Table 1, respectively.

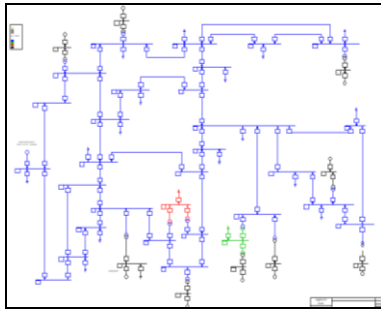
TABLE 1. PARAMETERS OF SIMULATION SERVERS

	QualNet simulator server	DigSILENT simulator server	Association controller simulator server
Operation system	Ubuntu 12.04	Windows 10	Windows 10
CPU	Intel xeon(R) E5-26090	Intel xeon(R) E5-26090	Intel xeon(R) E5-26090
RAM	23.5GiB	23.5GiB	23.5GiB

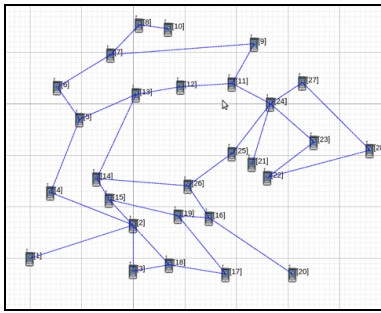
Without loss of generality, the IEEE 39 Bus System is considered as the simulation scenario of power grid system as shown in Fig. 4(a), which consists of 28 corresponding communication nodes. The corresponding simulation models in DigSILENT simulator and QualNet simulator are shown in Fig. 4(b) and Fig. 4(c), respectively. Node 1 in QualNet corresponds to the control center in the power grid system, which will make decisions of control command, e.g., the voltage correction parameter to each power station, through the analysis of the data received from the other nodes.



(a) Topology for IEEE 39 Bus System



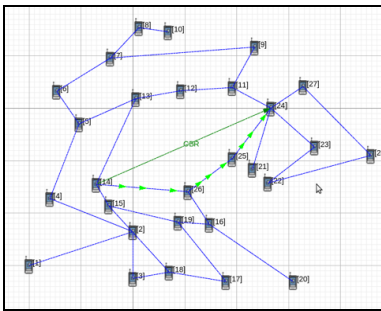
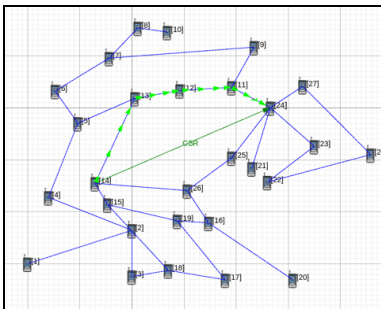
(b) Corresponding IEEE 39 Bus System in DIgSILENT



(b) Corresponding network topology in QualNet

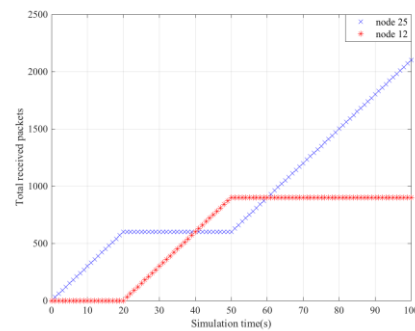
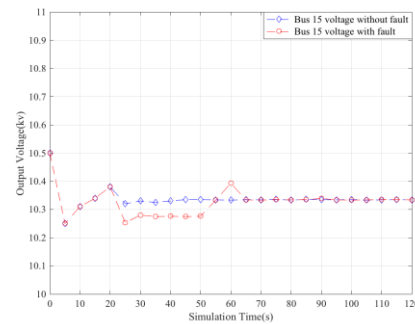
Figure 4. IEEE 39 Bus System for both QualNet and DIgSILENT

B. Experiment Results

**Figure 5.** CBR transmission from node 14 to node 24 without link fault configuration**Figure 6.** Path change in simulation scenario after link fault configuration

In experiments, a CBR (Constant Bit Rate) application is set between the node 14 and the node 24, where the packets are transmitted through the path of nodes, i.e., 14-26-25-24, as

shown in Fig. 5. In the experiment, a link fault between node 26 and node 25 is dynamically configured through the GUI of association controller at the simulation time of 20s, and then the link between node 25 and node 26 is restored through the GUI at the simulation time of 50s. Together with the link fault configuration, the packets transmission path changes from 14-26-25-24 to 14-13-12-11-24 as shown in Fig. 6. As shown in Fig. 7, nodes 25 and 12 are selected to monitor the packets reception. During the simulation time from 20s to 50s a flat trend of total received packet can be observed at node 25, since the CBR data are transmitted via path of 14-13-12-11-24, instead of 14-26-25-24. For the node 12, since the transmitting path is changed to 14-13-12-11-24, a linear increasing trend can be observed. When the link fault between node 25 and node 26 is restored, the transmitting path of CBR is changed back to 14-26-25-24, thus, a increasing trend of total received packets at node 25 can be observed. In addition, for the simulated IEEE 39 Bus System in DIgSILENT, its bus 15 corresponds to the node 25 in QualNet. Due to link fault configuration between node 26 and node 25, the bus 15 loses the voltage correction parameter from the dispatch center, which results into a fluctuation of its output voltage. However, after the simulation time at 50s, the link fault is restored and the voltage correction parameter can be correctly received. Thus, a stable output voltage of bus 15 can be observed as shown in Fig. 8.

**Figure 7.** Received packets at both node 12 and node 25**Figure 8.** Bus 15 voltage with and without link fault configuration

C. Access Delay time of Proposed Interfaces

The access delay of the proposed interfaces, i.e., DCI and DII, are composed of four parts: time to receive data packets, time to parse and rebuild data packets, time to process the event, and time to send data packets. In this paper, the averaged access delay of both DII and DCI is tested by intensive experiments, where 200 times of experiments are respectively performed to obtain the average time delay of DII and DCI. As shown in Fig. 9, the averaged delay time of 0.7422ms and 0.6502ms, which is negligible compared to the transmission delay among the power grid system, can be observed for the proposed DII and DCI, respectively. In addition, since more information packets are transmitted through DII than that via DCI, the average delay time of DII is a little higher than that of DCI.

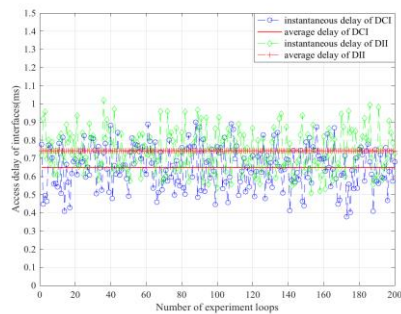


Figure 9. The access delay time of proposed DCI and DII

IV. CONCLUSIONS

In this paper, a collaborative simulation system is proposed to evaluate the impact of communication network fault on power grid system. With the proposed collaborative simulation architecture, the network simulator, i.e., QualNet, and power grid simulator, i.e., DigSILENT, are integrated to each other, where two interfaces of DCI and DII are designed for supporting the information exchanging between the DigSILENT and the QualNet, dynamical fault configuration of communication network, control message transmission from association controller to both DigSILENT and QualNet, and state information feedback from DigSILENT and QualNet to association controller. Experimental results show the efficiency of the proposed collaborative simulation architecture and the influence of communication network fault for power grid system can be obviously observed with a negligible access delay of DCI and DII.

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